Creation of first process by kernel

Why first process needs ‘special’ treatment?

- Normally process is created using fork()
  - and typically followed by a call to exec()
- Fork will use the PCB of existing process to create a new process
  - as a clone
- The first process has nothing to copy from!
- So it’s PCB needs to “built” by kernel code

Why first process needs ‘special’ treatment?

- XV6 approach
  - Create the process as if it was created by “fork”
  - Ensure that the process starts in a call to “exec”
  - Let “Exec” do the rest of the JOB as expected
  - In this case exec() will call
    - exec(“/init”, NULL);
- See the code of init.c
  - opens console() device for I/O; dups 0 on 1 and 2!
    - Same device file for I/O
  - forks a process and execs (“sh”) on it.
  - Itself keeps waiting for zombie processes

Why first process needs ‘special’ treatment?

- **What needs to be done ?**
  - **Build struct proc by hand**
  - **How data structures (proc, stack, etc) are hand-crafted so that when kernel returns, the process starts in code of init**

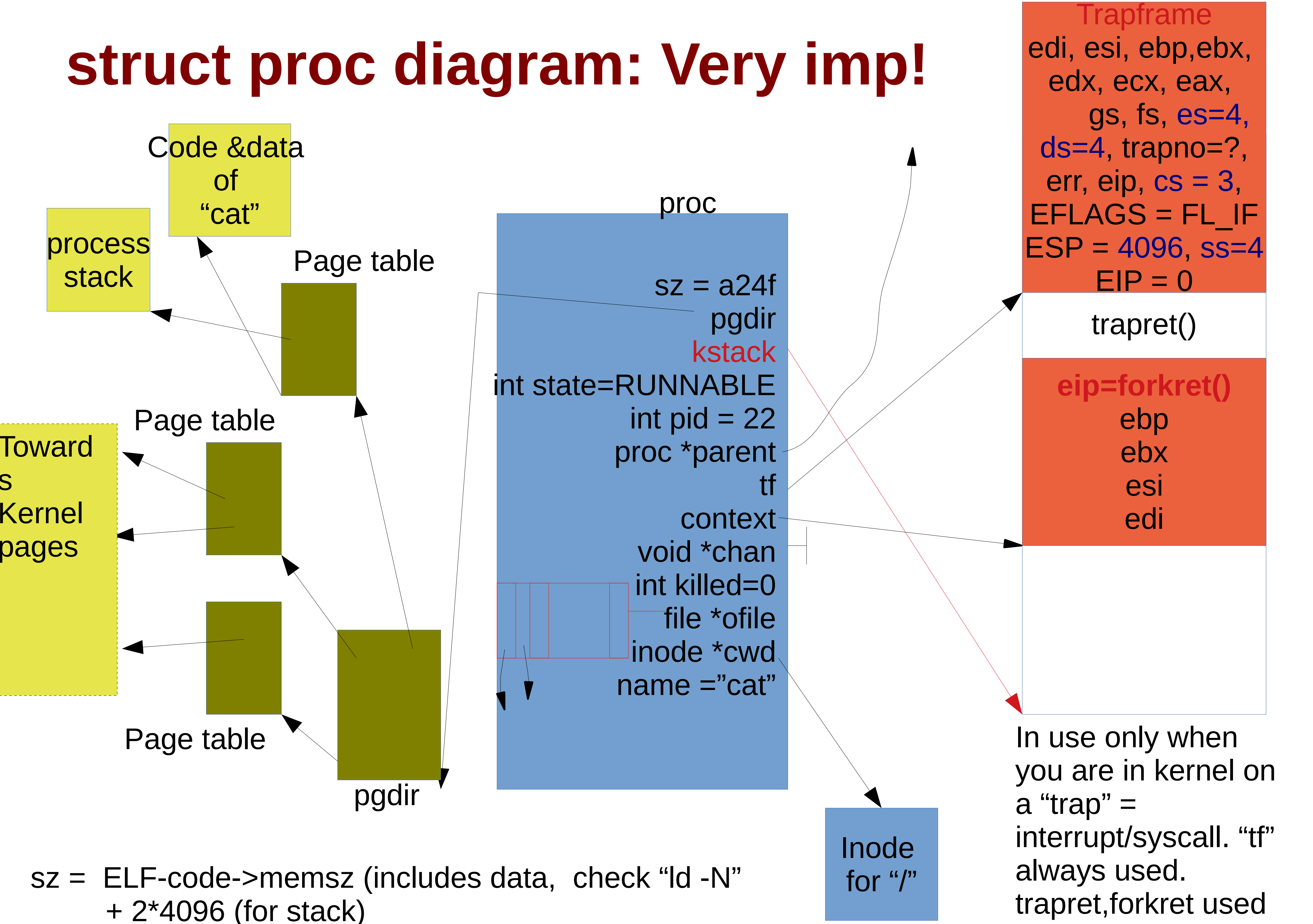
Imp Concepts

- A process has two stacks
  - user stack: used when user code is running
  - kernel stack: used when kernel is running on behalf of a process
- Note: there is a third stack also!
  - The kernel stack used by the scheduler itself
  - Not a per process stack

Imp Concepts

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

struct proc diagram: Very imp!

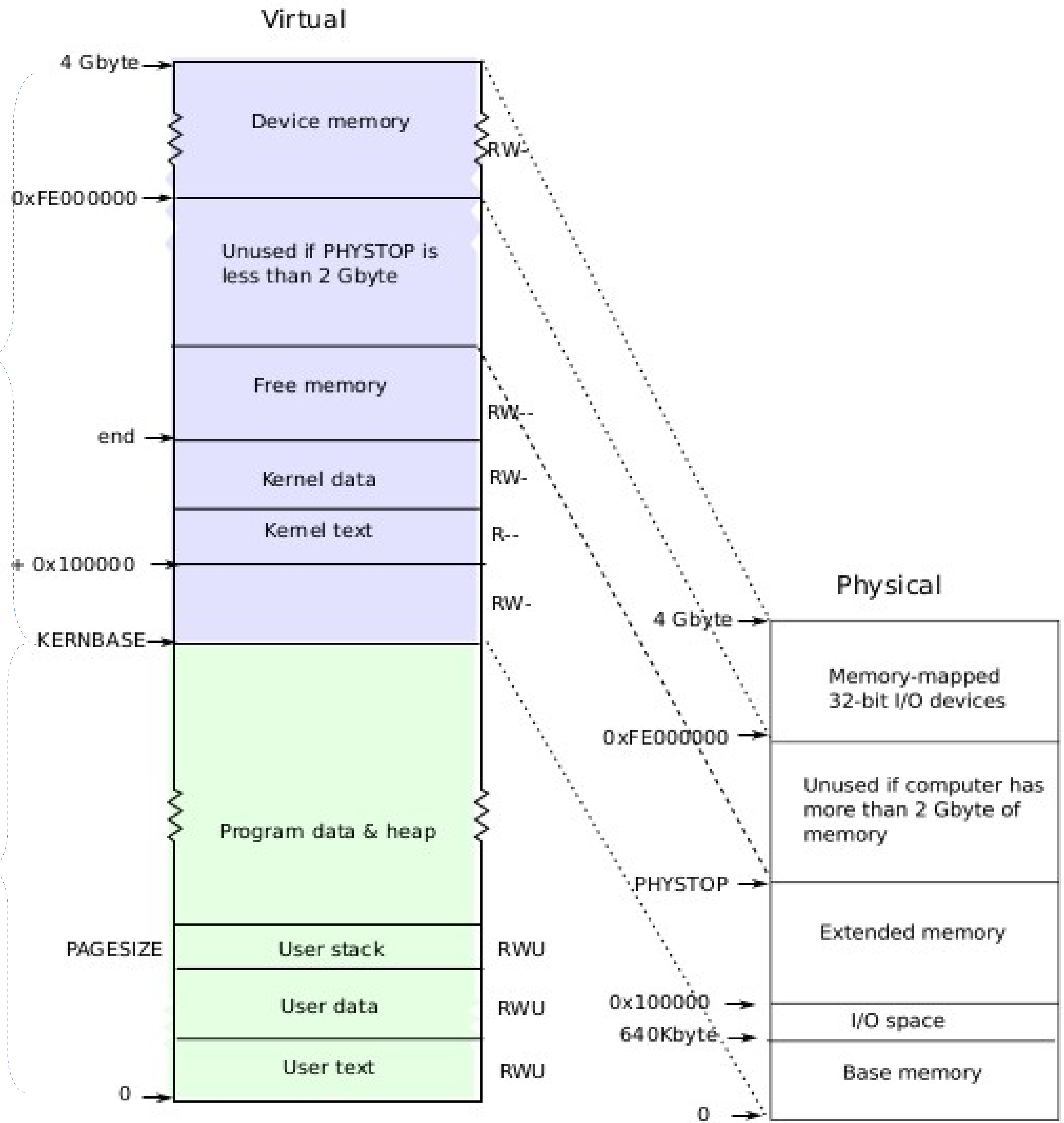


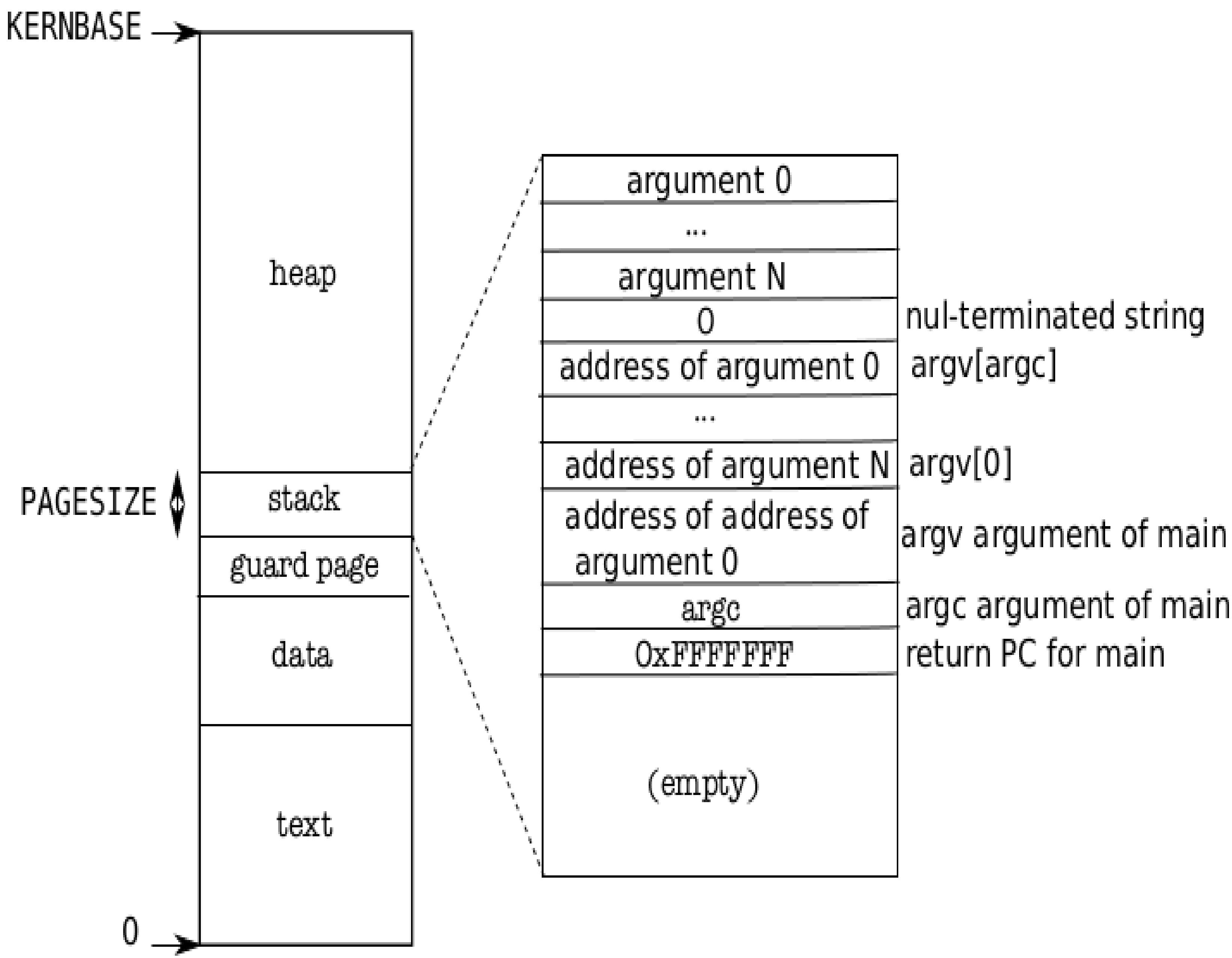
In use only when you are in kernel on a "trap" = interrupt/syscall. "tf" always used. trapret,forkret used during fork()

sz = ELF-code->memsz (includes data, check "ld -N"
+ 2*4096 (for stack)

setupkvm() does this mapping

These mappings need to be created per process





Memory Layout of a user process After exec()

Note the argc, argv on stack

stack is just one page.

size of text and data is derived from ELF file

main()->userinit()
Creating first process by hand

- Code of the first process
  - initcode.S and init.c
  - init.c is compiled into “/init” file
    - During make !
  - Trick:
    - Use initcode.S to “exec(“/init”)”
    - And let exec() do rest of the job
  - But before you do exec()
    - Process must exist as if it was forked() and running

main()->userinit()
Creating first process by hand

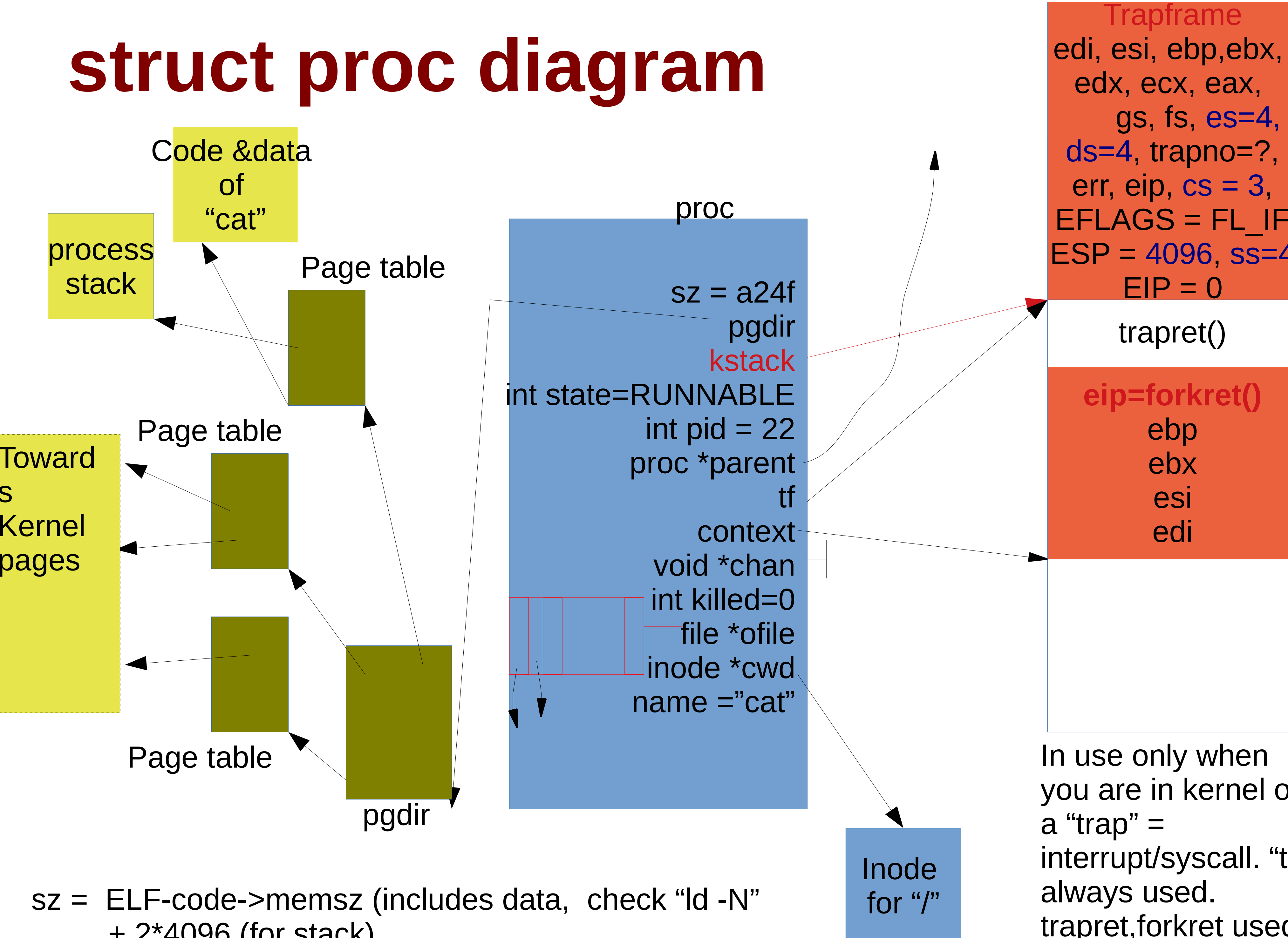
```
void
userinit(void)
{
  struct proc *p;
  extern char _binary_initcode_start[], _binary_initcode_size[];

  // Abhijit: obtain proc 'p', with stack initialized
  // and trapframe created and eip set to 'forkret'
  p = allocproc();
// let’s see what allocproc() does
```

First process creation
Let's revisit struct proc

```
// Per-process state
struct proc {
  uint sz;                    // Size of process memory (bytes)
  pde_t* pgdir;               // Page table
  char *kstack;               // Bottom of kernel stack for this process
  enum procstate state;       // Process state. allocated, ready to run, running, wait-
ing for I/O, or exiting.
  int pid;                    // Process ID
  struct proc *parent;        // Parent process
  struct trapframe *tf;       // Trap frame for current syscall
  struct context *context;    // swtch() here to run process. Process's context
  void *chan;                 // If non-zero, sleeping on chan. More when we discuss
sleep, wakeup
  int killed;                 // If non-zero, have been killed
  struct file *ofile[NOFILE]; // Open files, used by open(), read(),...
  struct inode *cwd;          // Current directory, changed with "chdir()"
  char name[16];              // Process name (for debugging)
};
```

struct proc diagram



sz = ELF-code->memsz (includes data, check “ld -N”
+ 2*4096 (for stack)

In use only when you are in kernel on a “trap” = interrupt/syscall. “tf” always used. trapret,forkret used during fork()

allocproc()

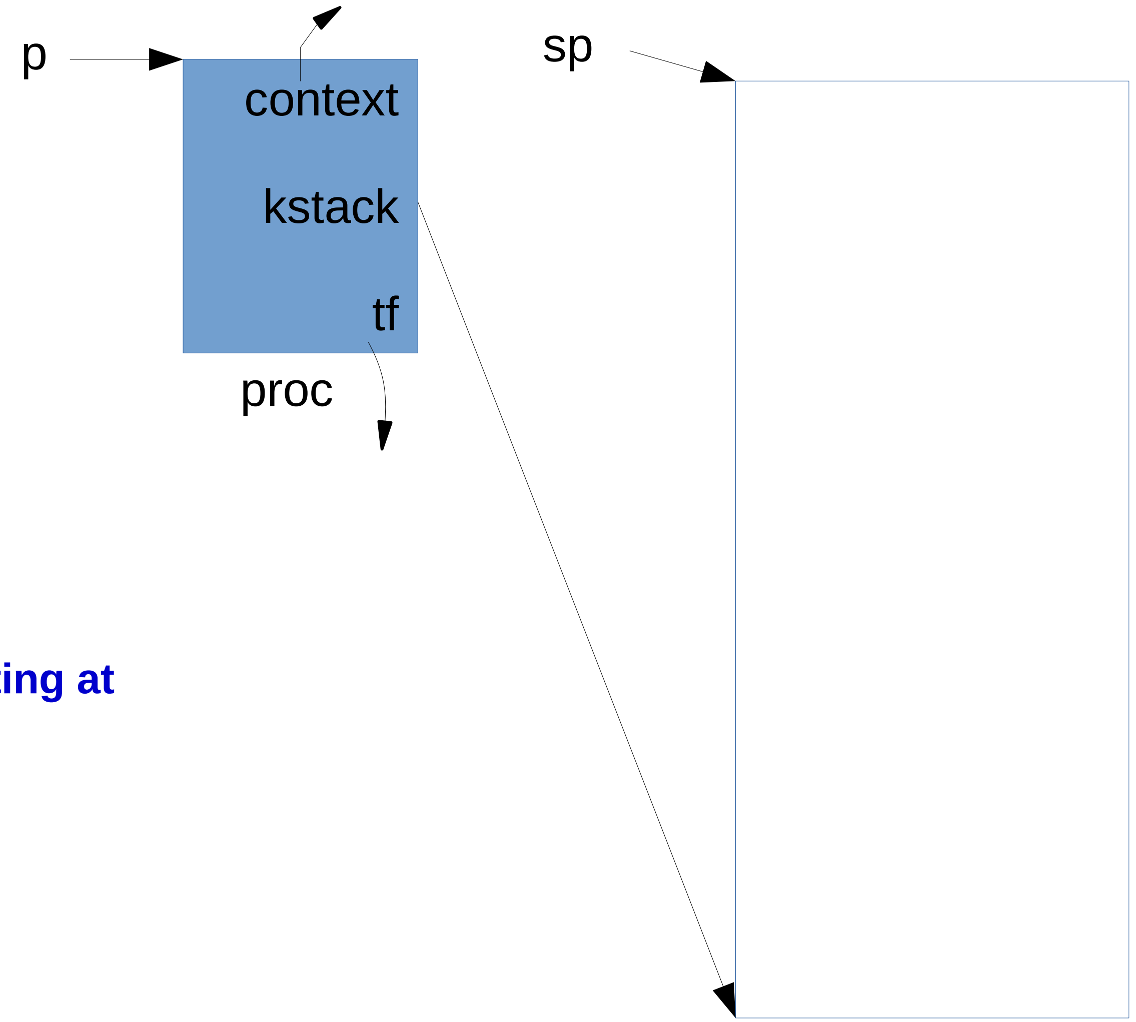
```
static struct proc*
allocproc(void)
{
  struct proc *p;
  char *sp;
  acquire(&ptable.lock);
  for(p = ptable.proc; p <
&ptable.proc[NPROC]; p++)
    if(p->state == UNUSED)
      goto found;
  release(&ptable.lock);
  return 0;
```

```
found:
  p->state = EMBRYO;
  p->pid = nextpid++;

release(&ptable.lock);
```

allocproc() setting up stack

```
if((p->kstack = kalloc()) == 0){
  p->state = UNUSED;
  return 0;
}
sp = p->kstack + KSTACKSIZE;
// Abhijit KSTCKSIZE = PGSIZE
// Leave room for trap frame.
sp -= sizeof *p->tf;
p->tf = (struct trapframe*)sp;
// Set up new context to start executing at
forkret,
// which returns to trapret.
sp -= 4;
*(uint*)sp = (uint)trapret;
sp -= sizeof *p->context;
p->context = (struct context*)sp;
memset(p->context, 0, sizeof *p->context);
p->context->eip = (uint)forkret;
```



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sp -= 4;
*(uint*)sp = (uint)trapret;
sp -= sizeof *p->context;
p->context = (struct context*)sp;
memset(p->context, 0, sizeof *p->context);
p->context->eip = (uint)forkret;
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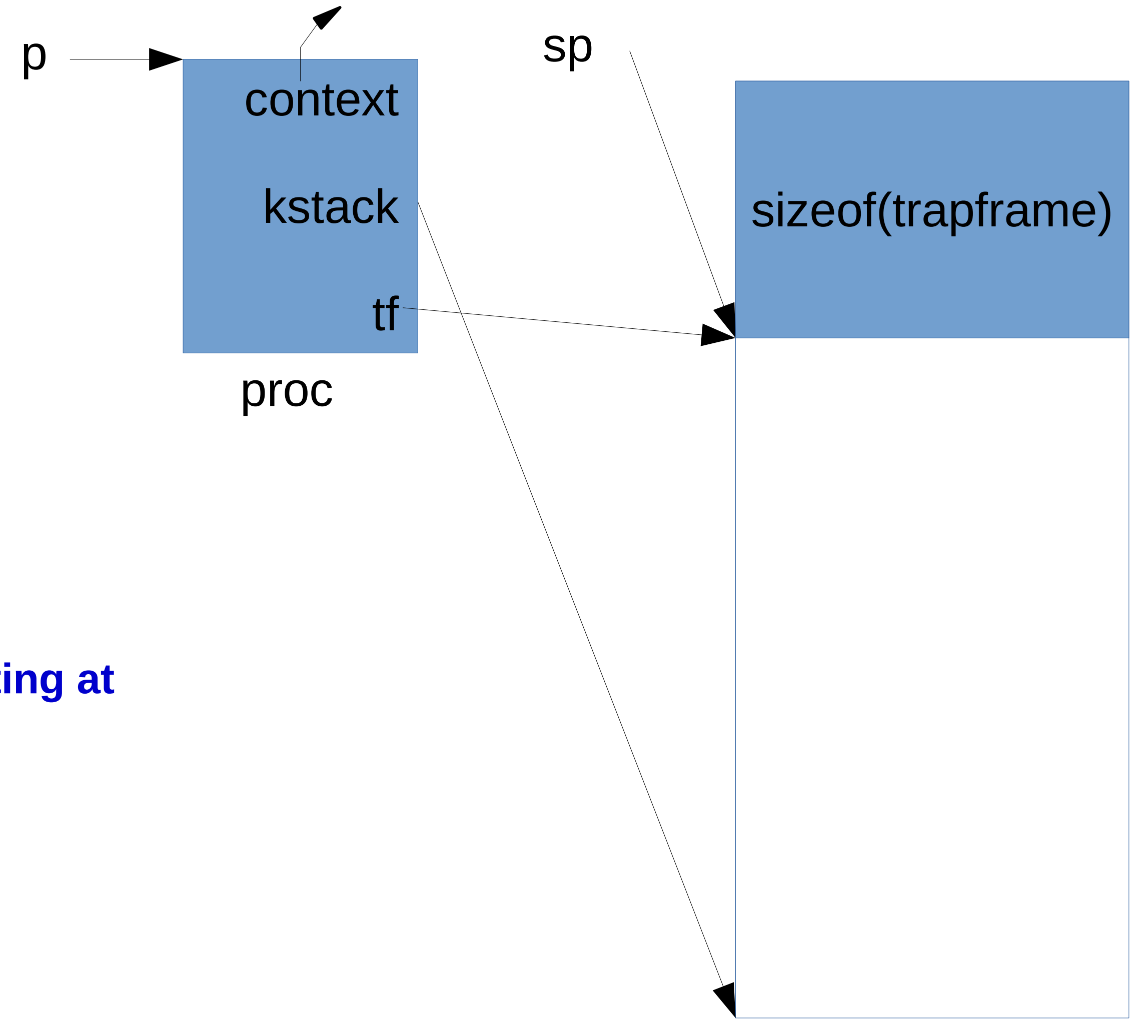

allocproc() setting up stack

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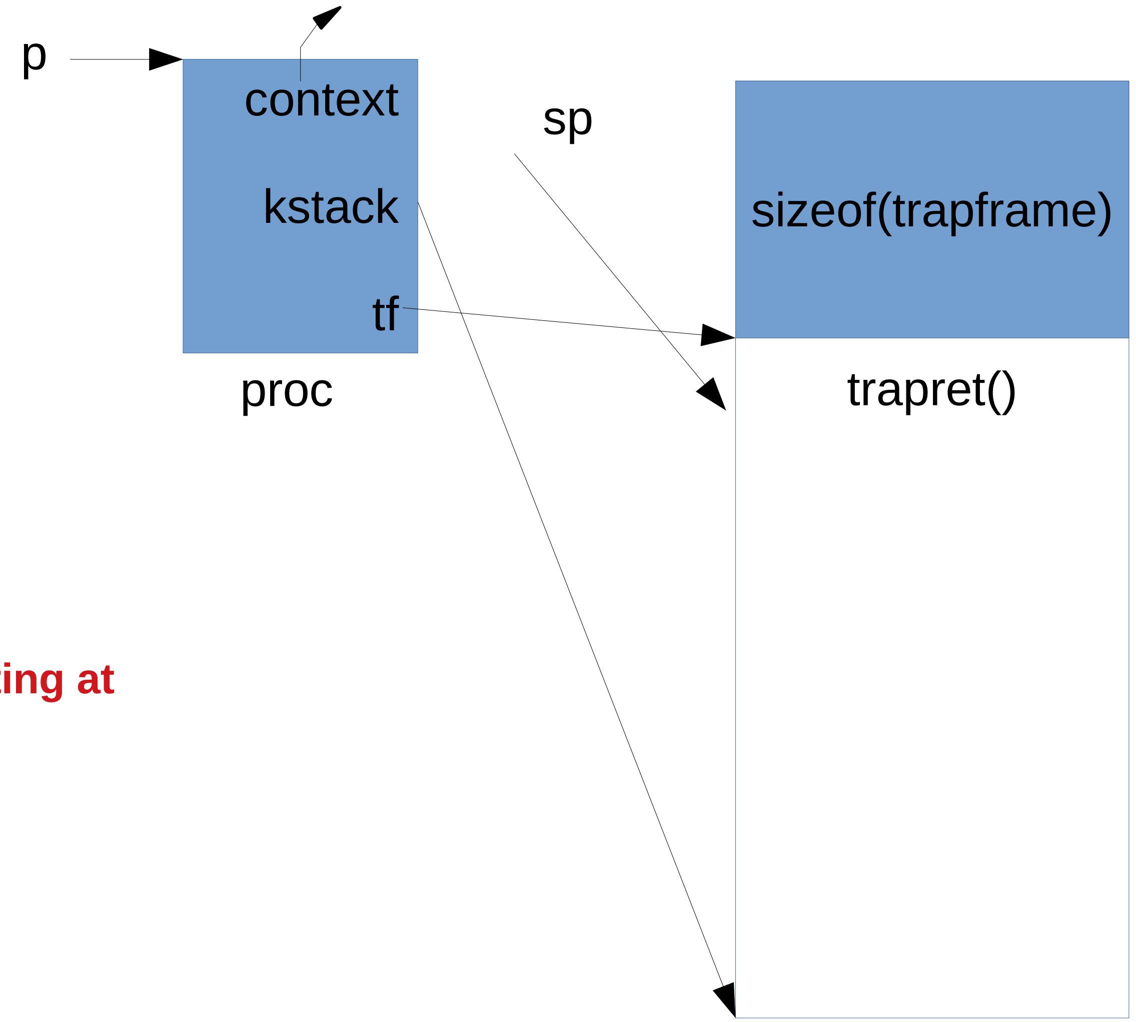
  // which returns to trapret.
  sp -= 4;
  *(uint*)sp = (uint)trapret;
  sp -= sizeof *p->context;
  p->context = (struct context*)sp;
  memset(p->context, 0, sizeof *p->context);
  p->context->eip = (uint)forkret;
```



allocproc() setting up stack

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  p->state = UNUSED;
  return 0;
}
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sp -= sizeof *p->tf;
p->tf = (struct trapframe*)sp;
// Set up new context to start executing at forkret,
// which returns to trapret.
sp -= 4;
*(uint*)sp = (uint)trapret;
sp -= sizeof *p->context;
p->context = (struct context*)sp;
memset(p->context, 0, sizeof *p->context);
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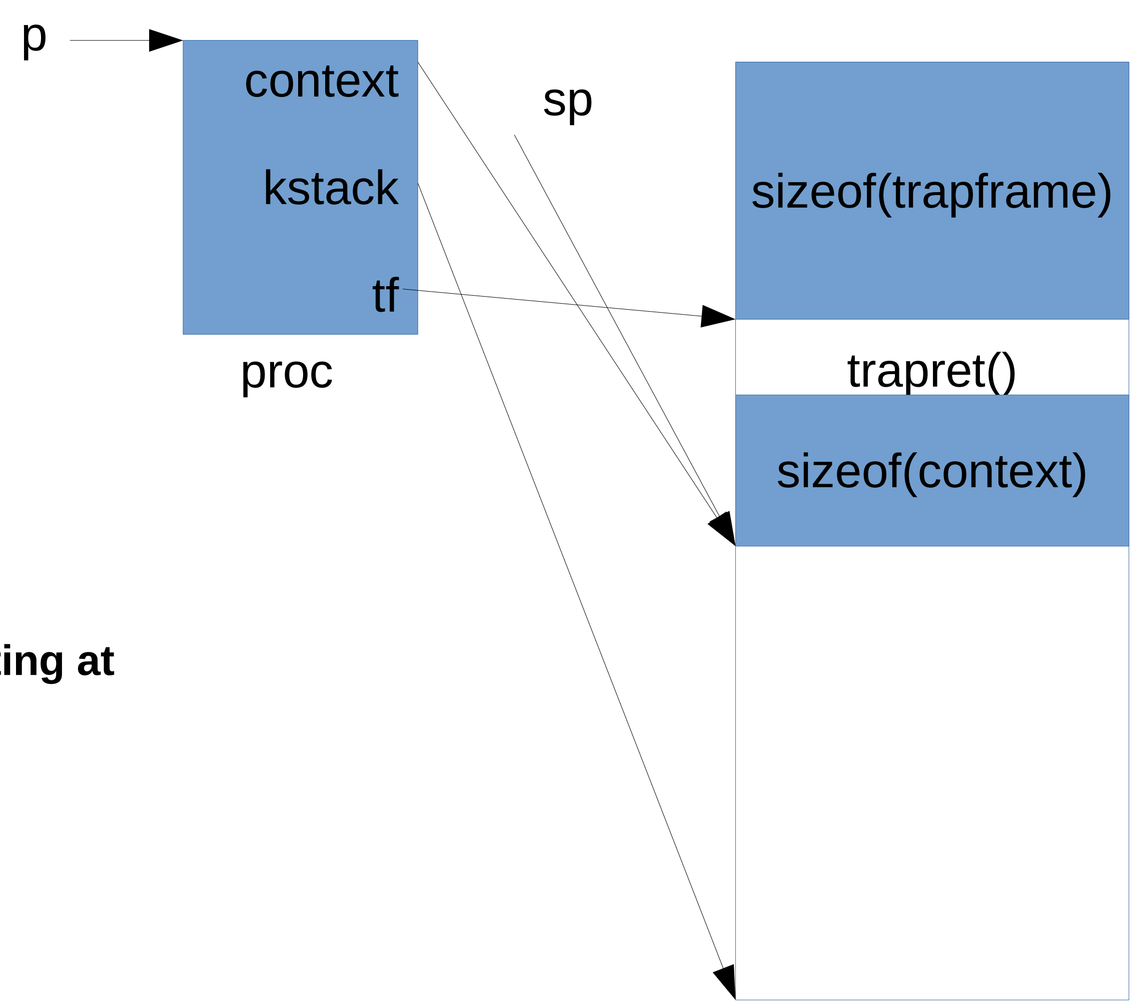

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sp -= sizeof *p->context;
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p->context->eip = (uint)forkret;
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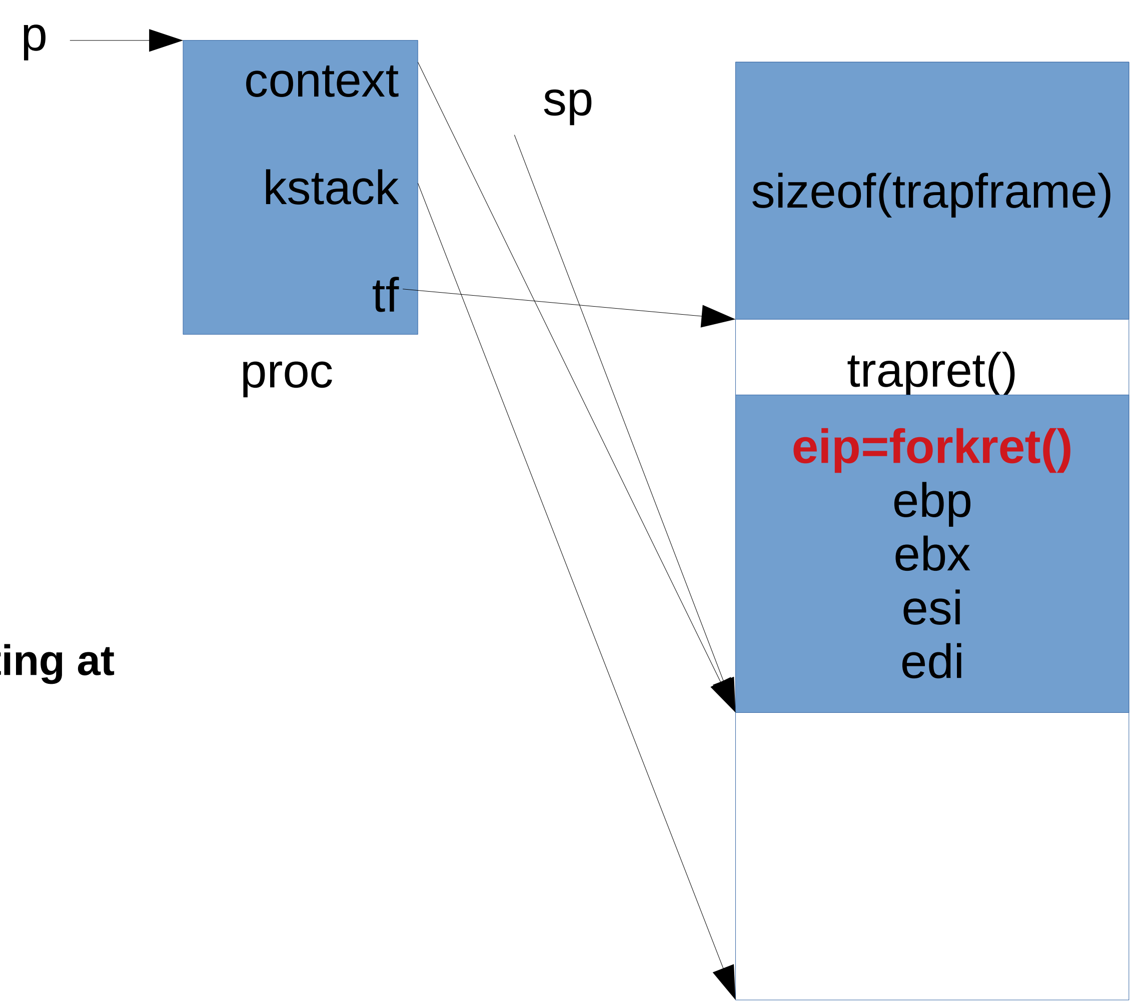
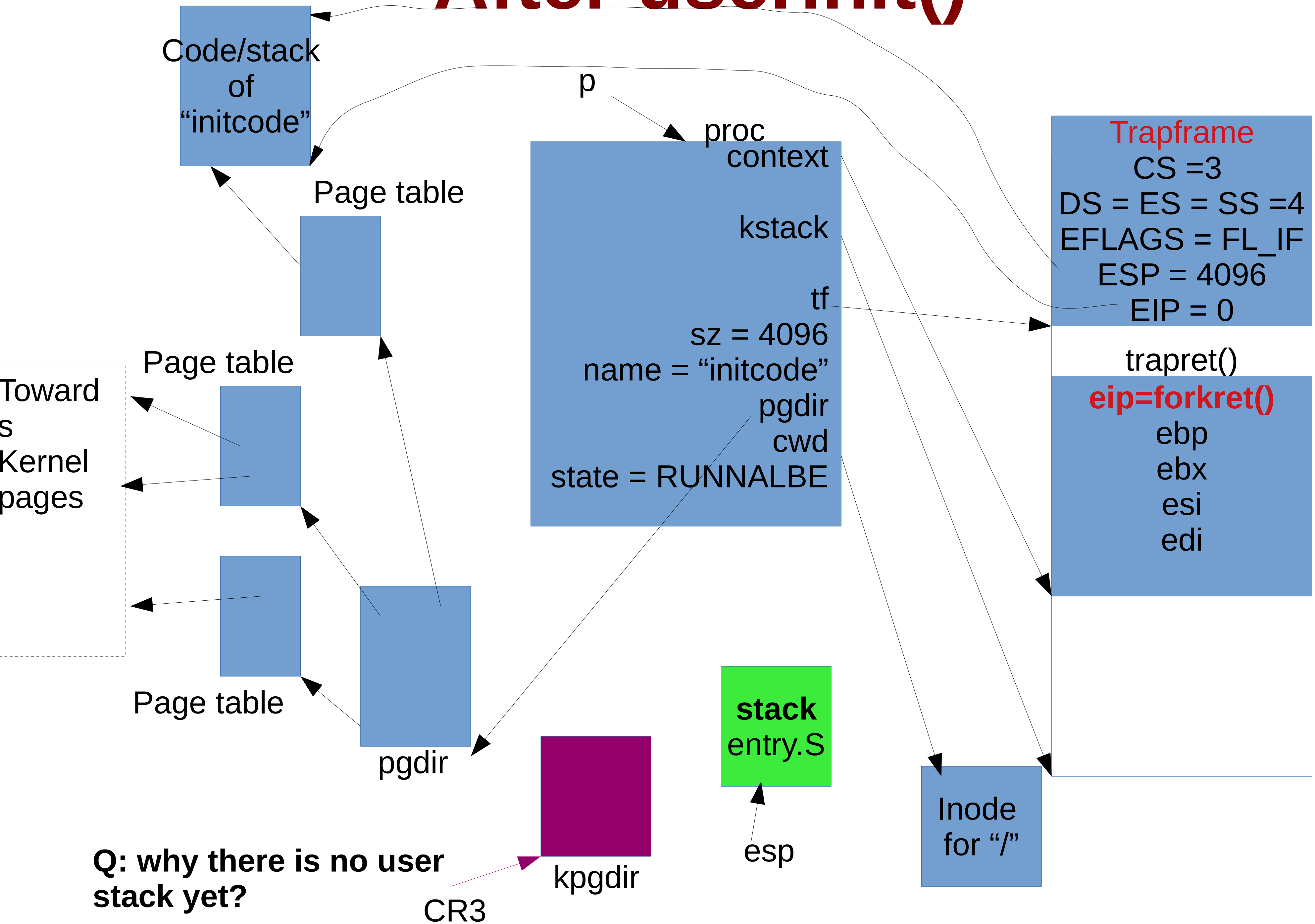


Next in userinit()

```
  initproc = p;
  if((p->pgdir = setupkvm()) == 0)
    panic("userinit: out of memory?");
  inituvm(p->pgdir, _binary_initcode_start, (int)_binary_initcode_size);
  p->sz = PGSIZE;
  memset(p->tf, 0, sizeof(*p->tf));
  p->tf->cs = (SEG_UCODE << 3) | DPL_USER;
  p->tf->ds = (SEG_UDATA << 3) | DPL_USER;
  p->tf->es = p->tf->ds;
  p->tf->ss = p->tf->ds;
  p->tf->eflags = FL_IF;
  p->tf->esp = PGSIZE;
  p->tf->eip = 0;  // beginning of initcode.S
  safestrcpy(p->name, "initcode", sizeof(p->name));
  p->cwd = namei("/");
  acquire(&ptable.lock);
  p->state = RUNNABLE;

  release(&ptable.lock);
```

After userinit()



Q: why there is no user stack yet?

main()->mpmain()

```
static void
mpmain(void)
{
  cprintf("cpu%d: starting %d\n", cpuid(), cpuid());
  idtinit();       // load idt register
  xchg(&(mycpu()->started), 1); // tell startothers() we're up
  scheduler();     // start running processes
}
```

- **Load IDT register**
  - Copy from idt[] array into IDTR
- **Call scheduler()**
  - One process has already been made runnable
  - Let’s enter scheduler now

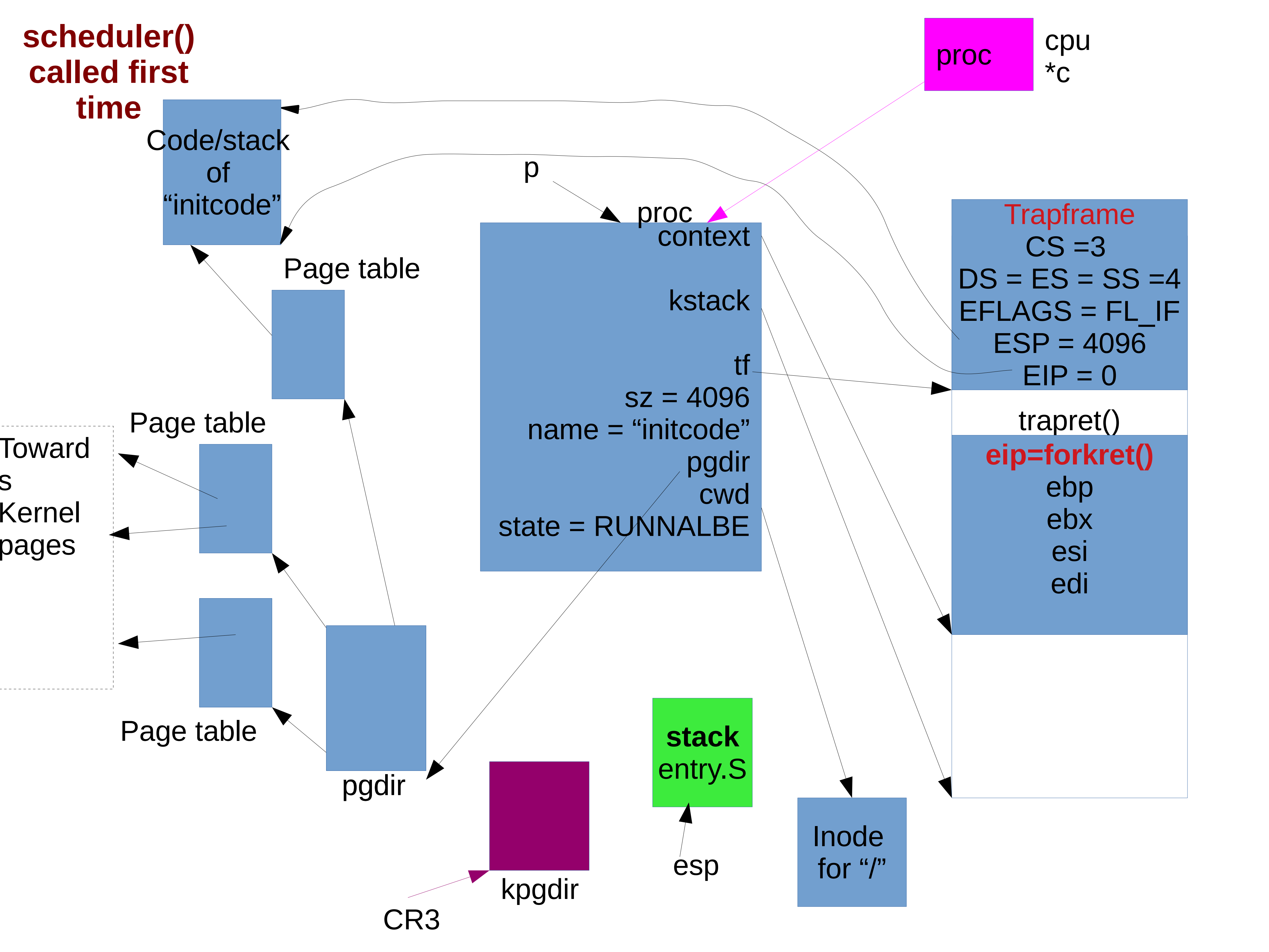
Before reading scheduler(): Note

- The esp is still pointing to the stack which was allocated in entry.S !
  - this is the kernel only stack
  - Not the per process kernel stack.
- CR3 points to kpgdir
- Struct cpu[ ] has been setup up already
  - apicid – in mpinit()
  - segdesc gdt – in seginit()
  - started – in mpmain()
- Fields in cpu[] not yet set
  - context * scheduler --> will be setup in sched()
  - taskstate ts --> large structure, only parts used in switchuvm()
  - ncli, intena --> used while locking
  - proc *proc -> set during scheduler()

scheduler()

```
void
scheduler(void)
{
  struct proc *p;
  struct cpu *c = mycpu();
  c->proc = 0;

  for(;;){
     sti();
    // Loop over process table looking for process to run.
    acquire(&ptable.lock);
    for(p = ptable.proc; p < &ptable.proc[NPROC]; p++){
      if(p->state != RUNNABLE)
        continue;
     // Switch to chosen process.  It is the process's job
      // to release ptable.lock and then reacquire it
      // before jumping back to us.
      c->proc = p;
```

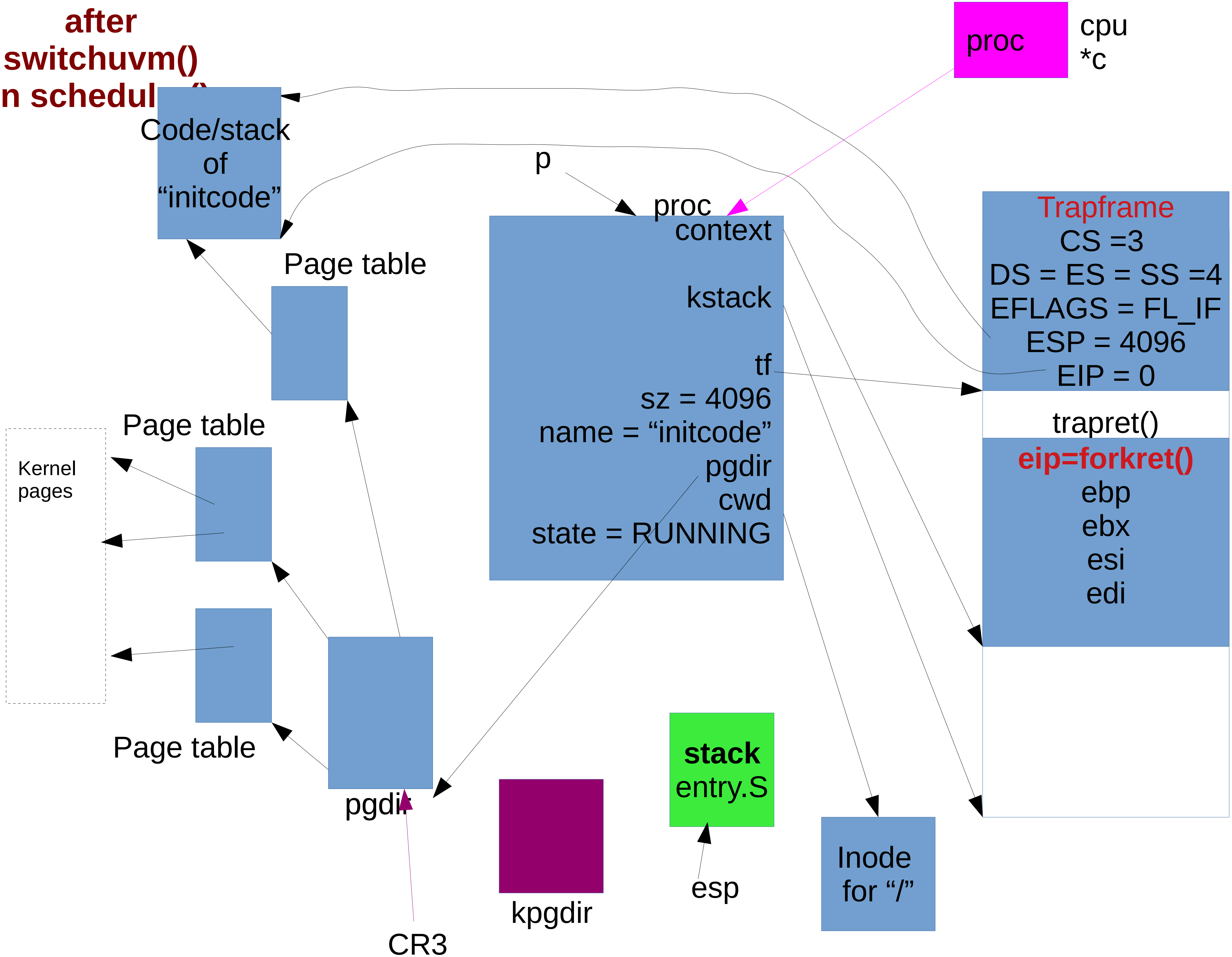

scheduler()
called first
time
proc
cpu
*c
Code/stack
of
"initcode"
p
proc
context
kstack
tf
sz = 4096
name = "initcode"
pgdir
cwd
state = RUNNALBE
Trapframe
CS =3
DS = ES = SS =4
EFLAGS = FL_IF
ESP = 4096
EIP = 0
trapret()
eip=forkret()
ebp
ebx
esi
edi
Page table
Page table
Towards
Kernel
pages
Page table
pgdir
kpgdir
CR3
stack
entry.S
esp
Inode
for "/"

scheduler()

```
acquire(&ptable.lock);
for(p = ptable.proc; p < &ptable.proc[NPROC]; p++){
  if(p->state != RUNNABLE)
    continue;

  // Switch to chosen process.  It is the process's job
  // to release ptable.lock and then reacquire it
  // before jumping back to us.
  c->proc = p;
  switchuvm(p);
  p->state = RUNNING;
```

after switchuvm() in schedul...()



scheduler()

```
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for(p = ptable.proc; p < &ptable.proc[NPROC]; p++){
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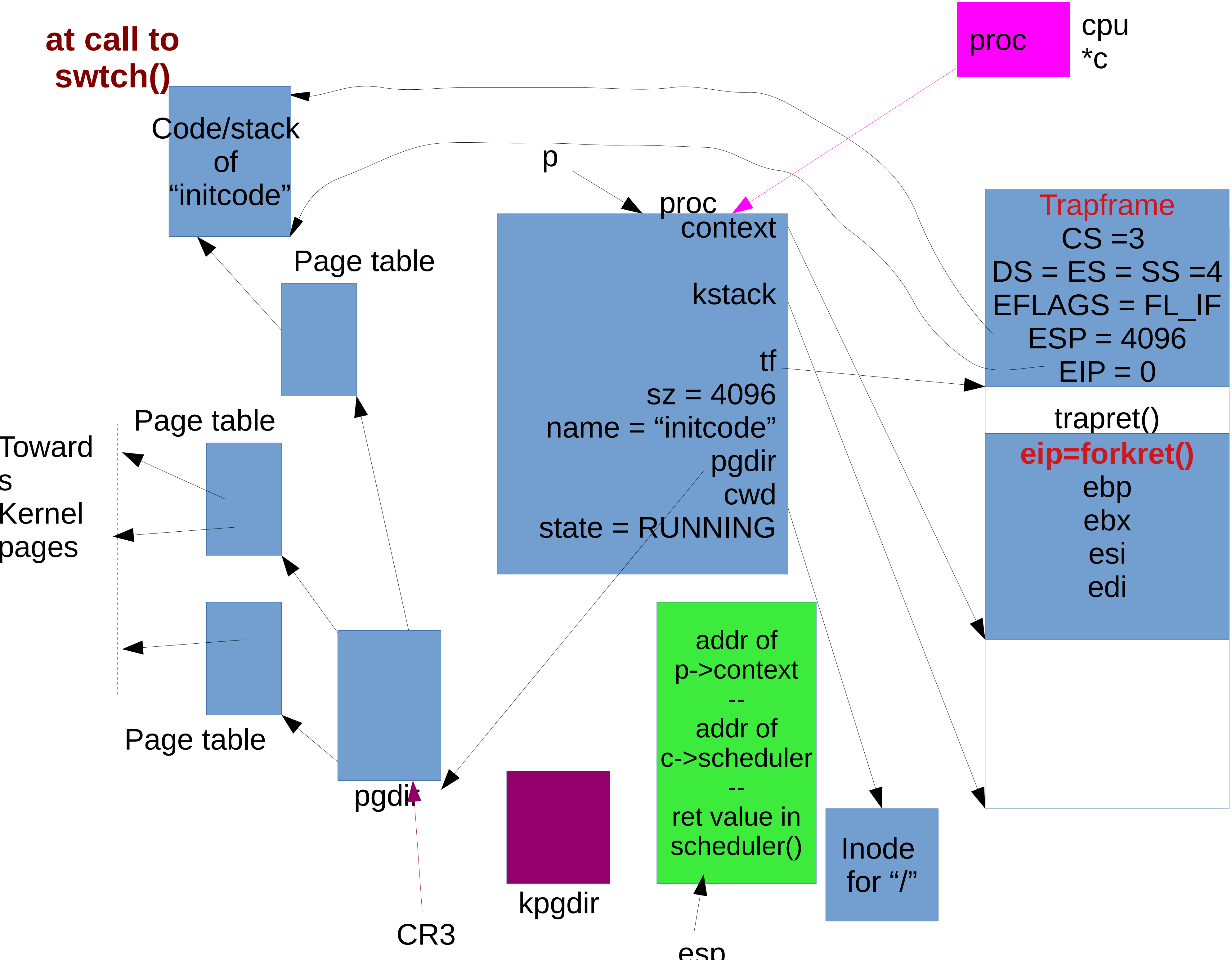
    continue;

  // Switch to chosen process.  It is the process's job
  // to release ptable.lock and then reacquire it
  // before jumping back to us.
  c->proc = p;
  switchuvm(p);
  p->state = RUNNING
  swtch(&(c->scheduler), p->context);
;
```


at call to swtch()
proc
cpu *c
Code/stack of “initcode”
p
proc
context
kstack
tf
sz = 4096
name = “initcode”
pgdir
cwd
state = RUNNING
Trapframe
CS =3
DS = ES = SS =4
EFLAGS = FL_IF
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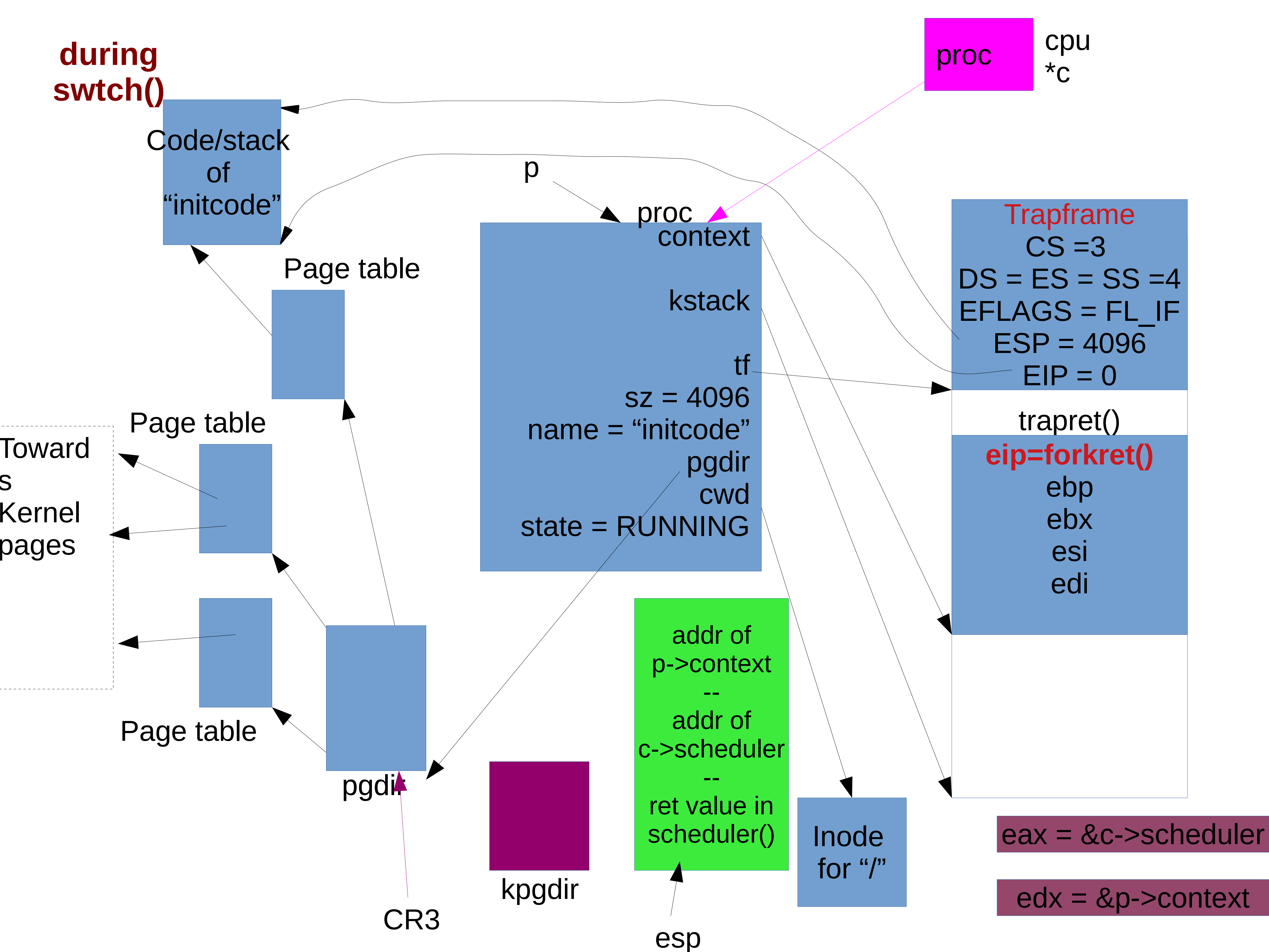
EIP = 0
trapret()
eip=forkret()
ebp
ebx
esi
edi
Page table
Page table
Towards Kernel pages
Page table
pgdir
CR3
kpgdir
addr of p->context
--
addr of c->scheduler
--
ret value in scheduler()
esp
Inode for “/”

swtch

```
swtch:
  #Abhijit: swtch was called through a function call.
  #So %eip was saved on stack already
  movl 4(%esp), %eax    # Abhijit: eax = old
  movl 8(%esp), %edx    # Abhijit: edx = new
```



during swtch()
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Code/stack of “initcode”
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Inode for “/”
eax = &c->scheduler
edx = &p->context

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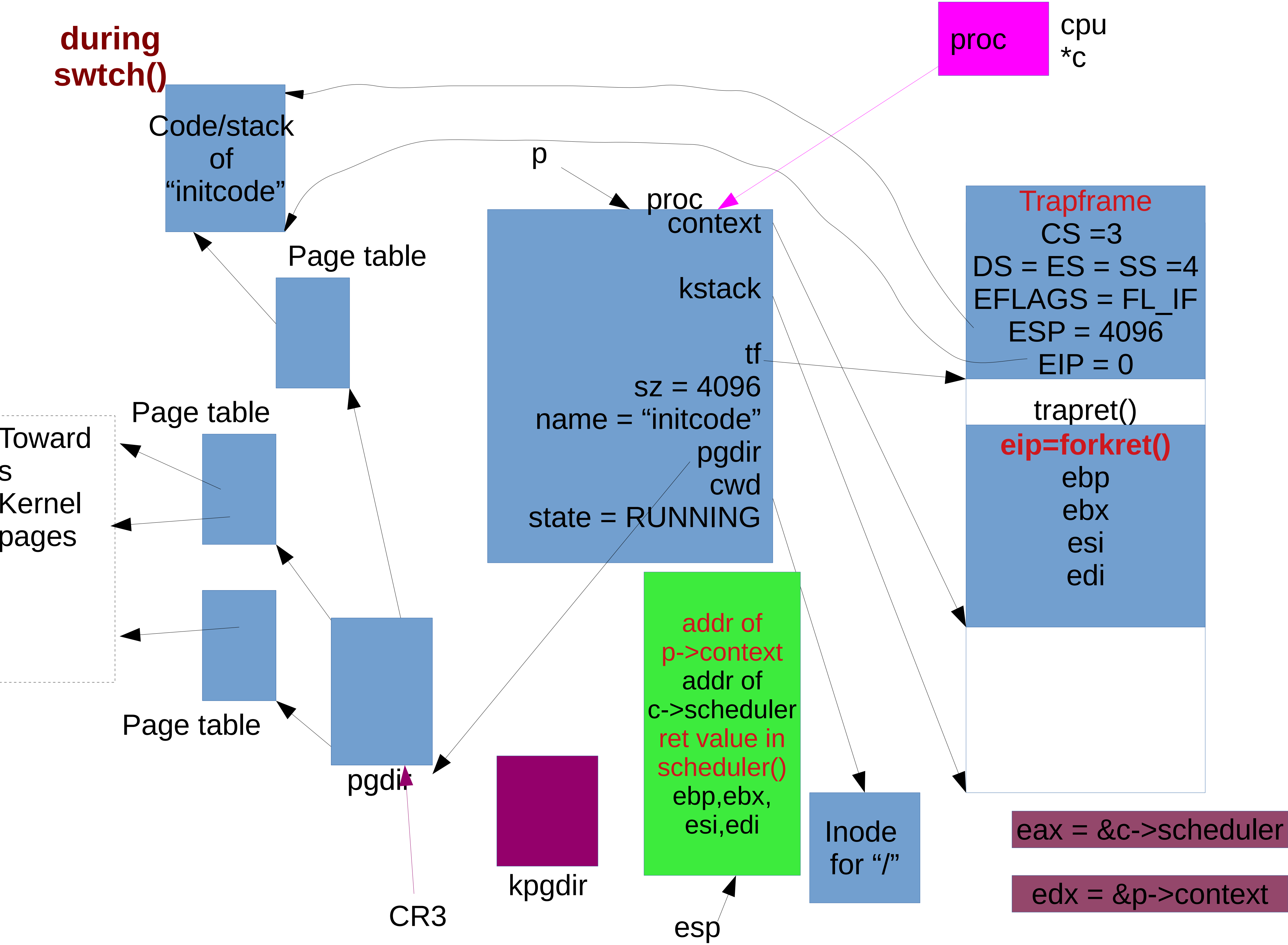
  movl 4(%esp), %eax    # Abhijit: eax = old
  movl 8(%esp), %edx    # Abhijit: edx = new
  # Save old callee-saved registers
  pushl %ebp
  pushl %ebx
  pushl %esi
  pushl %edi            # Abhijit: esp = esp + 16
```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esp
Inode for “/”
eax = &c->scheduler
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swtch

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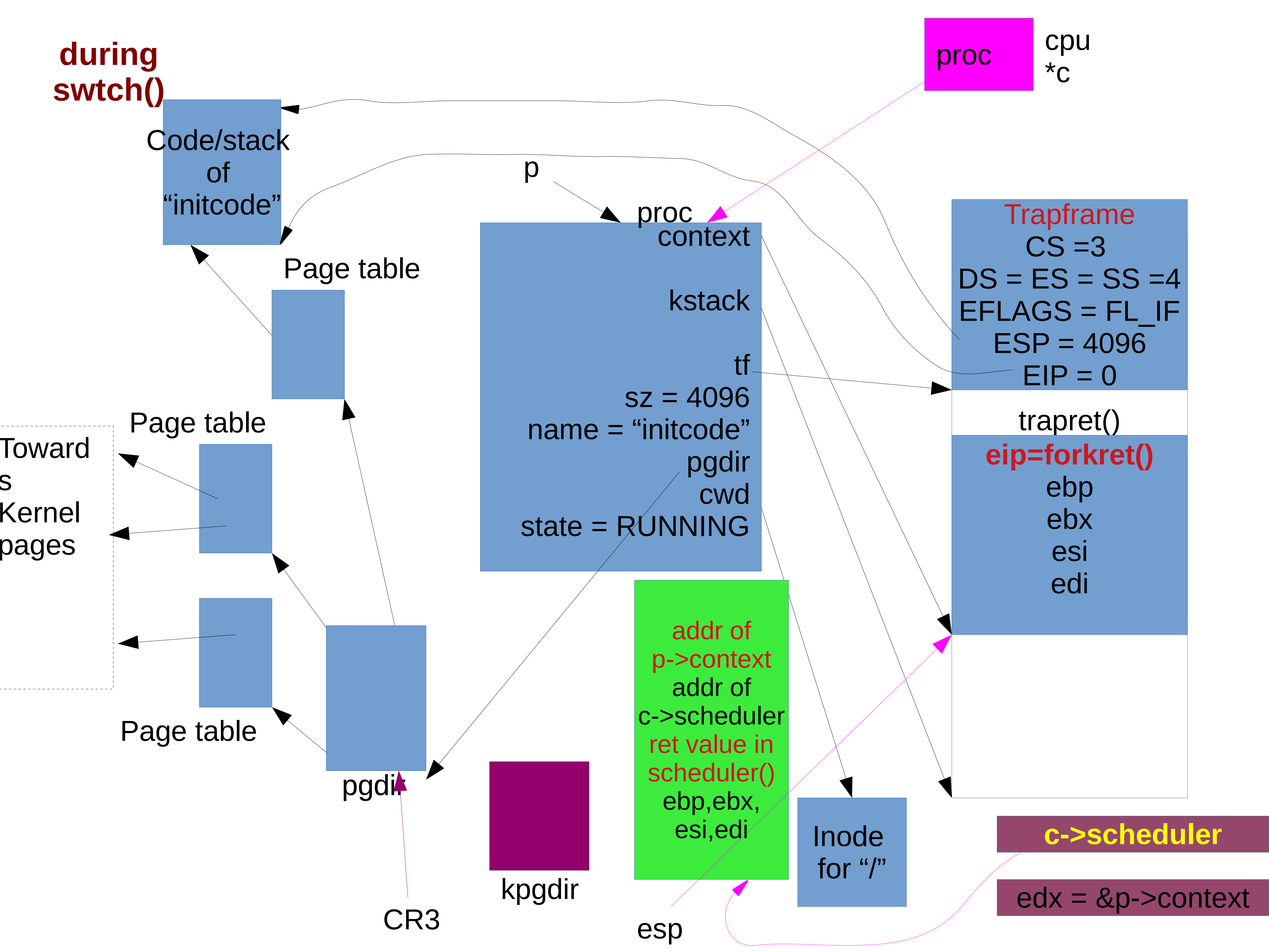
  movl 8(%esp), %edx    # Abhijit: edx = new
  # Save old callee-saved registers
  pushl %ebp
  pushl %ebx
  pushl %esi
  pushl %edi            # Abhijit: esp = esp + 16
  # Switch stacks
  movl %esp, (%eax)     # Abhijit: *old = updated old stack
  movl %edx, %esp       # Abhijit: esp = new
```



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Inode for “/”
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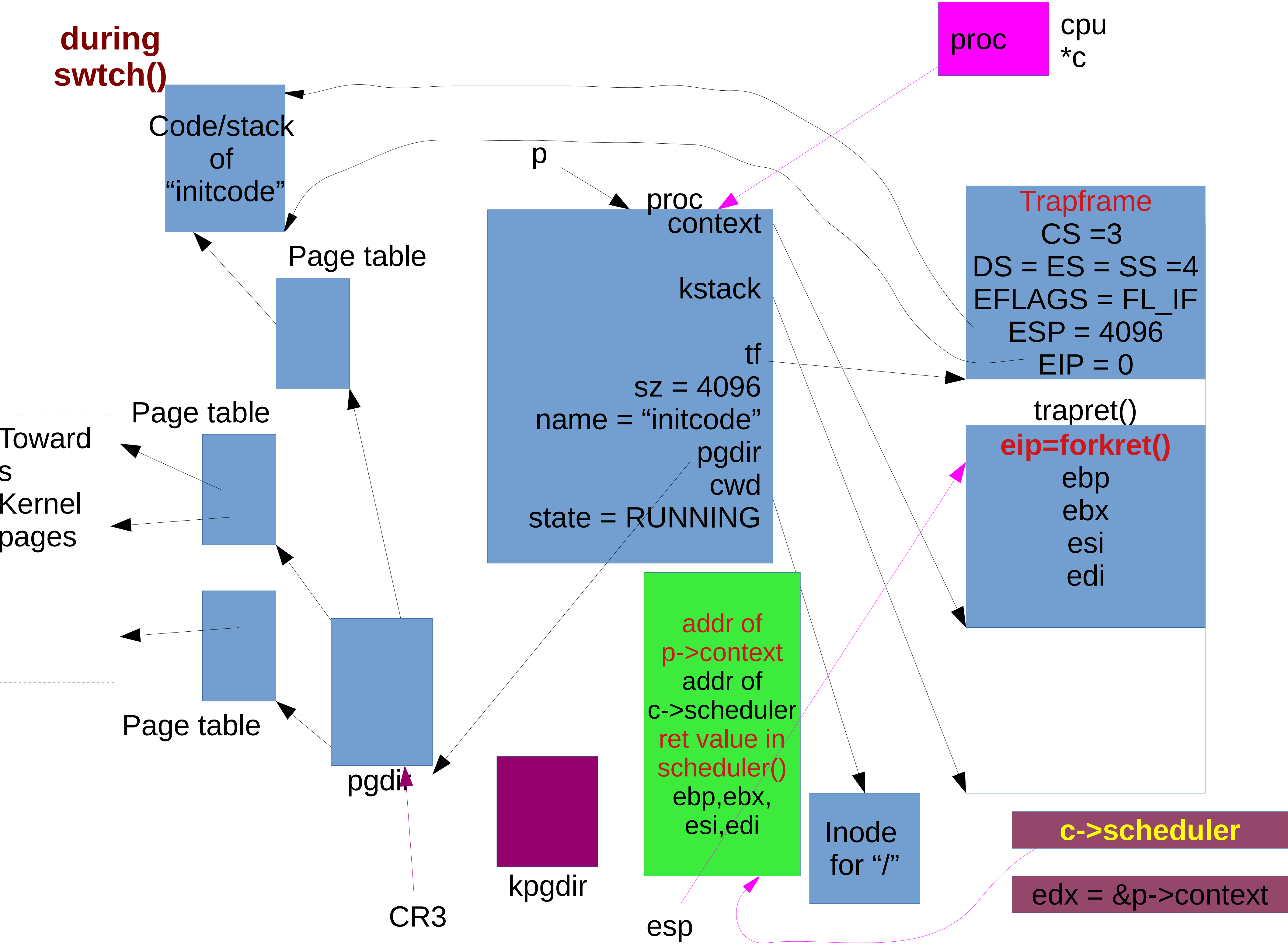
  # Save old callee-saved registers
  pushl %ebp
  pushl %ebx
  pushl %esi
  pushl %edi            # Abhijit: esp = esp + 16
  # Switch stacks
  movl %esp, (%eax)     # Abhijit: *old = updated old stack
  movl %edx, %esp       # Abhijit: esp = new
  # Load new callee-saved registers
  popl %edi
  popl %esi
  popl %ebx
  popl %ebp     # Abhijit: newesp = newesp - 16, context restored
```



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Code/stack of “initcode”
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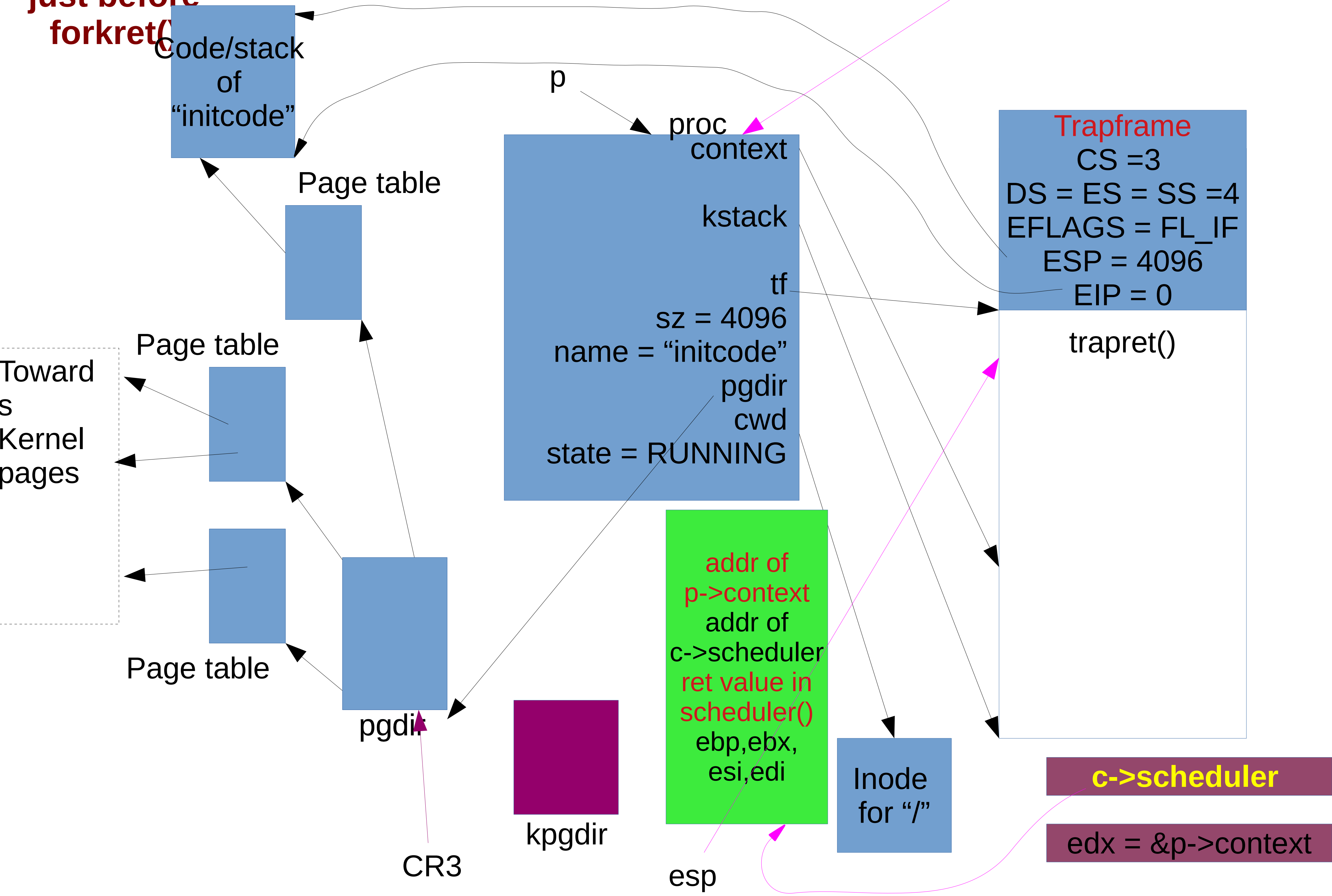
  pushl %esi
  pushl %edi            # Abhijit: esp = esp + 16
  # Switch stacks
  movl %esp, (%eax)     # Abhijit: *old = updated old stack
  movl %edx, %esp       # Abhijit: esp = new
  # Load new callee-saved registers
  popl %edi
  popl %esi
  popl %ebx
  popl %ebp      # Abhijit: newesp = newesp - 16, context restored
  ret            # Abhijit: will pop from esp now -> function where to return.
```

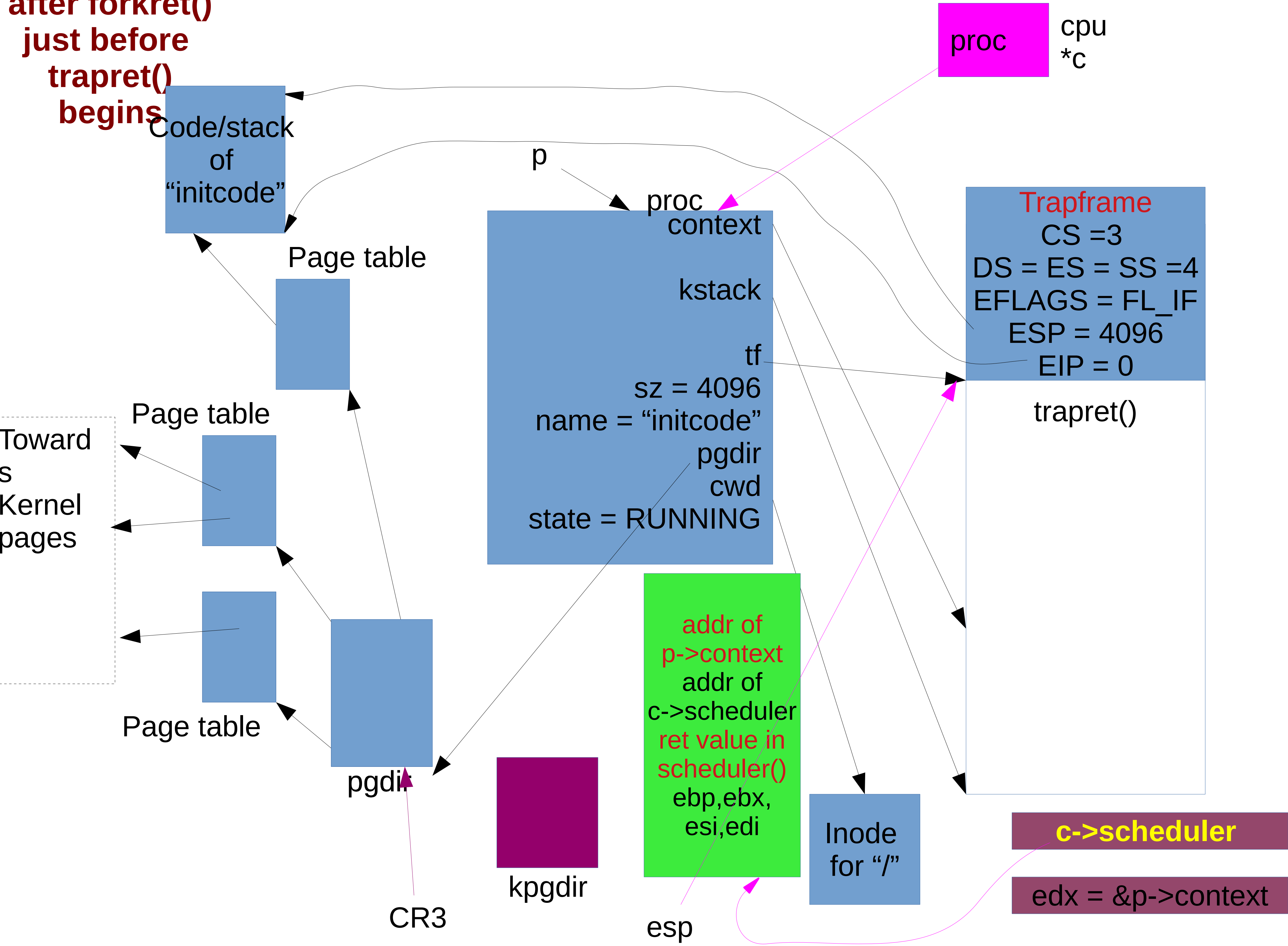
after "ret" from swtch() just before forkret()



After swtch()

- Process is running in forkret()
- c->cscheduler has saved the old kernel stack
  - with the context of p, return value in scheduler, ebp, ebx, esi, edi on stack
  - remember {edi, esi, ebx, ebp, ret-value } = context
  - The c->scheduler is pointing to old context
- CR3 is pointing to process pgdir

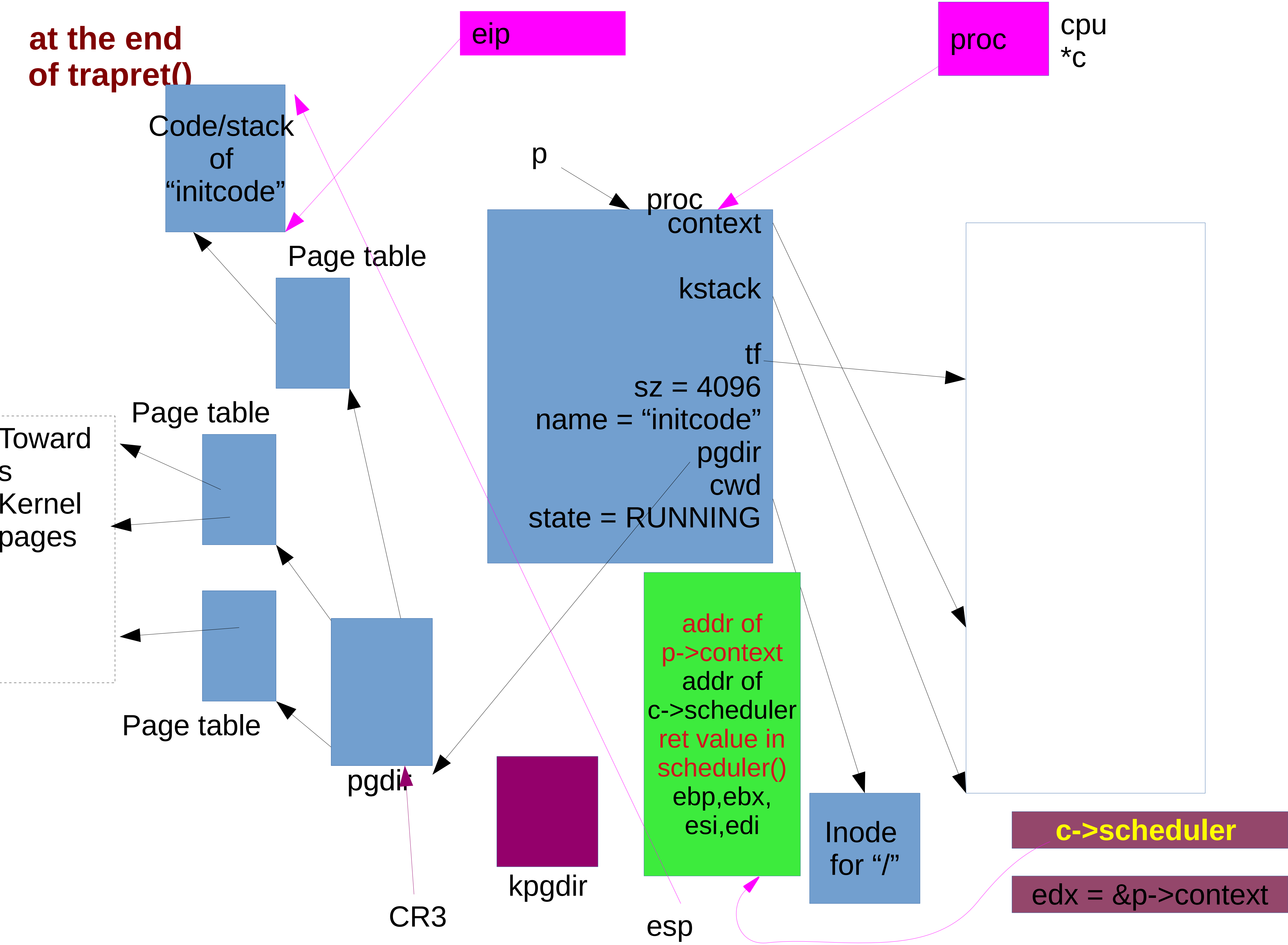
after forkret() just before trapret() begins



After iret in trapret

- **The CS, EIP, ESP will be changed**
  - **to values already stored on trapframe**
  - **this is done by iret**
- **Hence after this user code will run**
  - **On user stack!**
- **Hence code of *initcode* will run now**

at the end of trapret()



initcode

```
# char init[] = "/init\0";
init:
  .string "/init\0"

# char *argv[] = { init, 0 };
.p2align 2
argv:
  .long init
  .long 0
```

```
start:
  pushl $argv
  pushl $init
  pushl $0  // where caller pc would be
  movl $SYS_exec, %eax
  int $T_SYSCALL

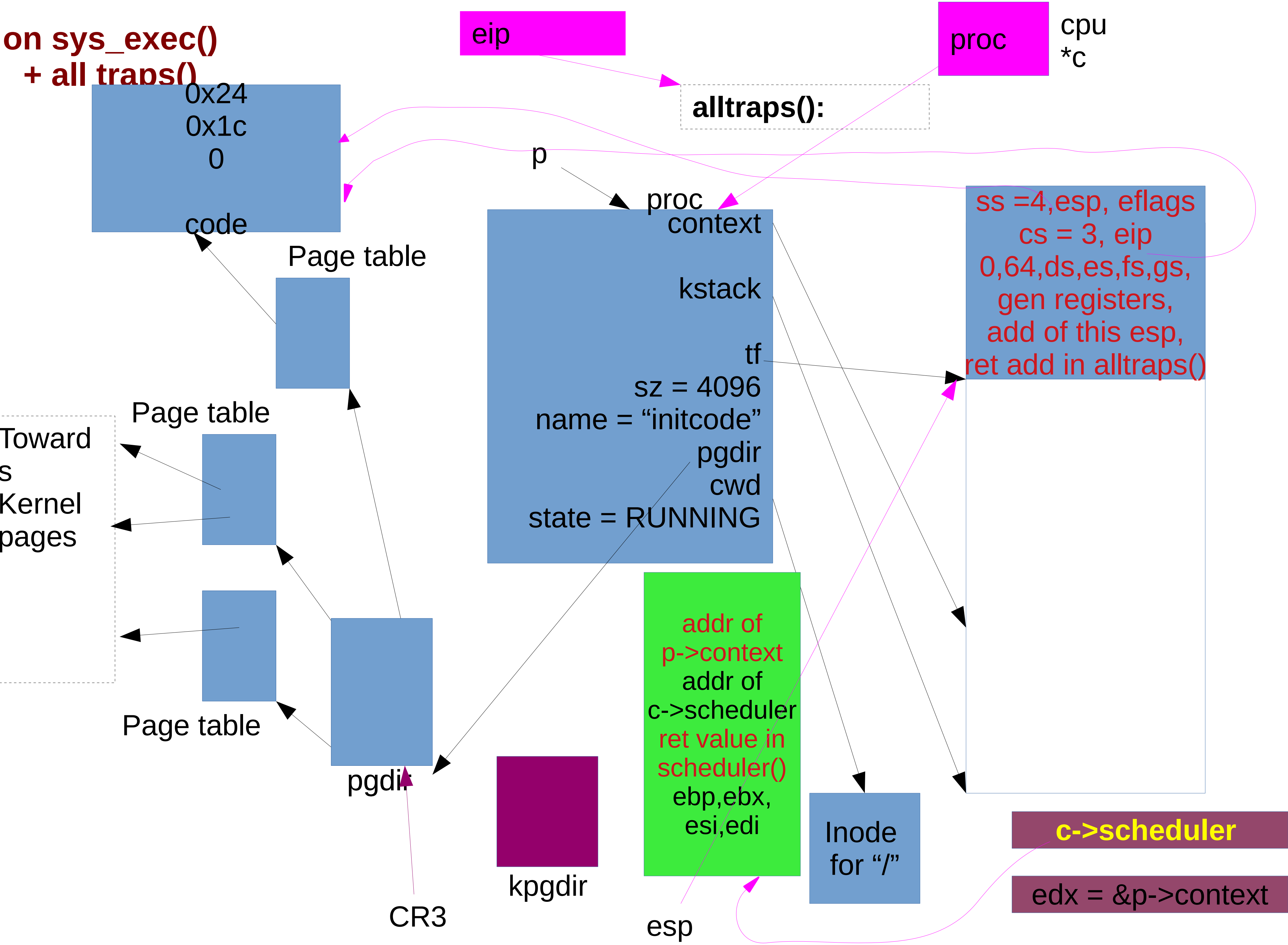
# for(;;) exit();
exit:
  movl $SYS_exit, %eax
  int $T_SYSCALL
  jmp exit
```

esp

0x24 = addr of argv
0x1c = addr of init
0x0

```
00000000 <start>:
   0:      68 24 00 00 00          push   $0x24
   5:      68 1c 00 00 00          push   $0x1c
   a:      6a 00                   push   $0x0
   c:      b8 07 00 00 00          mov    $0x7,%eax
  11:      cd 40                   int    $0x40

00000013 <exit>:
  13:      b8 02 00 00 00          mov    $0x2,%eax
  18:      cd 40                   int    $0x40
  1a:      eb f7                   jmp    13 <exit>
0000001c <init>:
           "/init\0"
00000024 <argv>:
       1c 00
       00 00
```


on sys_exec()
+ all traps()
eip
proc
cpu
*c
alltraps():
0x24
0x1c
0
code
p
proc
context
kstack
tf
sz = 4096
name = “initcode”
pgdir
cwd
state = RUNNING
ss =4,esp, eflags
cs = 3, eip
0,64,ds,es,fs,gs,
gen registers,
add of this esp,
ret add in alltraps()
Page table
Page table
Towards Kernel pages
Page table
pgdir
CR3
kpgdir
addr of
p->context
addr of
c->scheduler
ret value in
scheduler()
ebp,ebx,
esi,edi
esp
Inode
for “/”
c->scheduler
edx = &p->context

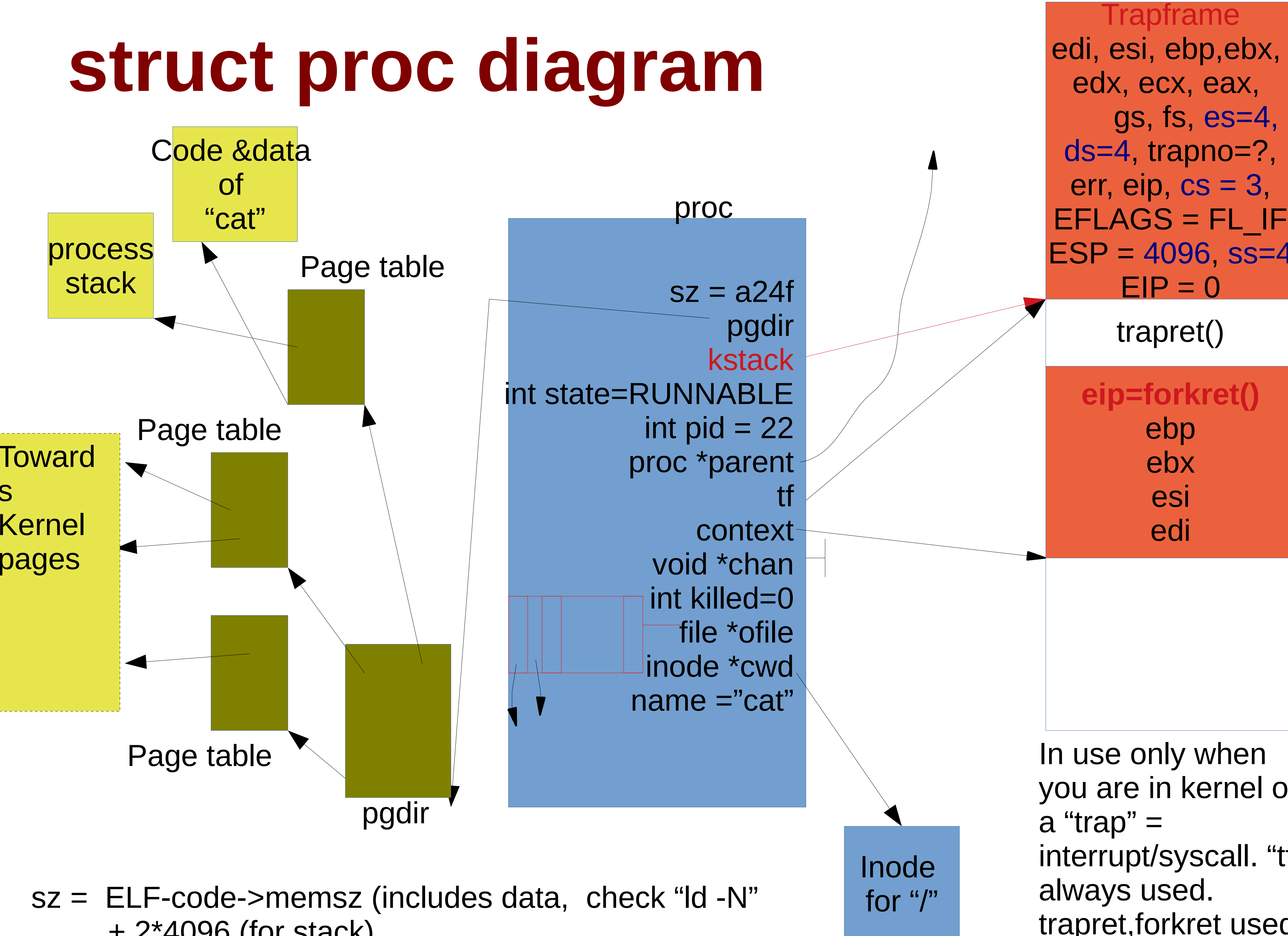
Understanding fork() and exec()

First, revising some concepts already learnt then code of fork(), exec()

First process creation
Let's revisit struct proc

```
// Per-process state
struct proc {
  uint sz;                     // Size of process memory (bytes)
  pde_t* pgdir;                // Page table
  char *kstack;                // Bottom of kernel stack for this process
  enum procstate state;        // Process state. allocated, ready to run, running, wait-
ing for I/O, or exiting.
  int pid;                     // Process ID
  struct proc *parent;         // Parent process
  struct trapframe *tf;        // Trap frame for current syscall
  struct context *context;     // swtch() here to run process. Process's context
  void *chan;                  // If non-zero, sleeping on chan. More when we discuss
sleep, wakeup
  int killed;                  // If non-zero, have been killed
  struct file *ofile[NOFILE];  // Open files, used by open(), read(),...
  struct inode *cwd;           // Current directory, changed with "chdir()"
  char name[16];               // Process name (for debugging)
};
```

struct proc diagram



sz = ELF-code->memsz (includes data, check “ld -N”
+ 2*4096 (for stack)

In use only when you are in kernel on a “trap” = interrupt/syscall. “tf” always used. trapret,forkret used during fork()

fork()/exec() are syscalls. On every syscall this happens

- Fetch the n’th descriptor from the IDT, where n is the argument of int.
- Check that CPL in %cs is <= DPL, where DPL is the privilege level in the descriptor.
- Save %esp and %ss in CPU-internal registers, but only if the target segment selector’s PL < CPL.
  - Switching from user mode to kernel mode. Hence save user code’s SS and ESP
- Load %ss and %esp from a task segment descriptor.
  - Stack changes to kernel stack now. TS descriptor is on GDT, index given by TR register. See switchuvm()

- Push %ss. // optional
- Push %esp. // optional (also changes ss,esp using TSS)
- Push %eflags.
- Push %cs.
- Push %eip.
- Clear the IF bit in %eflags, but only on an interrupt.
- Set %cs and %eip to the values in the descriptor.

After "int" 's job is done

- IDT was already set, during idtinit()
  - Remember vectors.S – gives jump locations for each interrupt
- "int 64" ->jump to 64th entry in vector table

```
vector64:
  pushl $0
  pushl $64
  jmp alltraps
```

  - So now stack has ss, esp,eflags, cs, eip, 0 (for error code), 64
  - Next run alltraps from trapasm.S

alltraps:

```
# Build trap frame.
pushl %ds
pushl %es
pushl %fs
pushl %gs
pushal // push all gen purpose regs
# Set up data segments.
movw $(SEG_KDATA<<3), %ax
movw %ax, %ds
movw %ax, %es
# Call trap(tf), where tf=%esp
pushl %esp # first arg to trap()
call trap
addl $4, %esp
```

- **Now stack contains**

  ss, esp,eflags, cs, eip, 0 (for error code), 64, ds, es, fs, gs, eax, ecx, edx, ebx, oesp, ebp, esi, edi

  - **This is the struct trapframe !**
  - **So the kernel stack now contains the trapframe**
  - **Trapframe is a part of kernel stcak**

trap()

```
void
trap(struct trapframe *tf)
{
  if(tf->trapno == T_SYSCALL){
    if(myproc()->killed)
      exit();
    myproc()->tf = tf;
    syscall();
    if(myproc()->killed)
      exit();
    return;
  }
  switch(tf->trapno){
  .....
```

- Argument is trapframe
- In alltraps
  - Before "call trap", there was "push %esp" and stack had the trapframe
  - Remember calling convention --> when a function is called, the stack contains the arguments in reverse order (here only 1 arg)

trap()

- Has a switch
  - switch(tf->trapno)
  - Q: who set this trapno?
- Depending on the type of trap
  - Call interrupt handler

- Timer
  - wakeup(&ticks)
- IDE: disk interrupt
  - Ideintr()
- KBD
  - Kbdintr()
- COM1
  - Uatrintr()
- If Timer
  - Call yield() -- calls sched()
- If process was killed (how is that done?
  - Call exit()!

when trap() returns

- #Back in alltraps

```
  call trap
  addl $4, %esp

  # Return falls through to trapret...
.globl trapret
trapret:
  popal
  popl %gs
  popl %fs
  popl %es
  popl %ds
  addl $0x8, %esp  # trapno and errcode
  iret
```

- Stack had (trapframe)
  - ss, esp,eflags, cs, eip, 0 (for error code), 64, ds, es, fs, gs, eax, ecx, edx, ebx, oesp, ebp, esi, edi, esp
- add $4 %esp
  - esp
- popal
  - eax, ecx, edx, ebx, oesp, ebp, esi, edi
- Then gs, fs, es, ds
- add $0x8, %esp
  - 0 (for error code), 64
- iret
  - ss, esp,eflags, cs, eip,

understanding fork()

- **What should fork do?**
  - **Create a copy of the existing process**
  - **child is same as parent, except pid, parent-child relation, return value (pid or 0)**
  - **Please go through every member of struct proc, understand it's meaning to appreciate what fork() should do**
  - **create a struct proc, and**
    - **duplicate pages, page directory, sz, state,trapframe,context, ofile (and files!), cwd, name**
    - **modify: pid, parent, trapframe, state**

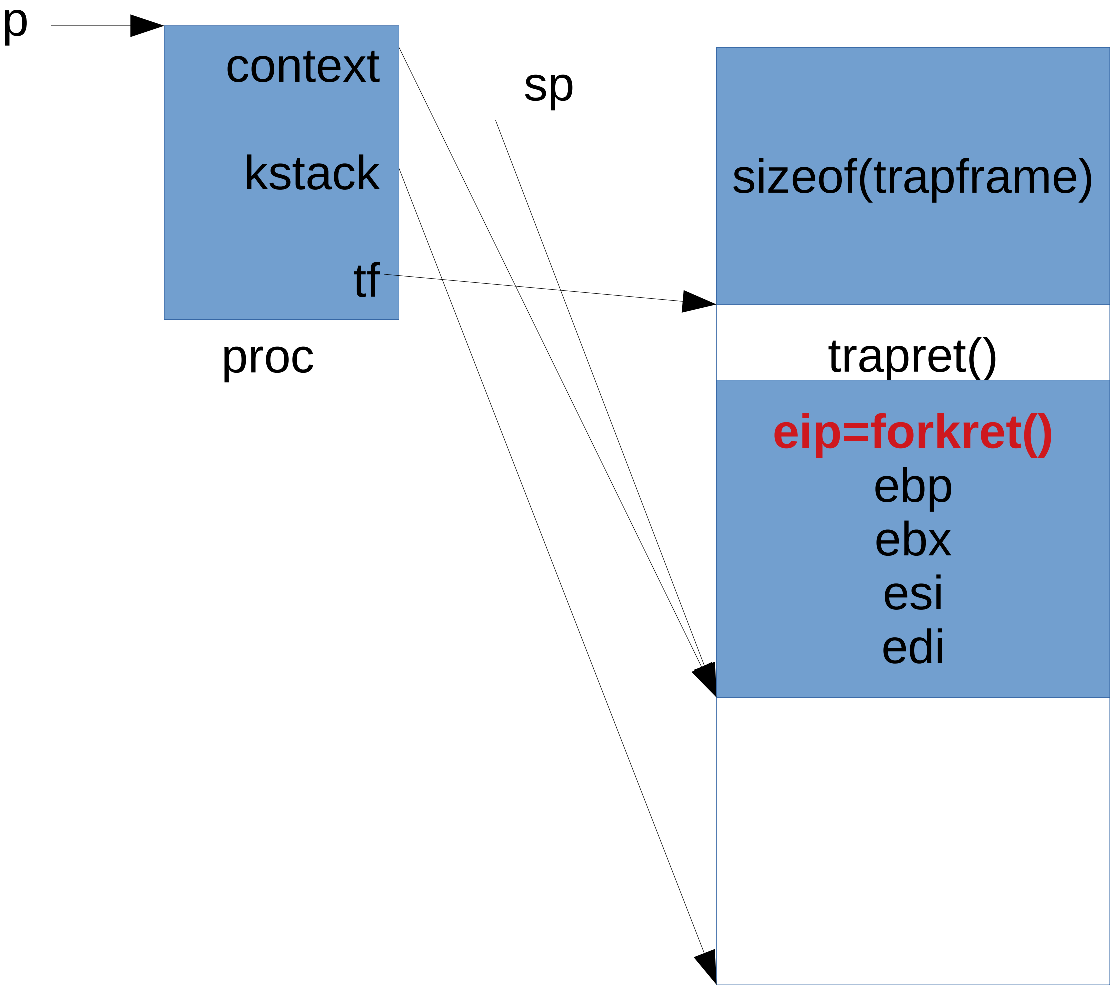
understanding fork()

```
int
sys_fork(void)
{
  return fork();
}
```

```
int
fork(void)
{
  int i, pid;
  struct proc *np;
  struct proc *curproc = myproc();

  // Allocate process.
  if((np = allocproc()) == 0){
    return -1;
  }
```

after allocproc()
-- we studied this -- same as creation of first process



understanding fork()

```
// Copy process state from proc.
if((np->pgdir = copyuvm(curproc->pgdir, curproc->sz)) == 0){
  kfree(np->kstack);
  np->kstack = 0;
  np->state = UNUSED;
  return -1;
}
np->sz = curproc->sz;
np->parent = curproc;
*np->tf = *curproc->tf;
```

- copy the pages, page tables, page directory
  - no copy on write here!
  - Rewind if operation of copyuvm() fails
- copy size
- set parent of child
- copy trapframe (structure is copied)

understanding fork()->copyuvm()

```
pde_t*
copyuvm(pde_t *pgdir, uint sz)
{
  pde_t *d;  pte_t *pte;  uint pa, i, flags;
  char *mem;
  if((d = setupkvm()) == 0)
    return 0;
  for(i = 0; i < sz; i += PGSIZE){
    if((pte = walkpgdir(pgdir, (void *) i, 0)) == 0)
      panic("copyuvm: pte should exist");
    if(!(*pte & PTE_P))
      panic("copyuvm: page not present");
    pa = PTE_ADDR(*pte);
    flags = PTE_FLAGS(*pte);
    if((mem = kalloc()) == 0)
      goto bad;
    memmove(mem, (char*)P2V(pa), PGSIZE);
    if(mappages(d, (void*)i, PGSIZE, V2P(mem), flags) < 0) {
      kfree(mem);
      goto bad;
    }
  }
  return d;
bad:
  freevm(d);
  return 0;
}
```

- Map kernel pages
- for every page in parent's VM address space
  - allocate a PTE for child
  - set flags
  - copy data
  - map pages in child's page directory/tables

understanding fork()

```
np->tf->eax = 0;
for(i = 0; i < NOFILE; i++)
  if(curproc->ofile[i])
    np->ofile[i] = filedup(curproc->ofile[i]);
np->cwd = idup(curproc->cwd);
safestrcpy(np->name, curproc->name, sizeof(curproc->name));
pid = np->pid;
acquire(&ptable.lock);
np->state = RUNNABLE;
release(&ptable.lock);
```

- set return value of child to 0
  - eax contains return value, it’s on TF
- copy each struct file
- copy current working dir inode
- copy name
- set pid of child
- set child “RUNNABLE”

exec() - different prototype

- **int exec(char*, char**);**
  - **usage: to print README and test.txt using “cat”**

```
int main(int argc, char *argv[])
{
    char *cmd = "/cat";
    char *argstr[4] = { "/cat", "README",
"test.txt", 0};
    exec(cmd, argstr);
}
```

note: to really run this code in xv6, you need to make changes to Makefile. First, add this program to UPROGS, then write a file test.txt using Linux, and add ‘test.txt’ to list of files in ‘mkfs’ target in Makefile

```c
int
sys_exec(void)
{
  char *path, *argv[MAXARG];
  int i;
  uint uargv, uarg;
  if(argstr(0, &path) < 0 || argint(1, (int*)&uargv) < 0){
    return -1;
  }
  memset(argv, 0, sizeof(argv));
  for(i=0;; i++){
    if(i >= NELEM(argv))
      return -1;
    if(fetchint(uargv+4*i, (int*)&uarg) < 0)
      return -1;
    if(uarg == 0){
      argv[i] = 0;
      break;
    }
    if(fetchstr(uarg, &argv[i]) < 0)
      return -1;
  }
  return exec(path, argv);
}
```

sys_exec()

- **argstr(n,), argint(n,)**
  - **Fetch the n'th argument from *process stack* using p->tf->esp + offset**
  - **Again: revise calling conventions**
  - **0'th argument: name of executable file**
  - **1st Argument: address of the array of arguments**
    - **store in *uargv***

sys_exec()

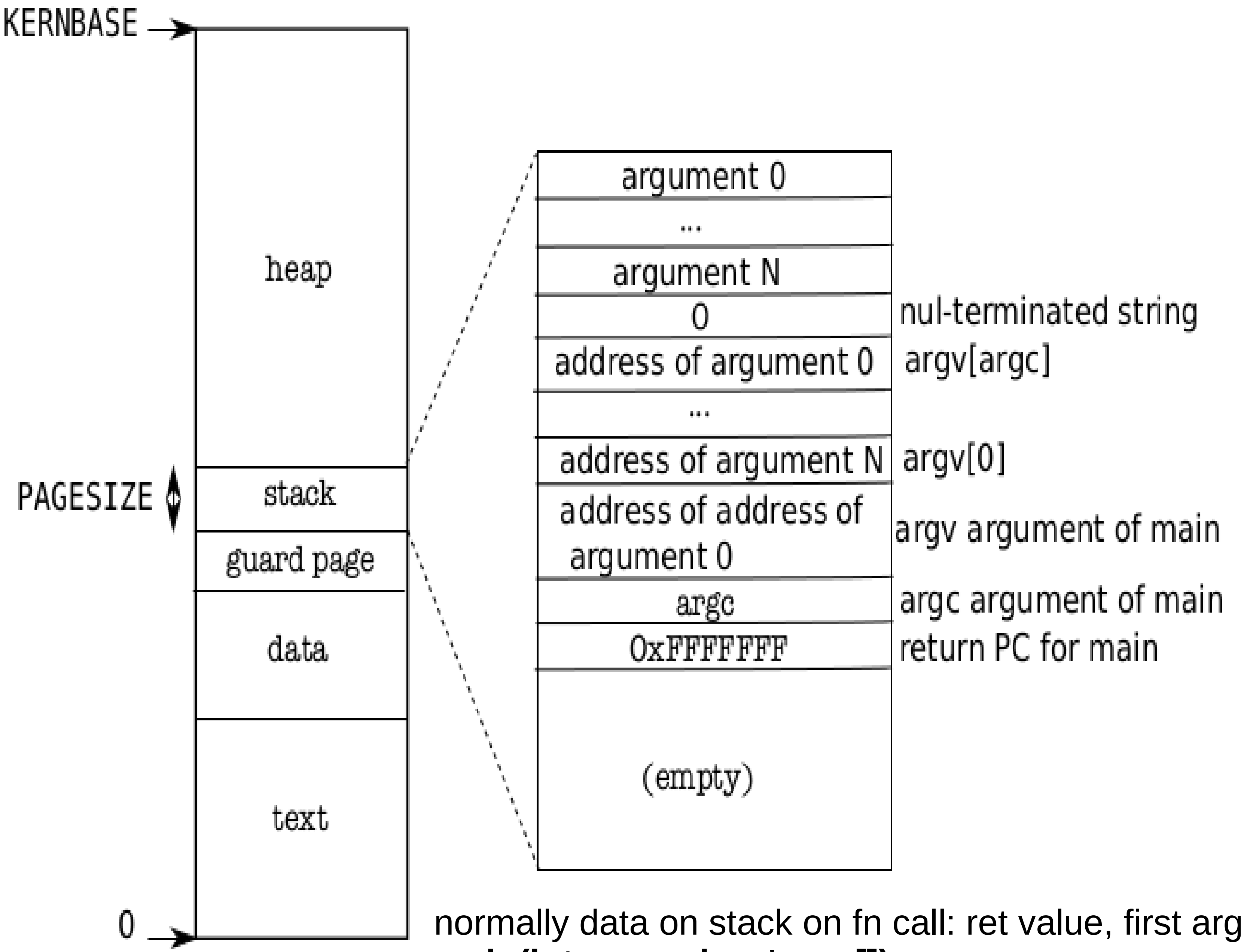
```
int sys_exec(void)
{
  char *path, *argv[MAXARG];
  int i;   uint uargv, uarg;
  if(argstr(0, &path) < 0 || argint(1,
(int*)&uargv) < 0){
    return -1;
  }
  memset(argv, 0, sizeof(argv));
  for(i=0;; i++){
    if(i >= NELEM(argv))    return -1;
    if(fetchint(uargv+4*i, (int*)&uarg) < 0)
      return -1;
    if(uarg == 0){
      argv[i] = 0;      break;
    }
    if(fetchstr(uarg, &argv[i]) < 0)
      return -1;
  }
  return exec(path, argv);
}
```

- the local array argv[] (allocated on kernel stack, obviously) set to 0
- fetch every next argument from array of arguments
  - Sets the address of argument in argv[1]
- call exec
  - beware: mistake to assume that this exec() is the exec() called from user code! NO!

What should exec() do?

- Remember, it came from fork()
  - so proc & within it tf, context, kstack, pgdir-tables-pages, all exist.
  - Code, stack pages exist, and mappings exist through proc->pgdir
- Hence
  - read the ELF executable file (argv[0])
  - create a new page dir – create mappings for kernel and user code+data; copy data from ELF to these pages (later discard old pagedir)
  - Copy the argv onto the user stack – so that when new process starts it has it's main(argc, argv[]) built
  - set values of other fields in proc to start program correctly

User stack after call to exec() is over



normally data on stack on fn call: ret value, first arg, second arg, ...
main(int argc, char *argv[])
argv[] is address of array of string; string itself is an adress. Hence 2 levels of indirection on stack

exec()

```
int
exec(char *path, char **argv)
{
...
  uint argc, sz, sp, ustack[3+MAXARG+1];
...
  if((ip = namei(path)) == 0){
    end_op();
    cprintf("exec: fail\n");
    return -1;
  }
```

- **ustack**
  - used to build the arguments to be pushed on user-stack
- **namei**
  - get the inode of the executable file

exec()

```
// Check ELF header
if(readi(ip, (char*)&elf, 0, sizeof(elf)) != sizeof(elf))
  goto bad;
if(elf.magic != ELF_MAGIC)
  goto bad;

if((pgdir = setupkvm()) == 0)
  goto bad;
```

- **readi**
  - **read ELF header**
- **setupkvm()**
  - **creating a *new* page directory and mapping kernel pages**

exec()

```
sz = 0;
for(i=0, off=elf.phoff; i<elf.phnum; i++, off+=sizeof(ph)){
  if(readi(ip, (char*)&ph, off, sizeof(ph)) != sizeof(ph))
    goto bad;
  if(ph.type != ELF_PROG_LOAD)
    continue;
  if(ph.memsz < ph.filesz)
    goto bad;
  if(ph.vaddr + ph.memsz < ph.vaddr)
    goto bad;
  if((sz = allocuvm(pgdir, sz, ph.vaddr + ph.memsz)) == 0)
    goto bad;
  if(ph.vaddr % PGSIZE != 0)
    goto bad;
  if(loaduvm(pgdir, (char*)ph.vaddr, ip, ph.off, ph.filesz) <
0)
    goto bad;
}
```

- Read ELF program headers from ELF file
- Map the code/data into pagedir-pagetable-pages
- Copy data from ELF file into the pages allocated

exec()

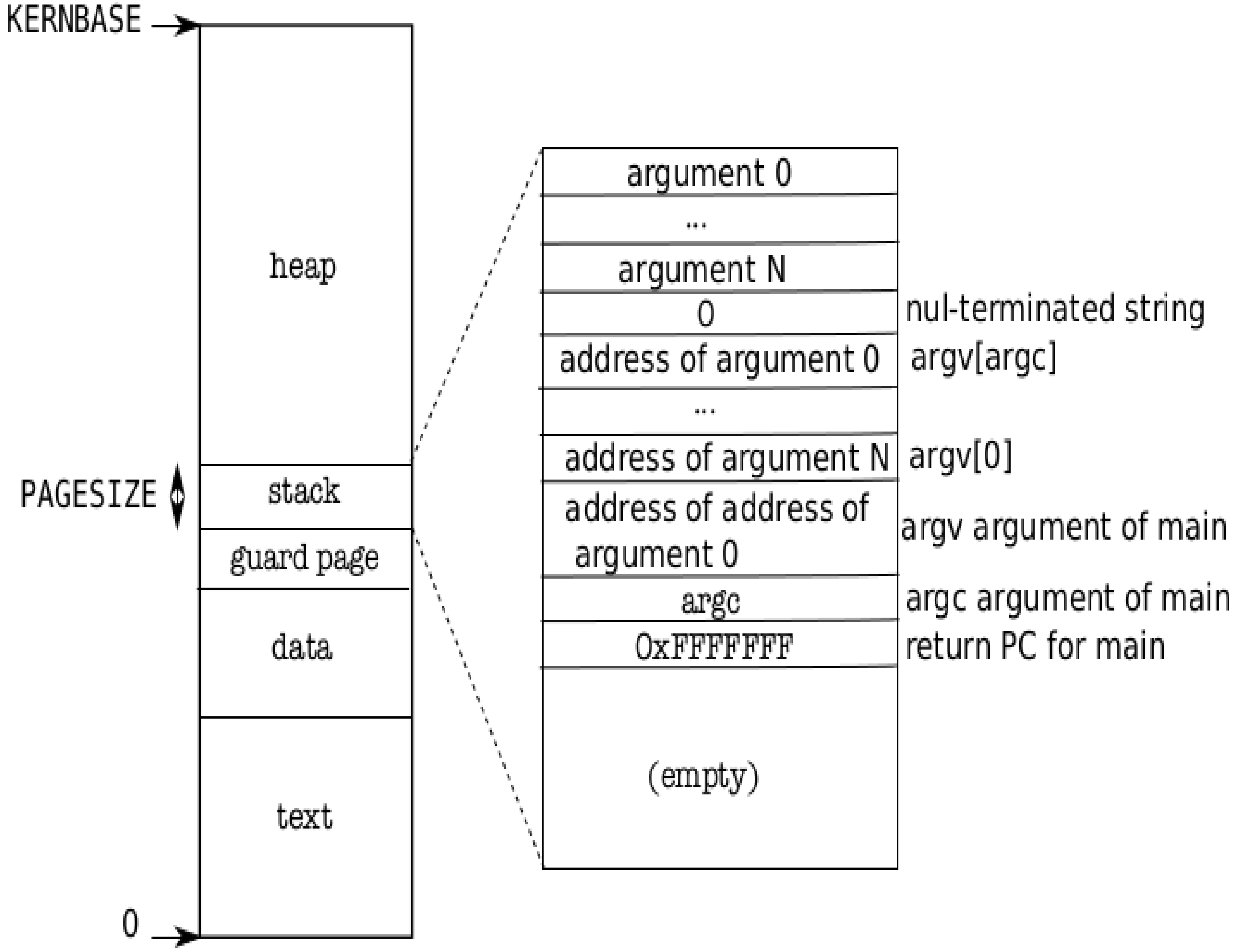
```
sz = PGROUNDUP(sz);
if((sz = allocuvm(pgdir, sz, sz + 2*PGSIZE)) == 0)
  goto bad;
clearpteu(pgdir, (char*)(sz - 2*PGSIZE));
sp = sz;
```

- Allocate 2 pages on top of proc->sz
- One page for stack
- one page for guard page
- Clear the valid flag on guard page

exec()

```
  // Push argument strings, prepare rest of stack
in ustack.
  for(argc = 0; argv[argc]; argc++) {
    if(argc >= MAXARG)
      goto bad;
    sp = (sp - (strlen(argv[argc]) + 1)) & ~3;
    if(copyout(pgdir, sp, argv[argc],
strlen(argv[argc]) + 1) < 0)
      goto bad;
    ustack[3+argc] = sp;
  }
  ustack[3+argc] = 0;
  ustack[0] = 0xffffffff;  // fake return PC
  ustack[1] = argc;
  ustack[2] = sp - (argc+1)*4;  // argv pointer
  sp -= (3+argc+1) * 4;
  if(copyout(pgdir, sp, ustack, (3+argc+1)*4) < 0)
    goto bad;
```

- For each entry in argv[]
  - copy it on user-stack
  - remember it's location on user stack in ustack
- add extra entries (to be copied to user stack) to ustack
- copy argc, argv pointer
- take sp to bottom
- copy ustack to user stack



This is what the code on earlier slide did

```
// Save program name for debugging.
for(last=s=path; *s; s++)
  if(*s == '/')
    last = s+1;
safestrcpy(curproc->name, last,
sizeof(curproc->name));

// Commit to the user image.
oldpgdir = curproc->pgdir;
curproc->pgdir = pgdir;
curproc->sz = sz;
curproc->tf->eip = elf.entry;  // main
curproc->tf->esp = sp;
switchuvm(curproc);
freevm(oldpgdir);
return 0;
```

exec()

- copy name of new process in proc->name
- change to new page directory
- change new size
- tf->eip will be used when we return from exec() to jump to user code. Set to to first instruction of code, given by elf.entry
- Set user stack pointer to “sp” (bottom of stack of arguments)
- Update TSS, change CR3 to newpagedir
- free old page dir

return 0 from exec()?

- We know exec() does not return !
- This was exec() function !
  - Returns to sys_exec()
- sys_exec() also returns , where?
  - Remember we are still in kernel code, running on kernel stack. p->kstack has the trapframe setup
  - There is context struct on stack. Why?
  - sys_exec() returns to trapret(), the trap frame will be popped !
    - with “iret” jump into new program !
  - New program is not old program , which could have accessed return value of sys_exec()