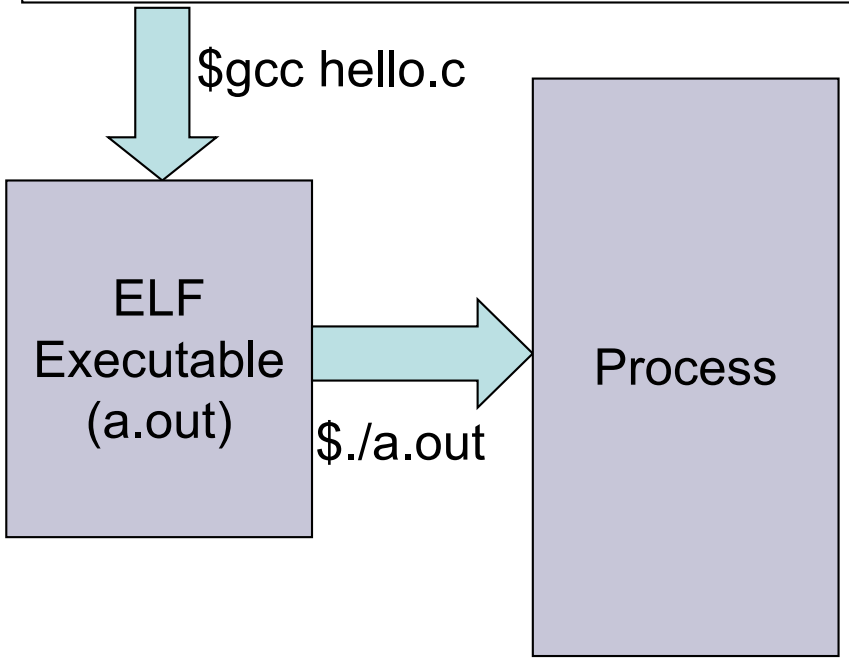
Processes

Chester Rebeiro
IIT Madras

Executing Apps (Process)

```c
#include <stdio.h>

int main(){
  char str[] = "Hello World\n";
  printf("%s", str);
}
```



- Process
  - A program in execution
  - Most important abstraction in an OS
  - Comprises of
    - Code
    - Data
    - Stack
    - Heap
    - State in the OS
    - Kernel stack

    (Code, Data: from ELF; Stack, Heap, State in the OS, Kernel stack: In the user space of process; State in the OS, Kernel stack: In the kernel space)
  - State contains : registers, list of open files, related processes, etc.

note that each process has two stacks - the user stack to store variables and stuff
a kernel stack to store local variables for syscall handlers.
the trapframe is used to store context during switches or system calls

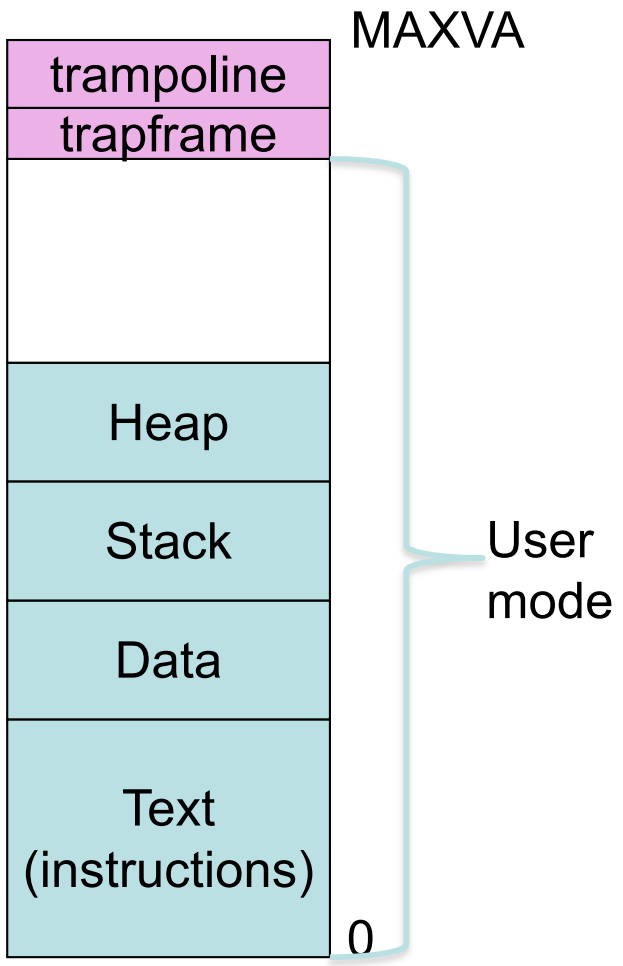
Program ≠ Process

Program	Process
code + static and global data	Dynamic instantiation of code + data + heap + stack + process state
One program can create several processes	A process is unique isolated entity

Process Address Space

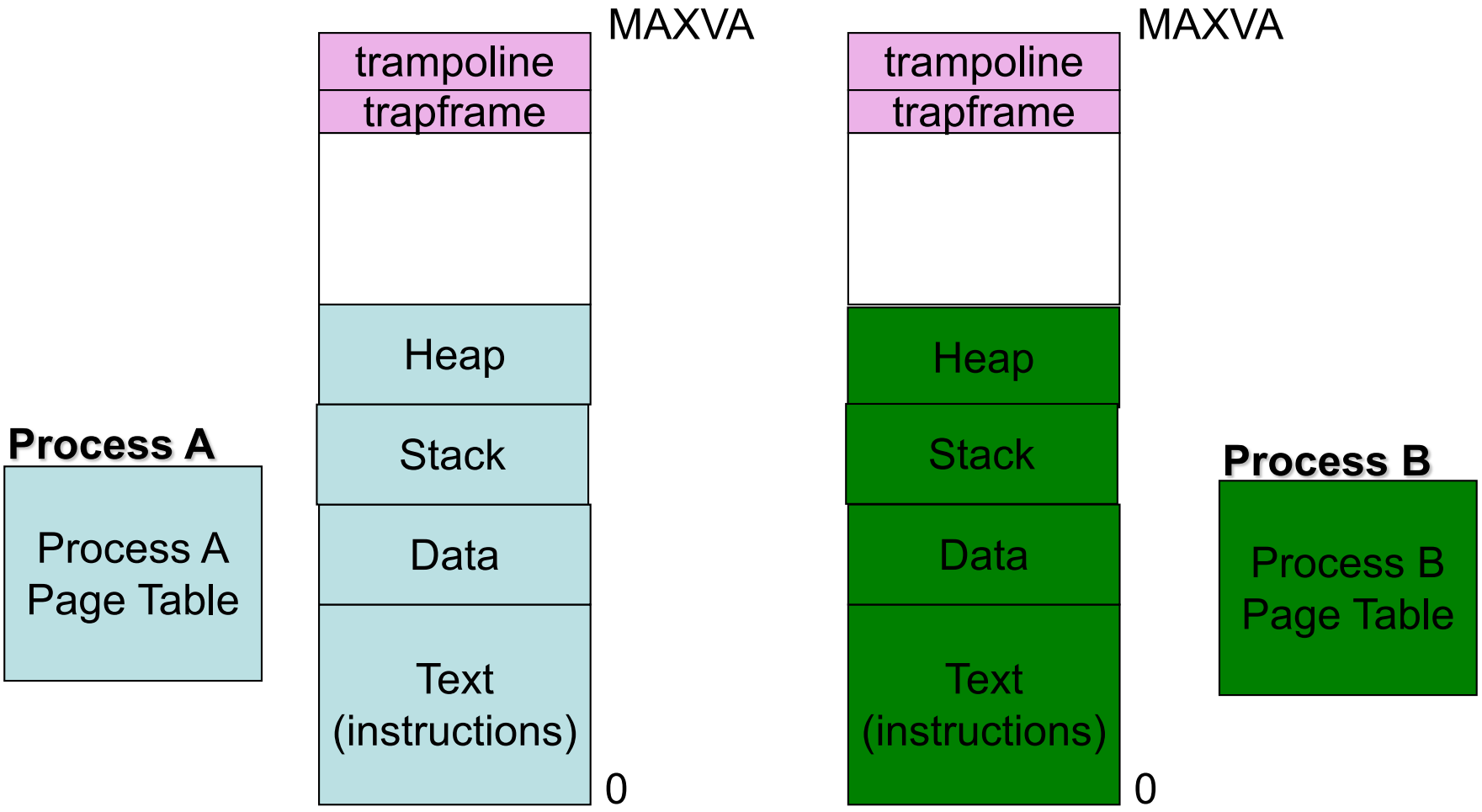
a user process can touch any of the regions except the pink(mapped to sv)

- Virtual Address Map
  - All memory a process can address
  - Large contiguous array of addresses from 0 to MAXVA

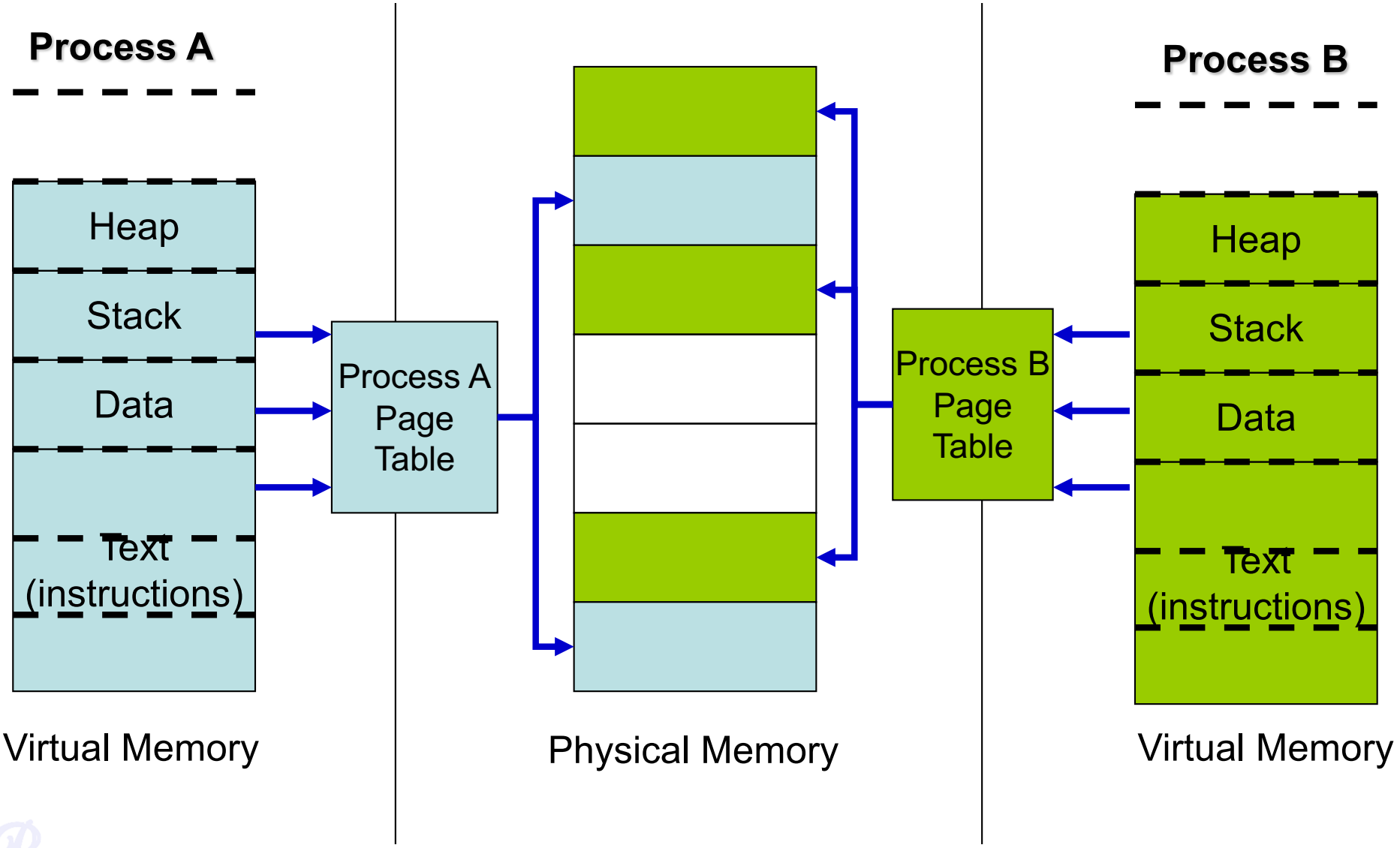


Process Address Space

- Each process has a different address space
- This is achieved by the use of virtual memory
- Ie. 0 to MAXVA are virtual memory addresses



Virtual Address Mapping



Advantages of Virtual Address Map

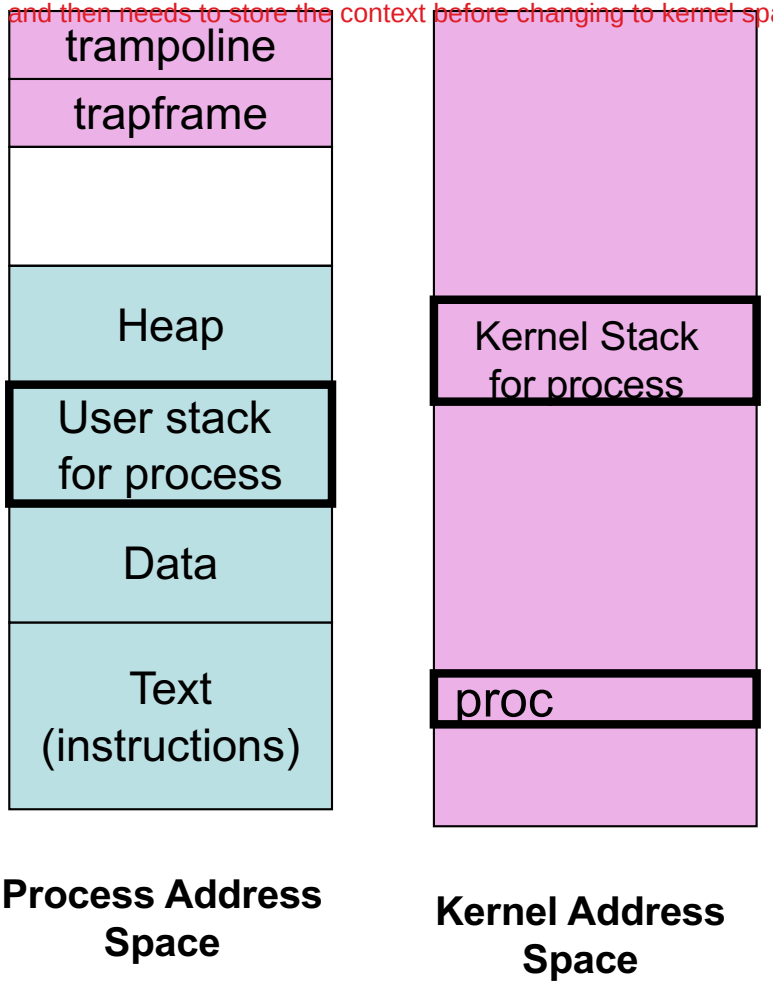
- Isolation (private address space)
  - One process cannot access another process' memory
- Relocatable
  - Data and code within the process is relocatable
- Size
  - Processes can be much larger than physical memory

Process Stacks

- Each process has 2 stacks
  - User space stack
    - Used when executing user code
  - Kernel space stack
    - Used when executing kernel code (for eg. during system calls)
  - Advantage : Kernel can execute even if user stack is corrupted

    (Attacks that target the stack, such as buffer overflow attack, will not affect the kernel)

pink regions are accessible only to the kernel
the pink region in the user space is used when it has moved to sv mode and then needs to store the context before changing to kernel space



the kernel does not have demand paging to prevent the possibility of the page fault handler getting swapped out and there being no way to handle page faults after that

the kernel is needed to store the context into satp
also to store the register context in memory locations of trapframes

Process Management in xv6

- Each process has a PCB (process control block) defined by struct proc in xv6
- Holds important process specific information
- Why?
  - Allows process to resume execution after a while
  - Keep track of resources used
  - Track the process state

ref : proc.h (struct proc)

Summary of entries in PCB

proc.c

```
struct proc proc[NPROC];
```

proc.h

```
 86 struct proc {
 87   struct spinlock lock;
 88
 89   // p->lock must be held when using these:
 90   enum procstate state;        // Process state
 91   struct proc *parent;         // Parent process
 92   void *chan;                  // If non-zero, sleeping on chan
 93   int killed;                  // If non-zero, have been killed
 94   int xstate;                  // Exit status to be returned to parent's wait
 95   int pid;                     // Process ID
 96
 97   // these are private to the process, so p->lock need not be held.
 98   uint64 kstack;               // Bottom of kernel stack for this process
 99   uint64 sz;                   // Size of process memory (bytes)
100   pagetable_t pagetable;       // Page table
101   struct trapframe *tf;        // data page for trampoline.S
102   struct context context;      // swtch() here to run process
103   struct file *ofile[NOFILE];  // Open files
104   struct inode *cwd;           // Current directory
105   char name[16];               // Process name (debugging)
106 };
```

Entries in PCB

```
95    int pid;                    // Process ID
```

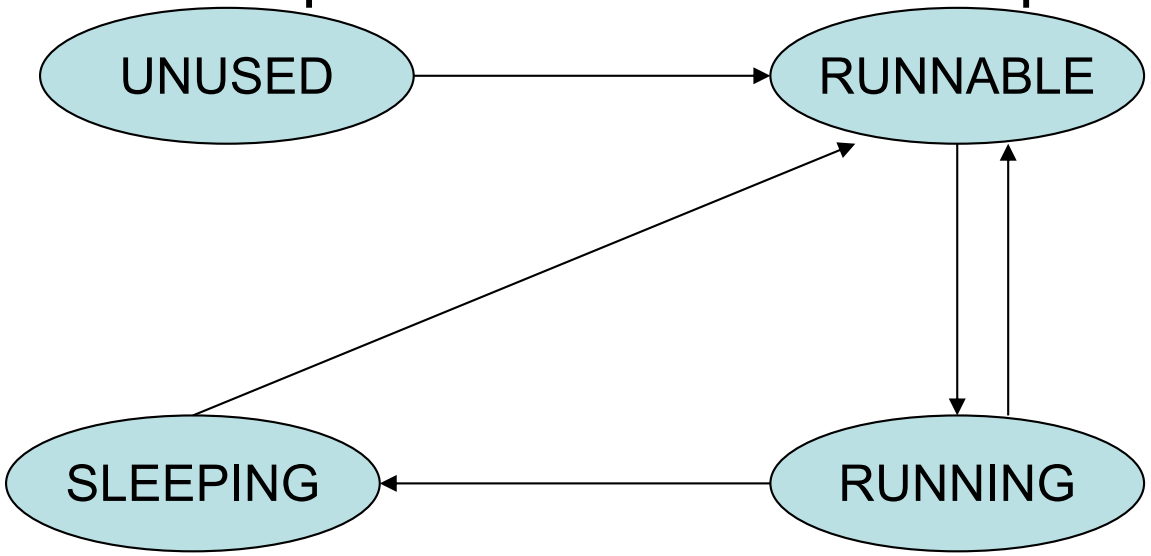
- PID
  - Process Identifier
  - Number incremented sequentially
    - When maximum is reached the size of the int type is limiting on the pid of the process
    - Reset and continue to increment.
    - This time skip already allocated PID numbers

Process States

```
90    enum procstate state;          // Process state
```

```
enum procstate { UNUSED, SLEEPING, RUNNABLE, RUNNING, ZOMBIE };
```

Process State : specifies the state of the process



when a program is executed it is initiially in the unused state. here the stack and other things required to run the process is setup and then finally assigns a pid to the process making it ready to be run on the cpu. this movs it to the runnable state where it is ready to run

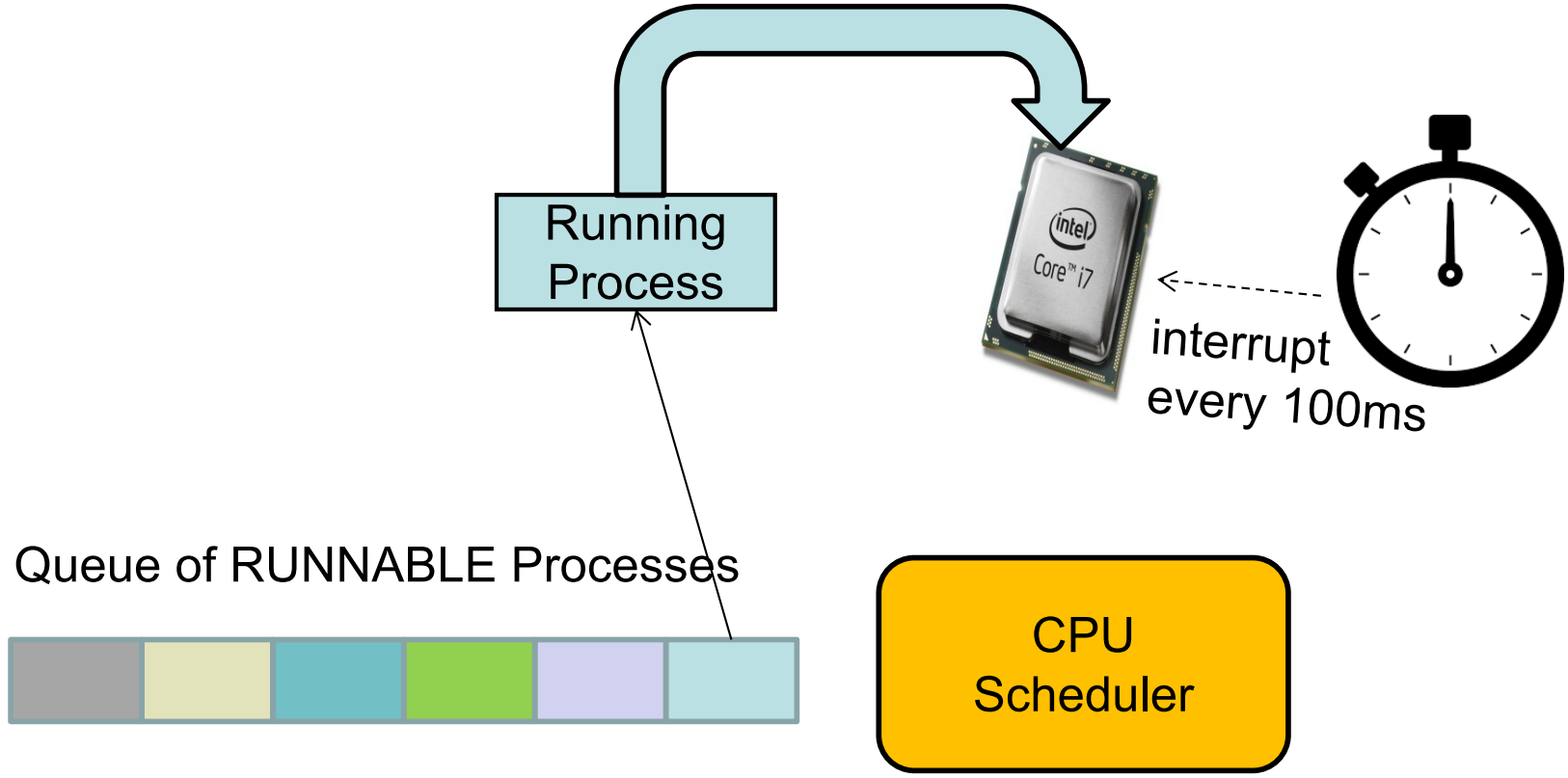
when the cpu is allocated to a process in the runnable queue, it moves to the running state where the process is running on the cpu.

the number of running processes has to be equal to the number of cpus

UNUSED → Unused PID
RUNNABLE → Ready to run
RUNNING → Currently executing
SLEEPING → Blocked for an I/O
Other states ZOMBIE (later)

ref : proc.h (enum procstate)

Scheduling Runnable Processes



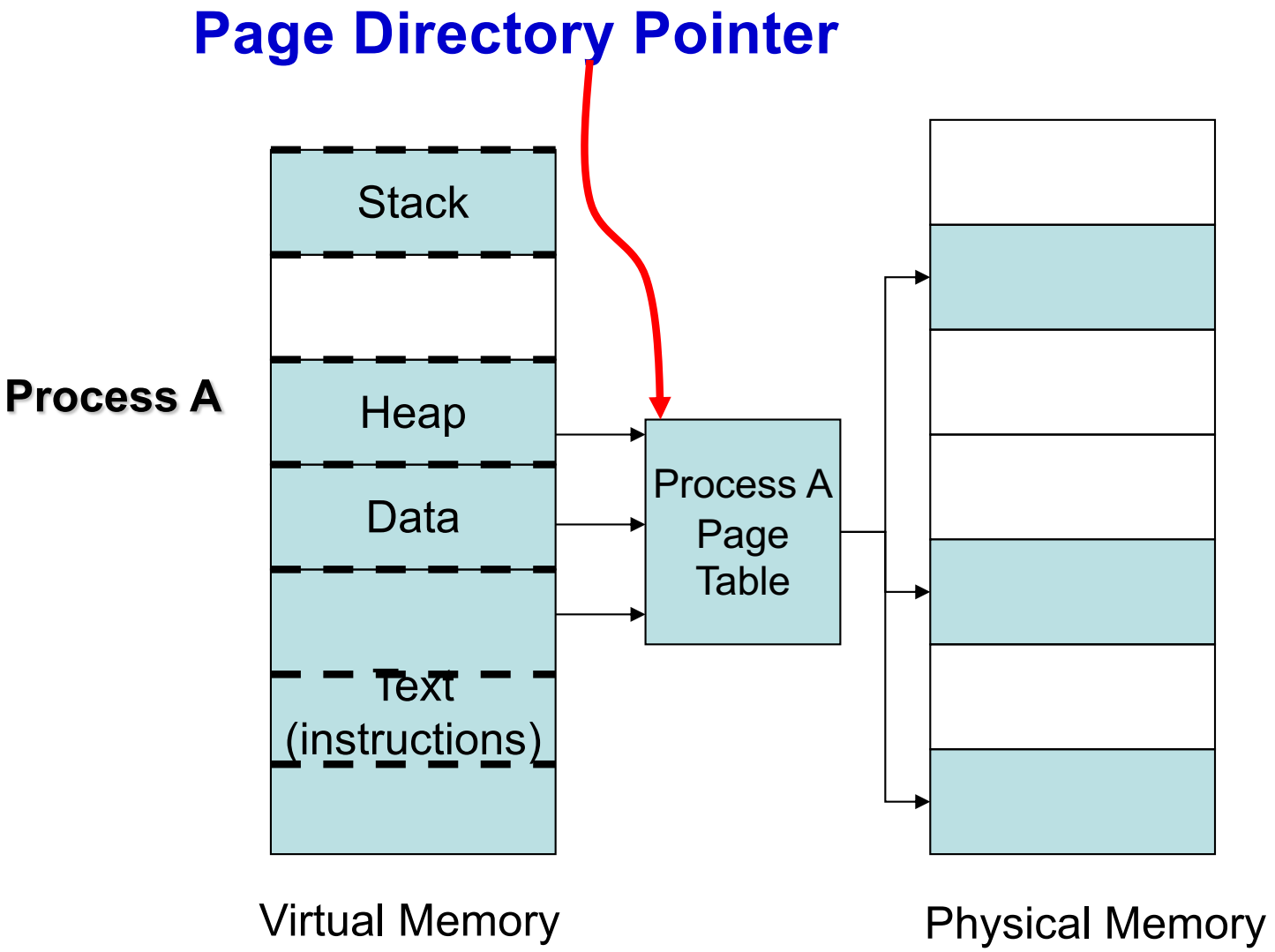
Scheduler triggered to run when timer interrupt occurs or when running process is blocked on I/O

Scheduler picks another process from the ready queue

Performs a context switch

Page Directory Pointer

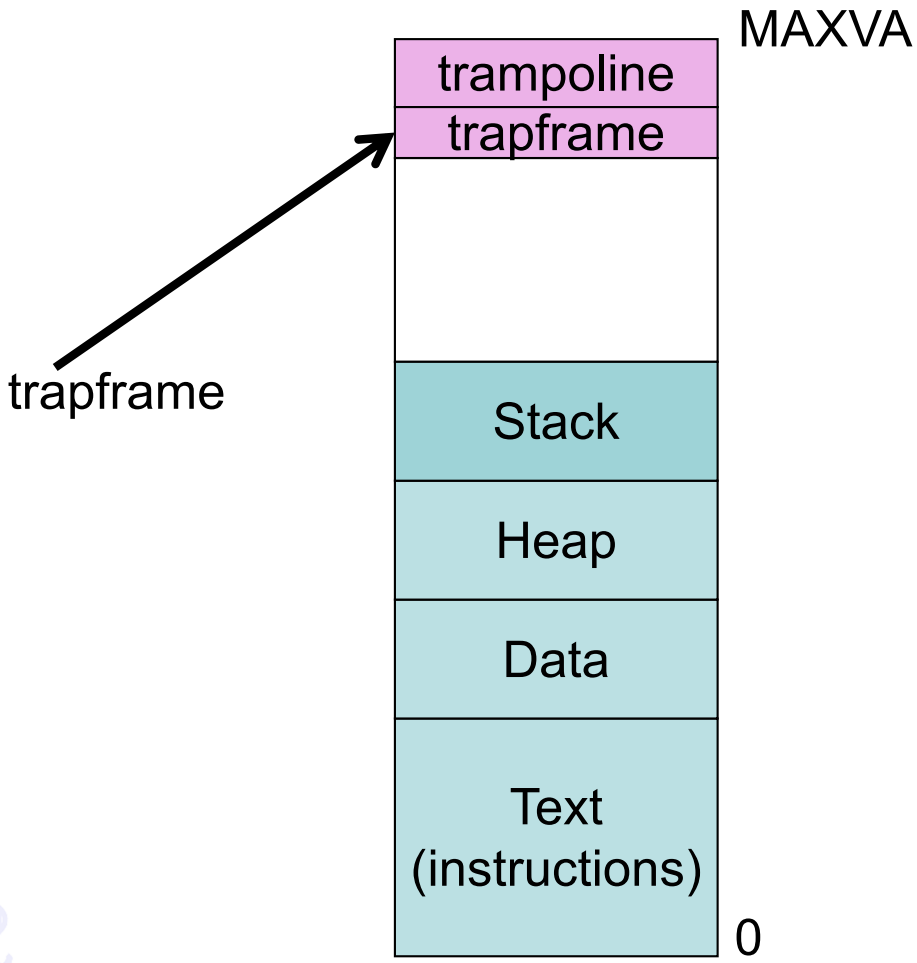
```
100    pagetable_t pagetable;          // Page table
```



Entries in PCB

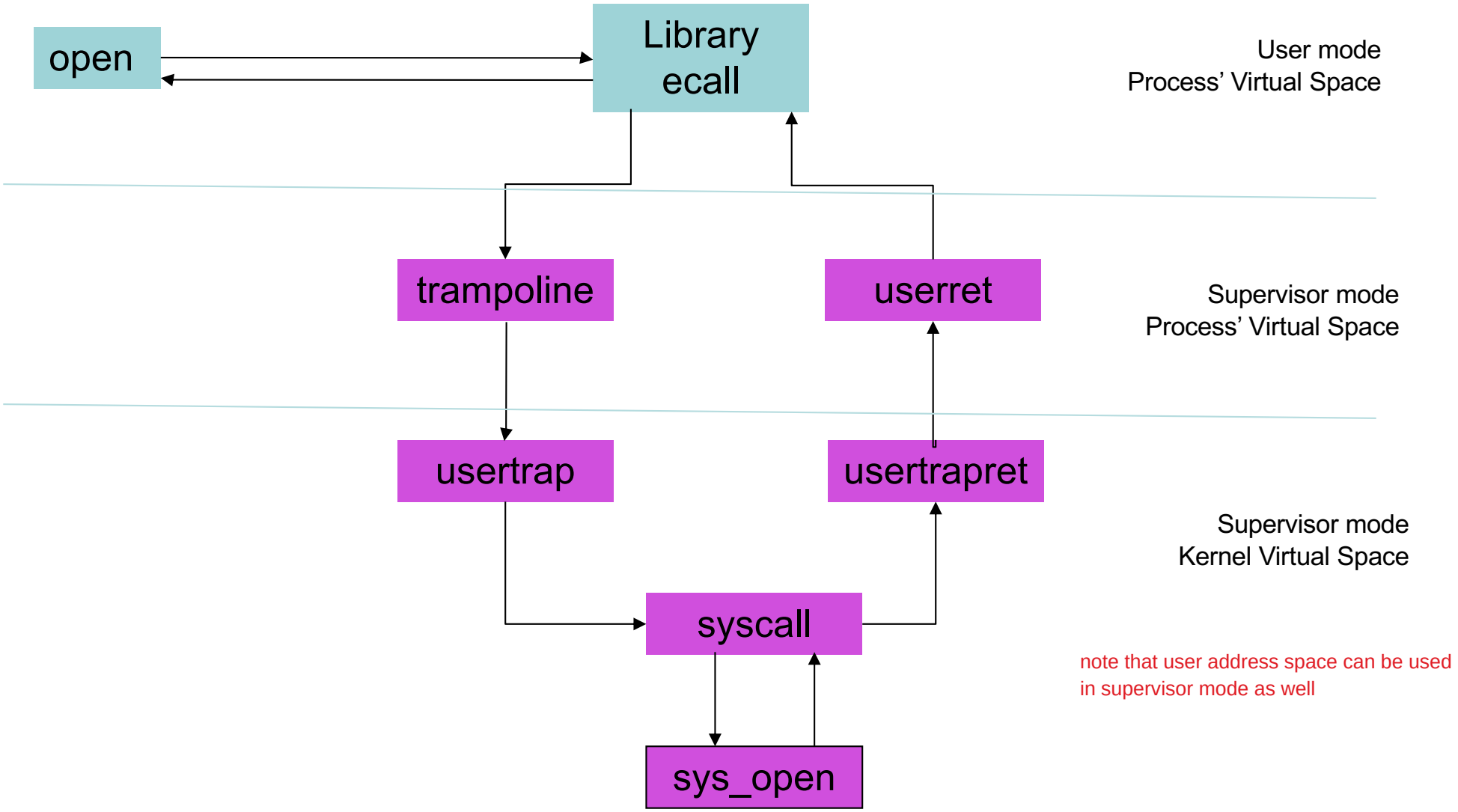
```
101    struct trapframe *tf;          // data page for trampoline.S
```

- Pointer to trapframe




```
struct trapframe {
  /*   0 */ uint64 kernel_satp;   // kernel page table
  /*   8 */ uint64 kernel_sp;     // top of process's kernel stack
  /*  16 */ uint64 kernel_trap;   // usertrap()
  /*  24 */ uint64 epc;           // saved user program counter
  /*  32 */ uint64 kernel_hartid; // saved kernel tp
  /*  40 */ uint64 ra;
  /*  48 */ uint64 sp;
  /*  56 */ uint64 gp;
  /*  64 */ uint64 tp;
  /*  72 */ uint64 t0;
  /*  80 */ uint64 t1;
  /*  88 */ uint64 t2;
  /*  96 */ uint64 s0;
  /* 104 */ uint64 s1;
  /* 112 */ uint64 a0;
  /* 120 */ uint64 a1;
  /* 128 */ uint64 a2;
  /* 136 */ uint64 a3;
```

Progress of a system call



Context Pointer

- Context pointer
  - Contains registers used for context switches.
  - Callee saved registers

```
struct context {
  uint64 ra;
  uint64 sp;

  // callee-saved
  uint64 s0;
  uint64 s1;
  uint64 s2;
  uint64 s3;
  uint64 s4;
  uint64 s5;
  uint64 s6;
  uint64 s7;
  uint64 s8;
  uint64 s9;
  uint64 s10;
  uint64 s11;
};
```

Storing procs in xv6

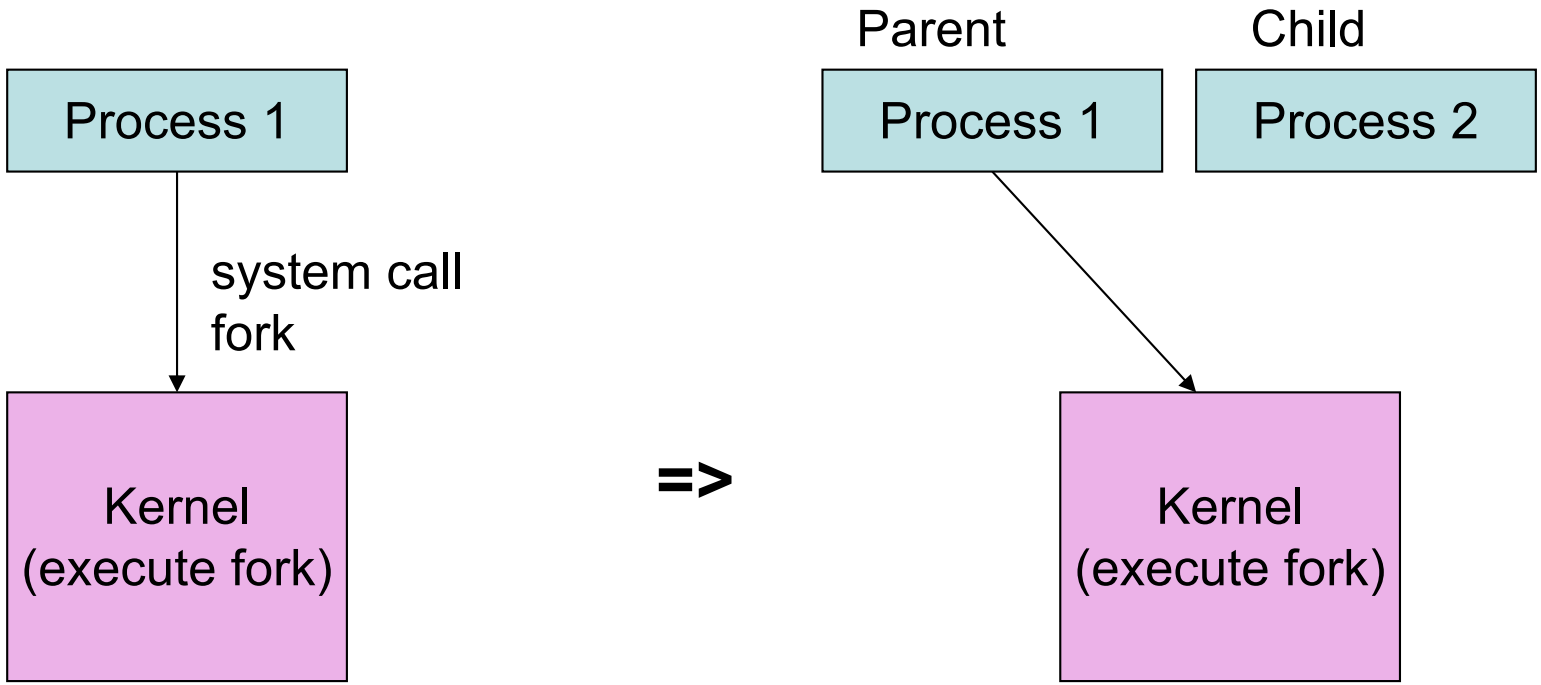
- In a globally defined array present in ptable
- NPROC is the maximum number of processes that can be present in the system (#define NPROC 64)
- Also present in ptable is a lock that seralizes access to the array.

```
struct {
  struct spinlock lock;
  struct proc proc[NPROC];
} ptable;
```

ref : proc.c (struct ptable) 2409, params.h (NPROC) 0150

Creating a Process by Cloning

- Cloning
  - Child process is an exact replica of the parent
  - Fork system call



Creating a Process by Cloning (using fork system call)

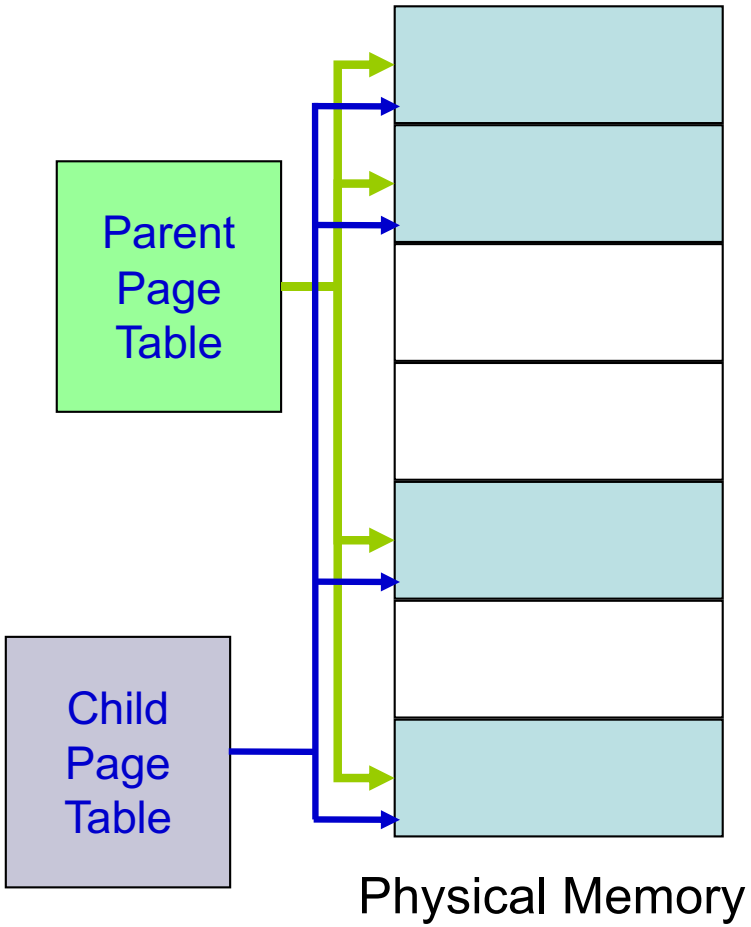
- In parent
  - fork returns child pid
- In child process
  - fork returns 0
- Other system calls
  - Wait, returns pid of an exiting child

```
int pid;

pid = fork();
if (pid > 0){
   printf("Parent : child PID = %d", pid);
   pid = wait();
   printf("Parent : child %d exited\n", pid);
} else{
  printf("In child process");
  exit(0);
}
```

Virtual Addressing Advantage (easy to make copies of a process)

- Making a copy of a process is called forking.
  - Parent (is the original)
  - child (is the new process)
- When fork is invoked,
  - child is an exact copy of parent
    - When fork is called all pages are shared between parent and child
    - Easily done by copying the parent's page tables



Modifying Data in Parent or Child

HOW ARE THE COW INSTANCES DETECTED?

Output

```
parent : 0
child  : 1
```

```
int i=0, pid;
pid = fork();
if (pid > 0){
        sleep(1);
        printf("parent : %d\n", i);
        wait();
} else{
        i = i + 1;
        printf("child : %d\n", i);
}
```

when the write is done, the page for i is duplicated and updated in the child

in riscv the return values are placed in the a0 register - this is different for the parent and child
everything else is pretty much identical for the two processes

Executing a Program (exec system call)

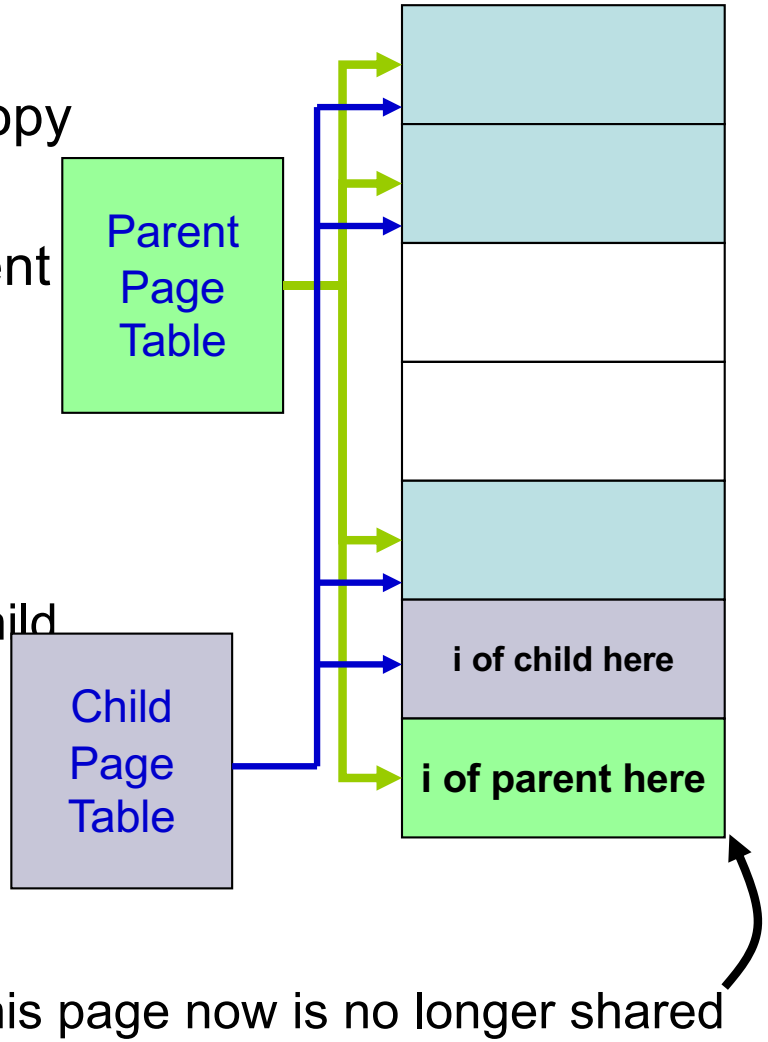
- exec system call
  - Load into memory and then execute
- COW big advantage for exec
  - Time not wasted in copying pages.
  - Common code (for example shared libraries) would continue to be shared

```
int pid;

pid = fork();
if (pid > 0){
   pid = wait();
} else{
  execlp("ls", "", NULL);
  exit(0);
```

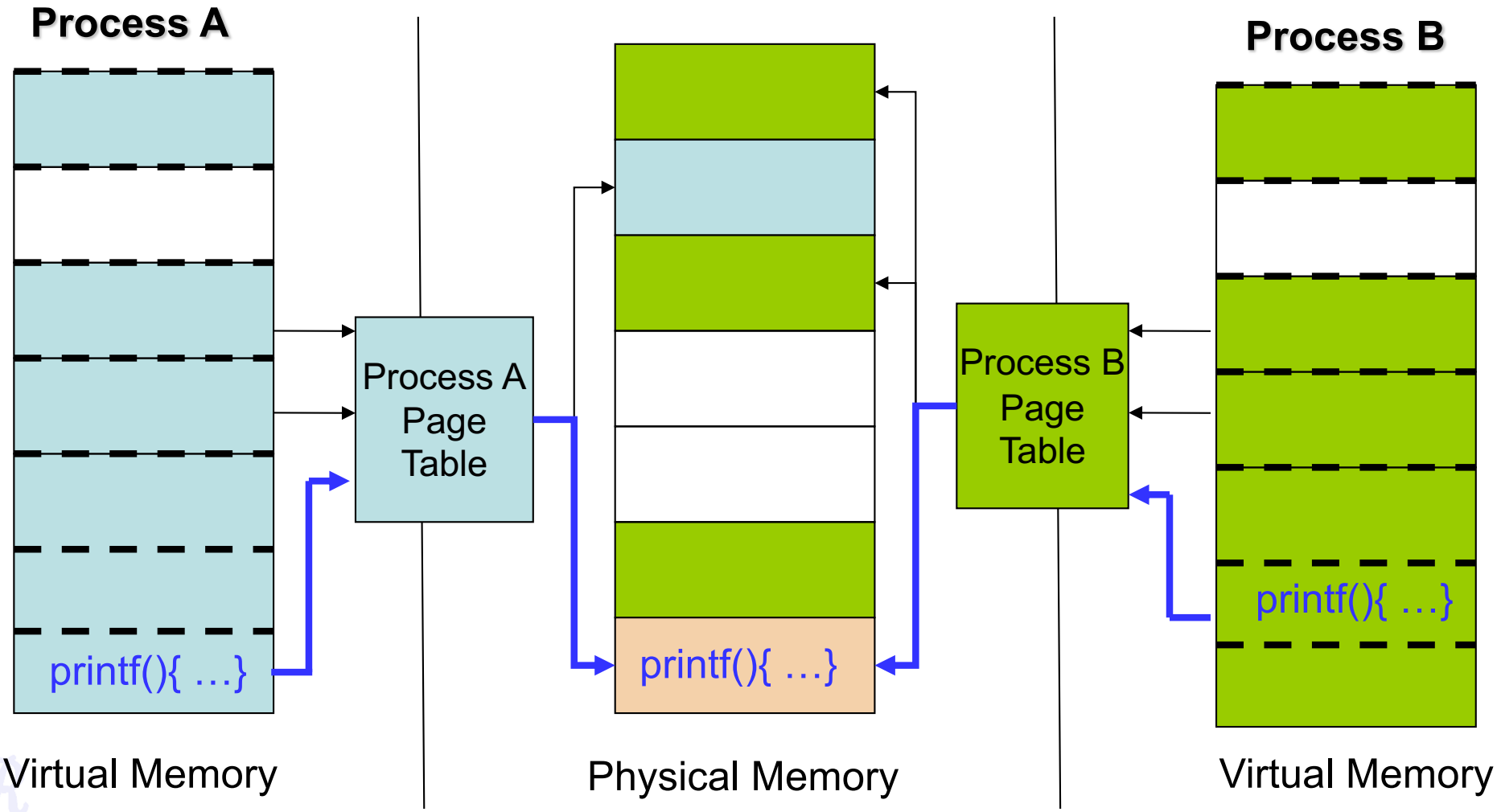
Copy on Write (COW)

- When data in any of the shared pages change, OS intercepts and makes a copy of the page.
- Thus, parent and child will have different copies of this page
- Why?
  - A large portion of executables are not used.
  - Copying each page from parent and child would incur significant disk swapping.. huge performance penalties.
  - Postpone coping of pages as much as possible thus optimizing performance



Virtual Addressing Advantages (Shared libraries)

- Many common functions such as *printf* implemented in shared libraries
- Pages from shared libraries, shared between processes



How COW works

- When forking,
  - Kernel makes COW pages as read only
  - Any write to the pages would cause a page fault
  - The kernel detects that it is a COW page and duplicates the page

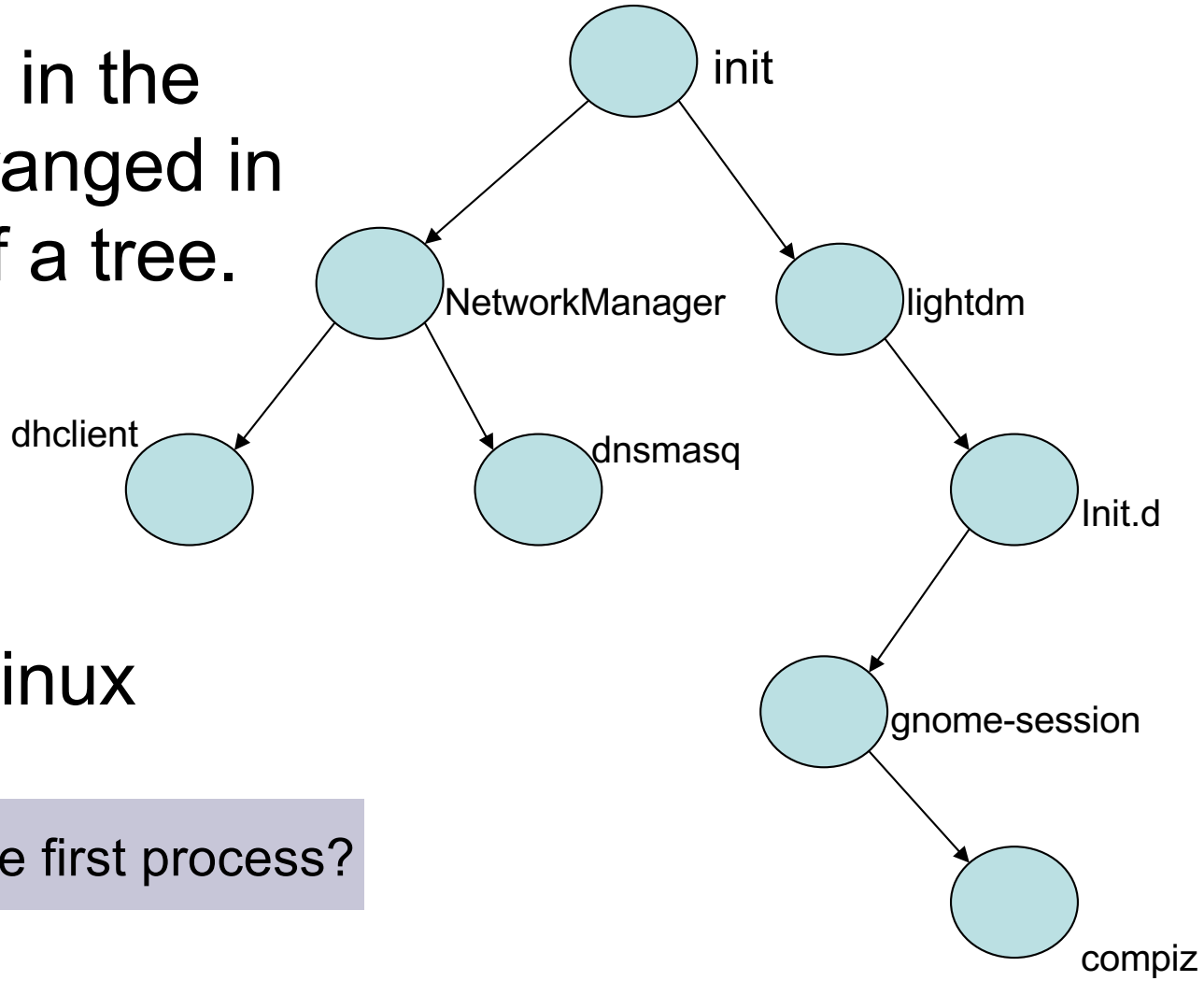
cow pages are detected as - when the fork is done, all the common pages with the W flag set is rewritten with the R flag
now whenever the daddy or the child tries to write to one of these pages, there is a page fault which then handles the copying functionality

The first process

- Unix : **/sbin/init**
  - Unlike the others, this is created by the kernel during boot
  - **Super parent.**
    - Responsible for forking all other processes
    - Typically starts several scripts present in /etc/init.d in Linux

Process tree

Processes in the system arranged in the form of a tree.



pstree in Linux

Who creates the first process?

Process Termination

- Voluntary : exit(status)
  - OS passes exit status to parent via wait(&status)
  - OS frees process resources

when ctl+c is done,
there is a keyboard interrupt
which the cpu detects
and then infers that sigint
must be sent to the process

- Involuntary : kill(pid, signal)
  - Signal can be sent by another process or by OS
  - pid is for the process to be killed
  - signal a signal that the process needs to be killed
    - Examples : SIGTERM, SIGQUIT (ctrl+\), SIGINT (ctrl+c), SIGHUP

the processes themselves will have a signal handler, which will look for the entry for the signal provided and appropriately does soemthing to exit
if there is no signal handler, then an exit is done by default

in unix, only processes in the same user space(or sudo) can be killed by a user

Zombies

when the exit() call is made, all that happens is all the open files are closed and the process state is changed to the zombie the PCB is not cleared up yet. this is done only after the parent can read the return or exit status and then the OS cleans up

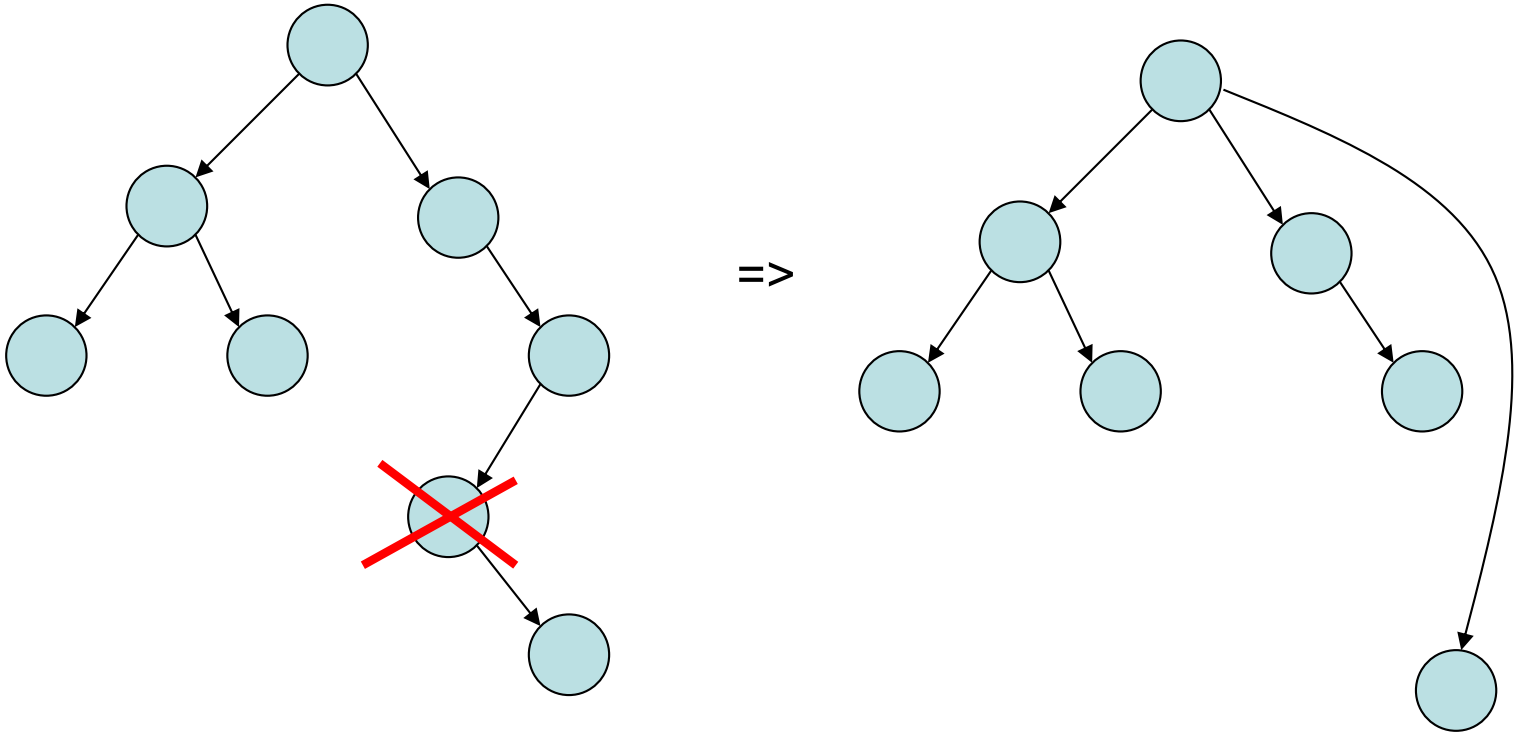
note that if this killed process has children, it makes the init process adopt these processes

- When a process terminates it becomes a zombie (or defunct process)
  - PCB in OS still exists even though program no longer executing
  - Why? So that the parent process can read the child's exit status (through wait system call)
- When parent reads status,
  - zombie entries removed from OS… process reaped!
- Suppose parent does'nt read status
  - Zombie will continue to exist infinitely … a resource leak
  - These are typically found by a reaper process

CAN TWO PROCESSES DIE AT THE SAME TIME?!

Orphans

- When a parent process terminates before its child
- Adopted by first process (/sbin/init)



Orphans contd.

- Unintentional orphans
  - When parent crashes
- Intentional orphans
  - Process becomes detached from user session and runs in the background
  - Called daemons, used to run background services
  - See nohup

The first process in xv6

The first process

- Initcode
- Creating the first process
  - main invokes userinit
  - userinit
    - allocate a process id, trapframe,
    - Create page directory
    - copy initcode.S to 0x0 this is the lowest address in the new address space that has been created
    - create a user stack at 0x0 (SP starts at 0x0+PGSIZE)
    - set process to runnable
      - the scheduler would then execute the process

```
184 // od -t xC initcode
185 uchar initcode[] = {
186   0x17, 0x05, 0x00, 0x00, 0x13, 0x05, 0x05, 0x02,
187   0x97, 0x05, 0x00, 0x00, 0x93, 0x85, 0x05, 0x02,
188   0x9d, 0x48, 0x73, 0x00, 0x00, 0x00, 0x89, 0x48,
189   0x73, 0x00, 0x00, 0x00, 0xef, 0xf0, 0xbf, 0xff,
190   0x2f, 0x69, 0x6e, 0x69, 0x74, 0x00, 0x00, 0x01,
191   0x20, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00,
192   0x00, 0x00, 0x00
193 };
194
195 // Set up first user process.
196 void
197 userinit(void)
198 {
199   struct proc *p;
200   p = allocproc(); effectively creates a new virtual address space
201   initproc = p;
202
203   // allocate one user page and copy init's instructions
204   // and data into it.
205   uvminit(p->pagetable, initcode, sizeof(initcode));
206   p->sz = PGSIZE;
207
208   // prepare for the very first "return" from kernel to user.
209   p->tf->epc = 0;      // user program counter
210   p->tf->sp = PGSIZE;  // user stack pointer
211
212   safestrcpy(p->name, "initcode", sizeof(p->name));
213   p->cwd = namei("/");
214   p->state = RUNNABLE;
215   release(&p->lock);
216 }
```

userinit

proc.c

userinit

```
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188   0x9d, 0x48, 0x73, 0x00, 0x00, 0x00, 0x89, 0x48,
189   0x73, 0x00, 0x00, 0x00, 0xef, 0xf0, 0xbf, 0xff,
190   0x2f, 0x69, 0x6e, 0x69, 0x74, 0x00, 0x00, 0x01,
191   0x20, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00,
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205   uvminit(p->pagetable, initcode, sizeof(initcode)
206   p->sz = PGSIZE;
207
208   // prepare for the very first "return" from kern
209   p->tf->epc = 0;      // user program counter
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216 }
```

user/initcode.S

```
 1 # Initial process execs /init.
 2 # This code runs in user space.
 3
 4 #include "syscall.h"
 5
 6 # exec(init, argv)
 7 .globl start
 8 start:
 9         la a0, init
10         la a1, argv
11         li a7, SYS_exec
12         ecall
13
14 # for(;;) exit();
15 exit:
16         li a7, SYS_exit
17         ecall
18         jal exit
19
20 # char init[] = "/init\0";
21 init:
22   .string "/init\0"
23
24 # char *argv[] = { init, 0 };
25 .p2align 2
26 argv:
27   .long init
28   .long 0
```

userinit

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189   0x73, 0x00, 0x00, 0x00, 0xef, 0xf0, 0xbf, 0xff,
190   0x2f, 0x69, 0x6e, 0x69, 0x74, 0x00, 0x00, 0x01,
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210   p->tf->sp = PGSIZE;  // user stack pointer
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212   safestrcpy(p->name, "initcode", sizeof(p->name))
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26 argv:
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userinit

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  0x17, 0x05, 0x00, 0x00, 0x13, 0x05, 0x05, 0x02,
  0x97, 0x05, 0x00, 0x00, 0x93, 0x85, 0x05, 0x02,
  0x9d, 0x48, 0x73, 0x00, 0x00, 0x00, 0x89, 0x48,
  0x73, 0x00, 0x00, 0x00, 0xef, 0xf0, 0xbf, 0xff,
  0x2f, 0x69, 0x6e, 0x69, 0x74, 0x00, 0x00, 0x01,
  0x20, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00,
  0x00, 0x00, 0x00
};

// Set up first user process.
void
userinit(void)
{
  struct proc *p;
  p = allocproc();
  initproc = p;

  // allocate one u
  // and data into
  uvminit(p->pageta
  p->sz = PGSIZE;

  // prepare for th
  p->tf->epc = 0;
  p->tf->sp = PGSIZ

  safestrcpy(p->nam
  p->cwd = namei("/
  p->state = RUNNAB
  release(&p->lock);
}
```

1. Find an unused proc entry
   First entry will be used.
   so, pid = 1 pid 0 is not used because that is the default return of a fork to a child
2. Create trapframe
3. Create empty user process' page table
   1. Map trampoline high
   2. Map trapframe just below it
4. Create context for process
   1. ra points to forkret
   2. Kernel stack pointer set

```
static struct proc*
allocproc(void)
{
  struct proc *p;

  for(p = proc; p < &proc[NPROC]; p++) {
    acquire(&p->lock);
    if(p->state == UNUSED) {
      goto found;
    } else {
      release(&p->lock);
    }
  }
  return 0;

found:    checks the nextpid and gives it
  p->pid = allocpid();
  // Allocate a trapframe page.
  if((p->tf = (struct trapframe *)kalloc()) == 0) {
    release(&p->lock);
    return 0;
  }

  // An empty user page table.
  p->pagetable = proc_pagetable(p);

  // Set up new context to start executing at forkret,
  // which returns to user space.
  memset(&p->context, 0, sizeof p->context);
  p->context.ra = (uint64)forkret;
  p->context.sp = p->kstack + PGSIZE;

  return p;
}
```

1

gets a page from freelist

2

3

4

```
184 // od -t xC initcode
185 uchar initcode[] = {
186   0x17, 0x05, 0x00, 0x00, 0x13, 0x05, 0x05, 0x02,
187   0x97, 0x05, 0x00, 0x00, 0x93, 0x85, 0x05, 0x02,
188   0x9d, 0x48, 0x73, 0x00, 0x00, 0x00, 0x89, 0x48,
189   0x73, 0x00, 0x00, 0x00, 0xef, 0xf0, 0xbf, 0xff,
190   0x2f, 0x69, 0x6e, 0x69, 0x74, 0x00, 0x00, 0x01,
191   0x20, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00,
192   0x00, 0x00, 0x00
193 };
194
195 // Set up first user process.
196 void
197 userinit(void)
198 {
199   struct proc *p;
200   p = allocproc();
201   initproc = p;
202
203   // allocate one u                    ructions
204   // and data into
205   uvminit(p->pageta                    e));
206   p->sz = PGSIZE;
207
208   // prepare for th                    rnel to user.
209   p->tf->epc = 0;
210   p->tf->sp = PGSI
211
212   safestrcpy(p->nam                    ));
213   p->cwd = namei("/
214   p->state = RUNNAB
215   release(&p->lock);
216 }
```

1. Find an unused proc entry
   First entry will be used.
   so, pid = 1
2. Create trapframe
3. Create empty user process' page table
   1. Map trampoline high
   2. Map trapframe just below it
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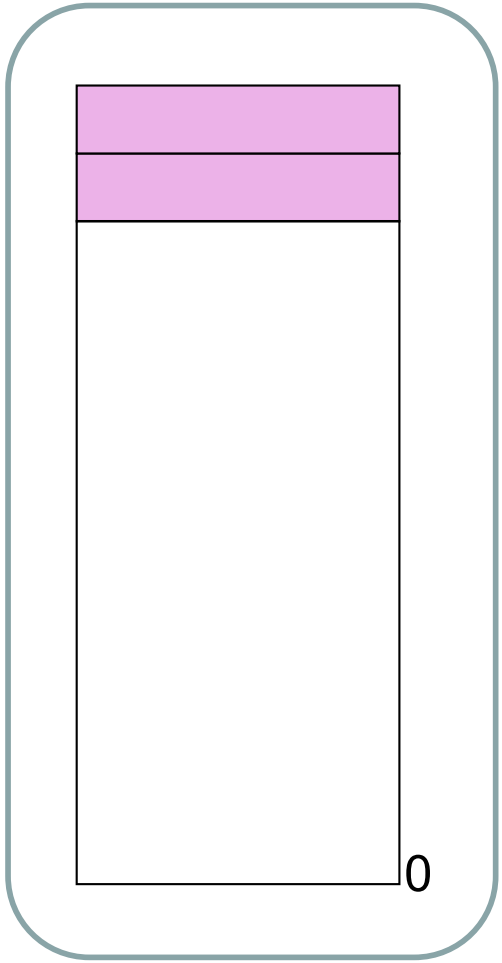
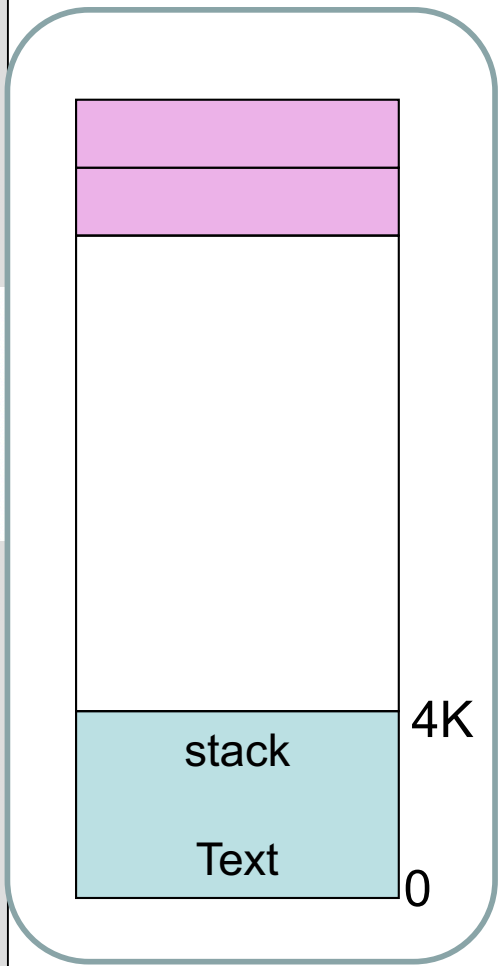
userinit



userinit

```
184 // od -t xC initcode
185 uchar initcode[] = {
186   0x17, 0x05, 0x00, 0x00, 0x13, 0x05, 0x05, 0x02,
187   0x97, 0x05, 0x00, 0x00, 0x93, 0x85, 0x05, 0x02,
188   0x9d, 0x48, 0x73, 0x00, 0x00, 0x00, 0x89, 0x48,
189   0x73, 0x00, 0x00, 0x00, 0xef, 0xf0, 0xbf, 0xff,
190   0x2f, 0x69, 0x6e, 0x69, 0x74, 0x00, 0x00, 0x01,
191
192
193 };
194
195 //
196 vo
197 us
198 {
199
200
201   initproc = p;
202
203   // allocate one user page and copy init's instructions
204   // and data into it.
205   uvminit(p->pagetable, initcode, sizeof(initcode));
206   p->sz = PGSIZE;
207
208   // prepare for the very first "return" from kernel to user.
209   p->tf->epc = 0;      // user program counter
210   p->tf->sp = PGSIZE;  // user stack pointer
211
212   safestrcpy(p->name, "initcode", sizeof(p->name));
213   p->cwd = namei("/");
214   p->state = RUNNABLE;
215   release(&p->lock);
216 }
```

```
220 void
221 uvminit(pagetable_t pagetable, uchar *src, uint sz)
222 {
223   char *mem;
224
225   if(sz >= PGSIZE)
226     panic("inituvm: more than a page");
227   mem = kalloc();
228   memset(mem, 0, PGSIZE);
229   mappages(pagetable, 0, PGSIZE, (uint64)mem, PTE_W|PTE_R|PTE_X|PTE_U);
230   memmove(mem, src, sz);
231 }
```



userinit

```
184 // od -t xC initcode
185 uchar initcode[] = {
186   0x17, 0x05, 0x00, 0x00, 0x13, 0x05, 0x05, 0x02,
187   0x97, 0x05, 0x00, 0x00, 0x93, 0x85, 0x05, 0x02,
188   0x9d, 0x48, 0x73, 0x00, 0x00, 0x00, 0x89, 0x48,
189   0x73, 0x00, 0x00, 0x00, 0xef, 0xf0, 0xbf, 0xff,
190   0x2f, 0x69, 0x6e, 0x69, 0x74, 0x00, 0x00, 0x01,
191   0x20, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00,
192   0x00, 0x00, 0x00
193 };
194
195 // Set up first user process.
196 void
197 userinit(void)
198 {
199   struct proc *p;
200   p = allocproc();
201   initproc = p;
202
203   // allocate one user page and copy init's instructions
204   // and data into it.
205   uvminit(p->pagetable, initcode, sizeof(initcode));
206   p->sz = PGSIZE;
207
208   // prepare for the very first "return" from kernel to user.
209   p->tf->epc = 0;      // user program counter
210   p->tf->sp = PGSIZE;  // user stack pointer
211
212   safestrcpy(p->name, "initcode", sizeof(p->name));
213   p->cwd = namei("/");
214   p->state = RUNNABLE;
215   release(&p->lock);
216 }
```

Executing User Code

- The kernel stack of the process has a trap frame and context
- The process is set as RUNNABLE
- The scheduler is then invoked from main

main →scheduler

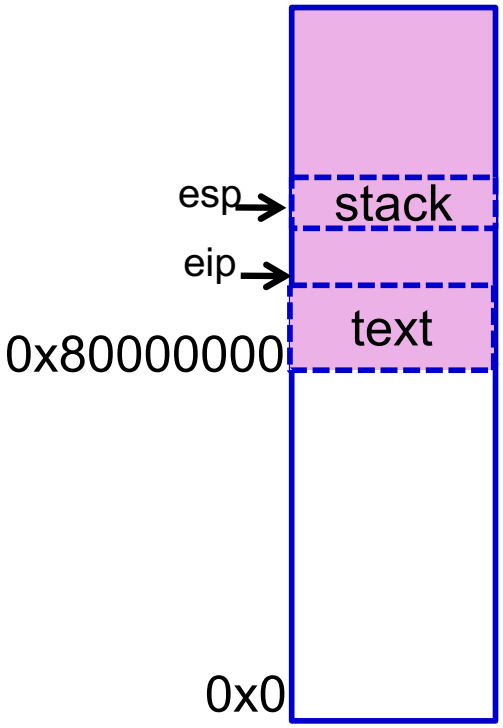
The initcode process is selected

(as it is the only process runnable)

– …and is then executed

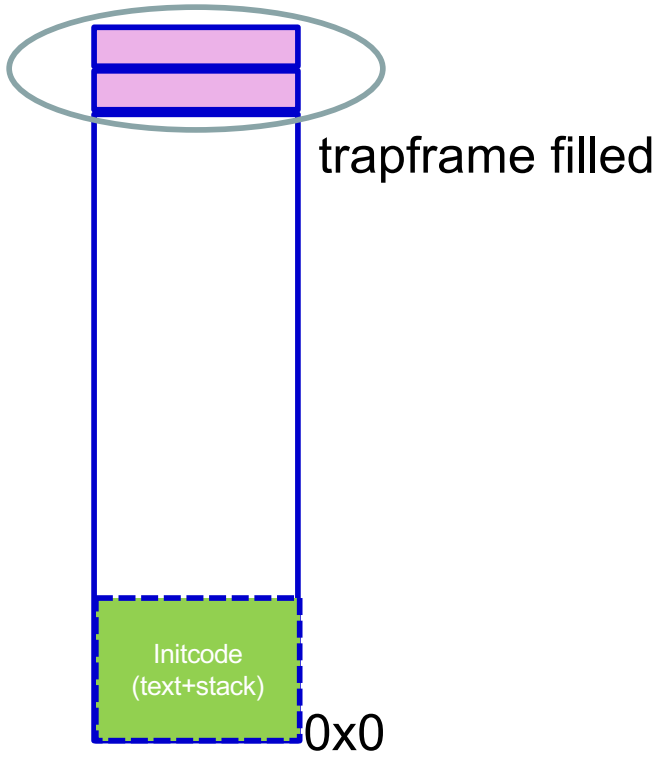
Scheduling the first process

What we need!



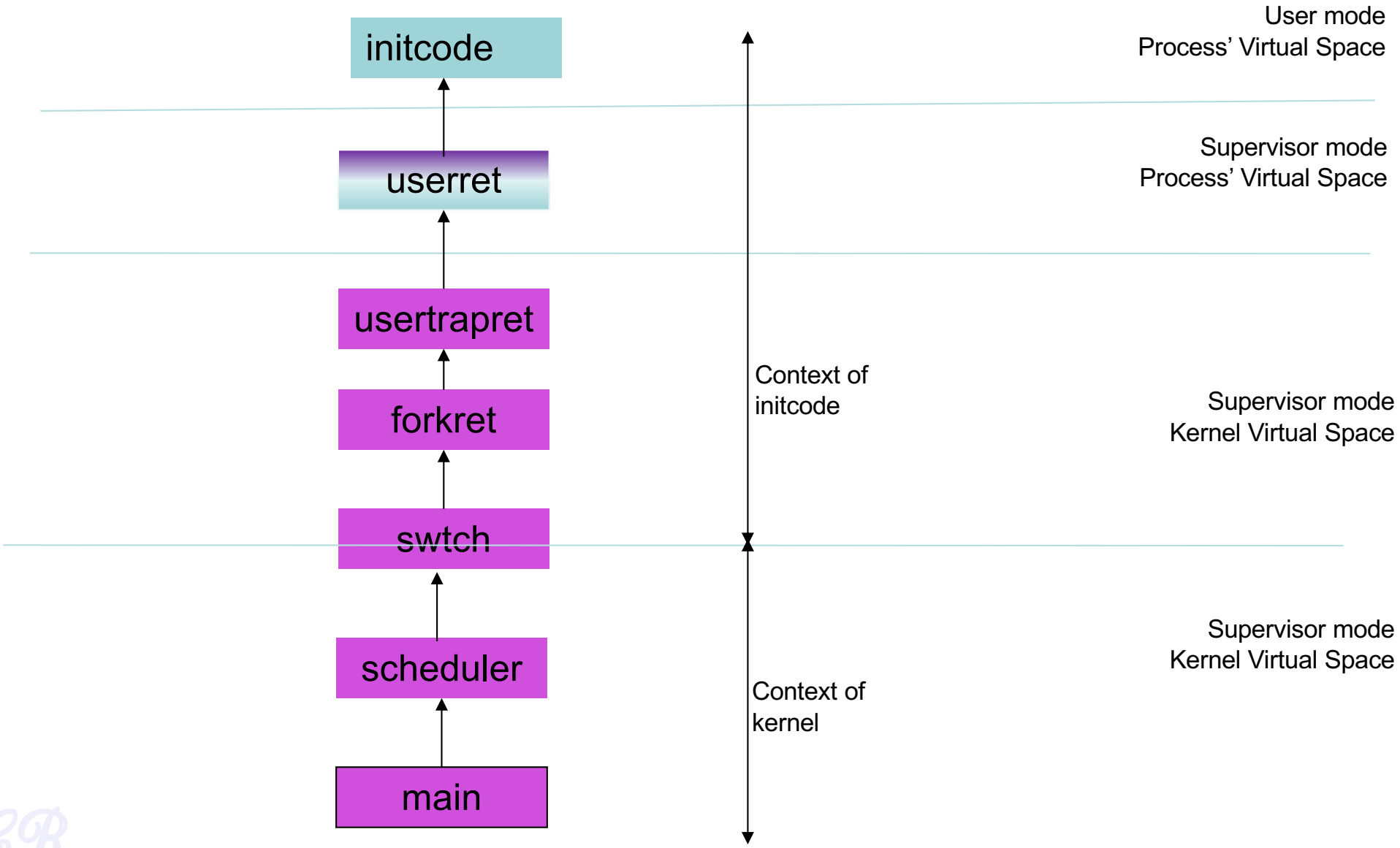
before userinit

Paging Unit uses the kernel page tables



Paging Unit uses the initcode's newly formed page tables

Progress of a system call



Scheduler ()

sched.c

```
438 void
439 scheduler(void)
440 {
441   struct proc *p;
442   struct cpu *c = mycpu();
443
444   c->proc = 0;
445   for(;;){
446     // Avoid deadlock by ensuring that devices can interrupt.
447     intr_on();
448
449     for(p = proc; p < &proc[NPROC]; p++) {
450       acquire(&p->lock);
451       if(p->state == RUNNABLE) {
452         // Switch to chosen process.  It is the process's job
453         // to release its lock and then reacquire it
454         // before jumping back to us.
455         p->state = RUNNING;
456         c->proc = p;
457         swtch(&c->scheduler, &p->context);
458
459         // Process is done running for now.
460         // It should have changed its p->state before coming back.
461         c->proc = 0;
462       }
463       release(&p->lock);
464     }
465   }
466 }
```

1. Find the process which is RUNNABLE.
   - currently only one process is RUNNABLE
   - set it to RUNNING
   - set CPU to run the initcode

2. context switch to initcode (swtch)

Switches context from scheduler's context to p
Function does not return

asm("%gs:4"); // this is a per cpu

swtch

swtch.S

```
.globl swtch
swtch:
        sd ra, 0(a0)
        sd sp, 8(a0)
        sd s0, 16(a0)
        sd s1, 24(a0)
        sd s2, 32(a0)
        sd s3, 40(a0)
        sd s4, 48(a0)
        sd s5, 56(a0)
        sd s6, 64(a0)
        sd s7, 72(a0)
        sd s8, 80(a0)
        sd s9, 88(a0)
        sd s10, 96(a0)
        sd s11, 104(a0)

        ld ra, 0(a1)
        ld sp, 8(a1)
        ld s0, 16(a1)
        ld s1, 24(a1)
        ld s2, 32(a1)
        ld s3, 40(a1)
        ld s4, 48(a1)
        ld s5, 56(a1)
        ld s6, 64(a1)
        ld s7, 72(a1)
        ld s8, 80(a1)
        ld s9, 88(a1)
        ld s10, 96(a1)
        ld s11, 104(a1)

        ret
```

a0 (1st parameter passed to swtch) contains pointer to scheduler context. Here we store the CPU registers into the scheduler's context

a1 (2nd parameter passed to swtch) contains pointer to p->context. Here we load the context intovCPU registers

```
// Saved registers
struct context {
  uint64 ra;
  uint64 sp;

  // callee-saved
  uint64 s0;
  uint64 s1;
  uint64 s2;
  uint64 s3;
  uint64 s4;
  uint64 s5;
  uint64 s6;
  uint64 s7;
  uint64 s8;
  uint64 s9;
  uint64 s10;
  uint64 s11;
};
```

For initcode,
* ra set to forkret
* sp set to kstack+PGSIZE (refer allocproc)

This function returns to forkret and SP= kstack of initcode

forkret

proc.c

```
// A fork child's very first scheduling by scheduler()
// will swtch to forkret.
void
forkret(void)
{
  static int first = 1;

  // Still holding p->lock from scheduler.
  release(&myproc()->lock);

  if (first) {
    // File system initialization must be run in the context of a
    // regular process (e.g., because it calls sleep), and thus cannot
    // be run from main().
    first = 0;
    fsinit(ROOTDEV);
  }

  usertrapret();
}
```

usertrapret

trap.c

```
void
usertrapret(void)
{
  struct proc *p = myproc();

  // turn off interrupts, since we're switching
  // now from kerneltrap() to usertrap().
  intr_off();

  // send syscalls, interrupts, and exceptions to trampoline.S
  w_stvec(TRAMPOLINE + (uservec - trampoline));

  // set up trapframe values that uservec will need when
  // the process next re-enters the kernel.
  p->tf->kernel_satp = r_satp();         // kernel page table
  p->tf->kernel_sp = p->kstack + PGSIZE; // process's kernel stack
  p->tf->kernel_trap = (uint64)usertrap;
  p->tf->kernel_hartid = r_tp();         // hartid for cpuid()

  // set up the registers that trampoline.S's sret will use
  // to get to user space.

  // set S Previous Privilege mode to User.
  unsigned long x = r_sstatus();
  x &= ~SSTATUS_SPP; // clear SPP to 0 for user mode
  x |= SSTATUS_SPIE; // enable interrupts in user mode
  w_sstatus(x);

  // set S Exception Program Counter to the saved user pc.
  w_sepc(p->tf->epc);

  // tell trampoline.S the user page table to switch to.
  uint64 satp = MAKE_SATP(p->pagetable);

  // jump to trampoline.S at the top of memory, which
  // switches to the user page table, restores user registers,
  // and switches to user mode with sret.
  uint64 fn = TRAMPOLINE + (userret - trampoline);
  ((void (*)(uint64,uint64))fn)(TRAPFRAME, satp);
}
```

Set up interrupt handlers so in the trampoline

This will act as interrupt handler when syscalls / interrupts occur.

These trapframe entries will permit handling syscalls, interrupts and traps

Set SPP so that when interrupt returns, switches to user mode.

p->tf->epc set to 0 in userinit

satp is going as first argument (a1 register) to userret

```
88 userret:
89         # userret(TRAPFRAME, pagetable)
90         # switch from kernel to user.
91         # usertrapret() calls here.
92         # a0: TRAPFRAME, in user page table.
93         # a1: user page table, for satp.
94
95         # switch to the user page table.
96         csrw satp, a1
97         sfence.vma zero, zero
98
99         # put the saved user a0 in sscratch, so we
100        # can swap it with our a0 (TRAPFRAME) in the last step.
101        ld t0, 112(a0)
102        csrw sscratch, t0
103
104        # restore all but a0 from TRAPFRAME
105        ld ra, 40(a0)
106        ld sp, 48(a0)
107        ld gp, 56(a0)
108        ld tp, 64(a0)
109        ld t0, 72(a0)
110        ld t1, 80(a0)
111        ld t2, 88(a0)
112        ld s0, 96(a0)
113        ld s1, 104(a0)
114        ld a1, 120(a0)
115        ld a2, 128(a0)
116        ld a3, 136(a0)
117        ld a4, 144(a0)
118        ld a5, 152(a0)
119        ld a6, 160(a0)
120        ld a7, 168(a0)
121        ld s2, 176(a0)
122        ld s3, 184(a0)
123        ld s4, 192(a0)
124        ld s5, 200(a0)
125        ld s6, 208(a0)
126        ld s7, 216(a0)
127        ld s8, 224(a0)
128        ld s9, 232(a0)
129        ld s10, 240(a0)
130        ld s11, 248(a0)
131        ld t3, 256(a0)
132        ld t4, 264(a0)
133        ld t5, 272(a0)
134        ld t6, 280(a0)
```

useret

finally … initcode.S ☺

- Invokes system call exec to invoke /init

exec(‘/init’)

```
# Initial process execs /init.

#include "syscall.h"
#include "traps.h"


# exec(init, argv)
.globl start
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

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

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

init.c

```c
#include "types.h"
#include "stat.h"
#include "user.h"
#include "fcntl.h"

char *argv[] = { "sh", 0 };

int
main(void)
{
  int pid, wpid;

  if(open("console", O_RDWR) < 0){
    mknod("console", 1, 1);
    open("console", O_RDWR);
  }
  dup(0);  // stdout
  dup(0);  // stderr

  for(;;){
    printf(1, "init: starting sh\n");
    pid = fork();
    if(pid < 0){
      printf(1, "init: fork failed\n");
      exit();
    }
    if(pid == 0){
      exec("sh", argv);
      printf(1, "init: exec sh failed\n");
      exit();
    }
    while((wpid=wait()) >= 0 && wpid != pid)
      printf(1, "zombie!\n");
  }
}
```

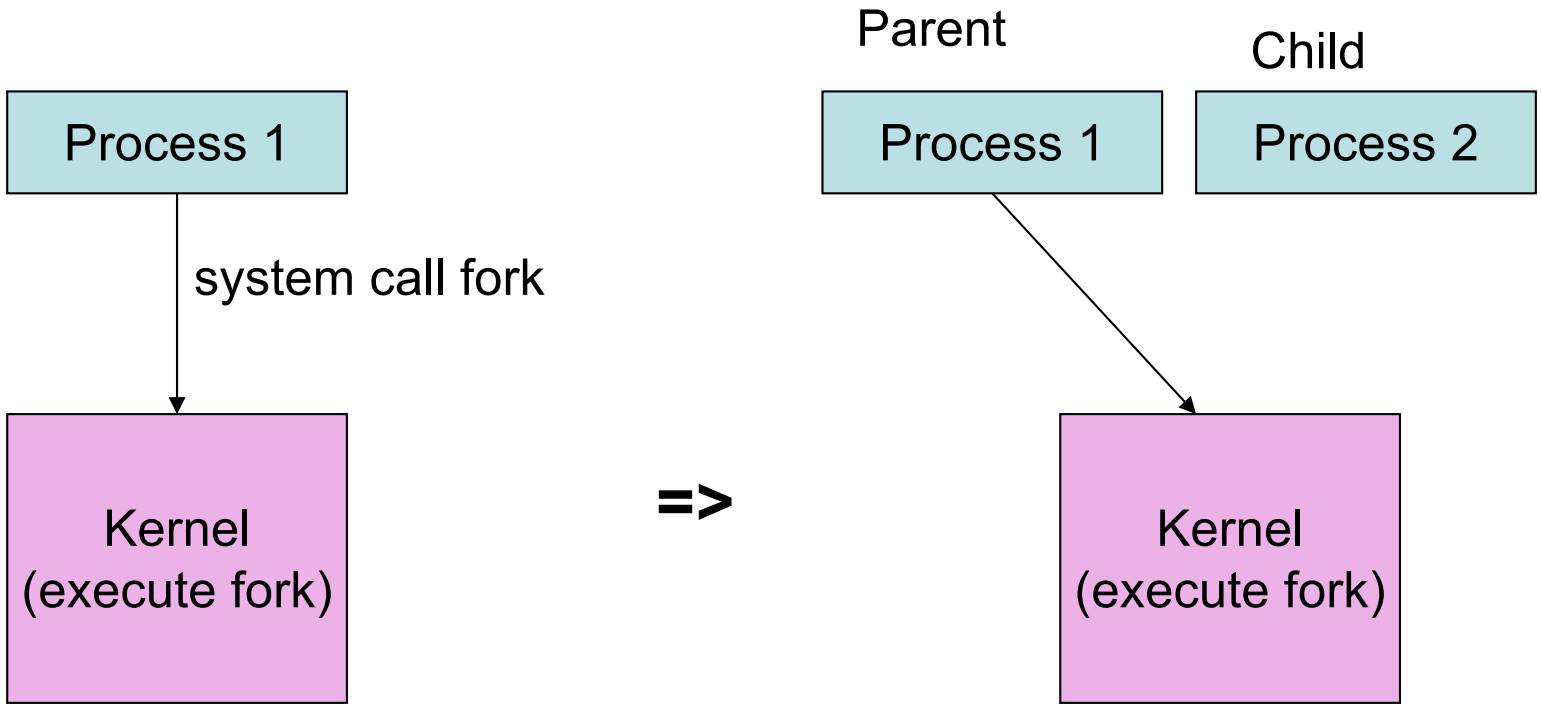
Handle orphans

- forks and creates a shell (sh)

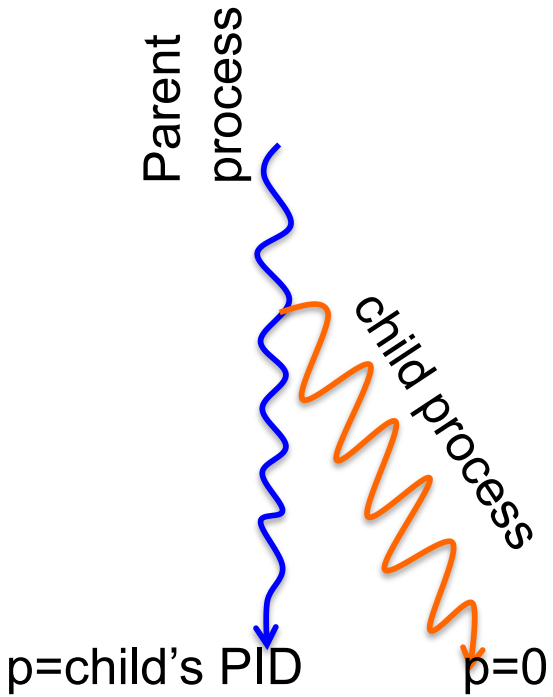
System Calls for Process Management

Creating a Process by Cloning

- Cloning
  - Child process is an exact replica of the parent
  - Fork system call

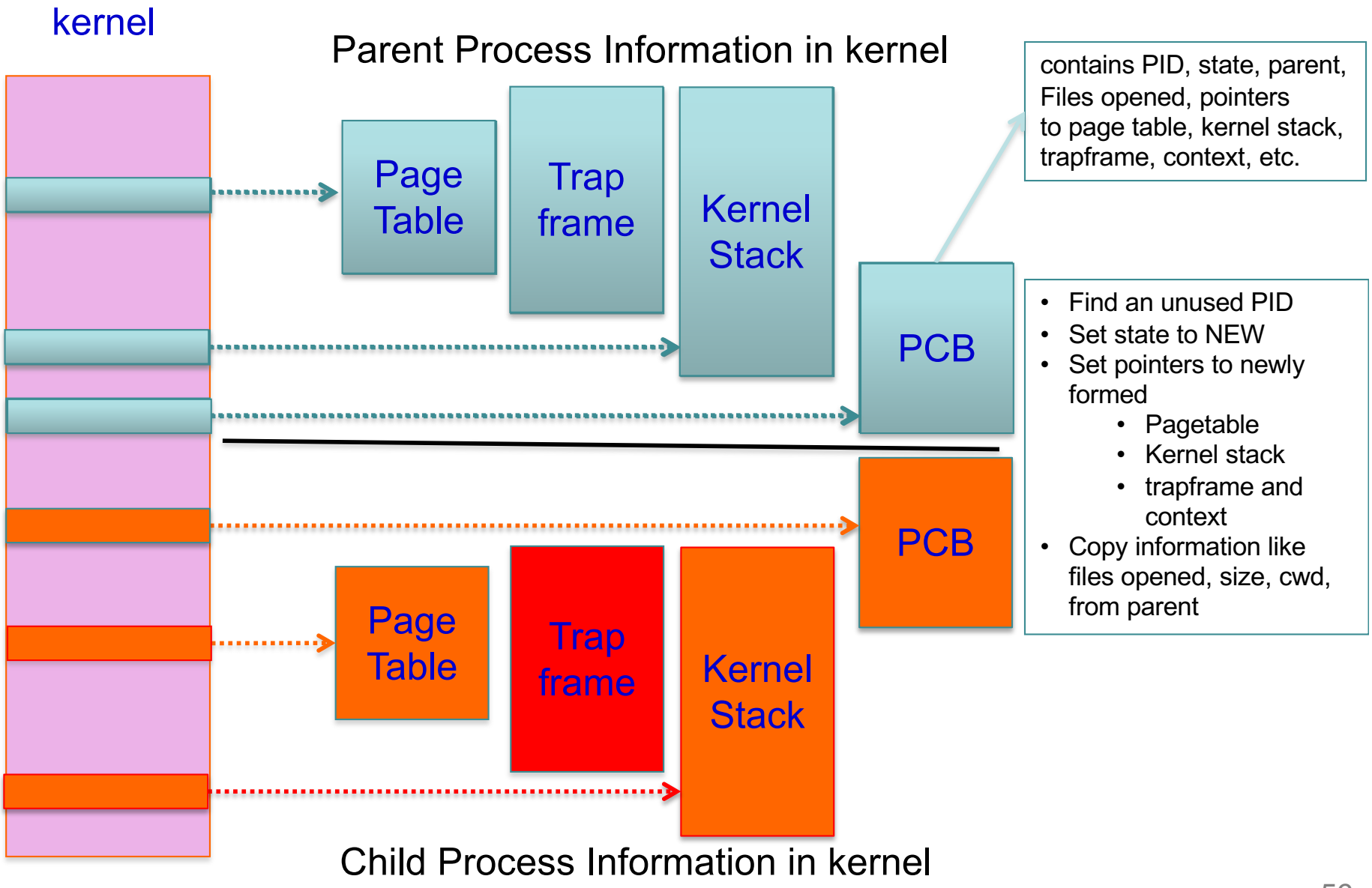


Creating a Process by Cloning (using fork system call)

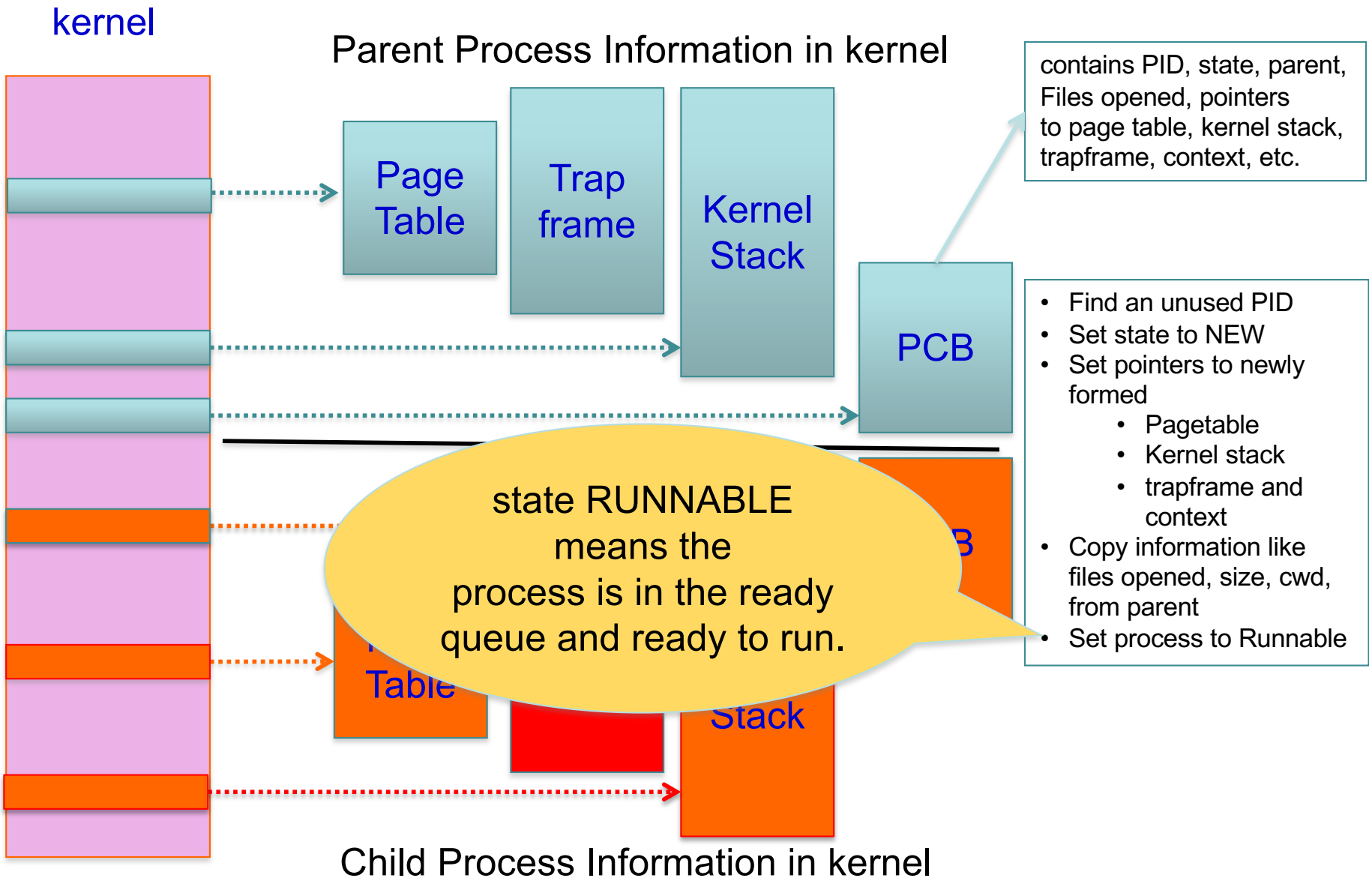



```
int p;

p = fork();
if (p > 0){
   printf("Parent : child PID = %d", p);
   p = wait();
   printf("Parent : child %d exited\n", p);
} else{
  printf("In child process");
  exit(0);
}
```

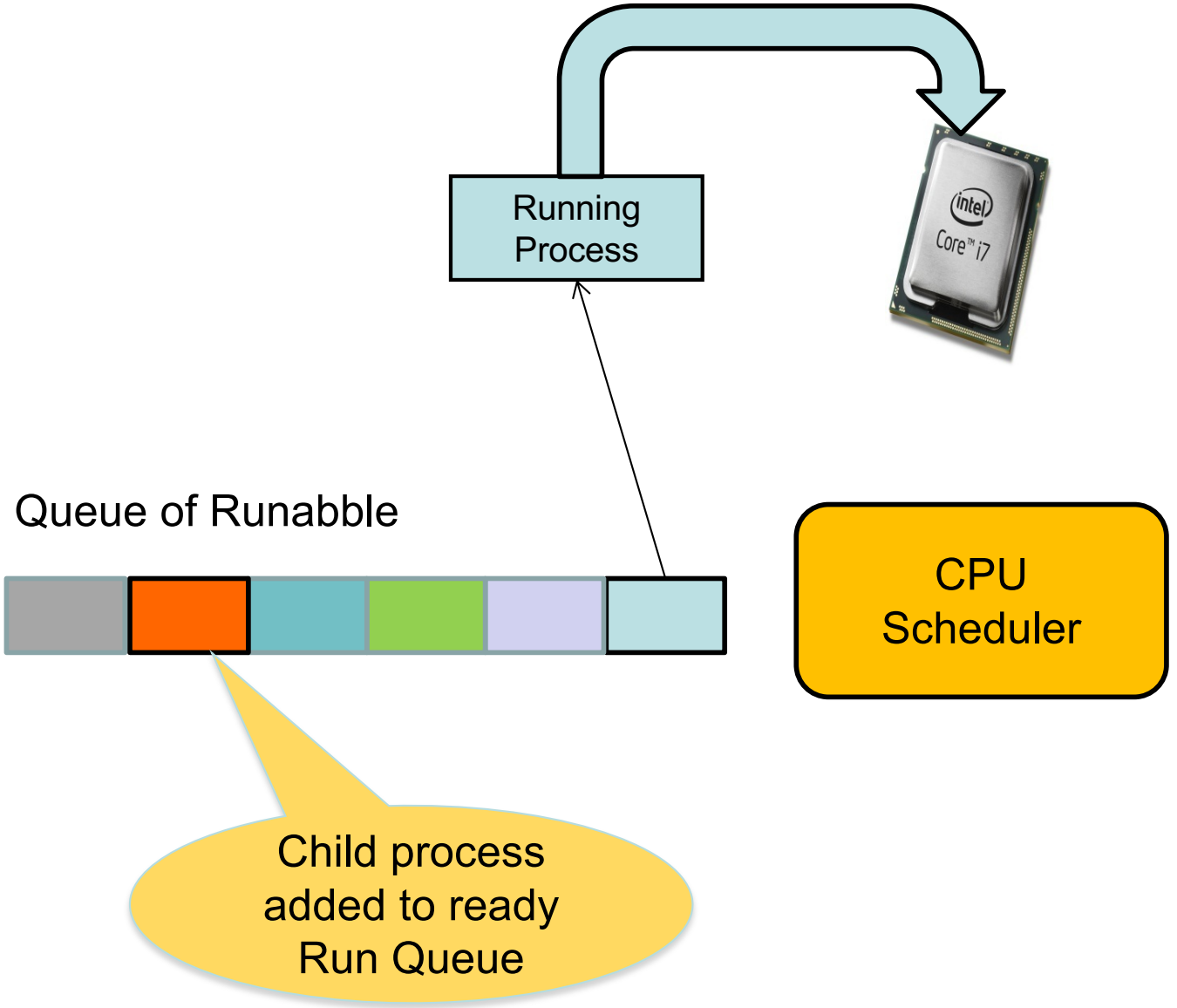
fork : from an OS perspective



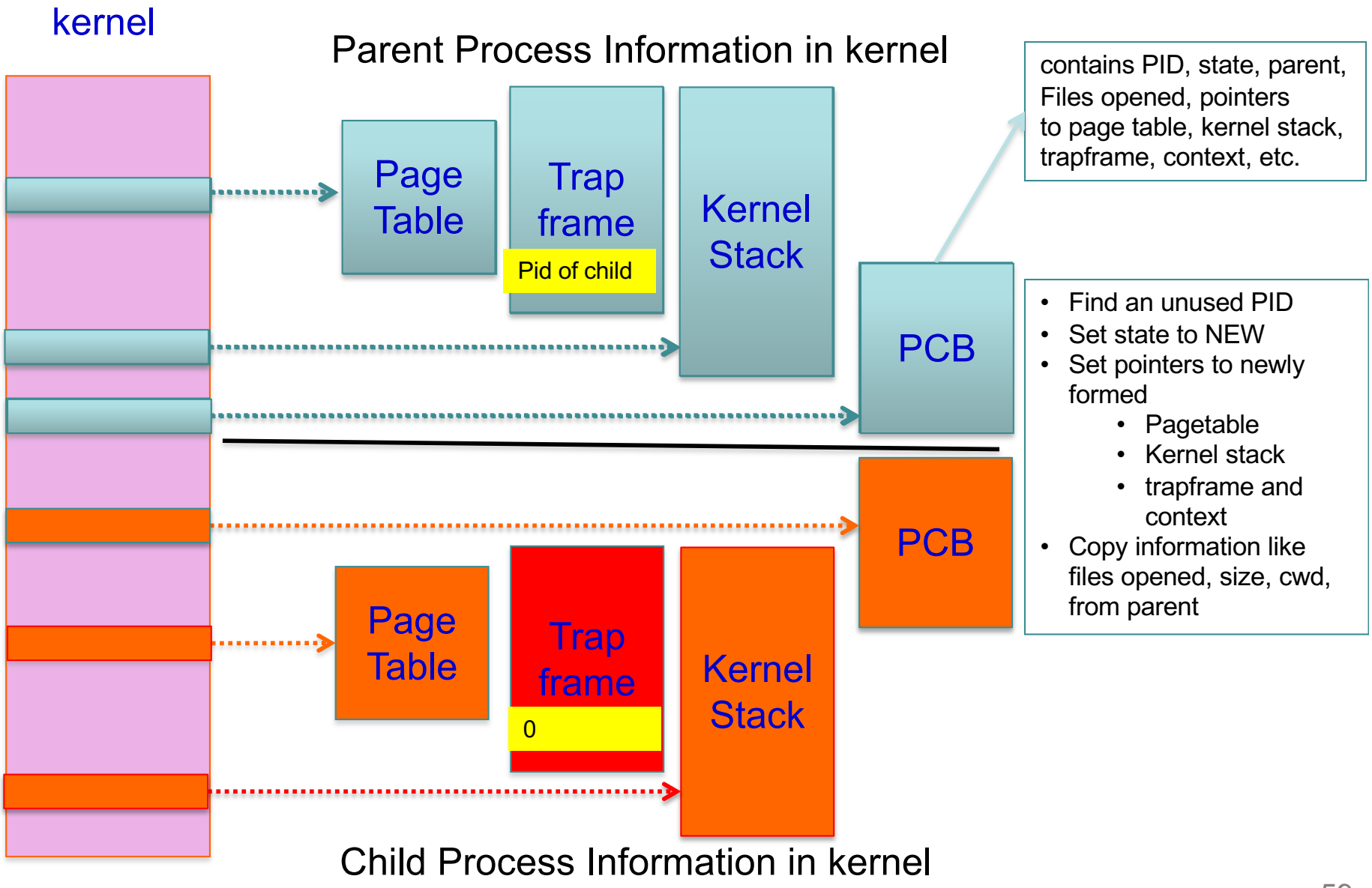
fork : from an OS perspective



Child Process in Ready Queue



Return from fork



fork, fills in the proc structure for a new process

```
 86 struct proc {
 87   struct spinlock lock;
 88
 89   // p->lock must be held when using these:
 90   enum procstate state;        // Process state
 91   struct proc *parent;         // Parent process
 92   void *chan;                  // If non-zero, sleeping on chan
 93   int killed;                  // If non-zero, have been killed
 94   int xstate;                  // Exit status to be returned to parent's wait
 95   int pid;                     // Process ID
 96
 97   // these are private to the process, so p->lock need not be held.
 98   uint64 kstack;               // Bottom of kernel stack for this process
 99   uint64 sz;                   // Size of process memory (bytes)
100   pagetable_t pagetable;       // Page table
101   struct trapframe *tf;        // data page for trampoline.S
102   struct context context;      // swtch() here to run process
103   struct file *ofile[NOFILE];  // Open files
104   struct inode *cwd;           // Current directory
105   char name[16];               // Process name (debugging)
106 };
```

The xv6 fork

```
240 int
241 fork(void)
242 {
243   int i, pid;
244   struct proc *np;
245   struct proc *p = myproc();
246
247   // Allocate process.
248   if((np = allocproc()) == 0){
249     return -1;
250   }
251
252   // Copy user memory from parent to child.
253   if(uvmcopy(p->pagetable, np->pagetable, p->sz) < 0){
254     freeproc(np);
255     release(&np->lock);
256     return -1;
257   }
258   np->sz = p->sz;
259   np->parent = p;
260
261   // copy saved user registers.
262   *(np->tf) = *(p->tf);
263
264   // Cause fork to return 0 in the child.
265   np->tf->a0 = 0;
266
267   // increment reference counts on open file descriptors.
268   for(i = 0; i < NOFILE; i++)
269     if(p->ofile[i])
270       np->ofile[i] = filedup(p->ofile[i]);
271   np->cwd = idup(p->cwd);
272
273   safestrcpy(np->name, p->name, sizeof(p->name));
274
275   pid = np->pid;
276   np->state = RUNNABLE;
277   release(&np->lock);
278   return pid;
279 }
```

(1) Pick an UNUSED proc. (2) allocate pid. and (3) allocate trapframe (4) create empty page directory; (5) setup context (p->context->ra = forkret); (p->context->sp = p->kstack + PGSIZE)

Copy page directory from the parent process (p→pagetable) to the child (np→pagetable)

Set size of np same as that of parent
Set parent of np
Copy trapframe from parent to child

In child process, set eax register in trapframe to 0. This is what fork returns in the child process

Other things… copy file pointer from parent, cwd, executable name

Child process is finally made runnable

Parent process returns the pid of the child

The xv6 fork

```
static struct proc*
allocproc(void)
{
  struct proc *p;

  for(p = proc; p < &proc[NPROC]; p++) {
    acquire(&p->lock);
    if(p->state == UNUSED) {
      goto found;
    } else {
      release(&p->lock);
    }
  }
  return 0;

found:
  p->pid = allocpid();

  // Allocate a trapframe page.
  if((p->tf = (struct trapframe *)kalloc()) == 0){
    release(&p->lock);
    return 0;
  }

  // An empty user page table.
  p->pagetable = proc_pagetable(p);

  // Set up new context to start executing at forkret,
  // which returns to user space.
  memset(&p->context, 0, sizeof p->context);
  p->context.ra = (uint64)forkret;
  p->context.sp = p->kstack + PGSIZE;

  return p;
}
```

(1) Pick an UNUSED proc.
(2) allocate pid.
(3) allocate trapframe
(4) create empty page directory;
(5) setup context
    (p->context->ra = forkret);
    (p->context->sp = p->kstack + PGSIZE)

forkret would ensure that the new child process gets 0 when fork returns

Copying Page Tables of Parent

xv6 does not support COW

- uvmcopy (in vm.c)
  - replicates parents memory pages
  - Constructs new table pointing to the new pages
  - Steps involved
    1. For each virtual page of the parent (starting from 0 to its sz)
       i. Find its page table entry (function walk)
       ii. Use kalloc to allocate a page (mem) in memory for the child
       iii. Use memmove to copy the parent page to mem
       iv. Use mappages to add a page table entry for mem

Register modifications w.r.t. parent

Registers modified in child process

- %eax = 0 so that pid = 0 in child process
- %eip = *forkret* so that child exclusively executes function *forkret*

Exit system call

```
int pid;

pid = fork();
if (pid > 0){
   printf("Parent : child PID = %d", pid);
   pid = wait();
   printf("Parent : child %d exited\n", pid);
} else{
   printf("In child process");
   exit();
}
```

exit internals

- init, the first process, can never exit
- For all other processes on exit,
  1. Decrement the usage count of all open files
     - If usage count is 0, close file
     - Drop reference to in-memory inode
  2. wakeup parent
     - If parent state is sleeping, make it runnable
     - Needed, cause parent may be sleeping due to a wait
  3. Make init adopt children of exited process
  4. Set process state to ZOMBIE
  5. Force context switch to scheduler

how is the tracking of these files done?

this is like a buffer's metadata
the harddrive data is cached in the RAM due to speed differences

note : page directory, kernel stack, not deallocated here

ref : proc.c (exit) 2604

```
311 exit(int status)
312 {
313   struct proc *p = myproc();
314
315   if(p == initproc)
316     panic("init exiting");
317
318   // Close all open files.
319   for(int fd = 0; fd < NOFILE; fd++){
320     if(p->ofile[fd]){
321       struct file *f = p->ofile[fd];
322       fileclose(f);
323       p->ofile[fd] = 0;
324     }
325   }
326
327   begin_op();
328   iput(p->cwd);
329   end_op();
330   p->cwd = 0;
331
332   acquire(&initproc->lock);
333   wakeup1(initproc);
334   release(&initproc->lock);
335
336   acquire(&p->lock);
337   struct proc *original_parent = p->parent;
338   release(&p->lock);
339
340   acquire(&original_parent->lock);
341
342   acquire(&p->lock);
343
344   // Give any children to init.
345   reparent(p);
346
347   // Parent might be sleeping in wait().
348   wakeup1(original_parent);
349
350   p->xstate = status;
351   p->state = ZOMBIE;
352
353   release(&original_parent->lock);
354
355   // Jump into the scheduler, never to return.
356   sched();
357   panic("zombie exit");
358 }
```

exit

initproc can never exit

Close all open files

Decrement in-memory inode usage

Wakeup parent of child.
The child may be an orphan, in which case init must be woken up

For every child of exiting process,
Set its parent to initproc

Set exiting process state to zombie

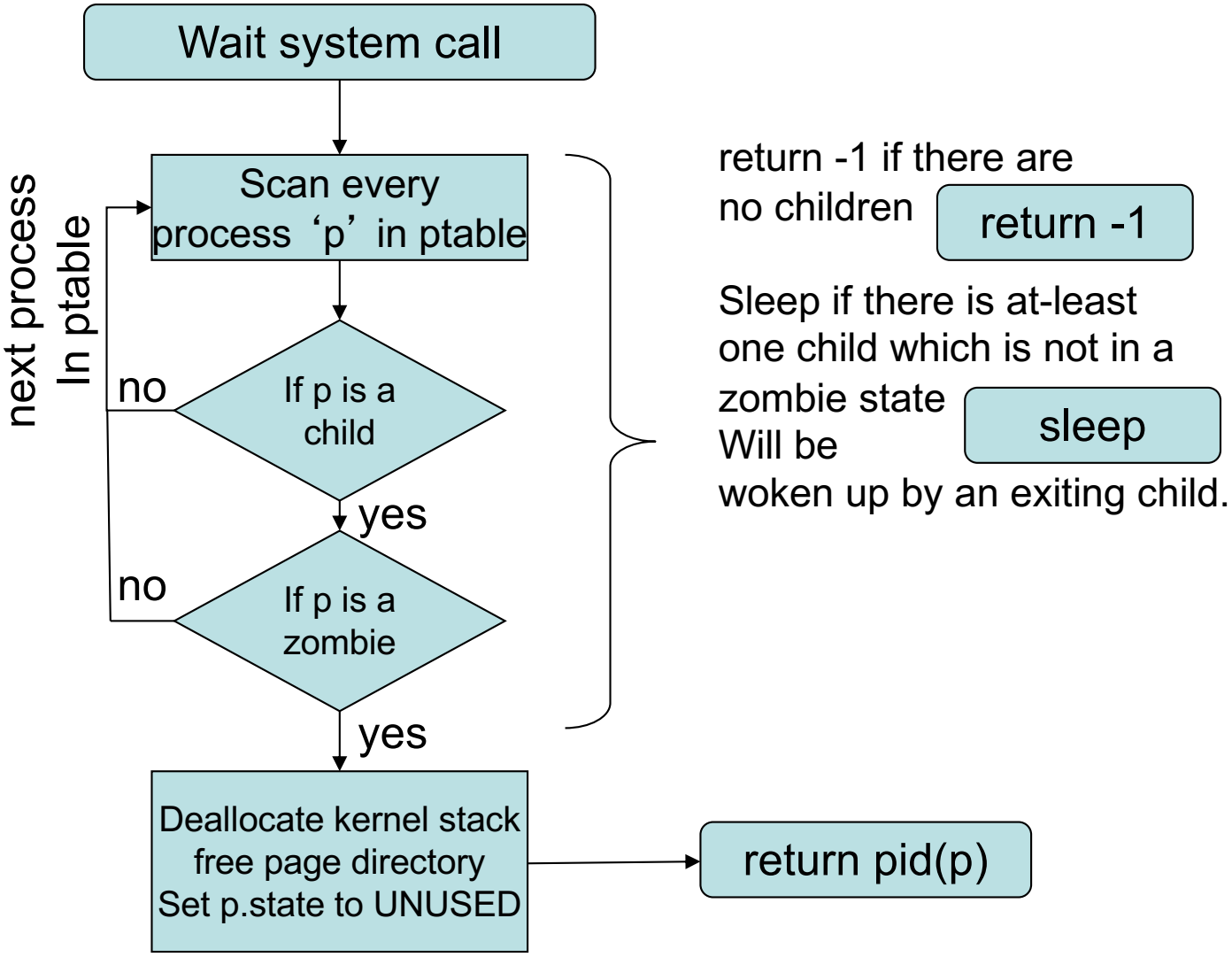
invoke the scheduler, which performs a context switch

wait system call

- Invoked in parent parent
- Parent ‘waits’ until child exits

```
int pid;

pid = fork();
if (pid > 0){
   printf("Parent : child PID = %d", pid);
   pid = wait();
   printf("Parent : child %d exited\n", pid);
} else{
  printf("In child process");
  exit();
}
```

wait internals



wait

```
363 wait(uint64 addr)
364 {
365   struct proc *np;
366   int havekids, pid;
367   struct proc *p = myproc();
368
369   // hold p->lock for the whole time to avoid lost
370   // wakeups from a child's exit().
371   acquire(&p->lock);
372   for(;;){
373     // Scan through table looking for exited children.
374     havekids = 0;
375     for(np = proc; np < &proc[NPROC]; np++){
376       // this code uses np->parent without holding np->lock.
377       // acquiring the lock first would cause a deadlock,
378       // since np might be an ancestor, and we already hold p->lock.
379       if(np->parent == p){
380         // np->parent can't change between the check and the acquire()
381         // because only the parent changes it, and we're the parent.
382         acquire(&np->lock);
383         havekids = 1;
384         if(np->state == ZOMBIE){
385           // Found one.
386           pid = np->pid;
387           if(addr != 0 && copyout(p->pagetable, addr, (char *)&np->xstate,
388                                   sizeof(np->xstate)) < 0) {
389             release(&np->lock);
390             release(&p->lock);
391             return -1;
392           }
393           freeproc(np);
394           release(&np->lock);
395           release(&p->lock);
396           return pid;
397         }
398         release(&np->lock);
399       }
400     }
401     // No point waiting if we don't have any children.
402     if(!havekids || p->killed){
403       release(&p->lock);
404       return -1;
405     }
406     // Wait for a child to exit.
407     sleep(p, &p->lock);  //DOC: wait-sleep
408   }
409 }
410
```

For every process in table, find if (a) p is a parent and (b) if the process is a zombie.

If ‘p’ is infact a child of proc and is in the ZOMBIE state then free remaining entries in p and return pid of p

Copy the exit status of the child process from kernel to user space.

note : page directory, kernel stack, deallocated here
… allows parent to peek into exited child’s process

Process will be set to SLEEPING state and wakeup only when the child exits

wait

```
363 wait(uint64 addr)
364 {
365   struct proc *np;
366   int havekids, pid;
367   struct proc *p = myproc();
368
369   // hold p->lock for the whole time to avoid lost
370   // wakeups from a child's exit().
371   acquire(&p->lock);
372   for(;;){
373     // Scan through table looking for exited children.
374     havekids = 0;
375     for(np = proc; np < &proc[NPROC]; np++){
376       // this code uses np->parent without holding np->lock.
377       // acquiring the lock first would cause a deadlock,
378       // since np might be an ancestor, and we already hold p->lock.
379       if(np->parent == p){
380         // np->parent can't change between the check and the acquire()
381         // because only the parent changes it, and we're the parent.
382         acquire(&np->lock);
383         havekids = 1;
384         if(np->state == ZOMBIE){
385           // Found one.
386           pid = np->pid;
387           if(addr != 0 && copyout(p->pagetable
388                                   sizeof(np->
389             release(&np->lock);
390             release(&p->lock);
391             return -1;
392           }
393           freeproc(np);
394           release(&np->lock);
395           release(&p->lock);
396           return pid;
397         }
398         release(&np->lock);
399       }
400     }
401     // No point waiting if we don't have any c
402     if(!havekids || p->killed){
403       release(&p->lock);
404       return -1;
405     }
406     // Wait for a child to exit.
407     sleep(p, &p->lock);  //DOC: wait-sleep
408   }
409 }
410
```

For every process in table, find if (a) p is a parent and (b) if the process is a zombie.

If ‘p’ is infact a child of proc and is in the ZOMBIE state then free remaining entries in p and return pid of p

```
static void
freeproc(struct proc *p)
{
  if(p->tf)
    kfree((void*)p->tf);
  p->tf = 0;
  if(p->pagetable)
    proc_freepagetable(p->pagetable, p->sz);
  p->pagetable = 0;
  p->sz = 0;
  p->pid = 0;
  p->parent = 0;
  p->name[0] = 0;
  p->chan = 0;
  p->killed = 0;
  p->xstate = 0;
  p->state = UNUSED;
}
```

status of the child process
user space.

rectory, kernel stack,
ocated here
nt to peek into exited
’s process

Process will be set to SLEEPING state and wakeup only when the child exits

Executing a Program (exec system call)

- exec system call
  - Load a program into memory and then execute it
  - Here ‘ls’ executed.

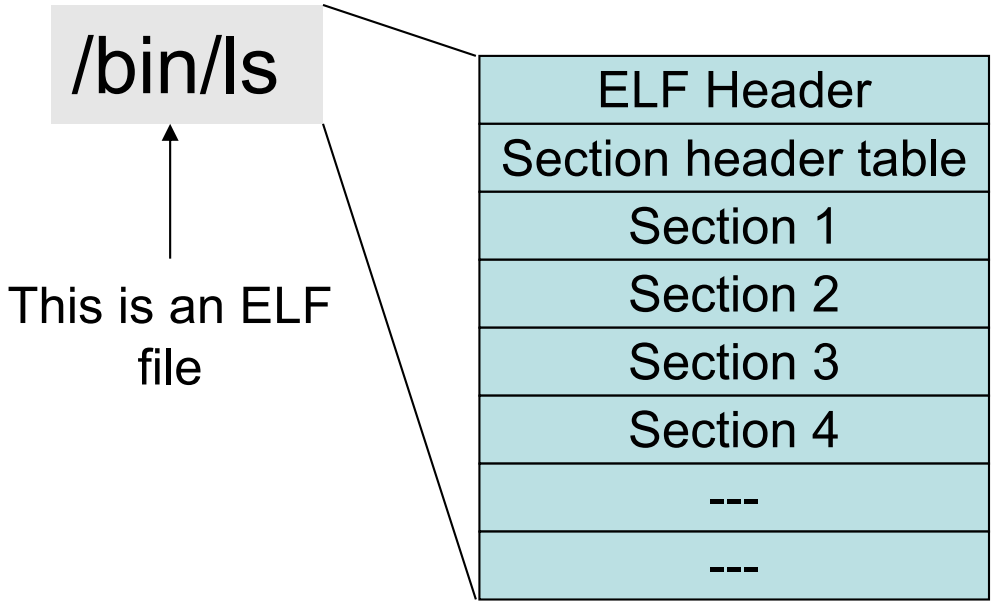
```
int pid;

pid = fork();
if (pid > 0){
   pid = wait();
} else{
   execlp("ls", "", NULL);
   exit(0);
```

ls has a bunch of flavors which differ on the arguments taken

unix and posix use elfs for the files while windows uses portable executables

not all of the executable is loading at the same time
when the executable is run, the os decides which sections are needed, parsed from the header table and loaded as needed
this is an instance of demand paging

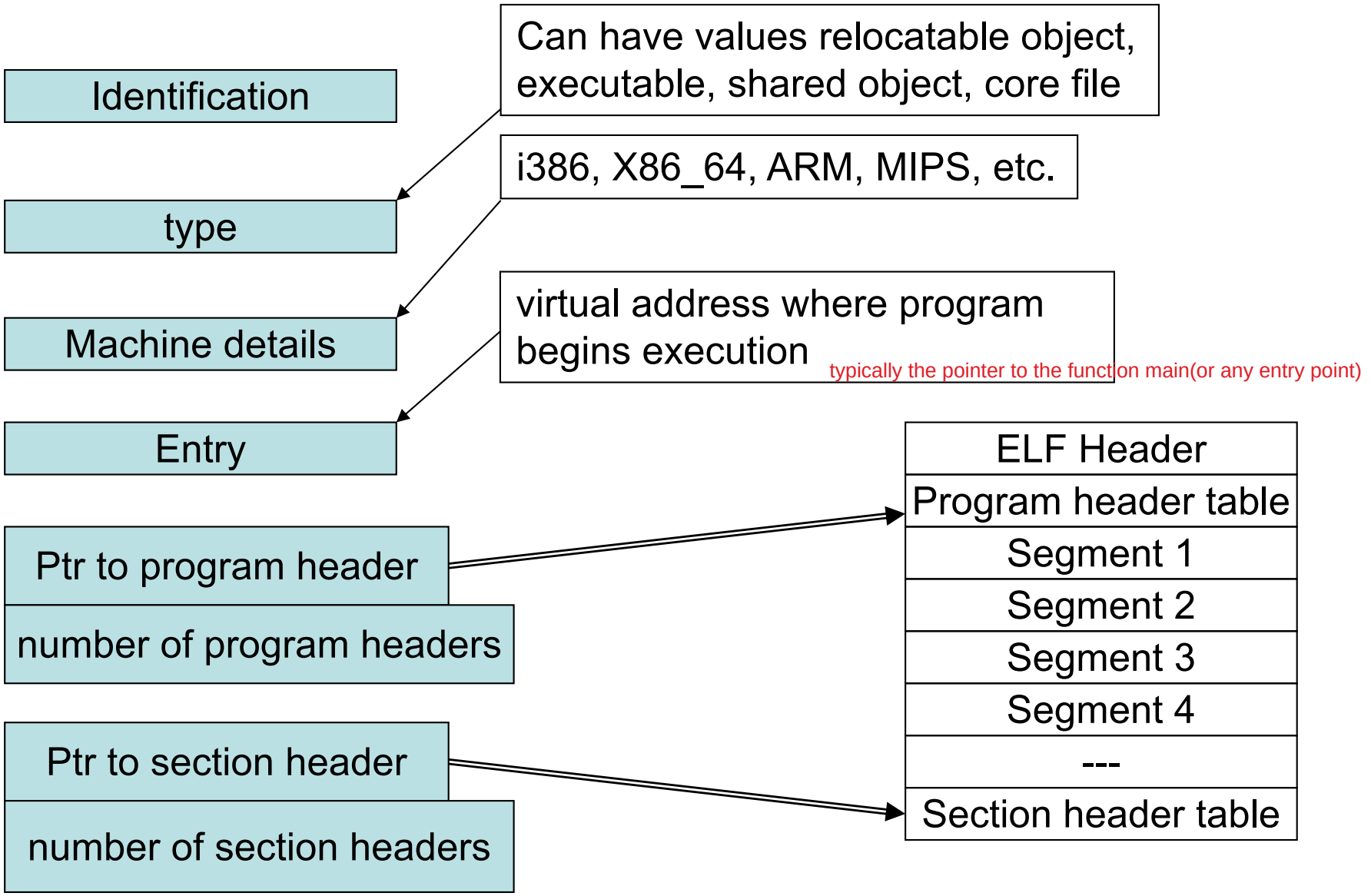
ELF Executables (linker view)



ELF format of executable

ref :www.skyfree.org/linux/references/ELF_Format.pdf
ref :man elf

ELF Header


Identification
Can have values relocatable object, executable, shared object, core file
type
i386, X86_64, ARM, MIPS, etc.
Machine details
virtual address where program begins execution
typically the pointer to the function main(or any entry point)
Entry
Ptr to program header
number of program headers
Ptr to section header
number of section headers
ELF Header
Program header table
Segment 1
Segment 2
Segment 3
Segment 4

Section header table

Hello World's ELF Header

```c
#include <stdio.h>

int main(){
  char str[] = "Hello World\n";
  printf("%s", str);
}
```

object files are the intermediates before the linking process
typically do not have an entry point and cannot be executed

relocatable code is that which need not be at some fixed position
an example of a non relocatable code is the boot rom located at 0x8xxxxx

relocatable code can ideally be placed in any valid locations

relocatable code is useful for shared libraries and intermediates
so when the linker is invoked with the other parts of the code
the linker can figure out where to place these pieces

modern systems have aslr for security as well

```
$ gcc hello.c –c
$ readelf –h hello.o
```

```
optiplex:~/tmp$ readelf -h hello.o
ELF Header:
  Magic:   7f 45 4c 46 02 01 01 00 00 00 00 00 00 00 00 00
  Class:                             ELF64
  Data:                              2's complement, little endian
  Version:                           1 (current)
  OS/ABI:                            UNIX - System V
  ABI Version:                       0
  Type:                              REL (Relocatable file)
  Machine:                           Advanced Micro Devices X86-64
  Version:                           0x1
  Entry point address:               0x0
  Start of program headers:          0 (bytes into file)
  Start of section headers:          368 (bytes into file)
  Flags:                             0x0
  Size of this header:               64 (bytes)
  Size of program headers:           0 (bytes)
  Number of program headers:         0
  Size of section headers:           64 (bytes)
  Number of section headers:         13
  Section header string table index: 10
```

all of the locations are specified as offsets with respect to the location of the header or typically the starting location of the file

Section Headers

- Contains information about the various sections

$ readelf –S hello.o

address is the point from where the sections need to be loaded
because this is a relocatable file, there are no specifications for the virtual address where those sections should be located

```
There are 13 section headers, starting at offset 0x170:

Section Headers:
  [Nr] Name              Type            Address          Offset Size              EntSize          Flags  Link  Info  Align
  [ 0]                   NULL            0000000000000000  00000000 0000000000000000  0000000000000000           0     0     0
  [ 1] .text             PROGBITS        0000000000000000  00000040 000000000000005c  0000000000000000  AX       0     0     1
  [ 2] .rela.text        RELA            0000000000000000  000005f8 0000000000000048  0000000000000018          11     1     8
  [ 3] .data             PROGBITS        0000000000000000  0000009c 0000000000000000  0000000000000000  WA       0     0     1
  [ 4] .bss              NOBITS          0000000000000000  0000009c 0000000000000000  0000000000000000  WA       0     0     1
  [ 5] .rodata           PROGBITS        0000000000000000  0000009c 0000000000000003  0000000000000000   A       0     0     1
  [ 6] .comment          PROGBITS        0000000000000000  0000009f 000000000000002a  0000000000000001  MS       0     0     1
  [ 7] .note.GNU-stack   PROGBITS        0000000000000000  000000c9 0000000000000000  0000000000000000           0     0     1
  [ 8] .eh_frame         PROGBITS        0000000000000000  000000d0 0000000000000038  0000000000000000   A       0     0     8
  [ 9] .rela.eh_frame    RELA            0000000000000000  00000640 0000000000000018  0000000000000018          11     8     8
  [10] .shstrtab         STRTAB          0000000000000000  00000108 0000000000000061  0000000000000000           0     0     1
  [11] .symtab           SYMTAB          0000000000000000  000004b0 0000000000000120  0000000000000018          12     9     8
  [12] .strtab           STRTAB          0000000000000000  000005d0 0000000000000026  0000000000000000           0     0     1
Key to Flags:
  W (write), A (alloc), X (execute), M (merge), S (strings), l (large)
  I (info), L (link order), G (group), T (TLS), E (exclude), x (unknown)
  O (extra OS processing required) o (OS specific), p (processor specific)
```

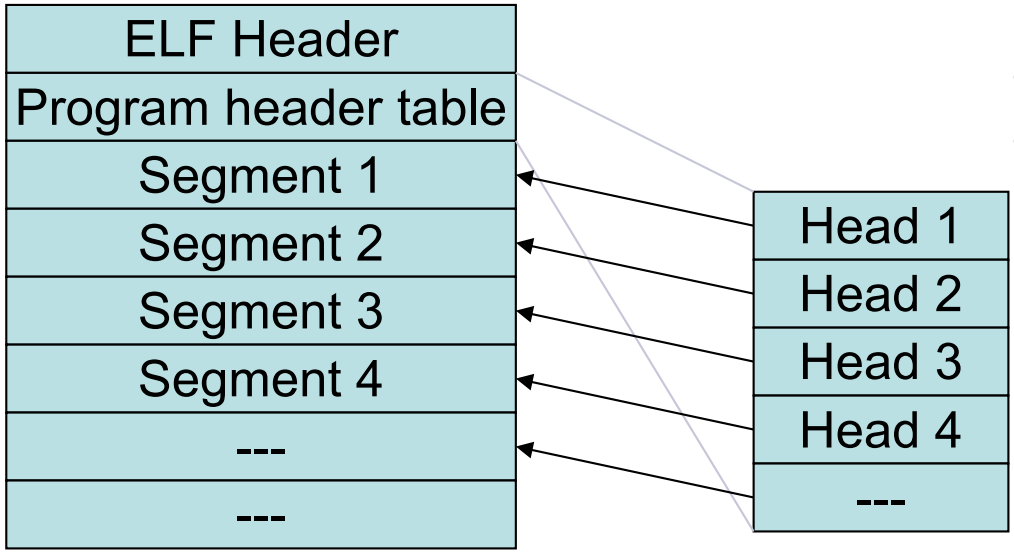
Offset and size of the section

Type of the section
PROGBITS : information defined by program
SYMTAB : symbol table
NULL : inactive section
NOBITS : Section that occupies no bits
RELA : Relocation table

Virtual address where the
Section should be loaded
(* all 0s because this is a .o file)

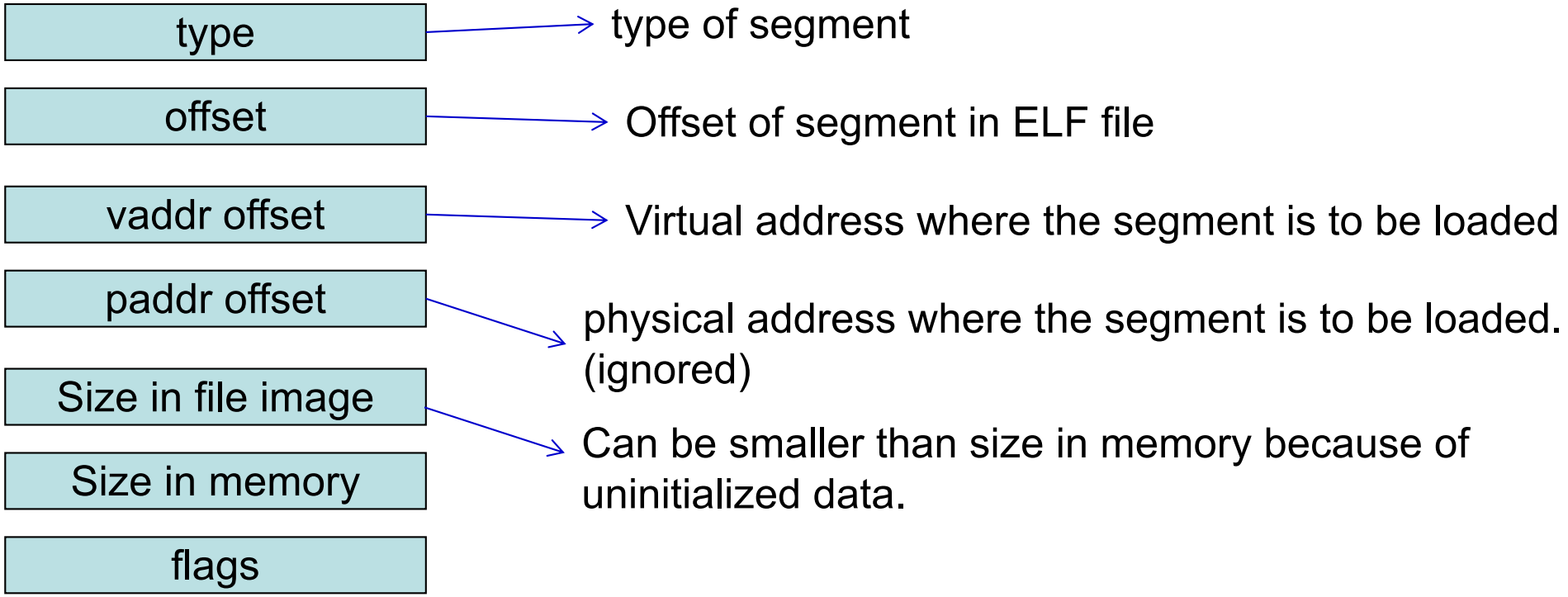
Size of the table if present else 0

Program Header (executable view)



- Contains information about each segment
- One program header for each segment
- A program header entry contains (among others)
  - Offset of segment in ELF file
  - Virtual address of segment
  - Segment size in file (filesz)
  - Segment size in memory (memsz)
  - Segment type
    - Loadable segment
    - Shared library
    - etc

Program Header Contents



Program headers for Hello World

- readelf –l hello

```
Elf file type is EXEC (Executable file)
Entry point 0x4004b0
There are 9 program headers, starting at offset 64

Program Headers:
  Type           Offset             VirtAddr           PhysAddr FileSiz            MemSiz              Flags  Align
  PHDR           0x0000000000000040 0x0000000000400040 0x0000000000400040 0x00000000000001f8 0x00000000000001f8  R E    8
  INTERP         0x0000000000000238 0x0000000000400238 0x0000000000400238 0x000000000000001c 0x000000000000001c  R      1
      [Requesting program interpreter: /lib64/ld-linux-x86-64.so.2]
  LOAD           0x0000000000000000 0x0000000000400000 0x0000000000400000 0x00000000000007b4 0x00000000000007b4  R E    200000
  LOAD           0x0000000000000e10 0x0000000000600e10 0x0000000000600e10 0x0000000000000238 0x0000000000000240  RW     200000
  DYNAMIC        0x0000000000000e28 0x0000000000600e28 0x0000000000600e28 0x00000000000001d0 0x00000000000001d0  RW     8
  NOTE           0x0000000000000254 0x0000000000400254 0x0000000000400254 0x0000000000000044 0x0000000000000044  R      4
  GNU_EH_FRAME   0x0000000000000688 0x0000000000400688 0x0000000000400688 0x0000000000000034 0x0000000000000034  R      4
  GNU_STACK      0x0000000000000000 0x0000000000000000 0x0000000000000000 0x0000000000000000 0x0000000000000000  RW     10
  GNU_RELRO      0x0000000000000e10 0x0000000000600e10 0x0000000000600e10 0x00000000000001f0 0x00000000000001f0  R      1

 Section to Segment mapping:
  Segment Sections...
   00
   01     .interp
   02     .interp .note.ABI-tag .note.gu.build-id .gnu.hash .dynsym .dynstr .gnu.version .gnu.version_r .rela.dyn .rela.plt .init .plt .text .fini .rodata .eh_frame_hdr .eh_frame
   03     .init_array .fini_array .jcr .dynamic .got .got.plt .data .bss
   04     .dynamic
   05     .note.ABI-tag .note.gu.build-id
   06     .eh_frame_hdr
   07
   08     .init_array .fini_array .jcr .dynamic .got
```

Mapping between segments and sections

exec

exec.c

```
12 int
13 exec(char *path, char **argv)
14 {
15   char *s, *last;
16   int i, off;
17   uint64 argc, sz, sp, ustack[MAXARG+1], stackbase;
18   struct elfhdr elf;
19   struct inode *ip;
20   struct proghdr ph;
21   pagetable_t pagetable = 0, oldpagetable;
22   struct proc *p = myproc();
23
24   begin_op();
25
26   if((ip = namei(path)) == 0){
27     end_op();
28     return -1;
29   }
30   ilock(ip);
31
32   // Check ELF header
33   if(readi(ip, 0, (uint64)&elf, 0, sizeof(elf)) != sizeof(elf))
34     goto bad;
35   if(elf.magic != ELF_MAGIC)
36     goto bad;
37
38   if((pagetable = proc_pagetable(p)) == 0)
39     goto bad;
```

Parameters are the path of executable and command line arguments

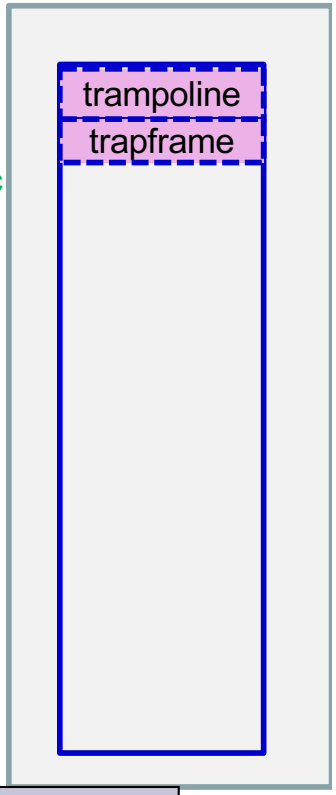
Get pointer to the inode for the executable

- Executable files begin with a signature.
- Sanity check for magic number. All executables begin with a ELF Magic number string : “\x7fELF”

Set up a new set of page tables.

Do we really need to do this?

Process Memory Map



ref : exec.c

exec contd.
(load segments into memory)

```
41  // Load program into memory.
42  sz = 0;
43  for(i=0, off=elf.phoff; i<elf.phnum; i++, off+=sizeof(ph)){
44    if(readi(ip, 0, (uint64)&ph, off, sizeof(ph)) != sizeof(ph))
45      goto bad;
46    if(ph.type != ELF_PROG_LOAD)
47      continue;
48    if(ph.memsz < ph.filesz)
49      goto bad;
50    if(ph.vaddr + ph.memsz < ph.vaddr)
51      goto bad;
52    if((sz = uvmalloc(pagetable, sz, ph.vaddr + ph.memsz)) == 0)
53      goto bad;
54    if(ph.vaddr % PGSIZE != 0)
55      goto bad;
56    if(loadseg(pagetable, ph.vaddr, ip, ph.off, ph.filesz) < 0)
57      goto bad;
58  }
```

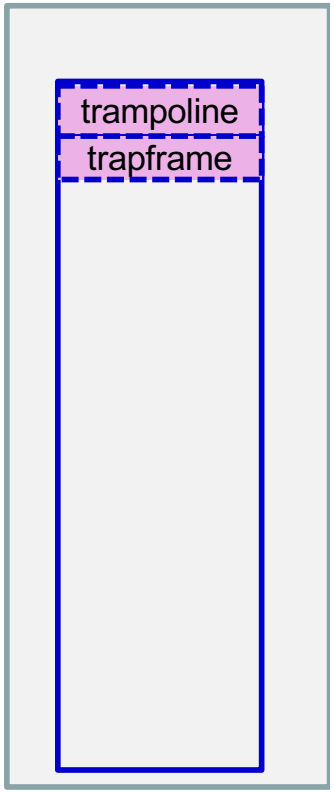
Parse through all the elf program headers.

Only load into memory segments of type LOAD

Add more page table entries to grow page tables from old size to new size (ph.vaddr + ph.memsz)

Load segment into RAM at the specified virtual address (ph.vaddr)

Virtual Memory Map

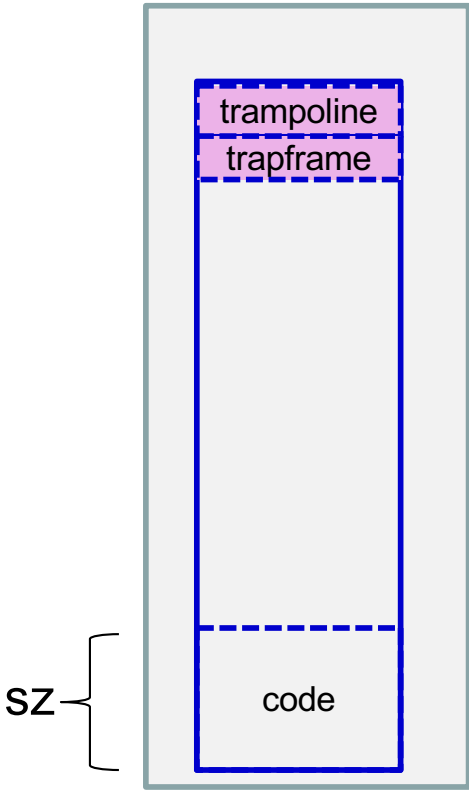


uvmalloc

Grow the process from oldsz
(initially 0) to newsz (vaddr+memsz)

```
235 uint64
236 uvmalloc(pagetable_t pagetable, uint64 oldsz, uint64 newsz)
237 {
238   char *mem;
239   uint64 a;
240
241   if(newsz < oldsz)
242     return oldsz;
243
244   oldsz = PGROUNDUP(oldsz);
245   a = oldsz;
246   for(; a < newsz; a += PGSIZE){
247     mem = kalloc();
248     if(mem == 0){
249       uvmdealloc(pagetable, a, oldsz);
250       return 0;
251     }
252     memset(mem, 0, PGSIZE);
253     if(mappages(pagetable, a, PGSIZE, (uint64)mem, PTE_W|PTE_X|PTE_R|PTE_U) != 0){
254       kfree(mem);
255       uvmdealloc(pagetable, a, oldsz);
256       return 0;
257     }
258   }
259   return newsz;
260 }
```

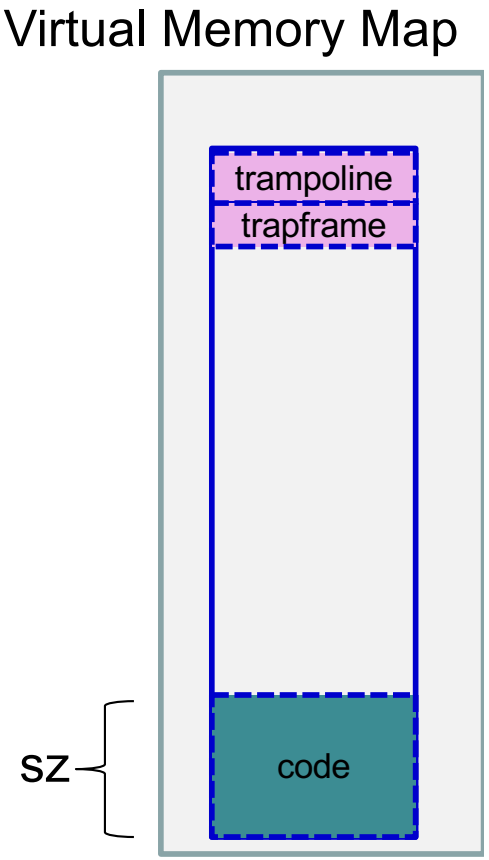
Virtual Memory Map



loadseg

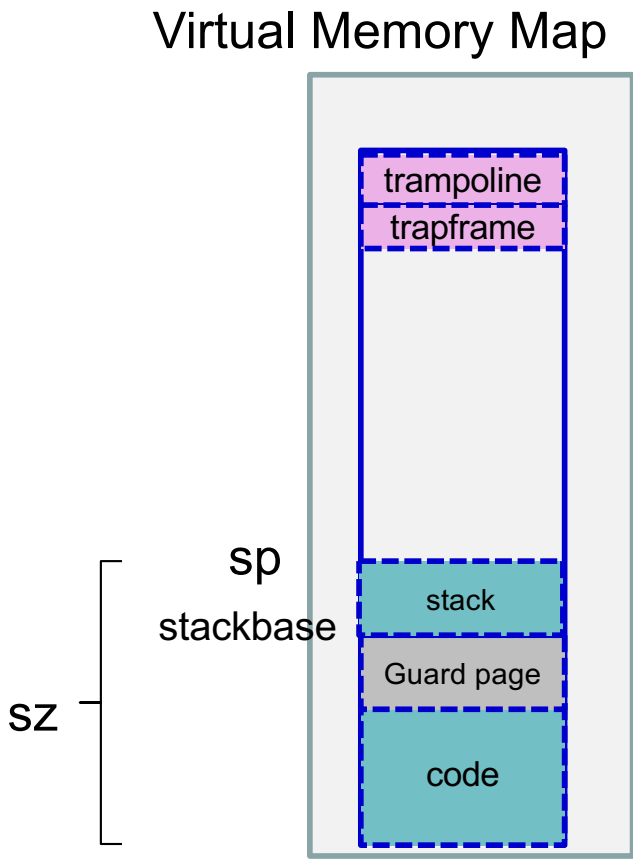
Load segment pointed to by ip + offset
to the specified virtual address va

```
static int
loadseg(pagetable_t pagetable, uint64 va, struct inode *ip, uint offset, uint sz)
{
  uint i, n;
  uint64 pa;

  if((va % PGSIZE) != 0)
    panic("loadseg: va must be page aligned");

  for(i = 0; i < sz; i += PGSIZE){
    pa = walkaddr(pagetable, va + i);
    if(pa == 0)
      panic("loadseg: address should exist");
    if(sz - i < PGSIZE)
      n = sz - i;
    else
      n = PGSIZE;
    if(readi(ip, 0, (uint64)pa, offset+i, n) != n)
      return -1;
  }

  return 0;
}
```



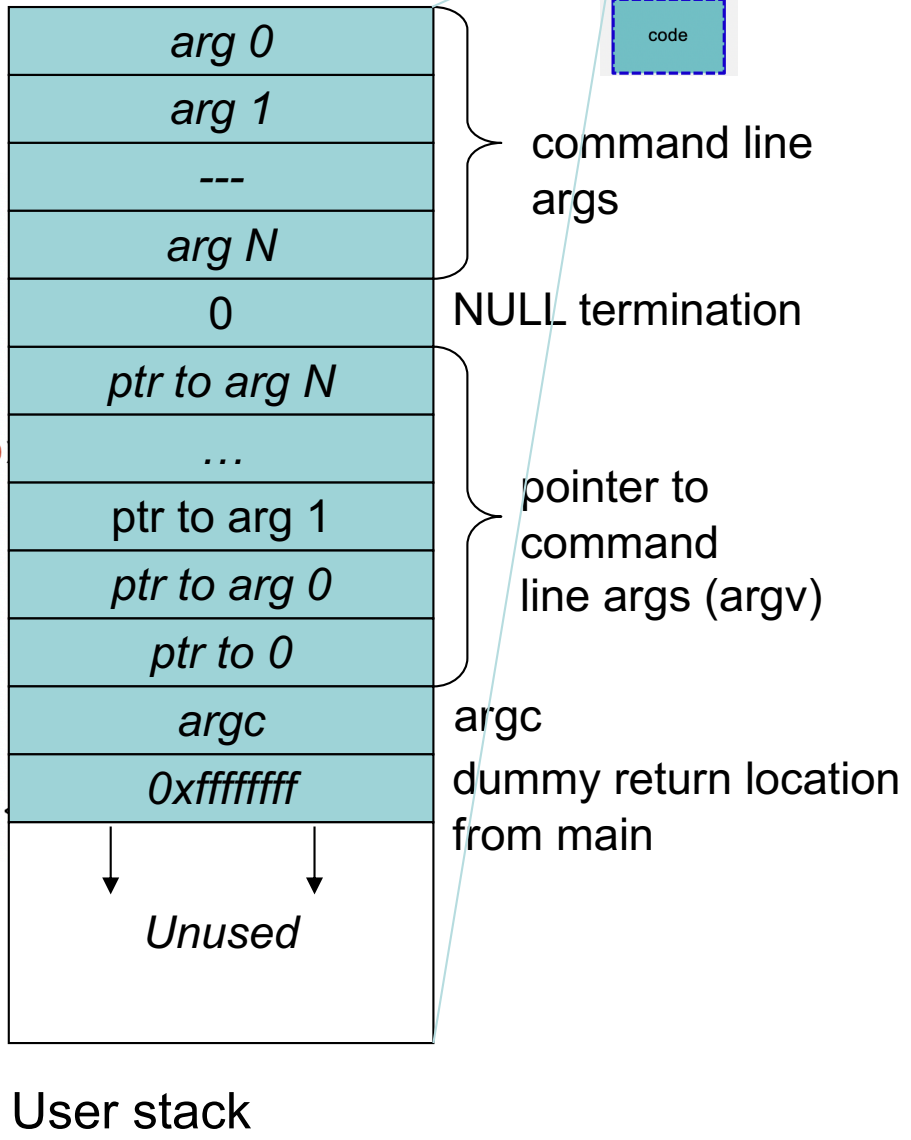
exec contd. (allocate user stacks)

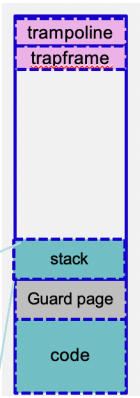
```
66   // Allocate two pages at the next page boundary.
67   // Use the second as the user stack.
68   sz = PGROUNDUP(sz);
69   if((sz = uvmalloc(pagetable, sz, sz + 2*PGSIZE)) == 0)
70     goto bad;
71   uvmclear(pagetable, sz-2*PGSIZE);
72   sp = sz;
73   stackbase = sp - PGSIZE;
```



exec contd. (fill user stack with command line args)

```
75  // Push argument strings, prepare rest of stack in ustack.
76  for(argc = 0; argv[argc]; argc++) {
77    if(argc >= MAXARG)
78      goto bad;
79    sp -= strlen(argv[argc]) + 1;
80    sp -= sp % 16; // riscv sp must be 16-byte aligned
81    if(sp < stackbase)
82      goto bad;
83    if(copyout(pagetable, sp, argv[argc], strlen(argv[argc]) + 1) < 0)
84      goto bad;
85    ustack[argc] = sp;
86  }
87  ustack[argc] = 0;
88
89  // push the array of argv[] pointers.
90  sp -= (argc+1) * sizeof(uint64);
91  sp -= sp % 16;
92  if(sp < stackbase)
93    goto bad;
94  if(copyout(pagetable, sp, (char *)ustack, (argc+1)*sizeof(uint64)) <
95    goto bad;
```





exec contd. (proc, trapframe, etc.)

```
 97  // arguments to user main(argc, argv)
 98  // argc is returned via the system call return
 99  // value, which goes in a0.
100  p->tf->a1 = sp;
101
102  // Save program name for debugging.
103  for(last=s=path; *s; s++)
104    if(*s == '/')
105      last = s+1;
106  safestrcpy(p->name, last, sizeof(p->name));
107
108  // Commit to the user image.
109  oldpagetable = p->pagetable;
110  p->pagetable = pagetable;
111  p->sz = sz;
112  p->tf->epc = elf.entry;  // initial program counter = main
113  p->tf->sp = sp; // initial stack pointer
114  proc_freepagetable(oldpagetable, oldsz);
115  return argc; // this ends up in a0, the first argument to main(argc, argv)
116
```

Set the executable file name in proc

these specify where execution should start for the new program.
Also specifies the stack pointer

Free the oldpagetable which was created during fork

Exercise

- How is the heap initialized in xv6?
  see sys_sbrk and growproc