Sistemas Operativos: Limited Direct Execution

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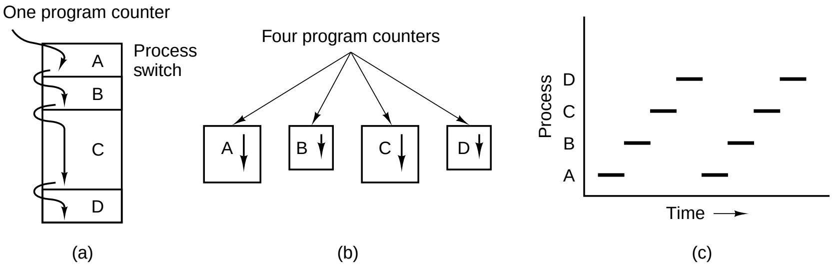
Multiprocess Execution



- The processor is **time shared** among processes
- The OS provides the illusion that each process executes in its own processor, i.e. each process executes in a virtual processor.

Kernel Data Structures (xv6 toy-OS)

```
// the registers xv6 will save and restore
// to stop and subsequently restart a process
struct context {
  int eip;
  int esp;
  int ebx;
  int ecx;
  int edx;
  int esi;
  int edi;
  int ebp;
};

// the different states a process can be in
enum proc_state { UNUSED, EMBRYO, SLEEPING,
                  RUNNABLE, RUNNING, ZOMBIE };

// the information xv6 tracks about each process
// including its register context and state
struct proc {
  char *mem;                  // Start of process memory
  uint sz;                    // Size of process memory
  char *kstack;               // Bottom of kernel stack
                              // for this process
  enum proc_state state;      // Process state
  int pid;                    // Process ID
  struct proc *parent;        // Parent 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
  struct context context;     // Switch here to run process
  struct trapframe *tf;       // Trap frame for the
                              // current interrupt
};
```

src: Arpaci-Dusseau & Arpaci-Dusseau

Multiprocess Execution: Challenges

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Approach **Limited Direct Execution**

Direct Execution

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Remove entry from process list	

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    - This is necessary to ensure that all processes are able to run
    - But, to ensure efficiency it is important to run processes directly on the HW.

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- Via system calls

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- **Upon a system call**, the CPU must change from user mode to kernel mode
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  trap (to kernel) jumps to the kernel code and raises the privilege level to kernel mode:

  1. Save CPU state (PC and a few registers)
     - On the x86, the CPU pushes the PC and some other registers to a per-process kernel stack

     Some of this must be done by HW, rest may be done by SW.
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  return-from-trap returns to the calling user process:

  1. Lowers the privilege level to user mode (may be done by 2)
  2. Restores the CPU state from before the system call
  3. Jumps to the instruction after the trap in user code

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	remember address of syscall handler

- This is similar to an interrupt table
- Upon handling a HW interrupt, the CPU also switches to kernel mode
  - Usually, the interrupt handler needs to do I/O
- On the x86, Linux uses the software interrupt instruction INT as trap instruction (x86 offers other trap instructions)

Limited Direct Execution Protocol

Assumption: Upon switching into/out of the kernel, the CPU saves/restores its registers in a **per process kernel stack**

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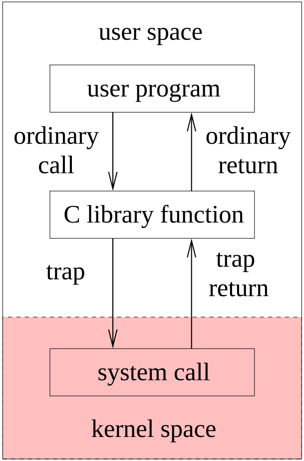
System Call Implementation



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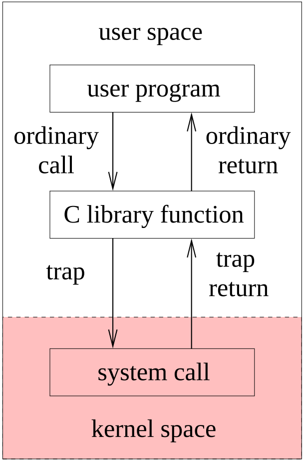
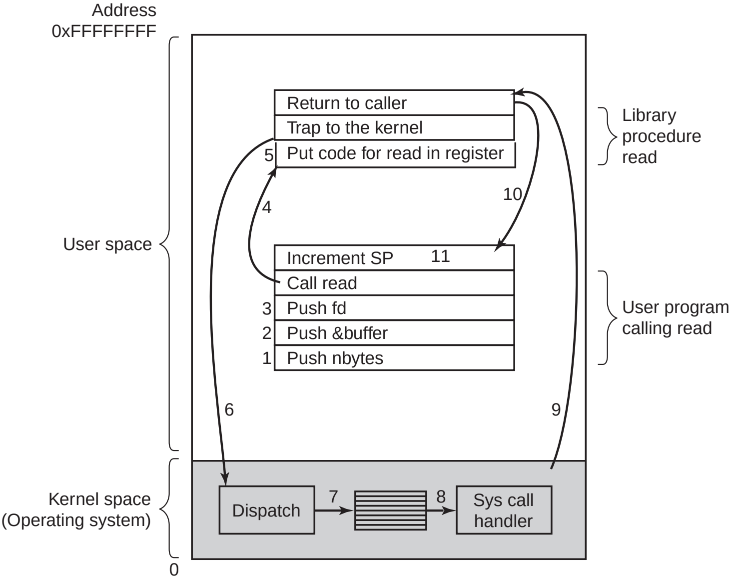


- Uses special HW instructions, e.g. (*call gates* ou *sw interrupts*, in the case of the x86) that switch automatically from one privilege mode to another
- For a programmer it is as if it had invoked a C library function:
  - Actually, that is what s/he does

```
ssize_t read(int fd, void *buffer,
size_t nbytes)
```



`read()` Execution Steps

1, 2, 3 push the arguments onto the stack;

4 call C library function `read()`;

5 setup register with system call #

6 switch CPU execution mode

7 dispatch to appropriate *handler*;

8 execute *handler*;

9 return back to the C library;

10 return from the C library function `read()`;

11 adjust *stack*.

LDE Issue # 2: Stopping a Running Process

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Alternatives

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- Someone (?Tanenbaum?) wrote that **`nice`** is the least used Unix command
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Non-cooperative Use timer interrupts

- Program a timer device to interrupt periodically (typically, a few ms)
- Upon an interrupt (by the timer or otherwise):
  - The currently running process is suspended
  - A pre-configured interrupt handler (IH) runs
  - At this point the kernel runs and can do what it wants

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- At boot time, the kernel must:

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  - configure the timer to interrupt every X ms
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- At boot time, the kernel must:
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  - configure the timer to interrupt every X ms
  - start the timer
- Upon an interrupt, the HW must:
  - Save the state of the process that is running (at least processor registers)
    - Process must be able to resume in the point it was, once the kernel has handled the interrupt
    - This is very similar to what is done upon a system call
      No wonder, Linux uses the `INT` instruction

Context Switch

- The kernel, or better the scheduler decides:
  1. Whether to allow the currently running process to continue
  2. Or to suspend it (move it to the READY state) and run another process instead.

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- By switching the kernel stacks, the kernel exits to the context of a process different of the one that was executing when of the call to the switch code
- When the kernel executes the return-from-trap instruction, the soon-to-be-running process becomes the currently running process

Limited Direct Execution Protocol: Timer Interrupt

OS @ boot (kernel mode)	**Hardware**	**Program (user mode)**

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	move to user mode	

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	move to user mode restore regs(B) from k-stack(B)	

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Context Switch

- Note that there are 2 types of register saves/restores

  Upon the timer-interrupt the **hardware** saves the **user registers** of the running process onto the **kernel stack** of that process

  - On the IA32 architecture, this happens every time the processor moves into kernel mode

  On context switching the **kernel**

  1. saves the current values of the **registers** of the running process into the **process structure** of that process
  2. restores the previously saved values of the **registers** of the soon-to-run process from the **process structure** of that process

Context Switch: xv6 code

```
# void swtch(struct context **old, struct context *new);
#
# Save current register context in old
# and then load register context from new.
.globl swtch
swtch:
    # Save old registers
    movl 4(%esp), %eax    # put old ptr into eax
    popl 0(%eax)          # save the old IP
    movl %esp, 4(%eax)    # and stack
    movl %ebx, 8(%eax)    # and other registers
    movl %ecx,12(%eax)
    movl %edx,16(%eax)
    movl %esi,20(%eax)
    movl %edi,24(%eax)
    movl %ebp,28(%eax)

    # Load new registers
    movl 4(%esp), %eax    # put new ptr into eax
    movl 28(%eax), %ebp   # restore other registers
    movl 24(%eax), %edi
    movl 20(%eax), %esi
    movl 16(%eax), %edx
    movl 12(%eax), %ecx
    movl 8(%eax), %ebx
    movl 4(%eax), %esp    # stack is switched here
    pushl 0(%eax)         # return addr put in place
    ret                   # finally return into new ctx
```

Kernel Data Structures (xv6 toy-OS)

```
// the registers xv6 will save and restore
// to stop and subsequently restart a process
struct context {
  int eip;
  int esp;
  int ebx;
  int ecx;
  int edx;
  int esi;
  int edi;
  int ebp;
};

// the different states a process can be in
enum proc_state { UNUSED, EMBRYO, SLEEPING,
                  RUNNABLE, RUNNING, ZOMBIE };

// the information xv6 tracks about each process
// including its register context and state
struct proc {
  char *mem;                  // Start of process memory
  uint sz;                    // Size of process memory
  char *kstack;               // Bottom of kernel stack
                              // for this process
  enum proc_state state;      // Process state
  int pid;                    // Process ID
  struct proc *parent;        // Parent 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
  struct context context;     // Switch here to run process
  struct trapframe *tf;       // Trap frame for the
                              // current interrupt
};
```

src: **Arpaci-Dusseau & Arpaci-Dusseau**