# Subroutines & Operating Systems

Part 8

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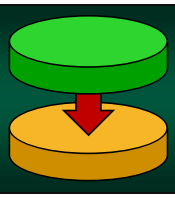

# The System Stack

Pile of… Data

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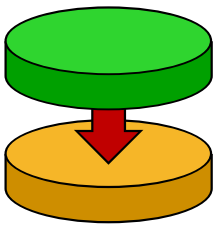
## The System Stack

- The processor maintains a stack in memory
- It allows *subroutines*
  - analogous to the "functions" you use in Java and other third-generation languages
  - but, much more simple





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## Examples of Stacks

- Page-visited "back button" history in a web browser
- Undo sequence in a text editor
- Deck of cards in Windows Solitaire



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## Implementing in Memory

- On a processor, the stack stores integers
  - size of the integer the bit-size of the system
  - 64-bit system → 64-bit integer
- Stacks is stored in memory
  - A fixed location pointer (S0) defines the bottom of the stack
  - A *stack pointer* (SP) gives the location of the top of the stack



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## Approaches

- Growing upwards
  - Bottom Pointer (S0) is the *lowest* address in the stack buffer
  - stack grows towards *higher* addresses
- Grow downwards
  - Bottom Pointer (S0) is the *highest* address in the stack buffer
  - stack grows towards *lower* addresses



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## Size of the Stack

- As an abstract data structure…
  - stacks are assumed to be infinitely deep
  - so, an arbitrary amount of data can be stored
- However…
  - stacks are implemented using memory buffers
  - which are finite in size
- If the data exceeds the allocated space, a *stack overflow* error occurs



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# Subroutine Call Basics

Organizing Your Program

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## Subroutine Call

- The stack is essential for subroutines to work
- How?
  - used to save the return addresses for call instructions
  - backup and restore registers
  - pass data between subroutines



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## When you call a subroutine…

1. Processor pushes the instruction pointer (IP) – an address – on the stack
2. IP is set to the address of the subroutine
3. Subroutine executes and ends with a "return" instruction
4. Processor pops & restores the original IP
5. Execution continues after the initial call



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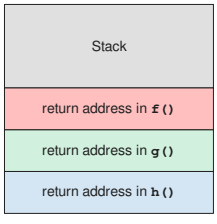
## Nesting is Possible

- Subroutines can call other subroutines
- `f()` calls `g()` which then calls `h()`, etc…
- The stack stores the return addresses of the callers
- Just like the "history button" in your web browser, you can store many return addresses



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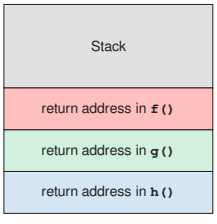
## Nesting is Possible

- Each time a subroutine completes, the processor pops the top of the stack
- …then returns to the *caller*
- This allows normal function calls and recursion (a powerful tool)



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# x64 Subroutines

Organizing Your Programs … with Intel

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## Instruction: Call

- The *Call Instruction* transfers control to a subroutine
- Other processors call it different names such as JSR (Jump Subroutine)
- The stack is used to save the current IP



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## Instruction: Call

Usually, a label (which is an address)

```
CALL address
```



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## Instruction: Return

- The Return Instruction is used mark the end of subroutine
- When the instruction is executed…
  - the old instruction pointer is read from the system stack
  - the current instruction pointer is updated – restoring execution after the initial call



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## Instruction: Return

- Do not forget this!
- If you do…
  - execution will simply continue, in memory, until a return instruction is encountered
  - often is can run past the end of your program
  - …and run data!



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## Instruction: Return

No arguments!

```
RET
```



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## Subroutine Example

```
_start:
    mov  rcx, 4
    mov  rbx, 12
    call AddIt
    add  rbx, 1
    ...
AddIt:
    add  rbx, rcx
    ret
```



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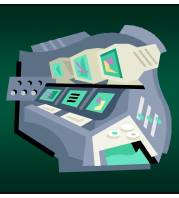

## Operating Systems

The master software

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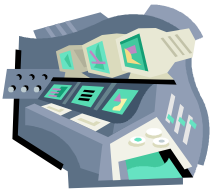
## What is an operating system?

- The operating system is simply a series of programs
- These programs, however, run with special privileges which are needed by the OS
- Processors support two modes for executing programs





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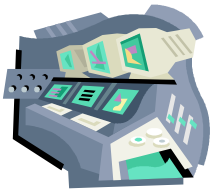
## Execution Modes

- *Privileged (supervisor) mode*
  - can run special instructions
  - can talk to all the hardware
  - etc…
- *User mode*
  - can only execute certain instructions
  - can't talk to all the hardware





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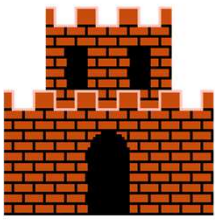
## Vector Tables

- Programs (and hardware) often need to talk to the operating system
- Examples:
  - software needs talk to the OS
  - USB port notifies the OS that a device was plugged in





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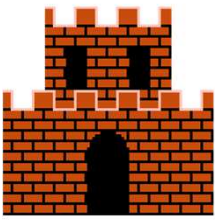
## Vector Tables

- But how does this happen?
- The processor can be *interrupted* – alerted – that something must be handled
- It then runs a special program that handles the event





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## Vector Table

- During an interrupt, the device sends the processor an *interrupt number*
- The processor looks up the number in the *vector table*
- Table contains the address of *Interrupt Service Routine (ISR)* to execute



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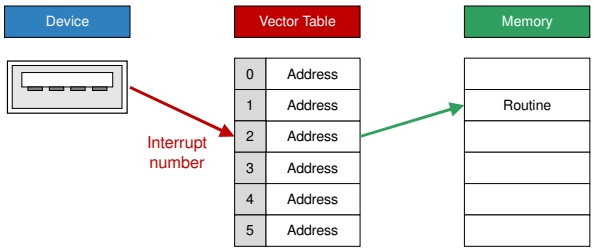
## How It Works



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## The Processor Actions

1. Backup the register file
2. Backups the instruction pointer
3. Executes the ISR
4. Restores the register file
5. Restores the Instruction Pointer



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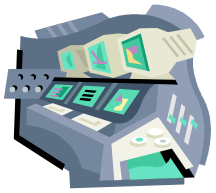
## The Kernal

- All these Interrupt Service Routines belong to the *kernal* – the core of the operating system
- Vast majority of the operating system is hidden from the end user





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## Interact with Applications

How do WE talk to the OS

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## Interact with Applications

- Software also needs to talk to the operating system
- For example:
  - draw a button
  - print a document
  - close this program
  - etc…



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## Interact with Applications

- Software can interrupt itself with a specific number
- This interrupt is *designated specifically for software*
- The operating system then handles the software's request



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## Application Program Interface

- Programs "talk" to the OS using *Application Program Interface (API)*
- Application → Operating System → IO
- Benefits:
  - makes applications faster and smaller
  - also makes the system more secure since apps do not directly talk to IO



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## Instruction: syscall (64-bit)

**SYSCALL**

**Calls interrupt number reserved for programs needing attention**



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## Subroutine vs. Interrupt

| Subroutine | Interrupt |
|---|---|
| Executes code | Executes code |
| Returns when complete | Returns when complete |
| Called by the application | Executed by the processor |
| Part of the application | Handles events for the OS |



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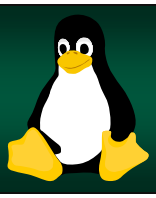

## Linux System Calls

How software and hardware "talk"

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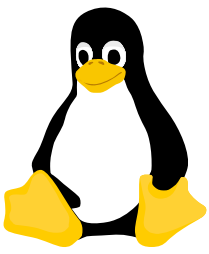
## Interrupts on the Linux

- Linux, like other operating systems communicate with applications using *interrupts*
- Applications do not know where (in memory) to contact the kernal – so they ask the processor to do it





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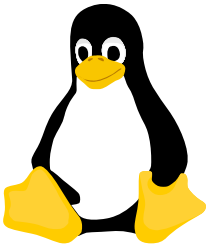
## How It Works

1. Fill the registers
2. Interrupt using syscall (or INT 0x80 if on 32-bit)
3. Any results will be stored in the registers





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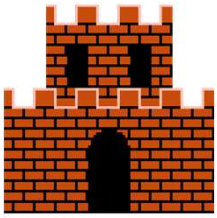
## How to Call Linux – 64 bit



- The **rax** register must contain the *system call number*
- This number indicates what you asking the OS to do
- There are only 329 total calls in the entire 64-bit UNIX operating system!



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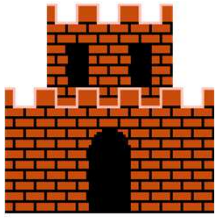
## How to Call Linux – 64 bit



- Different registers are used to hold data
- The order is also quite odd: *rdi, rsi, rdx, r10, r8*



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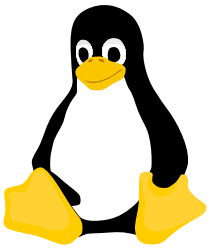
## Kernals are Simple!

- Linux only has **1** write and **1** read system call
- The location, number of bytes, and device only change *"write x many bytes from address y to device z"*
- So, writing to the screen, a file, a port, etc…use the same call!





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## Some Linux 64 Calls

| System Call | rax | rdi | rsi | rdx |
|---|---|---|---|---|
| read | 0 | file descriptor | address | max bytes |
| write | 1 | file descriptor | address | count |
| open | 2 | address | flags | mode |
| close | 3 | file descriptor | | |
| get pid | 39 | | | |
| exit | 60 | error code | | |



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## Linux 64: Sys Write

```
mov   rax, 1
mov   rdi, 1
lea   rsi, address
mov   rdx, length
syscall
```

Linux command for WRITE

1 = Screen

Call Linux



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## Linux 64: Sys Read

```
mov   rax, 0
mov   rdi, 0
lea   rsi, address
mov   rdx, maxBytes
syscall
```

Linux command for READ

0 = Keyboard

Maximum number of bytes to read

Call Linux



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## Write Example

```
SacState:
   .ascii "Stinger's up!\n"      #\n counts as 1 character
...
_start:
   mov  rax, 1                   #1 = write
   mov  rdi, 1                   #1 = screen
   lea  rsi, SacState
   mov  rdx, 14                  #14 bytes
   syscall
```



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## Saving Registers & Lost Data

Avoiding horrible side-effects

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## Saving Registers & Lost Data

- Each subroutine will use the registers as it needs
- So, when a sub is called, *it may modify the caller's registers*
- Some processors have few registers – so its very likely
- This can lead to hard-to-fix bugs if caution is not used – e.g. loop counter gets changed



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## Two Solutions

- Caller saves values
  - caller saves all their registers to memory before making the subroutine call
  - after, it restores the values before continuing
  - not recursion friendly – it pushes all of them!
- Subroutine saves the values
  - push registers (it will change) onto the stack
  - before it returns, it pops (and restores) the old values off the stack



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## Saving Registers… How nice! :-)

```
DoSomething:
   push rax
   push rbx
   push rcx

   ...

   pop rcx
   pop rbx
   pop rax
   ret
```

Save registers

Your code

Restore them.
Note the reverse order



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