# CS 143a
# Discussion 3

Harishankar Vishwanathan

# Overview

- Executable-and-linkable format (ELF) files
- Statically linked programs on linux
- Understand program entry point

# Statically linked programs

- Program doesn’t require any shared objects to run ( not even `libc`)
  - In  reality, this isn’t true, programs almost always will require shared objects

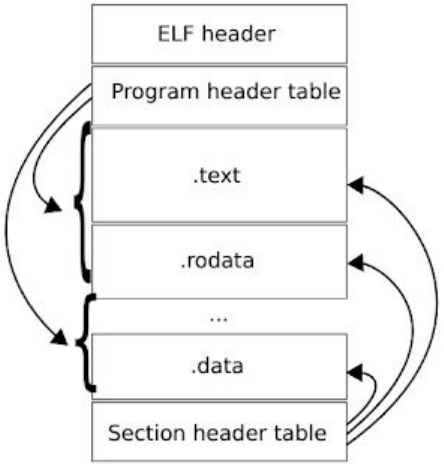
# Program execution

- Always begins in the kernel
- A process will call `exec`, which ends up issuing `sys_execve` system call
- The kernel supports different binary formats for an executable
  - It will try every format one-by-one until it succeeds.
- We will focus on `ELF`
  - `xv6/exec.c`

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

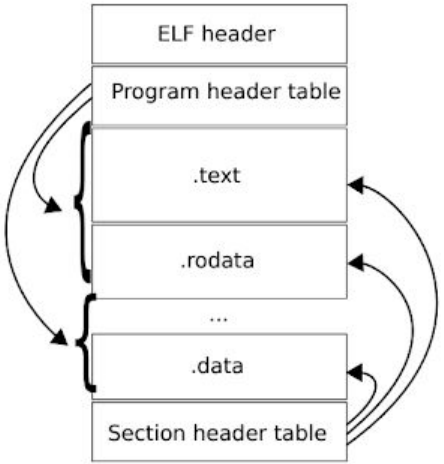
# ELF format

- Used by:
  - Linker: combines multiple ELF files into an executable or library
  - Loader: loads the executable in the memory of the process
- Both linker and loader need two views of the same elf file:
  - Linker (detailed view):  needs to know DATA, TEXT, BSS **sections** to merge them from with other sections from other objects
  - Loader (simpler view): needs to know only which parts of the ELF are executable, writable, read-only.

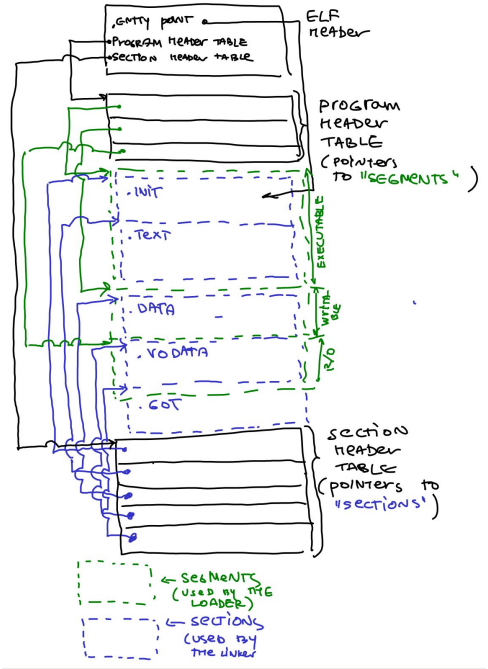


# ELF format

- The ELF binary is composed of:
  - ELF header
  - Program Header Table
  - Section Header Table
- ELF is mainly composed of segments and sections
- Segments:
  - Portions of the binary that are actually loaded into memory at runtime (composed of one or more sections)
- Sections:
  - Actual program code and data that is available in memory when a program runs
  - Metadata about other sections used only in the linking process

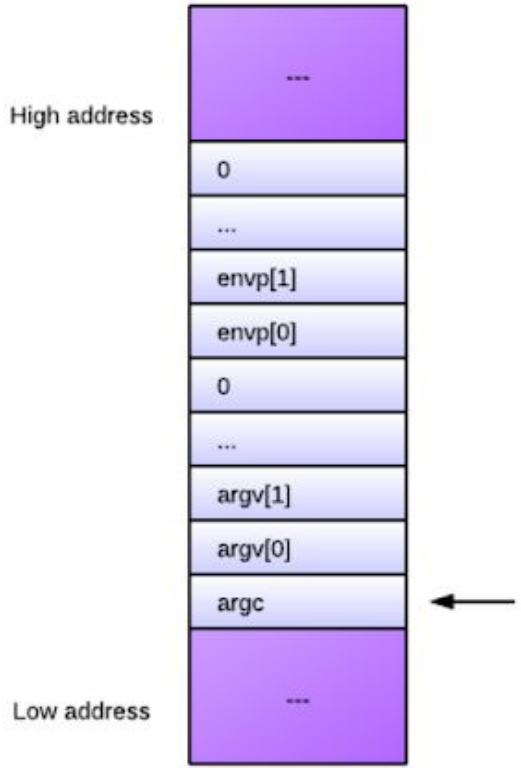


# ELF format


ENTRY point
Program Header table
Section Header table
ELF Header
Program Header TABLE (pointers to "SEGMENTS")
.INIT
.TEXT
.DATA
.rodata
.GOT
EXECUTABLE
WRITABLE
I/O
Section Header TABLE (pointers to "sections")
← SEGMENTS (used by the LOADER)
← SECTIONS (used by the linker)

# Reading ELF

- Kernel reads ELF
  - Maps programs segments into memory according to the PHT.
- Passes execution
  - Directly modifying EIP register, to the entry address read from ELF header of the program
  - Arguments are passed to the program on the stack



# Program entry point

- Several object files are linked into an executable ELF binary by using the linker `ld`
- **The linker looks for a special symbol called `_start` in one of the object files**
- Sets the entry point to the address of that symbol.This is where the program starts execution.
- `main` is really not the entry point of the program!

# Demo : Program entry point in .asm

```
; file: nasm_rc.asm
section    .text
    ; The _start symbol must be declared for the linker (ld)
    global _start

_start:
    ; Execute sys_exit call. Argument: status -> ebx
    mov     eax, 1  ; system call 1: sys_exit
    mov     ebx, 42 ; pass arguments to sys_exit
    int     0x80    ; call into kernel
```

- This simple program simply returns 42.

# Demo : Program entry point in .asm

- Compile with
  ```
  nasm -f elf32 nasm_rc.asm -o nasm_rc.o
  ```
- Link with
  ```
  ld -m elf_i386 -o nasm_rc nasm_rc.o
  ```
- Read the elf header, what entry point do you see?
  ```
  readelf -h nasm_rc
  ```
- Is it the same as the address of `_start`?
  ```
  objdump -M intel -d nasm_rc
  ```
- Run the program and check its exit code:
  ```
  $ ./c_rc
  $ echo $? # return code of a program
  42
  ```

# Demo : Program entry point in .c

```
/* file c_rc.c */

int main() {
    return 42;
}
```

# Demo : Program entry point in .c

- Use the -c flag in gcc to compile but not link.

```
gcc -c -m32 -fno-pic c_rc.c
```

- When we ask gcc to just compile (but not link), the generated object file object file is minimal:
  - `objdump -M intel -d c_rc.o`
  - Does it have an `_start` symbol?

- Now, link with

```
ld -m elf_i386 -o c_rc c_rc.o
```

- Does the linker give you a warning?
- What happens if you try to execute **`c_rc`**?
- How is c_rc different from c_rc.o?
  - `objdump -M intel -d c_rc.o`

# Demo : Program entry point in .c

- Since we just compiled (did not link) our minimal C file, the linker cannot find the entry point (it tries to guess).
- The linker clearly needs some additional object files, where it will find the entry point i.e. the `_start` symbol.

- We can specify the additional object files to the linker, but since we don’t know what those files exactly are, we will use gcc’s help.
- Gcc when invoked without the -c flag, will invoke the linker with the required object files

# Demo : Program entry point in .c

- Since this talk is about how statically linked programs work, we will specify the `-static` flag to gcc ( the flag is passed on to the linker internally, since we are invoking gcc and the linker together).
  ```
  gcc -o c_rc -m32 -static c_rc.o
  ```

- Run the program and check its exit code:
  ```
  $ ./c_rc
  $ $?
  ```

# Demo : Program entry point in .c

- How does gcc manage to do the linking correctly?

- To see a list of all the libraries the gcc passed on to the linker:
  `gcc -Wl,-verbose -m32 -o c_rc -static c_rc.o`

- We see that there are some additional object files needed (the whole static libc, `libc.a`).

# Demo : Program entry point in .c

- C code does not live in a vacuum!
- It has several dependant objects, most notably libc.

# Exercise

- Our code was clearly linked correctly and it worked: it should have the `_start` symbol.
- Check out if it does in `objdump -d c_rc | less`, (search for `_start`) and if the address matches the entry point in `readelf -h c_rc`
- The code at the symbol `_start` should call a libc related function: `__libc_start_main.`
- What are the arguments to `__libc_start_main?`
  - One of them should be the address of our `main` function!

# __libc_start_main

```
int __libc_start_main(
        /* Pointer to the program's main function */
        (int (*main) (int, char**, char**),
        /* argc and argv */
        int argc, char **argv,
        /* Pointers to initialization and finalization functions */
        __typeof (main) init, void (*fini) (void),
        /* Finalization function for the dynamic linker */
        void (*rtld_fini) (void),
        /* End of stack */
        void* stack_end)
```

# __libc_start_main

- What does it do?
  - Figure out where the environment variables are on the stack
  - Initialize libc
  - Call the program initialization function through the passed pointer (`init`)
  - Register the program finalization function (`fini`) for execution on exit
  - Call `main(argc, argv, envp)`
  - Call `exit` with the result of main as the exit code

# Conclusion

- How statically linked programs work
- Linux kernel, compiler, linker, the C library co-operate in the program execution process

# HW3: Reading elf

- `readelf` is your friend
  - Use it to figure out what exactly the binary of an executable contains, and at offset locations in that binary
- You have to, finally, load the ELF binary called `elf` into memory and run it.
- Two structs are provided to you, `read` into these structs and fill them up.
  - `elfhdr`
  - `Proghdr`
- `lseek, open, read, mmap` are the syscall wrappers you would need to work with.

# References

https://eli.thegreenplace.net/2012/08/13/how-statically-linked-programs-run-on-linux