ELF binaries and everything before main() starts

jj@deadzoft.org 2023-05-18

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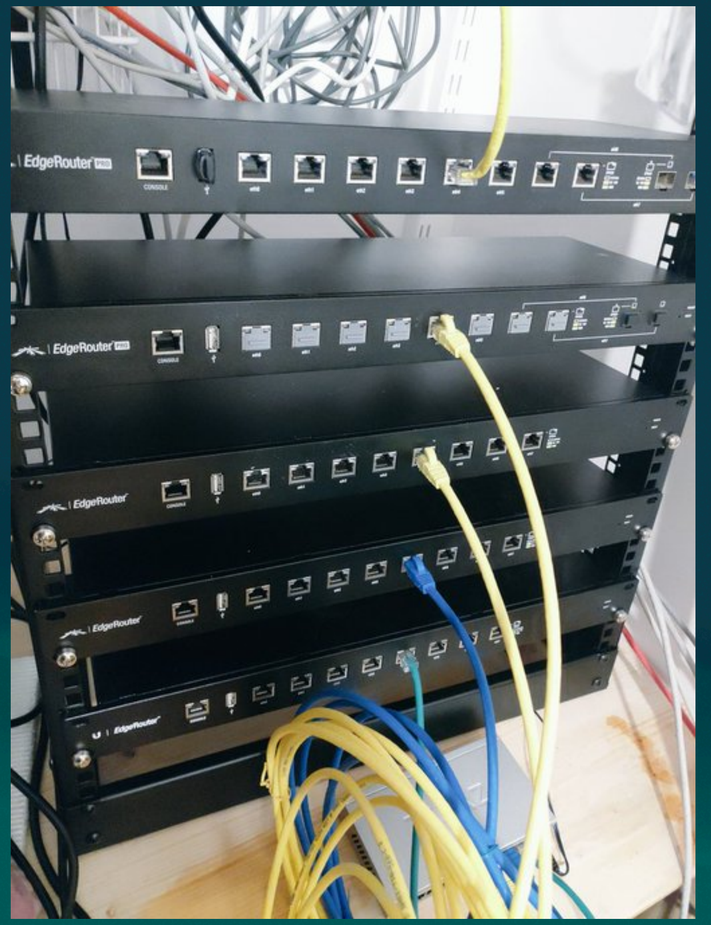

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- “IcePic” on IRC
- Collects octeon/mips64 based computers

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Contents

- A Simple(tm) Program
- Object files
- Shared libraries
- ELF sections
- Loading binaries into RAM
- The role of ld.so
- GOT / PLT
- OpenBSD recent changes

What will not be here

- Long lists of code or pictures of ELF-code C structs
- How Rust,Golang,Zig,… binaries work

A Simple(tm) Program

```
> mg hello.c
> cat hello.c
#include "stdio.h"

int main() {
        printf("Hello world!\n");
        return 0;
}
> make hello
cc     hello.c   -o hello
> ./hello
Hello world!
> ls -l hello
-rwxr-xr-x  1 jj  staff  49424 Jul 28 12:43 hello
>
```

A Simple(tm) Program

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- (cc —save-temps)

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  - Takes long time for huge source files
  - Split sources into separate files leading to multiple .o object files linked into one binary
  - a.c -> a.o
    b.c -> b.o
    ld a.o b.o -o ./c-prg

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- Building your C Program:
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  - Last chance for certain optimizations (LTO) or joining similar sections into one
  - Takes more than 4G RAM for linking browsers with full debug info

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  - Each object file lists which symbols it provides and which ones it requires

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  - C++ programs and objects “mangle” their functions (methods) to include information about what data types they accept and return

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  - int add_to_d(a,b)
    { int c; extern int d; return c=d+a+b; }

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- Building your C Program:
  - int add_to_d(a,b)
    { int c; extern int d; return c=d+a+b; }
  - will require “d” and provide “add_to_d” but not a,b or c. Those are just anonymous ints in the code

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  - Use objdump -t to list what an object file or a program requires and provides.

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  - Use objdump -t to list what an object file or a program requires and provides.
  - nm(1) also works, readelf(1) and many other utilities

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  - Perhaps an abc.c -> abc.o exists?

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  - Vendoring lib sources is boring

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  - Dynamic lib might in turn ALSO require symbols

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cc -O2 -pipe    -o hello hello.c
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0000000000002ba0 l     O .openbsd.randomdata    0000000000000008 .hidden __retguard_1773
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00000000000016b0 g       .text  0000000000000000 __start
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0000000000000000         F *UND*  0000000000000000 _csu_finish
0000000000001a20 g     F .text  0000000000000050 main
0000000000000000         F *UND*  0000000000000000 exit
0000000000001a80 g     F .fini  0000000000000000 __fini
0000000000001820  w    F .text  0000000000000020 __register_frame_info
0000000000000000  w      *UND*  0000000000000000 _Jv_RegisterClasses
0000000000000000         F *UND*  0000000000000000 atexit
0000000000001a00 g     F .text  0000000000000019 print
0000000000003db0 g     O .bss   0000000000000004 flurb
0000000000000000         F *UND*  0000000000000000 printf
0000000000000000         F *UND*  0000000000000000 puts
0000000000003db4 g       .bss   0000000000000000 _end


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  - strip(1) removes all “unused” sections

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  - Allows for godbolt style line-by-line assembler dumps/debugger listings

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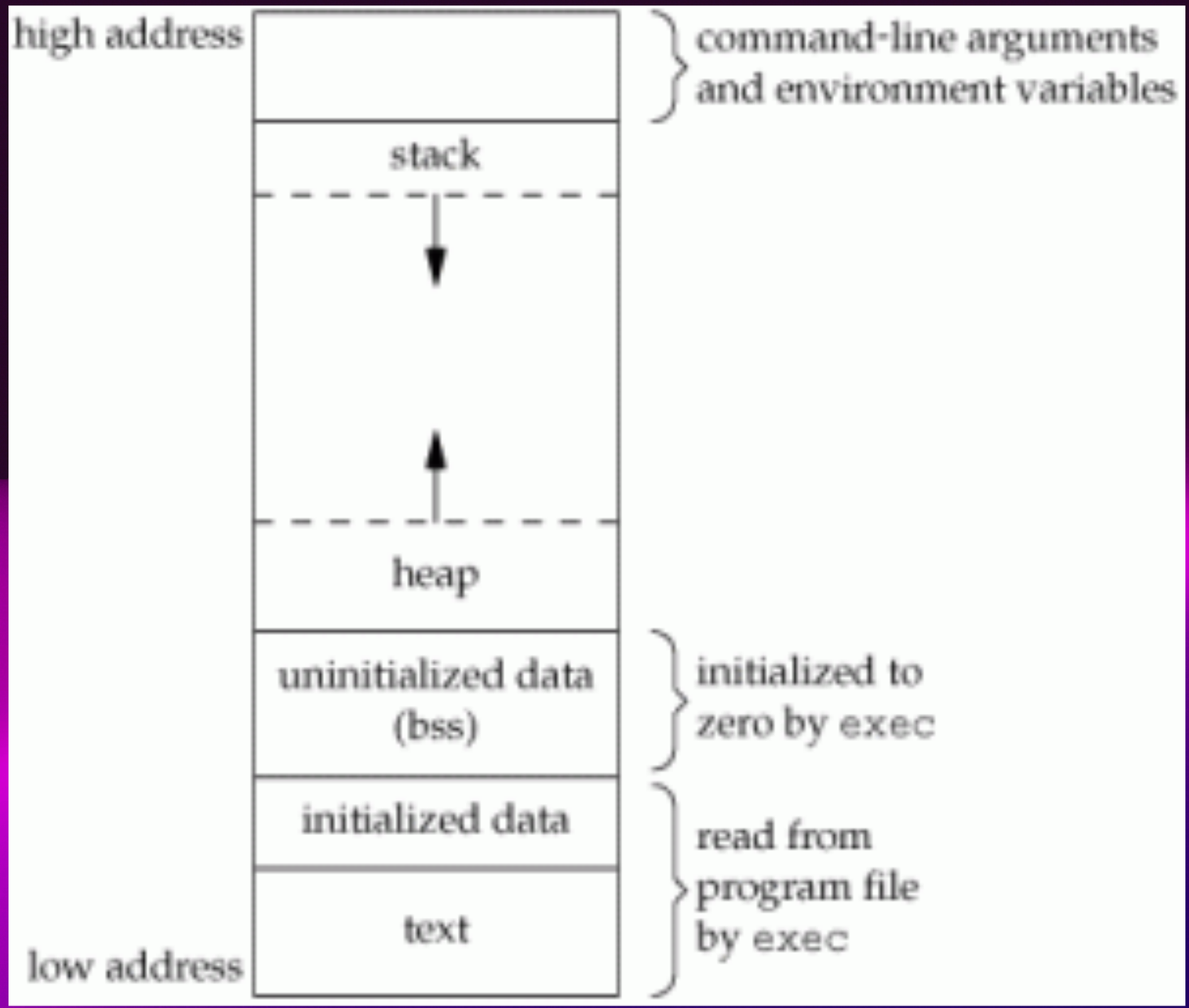
  - Text - Where the code goes. Readonly in mem
  - Data - All strings and variables with non-zero content
  - BSS - For all zero-filled variables and structs. The BSS section only has a size, then variables point into this calloc(3)ed space

ELF sections



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fido$ size hello
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```
fido$ size hello
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2172    472     92      2736    ab0
fido$ llvm-objdump -h   hello

hello:  file format elf64-x86-64

Sections:
Idx Name                  Size     VMA                 Type
  0                       00000000 0000000000000000
  1 .interp               00000013 00000000000002e0 DATA
  2 .note.openbsd.ident   00000018 00000000000002f4
  3 .dynsym               000000c0 0000000000000310
  4 .gnu.hash             00000020 00000000000003d0
  5 .hash                 00000048 00000000000003f0
  6 .dynstr               0000004b 0000000000000438
  7 .rela.dyn             00000030 0000000000000488
  8 .rela.plt             00000090 00000000000004b8
  9 .rodata               0000001e 0000000000000548 DATA
 10 .eh_frame_hdr         0000003c 0000000000000568 DATA
 11 .eh_frame             000000fc 00000000000005a8 DATA
 12 .text                 000003bc 00000000000016b0 TEXT
 13 .init                 0000000e 0000000000001a70 TEXT
 14 .fini                 0000000e 0000000000001a80 TEXT
 15 .plt                  000000f0 0000000000001a90 TEXT
 16 .openbsd.randomdata   00000038 0000000000002b80 DATA
 17 .jcr                  00000008 0000000000002bb8 DATA
 18 .ctors                00000010 0000000000002bc0 DATA
 19 .dtors                00000010 0000000000002bd0 DATA
 20 .dynamic              00000120 0000000000002be0
 21 .got                  00000010 0000000000002d00 DATA
 22 .got.plt              00000048 0000000000002d10 DATA
 23 .bss                  0000005c 0000000000003d58 BSS
 24 .comment              00000013 0000000000000000
 25 .symtab               00000330 0000000000000000
 26 .shstrtab             000000ee 0000000000000000
 27 .strtab               000001a9 0000000000000000
```

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  - Means you can make “fat binaries” with several CPU/Arch code sections that all reference same variables in data and BSS sections

ELF sections

- Data Section(s)

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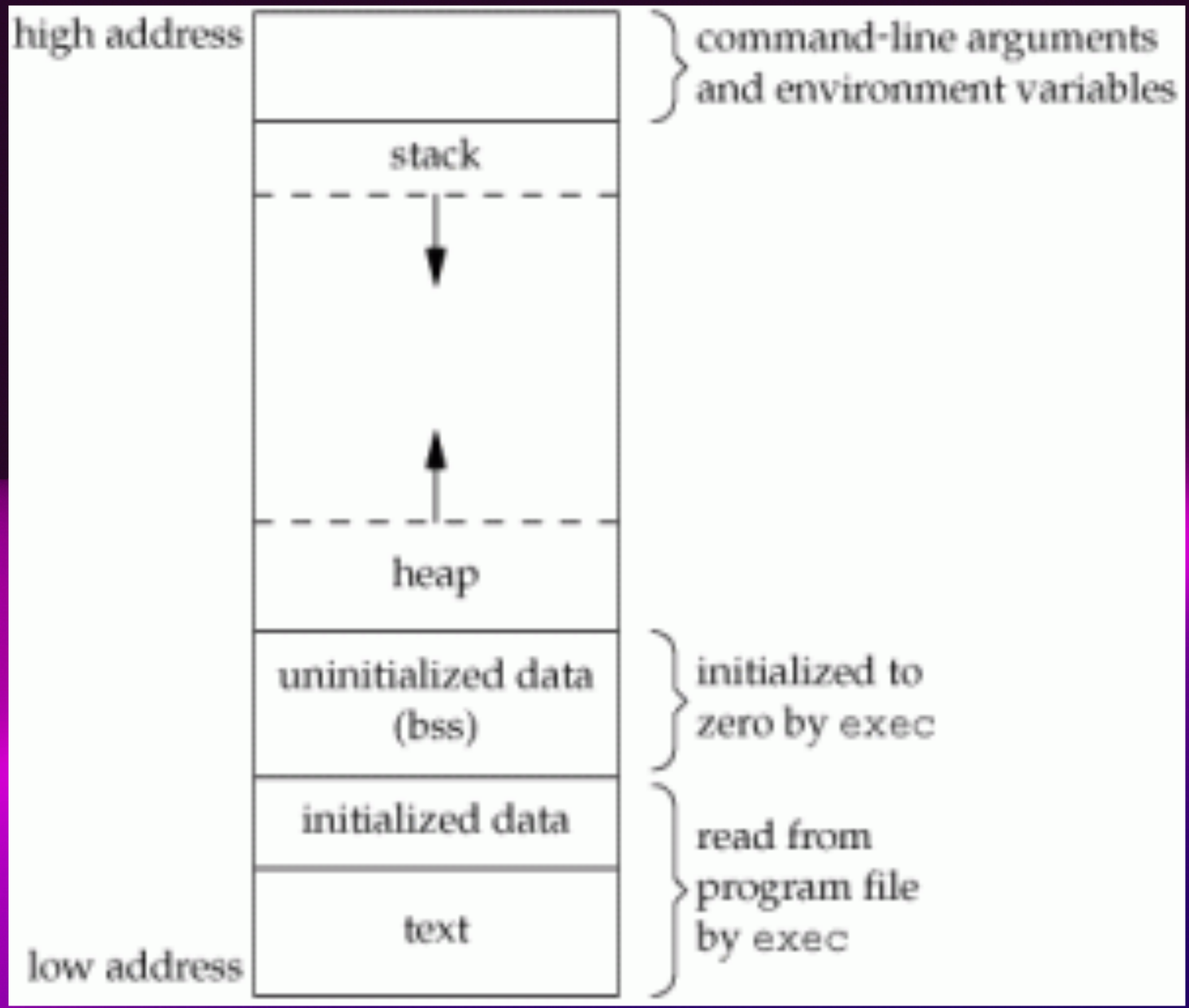
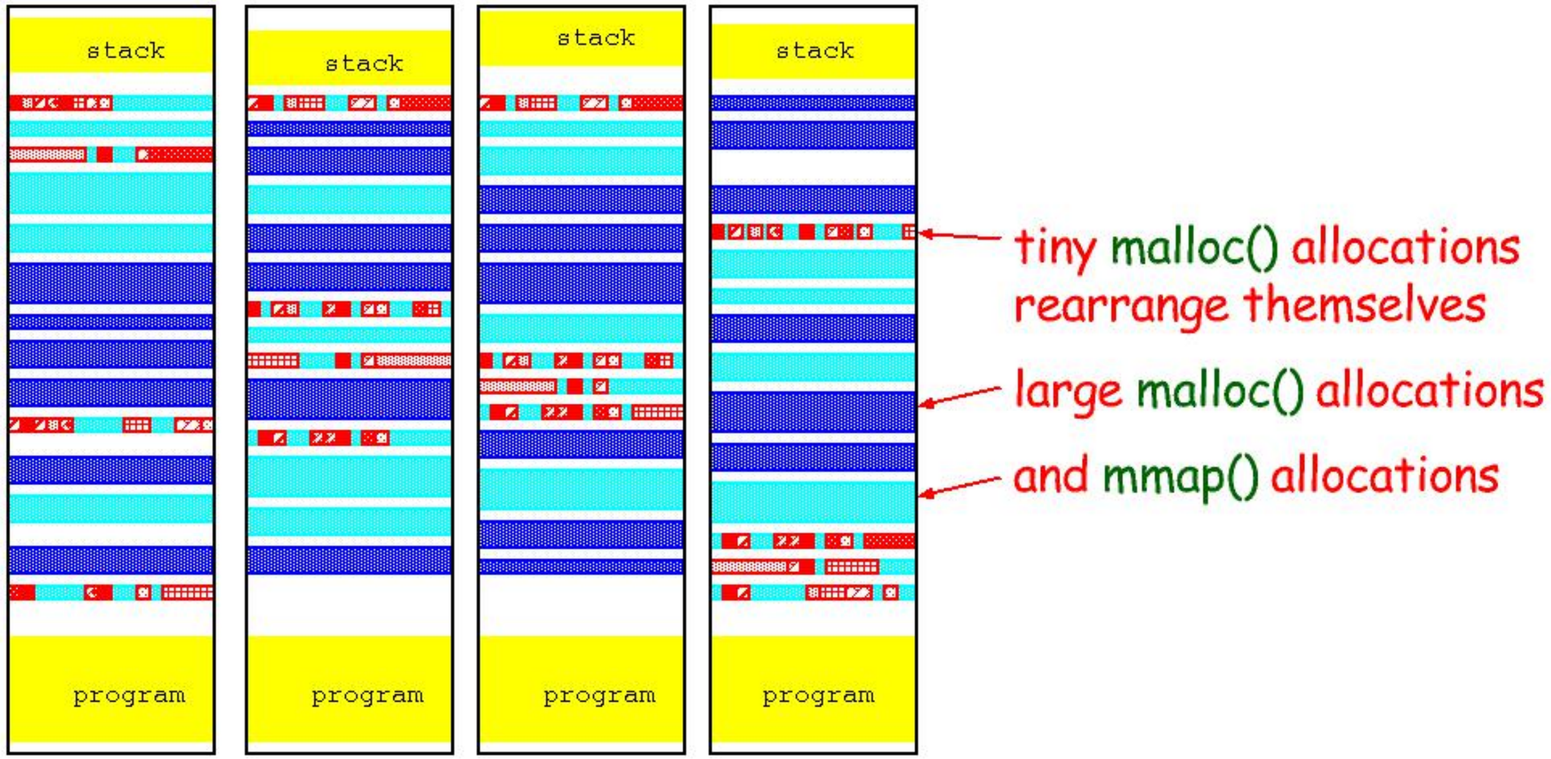


A Simple(tm) Program

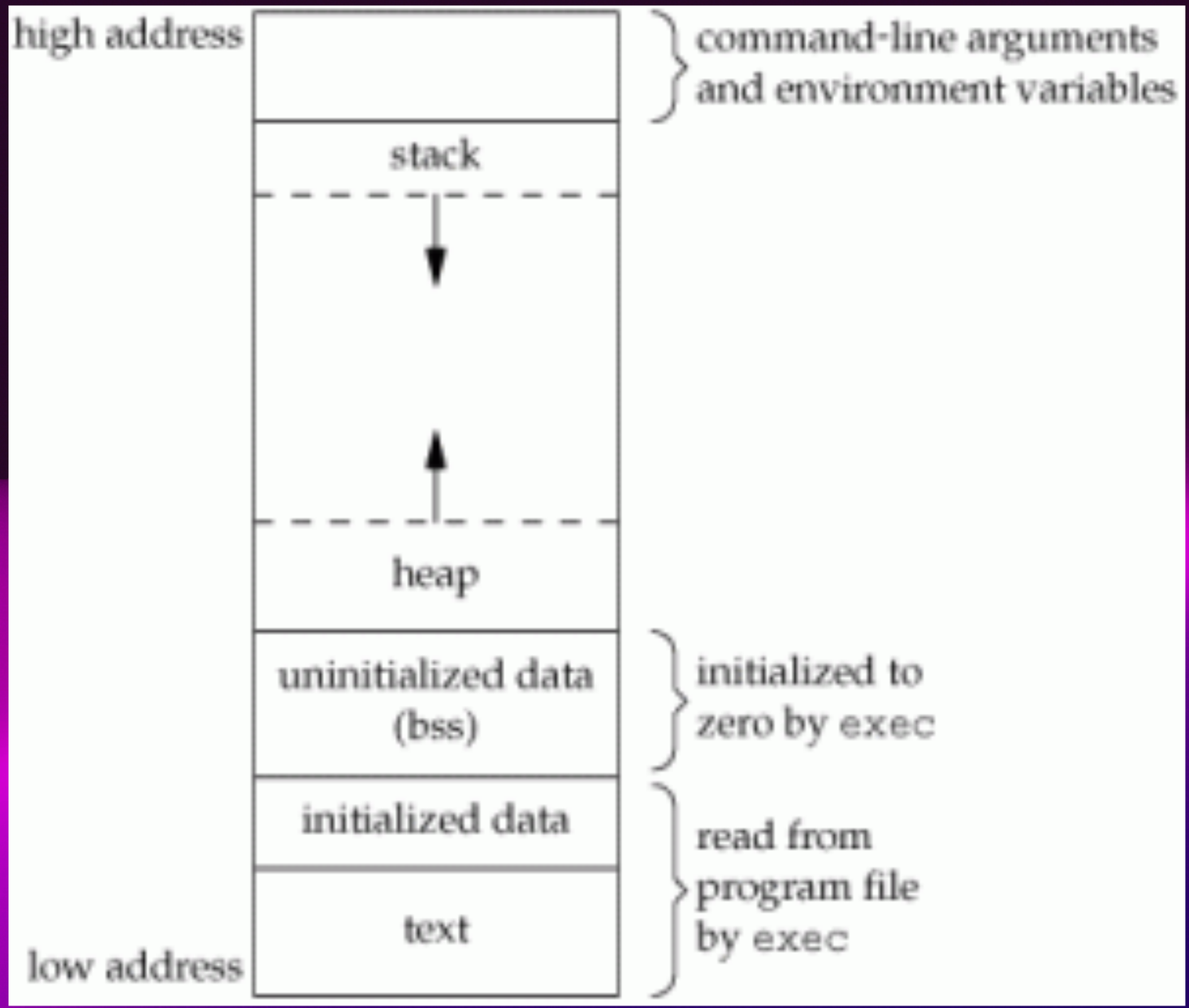
Randomized allocations..

Of course, each time you run the program the allocations change.



Note: Not showing the effects of many other changes, like shared library randomization, etc, etc

Loading into RAM



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  - Readonly Text section means forks and parallel instances can share code RAM

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- fstat(1) can list open files
- Linux with /proc/<PID>/exe could perhaps recreate a new binary

Loading into RAM

```
jj       less      1087 text /usr        52358  -r-xr-xr-x     r   156432
jj       less      1087   wd /home       16996  drwxr-xr-x     r      512
jj       less      1087    0 pipe 0x0 state:
jj       less      1087    1 /           26303  crw--w----    rw    ttyp3
jj       less      1087    2 /           26303  crw--w----    rw    ttyp3
jj       fstat    24155 text /usr        52319  -r-xr-xr-x     r    23288
jj       fstat    24155   wd /home       16996  drwxr-xr-x     r      512
jj       fstat    24155    0 /           26303  crw--w----    rw    ttyp3
jj       fstat    24155    1 pipe 0x0 state:
jj       fstat    24155    2 /           26303  crw--w----    rw    ttyp3
jj       ksh      70405 text /           52956  -r-xr-xr-x     r   607112
jj       ksh      70405   wd /home       16996  drwxr-xr-x     r      512
jj       ksh      70405    1 /           26303  crw--w----    rw    ttyp3
jj       ksh      70405    2 /           26303  crw--w----    rw    ttyp3
jj       ksh      70405   10 /           26984  crw-rw-rw-  rwep     tty
jj       ksh      70405   11 /           26303  crw--w----   rwe    ttyp3
jj       sshd     15960 text /usr       208176  -r-xr-xr-x     r   964176
jj       sshd     15960   wd /               2  drwxr-xr-x     r     1024
jj       sshd     15960    0 /           26987  crw-rw-rw-    rw     null
jj       sshd     15960    1 /           26987  crw-rw-rw-    rw     null
jj       sshd     15960    2 /           26987  crw-rw-rw-    rw     null
```

The role of ld.so

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The role of ld.so

- ld.so is “the interpreter” of all dynamically linked programs
- Just like #!/bin/bash is the interpreter for *.sh and #!/usr/bin/python3 for the *.py programs
- Only static binaries need no interpreter
  - Some of the tasks done by ld.so are in crt0.o for static binaries

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- Libc supplies some weak symbols so other libraries can override them; perhaps like zlib, could give transparent gunzip functionality to any program
- LD_RUN_PATH, LD_PRELOAD, LD_LIBRARY_PATH overrides OS defaults
- ldd(1) to test/show what would be loaded

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- ldd “half-runs” the binary and lists what gets picked up by ld.so along the way

```
> ldd ./hello
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        Start              End                Type  Open Ref GrpRef Name
        000000a8661bc000 000000a8661c0000 exe   1    0   0      ./hello
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- Having a very limited set for the half-run program ldd runs limits the security impact a lot
- Probably the best case currently for execpromises

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- /usr/local/lib/libabc.so -> libabc.so.12.3
- libpng16.so.16 ; compile with -lpng16

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  - For plugins and similar hot loadable code

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- Double check ldconfig(8) manpage

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  - atexit(3) might be commonly known
  - Each call to atexit() registers a subroutine to call before real exit. They run in reverse order.

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  - void __attribute__ ((constructor)) myconstructor() { … }

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  - The final order of all hooks is:

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  - Levels <=100 reserved for not-you

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- How you divide BSS into the ints, longs, structs the linker placed there

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- Threads, signal handlers and so on

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- If we race, symbol resolves happen twice. Ok worst case

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  - Next call(s) go directly from PLT#2 to libc-GOT

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  - First use from ld.so registers location and a cookie, later uses must come from same place and with same cookie

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  - Lots of ELF sections in libc, ld.so and crt0.o becomes immutable by default

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  - Currently (7.3) only execve()

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  - Potential defense against Blind ROP

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- Load bad libs -> *boom*
- Linux seemingly have tons of bad libs

ELF links

https://s3.inet6.se/links.html

Questions?