https://twitter.com/attrc/status/1004115834028126209

CS631 - Advanced Programming in the UNIX Environment
–
Shared Libraries

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Shared Libraries

```
#include <openssl/rand.h>
int main(int argc, char **argv) {
        int i; unsigned char data[NUM];

        if (RAND_bytes(data, NUM) == 0)
                err(EXIT_FAILURE, "Unable to generate random data: %s\n",
                                strerror(errno));
        for (i=0; i<NUM; i++)
                printf("%02X", data[i]);
        printf("\n");
        exit(EXIT_SUCCESS);
}
$ cc -Wall -c rand.c
$ cc -Wall rand.o
rand.o: In function ‘main’:
rand.c:(.text+0x1c): undefined reference to ‘RAND_bytes’
$ cc -Wall rand.o -lcrypto
```

Shared Libraries

What is a shared library, anyway?

- contains a set of callable C functions (i.e., implementation of function prototypes defined in `.h` header files)
- code is position-independent (i.e., code can be executed anywhere in memory)
- shared libraries can be loaded/unloaded at execution time or at will
- libraries may be *static* or *dynamic*

Shared Libraries

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- libraries may be *static* or *dynamic*

```
$ man 3 fprintf
$ grep " fprintf" /usr/include/stdio.h
```

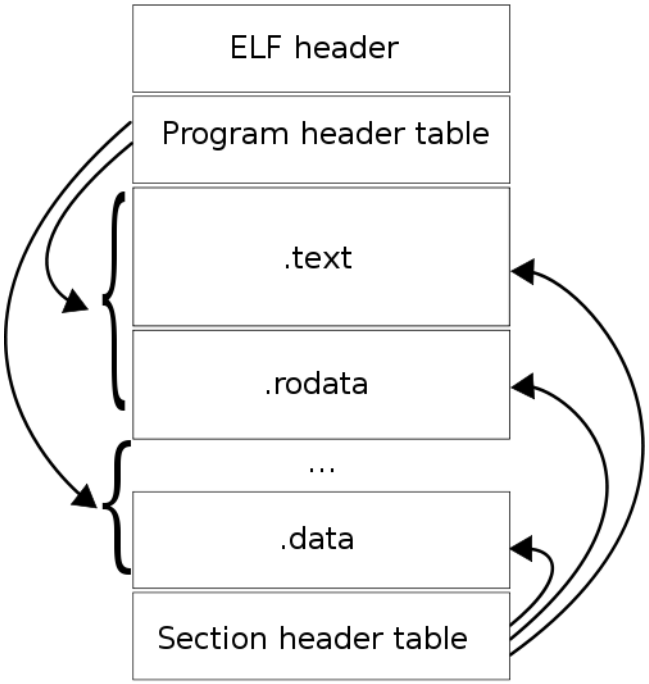
Shared Libraries

How do shared libraries work?

- contents of *static* libraries are pulled into the executable at link time
- contents of *dynamic* libraries are used to resolve symbols at **link time**, but loaded at **execution time** by the *dynamic linker*
- contents of *dynamic* libraries may be loaded at **any time** via explicit calls to the dynamic linking loader interface functions

Executable and Linkable Format

ELF is a file format for executables, object code, shared libraries etc.



More details: `http://www.cs.stevens.edu/~jschauma/631/elf.html`
`http://www.thegeekstuff.com/2012/07/elf-object-file-format/`

Executable and Linkable Format

ELF is a file format for executables, object code, shared libraries

- *relocatable file* – can be linked together with others to produce a shared library or an executable (e.g. `foo.o`)
- *shared object file* – position independent code; used by the dynamic linker to create a process image (e.g. `libfoo.so`)
- *executable* – just what it sounds like (e.g. `a.out`)

Executable and Linkable Format

```
$ cc -Wall -c main.c
$ hexdump -C main.o | head -2
00000000 7f 45 4c 46 02 01 01 00 00 00 00 00 00 00 00 00
00000010 01 00 3e 00 01 00 00 00 00 00 00 00 00 00 00 00

$ file main.o
main.o:  ELF 64-bit LSB relocatable, x86-64, version 1 (SYSV),
not stripped
```

Executable and Linkable Format

```
$ hexdump -C /lib/libc.so | head -2
00000000 7f 45 4c 46 02 01 01 00 00 00 00 00 00 00 00 00
00000010 03 00 3e 00 01 00 00 00 70 b7 03 00 00 00 00 00
$ readelf -h /lib/libc.so
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:                    DYN (Shared object file)
 Machine:                 Advanced Micro Devices X86-64
 Version:                 0x1
 Entry point address:     0x3b770
 ...
```

Executable and Linkable Format

```
$ hexdump -C a.out | head -2
00000000 7f 45 4c 46 02 01 01 00 00 00 00 00 00 00 00 00
00000010 02 00 3e 00 01 00 00 00 e0 07 40 00 00 00 00 00
$ readelf -h a.out
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:                    EXEC (Executable file)
 Machine:                 Advanced Micro Devices X86-64
 Version:                 0x1
 Entry point address:     0x4007e0
 ...
```

Understanding object files

```
$ cc -Wall ldtest1.c ldtest2.c main.c
$ nm a.out
                 U _libc_init
00000000004007a0 T _start
                 U atexit
0000000000600ea0 B environ
                 U exit
0000000000400990 T ldtest1
00000000004009b4 T ldtest2
00000000004009d8 T main
                 U printf
$ ldd a.out
a.out:
        -lgcc_s.1 => /usr/lib/libgcc_s.so.1
        -lc.12 => /usr/lib/libc.so.12
```

See also: `objdump -x a.out`

Statically Linked Shared Libraries

Static libraries:

- created by `ar(1)`
- usually end in `.a`
- contain a symbol table within the archive (see `ranlib(1)`)

Statically Linked Shared Libraries

```
$ cc -Wall -c ldtest1.c
$ cc -Wall -c ldtest2.c
$ cc -Wall main.c
[...]
$ cc -Wall main.c ldtest1.o ldtest2.o
$
```

Statically Linked Shared Libraries

```
$ cc -Wall -c ldtest1.c ldtest2.c
$ ar -vq libldtest.a ldtest1.o ldtest2.o
$ ar -t libldtest.a
$ nm libldtest.a

ldtest1.o:
0000000000000000 T ldtest1
                 U printf

ldtest2.o:
0000000000000000 T ldtest2
                 U printf
$ objdump -x libldtest.a
```

Statically Linked Shared Libraries

```
$ cc -Wall main.c libldtest.a
$ mv libldtest.a /tmp/
$ ./a.out

$ cc -Wall main.c -L/tmp -lldtest -o a.out.dyn
$ cc -static main.o -L/tmp -lldtest -o a.out.static
$ ls -l a.out.*
$ ldd a.out.*
$ nm a.out.dyn | wc -l
$ nm a.out.static | wc -l
```

Dynamically Linked Shared Libraries

Dynamic libraries:

- created by the compiler/linker (i.e. multiple steps)
- usually end in `.so`
- frequently have multiple levels of symlinks providing backwards compatibility / ABI definitions

Dynamically Linked Shared Libraries

```
$ cc -Wall -c -fPIC ldtest1.c ldtest2.c
$ mkdir lib
$ cc -shared -Wl,-soname,libldtest.so.1 -o lib/libldtest.so.1.0 ldtest1.o ldtest2.o
$ ln -s libldtest.so.1.0 lib/libldtest.so.1
$ ln -s libldtest.so.1.0 lib/libldtest.so
$ cc -static -Wall main.o -L./lib -lldtest
ld: cannot find -lldtest
$ mv /tmp/libldtest.a lib
$ cc -static -Wall main.o -L./lib -lldtest
$ ./a.out
[...]
$ cc -Wall main.o -L./lib -lldtest
$ ./a.out
[...]
$ ldd a.out
[...]
```

Dynamically Linked Shared Libraries

Wait, what?

```
$ export LD_LIBRARY_PATH=${LD_LIBRARY_PATH}:./lib
$ ldd a.out
[...]
$ ./a.out
[...]
$ mkdir lib2
$ cc -Wall -c -fPIC ldtest1.2.c
$ cc -shared -Wl,-soname,libldtest.so.1 -o lib2/libldtest.so.1.0 ldtest1.2.o ldtest2.
$ ln -s libldtest.so.1.0 lib2/libldtest.so.1
$ ln -s libldtest.so.1.0 lib2/libldtest.so
$ export LD_LIBRARY_PATH=./lib2:$LD_LIBRARY_PATH
$ ldd a.out  # note: no recompiling!
[...]
$ ./a.out
[...]
```

Dynamically Linked Shared Libraries

Avoiding `LD_LIBRARY_PATH`:

```
$ cc -Wall main.o -L./lib -lldtest -Wl,-rpath,./lib
$ echo $LD_LIBRARY_PATH
[...]
$ ldd a.out
[...]
$ ./a.out
[...]
$ unset LD_LIBRARY_PATH
$ ldd a.out
[...]
$ ./a.out
[...]
$
```

Dynamically Linked Shared Libraries

But:

```
$ cc -Wall -fPIC -c evil.c
$ cc -shared -Wl,-soname,libldtest.so.1 -o lib3/libldtest.so.1.0 \
        ldtest1.o ldtest2.o evil.o
$ export LD_PRELOAD=./lib3/libldtest.so.1.0
$ ldd a.out
[...]
$ ./a.out 2>/dev/null
[...]
$
```

Dynamically Linked Shared Libraries

```
$ export LD_DEBUG=help # glibc>=2.1 only
$ ./a.out
[...]
$ LD_DEBUG=all ./a.out
[...]
```

Dynamically Linked Shared Libraries

Explicit loading of shared libraries:

- `dlopen(3)` creates a handle for the given library
- `dlsym(3)` returns the address of the given symbol

```
$ cc -Wall rand.c -lcrypto
$ cc -Wall -rdynamic dlopenex.c
$ ./a.out
```

Homework

https://www.cs.stevens.edu/~jschauma/631/f17-hw4.html

```
$ cat hello.c
#include <greet.h>
#include <stdio.h>

int main(void) {
        greet();
        if (setgreeting("Howdy!") != 0) {
                fprintf(stderr, "Unable to set greeting!\n");
        }
        greet();
        hello("you there", getgreeting());
        return 0;
}
$ cc -Wall hello.c -I./libgreet -L./libgreet -Wl,-rpath,./libgreet -lgreet
```

Reading

- https://www.bell-labs.com/usr/dmr/www/man51.pdf
- https://en.wikipedia.org/wiki/Executable_and_Linkable_Format
- https://www.cs.stevens.edu/~jschauma/631/elf.html
- http://www.thegeekstuff.com/2012/07/elf-object-file-format/
- https://is.gd/XPn9Ul