CS 241: Systems Programming Lecture 28. Dynamic Libraries

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Last time

Static libraries (or archives) are a way of bundling a collection of object files together

- Use the compiler to create `.o` files
- Use `ar` to create `.a` file
- For each program, we want to create, use the `.a` at the end of the link line

  ```
  $ clang -o prog main.o libfoo.a
  ```

Using a library: -l (lower case L)

We specify a library using a command line option: `-l`

- `$ clang -o prog main.o -lfoo`

Using `-lfoo` tells the linker to look for the file

- `libfoo.a` — a static library
- `libfoo.so` — a dynamic library on ELF-based systems
- `libfoo.dyld` — a dynamic library on macOS

Dynamic libraries

Like static libraries, dynamic libraries start as a collection of object files (`.o`)

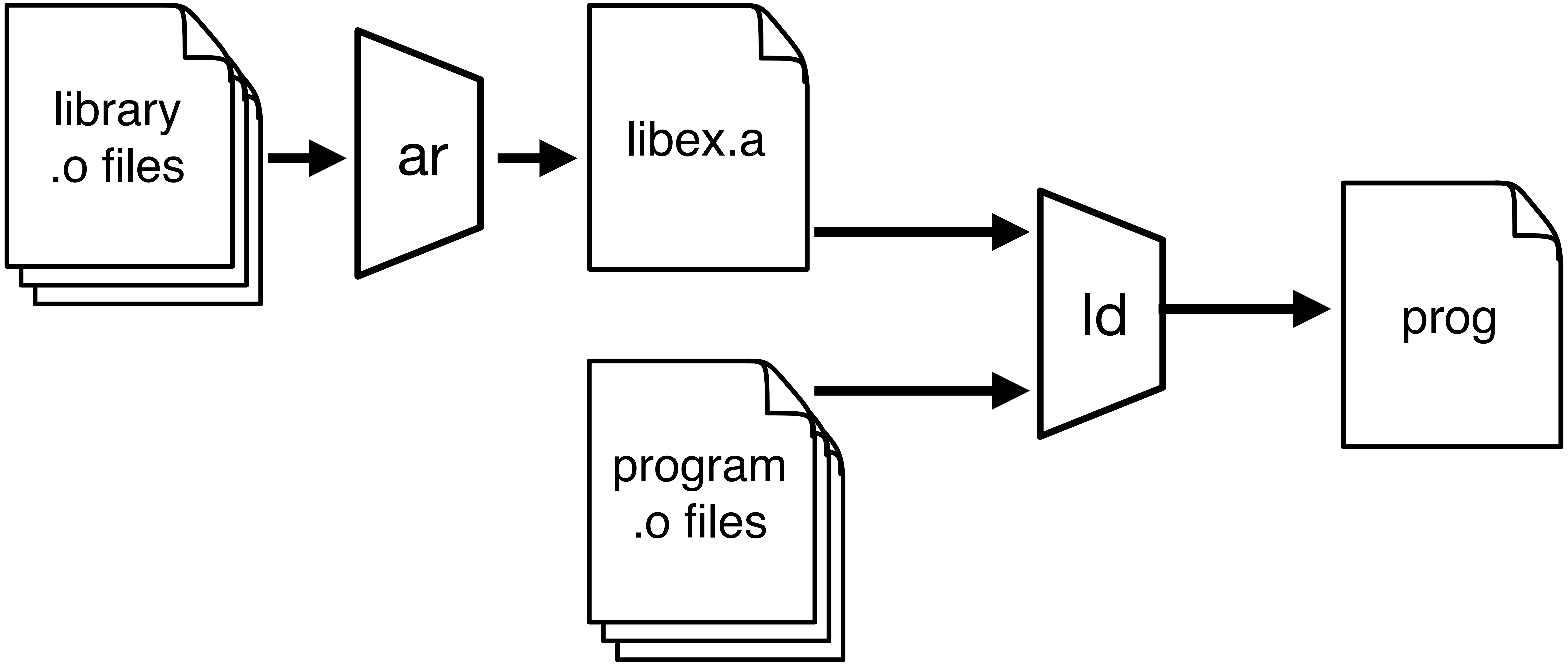
- When linking an executable against a static library, the **program linker** copies the relevant library code/data into the output

Unlike static libraries, dynamic libraries are produced by the linker

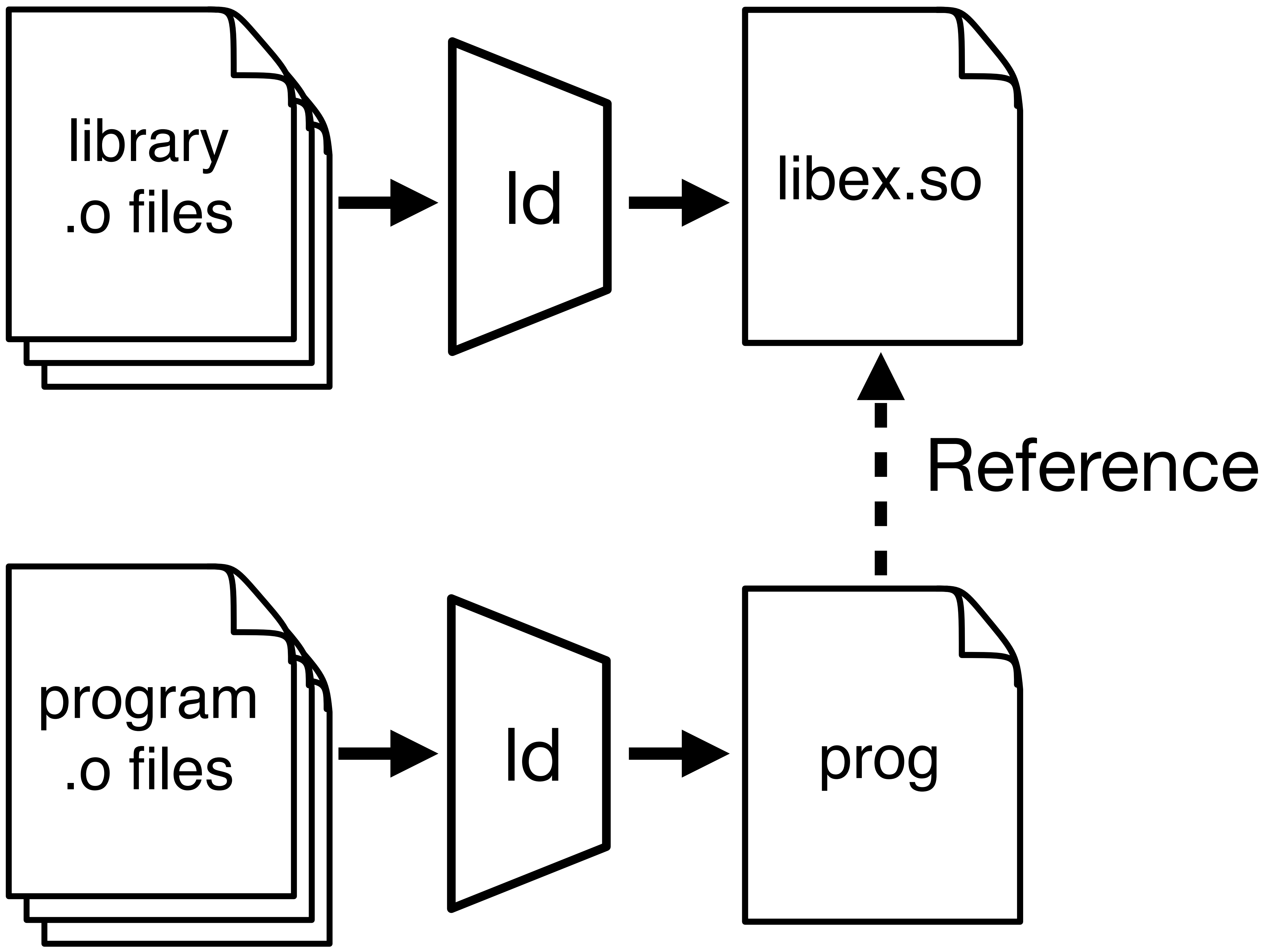
- When linking an executable against a dynamic library, the **program linker** inserts references to the library into the output, but does not copy the library code/data into the output

At run time the **dynamic linker** (the loader) loads the executable and all of its required libraries into memory

Static library



Dynamic library



Differences at runtime

Programs linked to static libraries

- Library code/data is part of the program
- Only the object files needed are included
- Code/data is placed at a known fixed address (or offset)
- Each such program has its own copy of the code/data

Programs linked to dynamic libraries

- Library code/data is loaded into memory separately
- The whole library is included, not just the needed bits
- Library code/data is loaded at a semi-arbitrary address
- Multiple programs can share a single copy of library code and read-only data; they need their own copy of the writable data
- The program loader needs to perform more work at program start up

When a library is used by many applications (e.g., libc), which of the following is **not** a benefit of using a **dynamic** library as compared to using a static library?

A. Smaller memory usage for an individual application

B. Smaller total memory usage across multiple applications

C. Smaller total disk usage across multiple applications

D. Faster program linking

When a library is used by only one application, which of the following is **not** a benefit of using a **static** library as compared to a dynamic library?

A. Smaller memory usage for the application

B. Smaller disk usage for the application

C. Faster program startup

D. Better program performance (it runs faster) separate from its start up speed

E. Bugs in the library can be fixed independently of the application

Creating a `foo` shared object

Steps

- Object files need to be compiled as position-independent code (PIC)
  ```
  $ clang -fPIC -o a.o a.c
  ```
- The compiler/linker needs to be informed that it's producing a shared object with a given soname (see next slide)
  ```
  $ clang -fPIC -shared -Wl,-soname=libfoo.so.1 \
      -o libfoo.so.1.0.0 *.o
  ```

Option details

- `-fPIC` — produce position-independent code
- `-shared` — produce a shared object
- `-Wl,-soname=blah` — pass `-soname=blah` to the linker

soname (ELF-based systems)

Each dynamic library has a **soname**

- `lib⟨`**`name`**`⟩.so.⟨ABI version⟩`
- ABI is application binary interface
- The soname specifies the name of the library and its ABI version
- Multiple versions of a library with a compatible ABI have the same soname
- Versions of a library with incompatible ABIs (different functions or parameters) have a different soname
  - `lib`**`c`**`.so.5`
  - `lib`**`c`**`.so.6`

soname vs. file name (Linux)

Example sonames

- zlib (a compression library) has the soname `libz.so.1`
- libc's soname is `libc.so.6`
- PCRE's library's soname is `libpcre.so.3`

On the file system the soname is a symbolic link to the actual library

- The file name is *usually* `lib⟨name⟩.so.⟨major⟩.⟨minor⟩.⟨patch⟩`
- The major version number is often the ABI version
  - `libz.so.1 -> libz.so.1.2.11`
  - `libpcre.so.3 -> libpcre.so.3.13.3`
  - `libc.so.6 -> libc-2.27.so` <- Nonstandard name!

One additional symbolic link

For a given library **foo**, there are typically two symbolic links

- `libfoo.so -> libfoo.so.1.0.0`
- `libfoo.so.1 -> libfoo.so.1.0.0`

The first symbol link is used at link time, the second at run time

The two need not be in the same directory

- `/usr/lib/x86_64-linux-gnu/libz.so -> /lib/x86_64-linux-gnu/libz.so.1.2.11`
- `/lib/x86_64-linux-gnu/libz.so.1 -> libz.so.1.2.11`
- `/lib/x86_64-linux-gnu/libz.so.1.2.11`

Linking to a .so

We specify a library using a command line option: `-l`

- `$ clang -o prog main.o -lblah`

`libblah.so` is a symlink to `libblah.so.1.0.0` which has a soname of `libblah.so.1`

- The compiler records `libblah.so.1` in the output `prog`

Example: bash

We can see the library sonames recorded in a binary using the `--dynamic` (`-d`) option to `readelf`

```
[clyde:~] steve$ readelf -d /bin/bash | grep NEEDED
 0x0000000000000001 (NEEDED)             Shared library: [libtinfo.so.5]
 0x0000000000000001 (NEEDED)             Shared library: [libdl.so.2]
 0x0000000000000001 (NEEDED)             Shared library: [libc.so.6]
```

Compiler search paths

When the compiler searches for files, it looks in a variety of paths

- Header files come from the header search path
- Library files come from the library search path

We can add a directory to a specific search path via command line arguments to `clang`

- Headers: `-Ipath` (e.g., `-Iinclude`)
- Libraries: `-Lpath` (e.g., `-Llib`)

Example

We have a library, foo, we want to link against with

- headers in `foo/include`
- libraries in `foo/lib`

In our `Makefile`, we add

- `-Ifoo/include` to `CFLAGS`
- `-Lfoo/lib -lfoo` to `LDFLAGS`

Runtime search paths

When the program starts, the dynamic linker looks at the sonames recorded in the binary and looks for a file with a matching name (which is usually a symlink) and loads that library

An additional runtime path can be added to the program at link time by using `-Wl,-rpath=⟨path⟩` to add path to the list of directories searched

By using the special symbol `$ORIGIN` we can add a path relative to the directory of the program

Actual library paths for bash

We can print the paths of the libraries that will be loaded

```
[clyde:~] steve$ ldd /bin/bash
   linux-vdso.so.1 (0x00007ffe065b4000)
   libtinfo.so.5 => /lib/x86_64-linux-gnu/libtinfo.so.5 (0x00007f50701b5000)
   libdl.so.2 => /lib/x86_64-linux-gnu/libdl.so.2 (0x00007f506ffb1000)
   libc.so.6 => /lib/x86_64-linux-gnu/libc.so.6 (0x00007f506fbc0000)
   /lib64/ld-linux-x86-64.so.2 (0x00007f50706f9000)
```

`linux-vdso.so.1` is a virtual dynamic library (see `$ man 7 vdso` for details)
`ld-linux-x86-64.so.2` is the actual dynamic linker (loads everything else into memory)