

Link 4A Library Search using -L and -I only

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- 2 Search libraries using `-L` and `-l` only
 - TOC: Search libraries using `-L` and `-l` only
 - 1. Example source code and dependencies
 - 2. Making shared libraries
 - 3. Making an application
 - 4. Running an application

"Study of ELF loading and relocs", 1999

http://netwinder.osuosl.org/users/p/patb/public_html/elf_relocs.html

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Compiling 32-bit program on 64-bit gcc

- `gcc -v`
- `gcc -m32 t.c`
- `sudo apt-get install gcc-multilib`
- `sudo apt-get install g++-multilib`
- `gcc-multilib`
- `g++-multilib`
- `gcc -m32`
- `objdump -m i386`

TOC: Search libraries using `-L` and `-l` only

- 1 Example source code and dependencies
- 2 Making shared libraries
- 3 Making an application
- 4 Running an application

TOC: 1. Example source code and dependencies

- Example source codes
- Function dependencies
- Direct and nested dependencies of a binary
- Example summary using `-L` and `-l`

Example source codes of foo(), bar(), foobar()

1. foo.c

```
#include <stdio.h>

void foo(void)
{
    puts(__func__);
    // puts("foo");
}
```

2. bar.c

```
#include <stdio.h>

void bar(void)
{
    puts(__func__);
    // puts("bar");
}
```

3. foobar.c

```
extern void foo(void);
extern void bar(void);

void foobar(void)
{
    foo();
    bar();
}
```

4. main.c

```
extern void foobar(void);

int main(void)
{
    foobar();
    return 0;
}
```

<https://stackoverflow.com/questions/49138195/whats-the-difference-between-rpath-1>

Function dependencies of `foo()`, `bar()`, `foobar()`

| | | |
|-----------------------|----------------|---------------------------|
| <code>main()</code> | <code>→</code> | <code>foobar()</code> |
| <code>foobar()</code> | <code>→</code> | <code>foo(), bar()</code> |

| | | |
|-----------------------|----|---------------------------|
| <code>main()</code> | in | <code>prog</code> |
| <code>foobar()</code> | in | <code>libfoobar.so</code> |
| <code>foo()</code> | in | <code>libfoo.so</code> |
| <code>bar()</code> | in | <code>libbar.so</code> |

<https://stackoverflow.com/questions/49138195/whats-the-difference-between-rpath-l>

Direct and nested dependencies of a binary

| binary | direct dependencies | nested dependencies |
|---------------------------|---|---|
| <code>libfoobar.so</code> | <code>→ libfoo.so,</code> <code>→ libbar.so</code> | |
| <code>prog</code> | <code>→ libfoobar.so</code> | <code>→ libfoo.so,</code> <code>→ libbar.so</code> |

Example summary using `-L` and `-l`

- 1 Make two shared libraries, `libfoo.so` and `libbar.so`:

```
$ gcc -c -Wall -fPIC foo.c bar.c
$ gcc -shared -o libfoo.so foo.o
$ gcc -shared -o libbar.so bar.o
```

- 2 Make a third shared library, `libfoobar.so`

```
$ gcc -c -Wall -fPIC foobar.c
$ gcc -shared -o libfoobar.so foobar.o -L. -lfoo -lbar
```

- 3 Make `prog` that depends on `libfoobar.so`:

```
$ gcc -c -Wall main.c
$ gcc -o prog main.o -L. -lfoobar -lfoo -lbar
```

- 4 Execute using `LD_LIBRARY_PATH`

```
$ export LD_LIBRARY_PATH=.
$ ./prog
foo
bar
```

<https://stackoverflow.com/questions/49138195/whats-the-difference-between-rpath-l>

TOC: 2. Making shared libraries

- Making `libfoo.so`, `libbar.so`
- Using `-L`
- Making `libfoobar.so`

Making libfoo.so and libbar.so (1) summary

- Make two shared libraries, `libfoo.so` and `libbar.so`:

```
$ gcc -c -Wall -fPIC foo.c
```

```
$ gcc -c -Wall -fPIC bar.c
```

```
-c -fPIC foo.c
```

```
-c -fPIC bar.c
```

<https://stackoverflow.com/questions/49138195/whats-the-difference-between-rpath-l>

Making libfoo.so and libbar.so (2) no dependencies

```
$ gcc -c -Wall -fPIC foo.c  
$ gcc -c -Wall -fPIC bar.c
```

- neither foo() nor bar() does depend on other user functions
- no need to specify *direct* dependencies
thus, **-l** was not used
- as a result, no **NEEDED** entries in the **.dynamic** section
for *direct* dependencies that are specified by a user

<https://stackoverflow.com/questions/49138195/whats-the-difference-between-rpath-1>

Making libfoo.so and libbar.so (3) NEEDED entries

```
$ gcc -c -Wall -fPIC foo.c
$ gcc -c -Wall -fPIC bar.c
```

- no **NEEDED** entries except lib.so.6
- libc.so.6 was not explicitly specified by a user
- i.e., **-l** was not used

```
$ readelf -d libfoo.so | grep NEEDED
Tag                Type                Name/Value
0x0000000000000001 (NEEDED)    Shared library: [libc.so.6]
```

```
$ readelf -d libbar.so | grep NEEDED
Tag                Type                Name/Value
0x0000000000000001 (NEEDED)    Shared library: [libc.so.6]
```

<https://stackoverflow.com/questions/49138195/whats-the-difference-between-rpath-l>

Using -L

- the `-L` option (`-Ldir`) tells the linker (`ld`) to search `dir` for libraries to resolve dependencies that are specified by the `-l` option
- the linker (`ld`) searches the `-L` directories, in their command line order;
 - eg. when multiple `-L` options are used like `-Ldir1 -Ldir2` `dir1` is searched first, then `dir2`
- then it searches its configured default directories, in their configured order.

<https://stackoverflow.com/questions/49138195/whats-the-difference-between-rpath-l>

Making libfoobar.so (1) summary

- Make a third shared library, `libfoobar.so` that depends on the first two (`libfoo.so`, `libbar.so`)

```
$ gcc -c -Wall -fPIC foobar.c
```

```
$ gcc -shared -o libfoobar.so foobar.o -L. -lfoo -lbar
```

```
-c -fPIC foobar.c  
-shared foobar.o -L. -lfoo -lbar
```

<https://stackoverflow.com/questions/49138195/whats-the-difference-between-rpath-l>

Making libfoobar.so (2) NEEDED entries

```
$ gcc -c -Wall -fPIC foobar.c
$ gcc -shared -o libfoobar.so foobar.o -L. -lfoo -lbar
```

- *direct dependencies* were specified by `-lfoo -lbar`
- these *dependencies* were recorded as the **NEEDED** entries in the `.dynamic` section of `libfoobar.so`

```
NEEDED [libfoo.so] ← -lfoo
```

```
NEEDED [libbar.so] ← -lbar
```

```
$ readelf -d libfoobar.so | grep NEEDED
```

| Tag | Type | Name/Value |
|--------------------|----------|----------------------------------|
| 0x0000000000000001 | (NEEDED) | Shared library: [libfoo.so] <--- |
| 0x0000000000000001 | (NEEDED) | Shared library: [libbar.so] <--- |
| ... | | |

<https://stackoverflow.com/questions/49138195/whats-the-difference-between-rpath-1>

Making libfoobar.so (3) if -L. is omitted

```
$ gcc -c -Wall -fPIC foobar.c
$ gcc -shared -o libfoobar.so foobar.o -lfoo -lbar
```

- if `-lfoo` and `-lbar` are specified without `-L.` being specified,
 - even though *direct dependencies* (`libfoo.so` and `libbar.so`) were specified
 - if where to find the necessary libraries (the current directory) was not specified, error messages is displayed

<https://stackoverflow.com/questions/49138195/whats-the-difference-between-rpath-1>

Making libfoobar.so (4) error messages

```
$ gcc -c -Wall -fPIC foobar.c
$ gcc -shared -o libfoobar.so foobar.o -lfoo -lbar
```

```
/usr/bin/ld: cannot find -lfoo
/usr/bin/ld: cannot find -lbar
collect2: error: ld returned 1 exit status
```

- if `-L.` is not specified, error messages is displayed
- saying that the **direct dependency** libraries (**libfoo.so** and **-libbar.so**) could not be located
- the linker (`ld`) didn't know where to look to *resolve* `-lfoo` or `-lbar` thus were not able to *resolve* them

<https://stackoverflow.com/questions/49138195/whats-the-difference-between-rpath-l>

TOC: 3. Making an application

- Making an application prog that uses `libfooba.so`
 - Not specifying nested dependencies
 - Warning and error messages
 - Using `-L` and `-l` to make an application

Making an application prog (1) summary

- make a program `prog` that depends on `libfoobar.so`:

```
$ gcc -c -Wall main.c
$ gcc -o prog main.o -L. -lfoobar
```

```
-c main.c
main.o -L. -lfoobar
```

- in this example, all the necessary shared libraries reside (`libfoo.so`, `libbar.so`, `libfoobar.so`) in the current directory `.`

<https://stackoverflow.com/questions/49138195/whats-the-difference-between-rpath-l>

Making an application prog (2)

```
$ gcc -c -Wall main.c
$ gcc -o prog main.o -L. -lfoobar
```

- only *direct* dependency is specified (`-lfoobar`) with the correct search path (`-L.`)
- `libfoo.so` and `libbar.so` are the *direct* dependencies of `libfoobar.so`, and thus the *nested* dependencies of `prog`
- *nested* dependencies are not specified (`-lfoo -lbar` not used)

<https://stackoverflow.com/questions/49138195/whats-the-difference-between-rpath-l>

Making an application prog that uses libfoobar.so (2)

- make a program `prog` that depends on `libfoobar.so`:

```
$ gcc -c -Wall main.c
```

```
$ gcc -o prog main.o -L. -lfoobar -Wl,-rpath-link=$(pwd)
```

- only *direct* dependency was specified (`-lfoobar`) with the correct search path (`-L.`)
- *nested* dependencies were not specified (`-lfoo -lbar`) but can be handled by `-rpath-link=$(pwd)`
 - `libfoo.so` and `libbar.so` are the *direct* dependencies of `libfoobar.so`, and thus the *nested* dependencies of `prog`

<https://stackoverflow.com/questions/49138195/whats-the-difference-between-rpath-l>

Creating **NEEDED** entries

- make a program **prog** that depends on **libfoobar.so**:

```
$ gcc -c -Wall main.c
```

```
$ gcc -o prog main.o -L. -lfoobar -Wl,-rpath-link=$(pwd)
```

- in the **.dynamic** section of **prog**
 - *direct dependency* specified by **-lfoobar** was recorded as **NEEDED** entries
 - *nested dependency*, even though specified by **-lfoo -lbar**, are not recorded as **NEEDED** entries

```
$ readelf -d prog | grep NEEDED
```

| Tag | Type | Name/Value |
|--------------------|----------|-------------------------------------|
| 0x0000000000000001 | (NEEDED) | Shared library: [libfoobar.so] <--- |
| 0x0000000000000001 | (NEEDED) | Shared library: [libc.so.6] |

<https://stackoverflow.com/questions/49138195/whats-the-difference-between-rpath-l>

NEEDED entries and nested dependencies (1)

- `libfoo.so`, `libbar.so` :
 - these are the *direct dependencies* of `libfoobar.so`
 - thus, these are the *nested dependencies* of `prog`
 - when `libfoobar.so` was made, its *direct dependencies* were specified with `-lfoo -lbar`
 - this allows the *direct dependencies* of `libfoobar.so` to be recorded as **NEEDED** entries in the `.dynamic` section of `libfoobar.so`

<https://stackoverflow.com/questions/49138195/whats-the-difference-between-rpath-1>

Not specifying *nested* dependencies

- although `-lfoo` and `-lbar` are not specified,

```
$ gcc -c -Wall main.c  
$ gcc -o prog main.o -L. -lfoobar
```

- by looking into `NEEDED` entry of the `.dynamic` section of `libfoobar.so`,
- the linker (`ld`) detects the *nested dynamic dependencies* but they were not specified with `-lfoo -lbar`
warning : not found libfoo.so, not found libbar.so
- the linker (`ld`) did not resolve the *nested* dependencies because they were not specified
error: undefined reference to foo, undefined reference to bar

<https://stackoverflow.com/questions/49138195/whats-the-difference-between-rpath-l>

Warning and error messages

- make a program `prog` that depends on `libfoobar.so`:
 - the *nested* dependencies are not specified (`-lfoo -lbar`) though with the correct search path (`-L.`)
 - not found `libfoo.so` ← `-lfoo` not specified
 - not found `libbar.so` ← `-lbar` not specified
 - undefined reference to `bar` ← `-lbar` not resolved
 - undefined reference to `foo` ← `-lfoo` not resolved

```
$ gcc -c -Wall main.c
$ gcc -o prog main.o -L. -lfoobar
/usr/bin/ld: warning: libfoo.so, needed by ./libfoobar.so, not found
(tryping using -rpath or -rpath-link)
/usr/bin/ld: warning: libbar.so, needed by ./libfoobar.so, not found
(tryping using -rpath or -rpath-link)
./libfoobar.so: undefined reference to 'bar'
./libfoobar.so: undefined reference to 'foo'
collect2: error: ld returned 1 exit status
```

<https://stackoverflow.com/questions/49138195/whats-the-difference-between-rpath-l>

Using only `-L` and `-l` to make an application

- to resolve the *nested dependencies*, we will consider the following ways
 - 1 `-L` and `-l`
 - 2 `-rpath-link`
 - 3 `-rpath`
- let us first ignore the gcc compiler's advice
try using `-rpath` or `-rpath-link`
- to handle *nested dependencies*, try first using `-L` and `-l`
 - search path for *nested dependencies* : `-L.`
(the same directory specified for `libfoobar.so`)
 - *nested dependencies* : `-lfoo -lbar`

```
$ gcc -o prog main.o -L. -lfoobar -lfoo -lbar
```

<https://stackoverflow.com/questions/49138195/whats-the-difference-between-rpath-l>

TOC: 4. Running an application

- Need to specify runtime search paths
- More experiment with nested dependencies
- Specifying the runtime shared library paths
- Using `LD_LIBRARY_PATH` to run an application

Need to specify runtime search paths

- now, the application `prog` can be made, but cannot be made to run:

```
$ gcc -o prog main.o -L. -lfoobar -lfoo -lbar
```

```
$ ./prog
```

```
./prog: error while loading shared libraries: libfoobar.so:\ncannot open shared object file: No such file or directory
```

- at the `runtime`, the loader (`ld.so`) could not find `libfoobar.so` nor `libfoo.so` nor `libbar.so`
- need to specify the `runtime` search paths

<https://stackoverflow.com/questions/49138195/whats-the-difference-between-rpath-1>

More experiment with nested dependencies

- before specifying runtime search paths, let's experiment more with *nested dependencies*
- move `libfoo.so` and `libbar.so` libraries to `lib2`

```
$ mkdir lib2
$ mv libfoo.so libbar.so lib2
```

- then, make `prog` as before

```
$ gcc -o prog main.o -L. -lfoobar -lfoo -lbar
```

- the *nested dependencies* were specified (`-lfoo -lbar`)
- but the linker (`ld`) could not find `libfoo.so` and `libbar.so` at the specified directory (`-L.`)

```
/usr/bin/ld: cannot find -lfoo
/usr/bin/ld: cannot find -lbar
collect2: error: ld returned 1 exit status
```

- the correct search path `-Llib2` must also be specified

<https://stackoverflow.com/questions/49138195/whats-the-difference-between-rpath-l>

Specifying the runtime shared library paths

- now move `libfoo.so`, `libbar.so` back to the current directory . and make `prog` again

```
mv lib2/libfoo.so lib2/libbar.so .  
$ gcc -o prog main.o -L. -lfoobar -lfoo -lbar
```

- the `-L` option is used to tell the linker (`ld`) where to *find the libraries* (shared objects) at the compile, and link time
- lots of ways to tell the runtime linker (dynamic loader `ld.so`) where to *find the libraries* (shared objects) at the runtime
 - `-R`
 - `LD_LIBRARY_PATH`
 - `LD_RUN_PATH`

<https://stackoverflow.com/questions/31455979/how-to-specify-libraries-paths-in-gcc>

Using LD_LIBRARY_PATH to run an application

- `prog` is made by using `-L` and `-l` only
not by using `-rpath` nor `-rpath-link`

```
$ gcc -o prog main.o -L. -lfoobar -lfoo -lbar
```

- `prog` is made run by us `LD_LIBRARY_PATH`

```
$ export LD_LIBRARY_PATH=.  
$ ./prog  
foo  
bar
```

- at the runtime, `LD_LIBRARY_PATH` enables the loader (`ld.so`)
to find `libfoobar.so`, `libfoo.so`, and `libbar.so`
in the current directory .

```
export LD_LIBRARY_PATH=.
```

<https://stackoverflow.com/questions/49138195/whats-the-difference-between-rpath-l>

NEEDED entries of each binary

| binary | dependencies | entry | section |
|---------------------------|---|--------|-----------------------|
| <code>prog</code> | <code>libfoobar.so</code> | NEEDED | <code>.dynamic</code> |
| <code>libfoobar.so</code> | <code>libfoo.so,</code> <code>libbar.so</code> | NEEDED | <code>.dynamic</code> |

<https://stackoverflow.com/questions/49138195/whats-the-difference-between-rpath-l>