Link 6. Library Search Examples

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Outline

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2. Examples of search libraries
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Based on

"Study of ELF loading and relocs", 1999
http://netwinder.osuosl.org/users/p/patb/public_html/elf_relocs.html

Compling 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: Examples of search libraries

TOC: 1. Example source code and dependencies

- Example source codes of `foo()`, `bar()`, `foobar()`
- Function dependencies of `foo()`, `bar()`, `foobar()`

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-li

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

main()	→	foobar()
foobar()	→	foo(), bar()

main()	in prog
foobar()	in libfoobar.so
foo()	in libfoo.so
bar()	in libbar.so

https://stackoverflow.com/questions/49138195/whats-the-difference-between-rpath-li

direct and nested dependencies of a binary

binary	direct dependencies	nested dependencies
`libfoobar.so`	→ `libfoo.so`, → `libbar.so`	
`prog`	→ `libfoobar.so`	→ `libfoo.so`, → `libbar.so`

Specifying dependencies and search paths (1)

	dependencies	link time search paths	runtime search paths
`-l`	○		
`-L`		○	
`-rpath-link`		○	
`-rpath`		○	○

Specifying dependencies and search paths (2)

	for direct dependencies	for nested dependencies
Method 1	`-L` *d_direct* `-l` *direct*	`-L` *d_nest* `-l` *nest*
Method 2	`-L` *d_direct* `-l` *direct*	`-rpath-link` *d_nest*
Method 3	`-L` *d_direct* `-l` *direct*	`-rpath` *d_nest*
Method 4	`-L` *d_direct* `-l` *direct*	`-rpath` *d_direct*

Specifying dependencies and search paths (3)

Method 1	-L *d_direct* -l *direct* -L *d_nest* -l *nest*
Method 2	-L *d_direct* -l *direct* -rpath-link *d_nest*
Method 3	-L *d_direct* -l *direct* -rpath *d_nest*

need to specify *runtime* search paths, e.g.,
`export LD_LIBRARY_PATH=dir1:dir2`

Method 4	-L *d_direct* -l *direct* -rpath *d_direct*

no need to specify *runtime* search paths
-rpath enables each binary to *record*
its *direct* search paths in the RUNPATH entry
of its .dynamic section

TOC: 2. -L and -l examples

- Example summary using -L and -l
- Making libfoo.so, +libbar.so=
- Making libfoobar.so
  - Using -L. -lfoo -lbar to make libfoobar.so
- Making an application prog that uses libfooba.so
  - Not specifying nested dependencies
  - Warning and error messages
  - Using -L and -l to make 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

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-li

Making libfoo.so and libbar.so

- 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
```

https://stackoverflow.com/questions/49138195/whats-the-difference-between-rpath-li

Making libfoobar.so

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

  - *direct* dependencies (libfoo.so and libbar.so)
    were specified by -lfoo and -lbar
  - but could not find the libraries (libfoo.so and -libbar.so)

```
/usr/bin/ld: cannot find -lfoo
/usr/bin/ld: cannot find -lbar
```

  - because 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-li

Using -L. -lfoo -lbar to make libfoobar.so

- The -L. informs where to look to resolve -lfoo and -lbar

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

- 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 mulitple -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-li

Making an application prog that uses libfoobar.so

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

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

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

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

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-li

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
(try using -rpath or -rpath-link)
/usr/bin/ld: warning: libbar.so, needed by ./libfoobar.so, not found
(try 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-li

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-li

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:\
cannot 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-li

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-li

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-gc

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_LIBRAY_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-li

TOC: 3. -rpath-link

Dependency related entries of the .dynamic section

- in the .dynamic section of an binary

DT_NEEDED	• created by -L -l options of gcc compiler • specifies direct dependencies • can be used to find nested dependencies
DT_RPATH / DT_RUNPATH	• created by -rpath option of ld linker • specifies runtime search path • DT_RPATH is deprecated → searches direct and nested dependency paths • DT_RUNPATH is not supported by all systems → searches only direct dependency paths

https://stackoverflow.com/questions/49138195/whats-the-difference-between-rpath-li

What is RPATH (1-1)

- if an executable `foo` links to the shared library `bar`,
  the library `bar` has to be *found* and *loaded*
  when the executable `foo` is *executed*.
- this (searching and loading the shared library)
  is done by the linker, `ld.so`.
- the linker *searches* a set of directories
  for the library `bar`, `libbar.so`

`https://gitlab.kitware.com/cmake/community/-/wikis/doc/cmake/RPATH-handling`

What is RPATH (1-2)

- The linker will search the shared libraries
  in the following directories in the given order:
  1. RPATH (deprecated)
  2. LD_LIBRARY_PATH
  3. RUNPATH (only direct dependency paths)
  4. /etc/ld.so.conf

https://gitlab.kitware.com/cmake/community/-/wikis/doc/cmake/RPATH-handling

What is RPATH (2)

1. RPATH
   - a list of directories which is linked into the executable
   - it is ignored if RUNPATH is present.
2. LD_LIBRARY_PATH
   - an environment variable which holds a list of directories
3. RUNPATH
   - same as RPATH, but searched after LD_LIBRARY_PATH, supported only on most current Linux systems
4. /etc/ld.so.conf
   - configuration file for ld.so which lists additional library directories (builtin directories) basically /lib and /usr/lib

https://gitlab.kitware.com/cmake/community/-/wikis/doc/cmake/RPATH-handling

What is RPATH (3)

- here are different reasons why search directories additional to the builtin ones can be needed
  - a user may install a library privately into his home directory, e.g. ~/lib/, or
  - there may be two or more versions of the same library installed, e.g. /opt/kde3/lib/libkdecore.so and /opt/kde4/lib/libkdecore.so.
  - For the first case it would work if the user would set LD_LIBRARY_PATH accordingly:
    export LD_LIBRARY_PATH=$HOME/lib:$LD_LIBRARY_PATH

https://gitlab.kitware.com/cmake/community/-/wikis/doc/cmake/RPATH-handling

What is RPATH (4)

- This will break for the second case,
  where for some programs /opt/kde3/lib has to be searched
  and for other applications /opt/kde4/lib has to be searched,
  but in no case both.
- The only way to have an executable-dependent library search path is by using RPATH (or RUNPATH, but this isn't supported everywhere).

`https://gitlab.kitware.com/cmake/community/-/wikis/doc/cmake/RPATH-handling`

Handling *direct* and *nested* dependencies

- *direct* dependecy must be handled
  by specifying `-L` and `-l`

- *nested* dependecies can be handled
  by specifying `-rpath-link` or `-rpath`

`https://stackoverflow.com/questions/49138195/whats-the-difference-between-rpath-li`

Specifying -L and -l handles *direct* dependencies

- the *direct* dependencies of the current binary must be handled by `-L` and `-l`
  - specifying `-L` and `-l` creates `NEEDED` entries in `.dynamic` section of the current binary
  - by specifying `-rpath-link` or `-rpath`
    - the `NEEDED` entries are not created, but
    - the `NEEDED` entries of each binary can be utilized to find the *nested* dependencies of a given binary

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

Specifying -rpath-link handles *nested* dependencies

- the -rpath-link=dir option tells the linker (ld) that when *dynamic nested* dependencies are requested, directory dir is searched to *resolve* them.
- only for a successful linkage,

  -rpath-link specifies the *directories* where the *nested* dependencies of the current binary can be found

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

https://stackoverflow.com/questions/49138195/whats-the-difference-between-rpath-li

-rpath-link v.s. -rpath

- -rpath-link=dir
  - provides the linker with runtime search path information
  - but does not instruct the linker to write that information into RUNPATH or RPATH entries in the .dynamic section
- -rpath=dir
  - also provides the linker with runtime search path information
  - and instructs the linker to write that information into RUNPATH or RPATH entries in the .dynamic section

https://stackoverflow.com/questions/49138195/whats-the-difference-between-rpath-li

-rpath-link does not create RUNPATH / RPATH entries

- -rpath-link=dir
  - does not guarantee us a *runnable prog*
    but only a *successful linkage*

```
$ gcc -o prog main.o -L. -lfoobar -Wl,-rpath-link=$(pwd)
$ ./prog
./prog: error while loading shared libraries: libfoobar.so
cannot open shared object file: No such file or directory
```

  - creates neither RUNPATH nor RPATH
  - therefore, in order to *execute* prog,
    runtime search path must be specified explicitly

https://stackoverflow.com/questions/49138195/whats-the-difference-between-rpath-li

-rpath creates RUNPATH / RPATH entries

- -rpath=dir
  - creates RUNPATH or RPATH entries
    in the .dynamic section
    to specify runtime search path
    - RUNPATH (for modern gcc)
    - RPATH (for older gcc)
  - guarantees us a *runnable prog*
  - no need to specify runtime search path explicitly

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

RPATH v.s. RUNPATH (1)

- in the .dynamic section of a binary (*executable* or *shared library*)
  - the RPATH entry is used by default
    in the *older* versions of gcc
    - RPATH allows nested dependencies
      to inherit the specified search path
  - the RUNPATH entry is used by default
    in *modern* versions of gcc
    - RUNPATH applies the search path
      only to the direct dependencies
      of the *current binary* (no recursive application)

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

RPATH v.s. RUNPATH (2)

older gcc	RPATH	all dependencies (direct, nested) utilize the specified path
modern gcc	RUNPATH	only direct dependencies utilize the specified path

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

Runtime search path precedence (1)

- at the runtime, to locate a dynamic library (`.so` file), the loader (dynamic linker) will try the followings
  - search RPATH (older versions of gcc)
  - search `LD_LIBRARY_PATH`
  - search RUNPATH (modern versions of gcc)
  - directories on the system search path, which consists of the entries in `/etc/ld.so.conf` plus `/lib` and `/usr/lib`

https://unix.stackexchange.com/questions/22926/where-do-executables-look-for-share
https://stackoverflow.com/questions/49138195/whats-the-difference-between-rpath-li

Runtime search path precedence (2)

- there are many other ways to specify the runtime search path
- `-rpath-link=dir` does not give any information of runtime search path

https://unix.stackexchange.com/questions/22926/where-do-executables-look-for-share
https://stackoverflow.com/questions/49138195/whats-the-difference-between-rpath-li

-rpath-link in bfd and gold linkers

	bfd ld	gold ld
-rpath-link	(O)	(X) ignored
DT_NEEDED	(0)	(X) not used

https://stackoverflow.com/questions/49138195/whats-the-difference-between-rpath-li

bfd ld and -rpath-link (1)

- The --rpath-link option is used by bfd ld
  to add to the search path used for
  finding DT_NEEDED shared libraries

  (direct dependencies of a given binary)

  when doing link-time symbol resolution

  - by following DT_NEEDED entries recursively
    indirect (nested) dependencies can be found

https://stackoverflow.com/questions/49138195/whats-the-difference-between-rpath-li

bfd ld and -rpath-link (2)

- It's basically telling the linker
  what to use as the runtime search path

  when attempting to mimic
    what the dynamic linker would do
    when resolving symbols

- as the runtime search path set
  by --rpath options or
  the LD_LIBRARY_PATH environment variable

https://stackoverflow.com/questions/49138195/whats-the-difference-between-rpath-li

gold ld and -rpath-link

- gold linker does not follow DT_NEEDED entries
  when resolving symbols in shared libraries,
- so the --rpath-link option is ignored
  when gold linker is used
- this was a deliberate design decision;
  indirect (nested) dependencies
  do not need to be present
  or in their runtime locations during the link process.

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

Example summary using -rpath-link

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 -Wl,-rpath-link=$(pwd)
```

4. Execute using LD_LIBRARY_PATH

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

https://stackoverflow.com/questions/49138195/whats-the-difference-between-rpath-li

Making libfoo.so and libbar.so

- 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
```

  - no *direct* dependencies
  - no specification with -l
  - no NEEDED entries for *direct* dependencies that are specified by a user

```
$ 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-li

Making libfoobar.so

- 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
```

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

```
$ 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-li

Making an application prog that uses libfoobar.so

- 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-li

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* dependecy specified by -lfoobar
    was recorded as NEEDED entries
  - *nested* dependecy, 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-li

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-li

NEEDED entries and nested dependencies (2)

- -rpath-link=dir
  - the *nested* dependencies of prog can be found through the NEEDED entries in the .dynamic section of the *direct* dependency of prog
    - when prog was made, its *direct* dependency were specified with -lfoobar
    - the *direct* dependencies of libfoobar.so can be found by looking the NEEDED entries in the .dyanmic section of libfoobar.so
  - the directory dir will be searched for these *nested* dependencies of prog

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

https://stackoverflow.com/questions/49138195/whats-the-difference-between-rpath-li

NEEDED entries of each binary

binary	dependencies	entry	section
prog	libfoobar.so	NEEDED	.dynamic
libfoobar.so	libfoo.so, libbar.so	NEEDED	.dynamic

https://stackoverflow.com/questions/49138195/whats-the-difference-between-rpath-li

Using LD_LIBRARY_PATH to specify a runtime search path

- but the loader might be able to locate them
  - through the ldconfig cache or
  - a setting of the LD_LIBRARY_PATH environment variable, e.g:

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

https://stackoverflow.com/questions/49138195/whats-the-difference-between-rpath-li

-rpath-link example (6)

- -rpath-link=dir
  - gives the linker (ld) the directory information that the loader (ld.so) *would* need to resolve some of the dynamic dependencies of prog at runtime
    - assuming that the directory information remained true at runtime
  - but does not write that directory information into the .dynamic section of prog
    - only the *direct* dependency (libfoobar.so) is written in the .dynamic section of prog

https://stackoverflow.com/questions/49138195/whats-the-difference-between-rpath-li

TOC: 5. -rpath examples

Example summary using -rpath (1)

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
   that depends on the first two;

```
$ gcc -c -Wall -fPIC foobar.c
$ gcc -shared -o libfoobar.so foobar.o -L. -lfoo -lbar -Wl,-rpath=$(pwd)
```

3. Make an application, prog that depends on libfoobar.so

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

4. Make prog run

```
# to show that this environment variable is not used
export LD_LIBRARY_PATH=    # clear the env variable
$ ./prog
```

https://stackoverflow.com/questions/49138195/whats-the-difference-between-rpath-li

-rpath example (4)

- prog contains the runtime search path information for shared libraries that porg depends on

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

# $(pwd) -->  /home/imk/develop/so/scrap


$ readelf -d prog

Dynamic section at offset 0xe08 contains 26 entries:
  Tag        Type                         Name/Value
 0x0000000000000001 (NEEDED)             Shared library: [libfoobar.so]
 0x0000000000000001 (NEEDED)             Shared library: [libc.so.6]
 0x000000000000000f (RUNPATH)            Library rpath: [/home/imk/develop/so/scrap]
 ...
 ...
```

https://stackoverflow.com/questions/49138195/whats-the-difference-between-rpath-li

-rpath example (5)

- libfoobar.so (direct dependency) will be found at runtime,
  but libfoo.so and libbar.so (nested dependencies) won't,
  - because libfoobar.so does not inherit
    RUNPATH information of prog
- -rpath=$(pwd) must be specified also for libfoobar.so
  to write *runtime search path* information
  into RUNPATH entry of the .dynamic section
  of libfoobar.so

```
$ gcc -c -Wall -fPIC foobar.c
$ gcc -shared -o libfoobar.so foobar.o -L. -lfoo -lbar -Wl,-rpath=$(pwd)
```

https://stackoverflow.com/questions/49138195/whats-the-difference-between-rpath-li

-rpath example (6)

- check what libraries are needed by `libfoobar.so` could be:

```
$ readelf -d ./libfoobar.so

Dynamic section at offset 0xe38 contains 22 entries:
  Tag        Type                         Name/Value
   0x0000000000000001 (NEEDED)    Shared library: [libfoo.so]
   0x0000000000000001 (NEEDED)    Shared library: [libbar.so]
   0x0000000000000001 (NEEDED)    Shared library: [libc.so.6]
   0x000000000000000f (RPATH)     Library rpath: [/home/imk/develop/so/scrap]
  (...)
```

https://unix.stackexchange.com/questions/571861/is-there-an-rpath-for-dynamic-linl

-rpath example (7)

- prog executable depends on libfoobar.so shared object
  RUNPATH entry of .dynamic section of prog set by

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

- libfoobar.so shared object depends on
  libfoo.so and libbar.so shared objects
  RUNPATH entry of .dynamic section of libfoobar.so set by

```
$ gcc -shared -o libfoobar.so foobar.o -L. -lfoo -lbar -Wl,-rpath=$(pwd)
```

- to run prog doses not need to set LD_LIBRARY_PATH

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

https://unix.stackexchange.com/questions/571861/is-there-an-rpath-for-dynamic-linl

-rpath example (8*)

- RPATH is searched in before LD_LIBRARY_PATH
- RUNPATH is searched in after LD_LIBRARY_PATH

1. search RPATH (older versions of gcc)
2. search LD_LIBRARY_PATH
3. search RUNPATH (modern versions of gcc)
4. search ldconfig-ed directories

https://stackoverflow.com/questions/49138195/whats-the-difference-between-rpath-li
https://refspecs.linuxbase.org/elf/gabi4+/ch5.dynamic.html

-rpath example (9*)

- if -Wl,--disable-new-dtags is specified
  RPATH is used as if 'older versions' of gcc were used,
  instead of RUNPATH
  - makes *nested* dependencies inherit the specified search path
  - thus, -rpath=$(pwd) need not be specified for libfoobar.so

```
$ export LD_LIBRARY_PATH=

$ gcc -shared -o libfoobar.so foobar.o -L. -lfoo -lbar
$ gcc -o prog main.o -L. -lfoobar -Wl,-rpath=$(pwd) -Wl,--disable-new-dtags
$ ./prog
foo
bar
```

https://stackoverflow.com/questions/49138195/whats-the-difference-between-rpath-li

TOC: 5. Summary and more examples

Directories for example shared libraries

1. using -L and -l
2. using -rpath-link
3. using -rpath (like -rpath-link)
4. using -rpath (using RUNPATH)

binaries	compile time	run time 1,2,3	run time 4
libfoo.so	./lib2	./lib2	./librun
libbar.so	./lib2	./lib2	./librun
libfoobar.so	./lib	./librun	./librun
prog	.	.	.

Specifying dependencies and search paths (1)

Method 1	-L *d_direct* -l *direct*	-L *d_nest* -l *nest*
Method 2	-L *d_direct* -l *direct*	-rpath-link *d_nest*
Method 3	-L *d_direct* -l *direct*	-rpath *d_nest*
Method 4	-L *d_direct* -l *direct*	-rpath *d_direct*

libfoobar.so	*direct*	foo and bar	*d_direct*	lib2
	nested	-	*d_nest*	-
prog	*direct*	libfoobar	*d_direct*	lib or librun
	nested	foo and bar	*d_nest*	lib2

Specifying dependencies and search paths (2)

- for `libfoobar.so`
  1. `-Llib2 -lfoo -lbar`
  2. `-Llib2 -lfoo -lbar`
  3. `-Llib2 -lfoo -lbar`
  4. `-Llib2 -lfoo -lbar -Wl,-rpath=lib:librun`
- for `prog`
  1. `-Llib -lfoobar -Llib2 -lfoo -lbar`
  2. `-Llib -lfoobar -Wl,-rpath-link=lib2`
  3. `-Llib -lfoobar -Wl,-rpath=lib2`
  4. `-Llib -lfoobar -Wl,-rpath=lib:librun`

Example2 summary using -L and -l

1. Make libfoo.so and libbar.so in ./lib2

```
$ gcc -c -Wall -fPIC foo.c bar.c
$ gcc -shared -o libfoo.so foo.o
$ gcc -shared -o libbar.so bar.o
$ mv libfoo.so libbar.so lib2
```

2. Make libfoobar.so in ./lib

```
$ gcc -c -Wall -fPIC foobar.c
$ gcc -shared -o libfoobar.so foobar.o -Llib2 -lfoo -lbar
$ mv libfoobar.so lib
```

3. Make prog in .

```
$ gcc -c -Wall main.c
$ gcc -o prog main.o -Llib -lfoobar -Llib2 -lfoo -lbar
```

4. Execute using LD_LIBRARY_PATH (libraries in librun, lib2)

```
$ mv lib/libfoobar.so librun
$ export LD_LIBRARY_PATH=librun:lib2
$ ./prog
```

Specifying *dependencies* using -l only

- unless `rpath-link` or `rpath` is used
  - *all* dependencies must be specified with `-l`
    (*direct* and *nested* dependencies)
  - specify `-lfoobar` (*direct* dependency of `prog`)
  - specify `-lfoo -lbar` (*nested* dependencies of `prog`)

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

  - the *direct* dependency of `prog` : `libfoobar.so`
  - the *nested* dependencies of `prog` : `libfoo.so`, `libbar.so`
    (the *direct* dependencies of `libfoobar.so`)

Specifying *link time* search paths using -L only

- `-Ldir1 -Ldir2` ...
  - when an input file *requests* dynamic dependencies
    the linker *searches* the specified directories to *resolve* them.
  - specify all the search paths for *direct* and *nested* dependencies
  - since *nested* dependencies does *inherit* the search path
  - the linker *searches* `dir1`, `dir2`, etc., only to *resolve* references
  - only for a successful linkage, not for a successful execution
  - in this example, to link successfully, `$(pwd)` is searched
    - for `libfoobar.so` (the *direct* dependency)
    - for `libfoo.so` and `libbar.so` (the *nested* dependencies)

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

Example2 summary using -rpath-link

1. Make libfoo.so and libbar.so in ./lib2

```
gcc -c -Wall -fPIC foo.c bar.c
gcc -shared -o libfoo.so foo.o
gcc -shared -o libbar.so bar.o
mv libfoo.so libbar.so lib2
```

2. Make y, libfoobar.so in ./lib

```
gcc -c -Wall -fPIC foobar.c
gcc -shared -o libfoobar.so foobar.o -Llib2 -lfoo -lbar
mv libfoobar.so lib
```

3. Make prog in .

```
gcc -c -Wall main.c
gcc -o prog main.o -Llib -lfoobar -Wl,-rpath-link=lib2
```

4. Execute using LD_LIBRARY_PATH (libraries in librun, lib2)

```
mv lib/libfoobar.so librun
export LD_LIBRARY_PATH=librun:lib
./prog
```

Specifying *dependencies* using -rpath-link=dir

- when rpath-link or rpath is used
  - specify only *direct* dependencies using -l
    and their search paths with -L
  - no need to specify *nested* dependencies
    - *nested* dependencies can be found
      by the NEEDED entry in the .dynamic section
      of a given *direct* dependency
  - -lfoobar necessary
  - -lfoo -lbar unnecessary

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

  - the *direct* dependency of prog : libfoobar.so
  - the *nested* dependencies of prog : libfoo.so, libbar.so
    (the *direct* dependencies of libfoobar.so)

Specifying *link time* search paths using -rpath-link=dir

- when -rpath-link=dir is used
  - since *nested* dependencies do *inherit* the search path
  - specify all the search paths for *direct* and *nested* dependencies using rpath-link=dir1:dir2 or multiple rpath-link options
  - only for a successful linkage, not for a successful execution
  - in this example, to link successfully, $(pwd) is searched
    - for libfoobar.so (the *direct* dependency)
    - for libfoo.so and libbar.so (the *nested* dependencies)

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

Example2 summary using -rpath (like -rpath-link)

1. Make libfoo.so and libbar.so in ./lib2

```
gcc -c -Wall -fPIC foo.c bar.c
gcc -shared -o libfoo.so foo.o
gcc -shared -o libbar.so bar.o
mv libfoo.so libbar.so lib2
```

2. Make libfoobar.so in ./lib

```
gcc -c -Wall -fPIC foobar.c
gcc -shared -o libfoobar.so foobar.o -Llib2 -lfoo -lbar
mv libfoobar.so lib
```

3. Make prog in .

```
gcc -c -Wall main.c
gcc -o prog main.o -Llib -lfoobar -Wl,-rpath=lib2
```

4. Execute using LD_LIBRARY_PATH (libraries in librun, lib2)

```
mv lib/libfoobar.so librun
export LD_LIBRARY_PATH=librun:lib
./prog
```

Example2 summary using -rpath (using RUNPATH)

1. Make libfoo.so and libbar.so in ./lib2

```
gcc -c -Wall -fPIC foo.c bar.c
gcc -shared -o libfoo.so foo.o
gcc -shared -o libbar.so bar.o
mv libfoo.so libbar.so lib2
```

2. Make libfoobar.so in ./lib

```
gcc -c -Wall -fPIC foobar.c
gcc -shared -o libfoobar.so foobar.o -Llib2 -lfoo -lbar -Wl,-rpath=lib:librun
mv libfoobar.so lib
```

3. Make prog in .

```
gcc -c -Wall main.c
gcc -o prog main.o -Llib -lfoobar -Wl,-rpath=lib2:librun
```

4. Execute without LD_LIBRARY_PATH (now all libraries in librun)

```
mv lib/libfoobar.so lib2/libfoo.so lib2/libbar.so librun
export  LD_LIBRARY_PATH=
./prog
```

Specifying *dependencies* using -rpath=dir

- when rpath-link or rpath is used
  - specify only *direct* dependencies using -l
    and their search paths with -L
  - no need to specify *nested* dependencies
    - *nested* dependencies can be found
      by the NEEDED entry in the .dynamic section
      of a given *direct* dependency
  - -lfoobar necessary
  - -lfoo -lbar unnecessary

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

  - the *direct* dependency of prog : libfoobar.so
  - the *nested* dependencies of prog : libfoo.so, libbar.so
    (the *direct* dependencies of libfoobar.so)

Specifying *link time* search paths using -rpath=dir

- when -rpath is used, there are two approaches for specifying the *link time* search paths
  1. specify *all* the search paths for *direct* and *nested* dependencies of a given binary using -rpath
     - for a successful linkage only, not for a successful execution
     - since *nested* dependencies *inherit* the search path
     - as long as specifying *link time* search paths are concerned, the rpath option is the same as the rpath-link option
  2. let each binary be specified with search paths using -rpath for its *direct* dependencies only
     - those paths are recorded as *runtime* search paths in the RUNPATH entry of .dynamic section of a binary

Specifying *run time* search paths using -rpath=dir

- -rpath=dir
  - the ld *searches* directory dir to *resolve* references
  - the ld.so *searches* directory dir to *load* shared libraries
  - to load shared libraries, *nested* dependencies may not *inherit* the search path
  - for modern versions of gcc that use RUNPATH instead RPATH do not allow the search path to be *inherited*
    - thus, each binary should be specified with search paths for its *direct* dependencies, using -rpath
    - that those paths may be recorded as *runtime* search path in the RUNPATH entry of .dynamic section of the binary

```
$ gcc -shared -o libfoobar.so foobar.o -L. -lfoo -lbar -Wl,-rpath=$(pwd)
$ gcc -o prog main.o -L. -lfoobar -Wl,-rpath=$(pwd)
```

TOC: 5. -Wl,-rpath,. examples

Using -Wl, rpath . (1)

- in order to pass -rpath . to the linker, consider them as two arguments (-rpath and .) to the -Wl
- you can write (-Wl,arg1,arg2) or (-Wl,arg1, -Wl,arg2)
  - -Wl,-rpath,.
  - -Wl,-rpath -Wl,.

https://stackoverflow.com/questions/6562403/i-dont-understand-wl-rpath-wl

Using -Wl,-rpath,. (2)

- the -Wl,xxx option for gcc passes
  a comma-separated list of tokens
  as a space-separated list of arguments
  to the linker (ld)

- to pass ld aaa bbb ccc (space separated)
  gcc -Wl,aaa,bbb,ccc (comma separated)

- to pass ld -rpath . (space separated)
  gcc -Wl,-rpath,. (comma separated)

https://stackoverflow.com/questions/6562403/i-dont-understand-wl-rpath-wl

Using -Wl,-rpath,. (3)

- alternatively, repeat instances of `-Wl` can be specified
- to pass `ld aaa bbb ccc` (space separated)
  `gcc -Wl,aaa -Wl,bbb -Wl,ccc` (repeated instances)
  - there is no comma between `-Wl,aaa` and the second `-Wl,bbb` but there is space
- thus, to pass `ld -rpath .`
  - `gcc -Wl,-rpath,.` (comma separated)
  - `gcc -Wl,-rpath -Wl,.` (repeated instances)

https://stackoverflow.com/questions/6562403/i-dont-understand-wl-rpath-wl

Using -Wl,-rpath,. (4)

- can remove the comma by using =

  `gcc -Wl,-rpath=.`
  - arguably more readable than adding extra commas
  - exactly what gets passed to `ld`

- thus, to pass `ld -rpath .`
  - `gcc -Wl,-rpath,.` (comma separated)
  - `gcc -Wl,-rpath -Wl,.` (repeated instances)
  - `gcc -Wl,-rpath=.` (using = instead of ,)

https://stackoverflow.com/questions/6562403/i-dont-understand-wl-rpath-wl

Using -Wl,-rpath,. (5)

- You may need to specify the -L option as well

  ```
  -Wl,-rpath,/path/to/foo -L/path/to/foo -lbaz
  ```

  or you may end up with an error like

  ```
  ld:  cannot find -lbaz
  ```

https://stackoverflow.com/questions/6562403/i-dont-understand-wl-rpath-wl