

Link 5A Library Search using RPATH / RUNPATH

Young W. Lim

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"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`

- ① Using `-rpath-link` and `-rpath`
- ② Using `-Wl,-rpath,.`

- What is RPATH / RUNPATH
- Dependency related entries of the `.dynamic` section

What is RPATH / RUNPATH (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, i.e., libbar.so

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

What is RPATH / RUNPATH (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 are searched)
 - 4 **/etc/ld.so.conf**

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

What is RPATH / RUNPATH (3)

① RPATH

- a list of directories which is linked into the **executable**
- ignored if **RUNPATH** is present (**RPATH** is deprecated)

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 / RUNPATH (4)

- different reasons for needs for other directories to be searched than the builtin ones
 - ① a user may install a library *privately* into his *home directory*, e.g. `~/lib/`
 - ② there may be different *versions* of the same library installed, e.g. `/opt/kde3/lib/libkdecore.so` and `/opt/kde4/lib/libkdecore.so`

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

What is RPATH / RUNPATH (5)

- 1 a user may install a library *privately* into his *home directory*, e.g. `~/lib/`
- in this case, `LD_LIBRARY_PATH` can be set
`export LD_LIBRARY_PATH=$HOME/lib:$LD_LIBRARY_PATH`

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

What is RPATH / RUNPATH (6)

- 2 there may be different *versions* of the same library installed, e.g. `/opt/kde3/lib/libkdecore.so` and `/opt/kde4/lib/libkdecore.so`
- cases for some programs `/opt/kde3/lib` has to be searched and for other applications `/opt/kde4/lib` has to be searched, but never both directories
- the only way to have an executable-dependent library search path is by using **RPATH** (deprecated) or **RUNPATH** (not always supported)

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

Dependency related entries of the `.dynamic` section

- 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
-

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-1>

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>

- Handling *direct* and *nested* dependencies
- Specifying `-L` and `-l` handles *direct* dependencies
- Specifying `-rpath-link` handles *nested* dependencies
- `-rpath-link` v.s. `-rpath`
- `-rpath-link` does not create `RUNPATH` / `RPATH` entries
- `-rpath` creates `RUNPATH` / `RPATH` entries
- `-rpath-link` in `bfd` and `gold` linkers
- `bfd ld` and `-rpath-link`
- `gold ld` and `-rpath-link`

Handling *direct* and *nested* dependencies

- *direct dependency* must be handled by specifying `-L` and `-l`
- *nested dependencies* can be handled by specifying `-rpath-link` or `-rpath`

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

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

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

-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-1>

-rpath-link makes only a successful linkage

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

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

<https://unix.stackexchange.com/questions/22926/where-do-executables-look-for-shared-libraries>

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

`-rpath-link` does not create `RUNPATH` / `RPATH` entries

- there are many other ways to specify the **runtime search path**
- `-rpath-link=dir` does not give any information of **runtime search path**
 - does not creates `RUNPATH`
 - does not creates `RPATH`
 - therefore, for a *successful execution*, explicit specification of **runtime search path** may be needed.

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

`-rpath` does create `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-1>

`-rpath-link` in `bfd` and `gold` linkers

	<code>bfd ld</code>	<code>gold ld</code>
<code>-rpath-link</code>	(0)	(X) ignored
<code>DT_NEEDED</code>	(0)	(X) not used

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

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-l>

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-l>

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-link>

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

Using `-Wl,option`

- Pass *option* as an option to the linker.
- If *option* contains commas, it is split into multiple options at the commas.
- You can use this syntax to pass an argument to the option.
- For example, `-Wl,-Map,output.map` passes `-Map output.map` to the linker.
- When using the GNU linker, you can also get the same effect with `-Wl,-Map=output.map`

<https://gcc.gnu.org/onlinedocs/gcc/Link-Options.html>

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>

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-1>

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

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

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

Direct and nested dependencies of a binary

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

Single Directory for example binaries

binaries	compile time	run time
<code>prog</code>	.	.
<code>libfoobar.so</code>	.	.
<code>libfoo.so</code>	.	.
<code>libbar.so</code>	.	.

- all binaries are in the current directory `.`

Multiple Directories for example binaries (1)

binaries	compile time	run time A	run time B
prog	.	.	.
libfoobar.so	./lib	./librun	./librun
libfoo.so	./lib2	./lib2	./librun
libbar.so	./lib2	./lib2	./librun

Multiple Directories for example binaries (2)

directories	compile time	run time A	run time B
.	prog	prog	prog
./lib	libfoobar.so		
./lib2	libfoo.so libbar.so	libfoo.so libbar.so	
./librun		libfoobar.so	libfoobar.so libfoo.so libbar.so

Four methods

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

	for direct dependencies	for nested dependencies
Method 1	<code>-L d_direct -l direct</code>	<code>-L d_nest -l nest</code>
Method 2	<code>-L d_direct -l direct</code>	<code>-rpath-link d_nest</code>
Method 3	<code>-L d_direct -l direct</code>	<code>-rpath d_nest</code>
Method 4	<code>-L d_direct -l direct</code>	<code>-rpath d_direct</code>

Specifying dependencies and search paths (1)

	dependencies	link time search paths	runtime search paths
<code>-l</code>	<input type="radio"/>		
<code>-L</code>		<input type="radio"/>	
<code>-rpath-link</code>		<input type="radio"/>	
<code>-rpath</code>		<input type="radio"/>	<input type="radio"/>

Specifying dependencies and search paths (2)

Method 1	<code>-L d_direct -l direct -L d_nest -l nest</code>
Method 2	<code>-L d_direct -l direct -rpath-link d_nest</code>
Method 3	<code>-L d_direct -l direct -rpath d_nest</code>

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

Method 4	<code>-L d_direct -l direct -rpath d_direct</code>
----------	--

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

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>

- 1 Example source code and dependencies
- 2 `-rpath-link` examples
- 3 `-rpath` examples

Ex1 M1 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>

Ex1 M2 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-l>

Ex1 M4 summary using `-rpath`

- 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-l>

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 `-lfoo`
 - the *direct dependencies* of `libfoo.so` can be found by looking the **NEEDED** entries in the `.dynamic` section of `libfoo.so`
 - the directory `dir` will be searched for these *nested dependencies* of `prog`

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

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

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-l>

-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-l>

-rpath example (4)

- `prog` contains the **runtime search path** information for shared libraries that `prog` 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-1>

-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-l>

-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-linking>

-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` does 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-linking>

-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-l>

<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-l>

① More Exammples

TOC: 5. More Examples

Specifying dependencies and search paths (1)

binaries	<i>d_direct</i>	<i>direct</i>	<i>d_nest</i>	<i>nest</i>
<code>libfoobar.so</code>	<code>lib2</code>	<code>foo</code> <code>bar</code>		-
<code>prog</code>	<code>lib</code>	<code>foobar</code>	<code>lib2</code>	<code>foo</code> <code>bar</code>

d_direct directories for direct dependencies *direct* direct dependencies
d_nest directories for nested dependencies *nest* nested dependencies

Specifying dependencies and search paths (2)

- for `libfoobar.so`

	for direct dependencies	for nested dependencies
Method 1.	<code>-Llib2 -lfoo -lbar</code>	
Method 2.	<code>-Llib2 -lfoo -lbar</code>	
Method 3.	<code>-Llib2 -lfoo -lbar</code>	
Method 4.	<code>-Llib2 -lfoo -lbar</code>	<code>-Wl,-rpath=lib:librun</code>

- for `prog`

	for direct dependencies	for nested dependencies
Method 1.	<code>-Llib -lfoobar</code>	<code>-Llib2 -lfoo -lbar</code>
Method 2.	<code>-Llib -lfoobar</code>	<code>-Wl,-rpath-link=lib2</code>
Method 3.	<code>-Llib -lfoobar</code>	<code>-Wl,-rpath=lib2</code>
Method 4.	<code>-Llib -lfoobar</code>	<code>-Wl,-rpath=lib:librun</code>

Using `-rpath-link=dir` for dependencies

- 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`)

# Using `-rpath-link=dir` for link time search paths

- 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)
```



# Using `-rpath=dir` for dependencies

- 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`)

# Using `-rpath=dir` for link time search paths

- 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

# Using `-rpath=dir` for run time search paths

- `-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)
```

# 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
```

## 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
```

# Example2 summary using `-rpath` (like 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 `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
```