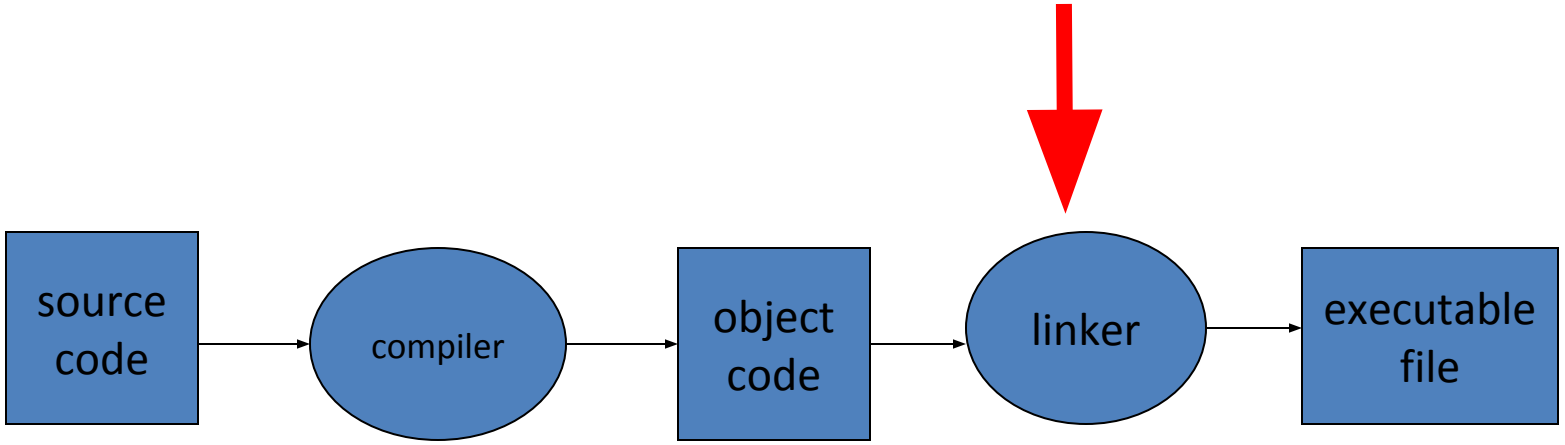
Dynamic Linking

CS 35L
Spring 2018 - Lab 3

Building an executable file

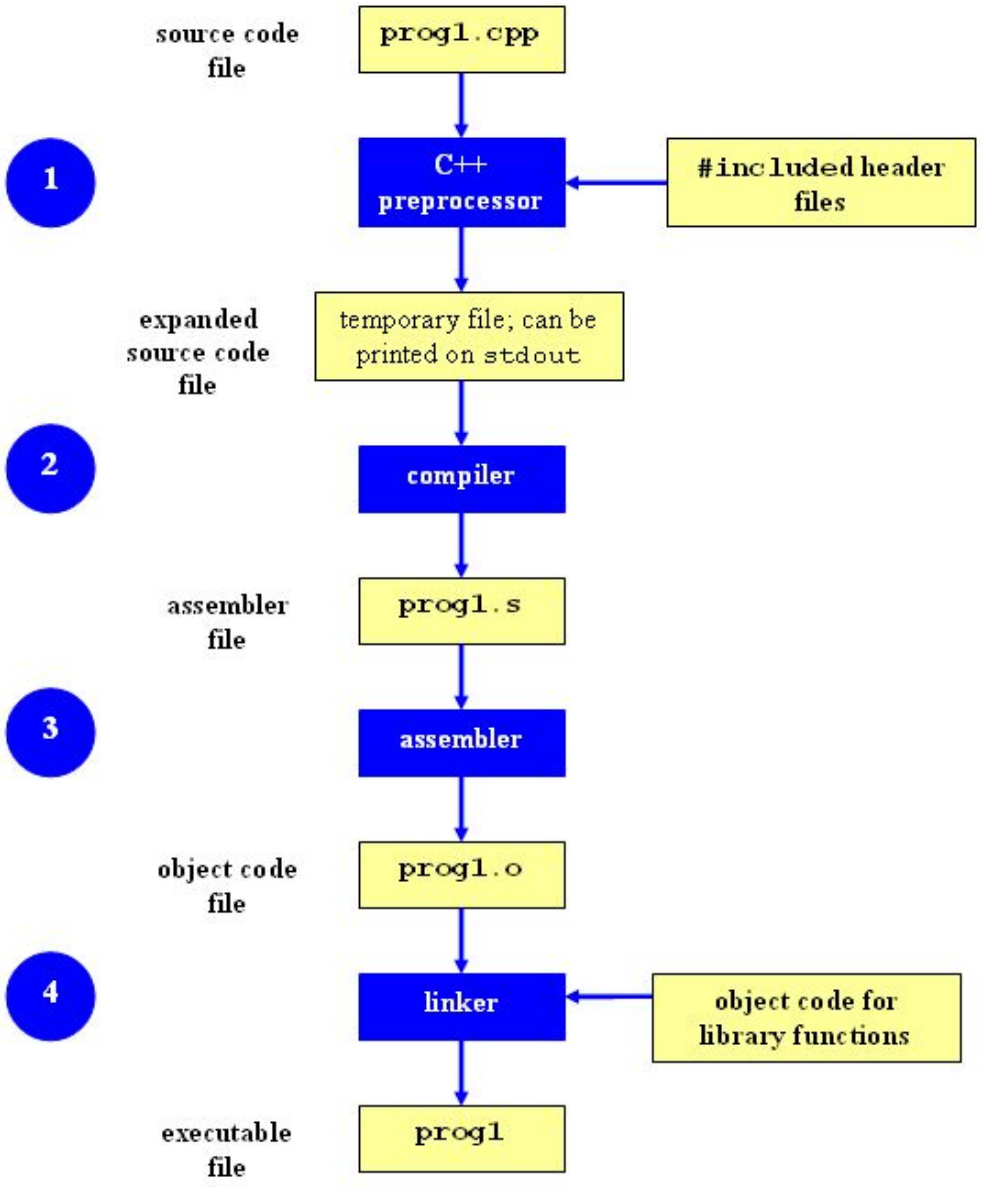


Translates programming language statements into cpu's machine-language instructions

Adjusts any memory references to fit the Operating System's memory model

Compilation Process

- Preprocessor
  - Expand Header includes, macros, etc
  - -E option in gcc to show the resulting code
- Compiler
  - Generates machine code for certain architecture
- Linker
  - Linkall modules together
  - Address resolution
- Loader
  - Loads the executable to memory to start execution

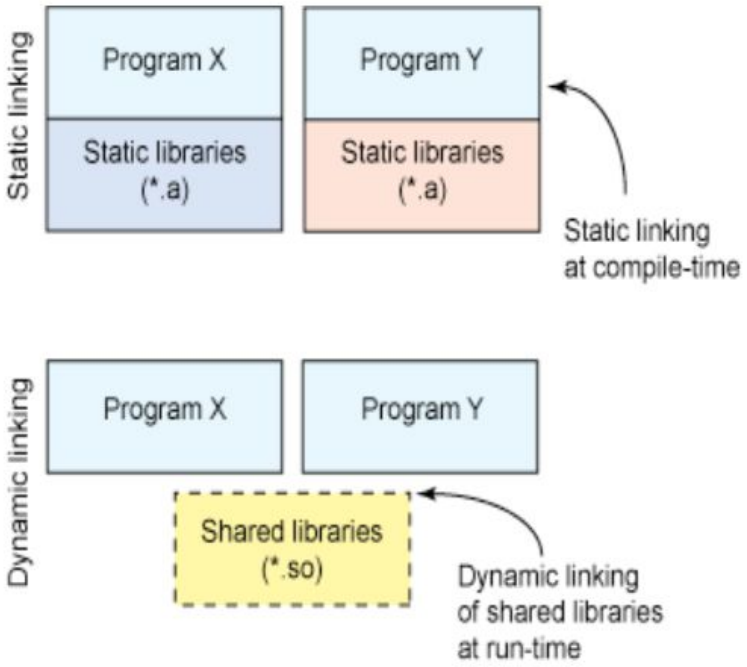


Linking and Loading

- Linker collects procedures and links them together object modules into one executable program
- Why isn't everything written as just one **big** program, saving the necessity of linking?
  - Efficiency: if just one function is changed in a 100K line program, why recompile the whole program? Just recompile the one function and relink.
  - Multiple-language programs
  - Other reasons?

Linux Libraries

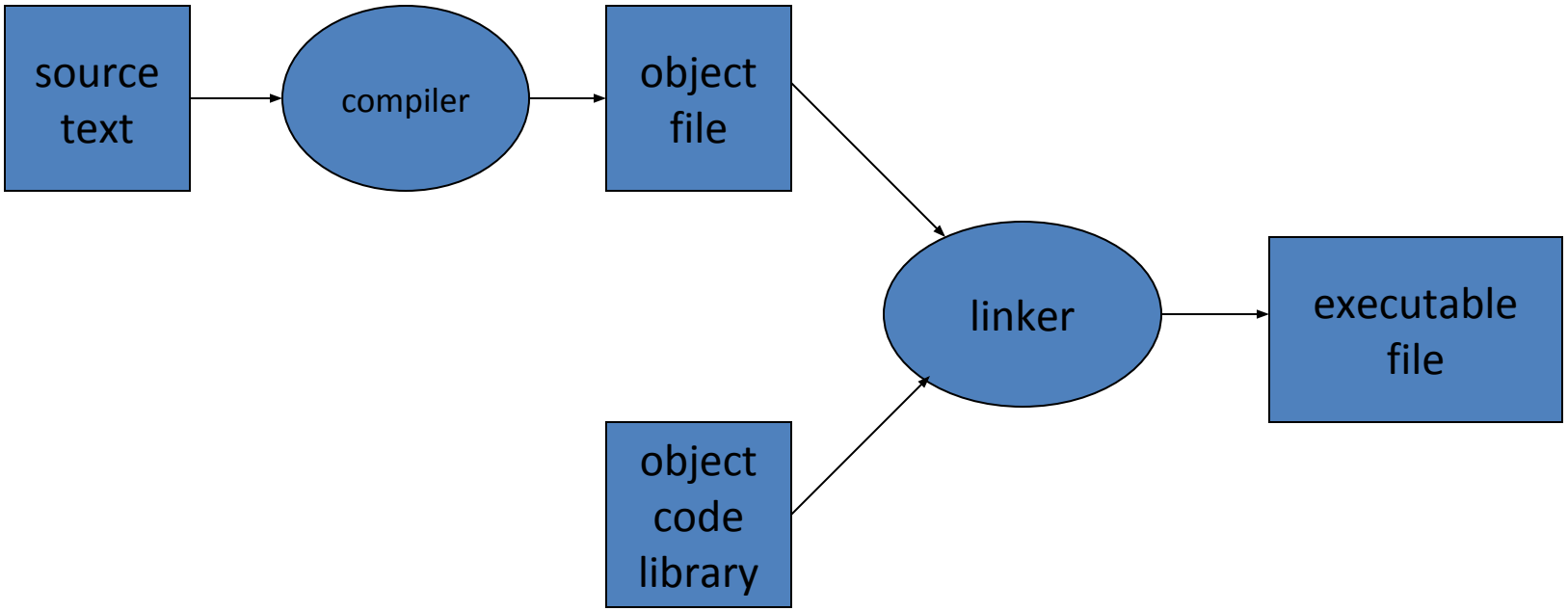
- **Static Library**
  - Statically linked
  - Every program has its own copy
  - More space in memory
  - Tied to a specific version of the lib. New version of the lib requires recompile of source code.
- **Shared Library (binding at run-time)**
  - Dynamically loaded/linking
    - **Dynamic Linking** – The OS loads the library when needed. A dynamic linker does the linking for the symbol used.
    - **Dynamic Loading** – The program "actively" loads the library it needs (DL API – dlopen(), dlclose()). More control to the program at run-time. Permits extension of programs to have new functionality.
  - Library is shared by multiple programs
  - Lower memory footprint
  - New version of the lib does not require a recompile of source code using the lib



Img Source : http://www.ibm.com/developerworks/library/l-dynamic-libraries/

Static Linking

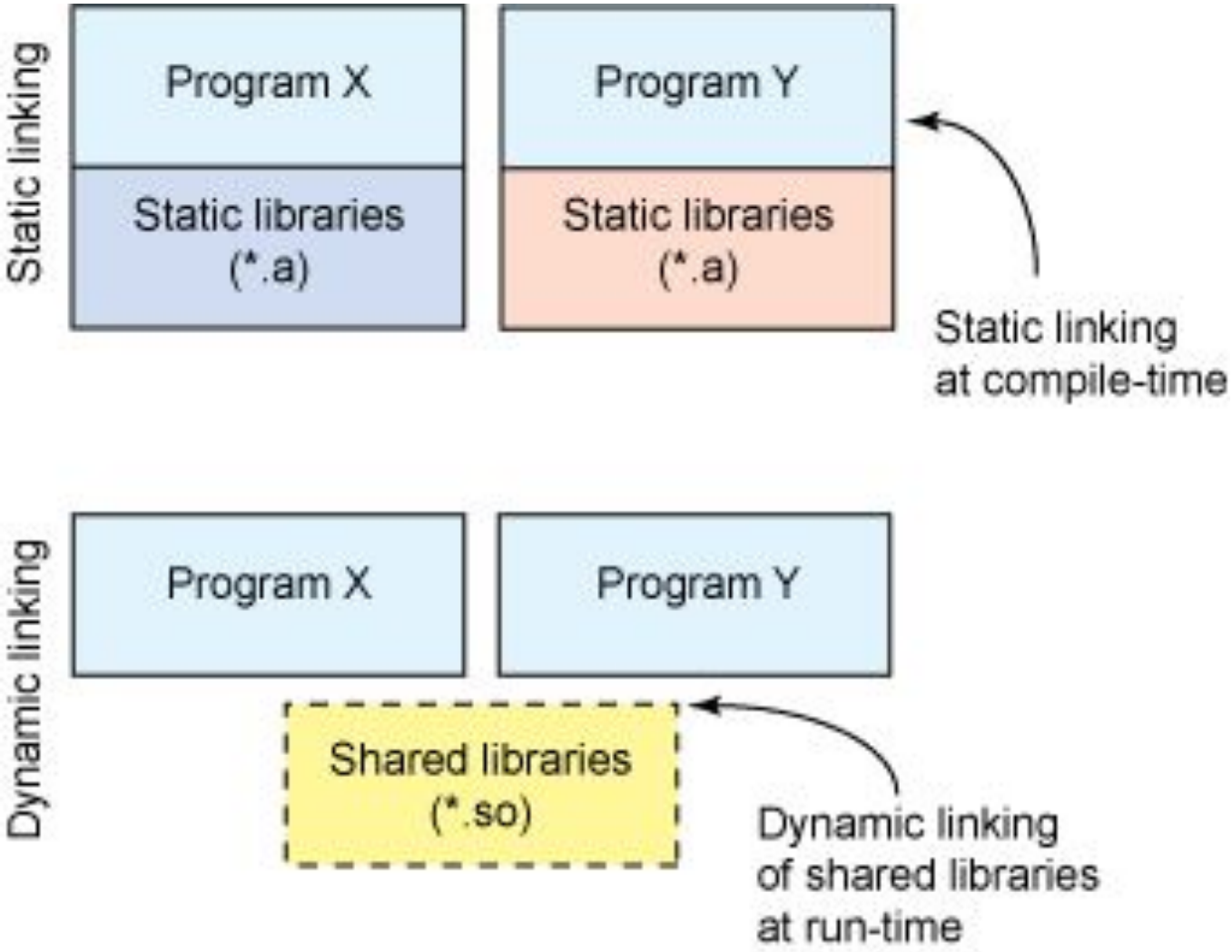
- Carried out only once to produce an executable file
- If static libraries are called, the linker will copy all the modules referenced by the program to the executable
- Static libraries are typically denoted by the .a file extension



A previously compiled collection of standard program functions

Dynamic Linking

- Allows a process to add, remove, replace or relocate object modules during its execution.
- If shared libraries are called:
  - Only copy a little reference information when the executable file is created
  - Complete the linking during loading time or running time
- Dynamic libraries are typically denoted by the .so (shared object) file extension
  - .dll (dynamically linked library) on Windows


Static linking
Program X
Static libraries
(*.a)
Program Y
Static libraries
(*.a)
Static linking
at compile-time
Dynamic linking
Program X
Program Y
Shared libraries
(*.so)
Dynamic linking
of shared libraries
at run-time

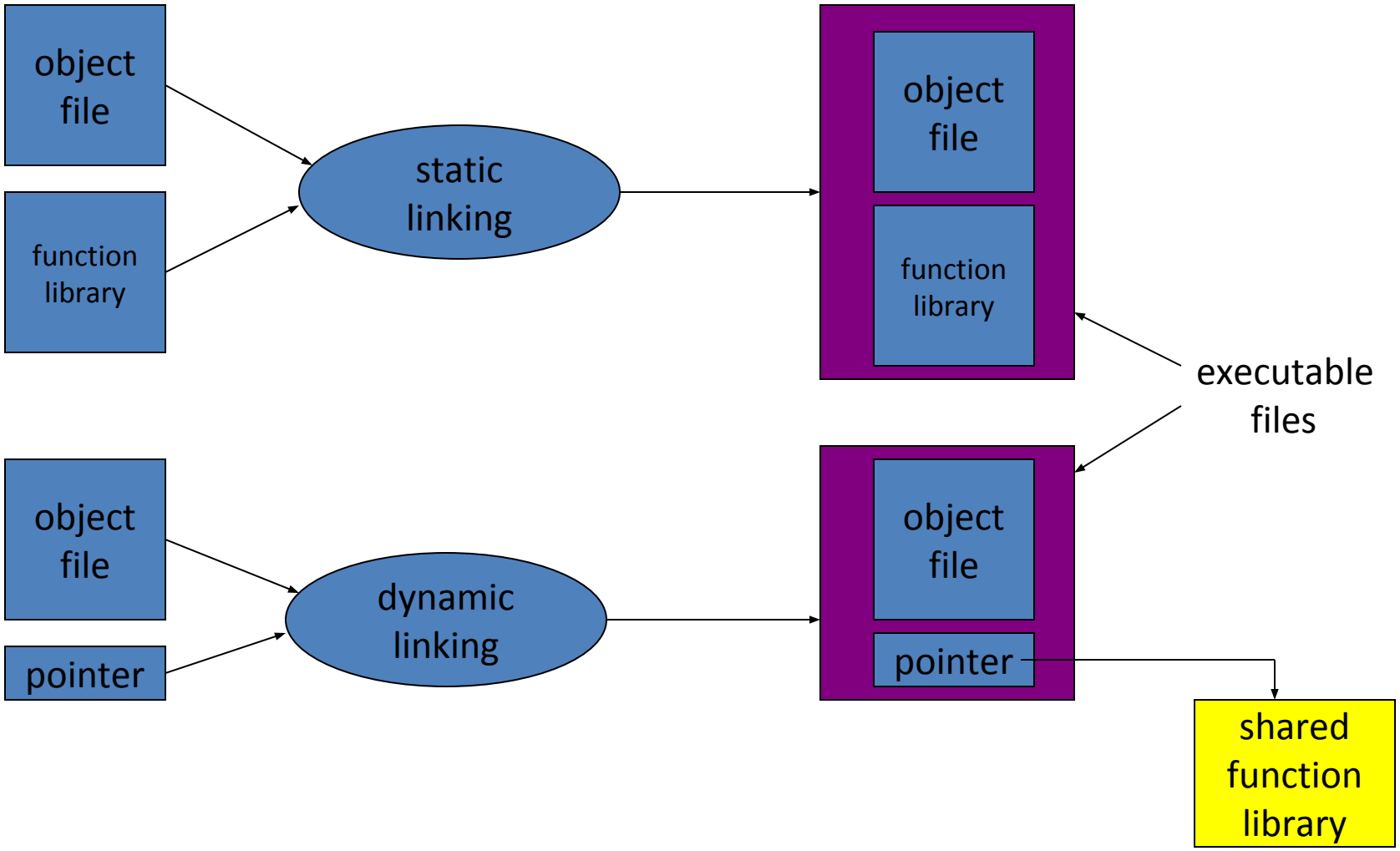
Dynamic linking

- Unix systems: Code is typically compiled as a *dynamic shared object* (DSO)
- Dynamic vs. static linking resulting size

```
$ gcc -static hello.c -o hello-static
$ gcc hello.c -o hello-dynamic
$ ls -l hello
     80 hello.c
  13724 hello-dynamic
    383 hello.s
1688756 hello-static
```

- If you are the sysadmin, which do you prefer?

Smaller is more efficient



Advantages of dynamic linking

- The executable is typically smaller
- When the library is changed, the code that references it does not usually need to be recompiled
- The executable accesses the .so at run time; therefore, multiple programs can access the same .so at the same time
  - Memory footprint amortized across all programs using the same .so

Disadvantages of dynamic linking

- Performance hit
  - Need to load shared objects (at least once)
  - Need to resolve addresses (once or every time)
  - Remember back to the system call assignment…
- What if the necessary dynamic library is missing?
- What if we have the library, but it is the wrong version?

How are libraries dynamically linked?

Table 1. The Dl API

Function	Description
dlopen	Makes an object file accessible to a program
dlsym	Obtains the address of a symbol within a `dlopen`ed object file
dlerror	Returns a string error of the last error that occurred
dlclose	Closes an object file

Dynamic loading

```
#include <stdio.h>
#include <dlfcn.h>

int main(int argc, char* argv[]) {
    int i = 10;
    void (*myfunc)(int *);
    void *dl_handle;
    char *error;

    dl_handle = dlopen("libmymath.so", RTLD_LAZY); //vs RTLD_NOW
    if (!dl_handle)
        { printf("dlopen() error - %s\n",dlerror()); return 1; }

    myfunc = dlsym(dl_handle, "mul5");
    error = dlerror();
    if (error != NULL)
        { printf("dlsym mul5 error - %s\n", error); return 1; }
    myfunc(&i);

    myfunc = dlsym(dl_handle, "add1");
    error = dlerror();
    if (error != NULL)
        { printf("dlsym add1 error - %s\n", error); return 1; }
    myfunc(&i);

    printf("i = %d\n", i);
    dlclose(dl_handle);
    return 0;
}
```

Copy this code into main.c

```
gcc main.c -o main -ldl
```

You will have to set the environment variable LD_LIBRARY_PATH to include a path that contai libmymath.so

GCC Flags

- `-fPIC`: Compiler directive to output position independent code, a characteristic required by shared libraries.
- `-lXXX`: Link with "`libXXX.so`"
  - Without `-L` to directly specify the path, `/usr/lib` is used.
- `-L`: At **compile** time, find `.so` from this path.
- `-Wl,rpath=.`: `-Wl` passes options to linker. `-rpath` at **runtime** finds `.so` from this path.
- `-c`: Generate object code from c code.
- `-shared`: Produce a shared object which can then be linked with other objects to form an executable.

Creating static and shared libs in GCC

- mymath.h

```
#ifndef _ MY_MATH_H

#define _ MY_MATH_H

void mul5(int *i);

void add1(int *i);

#endif
```

- mul5.c

```
#include "mymath.h"

void mul5(int *i)

{

  *i *= 5;

}
```

- add1.c

```
#include "mymath.h"

void add1(int *i)

{

  *i += 1;

}
```

- gcc -c mul5.c -o mul5.o
- gcc -c add1.c -o add1.o
- ar -cvq libmymath.a mul5.o add1.o → (static lib)
- gcc -shared -fpic -o libmymath.so mul5.o add1.o → (shared lib)

Attributes of Functions

- Used to declare certain things about functions called in your program
  - Help the compiler optimize calls and check code
- Also used to control memory placement, code generation options or call/return conventions within the function being annotated
- Introduced by the **attribute** keyword on a declaration, followed by an attribute specification inside double parentheses

Attributes of Functions

- `__attribute__ ((__constructor__))`
  - Is run when `dlopen()` is called
- `__attribute__ ((__destructor__))`
  - Is run when `dlclose()` is called
- Example:

```
__attribute__ ((__constructor__))
void to_run_before (void) {
   printf("pre_func\n");
}
```

Lab 8

- Write and build simple math program in C
  - compute cos(sqrt(3.0)) and print it using the printf format "%.17g"
  - Use `ldd` to investigate which dynamic libraries your hello world program loads
  - Use `strace` to investigate which system calls your hello world program makes
- Use "`ls /usr/bin | awk 'NR%101==SID%101'`" to find +-23 linux commands to use `ldd` on
  - Record output for each one in your log and investigate any errors you might see
  - From all dynamic libraries you find, create a sorted list
    - Remember to remove the duplicates!

Lab 8 hint

```
#!/bin/bash

for x in "$(ls /usr/bin | awk \
'NR%101==your_uid%101' $1)"; do
  y=`which $x`
  ldd $y
done
```

example run, unique sort, need to omit addresses at end:

```
./ldd_run | grep so | sort -u
```

Homework 8

- Split `randall.c` into 4 separate files
- Stitch the files together via static and dynamic linking to create the program
- `randmain.c` must use *dynamic loading, dynamic linking* to link up with `randlibhw.c` and `randlibsw.c` (using `randlib.h`)
- Write the `randmain.mk` makefile to do the linking

Homework 8

- randall.c outputs N random bytes of data
  - Look at the code and understand it
    - Helper functions that check if hardware random number generator is available, and if it is, generates number
      - Hw RNG exists if RDRAND instruction exists
      - Uses cpuid to check whether CPU supports RDRAND (30^{th} bit of ECX register is set)
    - Helper functions to generate random numbers using software implementation (/dev/urandom)
    - main function
      - Checks number of arguments (name of program, N)
      - Converts N to long integer, prints error message otherwise
      - Uses helper functions to generate random number using hw/sw

Homework 8

- Divide randall.c into dynamically linked modules and a main program
  - We don’t want resulting executable to load code that it doesn't need (dynamic loading)
    - **randcpuid.c**: contains code that determines whether the current CPU has the RDRAND instruction. Should include randcpuid.h and include interface described by it.
    - **randlibhw.c**: contains the hardware implementation of the random number generator. Should include randlib.h and implement the interface described by it.
    - **randlibsw.c**: contains the software implementation of the random number generator. Should include randlib.h and implement the interface described by it.
    - **randmain.c**: contains the main program that glues together everything else. Should include randcpuid.h (as the corresponding module should be linked statically) but not randlib.h (as the corresponding module should be linked after main starts up). Depending on whether the hardware supports the RDRAND instruction, this main program should dynamically load the hardware-oriented or software-oriented implementation of randlib.

Useful Resources

- Useful overview of dynamic libraries: Click here
- Man page for DL API: Click here
- www.ibm.com/developerworks/library/l-dynamic-libraries/
- www.ibm.com/developerworks/library/l-lpic1-102-3/
- tldp.org/HOWTO/Program-Library-HOWTO/index.html
- www.yolinux.com/TUTORIALS/LibraryArchives-StaticAndDynamic.html
- man7.org/linux/man-pages/man7/vdso.7.html