Compilation, Linking, Loading

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Review of last few lectures

Boot sequence: BIOS, boot-loader, kernel

- Boot sequence: Process world
  - kernel->init -> many forks+execs() -> ....
- Hardware interrupts, system calls, exceptions
- Event driven kernel
- System calls
  - Fork, exec, ... open, read, ...

What are compiler, assembler, linker and loader, and C library

System Programs/Utilities

Most essential to make a kernel really usable

Standard C Library

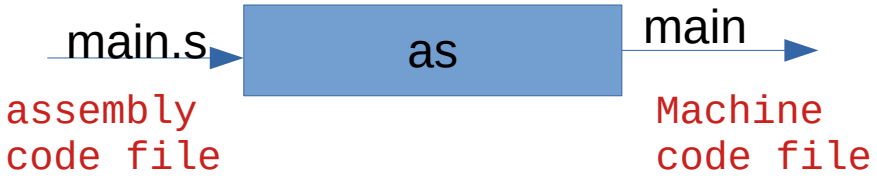
- A collection of some of the most frequently needed functions for C programs
  - scanf, printf, getchar, system-call wrappers (open, read, fork, exec, etc.), …
- An machine/object code file containing the machine code of all these functions
  - Not a source code! Neither a header file. More later.
- Where is the C library on your computer?
  - /usr/lib/x86_64-linux-gnu/libc-2.31.so

Compiler

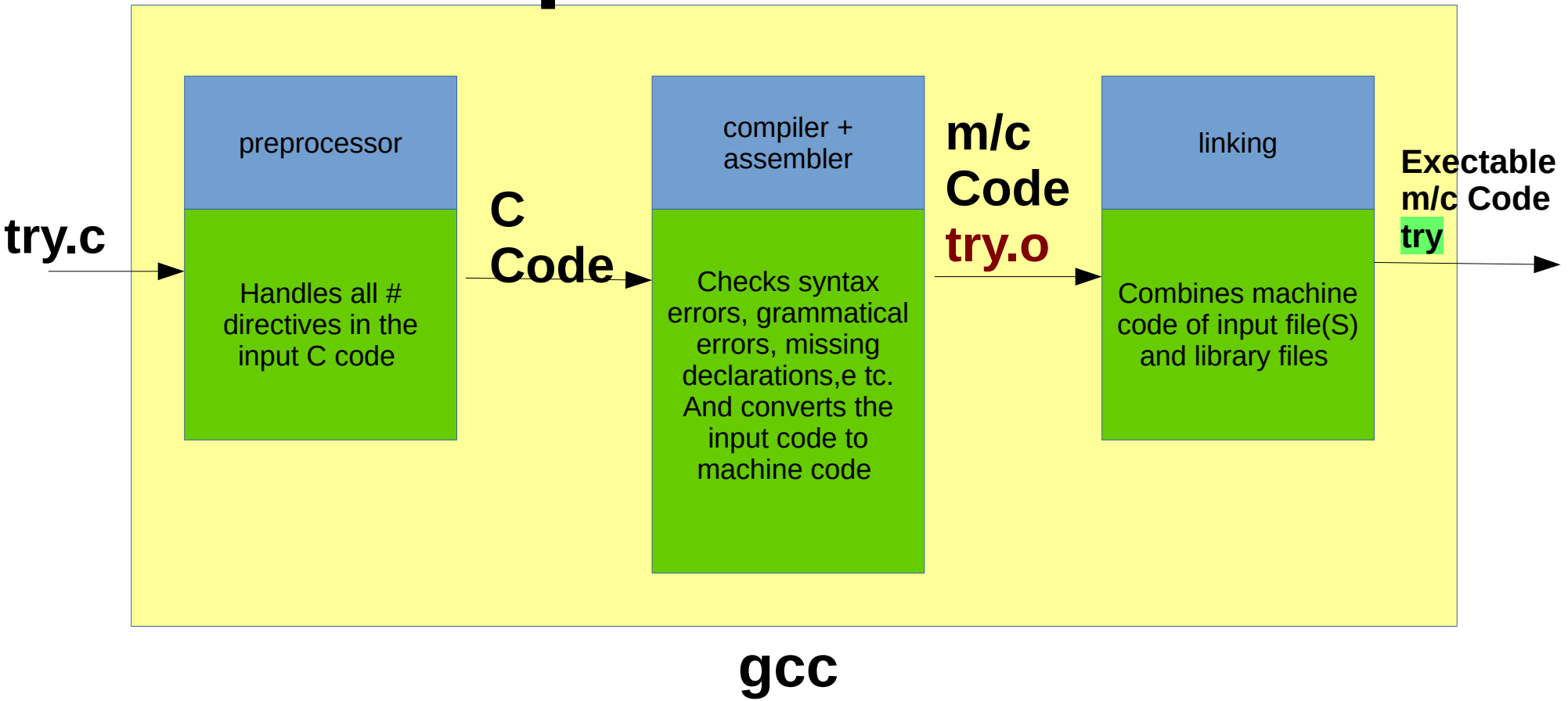
- application program, which converts one (programming) language to another
  - Most typically compilers convert a high level language like C, C++, etc. to Machine code language
- E.g. GCC /usr/bin/gcc
  - Usage: e.g.
  - $ gcc main.c -o main
  - Here main.c is the C code, and "main" is the object/machine code file generated
- Input is a file and output is also a file.
- Other examples: g++ (for C++), javac (for java)

Assembler

- application program, converts assembly code into machine code
- What is assembly language?
  - Human readable machine code language.
- E.g. x86 assembly code
  - mov 50, r1
  - add 10, r1
  - mov r1, 500
- Usage. eg..
  - $ as something.s -o something



Compilation Process



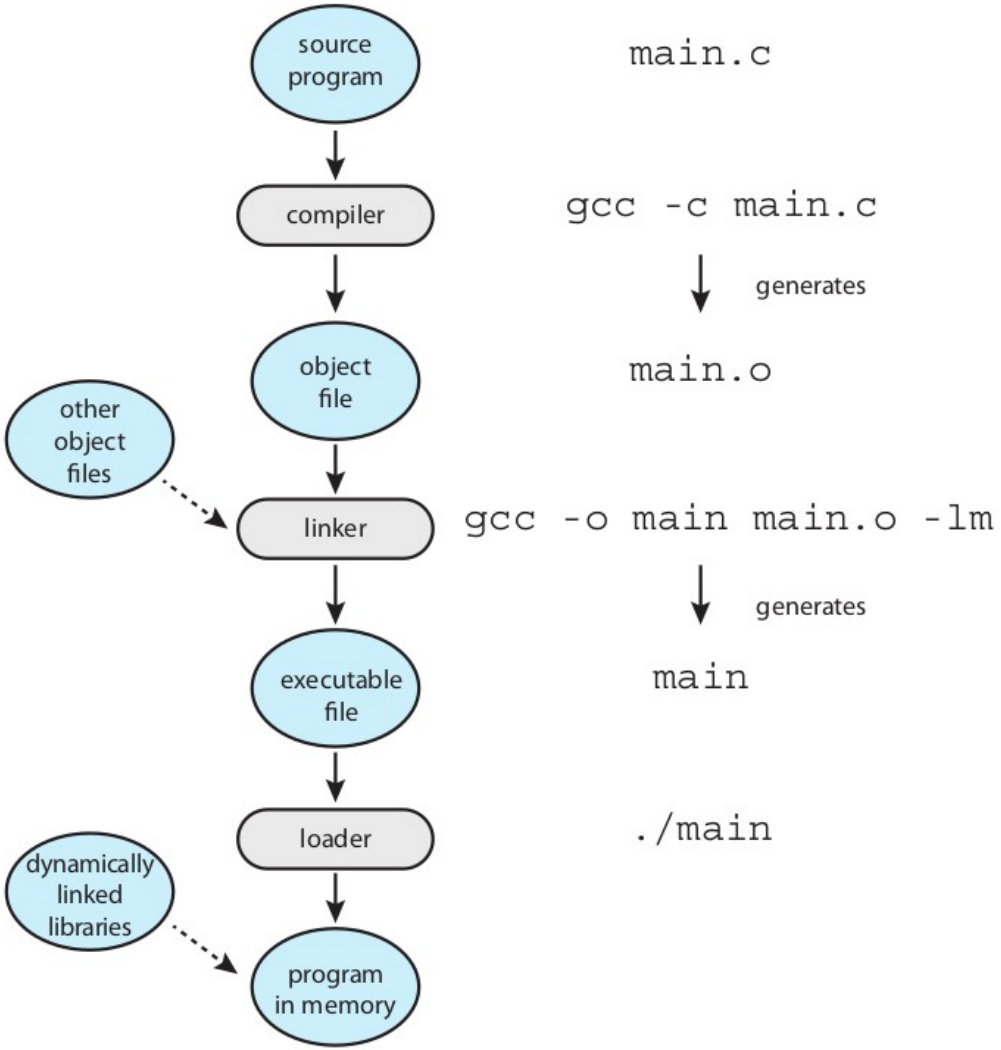


Figure 2.11 The role of the linker and loader.

- From the textbook

Example

try.c

```
#include <stdio.h>
#define MAX 30
int f(int, int);
int main() {
        int i, j, k;
        scanf("%d%d", &i, &j);
        k = f(i, j) + MAX;
        printf("%d\n", k);
        return 0;
}
```

f.c

```
int g(int);
#define ADD(a, b) (a + b)
int f(int m, int n) {
        return ADD(m,n) + g(10);
}
```

g.c

```
int g(int x) {
        return x + 10;
}
```

Try these commands, observe the output/errors/warnings, and try to understand what is happening

```
$ gcc try.c
$ gcc -c try.c
$ gcc -c f.c
$ gcc -c g.c
$ gcc try.o f.o g.o -o try
$ gcc -E try.c
$ gcc -E f.c
```

More about the steps

- Pre-processor
  - #define ABC XYZ
    - cut ABC and paste XYZ
  - # include <stdio.h>
    - copy-paste the file stdio.h
    - There is no CODE in stdio.h, only typedefs, #includes, #define, #ifdef, etc.
- Linking
  - Normally links with the standard C-library by default
  - To link with other libraries, use the -l option of gcc
    - `cc main.c -lm -lncurses -o main  # links with libm.so and`

Using gcc itself to understand the process

- Run only the preprocessor
  - cc -E test.c
  - Shows the output on the screen
- Run only till compilation (no linking)
  - cc -c test.c
  - Generates the “test.o” file , runs compilation + assembler
  - gcc -S main.c
  - One step before machine code generation, stops at assembly code
- Combine multiple .o files (only linking part)

Linking steps

- Linker is an application program
  - On linux, it's the "ld" program
  - E.g. you can run commands like $ ld a.o b.o -o c.o
  - Normally you have to specify some options to ld to get a proper executable file.
- When you run gcc
  - $ cc main.o f.o g.o -o try
  - the CC will internally invoke "ld" . ld does the job of linking

Linking steps

- The resultatnt file "try" here, will contain the codes of all the functions and linkages also.
- **What is linking?**
  - "connecting" the call of a function with the code of the function.
- What happens with the code of printf()?
  - The linker or CC will automatically pick up code from the libc.so.6 file for the functions.

Executable file format

- An executable file needs to execute in an environment created by OS and on a particular processor
  - Contains machine code + other information for OS
  - Need for a structured-way of storing machine code in it
- Different OS demand different formats
  - Windows: PE, Linux: ELF, Old Unixes: a.out, etc.

- ELF : The format on Linux.
- Try this
  - $ file */bin/ls*
  - $ file /usr/lib/x86_64-linux-gnu/libc-2.31.so

Exec() and ELF

- When you run a program
  - $ ./try
  - Essentially there willl be a fork() and exec("./try", ...")
  - So the kernel has to read the file "./try" and understand it.
  - So each kernel will demand it's own object code file format.
  - Hence ELF, EXE, etc. Formats
- ELF is used not only for executable (complete machine code) programs, but also for partially compiled files e.g. main.o and library files like libc.so.6
- What is a.out?
  - "a.out" was the name of a format used on earleir Unixes.
  - It so happened that the early compiler writers, also created executable with default name 'a.out'

Utilities to play with object code files

- objdump
  - $ objdump -D -x /bin/ls
  - Shows all disassembled machine instructions and “headers”
- hexdump
  - $ hexdump /*bin/*ls
  - Just shows the file in hexadecimal
- readelf
  - Alternative to objdump
- ar
  - To create a “statically linked” library file
  - $ ar -crs libmine.a one.o two.o
- Gcc to create shared library
  - $ gcc hello.o -shared -o libhello.so
- To see how gcc invokes as, ld, etc; do this
  - $ gcc -v hello.c -o hello
  - /* https://stackoverflow.com/questions/1170809/how-to-get-gcc-linker-command */

Linker, Loader, Link-Loader

- Linker or linkage-editor or link-editor
  - The “ld” program. Does linking.
- Loader
  - The exec(). It loads an executable in the memory.
- Link-Loader
  - Often the linker is called link-loader in literature. Because where were days when the linker and loader’s jobs were quite over-lapping.

Static, dynamic / linking, loading

- Both linking and loading can be
  - Static or dynamic
  - More about this when we learn memory management
- An important fundamental:
  - memory management features of processor, memory management architecture of kernel, executable/object-code file format, output of linker and job of loader, are all interdependent and in-separable.
  - They all should fit into each other to make a system work
  - That’s why the phrase “system programs”

Cross-compiler

- Compiler on system-A, but generate object-code file for system-B (target system)
  - E.g. compile on Ubuntu, but create an EXE for windows
- Normally used when there is no compiler available on target system
  - see gcc -m option
- See https://wiki.osdev.org/GCC_Cross-Compiler