Operating System Concepts

Lecture 3: System Calls, Linking and Loading

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MWF 12:00-12:50 VVC 2 215

Today's class

- Hardware support
  - System calls
  - Protection
- Basics of compiling, linking, and loading
- OS structure
  - Examples

System calls… what are they?

- Definition: services provided by the kernel to application programs
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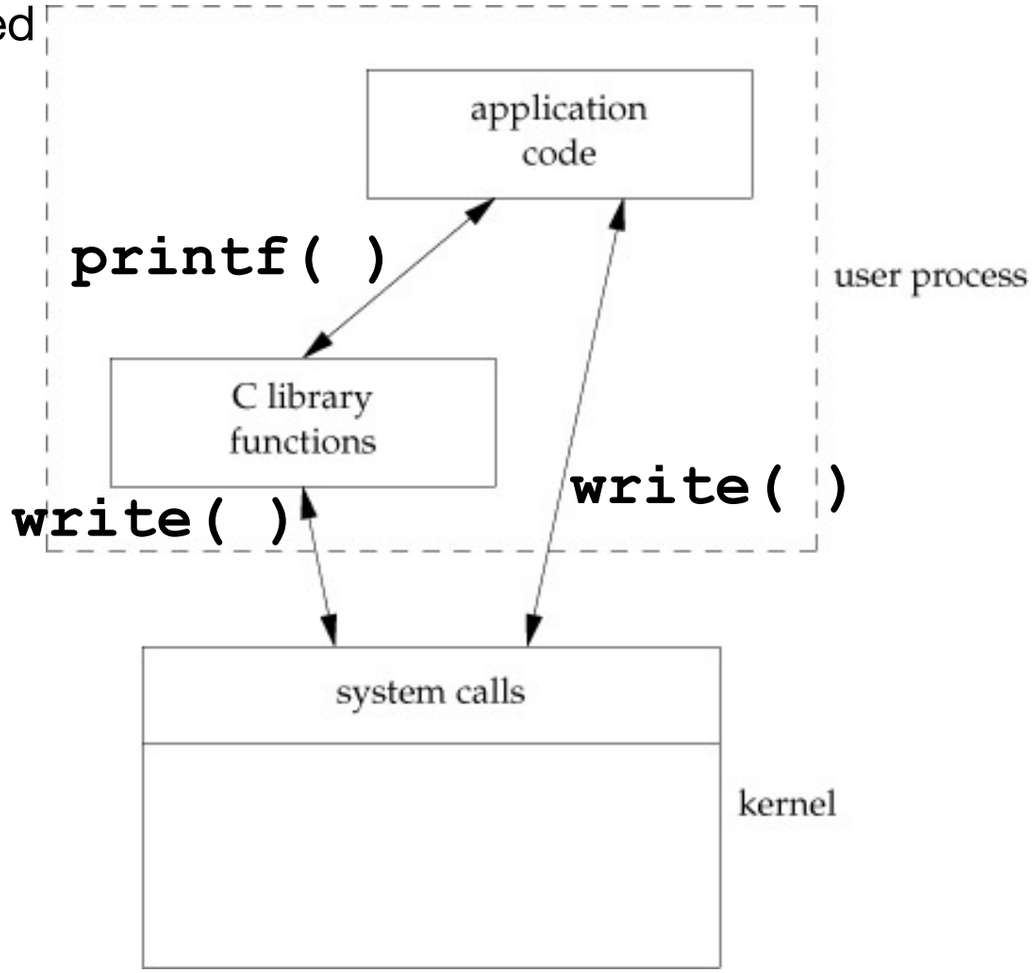

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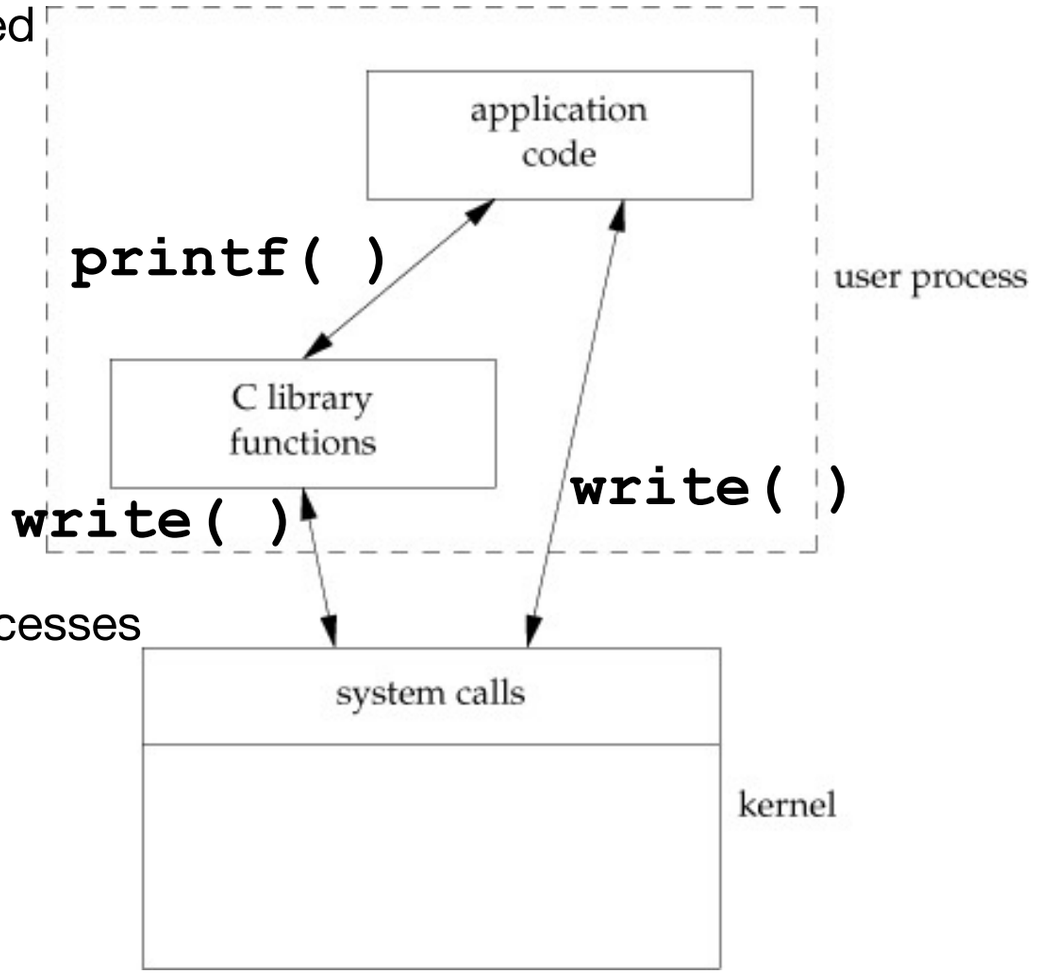
- System calls are necessary to
  - Access devices and files
  - Request memory
  - Set access permissions
  - Stop and start processes, and communicate with processes
  - Set a timer



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See Linux system calls here:
http://man7.org/linux/man-pages/man2/syscalls.2.html

Tracing system calls executed when you run an application

- use the `strace` command in Linux (see `strace` man page)

```
oardakan@ug01:~>strace pwd
execve("/bin/pwd", ["pwd"], [/* 40 vars */]) = 0
brk(NULL)                               = 0x10d9000
access("/etc/ld.so.nohwcap", F_OK)      = -1 ENOENT (No such file or directory)
access("/etc/ld.so.preload", R_OK)      = -1 ENOENT (No such file or directory)
open("/etc/ld.so.cache", O_RDONLY|O_CLOEXEC) = 3
fstat(3, {st_mode=S_IFREG|0644, st_size=349772, ...}) = 0
mmap(NULL, 349772, PROT_READ, MAP_PRIVATE, 3, 0) = 0x7f270431d000
close(3)                                = 0
access("/etc/ld.so.nohwcap", F_OK)      = -1 ENOENT (No such file or directory)
open("/lib/x86_64-linux-gnu/libc.so.6", O_RDONLY|O_CLOEXEC) = 3
read(3, "\177ELF\2\1\1\3\0\0\0\0\0\0\0\0\3\0>\0\1\0\0\0P\t\2\0\0\0\0\0"..., 832) = 832
fstat(3, {st_mode=S_IFREG|0755, st_size=1868984, ...}) = 0
mmap(NULL, 4096, PROT_READ|PROT_WRITE, MAP_PRIVATE|MAP_ANONYMOUS, -1, 0) = 0x7f270431c000
mmap(NULL, 3971488, PROT_READ|PROT_EXEC, MAP_PRIVATE|MAP_DENYWRITE, 3, 0) = 0x7f2703d84000
mprotect(0x7f2703f44000, 2097152, PROT_NONE) = 0
mmap(0x7f2704144000, 24576, PROT_READ|PROT_WRITE, MAP_PRIVATE|MAP_FIXED|MAP_DENYWRITE, 3, 0x1c0000) = 0x7f2704144000
mmap(0x7f270414a000, 14752, PROT_READ|PROT_WRITE, MAP_PRIVATE|MAP_FIXED|MAP_ANONYMOUS, -1, 0) = 0x7f270414a000
close(3)                                = 0
mmap(NULL, 4096, PROT_READ|PROT_WRITE, MAP_PRIVATE|MAP_ANONYMOUS, -1, 0) = 0x7f270431b000
mmap(NULL, 4096, PROT_READ|PROT_WRITE, MAP_PRIVATE|MAP_ANONYMOUS, -1, 0) = 0x7f270431a000
arch_prctl(ARCH_SET_FS, 0x7f270431b700) = 0
mprotect(0x7f2704144000, 16384, PROT_READ) = 0
mprotect(0x606000, 4096, PROT_READ)     = 0
mprotect(0x7f2704373000, 4096, PROT_READ) = 0
munmap(0x7f270431d000, 349772)          = 0
brk(NULL)                               = 0x10d9000
brk(0x10fa000)                          = 0x10fa000
open("/usr/lib/locale/locale-archive", O_RDONLY|O_CLOEXEC) = 3
fstat(3, {st_mode=S_IFREG|0644, st_size=2981280, ...}) = 0
mmap(NULL, 2981280, PROT_READ, MAP_PRIVATE, 3, 0) = 0x7f2703aac000
close(3)                                = 0
getcwd("/cshome/oardakan", 4096)        = 17
fstat(1, {st_mode=S_IFCHR|0620, st_rdev=makedev(136, 4), ...}) = 0
write(1, "/cshome/oardakan\n", 17/cshome/oardakan
)      = 17
close(1)                                = 0
close(2)                                = 0
exit_group(0)                           = ?
+++ exited with 0 +++
```

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- **Win32 API** is the standard API for Windows operating systems

Protection

- Hardware has a status bit that indicates the current operation mode
  - there could be more than two operation modes
    e.g., ARMv8 systems have seven modes
  - user applications run in the **user mode**
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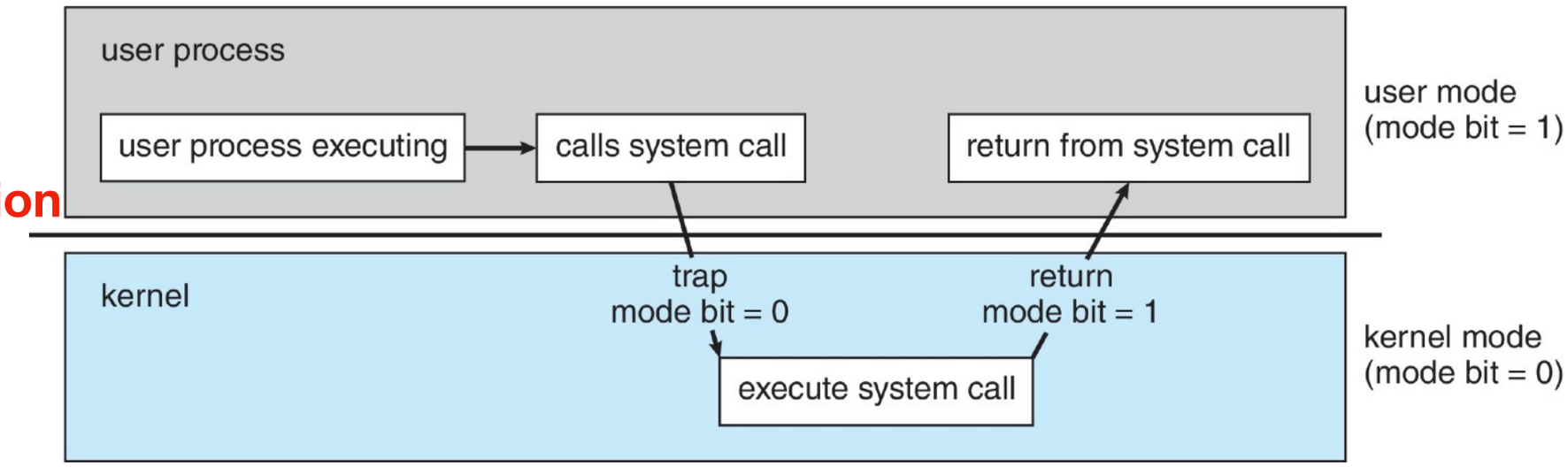
- invoking a system call allows a user program to run privileged instructions
- operation modes provide the means for protecting OS from errant users
  - the code could be buggy or malicious

crossing protection boundary



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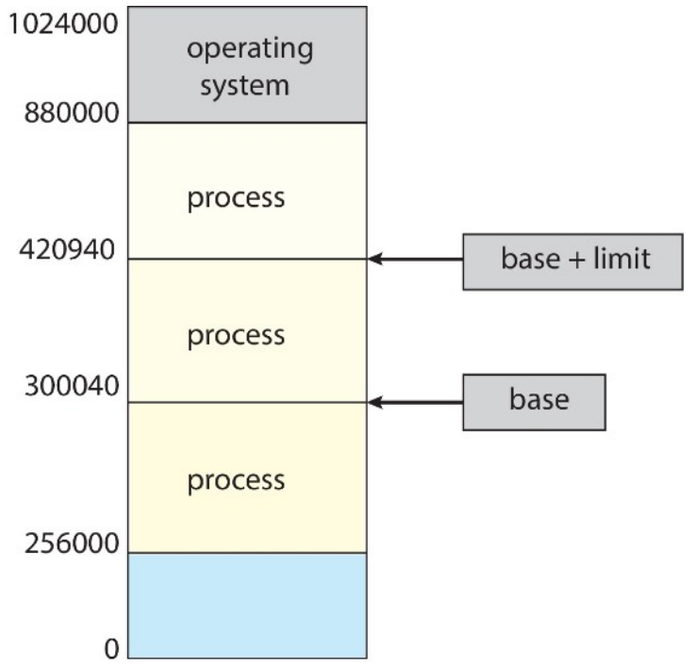
- the simplest technique is to use base and limit registers
  - base and limit registers are loaded by the OS before creating a process
  - base register holds the smallest legal physical memory address of the process
  - limit register holds the size of the memory allocated to a process
  - CPU checks each reference in user mode (instruction and data addresses) to ensure that it falls between base and base+limit



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- CPU is protected from being hogged using timer interrupts that occur at regular intervals (e.g., every 100 microseconds)
  - frequency is set by the kernel
  - yet another protection mechanism

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- interrupts can be temporarily deferred
  - it is crucial for implementing mutual exclusion

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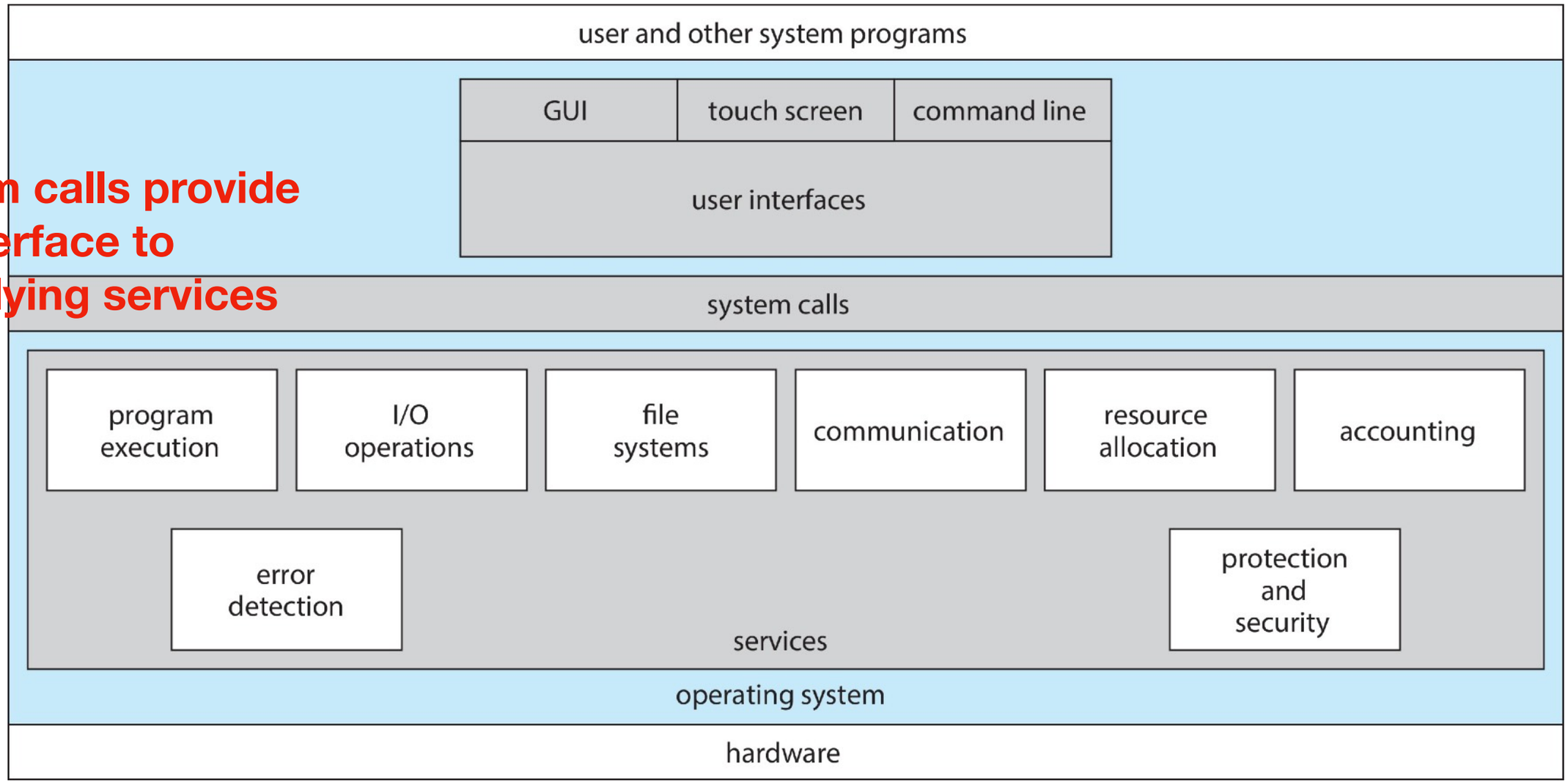
Interrupt Vector

Operating System services



system calls provide an interface to underlying services

- making the programming task easier and increasing the convenience of users
- ensuring the efficient operation of the system (i.e., resource allocation, logging, protection and security)

Summary

OS Services	Hardware Support
Interrupts	interrupt request lines, interrupt vector
System calls	trap vector
I/O	interrupt and memory mapping
Protection	operation modes, privileged instructions, base and limit registers, timer
Scheduling & accounting	timer
Synchronization	atomic operations
Virtual memory	MMU, translation look-aside buffer (TLB)

Running a user program

Program to Process

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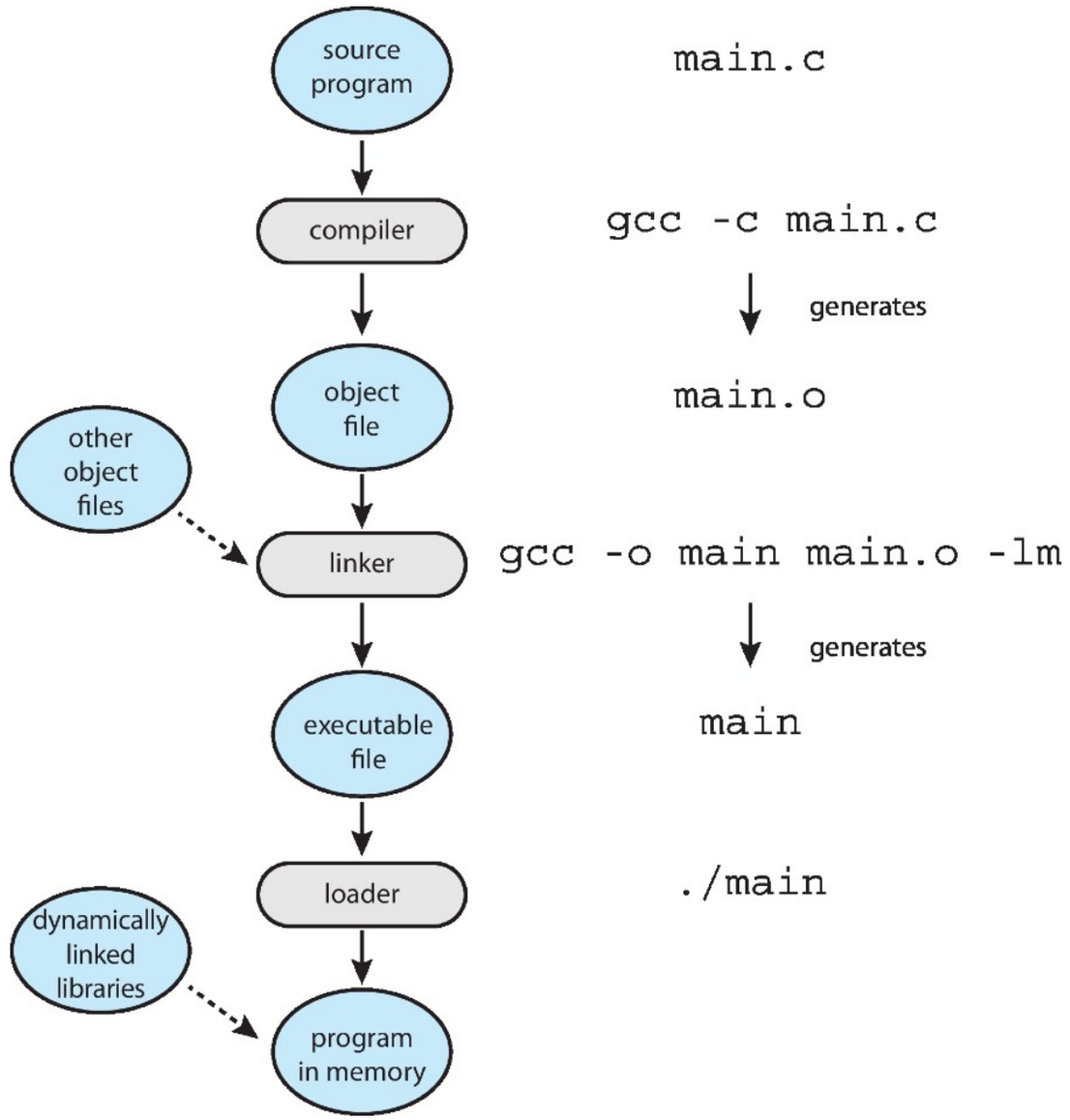
  - object files miss certain information, e.g., functions called from other files and libraries



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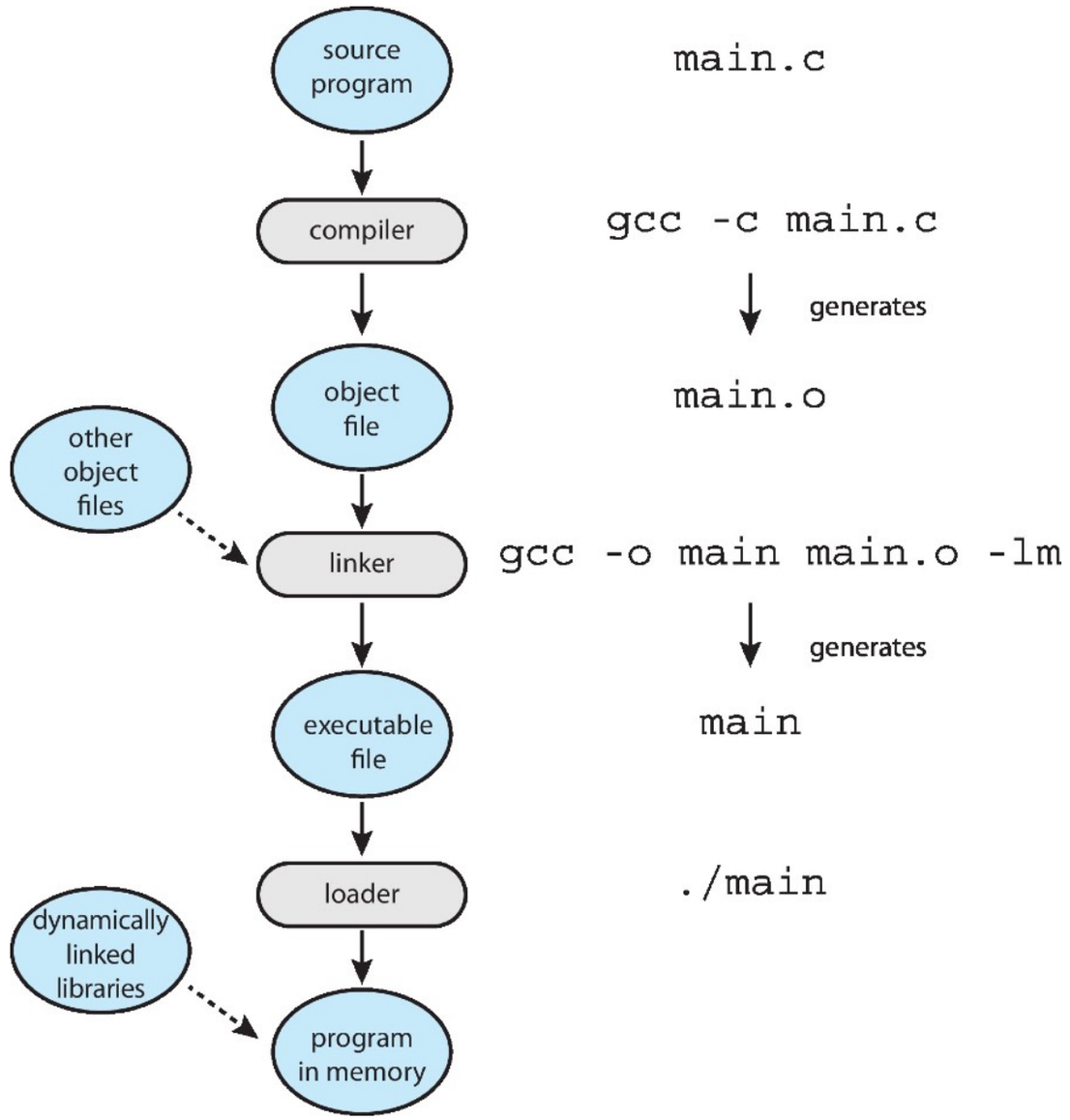

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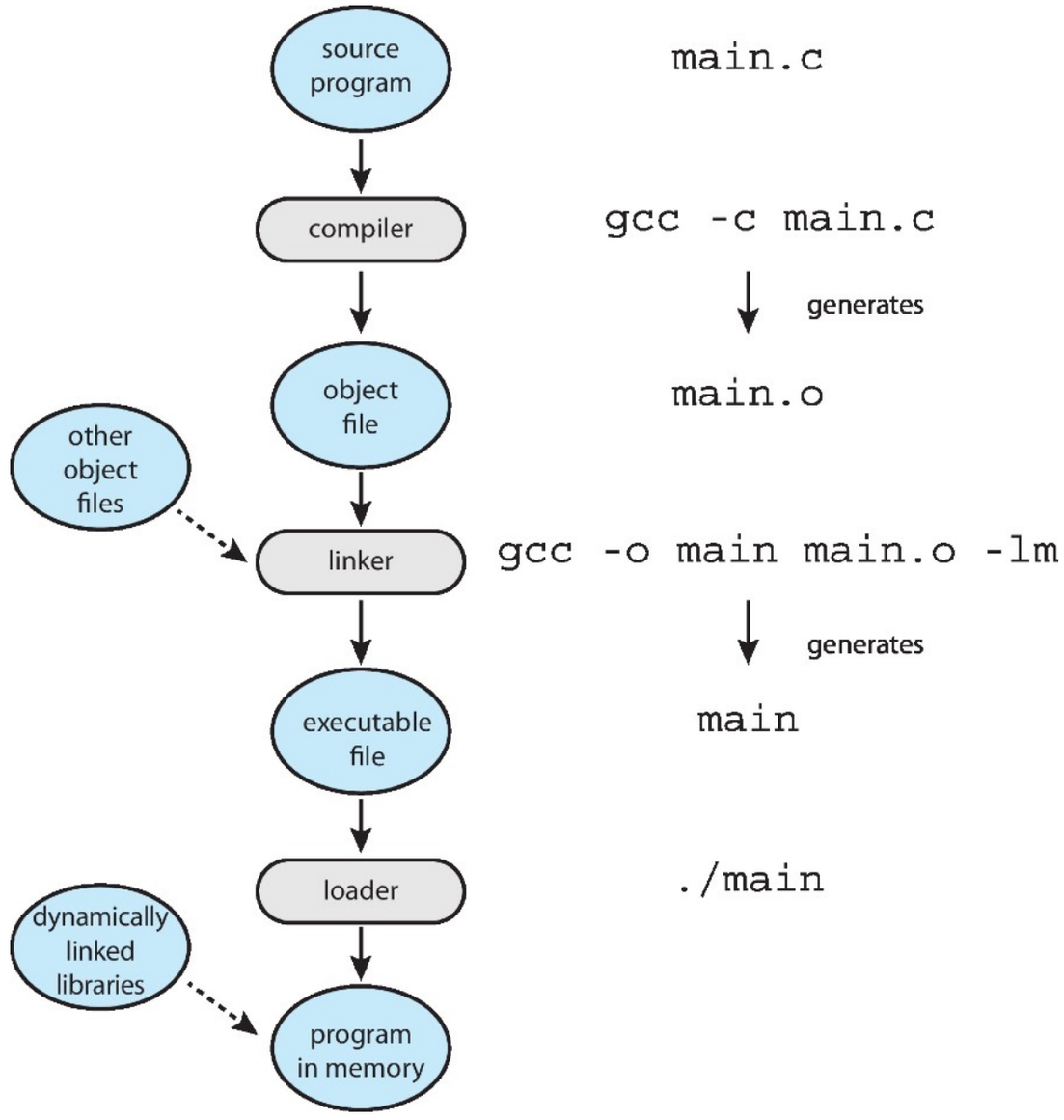
- Loading is the process of bringing this executable file into memory
  - the loader is executed when you enter the name of the executable file on the command line; this is done using `execve( )` system call
  - the loader sets up the process memory to contain code and data from executable
  - a library can be conditionally linked and loaded if it is required during the run time; this can be done using dynamically linked libraries (DLLs)



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- **ELF executable file** contains the address of the first instruction of the program (program's entry point: _start function)
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- the ELF header starts with a 4-byte magic string:
  - 0x7F followed by 0x45 0x4C 0x46 (ELF in ASCII)

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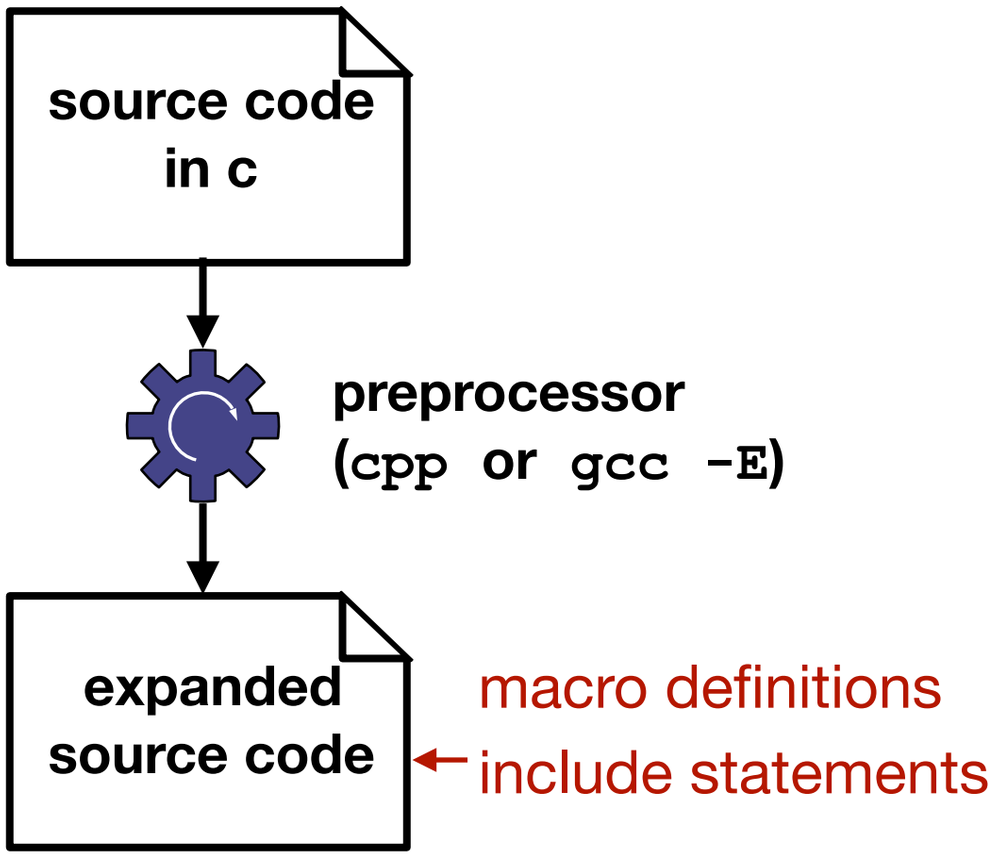
- **.rel.text** and **.rel.data** contain relocation information for functions and global variables that are referenced but not defined (external references)
  - linker modifies this section when combining the object files, resolving external references

Compiler, Linker and Loader in action



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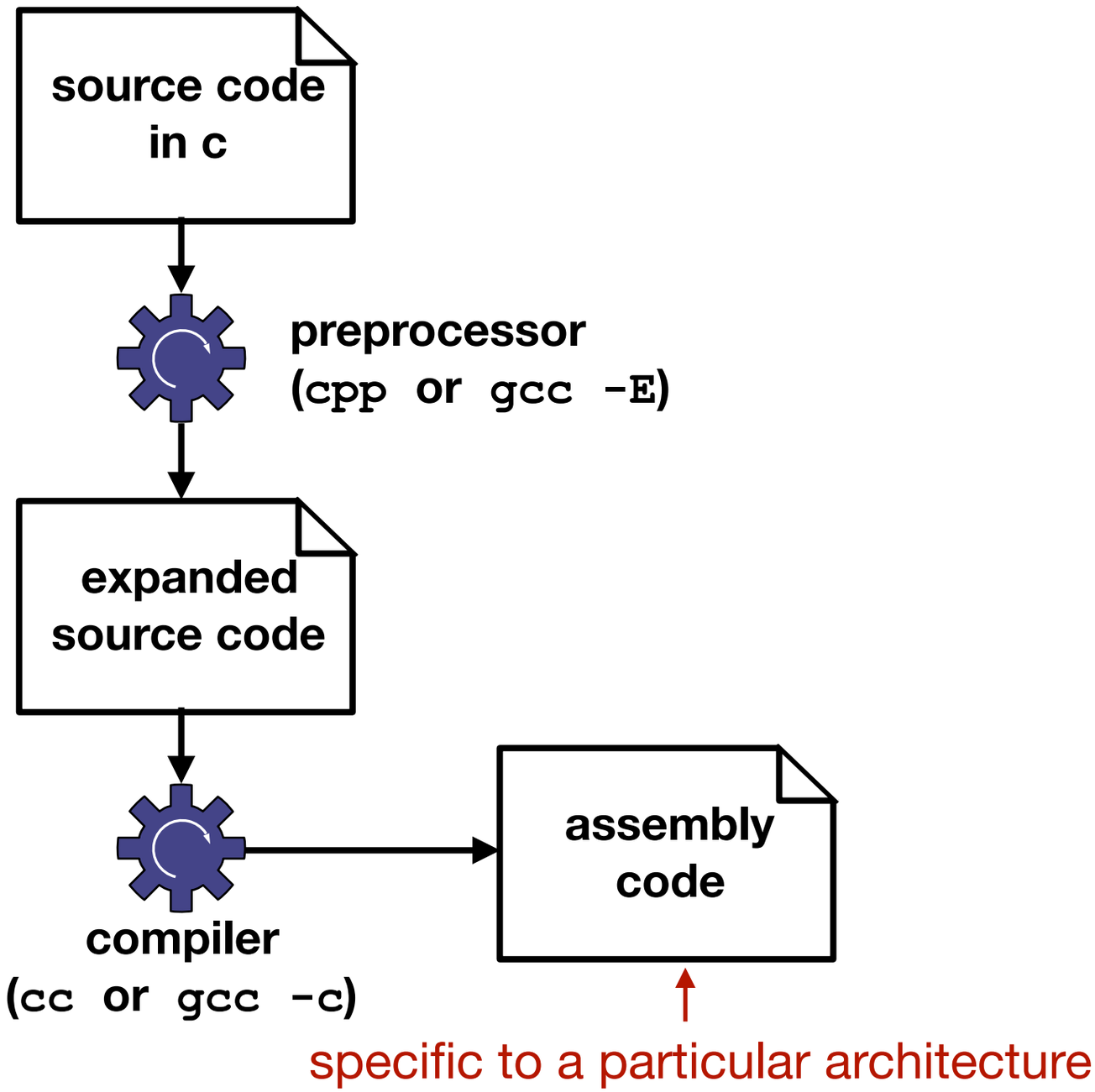

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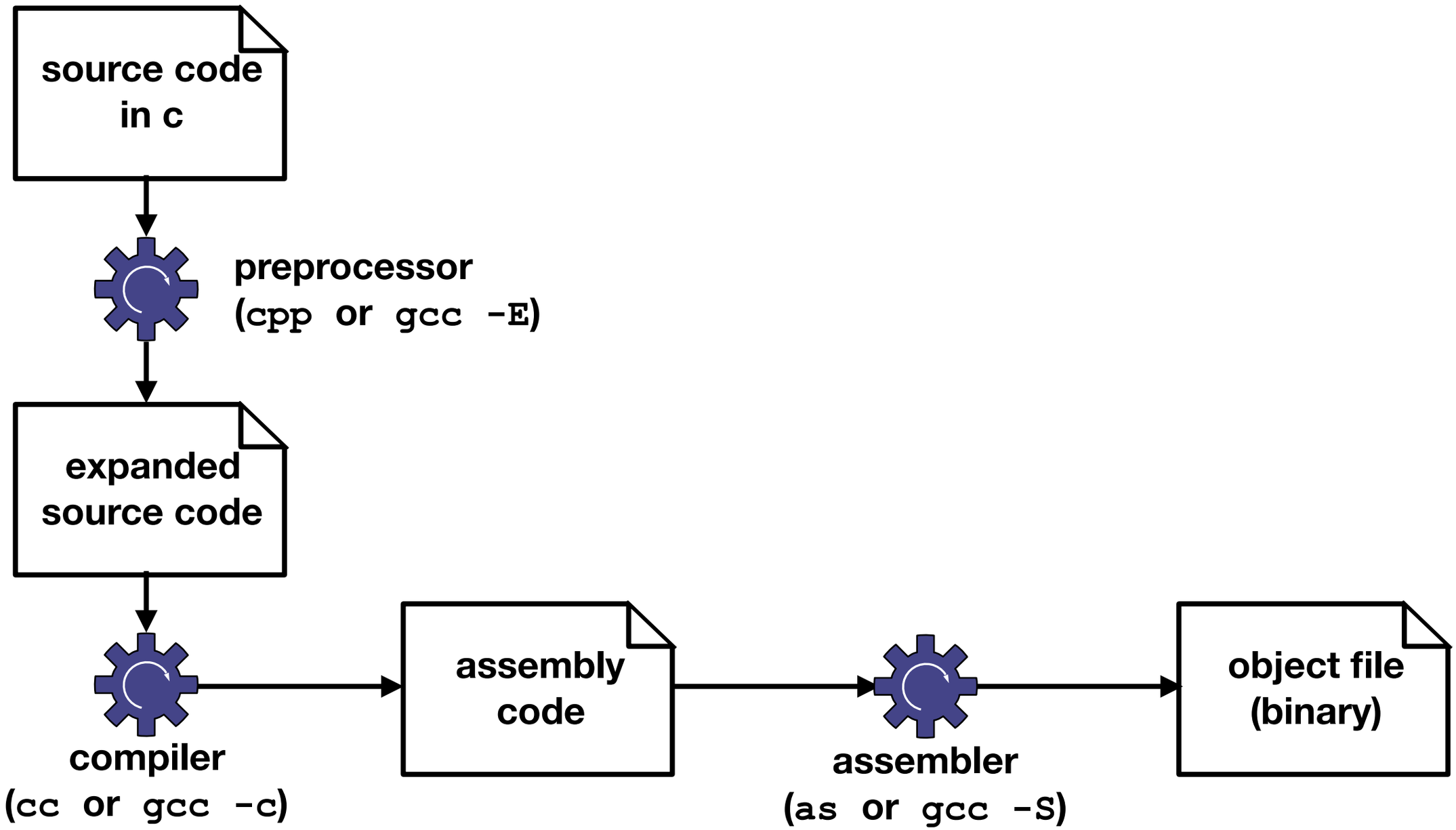

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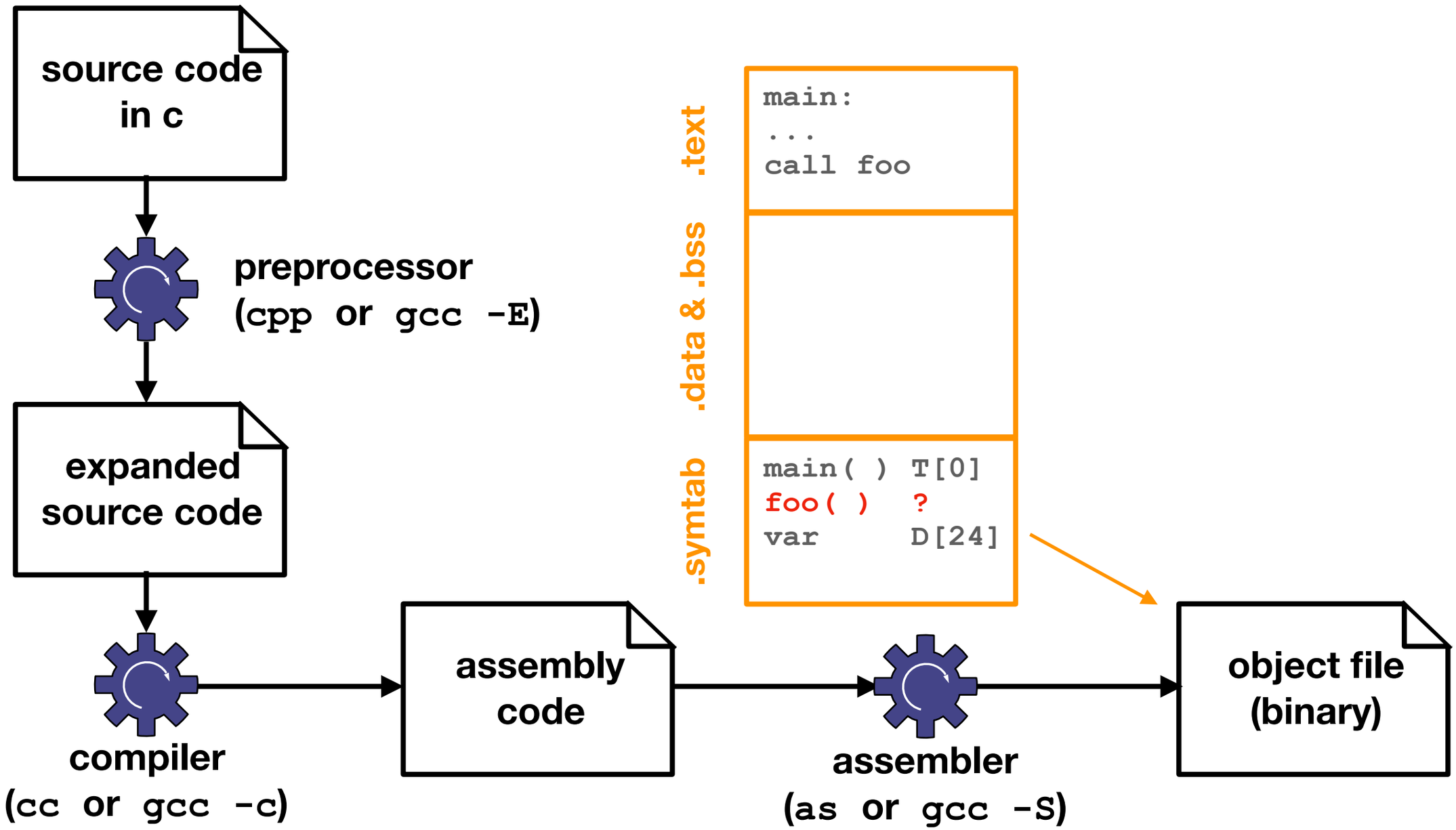

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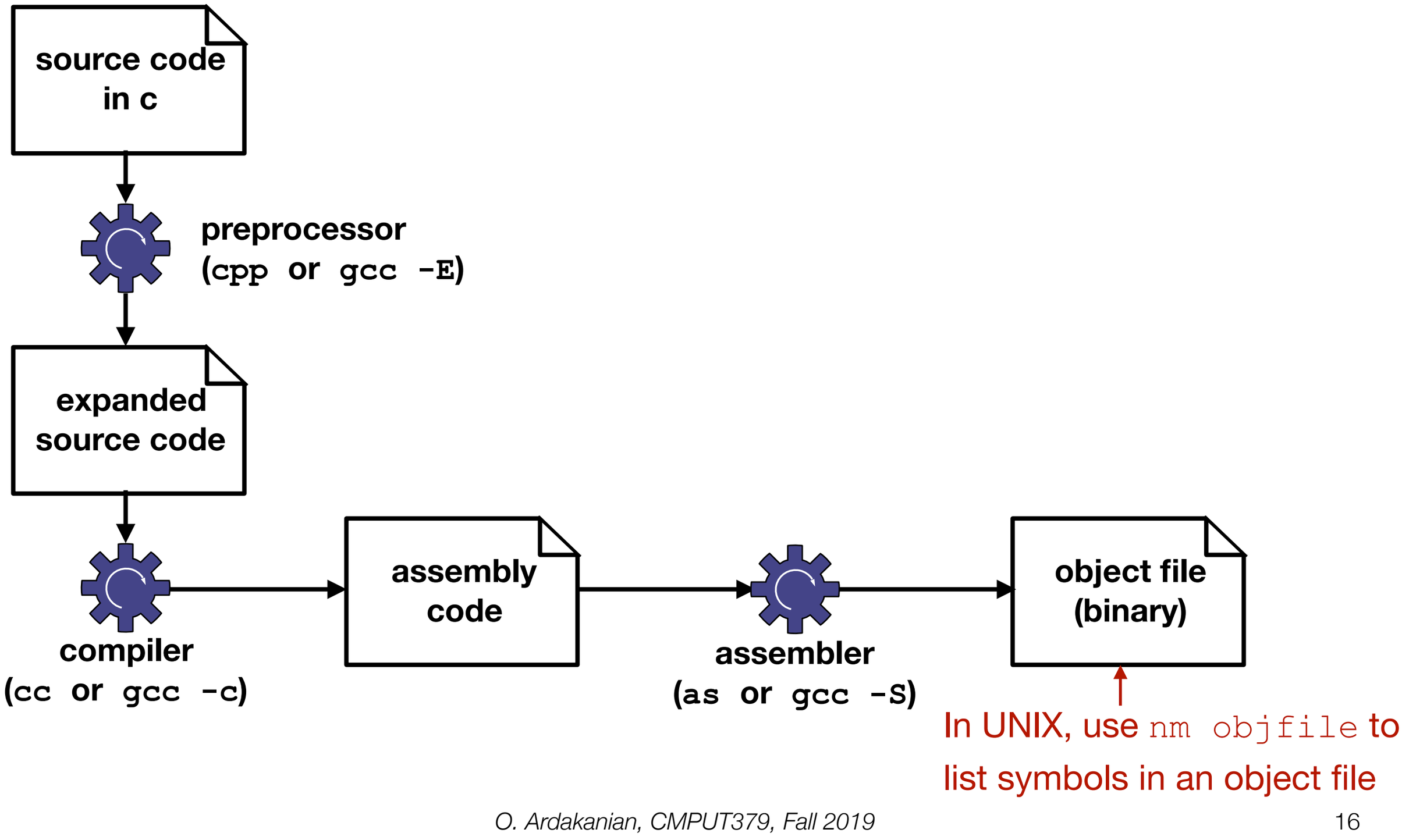

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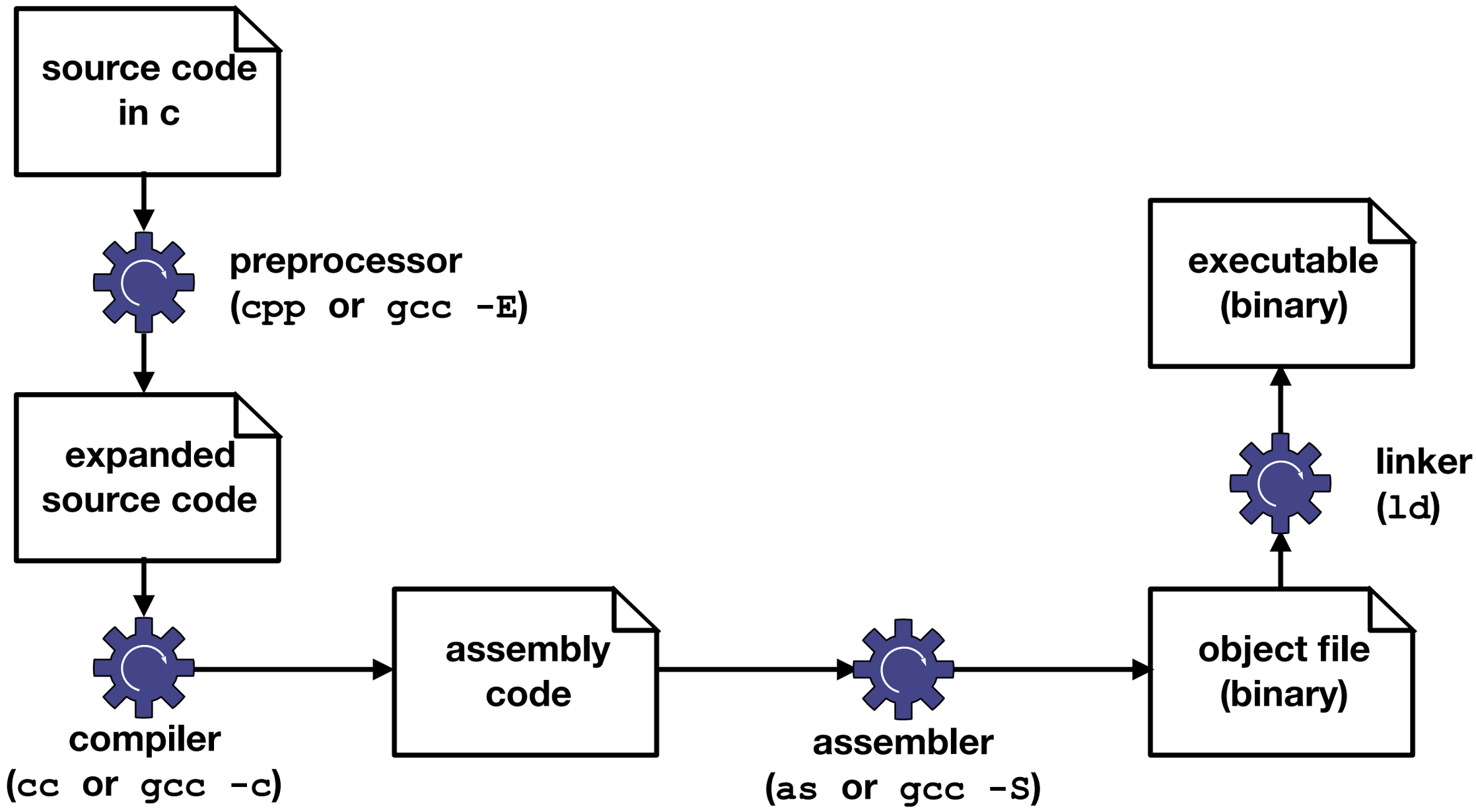

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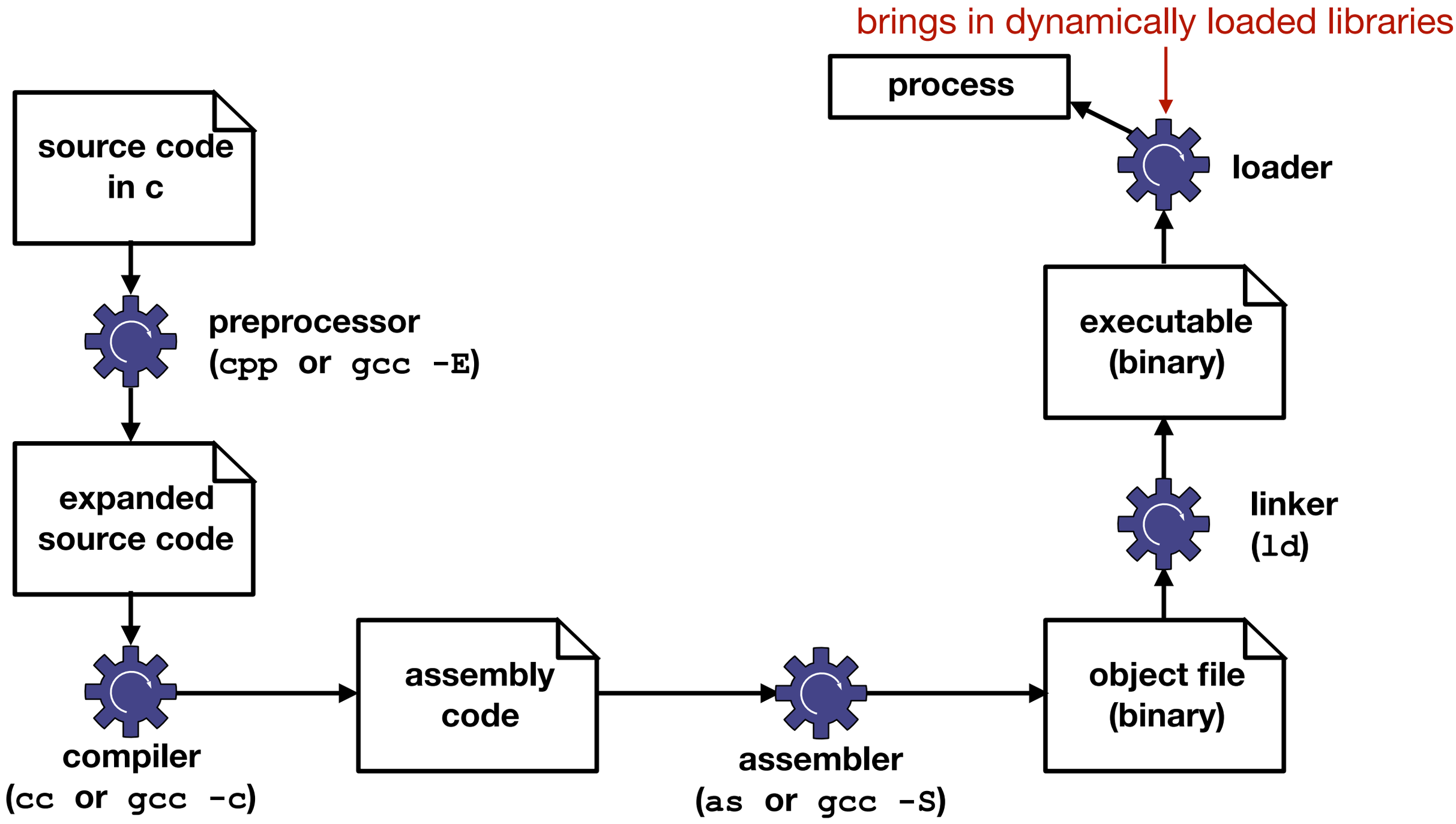
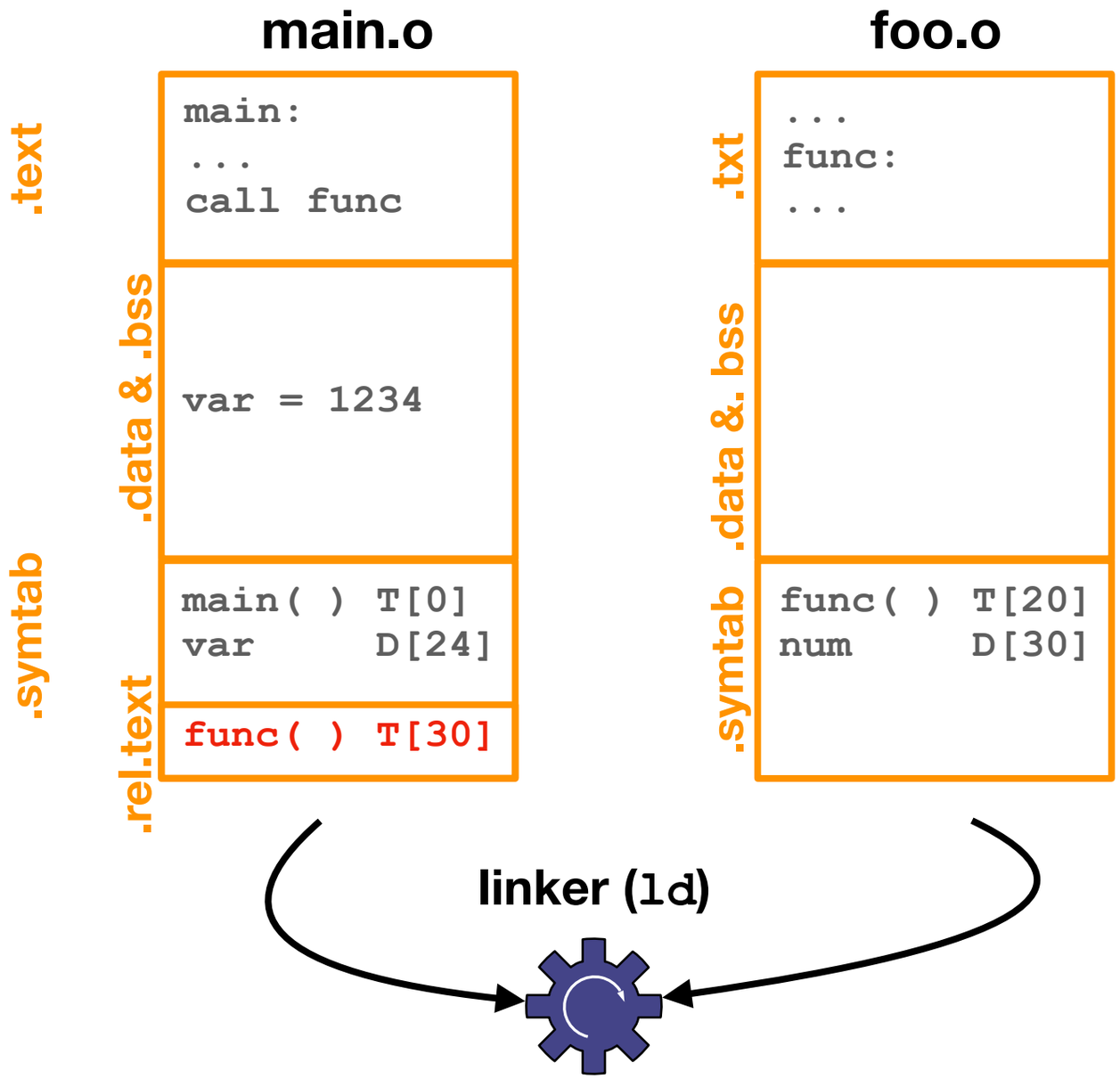


Linking



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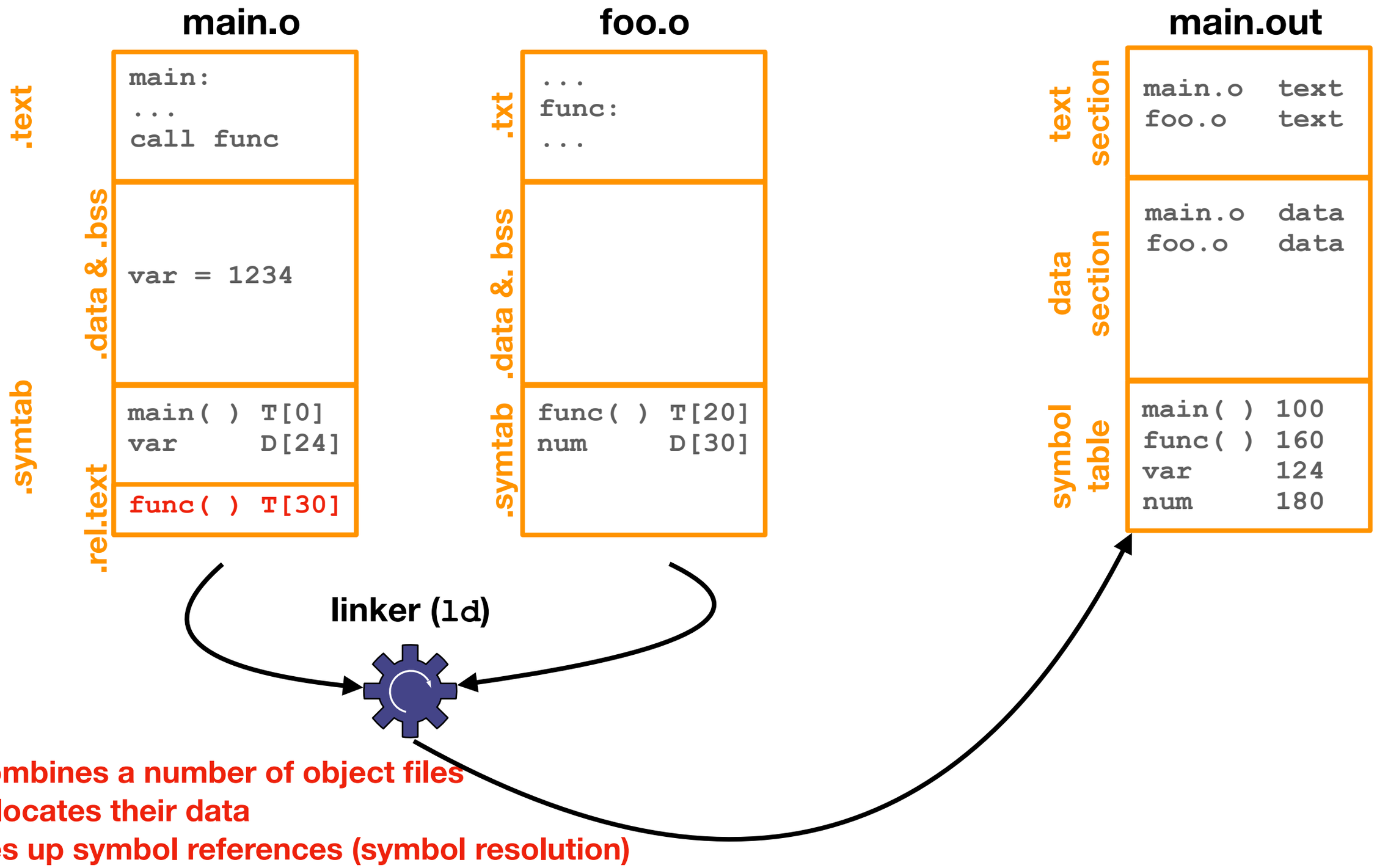

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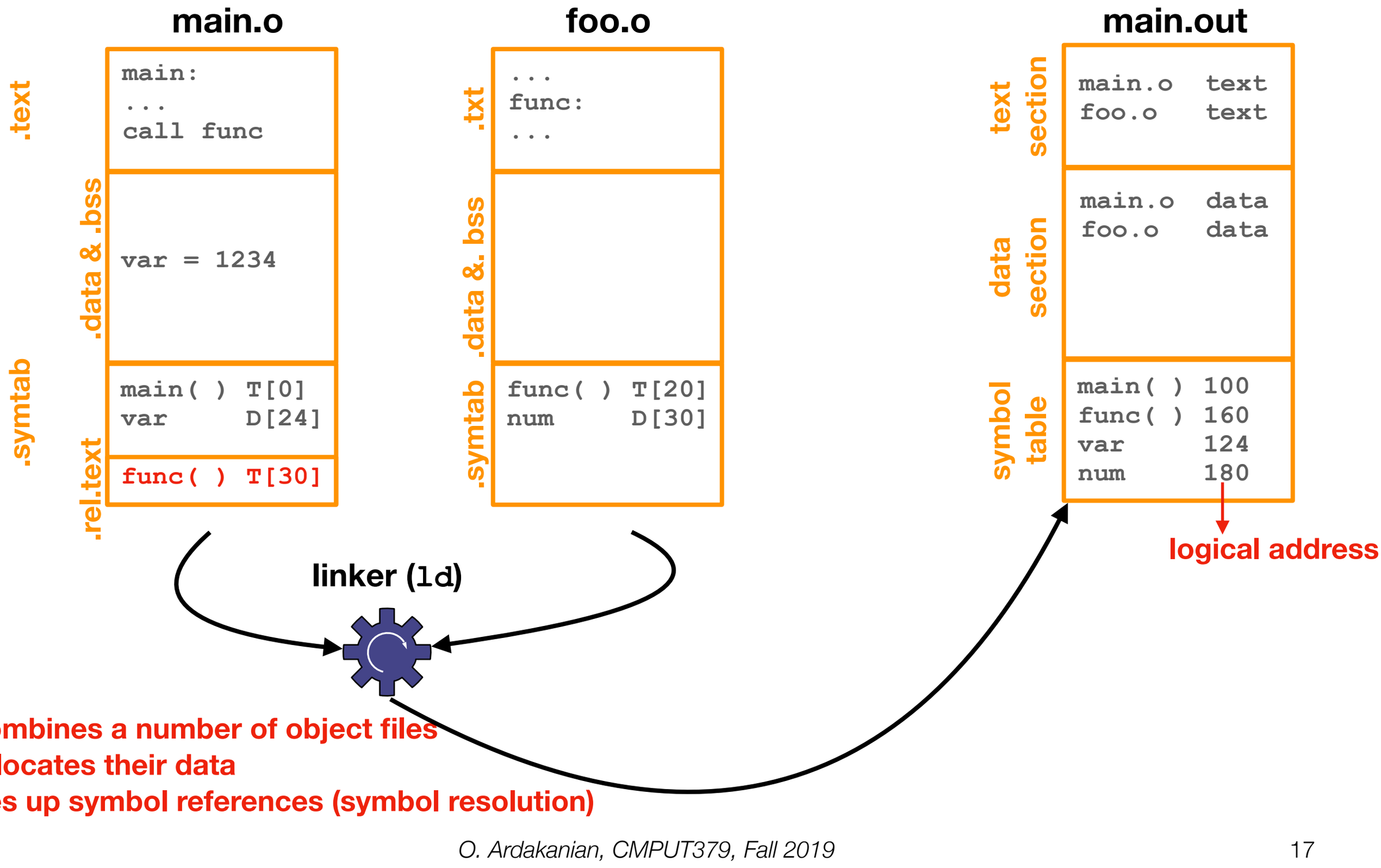
3. ties up symbol references (symbol resolution)

Linking



1. combines a number of object files
2. relocates their data
3. ties up symbol references (symbol resolution)

Homework

- Familiarize yourself with Linux and Windows system calls
- Read the Linux Journal article about linking and loading