An Evil Copy: How the Loader Betrays You

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Purdue University[2]
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Problem: A Motivating Example

```c
// main.c

extern const int foo;

int main()
{
    *(int *)&foo = 100;
    return 0;
}
```

```c
// test.c

const int foo = 10;
```

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Segmentation Fault

Problem: A Motivating Example

- 1 Executable
  - `cc main.c test.c`

- 1 Executable + 1 Library
  - `cc -fPIC –shared test.c –o libtest.so`
  - `cc [–fPIE] main.c -L. –ltest`

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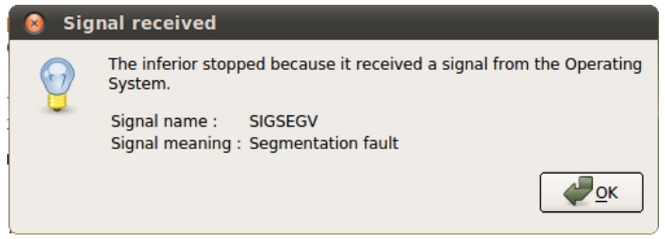

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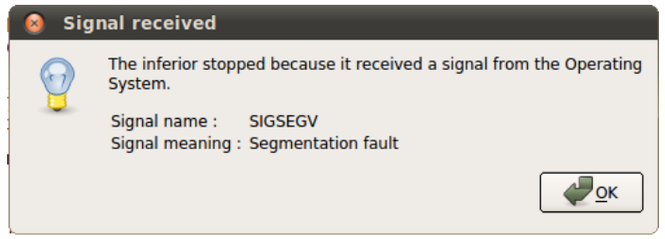

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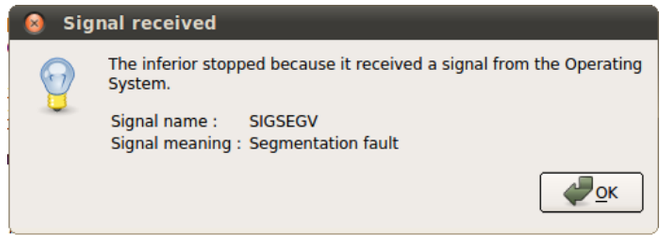

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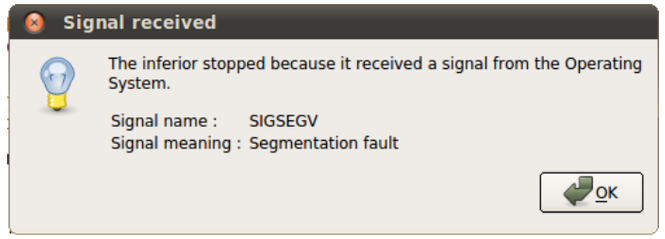
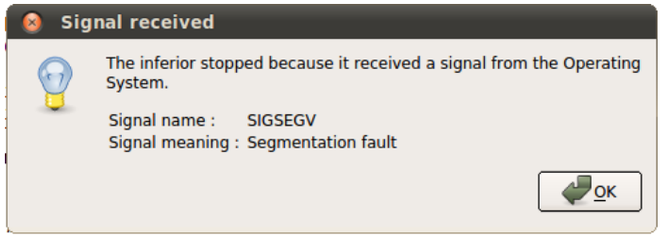
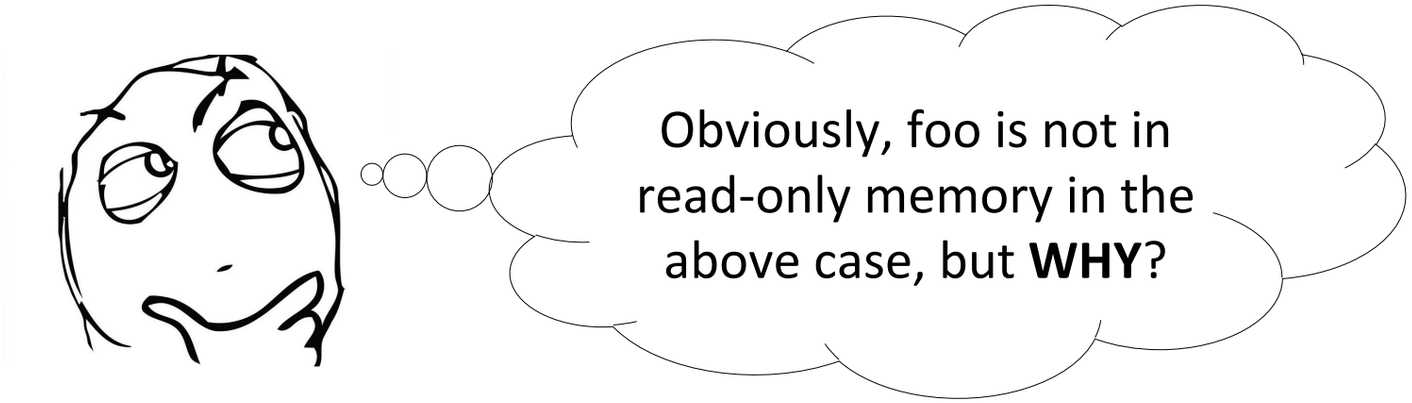
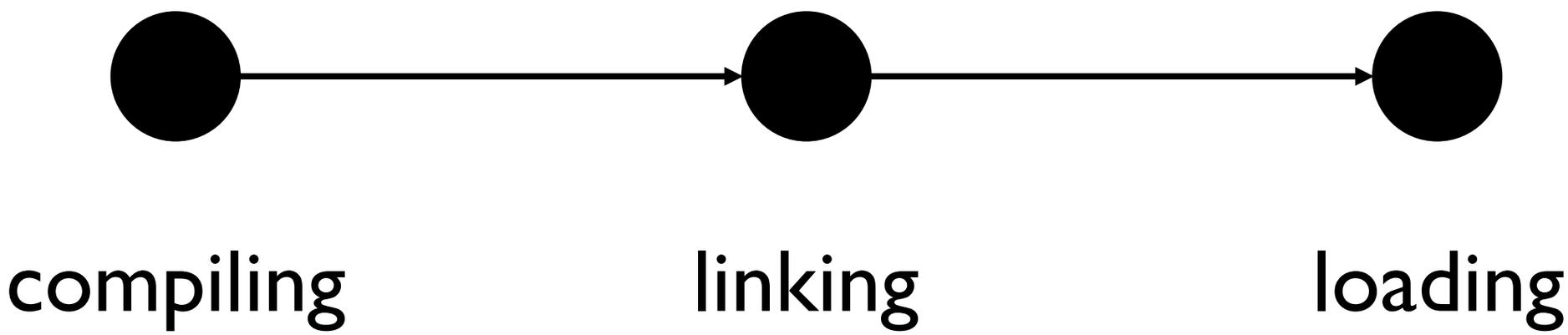


What happened so far...

	non-PIC executable	PIC executable
local "foo"		
foreign "foo"	…Nothing happened?	



Building Process



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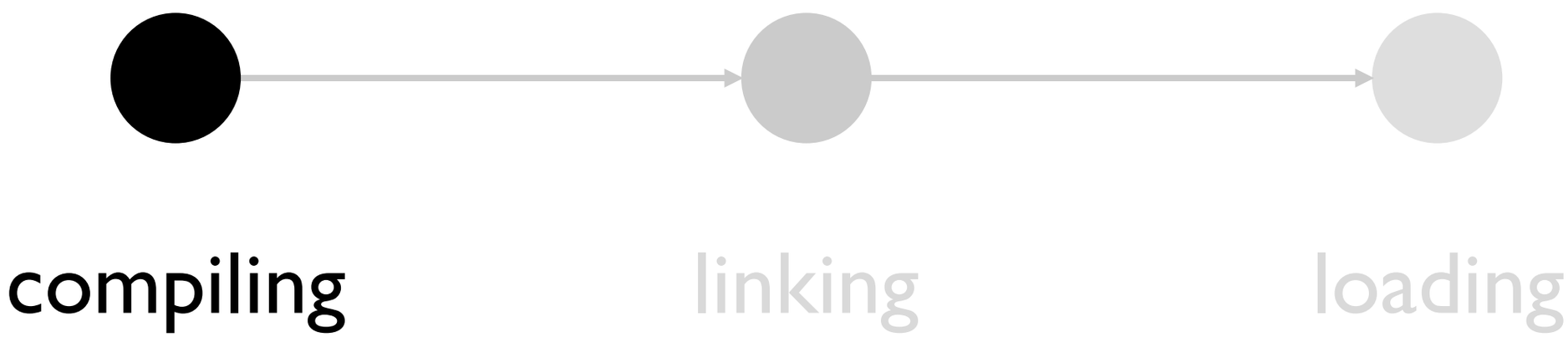

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foo is defined in a different file but still in the same image (**w/o -fPIC flag**)

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foo is defined in the same image

```
// main.o – assuming same image

<main>:
  push %rbp
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  mov  $0x64,offset_to_foo(%rip)
  mov  $0x0,%rax
  pop  %rbp
  ret
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```

The compiler assumes foo's location can be **statically** determined by the linker, and emits a single MOV instruction to write to foo.

foo is defined in the same image

```
// main.o - ms

<main>:
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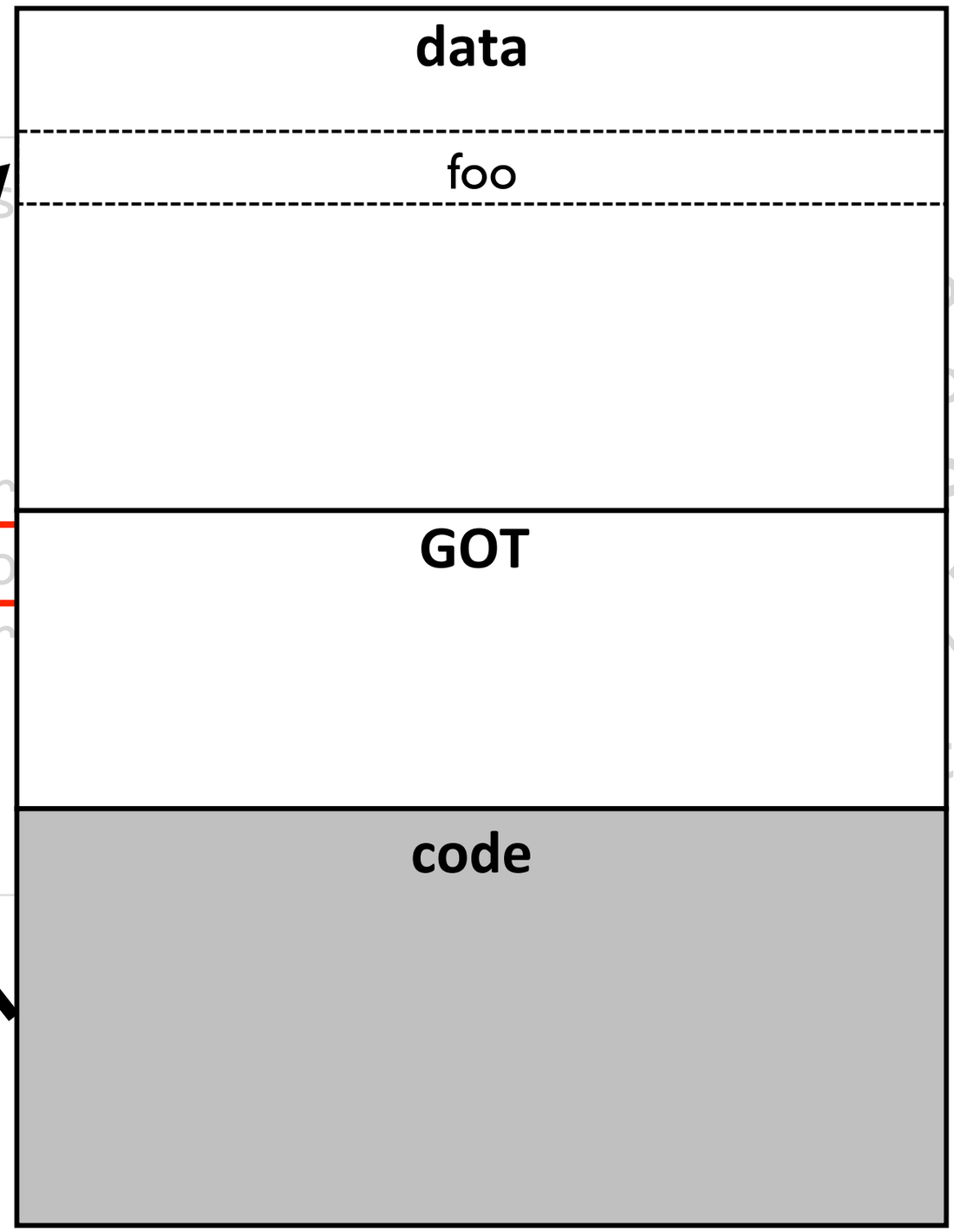
  mov  %rsp,%r
  mov  $0x64,o
  mov  $0x0,%r
  pop  %rbp
  ret
```



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// main.o – assuming same image

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  mov  $0x0,%rax
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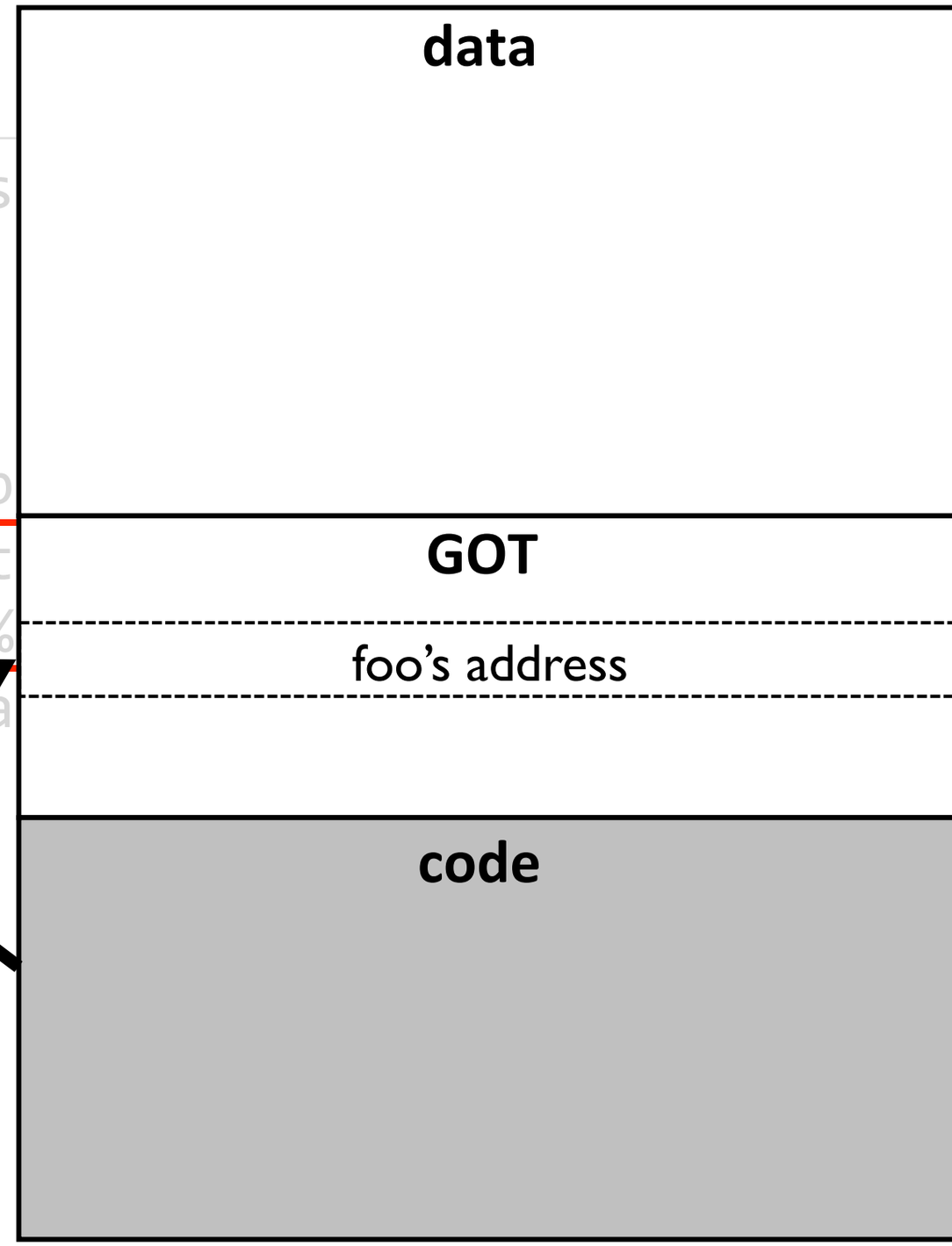
  ret
```

The compiler assumes foo's location cannot be statically determined and emits two MOV instructions: one to retrieve foo's address from its GOT slot, and the other to actually write to foo.

foo is defined in a different image

```
// main.o – ass

<main>:
  push %rbp
  mov  %rsp,%rb
  mov  offset_t
  mov  $0x64,(%
  mov  $0x0,%ra
  pop  %rbp
  ret
```



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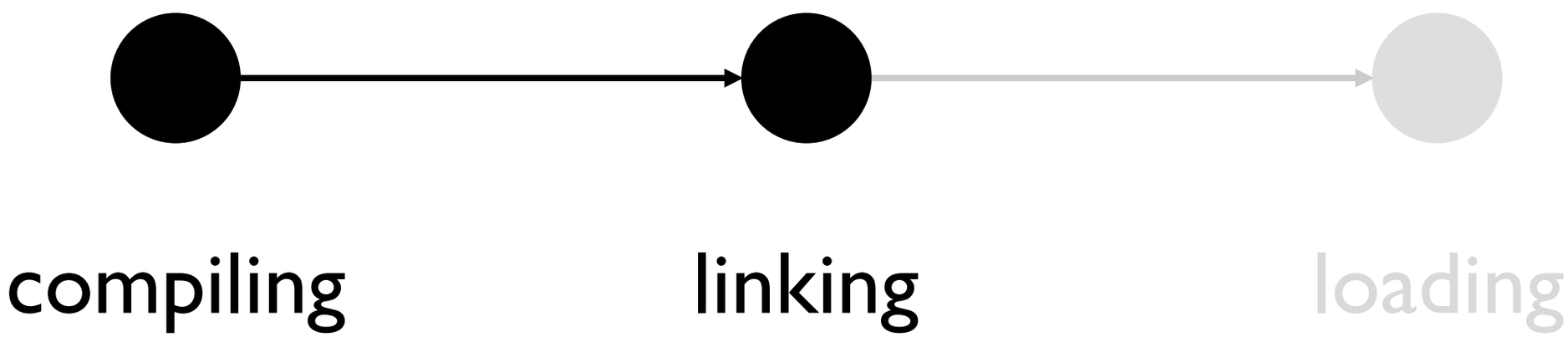
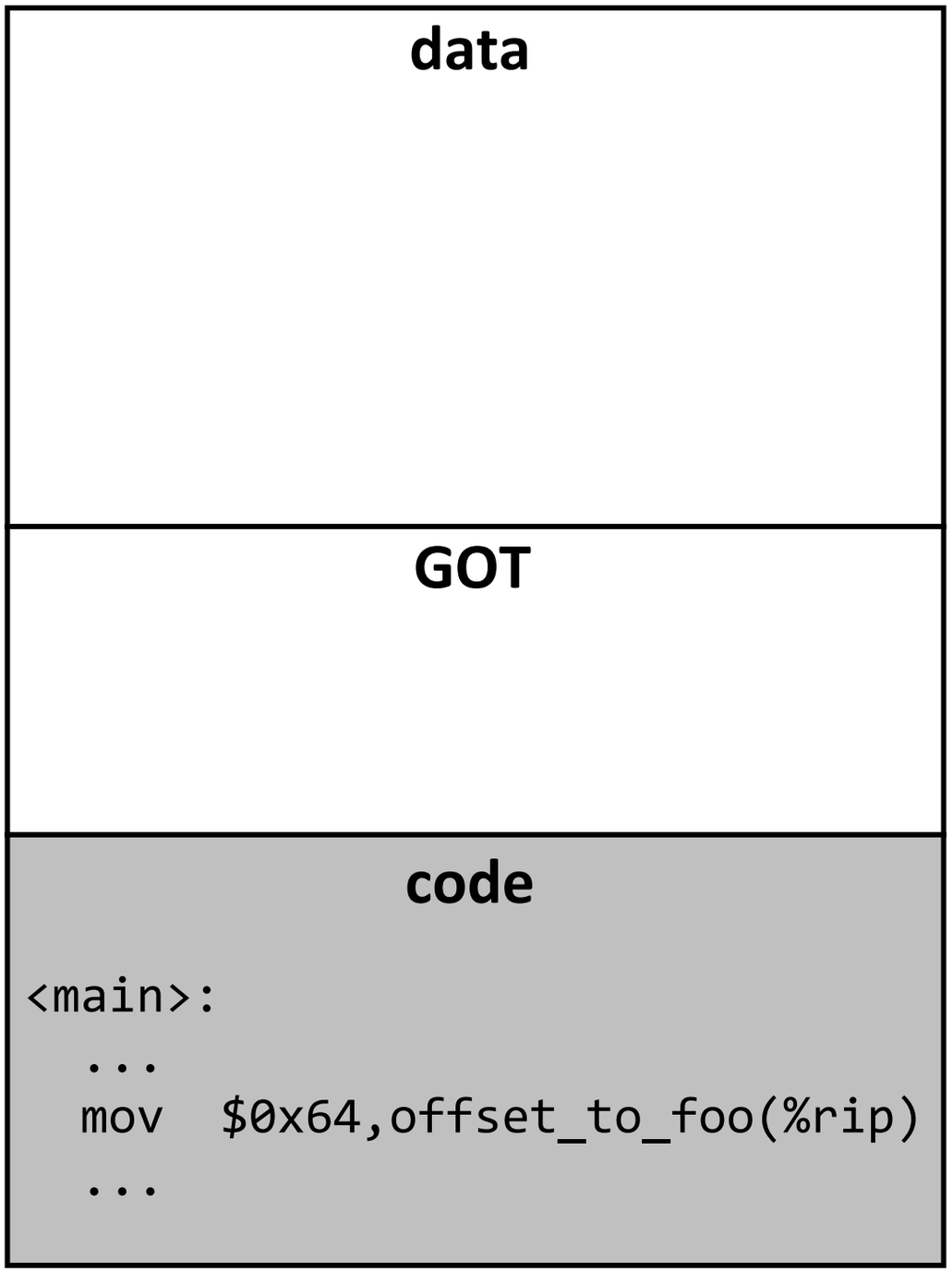
Without –fPIC flag, GCC and Clang on Linux assumes foo is defined in the same image.

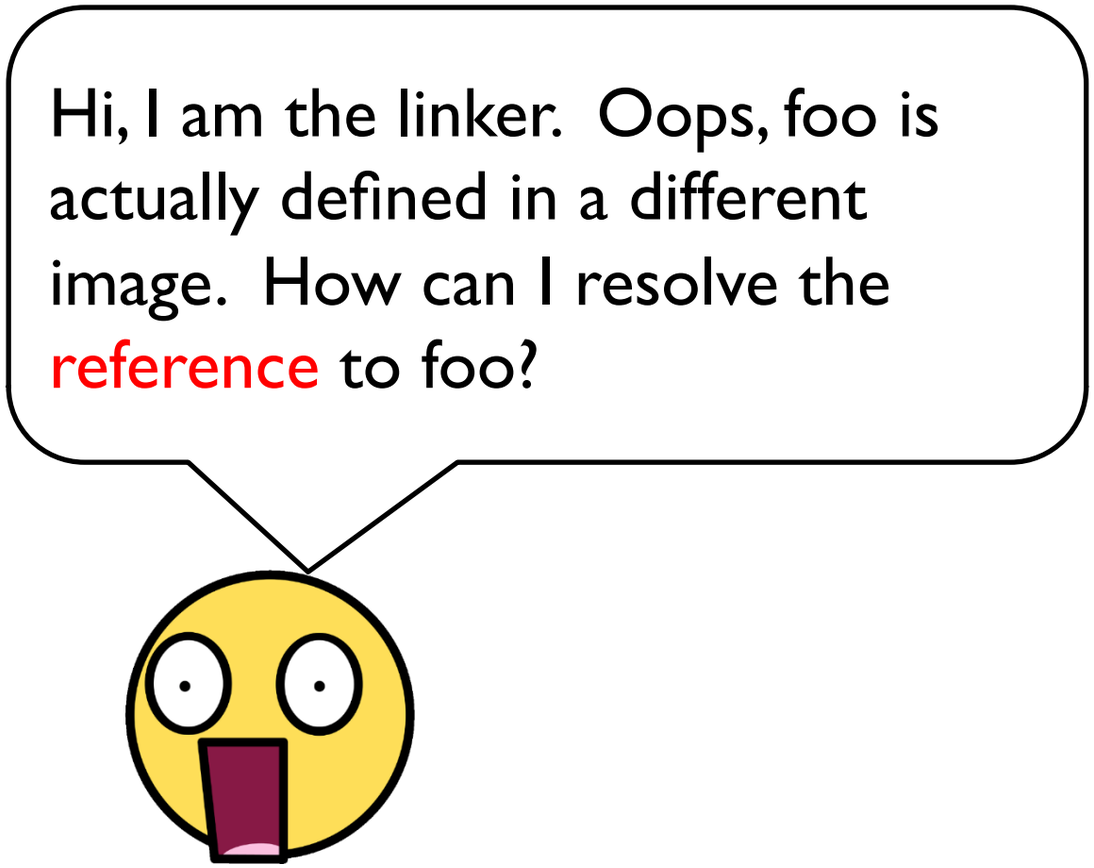
Building Process



Copy Relocation



executable



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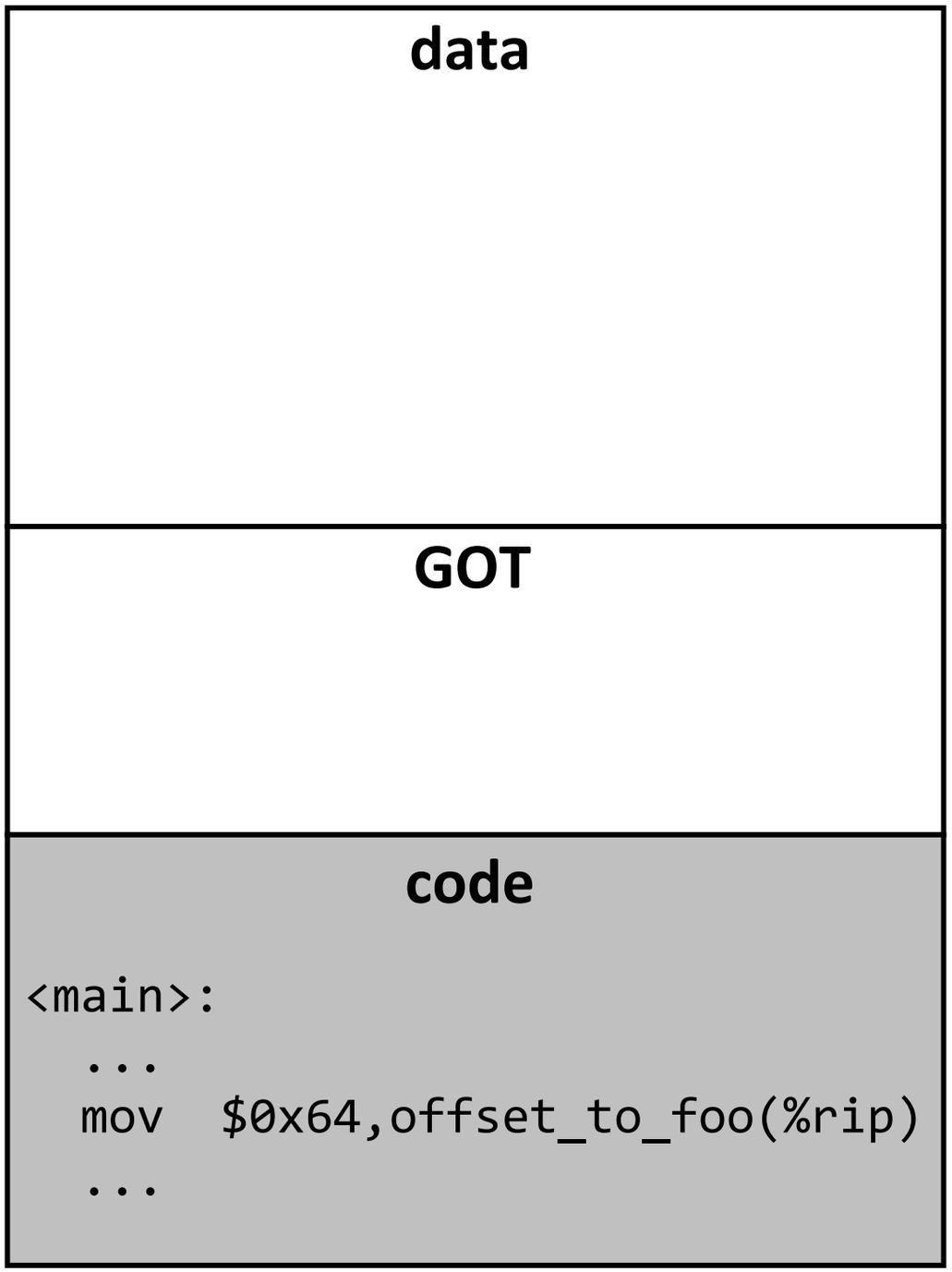
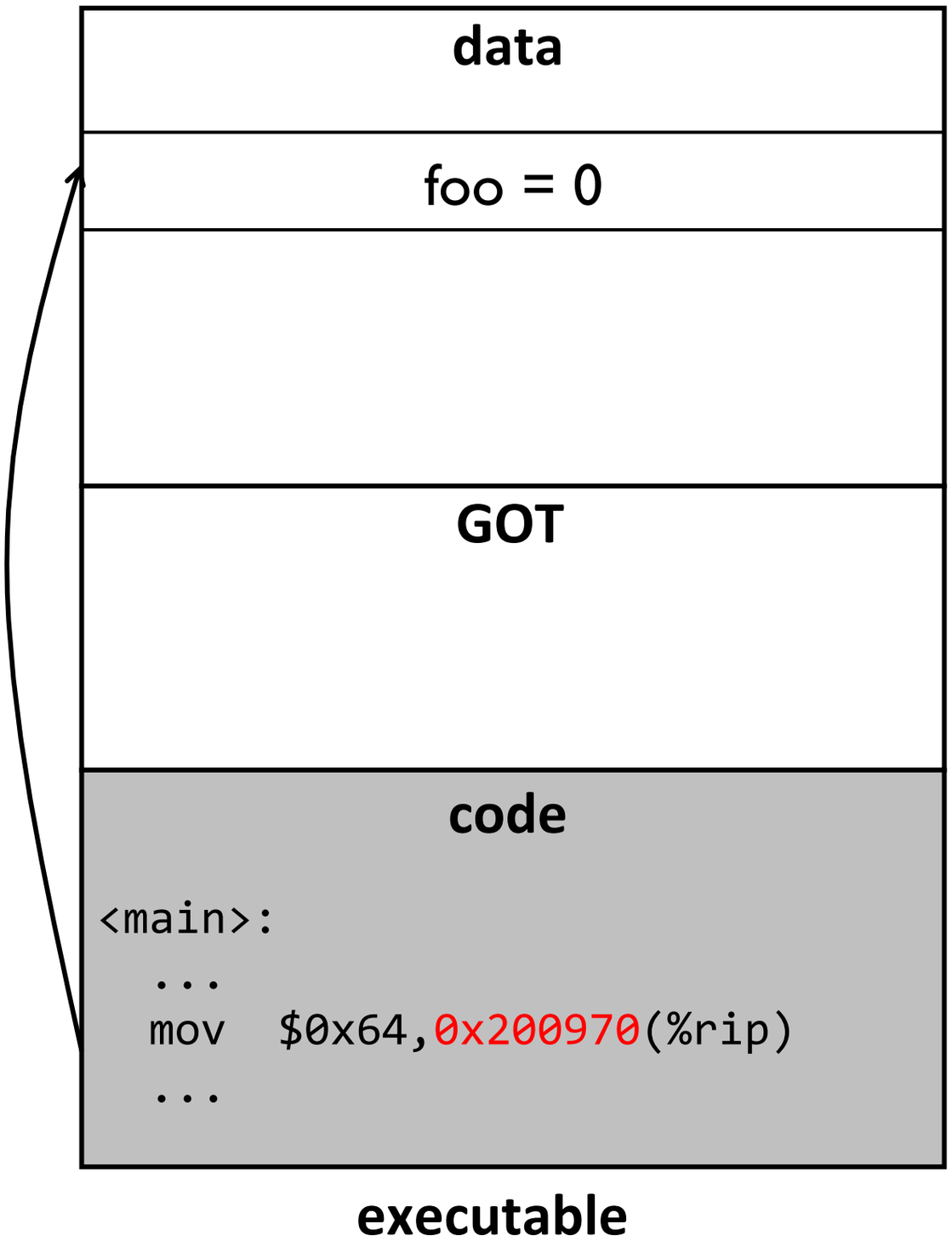
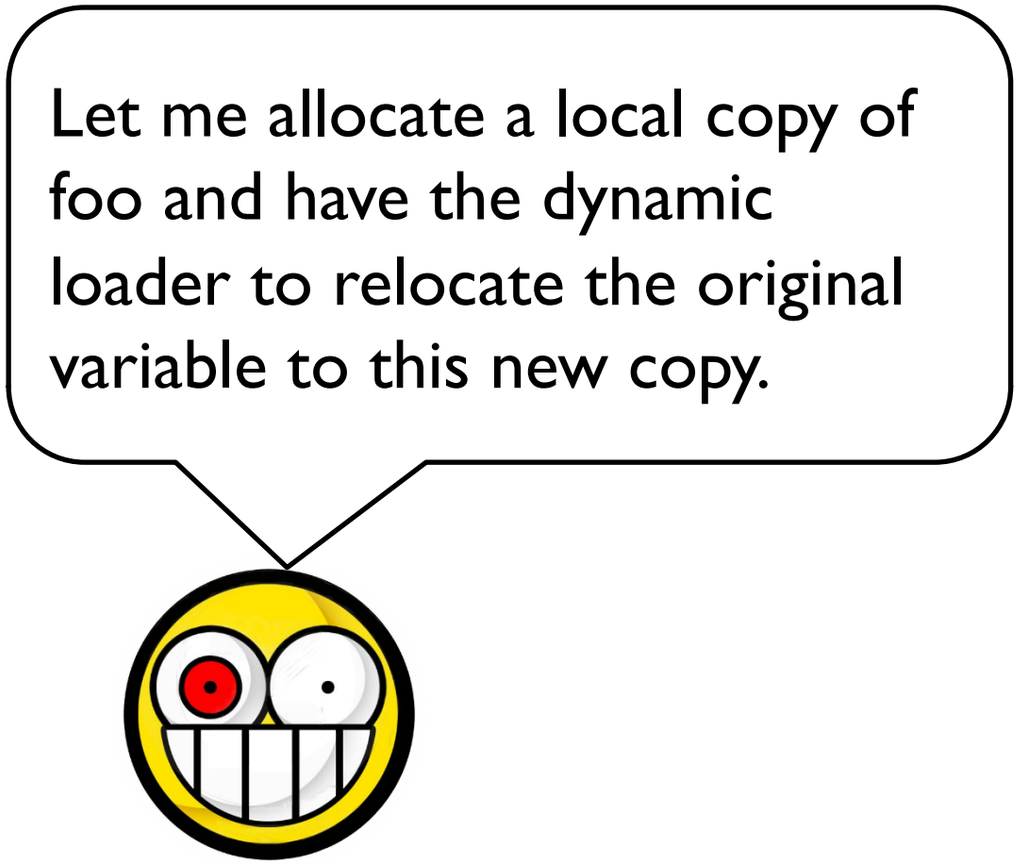


executable

Let me allocate a local copy of foo and have the dynamic loader to relocate the original variable to this new copy.

Copy Relocation





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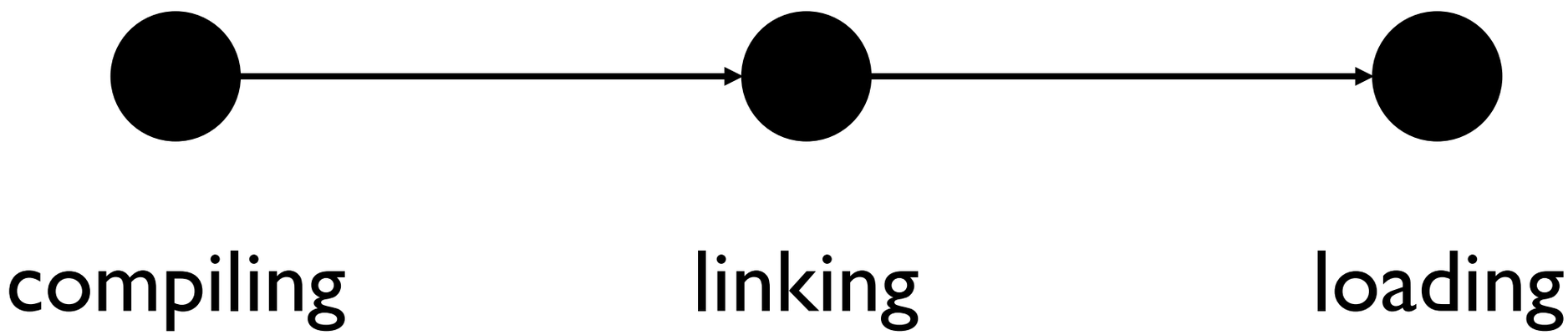

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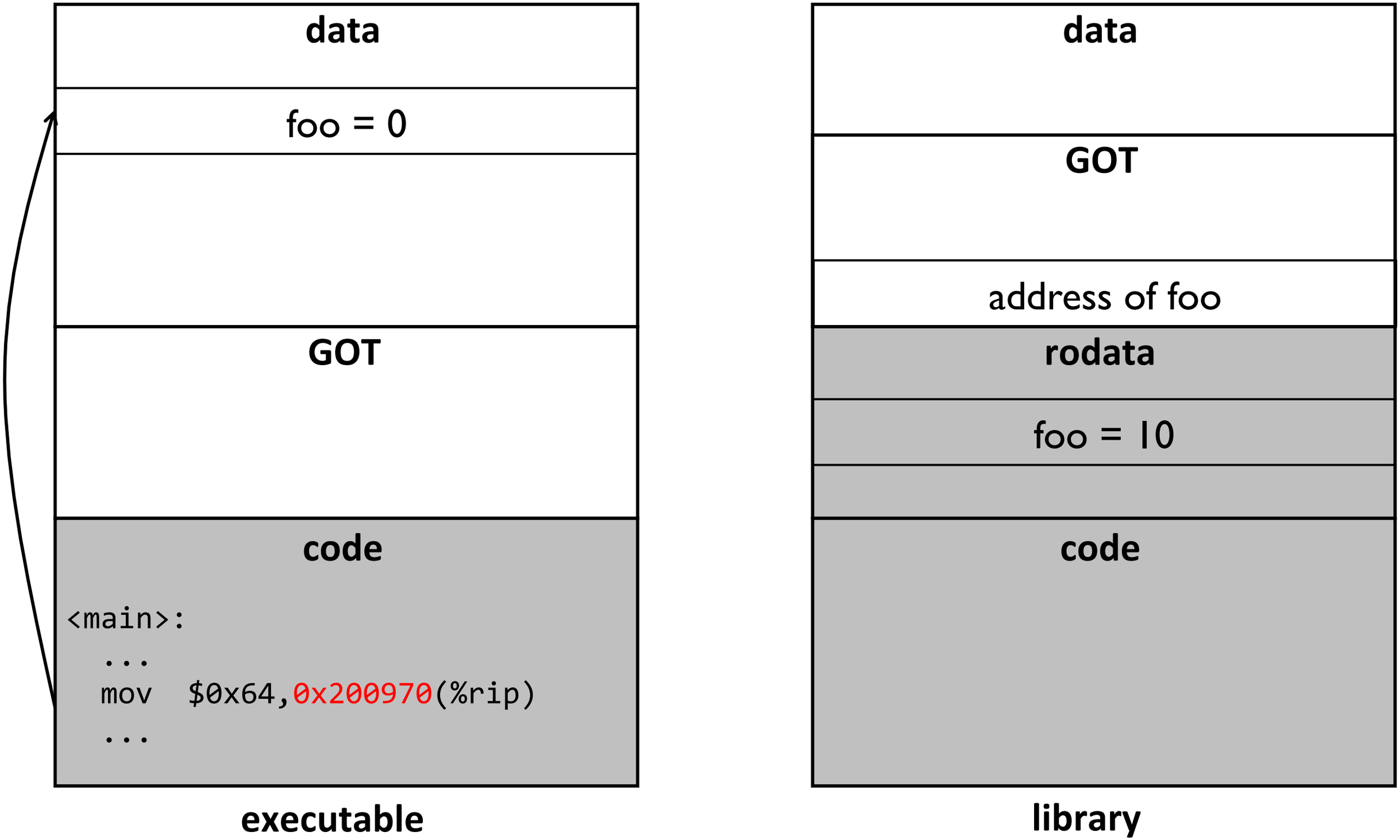

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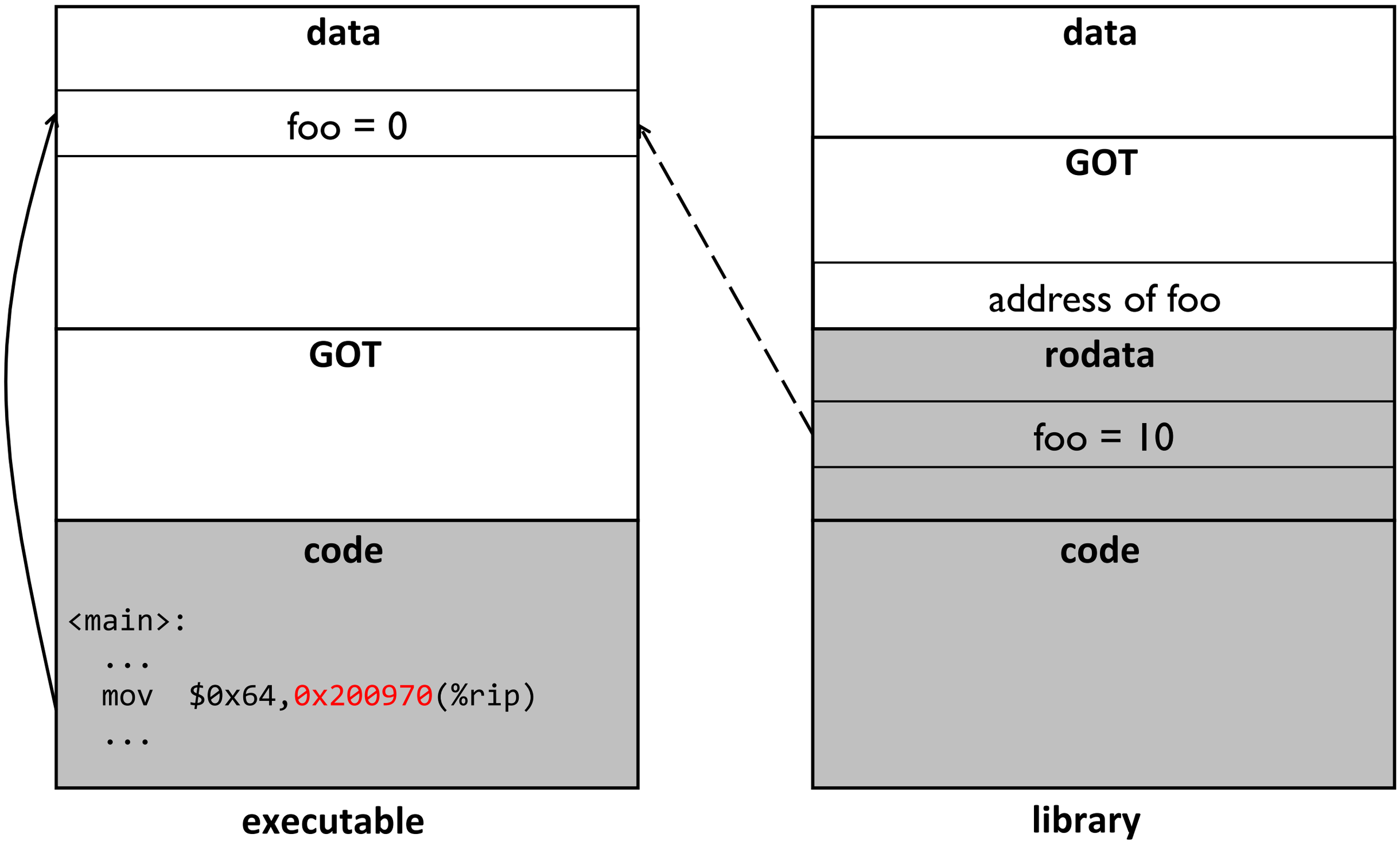

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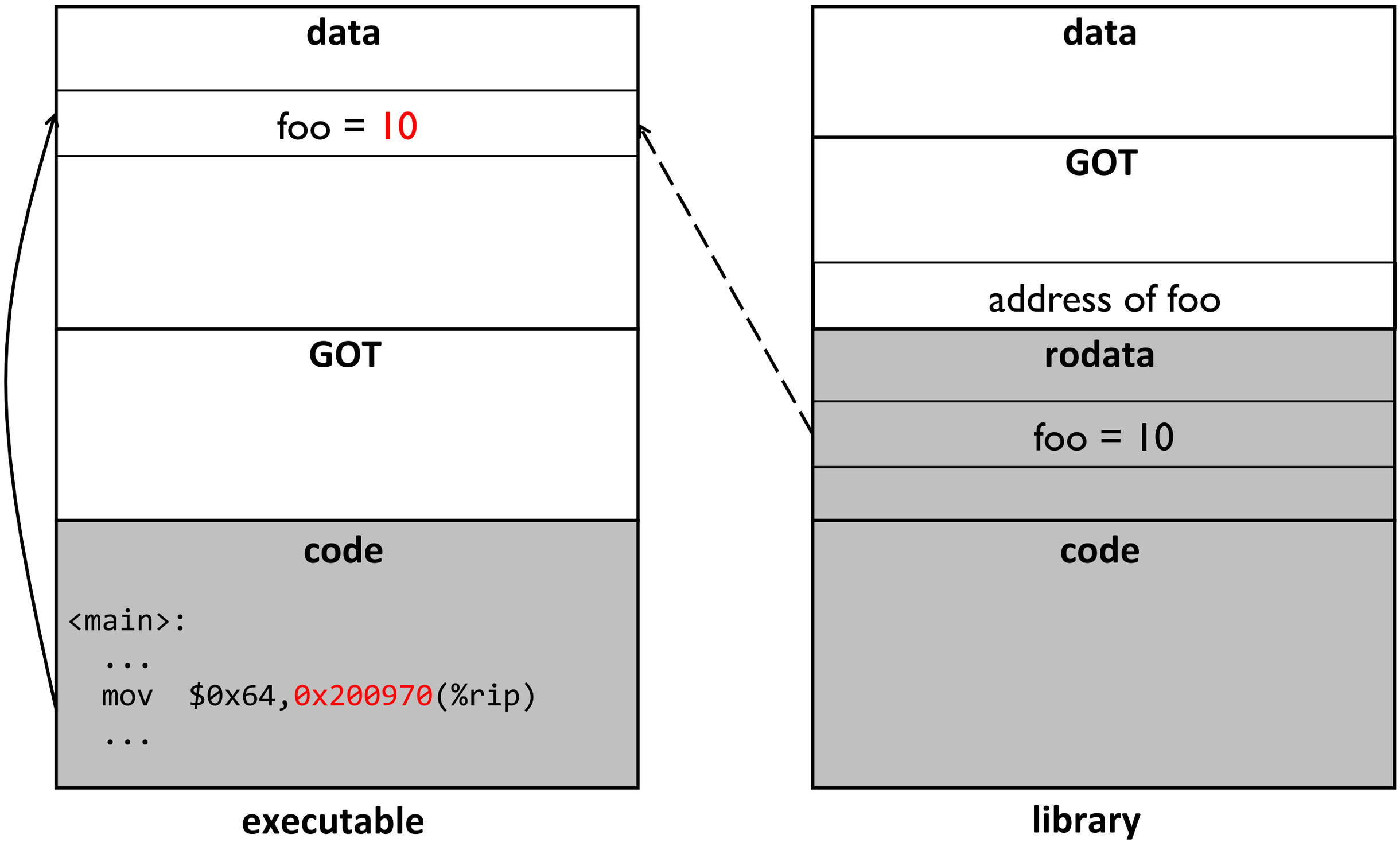

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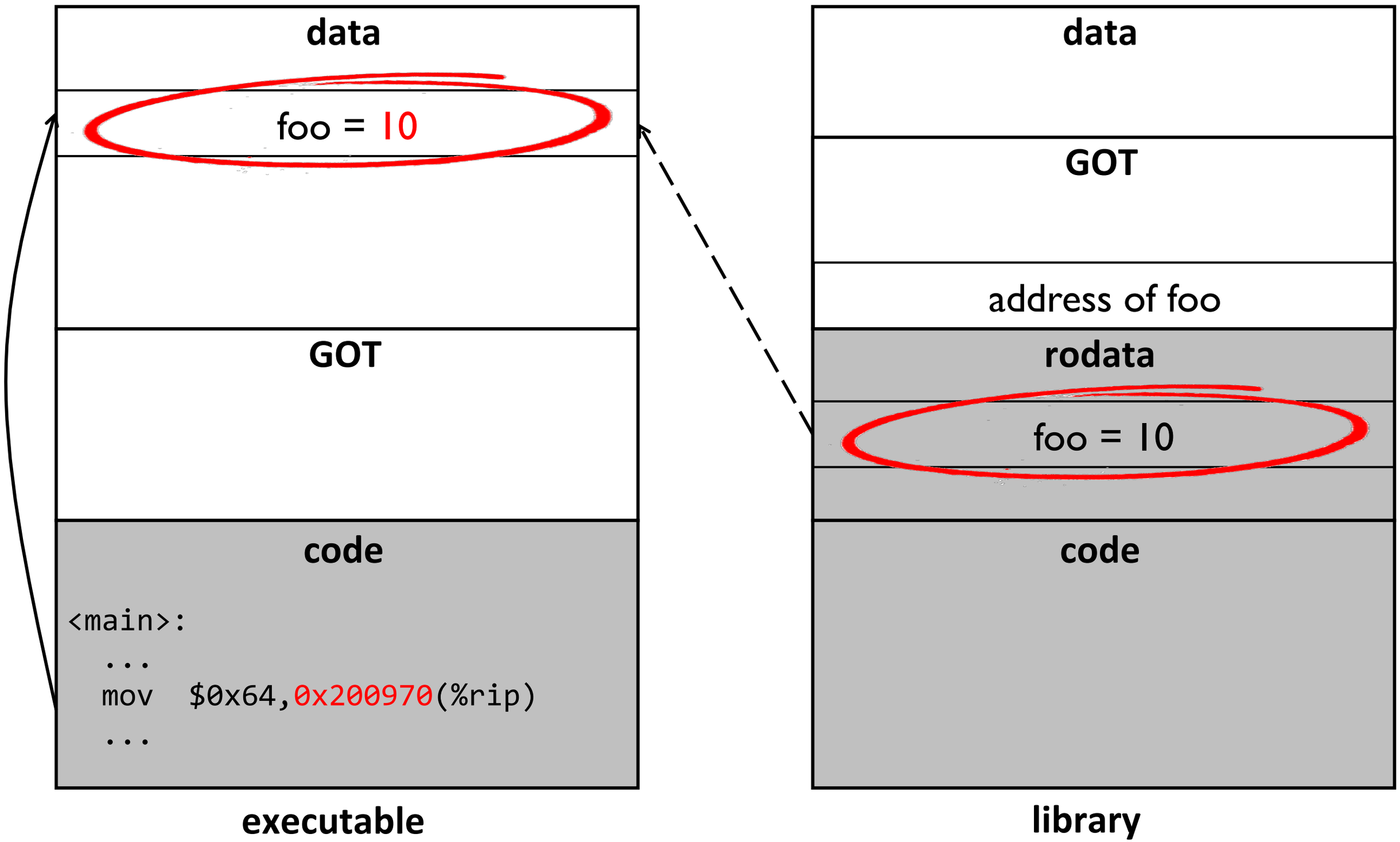
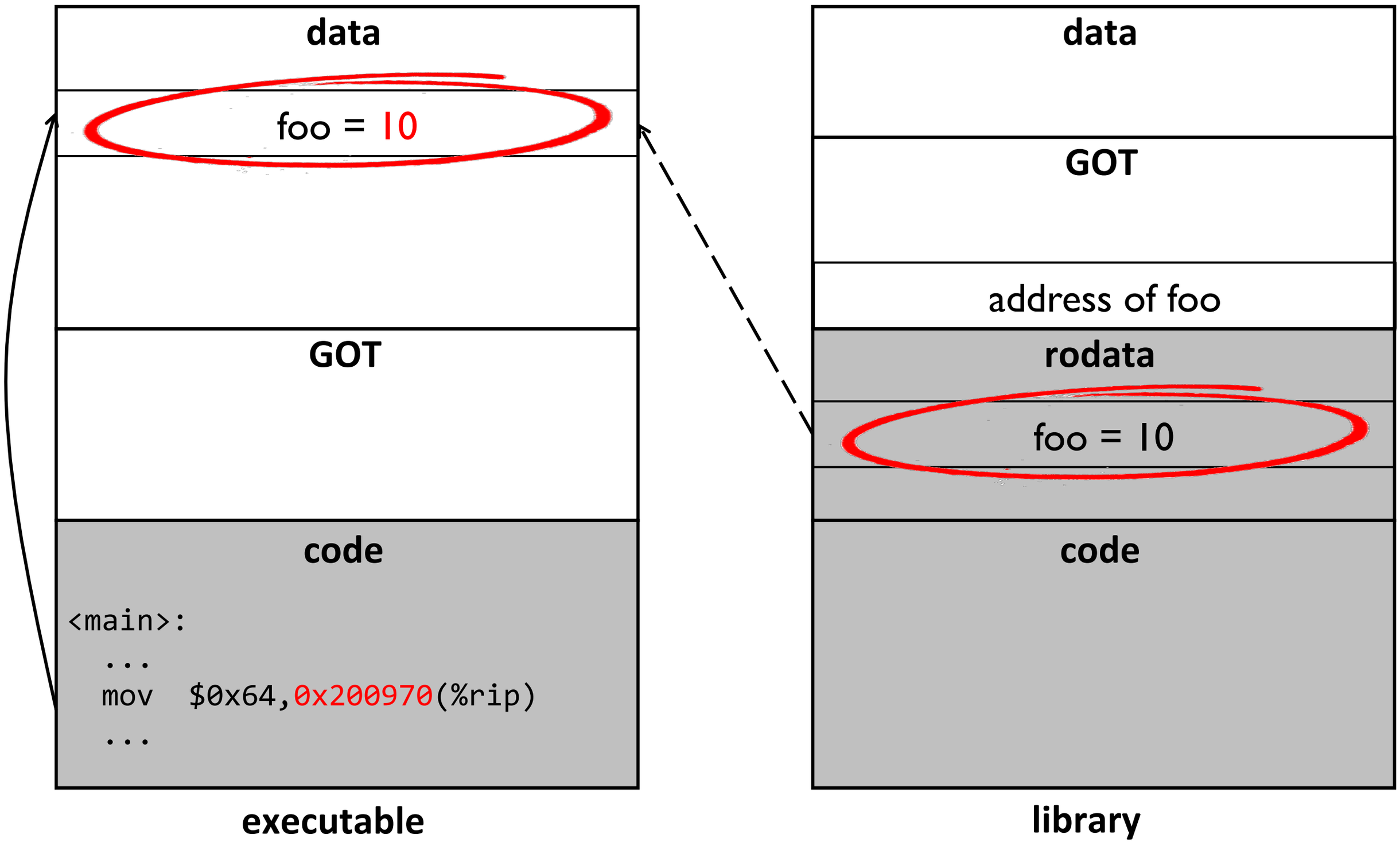


Copy Relocation Violation



Security Concerns

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- Expose "read-only" data to memory corruption attacks
  - Making C++ vtables mutable can break existing defenses
    - VTV, Interleaving, SafeDispatch
  - Making format string writable can enable printf-oriented programming
    - Printf-oriented programming requires mutable format string to implement branching
  - File names
  - IP addresses
  - ...

Security Concerns

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- Copy Relocation Violation does not directly lead to exploitation
- Defenses depending on read-only data being immutable can be bypassed
  - vtables
  - format strings
  - file names
  - IP addresses
  - ...

Evaluations

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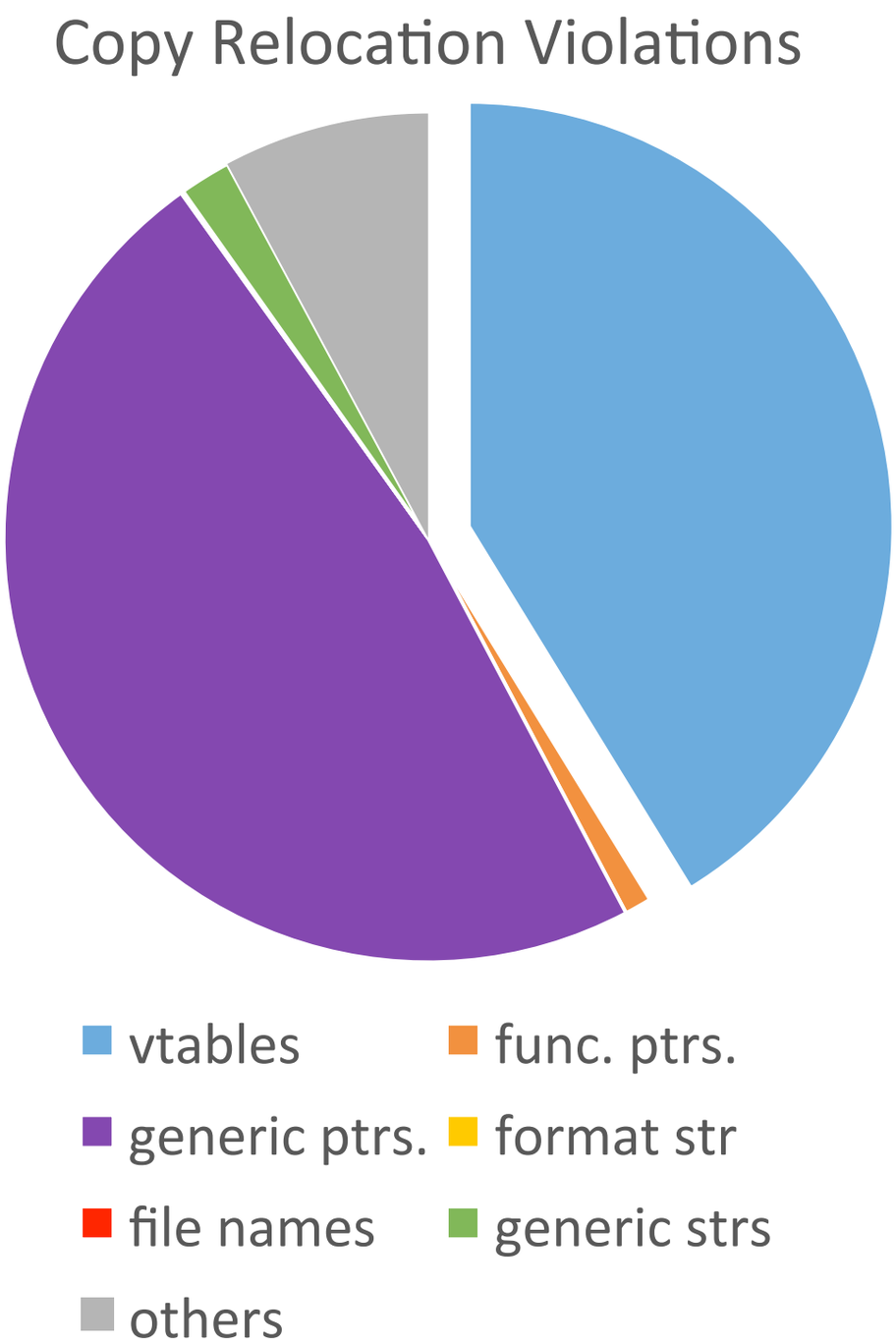
- Do Copy Relocation Violations commonly exist?
  - Analyze 54,045 packages in Ubuntu 16.04 LTS
    - 34,291 executables + 58,862 dynamic libraries
- Do Copy Relocation Violations weaken security mitigations?
  - Evaluate a set of CFI defenses in face of copy relocation violations
- Implications on other platforms?
  - Windows and macOS

Real-world Copy Relocation Violations



- 69,098 copy relocation violations in 6,449 (out of 34,291) executables
- 28,497 vtables copied to writable memory in 4,291 executables
- Among the top 10 most common copy relocation violations, 8 of them are vtables from libstdc++.so

Security Evaluation

- Developed a small C++ program that has an intentional vtable corruption vulnerability
- Evaluate the program under 7 CFI defenses

Defenses	Check Func Ptr	Check VTable	Bypassable
VTrust	✓	✓	✗
VTV	✗	✓	✓
vfGuard	✓	✗	✗
Interleaving	✗	✓	✓
SafeDispatch	✓	✗	✗
SafeDispatch2	✗	✓	✓
RockJIT	✓	✗	✗

Other Platforms

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- Windows
  - MSVC requires explicit annotation to differentiate "intra-module extern" from "inter-module extern"
  - The example program cannot be built on Windows
- macOS
  - The compiler conservatively assumes "extern" is from a different image
  - The linker uses GOT to serve those references
  - Copy relocations do not exist on macOS

macOS issue

- macOS has its own issue that results in the same consequence
  - macOS's compiler allocates data that **potentially** requires runtime patching in __DATA__.__const section
  - However, the loader does not reprotect it as read-only after runtime patching
  - Read-only data (e.g., vtable) remains writable

Copy relocation violations seem prevalent in current Linux systems. Then, how can we get rid of them?

Mitigations

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- Eliminate copy relocations entirely
  - Recompile executable using -fPIC flag, -fPIE not enough
  - -fPIC flag forces the compiler to treat non-static global variables as defined in a different image
- Respect the memory protection while performing copy relocations
  - Determine the memory protection permission at link time
  - Allocate the variable copy from a section protected by RELRO
  - Both GNU Binutils and LLVM are adopting this approach

Mitigations

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- es

D28272 ELF: Reserve

reviews.llvm.org/D28272

Phabricator

Search

Differential › D28272

ELF: Reserve space for copy relocations of read-only symbols in relro.

Closed Public

Authored by **pcc** on Jan 3 2017, 6:14 PM.

Details

Reviewers rafael, davide, ruiu, tstellarAMD

Commits rL291524: ELF: Reserve space for copy relocations of read-only symbols in relro.

SUMMARY

When reserving copy relocation space for a shared symbol, scan the DSO's program headers to see if the symbol is in a read-only segment. If so, reserve space for that symbol in a new synthetic section named .bss.rel.ro which will be covered by the relro program header.

This fixes the security issue disclosed on the binutils mailing list at: https://sourceware.org/ml/libc-alpha/2016-12/msg00914.html

Diff Detail

Repository rL LLVM

pcc retitled this revision from to *ELF: Reserve space for copy relocations of read-only symbols in relro.*. Jan 3 2017, 6:14 PM

pcc updated this object.

pcc added reviewers: **rafael**, **ruiu**, **davide**.

pcc added subscribers: **llvm-commits**, **tmsriram**, **eugenis**.

Edit Revision
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Tags

None

Subscribers

nhaehnle, emaste, eugenis and 2 others

Conclusions

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- Identified a design flaw in the compiler toolchain on Linux
  - Copy relocation can strip the "const" attribute specified by the programmer
- Proposed mitigations
  - Eliminate copy relocations entirely
  - Preserve the memory protection of the relocated variables
- Evaluated copy relocation violations in real world
  - Studied 54,045 packages in Ubuntu 16.04 LTS
  - Copy relocation violations occur commonly in many programs
  - Copy relocation violations can subvert existing defenses

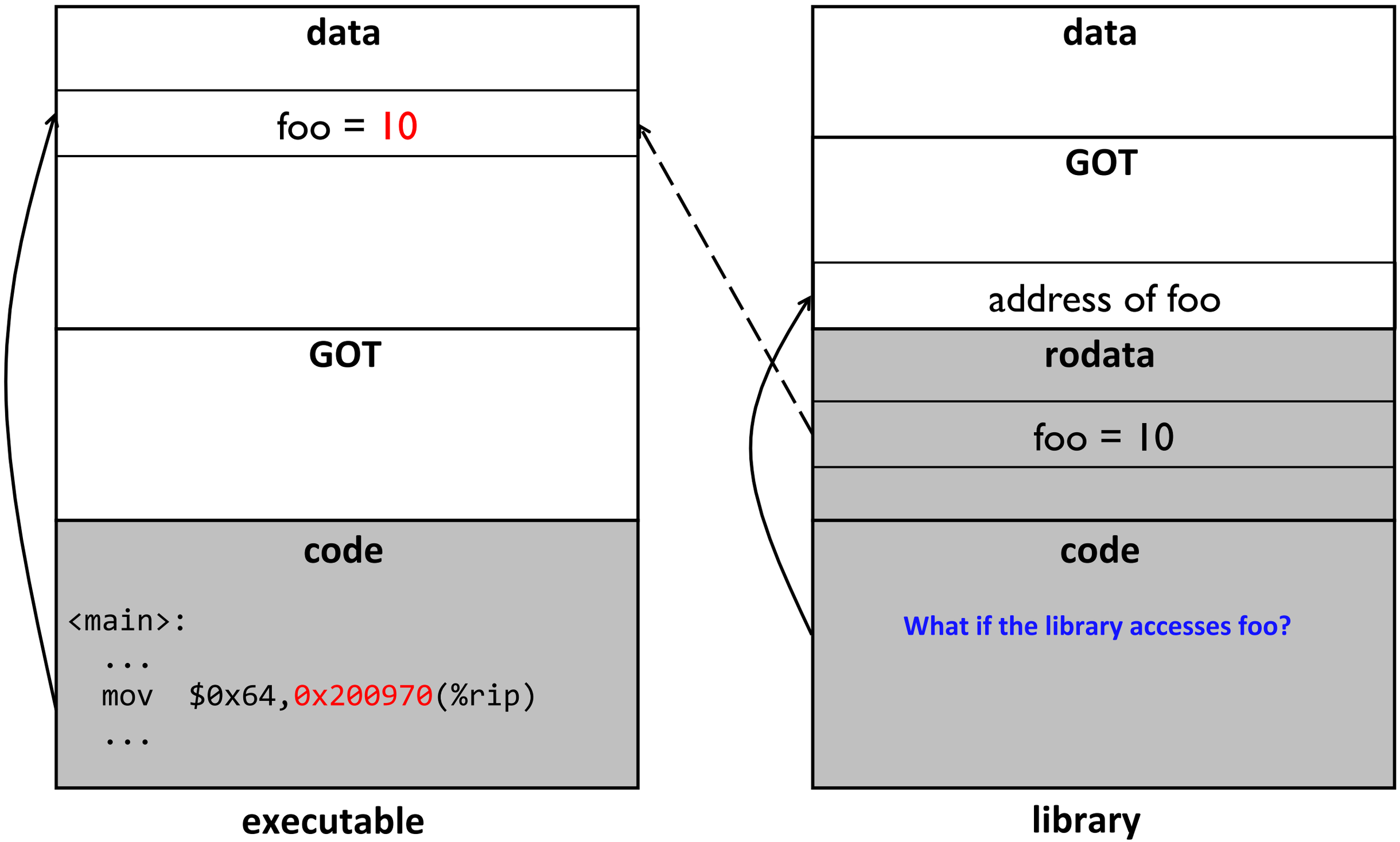
Questions

Variable Type Inference

- Requirements
  - No source code
  - No debug information

- Heuristics
  - Pointers:
    - Use relocation information to identify pointers in general
    - Use pointer value to determine code pointer vs data pointer
  - Strings:
    - All bytes are ASCII characters
    - Use '/' to determine file paths and '%' to determine format strings

Copy Relocation



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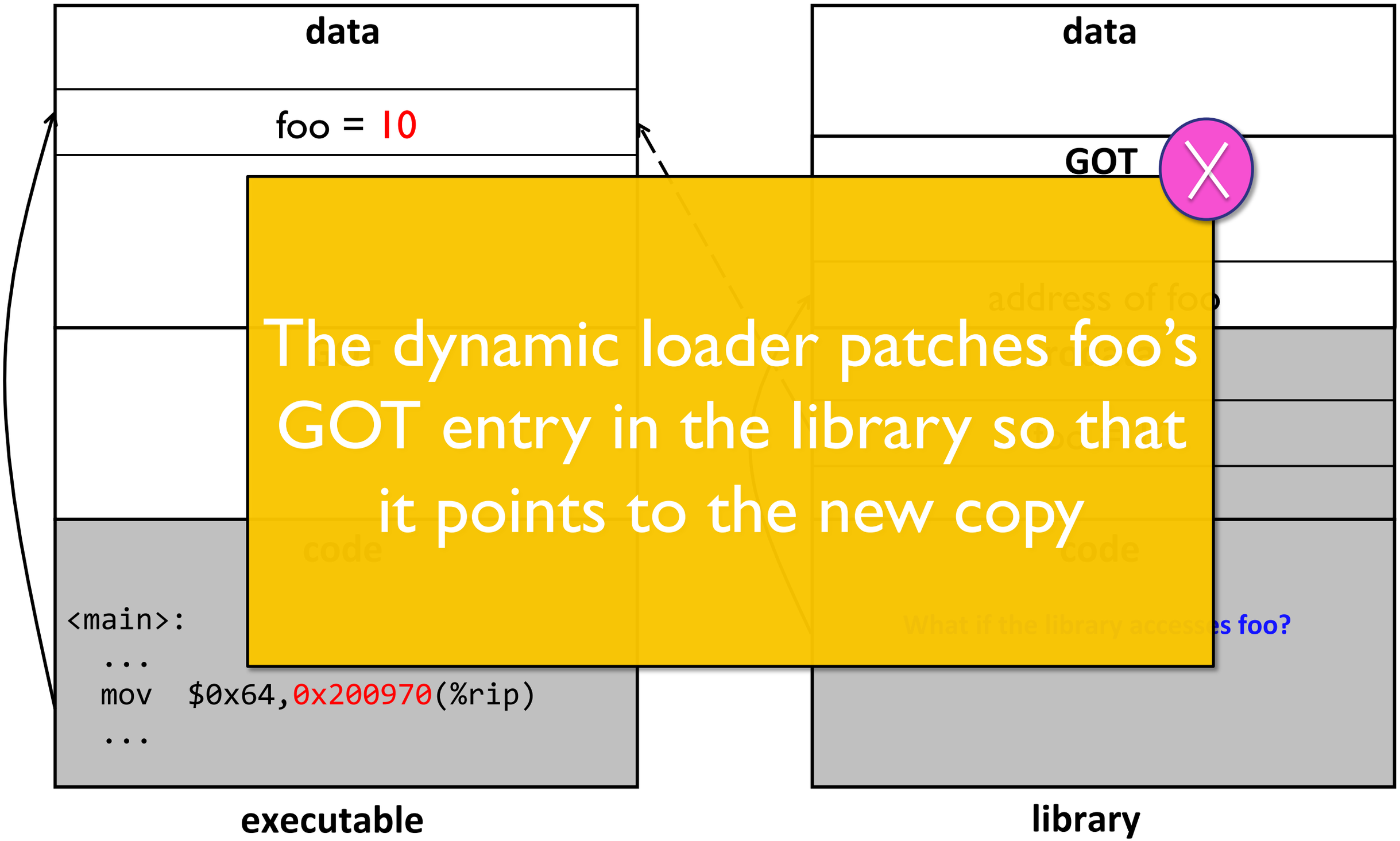
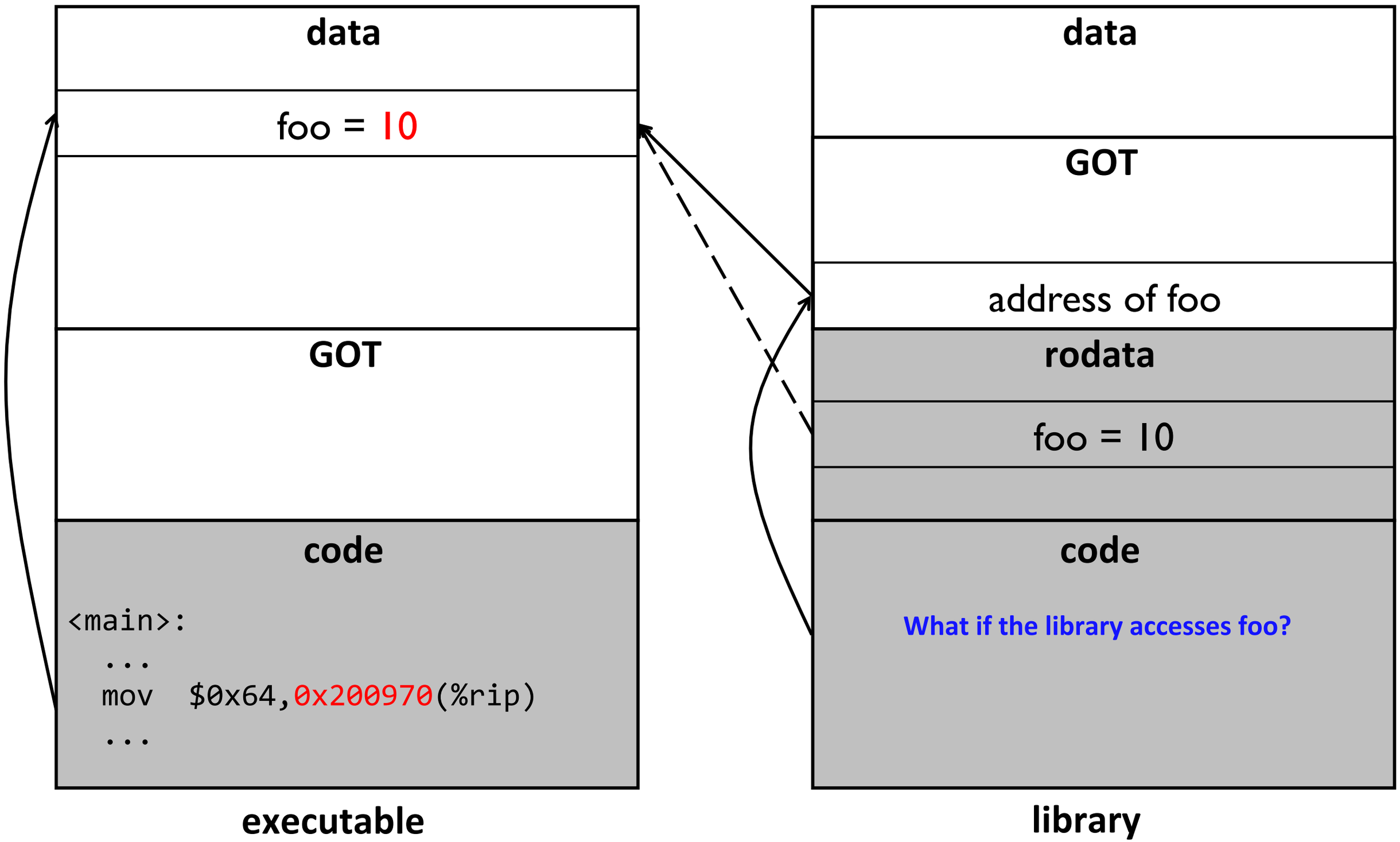


The dynamic loader patches foo's GOT entry in the library so that it points to the new copy

Copy Relocation



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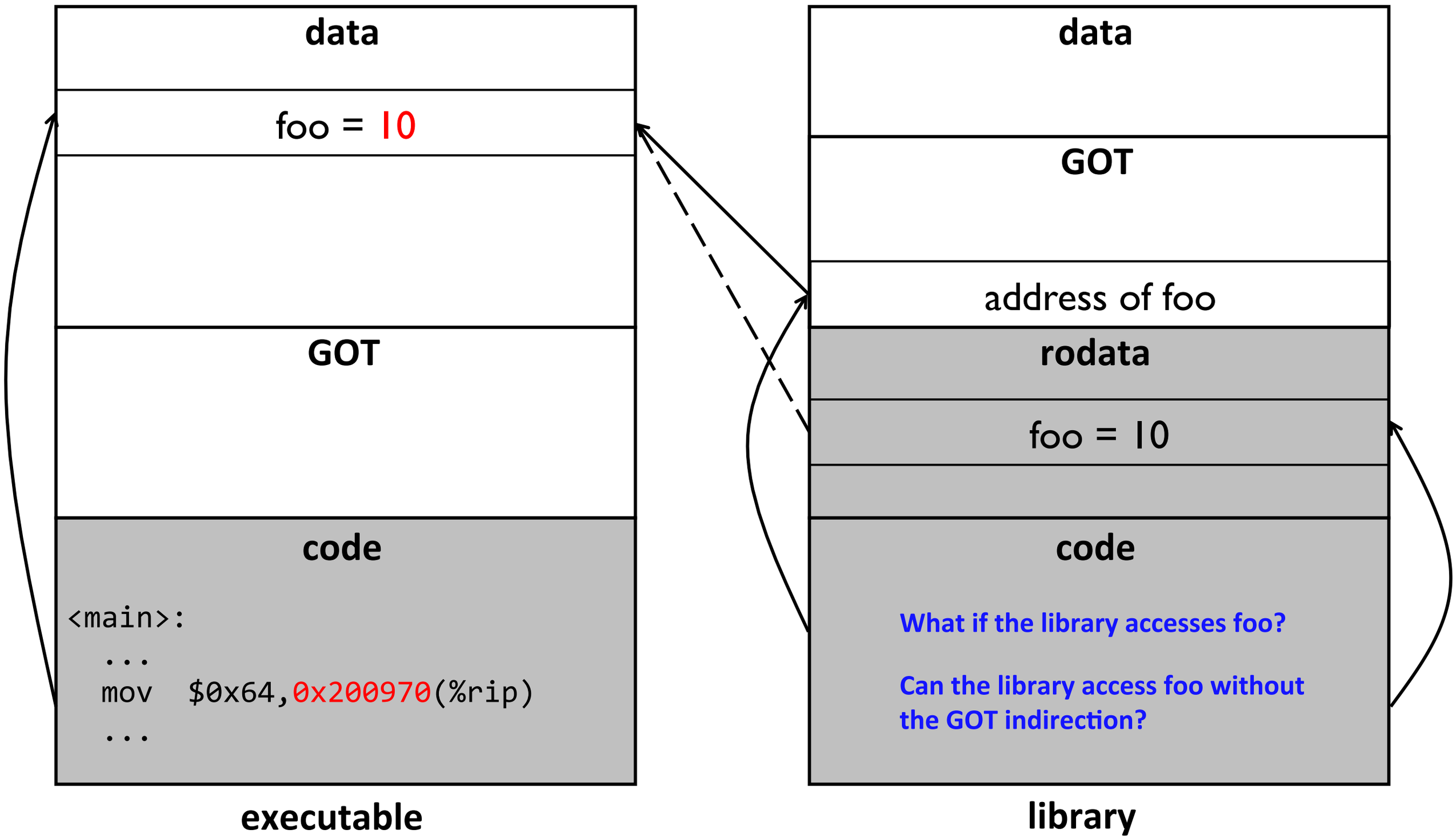

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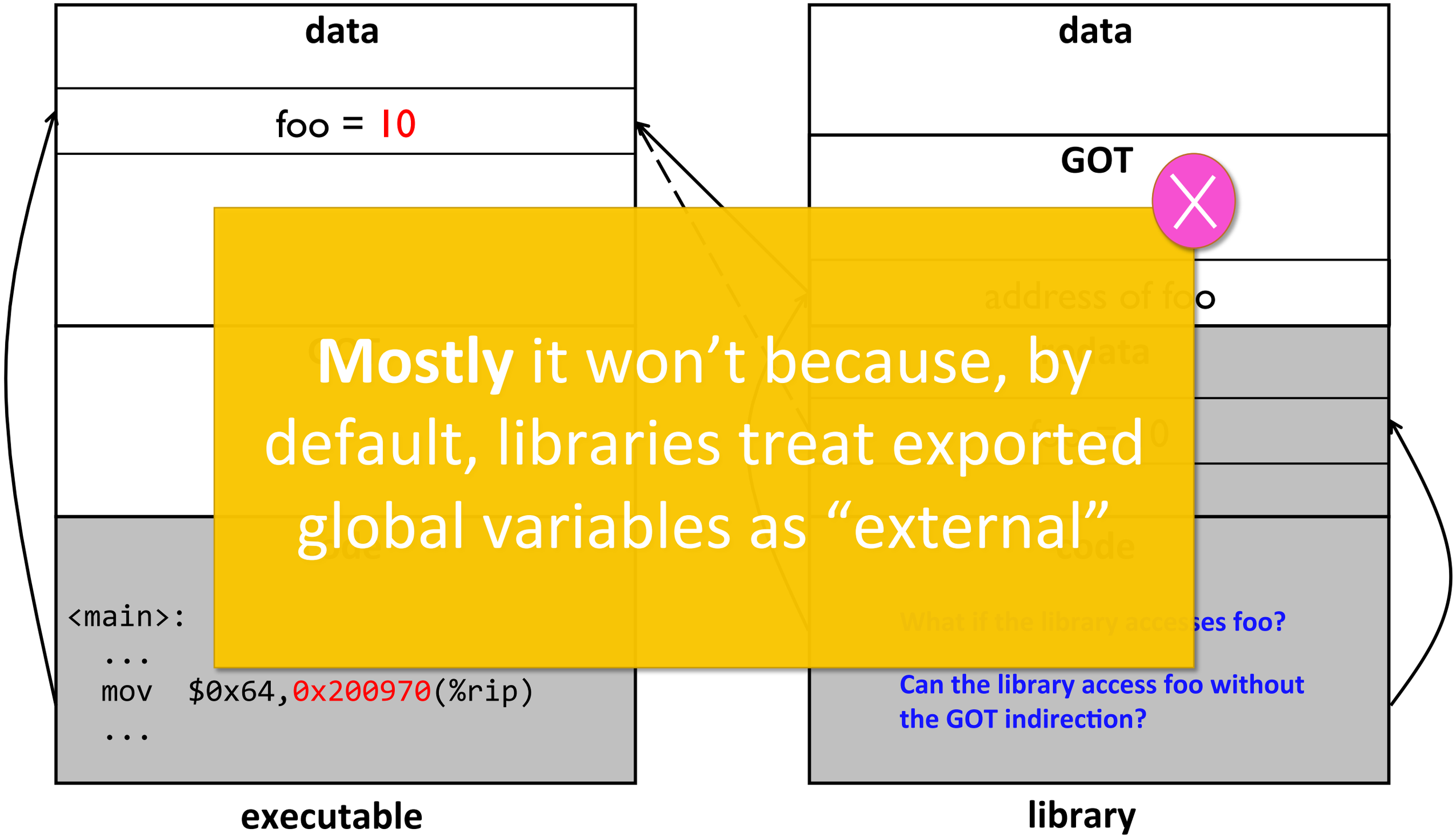
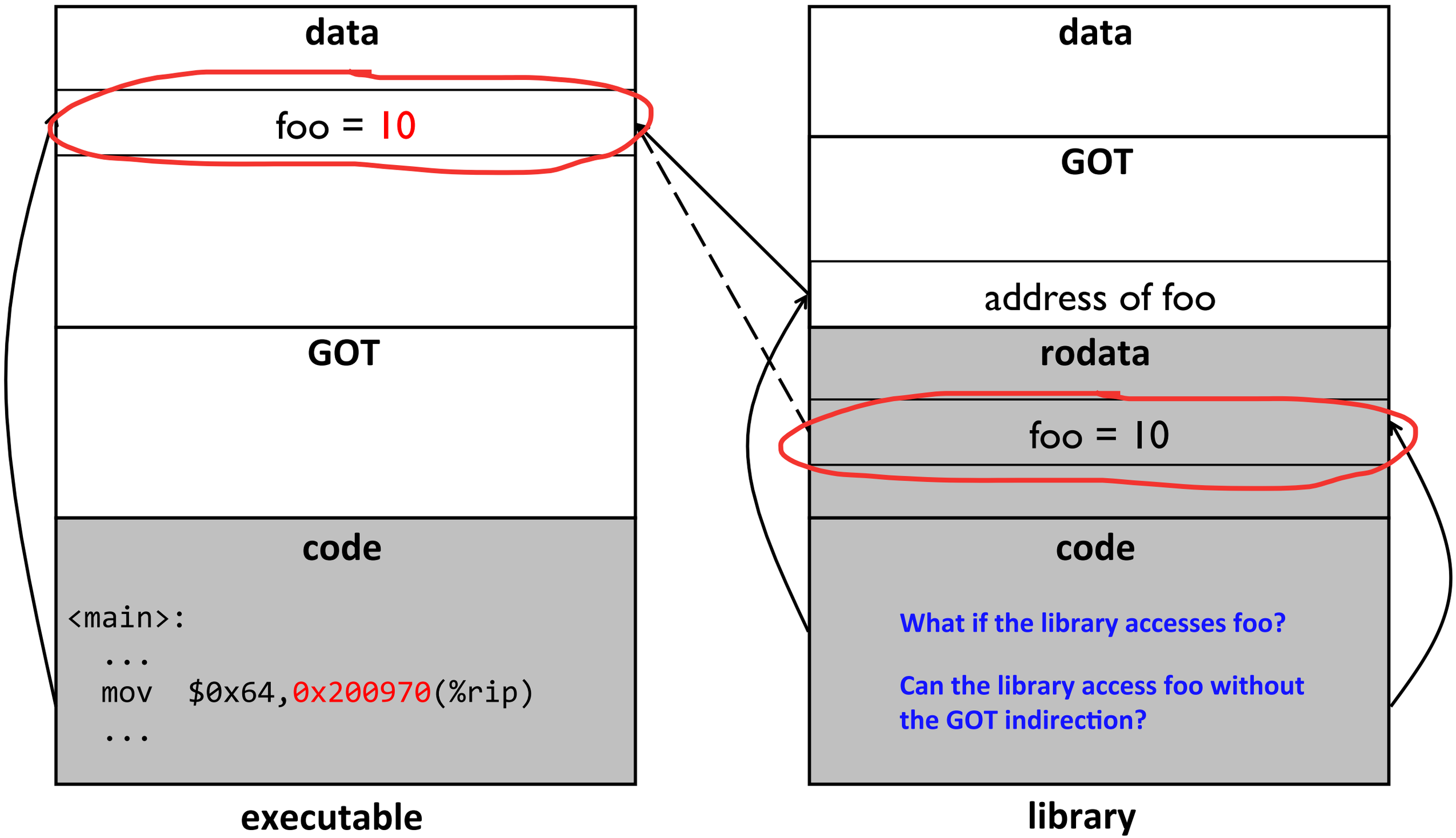


Mostly it won't because, by default, libraries treat exported global variables as "external"

Copy Relocation



Copy Relocation Violation