CS451 – Software Analysis

Lecture 4
Handling Library Functions

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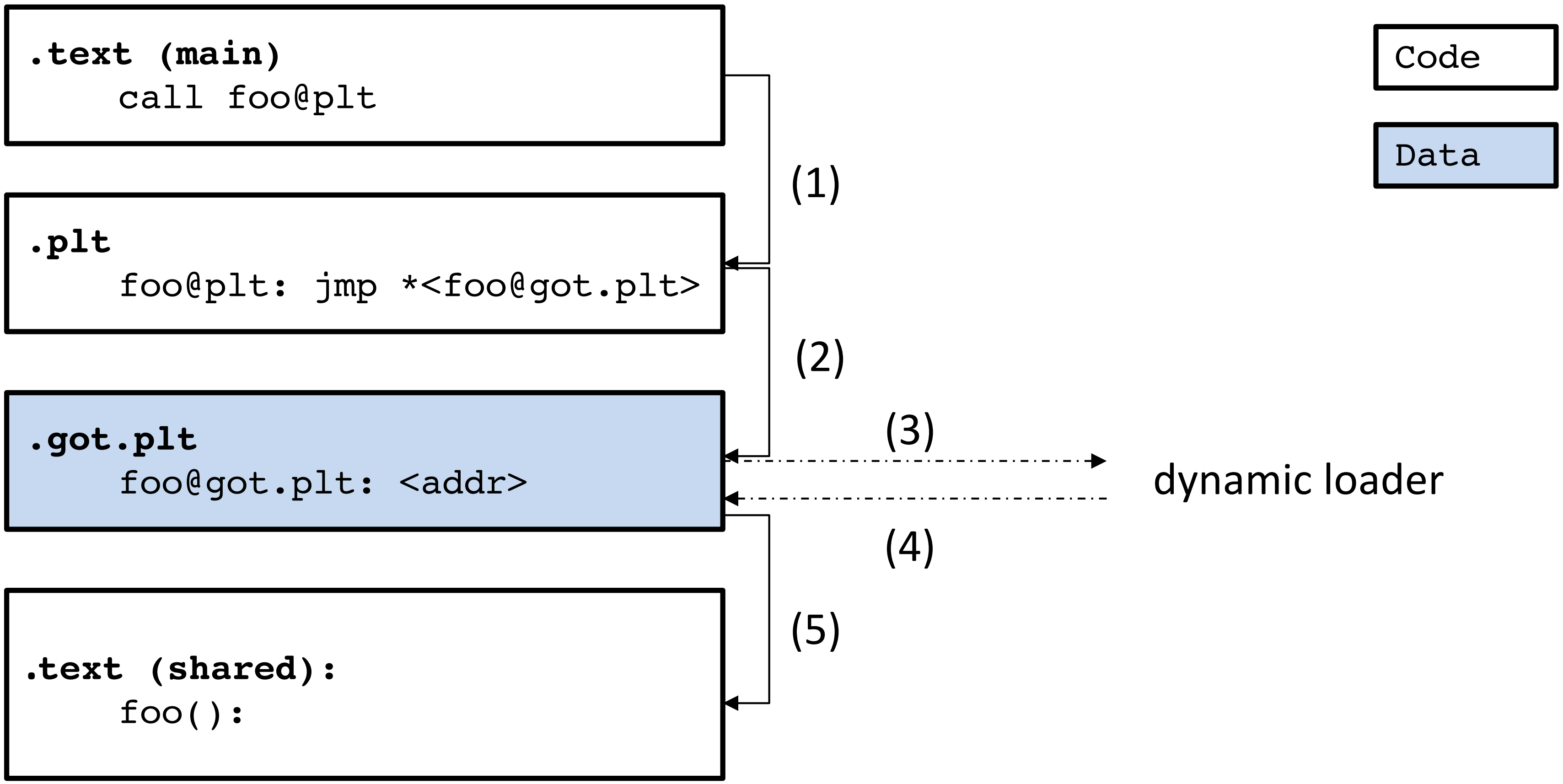
Library Functions

- Binaries call library functions
  - This code is located in a shared library
- Library functions do not generate events in the operating systems as system calls do
  - However, we can use ptrace() with a combination of other techniques to inspect library functions
  - This is how debuggers create breakpoints
- Since library functions are in shared libraries we can use another interesting direction to inspect and modify binary code

Shared libraries

- Recall that shared libraries host code that is used by many processes
- Recall that a library function is actually resolved at run-time
  - Using the PLT and the GOT
- The dynamic loader is *fixing* the address of the library function during the first call
  - Can we trick the loader to fix the address with the one we control?

Recall

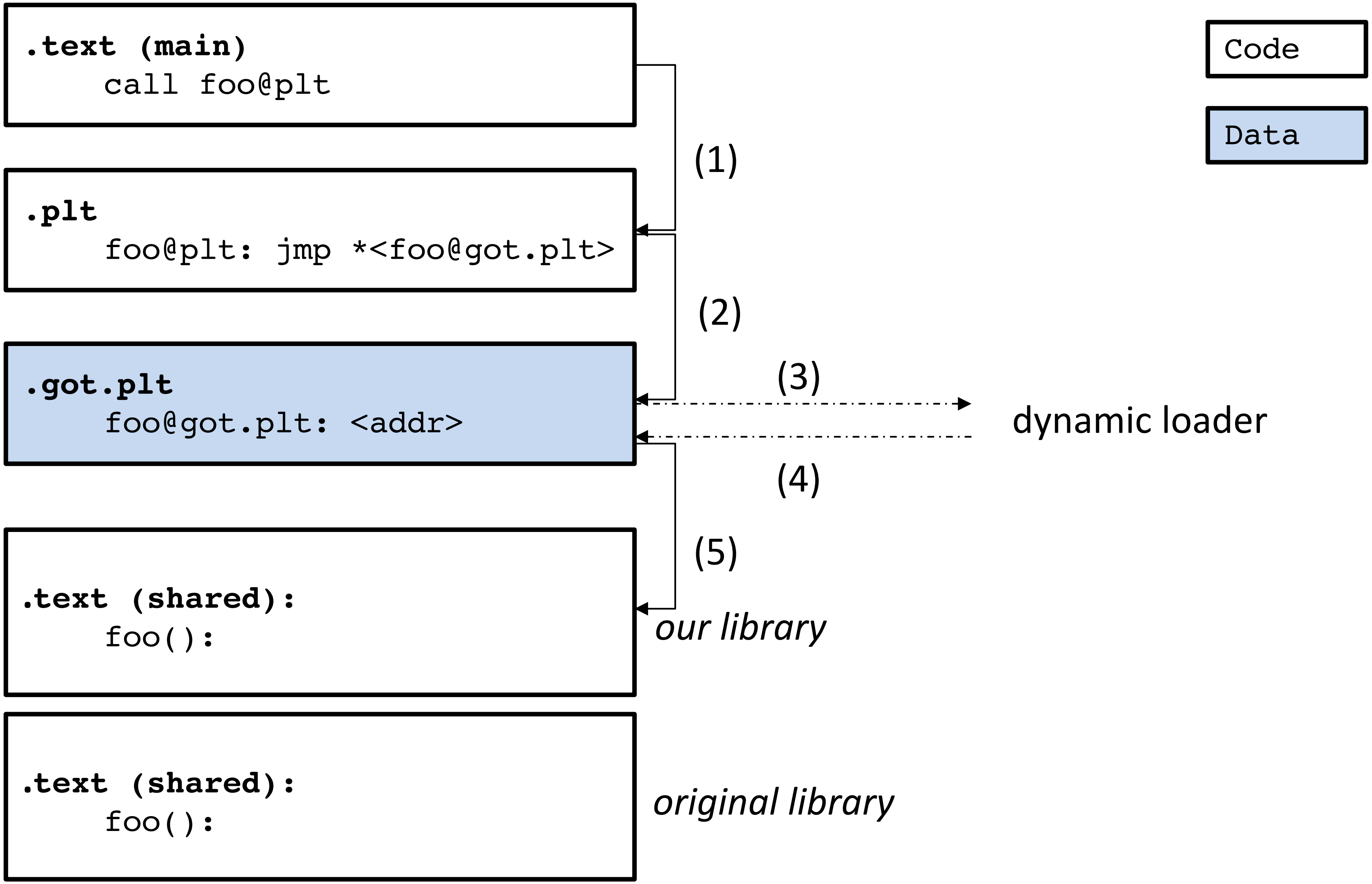


.text (main)
call foo@plt
.plt
foo@plt: jmp *<foo@got.plt>
.got.plt
foo@got.plt: <addr>
.text (shared):
foo():
(1)
(2)
(3)
(4)
(5)
dynamic loader
Code
Data

Dynamic loader resolution

- The same symbol may be available in multiple shared libraries
  - The dynamic loader will find the first one available
- If we can load a shared object first, that contains the exact same symbol, we can force the dynamic loader to use our code
  - Therefore, upon the library call, we will be able to execute our version of the library function
  - Our version may do simply nothing but call the original version (accounting)

The idea in high level



Load our library first

- We can force a program to load any shared library first using the LD_PRELOAD environment variable

```
$ LD_PRELOAD=./libfirst.so <program>
```

Preloaded object

- The preloaded shared library must have all symbols we need to replace
- Each symbol needs to have identical definition with the original one
- E.g., if we need to hook malloc() we need to provide a new implementation
  - The definition of our malloc() needs to be identical with the definition of the original malloc
  - If the definitions are different, then replacing the two symbols may cause the running program to crash

Inside the hook

- Our version of the library function can do different things
  - It can totally replace the functionality of the original function
  - It can provide some extra functionality on top of the original one
- In the second case, we need to be able to call the original function

Calling the original function

- The dynamic loader exports an API which we can use
- The API is implemented libdl.so
- The API contains functions for manually resolving specific symbols

```
typedef void *(*real_malloc_t)(size_t);
static real_malloc_t real_malloc = NULL;

real_malloc = (real_malloc_t) dlsym(RTLD_NEXT, "malloc");
```

Example of a memory profiler

- Memory management is realized by custom allocators that follow different strategies
- By default, libc.so offers a simple allocator, but more complicated programs may have their own
  - E.g., all web browsers have custom allocator implementations to separate the JS heap from the browser's heap
- Whichever allocator you use, the API is the same
  - Based on malloc(), calloc(), free(), etc.
- We can develop a memory profiler, that can simply count the number of malloc() and free() calls

Replacing malloc

- Our implementation increases a global counter and calls the original malloc() for handling the allocation

```
typedef void *(*real_malloc_t)(size_t);
static real_malloc_t real_malloc = NULL;

void * malloc(size_t size) {
    if (!real_malloc) {
        real_malloc = (real_malloc_t) dlsym(RTLD_NEXT, "malloc");
        if (!real_malloc) {
                die("real malloc problem: %s", dlerror());
        }
    }
    void *p = (void *)real_malloc(size);
    stats_total_malloc++;

    return p;
}
```

Replacing free

- Our implementation increases a global counter and calls the original free() to handle the deallocation

```c
typedef void *(*real_free_t)(void *);
static real_free_t real_free = NULL;

void free(void *ptr) {
    if (!real_free) {
        real_free = (real_free_t)dlsym(RTLD_NEXT, "free");
        if (!real_free)
            die("real free problem: %s", dlerror());
    }
    real_free(ptr);
    stats_total_free++;
    return;
}
```

How to print the statistics?

- C allows a process to execute a constructor and/or a destructor
  - main() is not the first function executed, in practice
- A destructor is the ideal place to insert code for printing the stats

```
__attribute__((destructor)) static void stats(void) {
    printf("malloc() calls: %ld\n", stats_total_malloc);
    printf("free() calls recorded: %ld\n", stats_total_free);
}
```

Some extra bits

- We need to define _GNU_SOURCE before dlfcn.h (the dynamic loader supported functions) for making RTLD_NEXT visible
  - This is for compatibility with other Unix systems

Example program to preload

```
#include <stdlib.h>

int main(int argc, char *argv[]) {

    for (int i = 0; i < 1028; i++) {
        void *p = malloc(16);
        if (i % 2) free(p);
    }

    return 1;
}
~
```

Compile and run

```
$ gcc -Wall -shared -fPIC -ldl memprofiler.c
-o libmemprofiler.so

$ gcc -Wall example.c -o example

$ LD_PRELOAD=./libmemprofiler.so ./example
malloc() calls recorded: 1028
free() calls recorded: 514
```

Homework

- Replace another library function call with one of your own
- Can you add some printing features inside malloc/free replacements?
  - I.e., print the size of the allocation
  - Beware, this can be a tricky task