# How the ELF ruined Christmas

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24th USENIX Security Symposium

# Overview

We're going to present an exploitation technique

1. able to call arbitrary library functions
2. not requiring a memory leak vulnerability
3. bypassing specific protections such as ASLR and RELRO

# Index

# The exploitation process

1. Find a useful vulnerability
2. Get control of the IP
3. Perform the desired actions

Our focus is on the last step

# *The IP is not enough*

- Controlling the IP is not enough
- The problem is then *where* to point execution

# The typical situation

- Suppose the main binary is not randomized (no PIE)
- Typically, to bypass ASLR, attackers...
  1. Leak the address of an imported function (e.g. printf)
  2. Compute the address of the target function (e.g. execve)
  3. Divert the execution to the computed address

$$\text{target} = \text{addressOf}(\textit{printf}) - \text{distance}(\textit{printf}, \textit{execve})$$

# The problem

- Requires a memory leak vulnerability
- Requires knowledge of the layout of the library
- Requires an interaction between the victim and the attacker

# Let’s re-think the attack

What are we trying to do?

We're trying to obtain the address of an arbitrary library function

But we already have
an OS component for that!

# Introducing...

The dynamic loader

# Index

- The exploit
- The dynamic loader
- The attacks
- RELRO
- Implementation
- Recap & countermeasures

# The dynamic loader

- The role of the dynamic loader is to resolve symbols
- An ELF executable imports a function from a library
- The dynamic loader provides it with its address

# Lazy loading in ELF

- The ELF standard provides a way to resolve function lazily
- This means that a function is resolved only if called

# Calling a library function

```
int main() {
  printf("Hello world!\n");
  return 0;
}
```

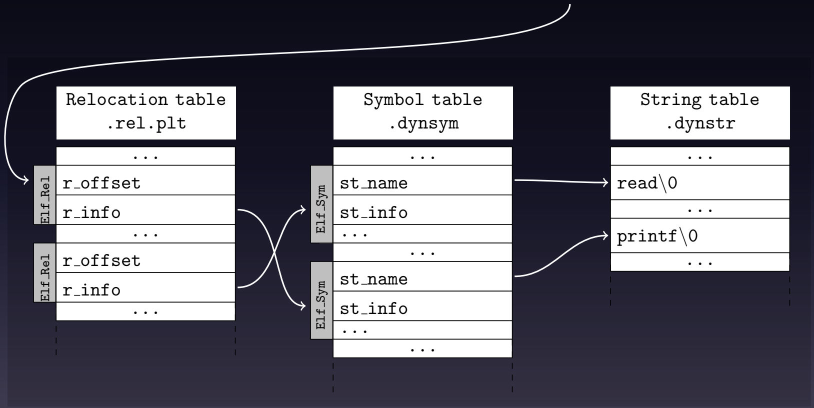
# Calling a library function

```
int main() {
  printf@plt("Hello world!\n");
  return 0;
}
```

# printf@plt pseudocode

```
int printf@plt(...) {
  if (first_call) {
    // Find printf, cache its address in the GOT
    // and call it
    _dl_runtime_resolve(elf_info, printf_index);
  } else {
    jmp *(printf_got_entry)
  }
}
```

_dl_runtime_resolve(elf_info, printf_index)



# Index

# The attack scenario

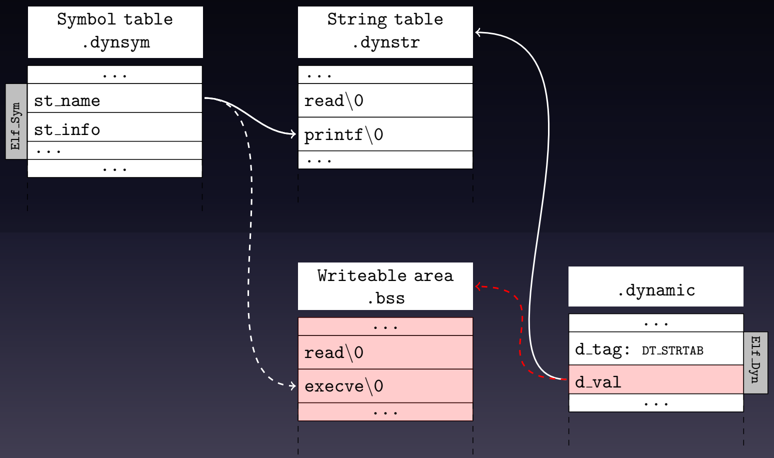
Suppose that:

- our exploit is able to run a ROP chain
- we can call `_dl_runtime_resolve`[1]
- the main binary has simple gadgets to write in memory

[1] There's a reserved GOT entry for it

Suppose we're able to force the loader to use a fake string table

We can replace `printf` with `execve`,
and force its resolution



Symbol table
.dynsym
...
Elf_Sym
st_name
st_info
...
...
String table
.dynstr
...
read\0
printf\0
...
Writeable area
.bss
...
read\0
execve\0
...
.dynamic
...
d_tag: DT_STRTAB
d_val
...
Elf_Dyn

# Index

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# RELocation ReadOnly

- RELRO is a binary hardening technique
- It aims to prevent attacks as those just described
- It’s available in two flavors: partial and full

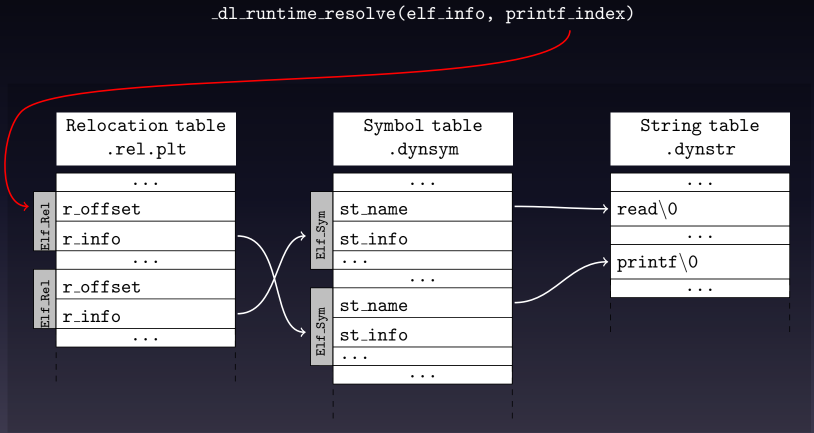
# Partial RELRO

- Some fields of `.dynamic` must be initialized at run-time
- This is the reason it's not marked as read-only in the ELF
- With partial RELRO[2] it is marked R/O after initialization

[2] `gcc -Wl,-z,relro`

The previous attack doesn’t work anymore

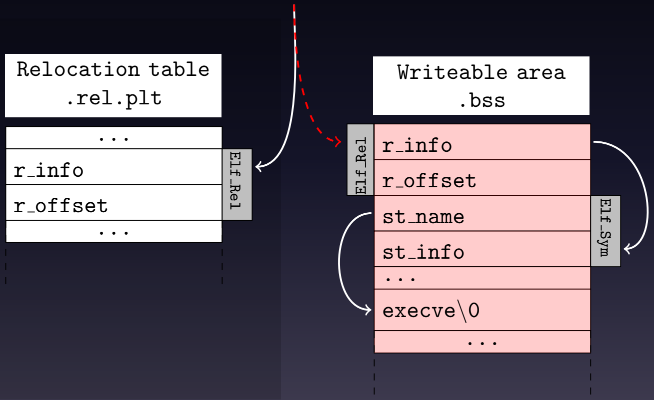
# Another idea



# What's after the relocation table?

```
$ readelf –S /bin/echo
Section Headers:
[Nr] Name      Addr     Flg
[ 5] .dynsym   08048484  A  [symbol table]
[ 6] .dynstr   080487f4  A  [string table]
[10] .rel.plt  08048b5c  A  [relocation table]
[21] .dynamic  0804fefc WA  [dynamic section]
[23] .got.plt  0804fff4 WA  [GOT]
[25] .bss      08050120 WA  [we can write here]
```

_dl_runtime_resolve(elf_info, printf_index)



This approach does not always work

[3] More details on the paper

# This approach does not always work

- If the dynamic loader checks the boundaries
- If symbol versioning and huge pages are enabled[3]

[3] More details on the paper

# Another option

```
_dl_runtime_resolve(elf_info, printf_index);
```

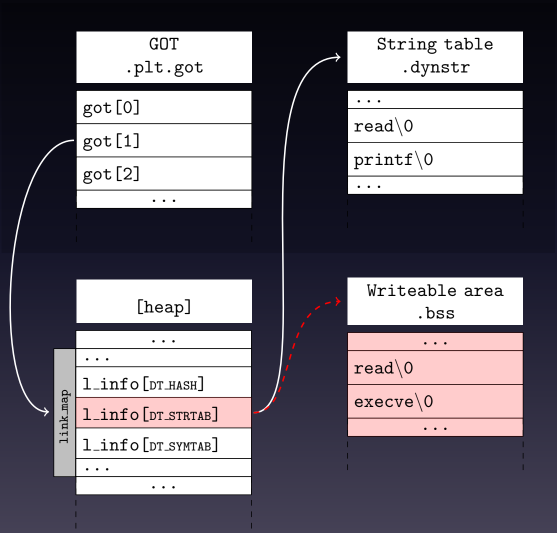
- We tried to abuse `printf_index`
- What about `elf_info`?
- Points to a `link_map` data structure
- It's available in a reserved entry in the `GOT`

# Another option

`link_map` keeps a pointer to the dynamic string table

# Another option

If we tamper with it we get back to the first attack


GOT
.plt.got
got[0]
got[1]
got[2]
...
String table
.dynstr
...
read\0
printf\0
...
[heap]
...
...
l_info[DT_HASH]
l_info[DT_STRTAB]
l_info[DT_SYMTAB]
...
...
link_map
Writeable area
.bss
...
read\0
execve\0
...

# The full RELRO situation

- Full RELRO[4] basically disables lazy loading
- All the functions are resolved at startup
- Some pointers are not initialized
- We lose the references to:
  - `_dl_runtime_resolve`
  - `elf_info`, i.e. the `link_map` data structure

[4] `gcc -Wl,-z,relro,-z,now`

# DT_DEBUG to the rescue

- The `.dynamic` section has a `DT_DEBUG` entry
- Points to a debug data structure
- It's used by gdb to track the loading of new libraries

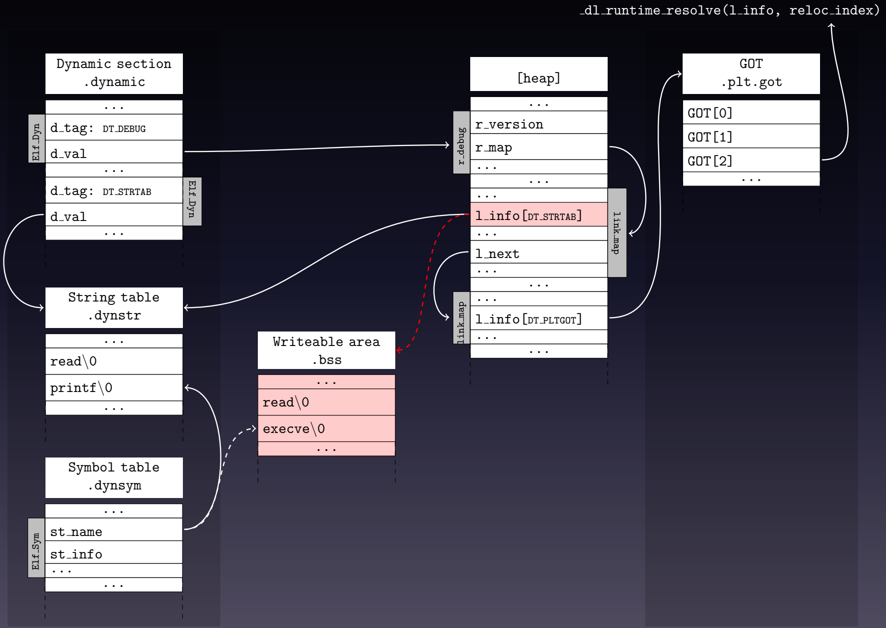
It holds a pointer to `link_map`!

# What about `_dl_runtime_resolve`?

- Full RELRO is typically applied to the main binary only
- Libraries' GOT still has a pointer to `_dl_runtime_resolve`
- How can we get to the memory area of a library?

# Traversing `link_map`

- `link_map` is part of a linked-list
- If we go to the next entry we can reach libraries' `link_map`
- From there we can get to their GOT



_dl_runtime_resolve(l_info, reloc_index)
Dynamic section
.dynamic
...
Elf_Dyn
d_tag: DT_DEBUG
d_val
...
d_tag: DT_STRTAB
d_val
...
Elf_Dyn
String table
.dynstr
...
read\0
printf\0
...
Symbol table
.dynsym
...
Elf_Sym
st_name
st_info
...
...
Writeable area
.bss
...
read\0
execve\0
...
[heap]
...
r_debug
r_version
r_map
...
...
...
l_info[DT_STRTAB]
...
l_next
...
link_map
...
...
link_map
l_info[DT_PLTGOT]
...
...
GOT
.plt.got
GOT[0]
GOT[1]
GOT[2]
...

# Index

# leakless

- leakless implements all these techniques
- Automatically detects which is the best approach
- Outputs:
  - Instructions on where to write what
  - If provided with gadgets, the ROP chain for the attack
- Check it out at

https://github.com/ucsb-seclab/leakless

# Gadgets

| Gadget | Attack 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| $\star(\textit{destination}) = \textit{value}$ | ✓ | ✓ | ✓ | ✓ |
| $\star(\star(\textit{pointer}) + \textit{offset}) = \textit{value}$ | | | ✓ | ✓ |
| $\star(\textit{destination}) = \star(\star(\textit{pointer}) + \textit{offset})$ | | | | ✓ |
| $\star(\textit{stack\_pointer} + \textit{offset}) = \star(\textit{source})$ | | | | ✓ |

# What loaders are vulnerable?

We deem vulnerable:

- The GNU C Standard Library (glibc)
- dietlibc, uClibc and newlib
- OpenBSD’s and NetBSD’s loader

Not vulnerable:

- Bionic (PIE-only)
- musl (no lazy loading)
- (FreeBSD’s loader)

# Index

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What are the advantages of leakless?

# 1. Single stage

- It doesn’t require a memory leak vulnerability
- It doesn’t require interaction with the victim
- “Offline” attacks are now feasible!

# 2. Reliable and portable

- If feasible, the attack is deterministic
- A copy of the target library is not required
- Since it mostly relies on ELF features it's portable
- Exception: `link_map`, but it's just minor fixes

# 3. Short

- One could implement the loader in ROP
  - longer ROP chains
  - increased complexity

# 4. Code reuse and stealthiness

- Everything is doable with syscalls
- But it's usually more invasive
- With leakless you can do this:

# Pidgin example

```
void *p , *a;
p = purple_proxy_get_setup(0);
purple_proxy_info_set_host(p, "legit.com");
purple_proxy_info_set_port(p, 8080);
purple_proxy_info_set_type(p, PURPLE_PROXY_HTTP);

a = purple_accounts_find("usr@xmpp", "prpl-xmpp");
purple_account_disconnect(a);
purple_account_connect(a);
```

# 5. Automated

- leakless automates most of the process
- The user only needs to provide gadgets

# Countermeasures

- Use PIE
- Use full RELRO everywhere
- Disable `DT_DEBUG` if not necessary
- Make loader’s data less accessible
- Isolate the dynamic loader

# Conclusion

Binary formats and core system components
should be designed, and implemented,
with security in mind

# Thanks

# License