Address Space Layout Randomization (ASLR)

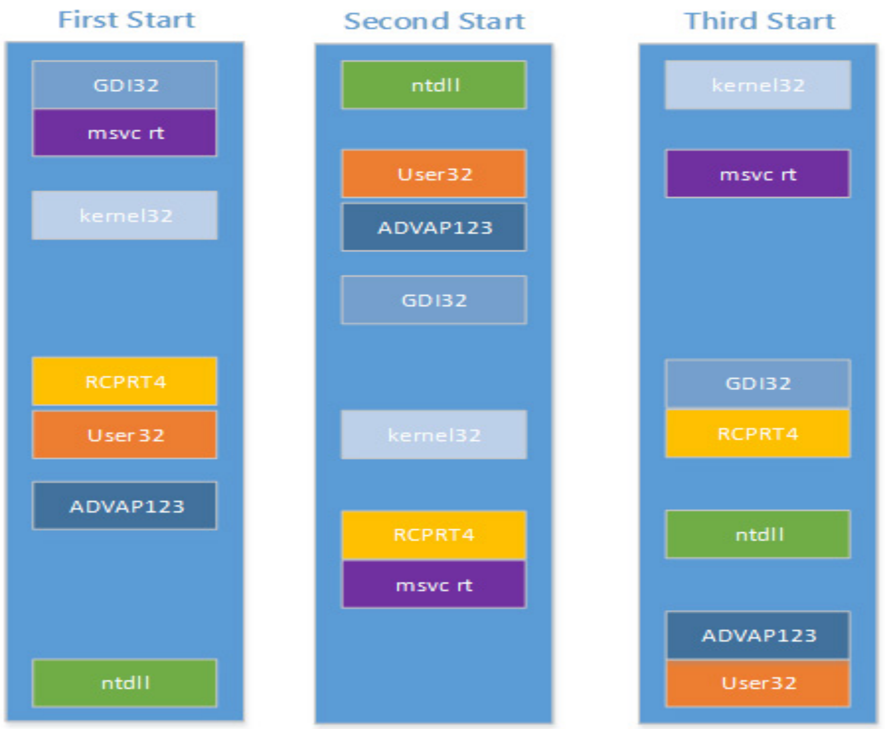
The Attacker’s Plan

- Find the bug in the source code (for eg. Kernel) that can be exploited
  - Eyeballing
  - Noticing something in the patches
  - Following CVE
- Use that bug to insert malicious code to perform something nefarious
  - Such as getting root privileges in the kernel

Attacker depends upon knowing where these functions reside in memory. Assumes that many systems use the same address mapping. Therefore one exploit may spread easily.

Address Space Randomization

- Address space layout randomization (ASLR) randomizes the address space layout of the process
- Each execution would have a different memory map, thus making it difficult for the attacker to run exploits
- Initiated by Linux PaX project in 2001
- Now a default in many operating systems



Memory layout across boots for a Windows box

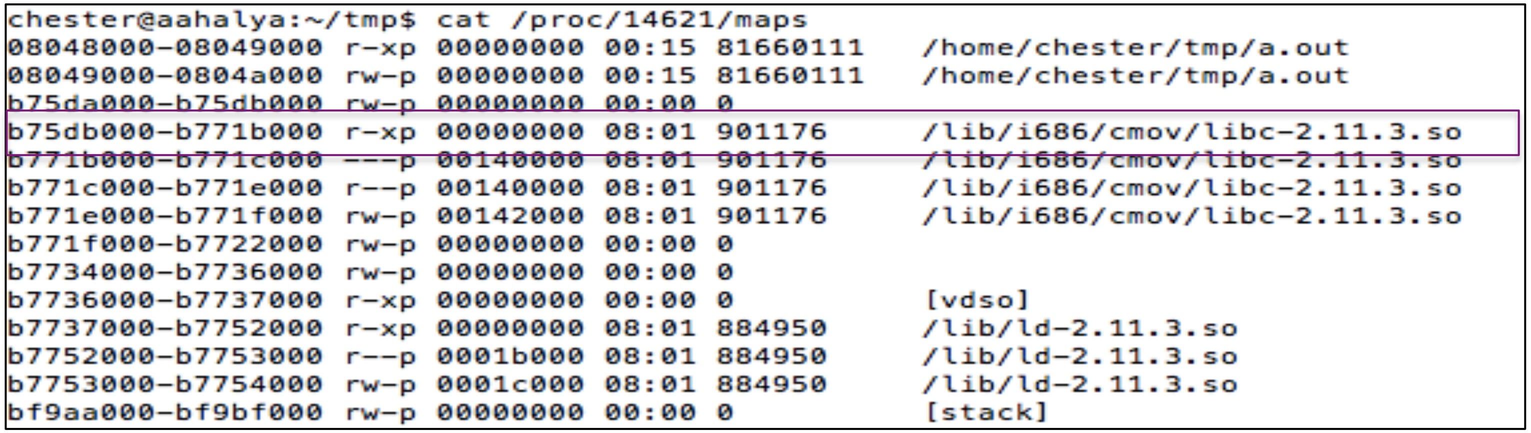
ASLR in the Linux Kernel

- Locations of the base, libraries, heap, and stack can be randomized in a process' address space

- Built into the Linux kernel and controlled by /proc/sys/kernel/randomize_va_space

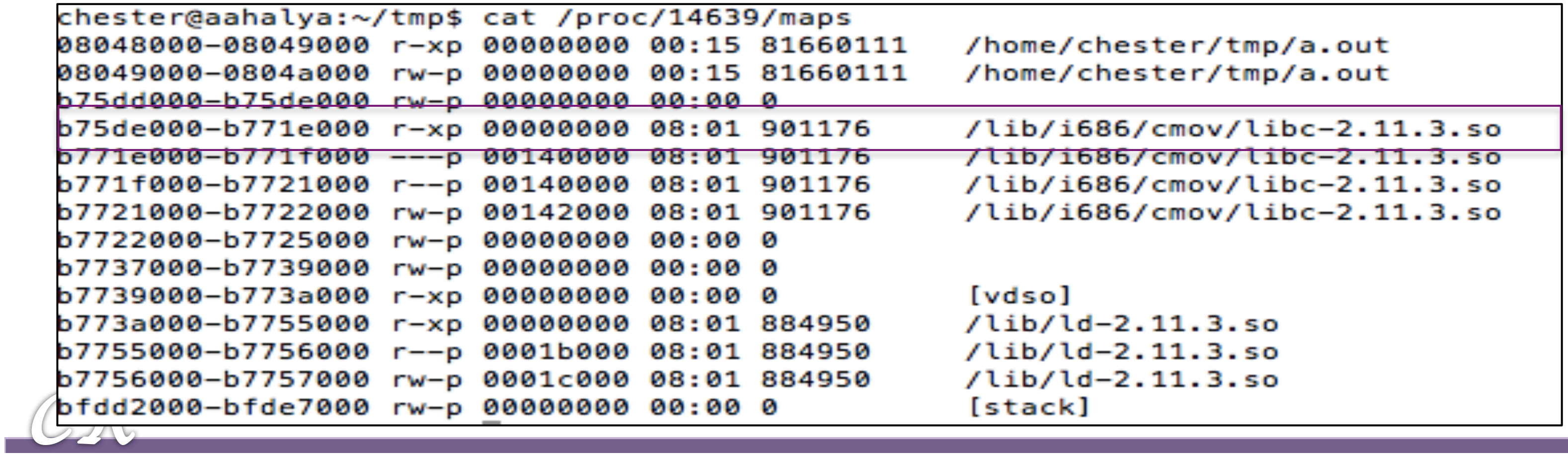
- randomize_va_space can take 3 values
  0 : disable ASLR
  1 : positions of stack, VDSO, shared memory regions are randomized
  the data segment is immediately after the executable code
  2 : (default setting) setting 1 as well as the data segment location is randomized

ASLR in Action



```
chester@aahalya:~/tmp$ cat /proc/14621/maps
08048000-08049000 r-xp 00000000 00:15 81660111   /home/chester/tmp/a.out
08049000-0804a000 rw-p 00000000 00:15 81660111   /home/chester/tmp/a.out
b75da000-b75db000 rw-p 00000000 00:00 0
b75db000-b771b000 r-xp 00000000 08:01 901176     /lib/i686/cmov/libc-2.11.3.so
b771b000-b771c000 ---p 00140000 08:01 901176     /lib/i686/cmov/libc-2.11.3.so
b771c000-b771e000 r--p 00140000 08:01 901176     /lib/i686/cmov/libc-2.11.3.so
b771e000-b771f000 rw-p 00142000 08:01 901176     /lib/i686/cmov/libc-2.11.3.so
b771f000-b7722000 rw-p 00000000 00:00 0
b7734000-b7736000 rw-p 00000000 00:00 0
b7736000-b7737000 r-xp 00000000 00:00 0          [vdso]
b7737000-b7752000 r-xp 00000000 08:01 884950     /lib/ld-2.11.3.so
b7752000-b7753000 r--p 0001b000 08:01 884950     /lib/ld-2.11.3.so
b7753000-b7754000 rw-p 0001c000 08:01 884950     /lib/ld-2.11.3.so
bf9aa000-bf9bf000 rw-p 00000000 00:00 0          [stack]
```

First Run



```
chester@aahalya:~/tmp$ cat /proc/14639/maps
08048000-08049000 r-xp 00000000 00:15 81660111   /home/chester/tmp/a.out
08049000-0804a000 rw-p 00000000 00:15 81660111   /home/chester/tmp/a.out
b75dd000-b75de000 rw-p 00000000 00:00 0
b75de000-b771e000 r-xp 00000000 08:01 901176     /lib/i686/cmov/libc-2.11.3.so
b771e000-b771f000 ---p 00140000 08:01 901176     /lib/i686/cmov/libc-2.11.3.so
b771f000-b7721000 r--p 00140000 08:01 901176     /lib/i686/cmov/libc-2.11.3.so
b7721000-b7722000 rw-p 00142000 08:01 901176     /lib/i686/cmov/libc-2.11.3.so
b7722000-b7725000 rw-p 00000000 00:00 0
b7737000-b7739000 rw-p 00000000 00:00 0
b7739000-b773a000 r-xp 00000000 00:00 0          [vdso]
b773a000-b7755000 r-xp 00000000 08:01 884950     /lib/ld-2.11.3.so
b7755000-b7756000 r--p 0001b000 08:01 884950     /lib/ld-2.11.3.so
b7756000-b7757000 rw-p 0001c000 08:01 884950     /lib/ld-2.11.3.so
bfdd2000-bfde7000 rw-p 00000000 00:00 0          [stack]
```

Another Run

ASLR in the Linux Kernel

- Permanent changes can be made by editing the /etc/sysctl.conf file

/etc/sysctl.conf, for example:

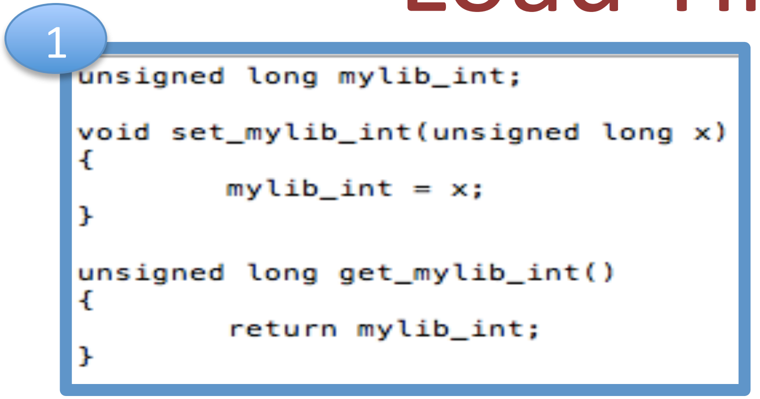
kernel.randomize_va_space = ***value***

sysctl -p

Internals : Making code relocatable

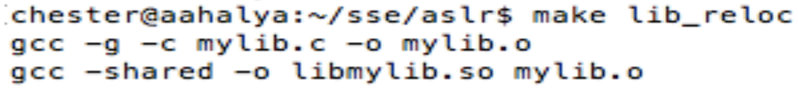
- **Load time relocatable**
  - where the loader modifies a program executable so that all addresses are adjusted properly
  - Relocatable code
    - Slow load time since executable code needs to be modified.
    - Requires a writeable code segment, which could pose problems
- **PIE : position independent executable**
  - a.k.a PIC (position independent code)
  - code that executes properly irrespective of its absolute address
  - Used extensively in shared libraries
    - Easy to find a location where to load them without overlapping with other modules

Load Time Relocatable



1

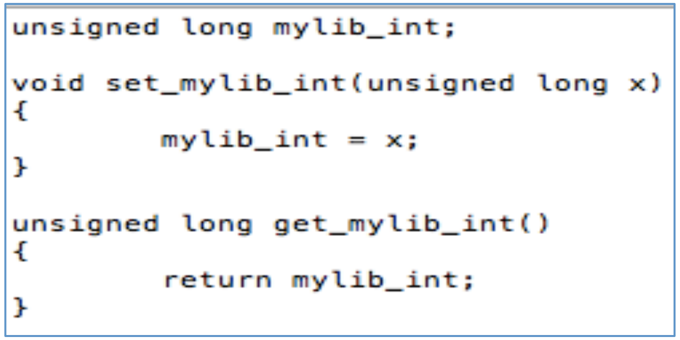
```
unsigned long mylib_int;

void set_mylib_int(unsigned long x)
{
        mylib_int = x;
}

unsigned long get_mylib_int()
{
        return mylib_int;
}
```



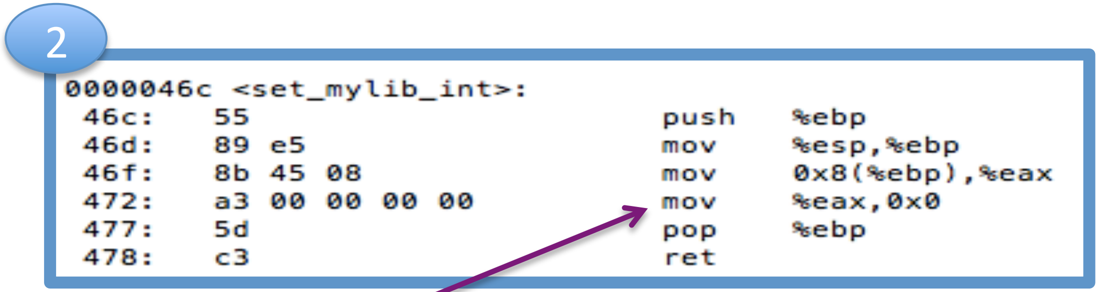
```
chester@aahalya:~/sse/aslr$ make lib_reloc
gcc -g -c mylib.c -o mylib.o
gcc -shared -o libmylib.so mylib.o
```

Refer https://chetrebeiro@bitbucket.org/casl/sse.git   (directory src/relocgot)

Load Time Relocatable



```
unsigned long mylib_int;

void set_mylib_int(unsigned long x)
{
        mylib_int = x;
}

unsigned long get_mylib_int()
{
        return mylib_int;
}
```

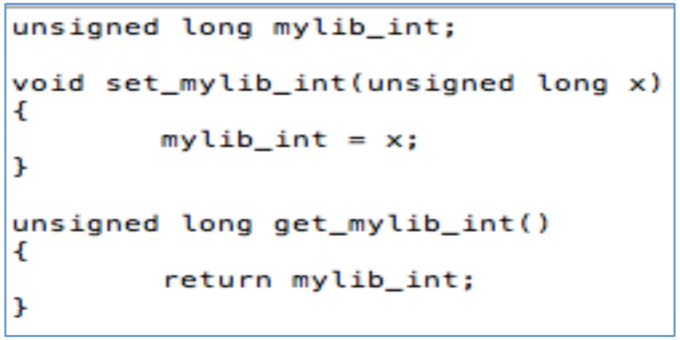


2

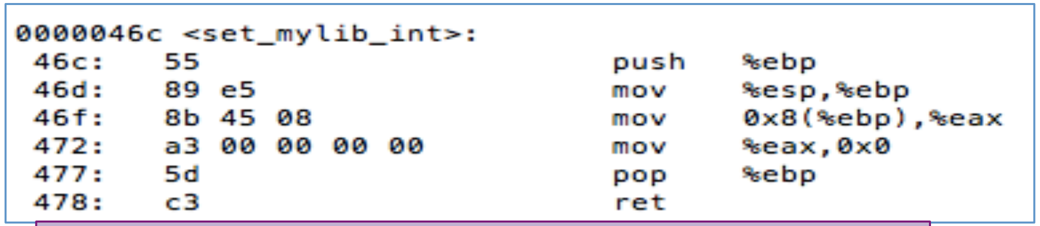
```
0000046c <set_mylib_int>:
 46c:    55                         push   %ebp
 46d:    89 e5                      mov    %esp,%ebp
 46f:    8b 45 08                   mov    0x8(%ebp),%eax
 472:    a3 00 00 00 00             mov    %eax,0x0
 477:    5d                         pop    %ebp
 478:    c3                         ret
```

note the 0x0 here…
the actual address of mylib_int is not filled in

Load Time Relocatable



```
unsigned long mylib_int;

void set_mylib_int(unsigned long x)
{
        mylib_int = x;
}

unsigned long get_mylib_int()
{
        return mylib_int;
}
```



```
0000046c <set_mylib_int>:
 46c:   55                          push   %ebp
 46d:   89 e5                       mov    %esp,%ebp
 46f:   8b 45 08                    mov    0x8(%ebp),%eax
 472:   a3 00 00 00 00              mov    %eax,0x0
 477:   5d                          pop    %ebp
 478:   c3                          ret
```

Relocatable table present in the executable that contains all references of mylib_int

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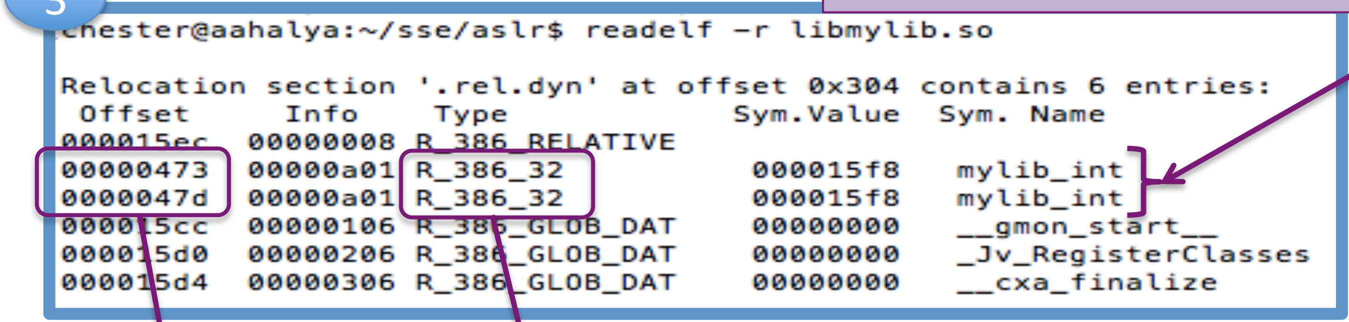
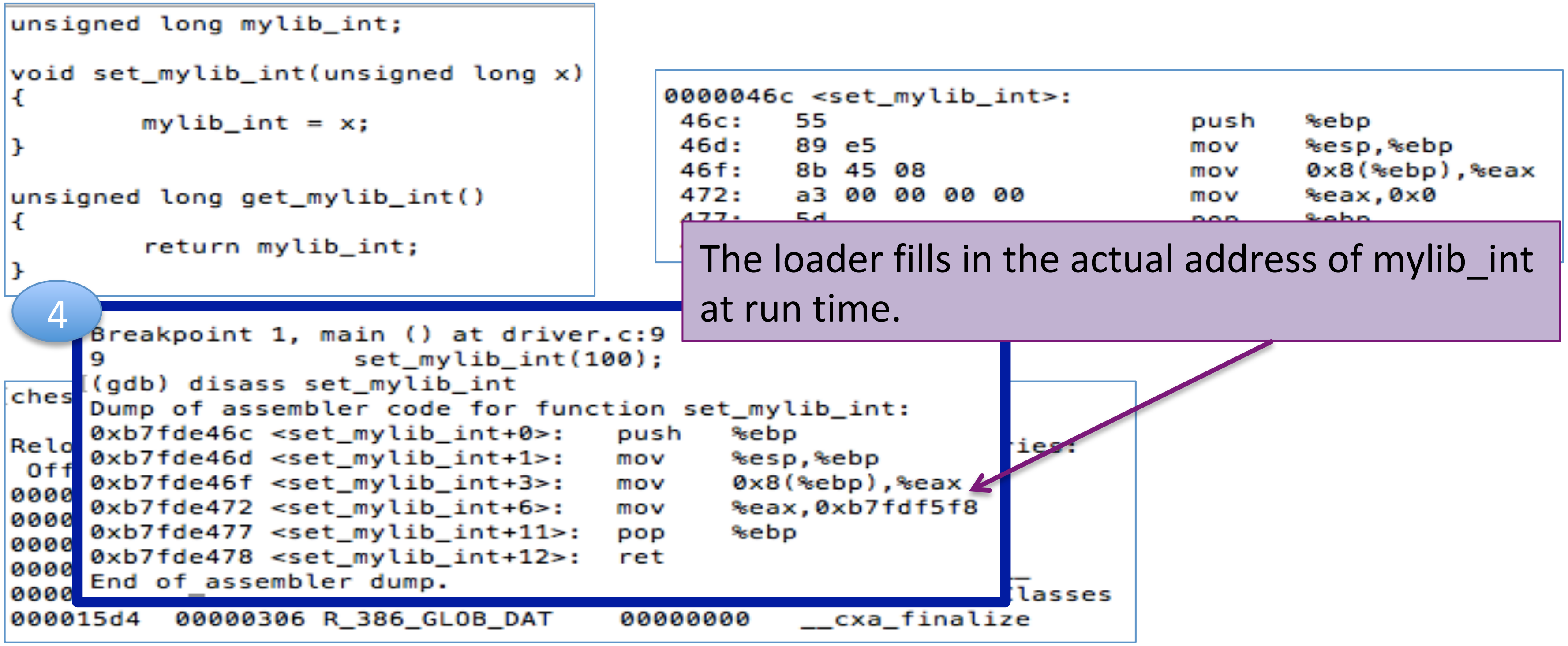


```
chester@aahalya:~/sse/aslr$ readelf -r libmylib.so

Relocation section '.rel.dyn' at offset 0x304 contains 6 entries:
 Offset     Info    Type            Sym.Value  Sym. Name
000015ec  00000008 R_386_RELATIVE
00000473  00000a01 R_386_32          000015f8   mylib_int
0000047d  00000a01 R_386_32          000015f8   mylib_int
000015cc  00000106 R_386_GLOB_DAT    00000000   __gmon_start__
000015d0  00000206 R_386_GLOB_DAT    00000000   _Jv_RegisterClasses
000015d4  00000306 R_386_GLOB_DAT    00000000   __cxa_finalize
```

Store binary value in the symbol memory location

Offset in memory where the fix needs to be made

Load Time Relocatable



```
unsigned long mylib_int;

void set_mylib_int(unsigned long x)
{
        mylib_int = x;
}

unsigned long get_mylib_int()
{
        return mylib_int;
}
```

```
0000046c <set_mylib_int>:
 46c:   55                          push   %ebp
 46d:   89 e5                       mov    %esp,%ebp
 46f:   8b 45 08                    mov    0x8(%ebp),%eax
 472:   a3 00 00 00 00              mov    %eax,0x0
 477:   5d                          pop    %ebp
```

The loader fills in the actual address of mylib_int at run time.

4

```
Breakpoint 1, main () at driver.c:9
9               set_mylib_int(100);
(gdb) disass set_mylib_int
Dump of assembler code for function set_mylib_int:
0xb7fde46c <set_mylib_int+0>:   push   %ebp
0xb7fde46d <set_mylib_int+1>:   mov    %esp,%ebp
0xb7fde46f <set_mylib_int+3>:   mov    0x8(%ebp),%eax
0xb7fde472 <set_mylib_int+6>:   mov    %eax,0xb7fdf5f8
0xb7fde477 <set_mylib_int+11>:  pop    %ebp
0xb7fde478 <set_mylib_int+12>:  ret
End of assembler dump.
```

```
ches
Relo                                                                ies:
 Off
0000
0000
0000
0000
0000                                                                lasses
000015d4  00000306 R_386_GLOB_DAT    00000000   __cxa_finalize
```

Load Time Relocatable

Limitations

- Slow load time since executable code needs to be modified
- Requires a writeable code segment, which could pose problems.
- Since executable code of each program needs to be customized, it would prevent sharing of code sections

PIC Internals

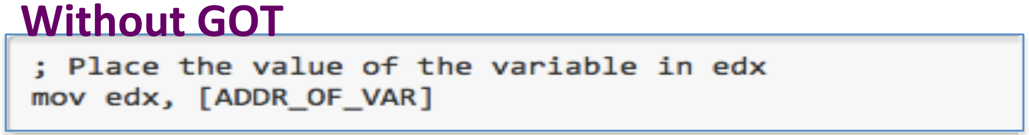
- An additional level of indirection for all global data and function references
- Uses a lot of relative addressing schemes and a global offset table (GOT)
- For relative addressing,
  - data loads and stores should not be at absolute addresses but must be relative

Details about PIC and GOT taken from …
http://eli.thegreenplace.net/2011/11/03/position-independent-code-pic-in-shared-libraries/

Global Offset Table (GOT)

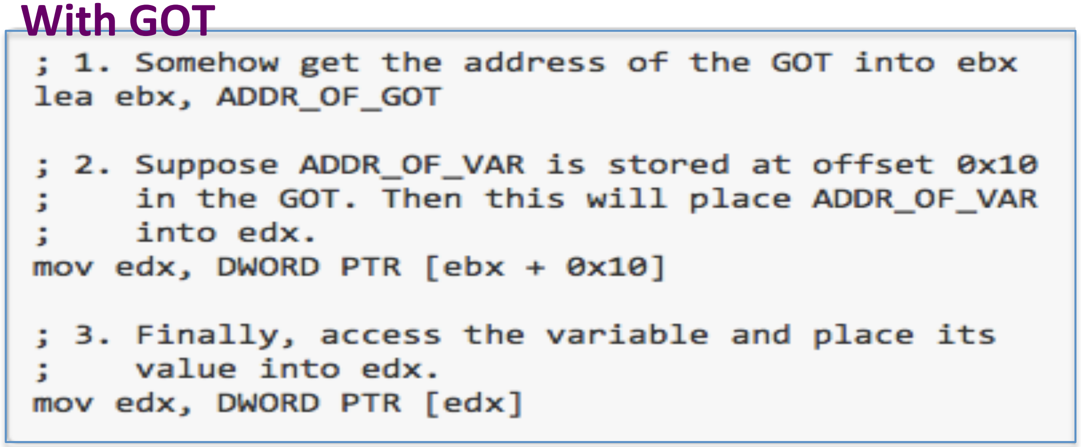
- Table at a fixed (known) location in memory space and known to the linker
- Has the location of the absolute address of variables and functions

Without GOT

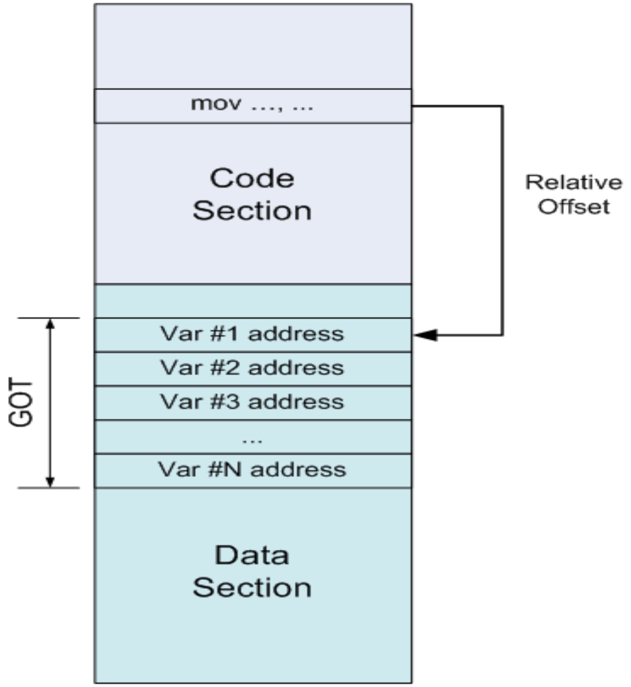


```
; Place the value of the variable in edx
mov edx, [ADDR_OF_VAR]
```

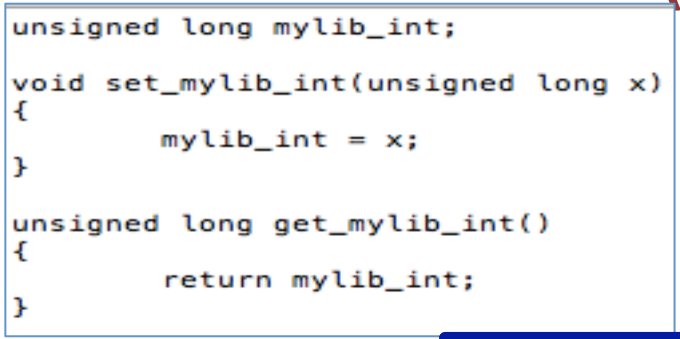
With GOT



```
; 1. Somehow get the address of the GOT into ebx
lea ebx, ADDR_OF_GOT

; 2. Suppose ADDR_OF_VAR is stored at offset 0x10
;    in the GOT. Then this will place ADDR_OF_VAR
;    into edx.
mov edx, DWORD PTR [ebx + 0x10]

; 3. Finally, access the variable and place its
;    value into edx.
mov edx, DWORD PTR [edx]
```

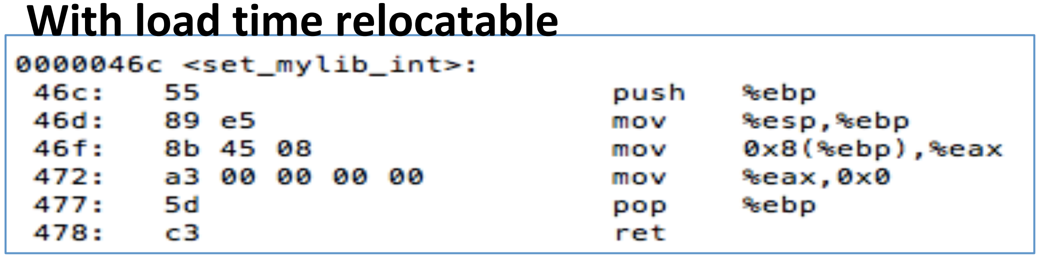


Enforcing Relative Addressing (example)



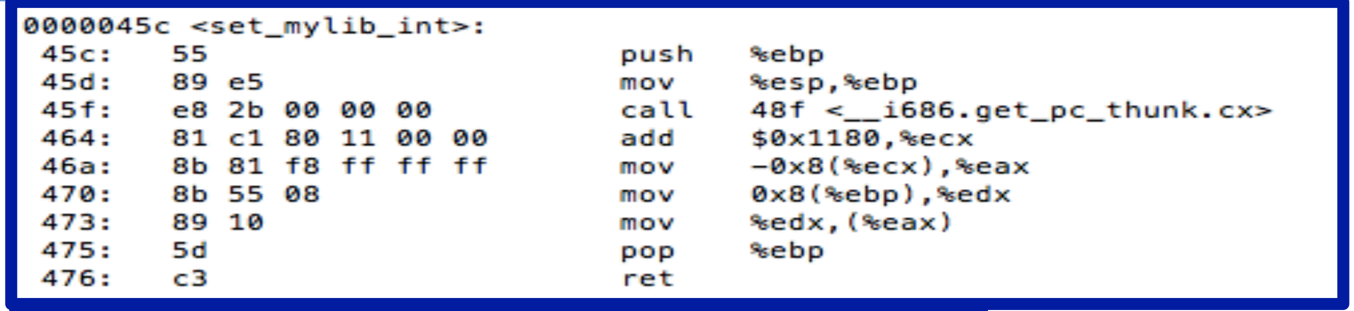
```
unsigned long mylib_int;

void set_mylib_int(unsigned long x)
{
        mylib_int = x;
}

unsigned long get_mylib_int()
{
        return mylib_int;
}
```

With load time relocatable

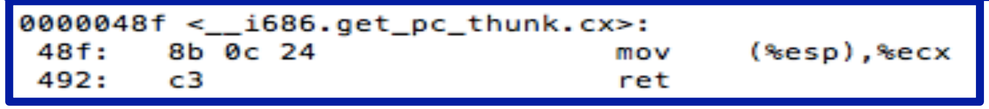


```
0000046c <set_mylib_int>:
 46c:    55                      push   %ebp
 46d:    89 e5                   mov    %esp,%ebp
 46f:    8b 45 08                mov    0x8(%ebp),%eax
 472:    a3 00 00 00 00          mov    %eax,0x0
 477:    5d                      pop    %ebp
 478:    c3                      ret
```

With PIC

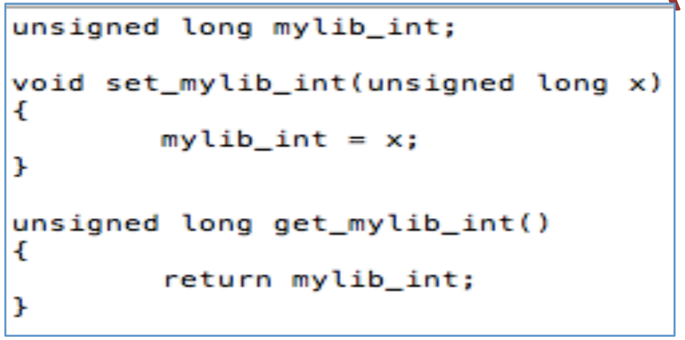


```
0000045c <set_mylib_int>:
 45c:    55                      push   %ebp
 45d:    89 e5                   mov    %esp,%ebp
 45f:    e8 2b 00 00 00          call   48f <__i686.get_pc_thunk.cx>
 464:    81 c1 80 11 00 00       add    $0x1180,%ecx
 46a:    8b 81 f8 ff ff ff       mov    -0x8(%ecx),%eax
 470:    8b 55 08                mov    0x8(%ebp),%edx
 473:    89 10                   mov    %edx,(%eax)
 475:    5d                      pop    %ebp
 476:    c3                      ret
```



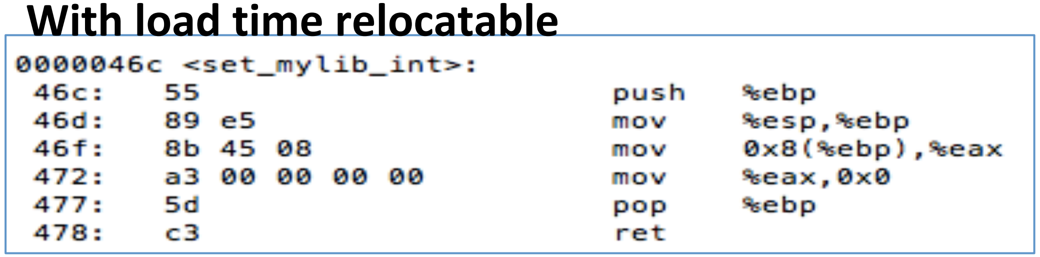
```
0000048f <__i686.get_pc_thunk.cx>:
 48f:    8b 0c 24                mov    (%esp),%ecx
 492:    c3                      ret
```

Enforcing Relative Addressing (example)



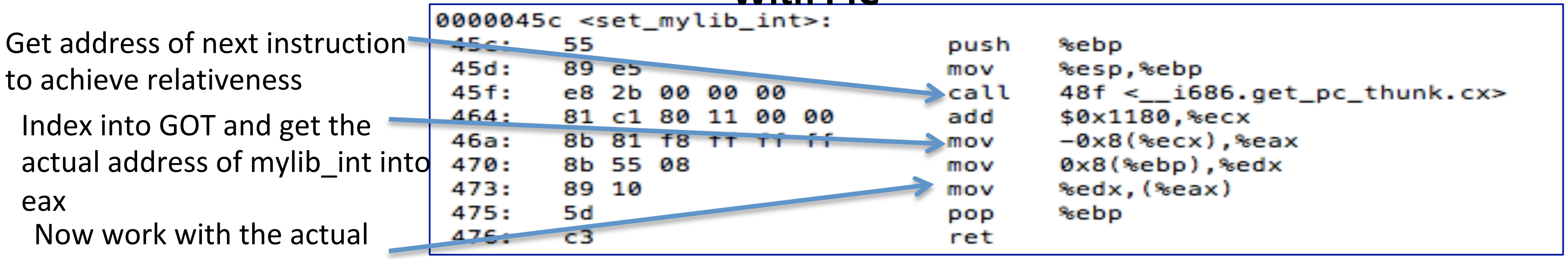
```
unsigned long mylib_int;

void set_mylib_int(unsigned long x)
{
        mylib_int = x;
}

unsigned long get_mylib_int()
{
        return mylib_int;
}
```

With load time relocatable



```
0000046c <set_mylib_int>:
 46c:    55                      push   %ebp
 46d:    89 e5                   mov    %esp,%ebp
 46f:    8b 45 08                mov    0x8(%ebp),%eax
 472:    a3 00 00 00 00          mov    %eax,0x0
 477:    5d                      pop    %ebp
 478:    c3                      ret
```

With PIC

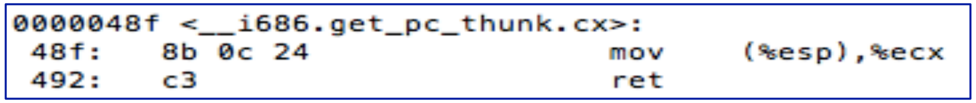


```
0000045c <set_mylib_int>:
 45c:    55                      push   %ebp
 45d:    89 e5                   mov    %esp,%ebp
 45f:    e8 2b 00 00 00          call   48f <__i686.get_pc_thunk.cx>
 464:    81 c1 80 11 00 00       add    $0x1180,%ecx
 46a:    8b 81 f8 ff ff ff       mov    -0x8(%ecx),%eax
 470:    8b 55 08                mov    0x8(%ebp),%edx
 473:    89 10                   mov    %edx,(%eax)
 475:    5d                      pop    %ebp
 476:    c3                      ret
```

Get address of next instruction to achieve relativeness

Index into GOT and get the actual address of mylib_int into eax

Now work with the actual address.

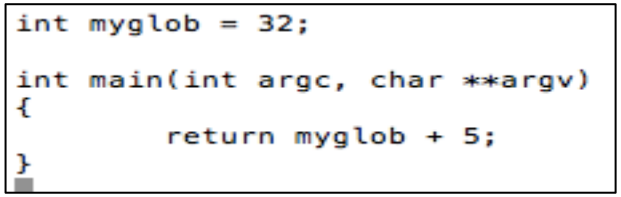


```
0000048f <__i686.get_pc_thunk.cx>:
 48f:    8b 0c 24                mov    (%esp),%ecx
 492:    c3                      ret
```

Advantage of the GOT

- With load time relocatable code, every variable reference would need to be changed
  - Requires writeable code segments
  - Huge overheads during load time
  - Code pages cannot be shared
- With GOT, the GOT table needs to be constructed just once during the execution
  - GOT is in the data segment, which is writeable
  - Data pages are not shared anyway
  - Drawback : runtime overheads due to multiple loads

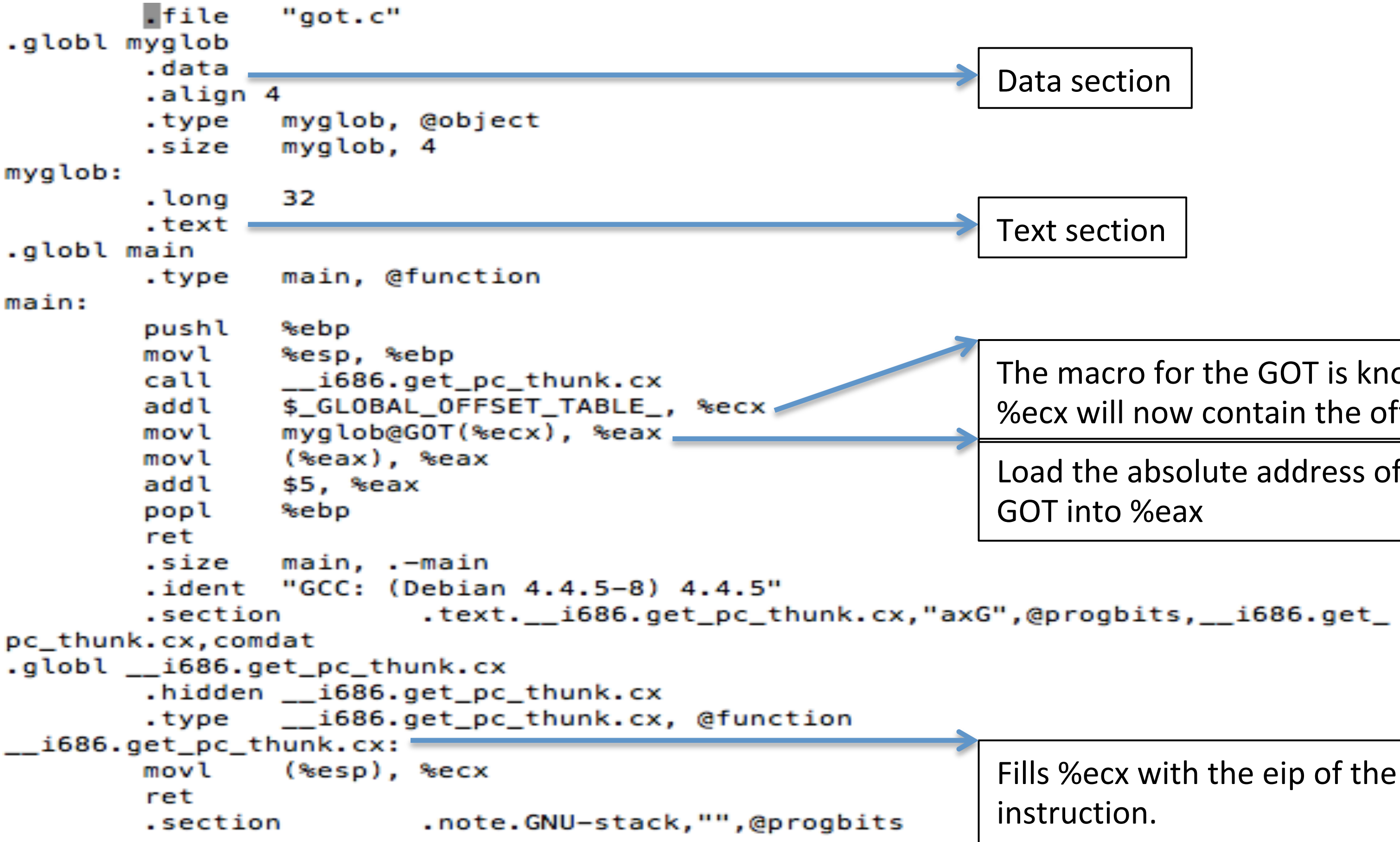
An Example of working with GOT



```
int myglob = 32;

int main(int argc, char **argv)
{
        return myglob + 5;
}
```

$gcc –m32 –shared –fpic –S got.c

Besides a.out, this compilation also generates got.s
The assembly code for the program



```
        .file   "got.c"
.globl myglob
        .data
        .align 4
        .type   myglob, @object
        .size   myglob, 4
myglob:
        .long   32
        .text
.globl main
        .type   main, @function
main:
        pushl   %ebp
        movl    %esp, %ebp
        call    __i686.get_pc_thunk.cx
        addl    $_GLOBAL_OFFSET_TABLE_, %ecx
        movl    myglob@GOT(%ecx), %eax
        movl    (%eax), %eax
        addl    $5, %eax
        popl    %ebp
        ret
        .size   main, .-main
        .ident  "GCC: (Debian 4.4.5-8) 4.4.5"
        .section        .text.__i686.get_pc_thunk.cx,"axG",@progbits,__i686.get_
pc_thunk.cx,comdat
.globl __i686.get_pc_thunk.cx
        .hidden __i686.get_pc_thunk.cx
        .type   __i686.get_pc_thunk.cx, @function
__i686.get_pc_thunk.cx:
        movl    (%esp), %ecx
        ret
        .section        .note.GNU-stack,"",@progbits
```

Data section

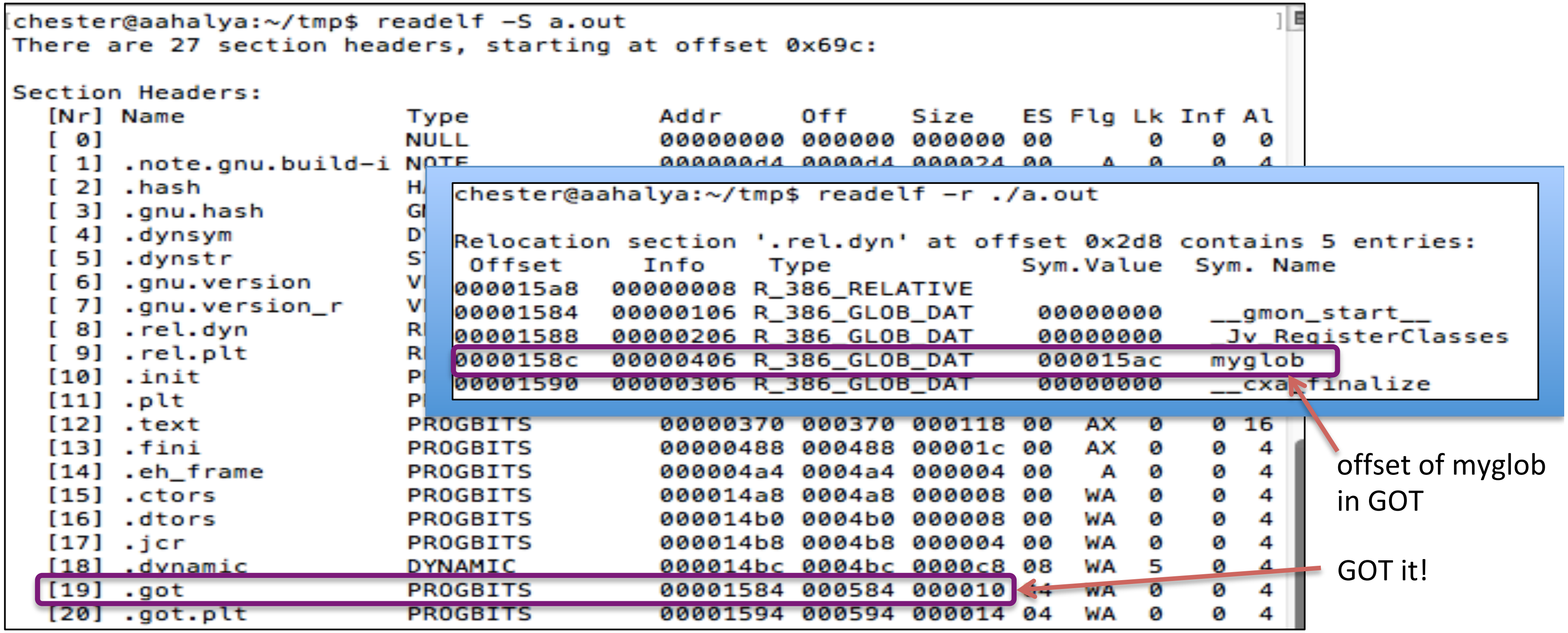
Text section

The macro for the GOT is known by the linker.
%ecx will now contain the offset to GOT

Load the absolute address of myglob from the GOT into %eax

Fills %ecx with the eip of the next instruction.
Why do we need this indirect way of doing this?
In this case what will %ecx contain?

More



```
chester@aahalya:~/tmp$ readelf -S a.out
There are 27 section headers, starting at offset 0x69c:

Section Headers:
  [Nr] Name              Type            Addr     Off    Size   ES Flg Lk Inf Al
  [ 0]                   NULL            00000000 000000 000000 00      0   0  0
  [ 1] .note.gnu.build-i NOTE            000000d4 0000d4 000024 00   A  0   0  4
  [ 2] .hash             H
  [ 3] .gnu.hash         G
  [ 4] .dynsym           D
  [ 5] .dynstr           S
  [ 6] .gnu.version      V
  [ 7] .gnu.version_r    V
  [ 8] .rel.dyn          R
  [ 9] .rel.plt          R
  [10] .init             P
  [11] .plt              P
  [12] .text             PROGBITS        00000370 000370 000118 00  AX  0   0 16
  [13] .fini             PROGBITS        00000488 000488 00001c 00  AX  0   0  4
  [14] .eh_frame         PROGBITS        000004a4 0004a4 000004 00   A  0   0  4
  [15] .ctors            PROGBITS        000014a8 0004a8 000008 00  WA  0   0  4
  [16] .dtors            PROGBITS        000014b0 0004b0 000008 00  WA  0   0  4
  [17] .jcr              PROGBITS        000014b8 0004b8 000004 00  WA  0   0  4
  [18] .dynamic          DYNAMIC         000014bc 0004bc 0000c8 08  WA  5   0  4
  [19] .got              PROGBITS        00001584 000584 000010 04  WA  0   0  4
  [20] .got.plt          PROGBITS        00001594 000594 000014 04  WA  0   0  4
```

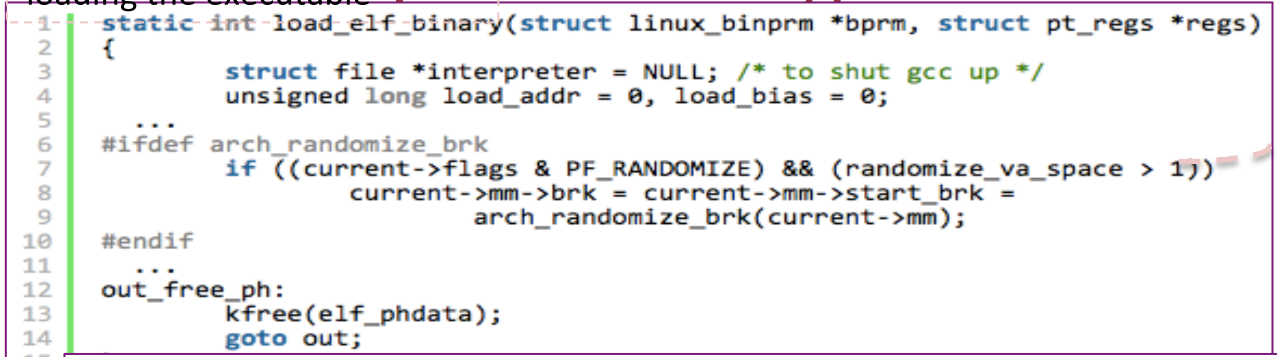
```
chester@aahalya:~/tmp$ readelf -r ./a.out

Relocation section '.rel.dyn' at offset 0x2d8 contains 5 entries:
 Offset     Info    Type            Sym.Value  Sym. Name
000015a8  00000008 R_386_RELATIVE
00001584  00000106 R_386_GLOB_DAT    00000000   __gmon_start__
00001588  00000206 R_386_GLOB_DAT    00000000   _Jv_RegisterClasses
0000158c  00000406 R_386_GLOB_DAT    000015ac   myglob
00001590  00000306 R_386_GLOB_DAT    00000000   __cxa_finalize
```

offset of myglob in GOT

GOT it!

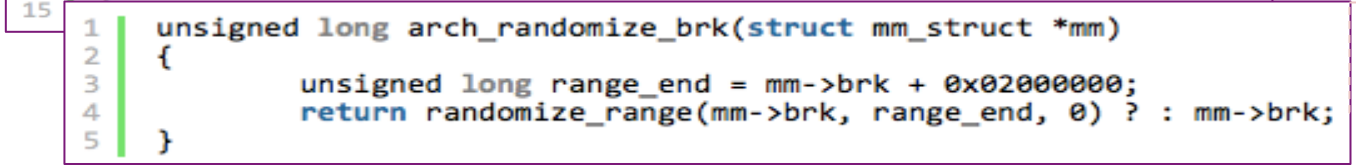
Deep Within the Kernel (randomizing the data section)

loading the executable



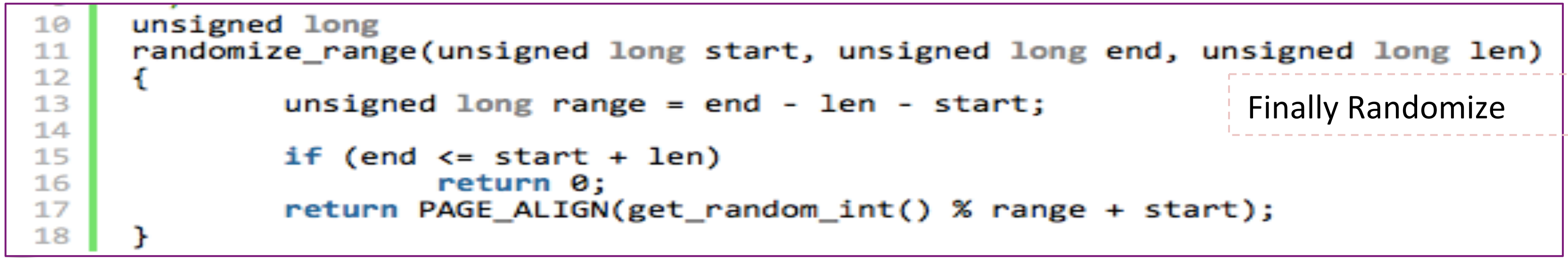
```c
static int load_elf_binary(struct linux_binprm *bprm, struct pt_regs *regs)
{
        struct file *interpreter = NULL; /* to shut gcc up */
        unsigned long load_addr = 0, load_bias = 0;
    ...
#ifdef arch_randomize_brk
        if ((current->flags & PF_RANDOMIZE) && (randomize_va_space > 1))
                current->mm->brk = current->mm->start_brk =
                        arch_randomize_brk(current->mm);
#endif
    ...
out_free_ph:
        kfree(elf_phdata);
        goto out;
```

Check if randomize_va_space is > 1 (it can be 1 or 2)



```c
unsigned long arch_randomize_brk(struct mm_struct *mm)
{
        unsigned long range_end = mm->brk + 0x02000000;
        return randomize_range(mm->brk, range_end, 0) ? : mm->brk;
}
```

Compute the end of the data segment (m->brk + 0x20)



```c
unsigned long
randomize_range(unsigned long start, unsigned long end, unsigned long len)
{
        unsigned long range = end - len - start;

        if (end <= start + len)
                return 0;
        return PAGE_ALIGN(get_random_int() % range + start);
}
```

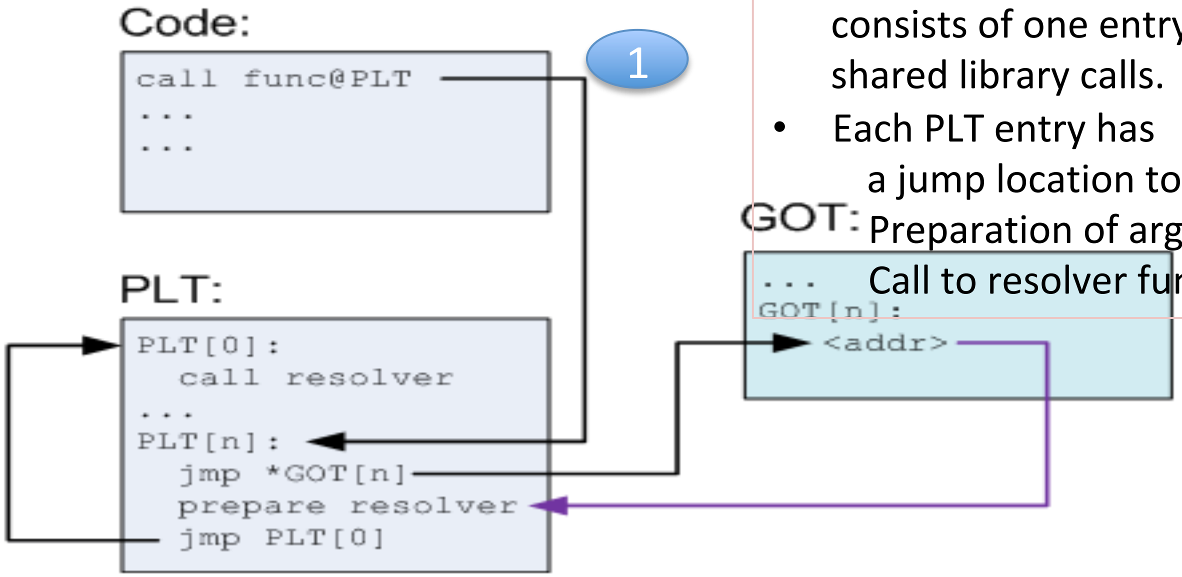
Finally Randomize

Function Calls in PIC

- Theoretically could be done similar with the data…
  - call instruction gets location from GOT entry that is filled in during load time (this process is called binding)
  - In practice, this is time consuming. Much more functions than global variables. Most functions in libraries are unused
- Lazy binding scheme
  - Delay binding till invocation of the function
  - Uses a double indirection – PLT – **p**rocedure **l**inkage **t**able in addition to GOT

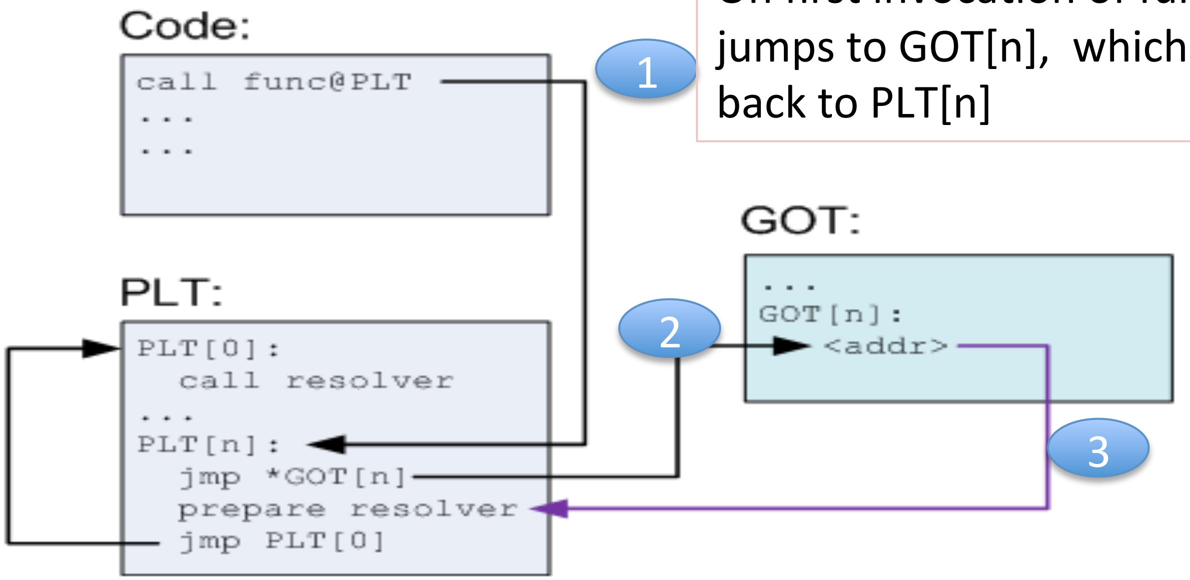
The PLT

- Instead of directly calling func, invoke an offset in the PLT instead.
- PLT is part of the executable text section, and consists of one entry for each external function the shared library calls.
- Each PLT entry has
  - a jump location to a specific GOT entry
  - Preparation of arguments for a ‘resolver’
  - Call to resolver function



First Invocation of Func

First Invocation of func



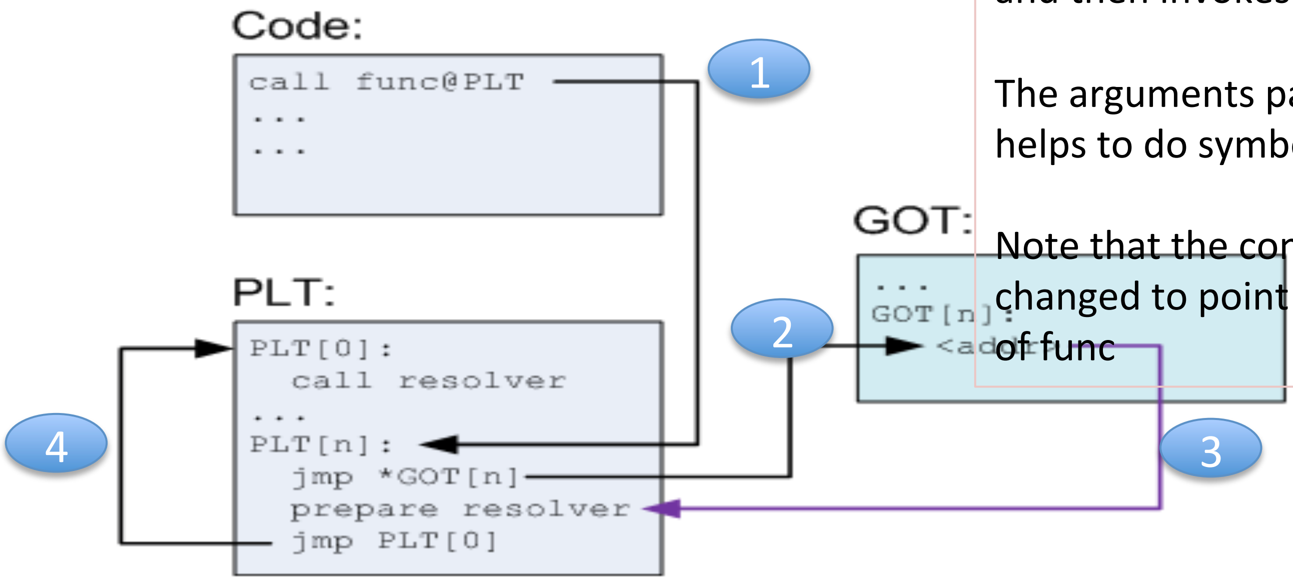
(steps 2 and 3)
On first invocation of func, PLT[n] jumps to GOT[n], which simply jumps back to PLT[n]

First Invocation of Func

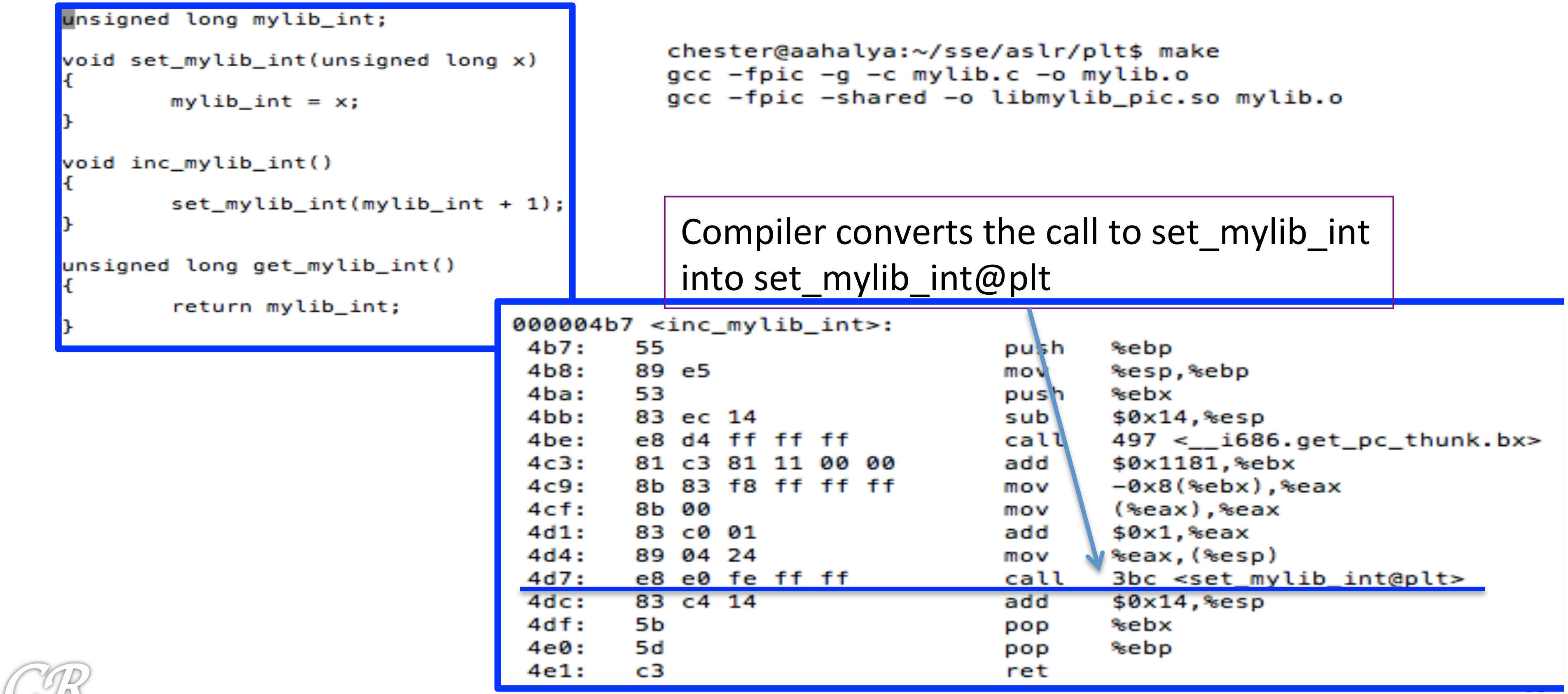
(step 4). Invoke resolver, which **resolves** the actual of func,
places this actual address into GOT
and then invokes func

The arguments passed to resolver, that helps to do symbol resolution

Note that the contents of GOT is now changed to point to the actual address of func



Example of PLT



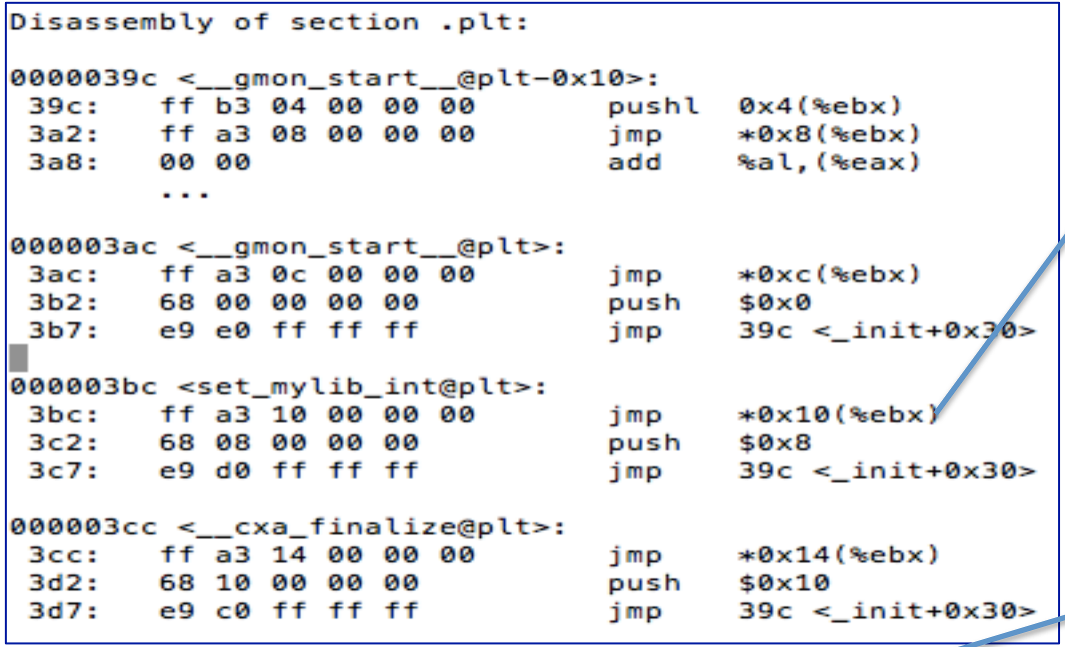
```
unsigned long mylib_int;

void set_mylib_int(unsigned long x)
{
        mylib_int = x;
}

void inc_mylib_int()
{
        set_mylib_int(mylib_int + 1);
}

unsigned long get_mylib_int()
{
        return mylib_int;
}
```

```
chester@aahalya:~/sse/aslr/plt$ make
gcc -fpic -g -c mylib.c -o mylib.o
gcc -fpic -shared -o libmylib_pic.so mylib.o
```

Compiler converts the call to set_mylib_int into set_mylib_int@plt

```
000004b7 <inc_mylib_int>:
 4b7:   55                      push   %ebp
 4b8:   89 e5                   mov    %esp,%ebp
 4ba:   53                      push   %ebx
 4bb:   83 ec 14                sub    $0x14,%esp
 4be:   e8 d4 ff ff ff          call   497 <__i686.get_pc_thunk.bx>
 4c3:   81 c3 81 11 00 00       add    $0x1181,%ebx
 4c9:   8b 83 f8 ff ff ff       mov    -0x8(%ebx),%eax
 4cf:   8b 00                   mov    (%eax),%eax
 4d1:   83 c0 01                add    $0x1,%eax
 4d4:   89 04 24                mov    %eax,(%esp)
 4d7:   e8 e0 fe ff ff          call   3bc <set_mylib_int@plt>
 4dc:   83 c4 14                add    $0x14,%esp
 4df:   5b                      pop    %ebx
 4e0:   5d                      pop    %ebp
 4e1:   c3                      ret
```

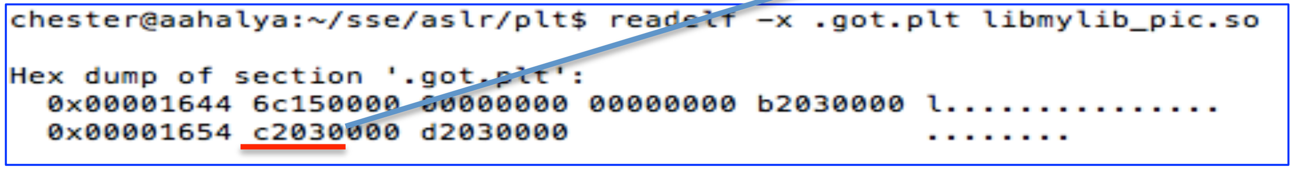
Example of PLT



```
Disassembly of section .plt:

0000039c <__gmon_start__@plt-0x10>:
 39c:   ff b3 04 00 00 00       pushl  0x4(%ebx)
 3a2:   ff a3 08 00 00 00       jmp    *0x8(%ebx)
 3a8:   00 00                   add    %al,(%eax)
        ...

000003ac <__gmon_start__@plt>:
 3ac:   ff a3 0c 00 00 00       jmp    *0xc(%ebx)
 3b2:   68 00 00 00 00          push   $0x0
 3b7:   e9 e0 ff ff ff          jmp    39c <_init+0x30>

000003bc <set_mylib_int@plt>:
 3bc:   ff a3 10 00 00 00       jmp    *0x10(%ebx)
 3c2:   68 08 00 00 00          push   $0x8
 3c7:   e9 d0 ff ff ff          jmp    39c <_init+0x30>

000003cc <__cxa_finalize@plt>:
 3cc:   ff a3 14 00 00 00       jmp    *0x14(%ebx)
 3d2:   68 10 00 00 00          push   $0x10
 3d7:   e9 c0 ff ff ff          jmp    39c <_init+0x30>
```

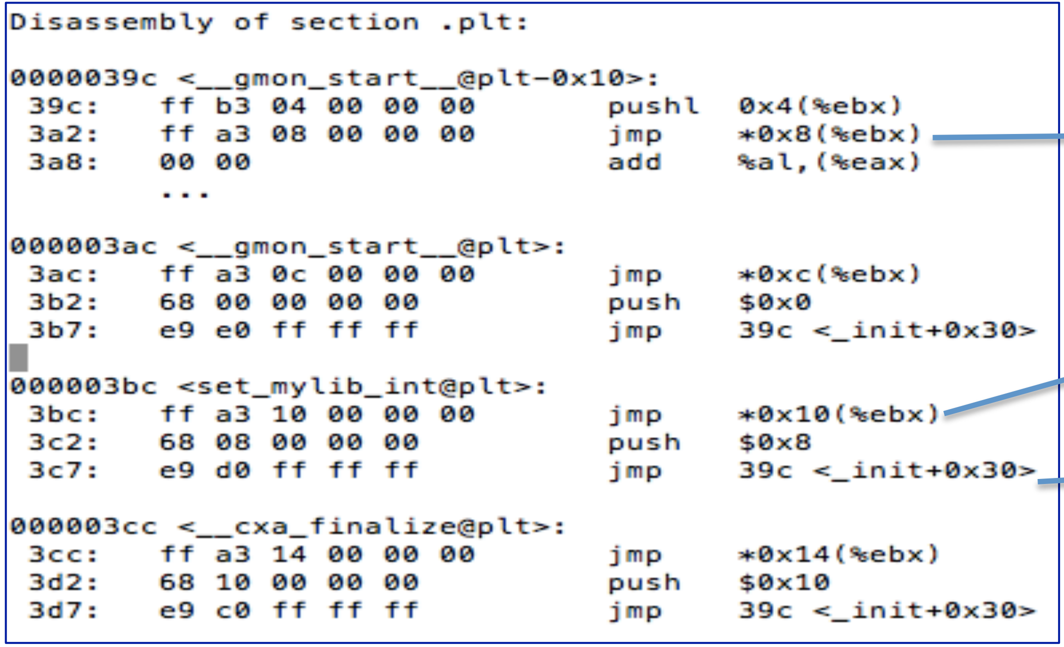
ebx points to the GOT table
ebx + 0x10 is the offset
corresponding
to set_mylib_int

Offset of set_mylib_int in the GOT (+0x10).
It contains the address of the next instruction (ie. 0x3c2)



```
chester@aahalya:~/sse/aslr/plt$ readelf -x .got.plt libmylib_pic.so

Hex dump of section '.got.plt':
  0x00001644 6c150000 00000000 00000000 b2030000 l...............
  0x00001654 c2030000 d2030000                   ........
```

Example of PLT



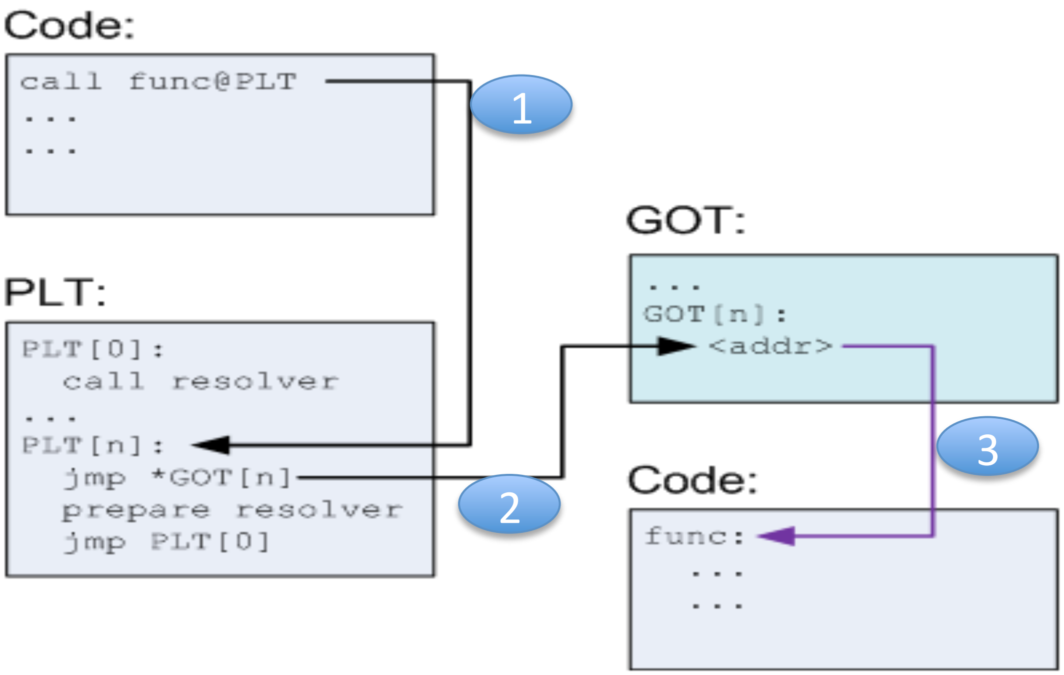
```
Disassembly of section .plt:

0000039c <__gmon_start__@plt-0x10>:
 39c:    ff b3 04 00 00 00        pushl  0x4(%ebx)
 3a2:    ff a3 08 00 00 00        jmp    *0x8(%ebx)
 3a8:    00 00                    add    %al,(%eax)
         ...

000003ac <__gmon_start__@plt>:
 3ac:    ff a3 0c 00 00 00        jmp    *0xc(%ebx)
 3b2:    68 00 00 00 00           push   $0x0
 3b7:    e9 e0 ff ff ff           jmp    39c <_init+0x30>

000003bc <set_mylib_int@plt>:
 3bc:    ff a3 10 00 00 00        jmp    *0x10(%ebx)
 3c2:    68 08 00 00 00           push   $0x8
 3c7:    e9 d0 ff ff ff           jmp    39c <_init+0x30>

000003cc <__cxa_finalize@plt>:
 3cc:    ff a3 14 00 00 00        jmp    *0x14(%ebx)
 3d2:    68 10 00 00 00           push   $0x10
 3d7:    e9 c0 ff ff ff           jmp    39c <_init+0x30>
```

Jump to the resolver, which resolves the actual address of set_mylib_int and fills it into the GOT

Push arguments for the resolver.

Jump to the first entry of the PLT Ie. PLT[0]

Subsequent invocations of Func



Code:

```
call  func@PLT
...
...
```

PLT:

```
PLT[0]:
   call  resolver
...
PLT[n]:
   jmp  *GOT[n]
   prepare  resolver
   jmp  PLT[0]
```

GOT:

```
...
GOT[n]:
    <addr>
```

Code:

```
func:
   ...
   ...
```

Advantages

- Functions are relocatable, therefore good for ASLR
- Functions resolved only on need, therefore saves time during the load phase

Bypassing ASLR

- Brute force
- Return-to-PLT
- Overwriting the GOT
- Timing Attacks