Relocation revisited

Example C Program

main.c

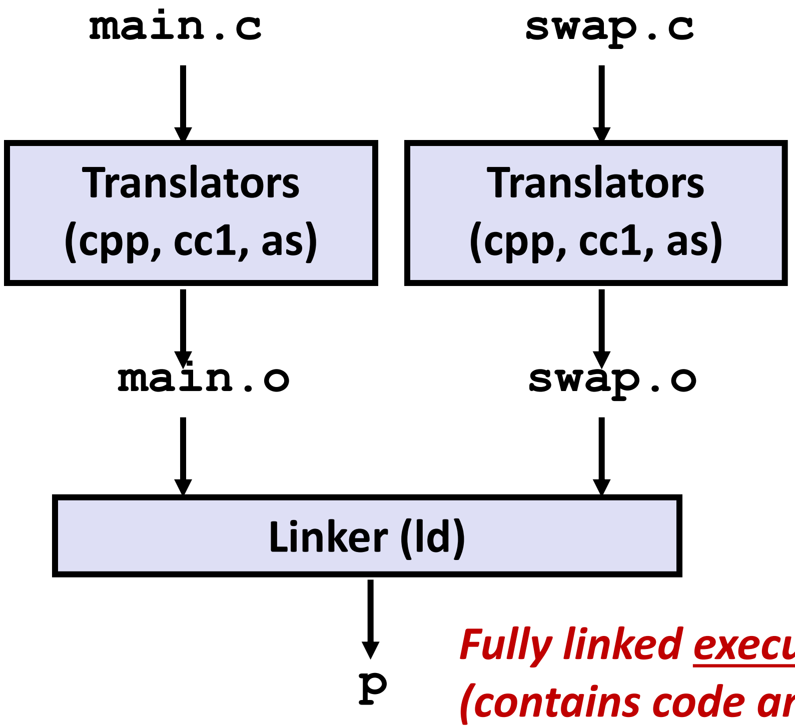
```
int buf[2] = {1, 2};

int main()
{
   swap();
   return 0;
}
```

swap.c

```
extern int buf[];

int *bufp0 = &buf[0];
static int *bufp1;

void swap()
{
   int temp;

   bufp1 = &buf[1];
   temp = *bufp0;
   *bufp0 = *bufp1;
   *bufp1 = temp;
}
```

Static Linking

- Programs are translated and linked using a *compiler driver*:
  - `unix> gcc -O2 -g -o p main.c swap.c`
  - `unix> ./p`



Source files

Separately compiled relocatable object files

Fully linked executable object file (contains code and data for all functions defined in `main.c` and `swap.c`)

What Do Linkers Do?

- **Step 1. Symbol resolution**

  - Programs define and reference *symbols* (variables and functions):

    ```
    void swap() {…}    /* define symbol swap */
    swap();            /* reference symbol swap */
    int *xp = &x;      /* define symbol xp, reference x */
    ```

  - Symbol definitions are stored (by compiler) in *symbol table*.
    - Symbol table is an array of structs
    - Each entry includes name, size, and location of symbol.

  - Linker associates each symbol reference with exactly one symbol definition.

What Do Linkers Do? (cont)

- **Step 2. Relocation**
  - Merges separate code and data sections into single sections
  - Relocates symbols from their relative locations in the `.o` files to their final absolute memory locations in the executable.
  - Updates all references to these symbols to reflect their new positions.

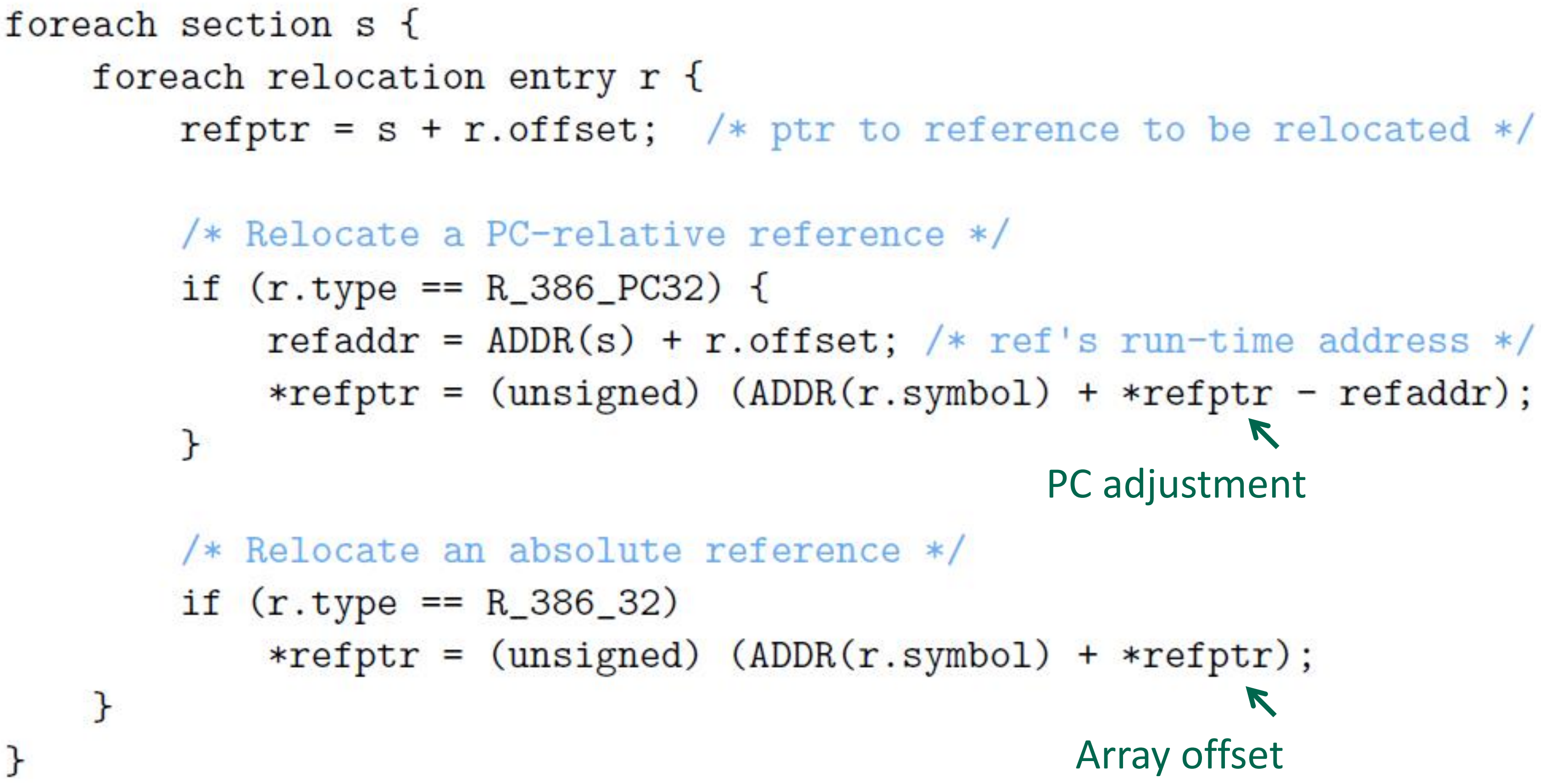
Relocation Entries

```
typedef struct {
   int offset;
   int symbol:24,
       type:8;
} Elf32_rel;
```

- Offset : section offset of the references to relocate
- Symbol : identifies the symbol that the modified reference should point to.
- Type : tells the linker how to modify the new reference

- ELF defines 11 relocation types.
- two most widely used :
  - R_386_PC32 : 32 bit PC_relative address
    - Add the 32 bit value to the current PC value (address of the next instruction)
  - R_386_32 : 32 bit absolute address

Relocation Algorithm



```
foreach section s {
    foreach relocation entry r {
        refptr = s + r.offset;  /* ptr to reference to be relocated */

        /* Relocate a PC-relative reference */
        if (r.type == R_386_PC32) {
            refaddr = ADDR(s) + r.offset; /* ref's run-time address */
            *refptr = (unsigned) (ADDR(r.symbol) + *refptr - refaddr);
        }

        /* Relocate an absolute reference */
        if (r.type == R_386_32)
            *refptr = (unsigned) (ADDR(r.symbol) + *refptr);
    }
}
```

PC adjustment

Array offset

Some compiler/linker store the value separately in relocation entry

Relocation Info (main)

```
Relocation entry{
    offset: 12
    symbol: swap
    type:R_386_PC32
    value: -4}
```

main.c

```
int buf[2] =
   {1,2};

int main()
{
   swap();
   return 0;
}
```

main.o

```
0000000 <main>:
   0:   8d 4c 24 04          lea    0x4(%esp),%ecx
   4:   83 e4 f0             and    $0xfffffff0,%esp
   7:   ff 71 fc             pushl  0xfffffffc(%ecx)
   a:   55                   push   %ebp
   b:   89 e5                mov    %esp,%ebp
   d:   51                   push   %ecx
   e:   83 ec 04             sub    $0x4,%esp
  11:   e8 fc ff ff ff       call   12 <main+0x12>
                12: R_386_PC32 swap
  16:   83 c4 04             add    $0x4,%esp
  19:   31 c0                xor    %eax,%eax
  1b:   59                   pop    %ecx
  1c:   5d                   pop    %ebp
  1d:   8d 61 fc             lea    0xfffffffc(%ecx),%esp
  20:   c3                   ret
```

-4(수행시의 PC 보정값)

Source: `objdump -r -d`

```
Disassembly of section .data:

 00000000 <buf>:
   0:    01 00 00 00 02 00 00 00
```

Relocation Info (swap, .text)

swap.c

```
extern int buf[];

int
   *bufp0 = &buf[0];

static int *bufp1;

void swap()
{
   int temp;

   bufp1 = &buf[1];
   temp = *bufp0;
   *bufp0 = *bufp1;
   *bufp1 = temp;
}
```

swap.o

```
Disassembly of section .text:

00000000 <swap>:
   0:   8b 15 00 00 00 00          mov    0x0,%edx
                 2: R_386_32       buf
   6:   a1 04 00 00 00             mov    0x4,%eax
                 7: R_386_32       buf
   b:   55                         push   %ebp
   c:   89 e5                      mov    %esp,%ebp
   e:   c7 05 00 00 00 00 04       movl   $0x4,0x0
  15:   00 00 00
                 10: R_386_32      .bss
                 14: R_386_32      buf
  18:   8b 08                      mov    (%eax),%ecx
  1a:   89 10                      mov    %edx,(%eax)
  1c:   5d
        89 0d 04 00 00 00
                 1f: R_386_32
        c3
```

```
Relocation entry{
   offset: 10
   symbol: bufp1
   type:R_386_32
   value: 0}
```

```
Relocation entry{
   offset: (7,14,1f)
   symbol: buf
   type:R_386_32
   value: 4}
```

```
Relocation entry{
   offset: 2
   symbol: buf
   type:R_386_32
   value: 0}
```

Relocation Info (swap, .data)

swap.c

```
extern int buf[];

int *bufp0 =
           &buf[0];
static int *bufp1;

void swap()
{
  int temp;

  bufp1 = &buf[1];
  temp = *bufp0;
  *bufp0 = *bufp1;
  *bufp1 = temp;
}
```

```
Disassembly of section .data:

00000000 <bufp0>:
   0:    00 00 00 00

         0: R_386_32 buf
```

Executable Before/After Relocation (.text)

-4(수행시의 PC 보정값)

```
0000000 <main>:
   . . .
  e:   83 ec 04              sub    $0x4,%esp
 11:   e8 fc ff ff ff        call   12 <main+0x12>
                  12: R_386_PC32 swap
 16:   83 c4 04              add    $0x4,%esp
  . . .
```

0x8048396 + 0x1a
= 0x80483b0

PC = <main+0x12>+4
 = <main+0x16>

```
08048380 <main>:
 .   .   .
804838e:      83 ec 04                sub    $0x4,%esp
8048391:      e8 1a 00 00 00          call   80483b0 <swap>
8048396:      83 c4 04                add    $0x4,%esp
 .   .   .
```

```
080483b0 <swap>:
 80483b0:     8b 15 20 96 04 08       mov    0x8049620,%edx
 80483b6:     a1 24 96 04 08          mov    0x8049624,%eax
 80483bb:     55                      push   %ebp
```

실제 계산에서는 PC를 모르기 때문에

080483b0 + (-4) - (08048380(section addr) + 12(offset))

를 계산한다. = 0x1a

```
   0:   8b 15 00 00 00 00       mov    0x0,%edx
                2: R_386_32     buf
   6:   a1 04 00 00 00          mov    0x4,%eax
                7: R_386_32     buf
  ...
   e:   c7 05 00 00 00 00 04    movl   $0x4,0x0
  15:   00 00 00
                 10: R_386_32   .bss
                 14: R_386_32   buf
  . . .
  1d:   89 0d 04 00 00 00       mov    %ecx,0x4
                 1f: R_386_32   buf
  23:   c3                      ret
```

```
080483b0 <swap>:
 80483b0:      8b 15 20 96 04 08       mov    0x8049620,%edx
 80483b6:      a1 24 96 04 08          mov    0x8049624,%eax
 80483bb:      55                      push   %ebp
 80483bc:      89 e5                   mov    %esp,%ebp
 80483be:      c7 05 30 96 04 08 24    movl   $0x8049624,0x8049630
 80483c5:      96 04 08
 80483c8:      8b 08                   mov    (%eax),%ecx
 80483ca:      89 10                   mov    %edx,(%eax)
 80483cc:      5d                      pop    %ebp
 80483cd:      89 0d 24 96 04 08       mov    %ecx,0x8049624
 80483d3:      c3                      ret
```

Executable After Relocation (.data)

```
Disassembly of section .data:

08049620 <buf>:
 8049620:       01 00 00 00 02 00 00 00

08049628 <bufp0>:
 8049628:       20 96 04 08

.bss

08049630 <bufp1>:
 8049630:       24 96 04 08
```

```
extern int buf[];

int *bufp0 = &buf[0];
static int *bufp1;

void swap()
{
  int temp;

  bufp1 = &buf[1];
  temp = *bufp0;
  *bufp0 = *bufp1;
  *bufp1 = temp;
}
```

Before Relocation (.text) main.o

```
Disassembly of section .text:

0000000000000000 <main>:
   0:    55                       push   %rbp
   1:    48 89 e5                 mov    %rsp,%rbp
   4:    b8 00 00 00 00           mov    $0x0,%eax
   9:    e8 00 00 00 00           callq  e <main+0xe>
                      a: R_386_PC32    <swap>
   e:    b8 00 00 00 00           mov    $0x0,%eax
  13:    5d                       pop    %rbp
  14:    c3                       retq
```

After Relocation (.text) main

```
00000000004004ed <main>:
  4004ed:       55                       push   %rbp
  4004ee:       48 89 e5                 mov    %rsp,%rbp
  4004f1:       b8 00 00 00 00           mov    $0x0,%eax
  4004f6:       e8 07 00 00 00           callq  400502 <swap>
  4004fb:       b8 00 00 00 00           mov    $0x0,%eax
  400500:       5d                       pop    %rbp
  400501:       c3                       retq
```

Before Relocation (.text) swap.o

(수행시의 PC 보정값)

```
0000000000000000 <swap>:
   0:   55                          push   %rbp
   1:   48 89 e5                    mov    %rsp,%rbp                 PC값
   4:   48 c7 05 00 00 00 00        movq   $0x0,0x0(%rip)          # f <swap+0xf>
                        7: R_386_PC32         bufp1   -0x8
   b:   00 00 00 00
                        b: R_386_32 buf+0x4
   f:   48 8b 05 00 00 00 00        mov    0x0(%rip),%rax          # 16 <swap+0x16>
                         12: R_386_PC32        bufp0   -0x4
  16:   8b 00                       mov    (%rax),%eax
  18:   89 45 fc                    mov    %eax,-0x4(%rbp)
  1b:   48 8b 05 00 00 00 00        mov    0x0(%rip),%rax          # 22 <swap+0x22>
                         1e: R_386_PC32        bufp0   -0x4
  22:   48 8b 15 00 00 00 00        mov    0x0(%rip),%rdx          # 29 <swap+0x29>
                         25: R_386_PC32        bufp1   -0x4
  29:   8b 12                       mov    (%rdx),%edx
  2b:   89 10                       mov    %edx,(%rax)
  2d:   48 8b 05 00 00 00 00        mov    0x0(%rip),%rax          # 34 <swap+0x34>
                         30: R_386_PC32        bufp1   -0x4
  34:   8b 55 fc                    mov    -0x4(%rbp),%edx
  37:   89 10                       mov    %edx,(%rax)
  39:   5d                          pop    %rbp
  3a:   c3                          retq
```

After Relocation (.text) swap

```
0000000000400502 <swap>:
  400502:   55                      push    %rbp
  400503:   48 89 e5                mov     %rsp,%rbp
  400506:   48 c7 05 3f 0b 20 00    movq    $0x60103c,0x200b3f(%rip) #601050 <bufp1>
  40050d:   3c 10 60 00
  400511:   48 8b 05 28 0b 20 00    mov     0x200b28(%rip),%rax      # 601040 <bufp0>
  400518:   8b 00                   mov     (%rax),%eax
  40051a:   89 45 fc                mov     %eax,-0x4(%rbp)
  40051d:   48 8b 05 1c 0b 20 00    mov     0x200b1c(%rip),%rax      # 601040 <bufp0>
  400524:   48 8b 15 25 0b 20 00    mov     0x200b25(%rip),%rdx      # 601050 <bufp1>
  40052b:   8b 12                   mov     (%rdx),%edx
  40052d:   89 10                   mov     %edx,(%rax)
  40052f:   48 8b 05 1a 0b 20 00    mov     0x200b1a(%rip),%rax      # 601050 <bufp1>
  400536:   8b 55 fc                mov     -0x4(%rbp),%edx
  400539:   89 10                   mov     %edx,(%rax)
  40053b:   5d                      pop     %rbp
  40053c:   c3                      retq
  40053d:   0f 1f 00                nopl    (%rax)
```

Main– Before Relocation

```
Disassembly of section .text:

0000000000000000 <main>:
   9:   e8 00 00 00 00          callq  e <main+0xe>
                        a: R_386_PC32   <swap>
   e:   b8 00 00 00 00          mov    $0x0,%eax
```

PC-relative Address:

ADDR(swap) - PC = 0x400502 – 0x4004fb

= 0x000007

Main – After Relocation

```
00000000004004ed <main>:
 4004f6: e8 07 00 00 00          callq  400502 <swap>
 4004fb: b8 00 00 00 00          mov    $0x0,%eax
```

```
0000000000400502 <swap>:
  400502:       55                    push   %rbp
  400503:       48 89 e5              mov    %rsp,%rbp
  …
```

Swap – Before Relocation

```
0000000000000000 <swap>:
   0:    55                        push    %rbp
   1:    48 89 e5                  mov     %rsp,%rbp
   4:    48 c7 05 00 00 00 00      movq    $0x0,0x0(%rip)        # f <swap+0xf>
                         7: R_386_PC32          bufp1     -0x8
   b:    00 00 00 00
                         b: R_386_32S buf+0x4
   f:    48 8b 05 00 00 00 00      mov     0x0(%rip),%rax        # 16 <swap+0x16>
```

Swap – After Relocation

```
0000000000400502 <swap>:
  400502:  55                      push    %rbp
  400503:  48 89 e5                mov     %rsp,%rbp
  400506:  48 c7 05 3f 0b 20 00    movq    $0x60103c,0x200b3f(%rip)  #601050 <bufp1>
  40050d:  3c 10 60 00
  400511:  …
```

```
Disassembly of section .bss:
0000000000601050 <bufp1>:
```

```
Disassembly of section .data:
0000000000601038 <buf>:
  601038:          01 00
  60103a:          00 00
. 60103c:          02 00
```

PC-relative Address:

ADDR(bufp1) - PC = 0x601050 – 0x400511

= 0x200b3f

Absolute Address:

ADDR(buf) + 0x4 = 0x601038 + 0x4

= 0x60103c

Swap – Before Relocation

```
0000000000000000 <swap>:
  f:    48 8b 05 00 00 00 00     mov     0x0(%rip),%rax       # 16 <swap+0x16>
                        12: R_386_PC32          bufp0      -0x4
  16:    8b 00                     mov     (%rax),%eax
```

Swap – After Relocation

```
0000000000400502 <swap>:
  400511:   48 8b 05 28 0b 20 00    mov     0x200b28(%rip),%rax       # 601040 <bufp0>
  400518:   …                             (next instruction)
```

```
Disassembly of section .data:
0000000000601040 <bufp0>:
```

PC-relative Address:

ADDR(bufp0) - PC = 0x601040 – 0x400518

= 0x200b28

Swap – Before Relocation

```
0000000000000000 <swap>:
  16:   8b 00                    mov    (%rax),%eax
  18:   89 45 fc                 mov    %eax,-0x4(%rbp)
  1b:   48 8b 05 00 00 00 00     mov    0x0(%rip),%rax        # 22 <swap+0x22>
                        1e: R_386_PC32        bufp0      -0x4
  22:   48 8b 15 00 00 00 00     mov    0x0(%rip),%rdx
```

Swap – After Relocation

```
0000000000400502 <swap>:
  400518:   8b 00                    mov    (%rax),%eax
  40051a:   89 45 fc                 mov    %eax,-0x4(%rbp)
  40051d:   48 8b 05 1c 0b 20 00     mov    0x200b1c(%rip),%rax  # 601040 <bufp0>
  400524:   …                      (next instruction)
```

```
Disassembly of section .data:
0000000000601040 <bufp0>:
```

PC-relative Address:

ADDR(bufp0) - PC = 0x601040 – 0x400524

= 0x200b1c

Swap – Before Relocation

```
0000000000000000 <swap>:
  22:    48 8b 15 00 00 00 00     mov    0x0(%rip),%rdx        # 29 <swap+0x29>
                        25: R_386_PC32      bufp1     -0x4
  29:    8b 12                    mov    (%rdx),%edx
```

Swap – After Relocation

```
0000000000400502 <swap>:
  400524:   48 8b 15 25 0b 20 00    mov    0x200b25(%rip),%rdx      # 601050 <bufp1>
  40052b:   …                             (next instruction)
```

```
Disassembly of section .bss:
0000000000601050 <bufp1>:
```

PC-relative Address:

ADDR(bufp1) - PC = 0x601050 – 0x40052b

= 0x200b25

Swap – Before Relocation

```
0000000000000000 <swap>:
  2d:    48 8b 05 00 00 00 00     mov    0x0(%rip),%rax        # 34 <swap+0x34>
                       30: R_386_PC32       bufp1      -0x4
  34:    8b 55 fc                 mov    -0x4(%rbp),%edx
```

Swap – After Relocation

```
0000000000400502 <swap>:
  40052f:   48 8b 05 1a 0b 20 00    mov    0x200b1a(%rip),%rax      # 601050 <bufp1>
  400536:   …                           (next instruction)
```

```
Disassembly of section .bss:
0000000000601050 <bufp1>:
```

PC-relative Address:

ADDR(bufp1) - PC = 0x601050 – 0x400536

= 0x200b1a