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Reverse engineering: *executable file format*

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Reverse engineering

reverse engineering is the process of extracting the knowledge or design blueprints from anything man-made

- contesti differenti (e.g., elettronica, informatica, . . .)

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Software reverse engineering: *perché*?

- studiare architettura interna (dal sorgente)
- ricostruire codice sorgente (dal binario)
- modificare comportamento (programmi *closed-source*)
- comprendere l'attività di rete (protocolli proprietari)

Software reverse engineering

Applicazioni

- plagiarismo
- interoperabilità. Alcuni esempi:
  - Samba → protocollo SMB
  - WINE → Windows API
  - ReactOS → Windows XP/2003
  - OpenOffice → Microsoft Office
- malware analysis
- *cracking*

Come?

1. tecniche **statiche**
2. tecniche **dinamiche**

Software reverse engineering

Tecniche statiche

il programma *non* viene eseguito

- documentazione
- codice sorgente
- analisi di stringhe, simboli, funzioni di libreria
- **disassembly** e analisi codice assembly

Tecniche dinamiche

esecuzione (monitorata) dell'applicazione

- interazioni con l'ambiente (e.g., file system, rete, registro)
- interazioni con il sistema operativo (system call)
- **debugging**

Background
I formati eseguibili

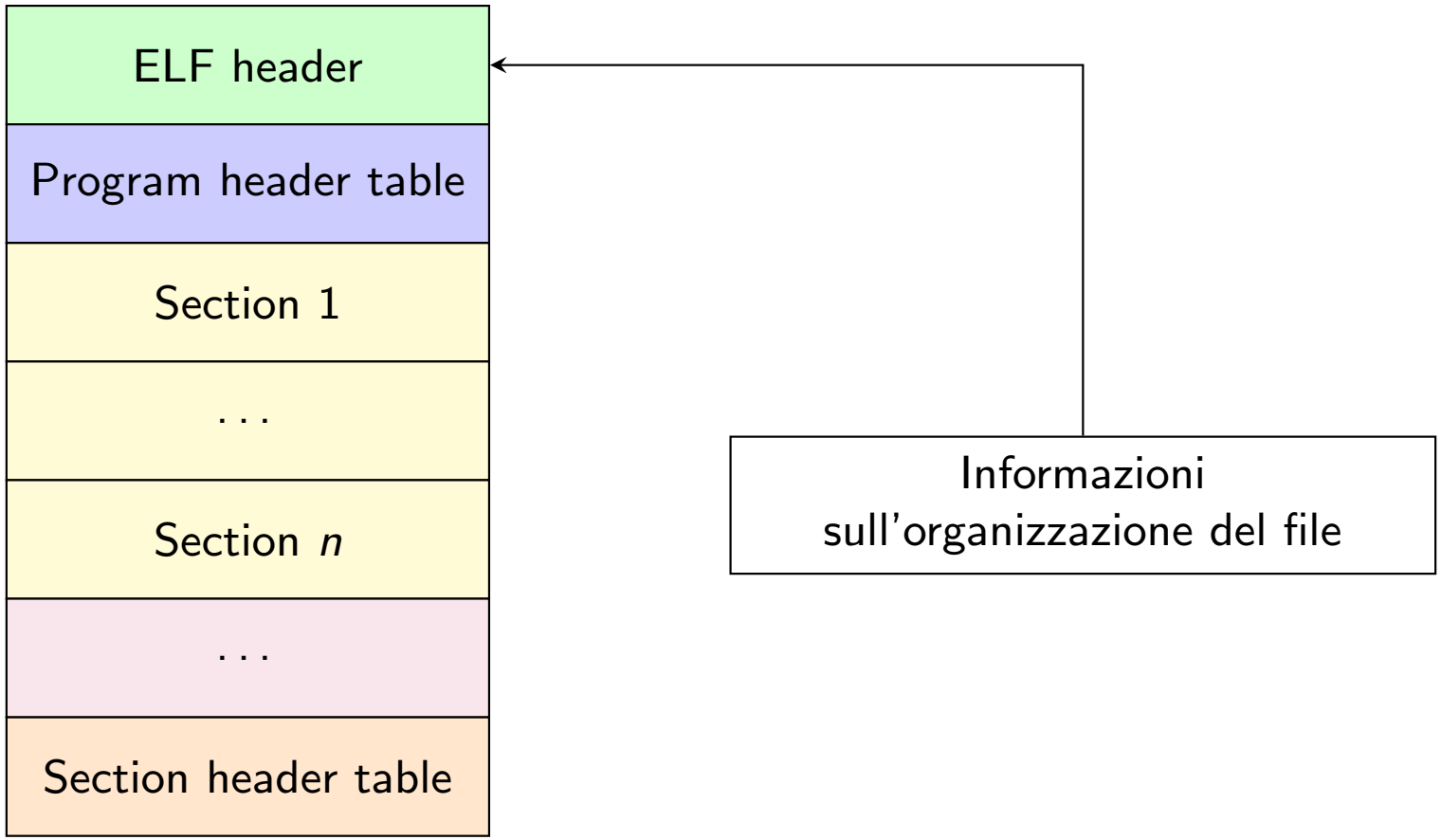
Struttura file eseguibili

- file eseguibili "moderni" hanno una struttura complessa
  - Linux $\rightarrow$ Executable and Linkable Format (**ELF**)
  - Windows $\rightarrow$ Portable Executable (**PE**)

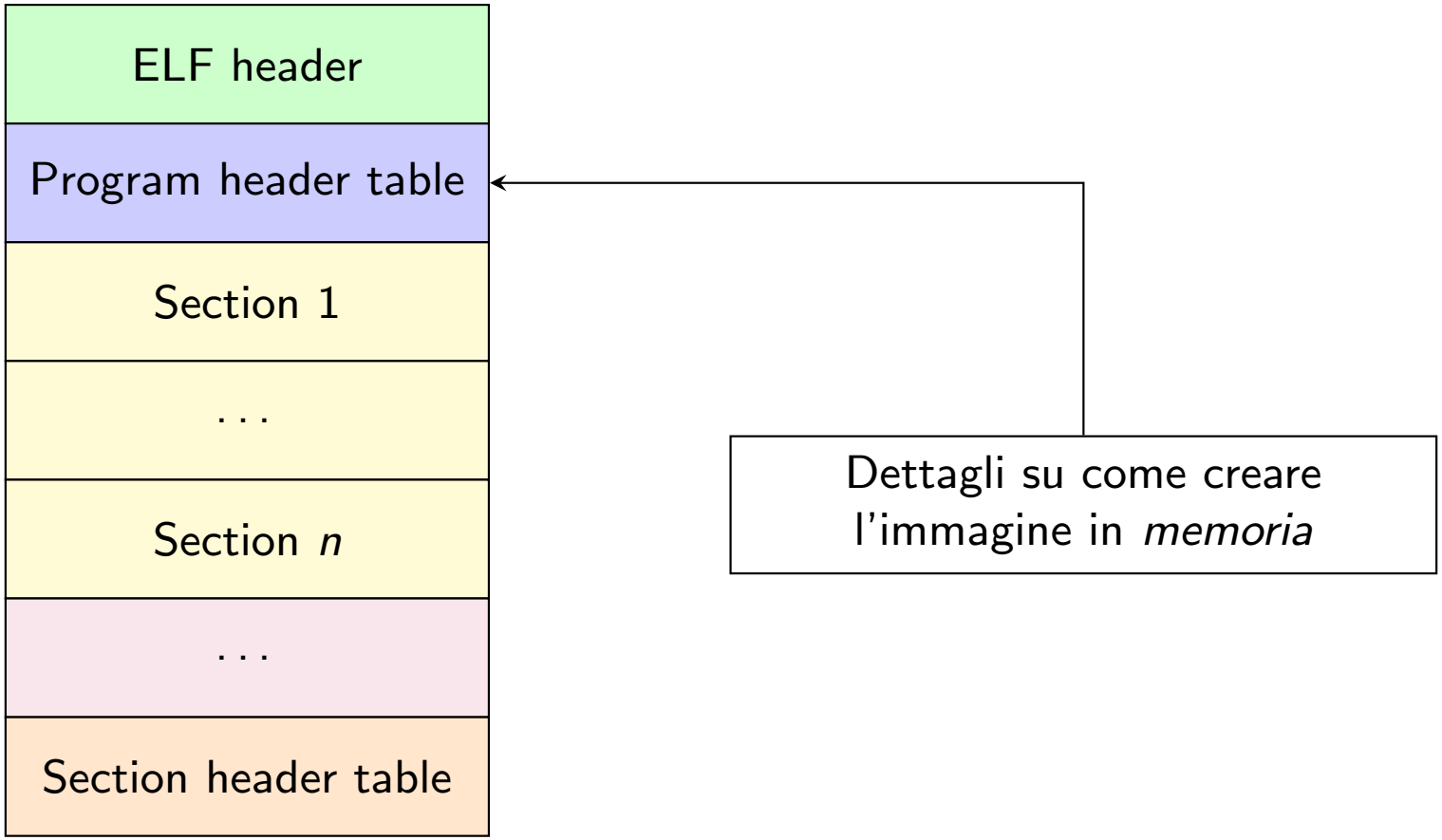
1. *relocatable*
2. *executable*
3. *shared object*

Esempio

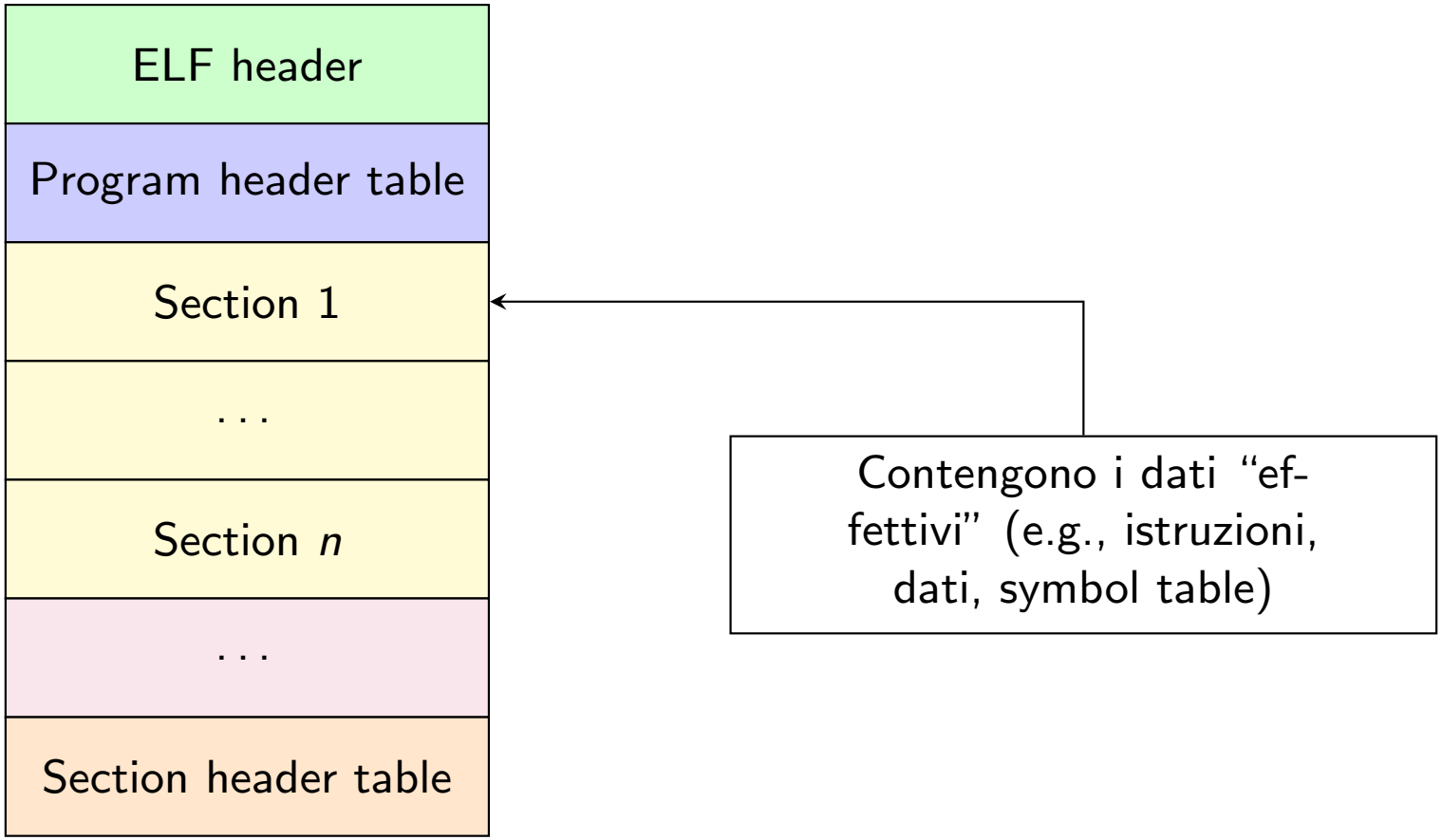
```
sicurezza@sicurezza:/tmp$ gcc -c test.c -o test.o
sicurezza@sicurezza:/tmp$ file test.o
test.o: ELF 32-bit LSB relocatable, Intel 80386, version 1 (SYSV) ...
sicurezza@sicurezza:/tmp$ gcc test.c -o test
sicurezza@sicurezza:/tmp$ file test
test: ELF 32-bit LSB executable, Intel 80386, version 1 (SYSV) ...
sicurezza@sicurezza:/tmp$ gcc -shared test.c -o test.so
sicurezza@sicurezza:/tmp$ file test.so
test.so: ELF 32-bit LSB shared object, Intel 80386, version 1 (SYSV) ...
```



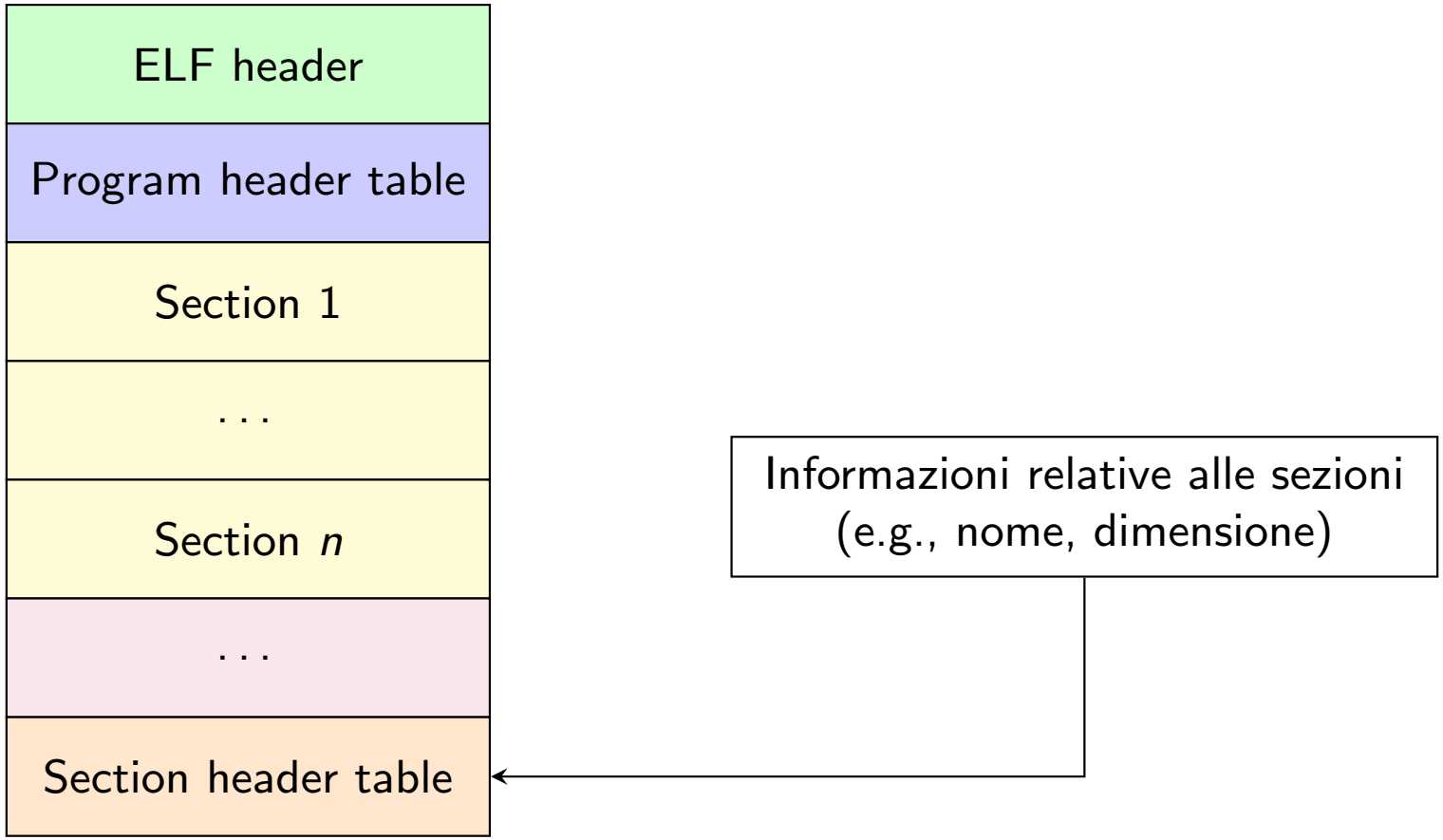
ELF executable file



ELF executable file



ELF executable file



ELF executable file

Elf32_Ehdr in /usr/include/linux/elf.h

- magic number (\x7fELF), ELF type & version
- architettura & *endianness*
- entry point (virtual address)
- offset (nel file) di program & section header table
- ...

Esempio

```
sicurezza@sicurezza:/tmp$ readelf -h test
ELF Header:
  Magic:   7f 45 4c 46 01 01 01 00 00 00 00 00 00 00 00 00
  ...
  Type:                              EXEC (Executable file)
  Machine:                           Intel 80386
  Version:                           0x1
  Entry point address:               0x80482f0
  ...
```

Array di `Elf32_Shdr` in `/usr/include/linux/elf.h`

specifica, per ogni sezione

- nome (i.e., indice nella section header string table)
- posizione nel file e memoria
- dimensione
- ...

Esempio

```
sicurezza@sicurezza:/tmp$ objdump -h test
Idx Name          Size      VMA       LMA       File off  Algn
  0 .interp       00000013  08048114  08048114  00000114  2**0
                  CONTENTS, ALLOC, LOAD, READONLY, DATA
  ...
 12 .text         0000017c  080482f0  080482f0  000002f0  2**4
                  CONTENTS, ALLOC, LOAD, READONLY, CODE
  ...
 22 .data         00000008  080495a4  080495a4  000005a4  2**2
                  CONTENTS, ALLOC, LOAD, DATA
 23 .bss          00000008  080495ac  080495ac  000005ac  2**2
                  ALLOC
```

Array di `Elf32_Phdr` in `/usr/include/linux/elf.h`

array di strutture, ciascuna delle quali definisce

- un segmento (i.e., 1^+ sezioni in memoria); oppure,
- altre informazioni necessarie per organizzare l'immagine in memoria

Esempio

```
sicurezza@sicurezza:/tmp$ objdump -p test
Program Header:
    PHDR off    0x00000034 vaddr 0x08048034 paddr 0x08048034 align 2**2
         filesz 0x000000e0 memsz 0x000000e0 flags r-x
  INTERP off    0x00000114 vaddr 0x08048114 paddr 0x08048114 align 2**0
         filesz 0x00000013 memsz 0x00000013 flags r--
    LOAD off    0x00000000 vaddr 0x08048000 paddr 0x08048000 align 2**12
         filesz 0x000004a4 memsz 0x000004a4 flags r-x
    LOAD off    0x000004a4 vaddr 0x080494a4 paddr 0x080494a4 align 2**12
         filesz 0x00000108 memsz 0x00000110 flags rw-
 DYNAMIC off    0x000004b8 vaddr 0x080494b8 paddr 0x080494b8 align 2**2
         filesz 0x000000d0 memsz 0x000000d0 flags rw-
    NOTE off    0x00000128 vaddr 0x08048128 paddr 0x08048128 align 2**2
         filesz 0x00000020 memsz 0x00000020 flags r--
   STACK off    0x00000000 vaddr 0x00000000 paddr 0x00000000 align 2**2
         filesz 0x00000000 memsz 0x00000000 flags rw-
```

- sezione con una entry per simbolo
- debugging, dynamic linking, relocation, . . .

Esempio

```
sicurezza@sicurezza:/tmp$ readelf -s test

Symbol table '.dynsym' contains 5 entries:
   Num:    Value  Size Type    Bind   Vis      Ndx Name
     0: 00000000     0 NOTYPE  LOCAL  DEFAULT  UND
     ...
     3: 00000000   460 FUNC    GLOBAL DEFAULT  UND puts@GLIBC_2.0 (2)
     4: 0804848c     4 OBJECT  GLOBAL DEFAULT   15 _IO_stdin_used

Symbol table '.symtab' contains 74 entries:
   Num:    Value  Size Type    Bind   Vis      Ndx Name
     0: 00000000     0 NOTYPE  LOCAL  DEFAULT  UND
     1: 08048114     0 SECTION LOCAL  DEFAULT    1
     ...
    70: 080495ac     0 NOTYPE  GLOBAL DEFAULT  ABS _edata
    71: 0804843a     0 FUNC    GLOBAL HIDDEN   13 __i686.get_pc_thunk.bx
    72: 080483a4    38 FUNC    GLOBAL DEFAULT   13 main
    73: 08048274     0 FUNC    GLOBAL DEFAULT   11 _init
```

- sezione con una entry per simbolo
- debugging, dynamic linking, relocation, . . .

Esempio

```
sicurezza@sicurezza:/tmp$ readelf -S test | grep '\.symtab'
  [34] .symtab           SYMTAB   ...
sicurezza@sicurezza:/tmp$ strip test
sicurezza@sicurezza:/tmp$ readelf -s test

Symbol table '.dynsym' contains 5 entries:
   Num:    Value  Size Type    Bind   Vis      Ndx Name
     0: 00000000     0 NOTYPE  LOCAL  DEFAULT  UND
     ...
     3: 00000000   460 FUNC    GLOBAL DEFAULT  UND puts@GLIBC_2.0 (2)
     4: 0804848c     4 OBJECT  GLOBAL DEFAULT   15 _IO_stdin_used
sicurezza@sicurezza:/tmp$ readelf -S test | grep '\.symtab'
sicurezza@sicurezza:/tmp$
```

parte delle operazioni di *linking* vengono rimandate a *runtime*

- facilita l'aggiornamento delle *shared library*
- consente caricamento delle librerie a *runtime*
- *overhead* a *runtime* superiore rispetto a *linking* statico
- simboli linkati dinamicamente devono essere risolti "al volo"

Global Offset Table e *Procedure Linkage Table*

- sezioni (`.got` e `.plt`) presenti in eseguibili che utilizzano *dynamic linking*
- PLT aggiunge un livello di indirettezza alle chiamate a funzione, consentendo anche il *lazy binding* dei relativi indirizzi

Esempio

```
sicurezza@sicurezza:~$ objdump -h $(which ls)
Sections:
Idx Name          Size      VMA       LMA       File off  Algn
...
 11 .plt          00000610  08049538  08049538  00001538  2**2
                  CONTENTS, ALLOC, LOAD, READONLY, CODE
...
 21 .got          00000008  0805b5d4  0805b5d4  000125d4  2**2
                  CONTENTS, ALLOC, LOAD, DATA
```

Chiamata ad una funzione *shared*

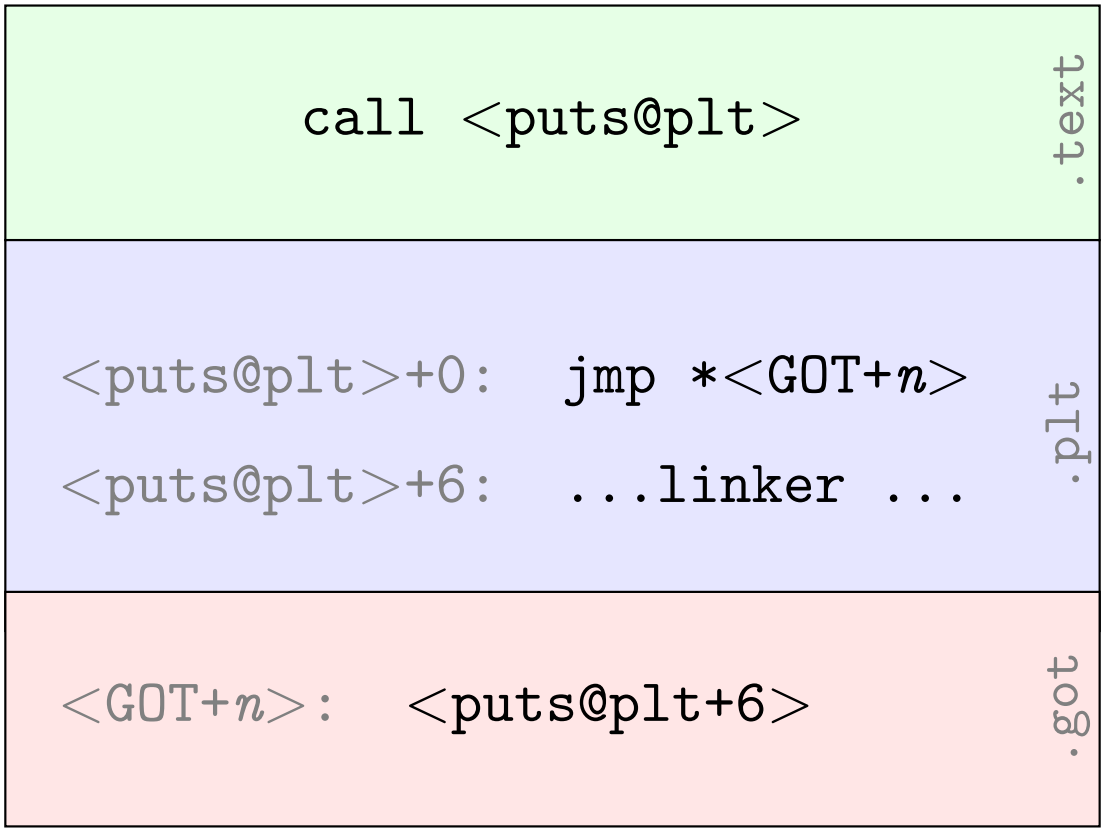
1. chiamata `f()` *shared* → chiamata ad una entry della `PLT`
2. `PLT`: `jmp` indiretto ad una *entry* della `GOT` che conterrà:
   - la *prima volta*, l'indirizzo di una *entry* della `PLT` che trasferisce il controllo al linker, per risoluzione e aggiornamento della `GOT`
   - *successivamente*, l'indirizzo effettivo della *shared function*

Esempio

```
sicurezza@sicurezza:/tmp$ objdump -d test
 ...
0804830c <puts@plt>:
 804830c:       ff 25 08 96 04 08       jmp    *0x8049608
 8048312:       68 18 00 00 00          push   $0x18
 8048317:       e9 b0 ff ff ff          jmp    80482cc <_init+0x30>
 ...
080483d4 <main>:
 ...
 80483ec:       e8 1b ff ff ff          call   804830c <puts@plt>
 ...
```

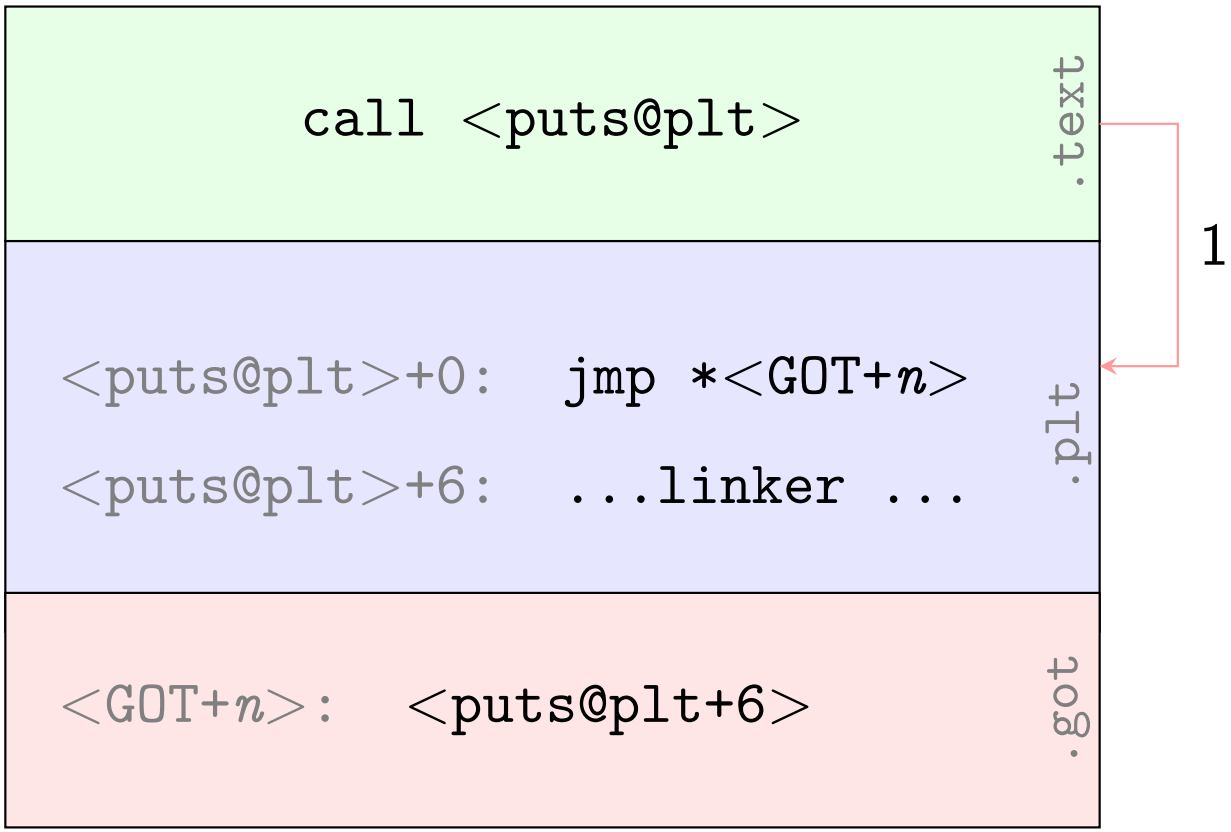
ELF: supporto al dynamic linking

Esempio `.got` e `.plt`



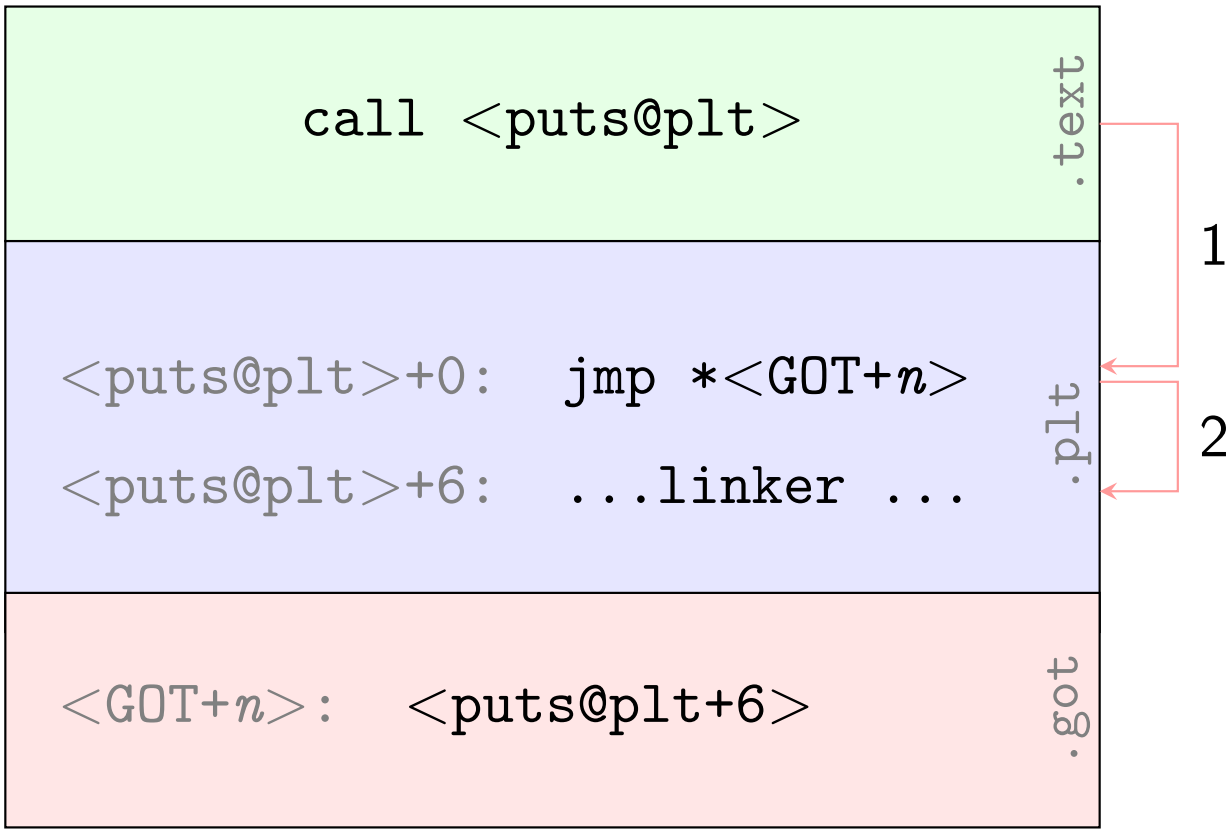
ELF: supporto al dynamic linking

Esempio `.got` e `.plt`



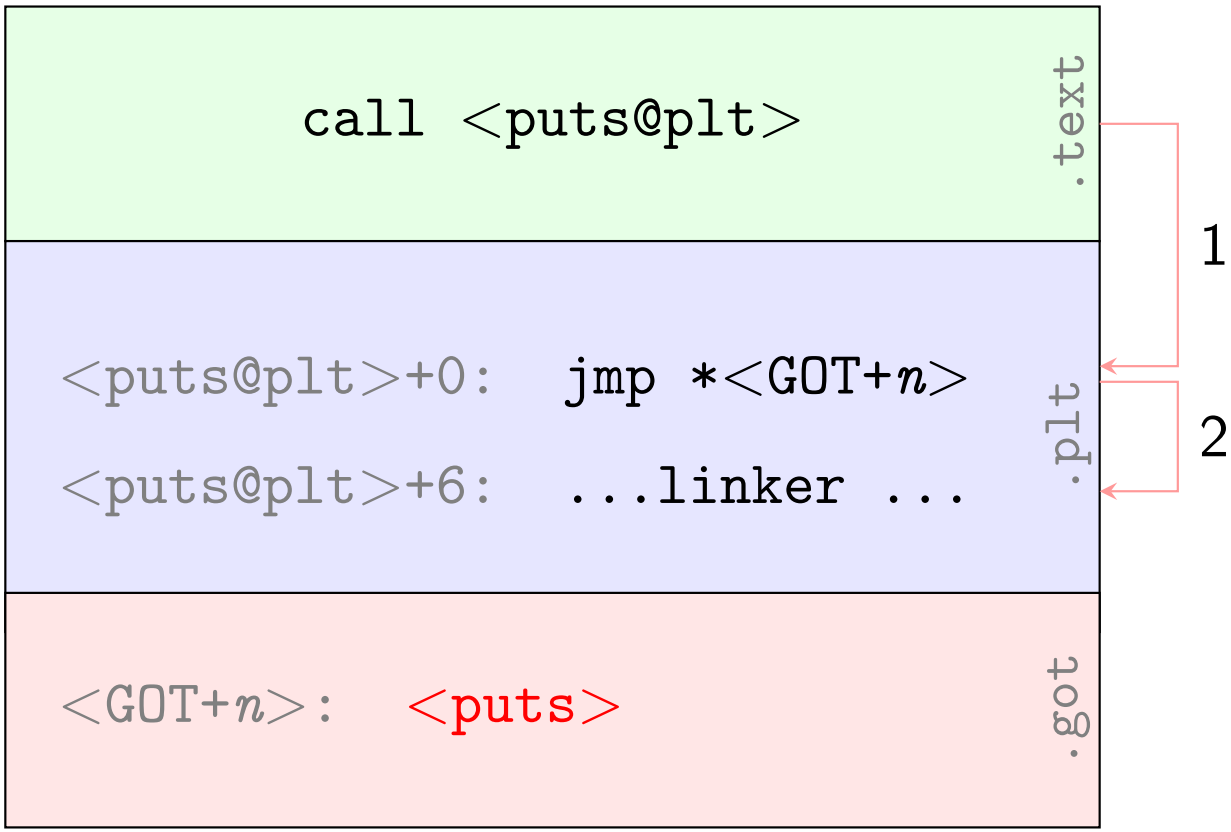
ELF: supporto al dynamic linking

Esempio `.got` e `.plt`



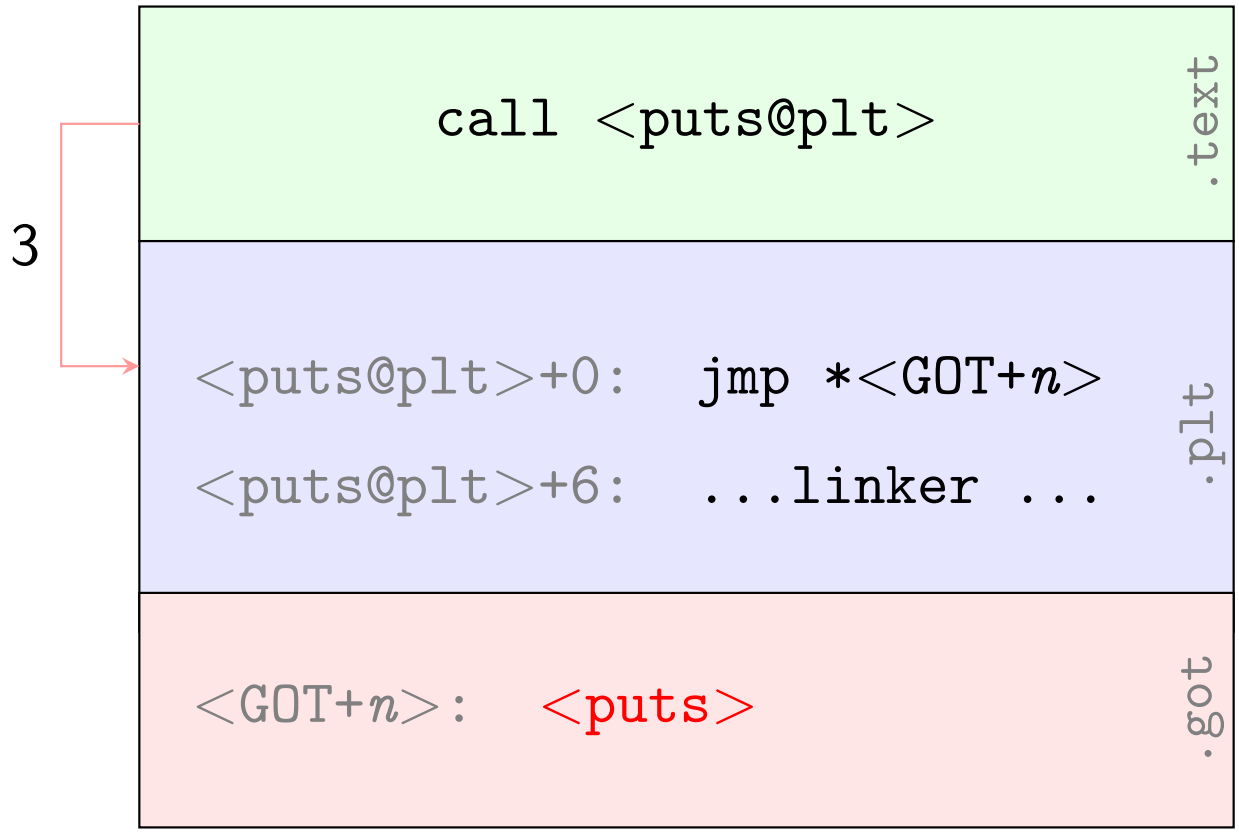
ELF: supporto al dynamic linking

Esempio .got e .plt



ELF: supporto al dynamic linking

Esempio `.got` e `.plt`



ELF: supporto al dynamic linking

Lazy binding: performance

```
$ time (mplayer >/dev/null)          $ time (LD_BIND_NOW=1 mplayer >/dev/null)
real    0m0.039s                     real    0m0.141s
user    0m0.024s                     user    0m0.100s
sys     0m0.012s                     sys     0m0.016s
```

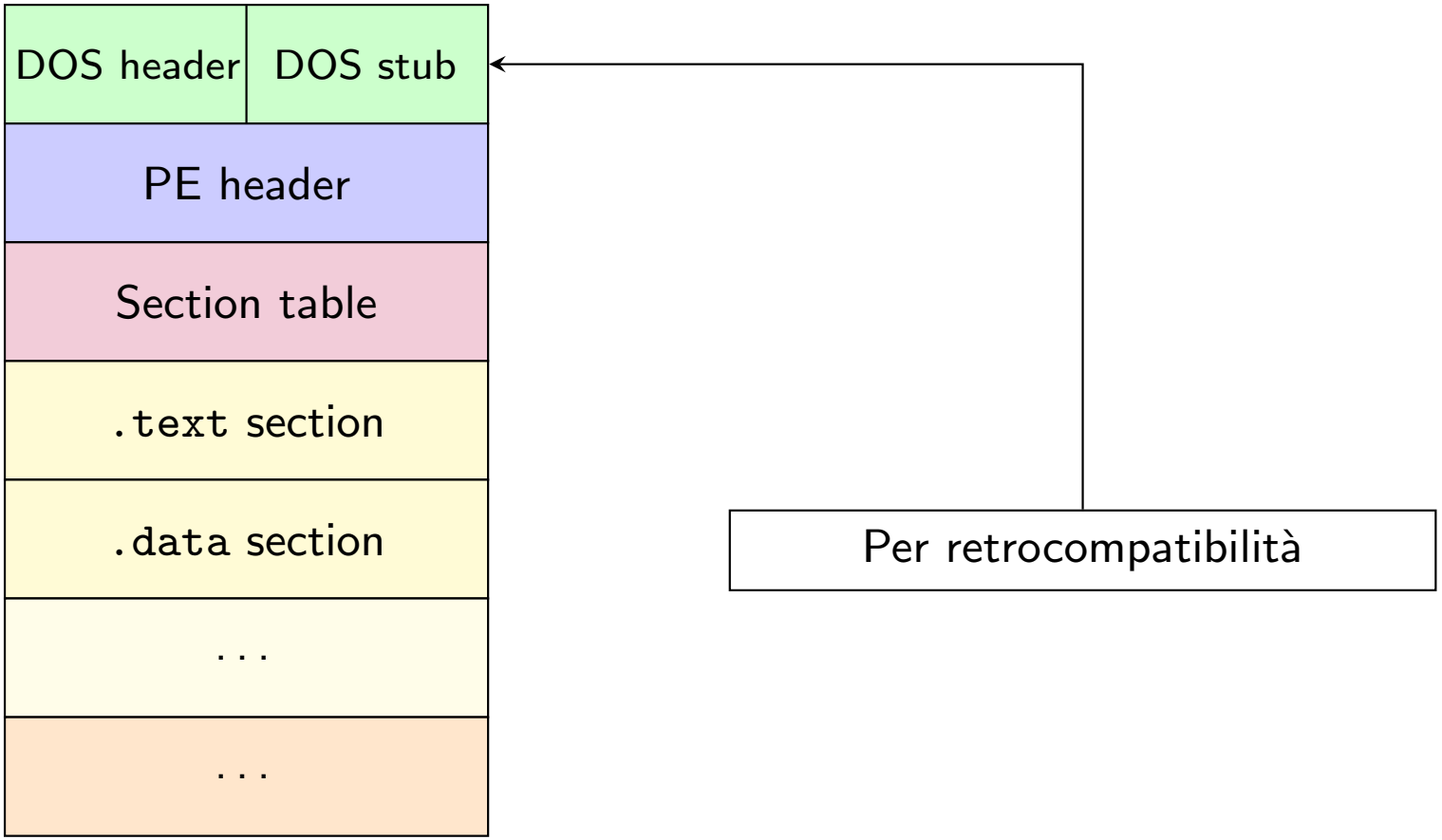
Esempio: dump librerie e dynamic loader

```
$ ldd /tmp/test
        linux-gate.so.1 =>  (0xb7faf000)
        libc.so.6 => /lib/i686/cmov/libc.so.6 (0xb7e43000)
        /lib/ld-linux.so.2 (0xb7fb0000)

sicurezza@sicurezza:/tmp$ readelf ./test -x .interp

Hex dump of section '.interp':
  0x08048114 2f6c6962 2f6c642d 6c696e75 782e736f /lib/ld-linux.so
  0x08048124 2e3200                              .2.
```

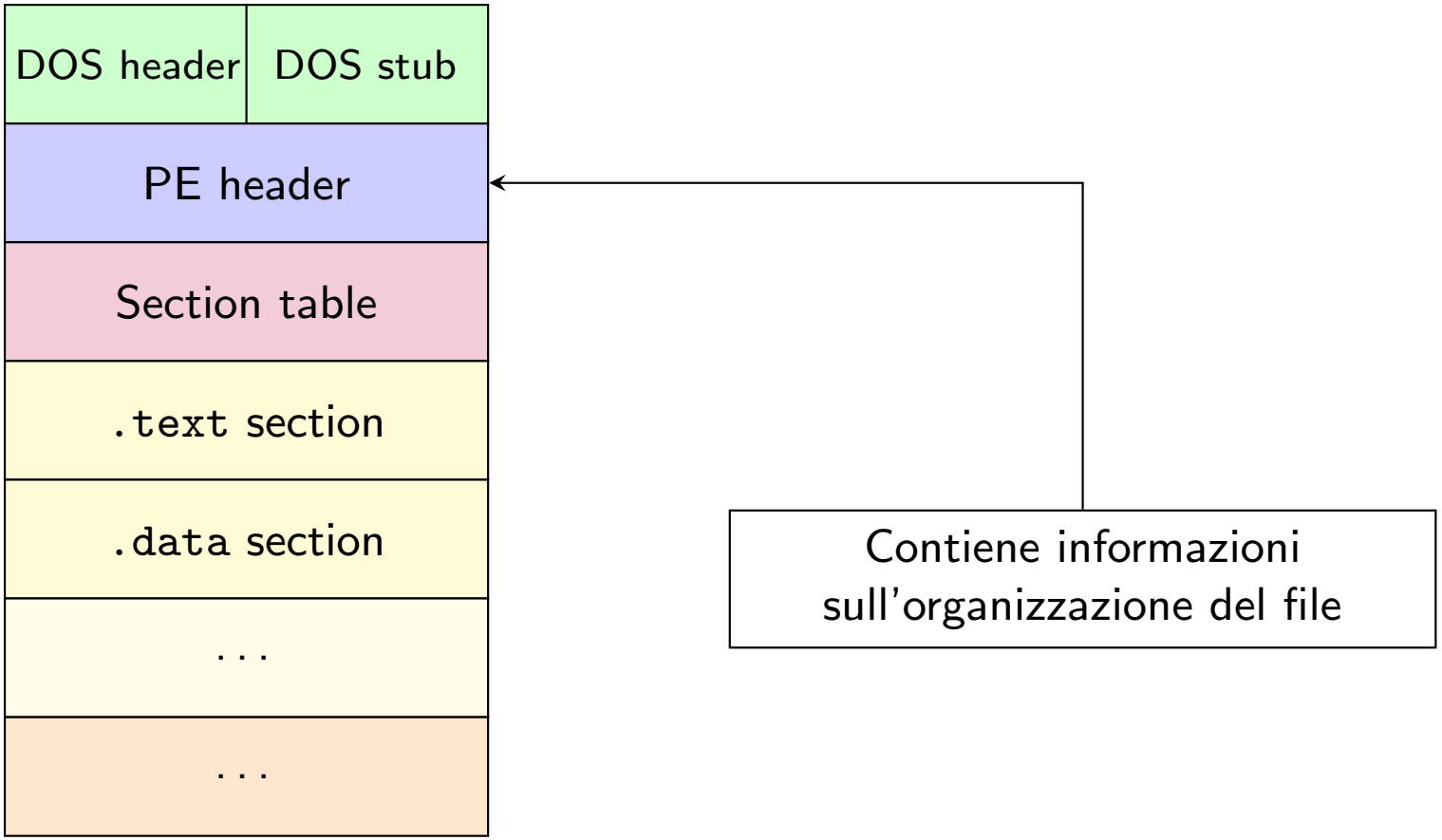
1. *executable*
2. *object*
3. *DLL*
4. *COM files, OCX controls, CLP applets, .NET executables*
5. *device driver*
6. ...

Esempio

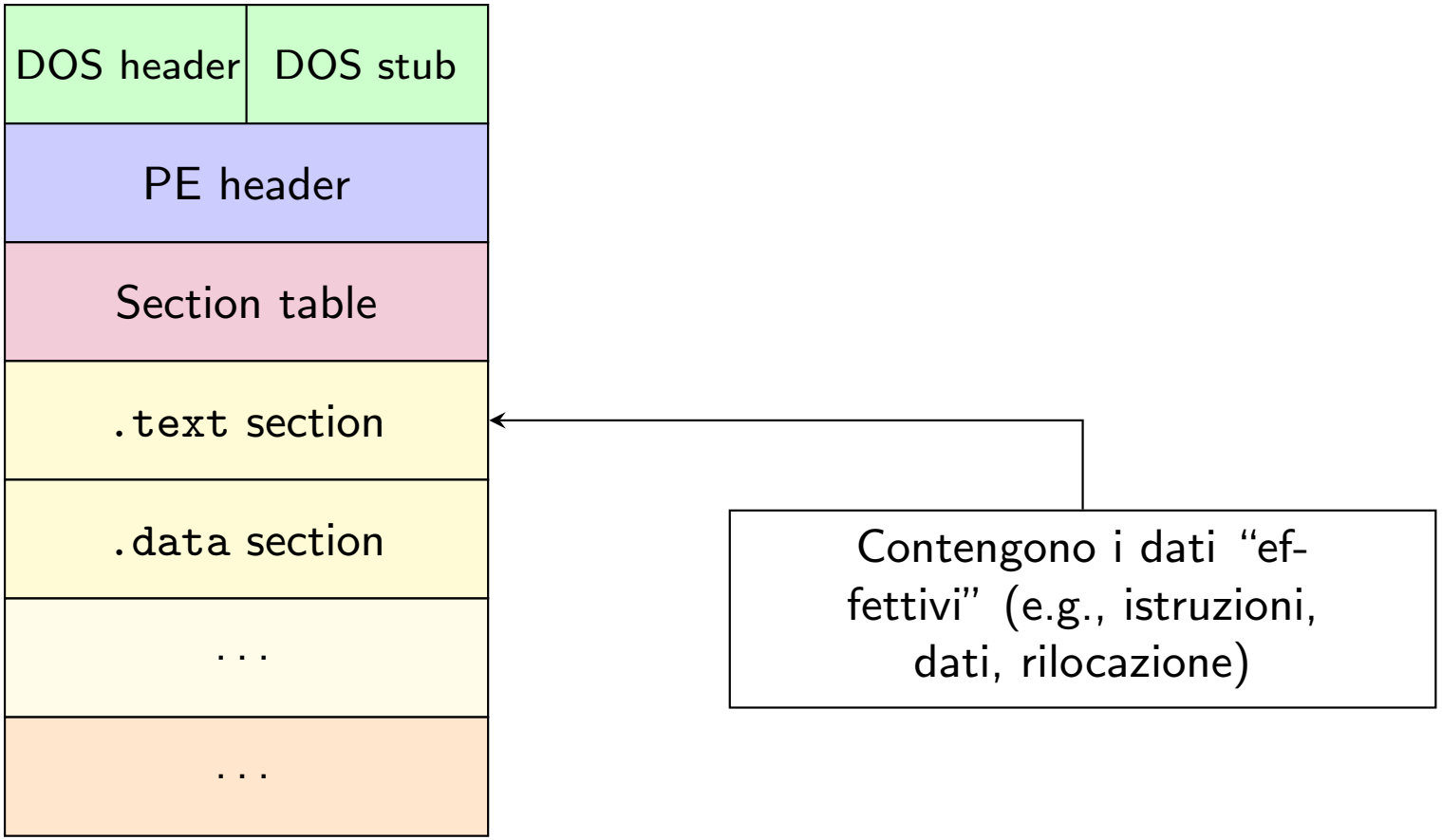
```
sicurezza@sicurezza:/tmp$ file test.exe
test.exe: PE32 executable for MS Windows (console) Intel 80386 32-bit
sicurezza@sicurezza:/tmp$ file test.o
test.o: 80386 COFF executable not stripped - version 30821
sicurezza@sicurezza:/tmp$ file test.dll
test.dll: PE32 executable for MS Windows (DLL) (console) Intel ...
sicurezza@sicurezza:/tmp$ file test.sys
test.sys: PE32 executable for MS Windows (DLL) (native) Intel ...
```



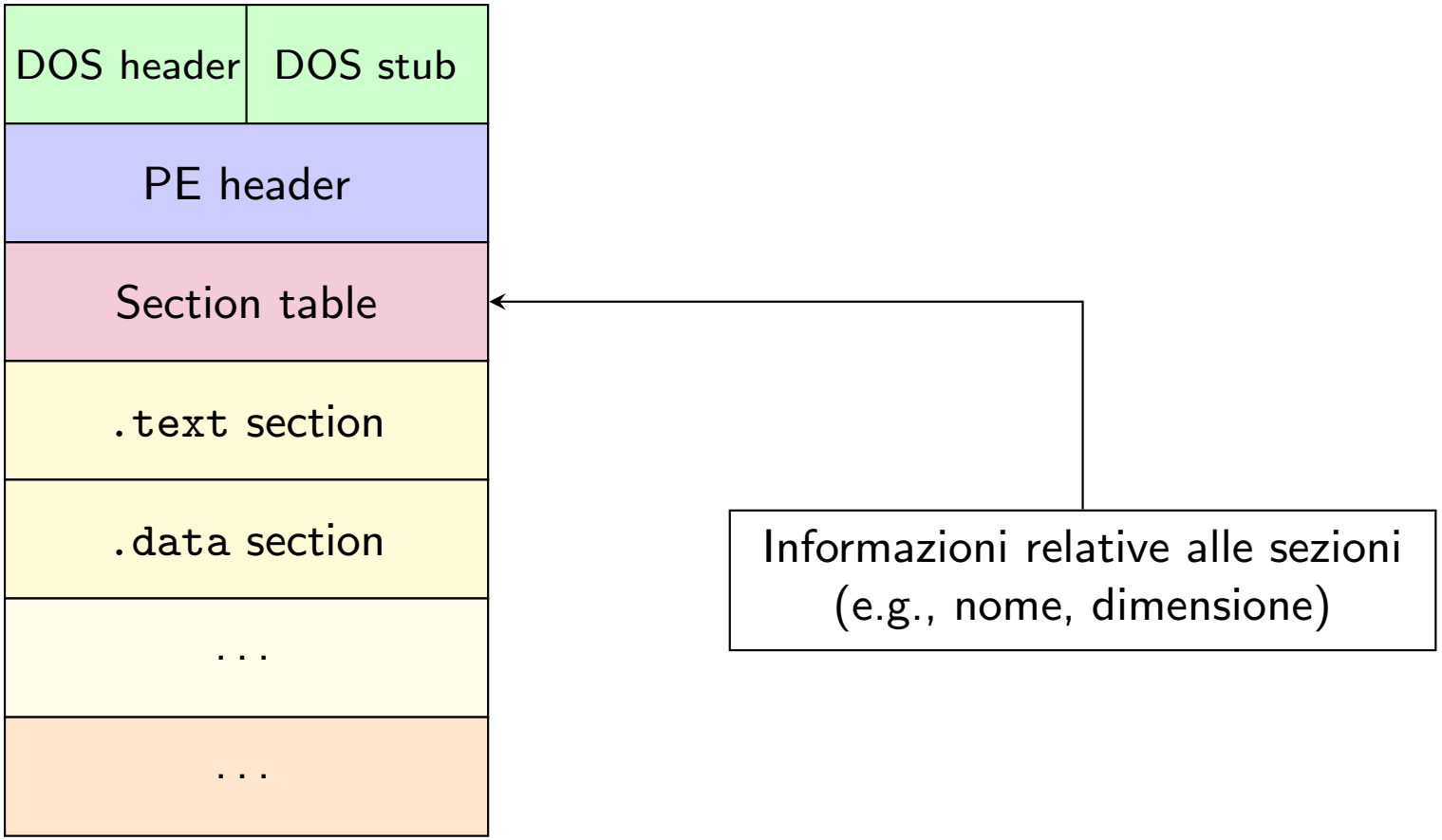
PE executable file



PE executable file



PE executable file



PE executable file

- *modulo*: file PE caricato in memoria (e "riorganizzato" dal loader)
- *RVA*: **R**elative **V**irtual **A**ddress
  - indirizzo relativo al *base address* dell'immagine in memoria
  - `CODE @ 0x401000, base address 0x400000`
    `RVA(CODE) = 0x1000`
  - RVA $\neq$ file offset
- strutture definite in `winnt.h`

DOS header

```
typedef struct _IMAGE_DOS_HEADER {
    WORD e_magic;
    ...
    LONG e_lfanew;
} IMAGE_DOS_HEADER,*PIMAGE_DOS_HEADER;
```

- 64 byte, magic number `\x4d\x5a` ("MZ")
- `e_lfanew`: offset PE header
- segue DOS stub

DOS stub

- "*This program cannot be run in DOS mode*"

```
typedef struct _IMAGE_NT_HEADERS {
    DWORD Signature; // "\x50\x45\x00\x00" ("PE\x00\x00")
    IMAGE_FILE_HEADER FileHeader;
    IMAGE_OPTIONAL_HEADER OptionalHeader;
} IMAGE_NT_HEADERS32,*PIMAGE_NT_HEADERS32;

typedef struct _IMAGE_FILE_HEADER {
    WORD Machine;
    WORD NumberOfSections;
    ...
} IMAGE_FILE_HEADER,*PIMAGE_FILE_HEADER;

typedef struct _IMAGE_OPTIONAL_HEADER { // non e' opzionale!
    ...
    DWORD AddressOfEntryPoint;
    ...
    DWORD ImageBase;
    DWORD SectionAlignment;
    DWORD FileAlignment;
    ...
    WORD Subsystem;
    ...
    IMAGE_DATA_DIRECTORY DataDirectory[IMAGE_NUMBEROF_DIRECTORY_ENTRIES];
} IMAGE_OPTIONAL_HEADER32,*PIMAGE_OPTIONAL_HEADER32;
```

```
typedef struct _IMAGE_SECTION_HEADER {
    BYTE Name[IMAGE_SIZEOF_SHORT_NAME];
    union {
        DWORD PhysicalAddress;
        DWORD VirtualSize;
    } Misc;
    DWORD VirtualAddress;
    DWORD SizeOfRawData;
    DWORD PointerToRawData;
    ...
    DWORD Characteristics;
} IMAGE_SECTION_HEADER,*PIMAGE_SECTION_HEADER;
```

Alcune sezioni

1. *executable code section* (`.text`) (di solito, `AddressOfEntryPoint` $\in$ `.text`)
2. *data sections* (`.data`, `.rdata`, `.bss`, ...)

Reverse engineering

Alcuni esempi

Reverse engineering: alcuni esempi
Variabili

```
1   #include <string.h>
2
3   int global;
4
5   int main(int argc, char **argv)
6   {
7     int local;
8     char v[256];
9
10    local = 10;
11    global = 11;
12
13    v[5] = 'a';
14
15    return 0;
16  }
```

```
1   <main>:
2     ...
3     8048374: lea 0x4(%esp),%ecx
4     8048378: and $0xfffffff0,%esp
5     804837b: pushl -0x4(%ecx)
6     804837e: push %ebp
7     804837f: mov %esp,%ebp
8     8048381: push %ecx
9     8048382: sub $0x110,%esp
10    8048388: movl $0xa,−0x8(%ebp)
11    804838f: movl $0xb,0x8049590
12    8048399: movb $0x61,−0x103(%ebp)
13    80483a0: mov $0x0,%eax
14    80483a5: add $0x110,%esp
15    80483ab: pop %ecx
16    80483ac: pop %ebp
17    80483ad: lea -0x4(%ecx),%esp
18    80483b0: ret
19    ...
```

Reverse engineering: alcuni esempi
Chiamata a funzione

```
1   int sum(int a, int b)
2   {
3     int c;
4
5     c = a + b;
6     return c;
7   }
8
9   int main(int argc, char **argv)
10  {
11    int a;
12
13    a = sum(2,3);
14    return 0;
15  }
```

```
1   <sum>:
2    push %ebp
3    mov %esp,%ebp
4    sub $0x10,%esp
5    mov 0xc(%ebp),%edx
6    mov 0x8(%ebp),%eax
7    add %edx,%eax
8    mov %eax,-0x4(%ebp)
9    mov -0x4(%ebp),%eax
10   leave
11   ret
12
13  <main>:
14   ...
15   sub $0x18,%esp
16   movl $0x3,0x4(%esp)
17   movl $0x2,(%esp)
18   call <sum>
19   mov %eax,-0x8(%ebp)
20   ...
```

Reverse engineering: alcuni esempi

Costrutto `if`

```
1   #include <stdio.h>
2
3   int main(int argc, char **argv)
4   {
5     if (argc < 2) {
6       printf("! syntax error.\n");
7     } else {
8       printf("ok.\n");
9     }
10
11    return 0;
12  }
```

```
1   <main>:
2     ...
3     80483b7: mov %eax,−0x8(%ebp)
4     80483ba: cmpl $0x1,(%ecx)
5     80483bd: jg 80483cd <main+0x29>
6     80483bf: movl $0x80484b0,(%esp)
7     80483c6: call 80482d4 <puts@plt>
8     80483cb: jmp 80483d9 <main+0x35>
9     80483cd: movl $0x80484c0,(%esp)
10    80483d4: call 80482d4 <puts@plt>
11    80483d9: mov $0x0,%eax
12    ...
```

Reverse engineering: alcuni esempi

Costrutto `while`

```
1   #include <stdio.h>
2
3   int main(int argc, char **argv)
4   {
5     int i;
6
7     i = 0;
8     while (i < 10) {
9       printf("* %02d\n", i);
10      i += 1;
11    }
12
13    return 0;
14
15  }
```

```
1   <main>:
2     ...
3     80483b5: movl $0x0,−0x8(%ebp)
4     80483bc: jmp 80483d5 <main+0x31>
5     80483be: mov −0x8(%ebp),%eax
6     80483c1: mov %eax,0x4(%esp)
7     80483c5: movl $0x80484b0,(%esp)
8     80483cc: call 80482d8 <printf@plt>
9     80483d1: addl $0x1,−0x8(%ebp)
10    80483d5: cmpl $0x9,−0x8(%ebp)
11    80483d9: jle 80483be <main+0x1a>
12    80483db: mov $0x0,%eax
13    ...
```

Reverse engineering: alcuni esempi

Costrutto `for`

```
1   #include <stdio.h>
2
3   int main(int argc, char **argv)
4   {
5     int i;
6
7     for(i=0; i<10; i++) {
8       printf("* %02d\n", i);
9     }
10
11    return 0;
12
13  }
```

```
1   <main>:
2    ...
3    80483b5: movl $0x0,-0x8(%ebp)
4    80483bc: jmp 80483d5 <main+0x31>
5    80483be: mov -0x8(%ebp),%eax
6    80483c1: mov %eax,0x4(%esp)
7    80483c5: movl $0x80484b0,(%esp)
8    80483cc: call 80482d8 <printf@plt>
9    80483d1: addl $0x1,-0x8(%ebp)
10   80483d5: cmpl $0x9,-0x8(%ebp)
11   80483d9: jle 80483be <main+0x1a>
12   80483db: mov $0x0,%eax
13   ...
```

Reverse engineering: alcuni esempi

Costrutto `switch`

```
1   int main(int argc, char **argv)
2   {
3     int a;
4
5     a = argc;
6
7     switch(a) {
8     case 0:
9       printf("case 0\n"); break;
10    case 1:
11      printf("case 1\n"); break;
12    ...
13    case 4:
14      printf("case 4\n"); break;
15    default:
16      printf("default\n"); break;
17    }
18
19    return 0;
20  }
```

```
1   <main>:
2     ...
3     80483b7: mov %eax,−0x8(%ebp)
4     80483ba: cmpl $0x4,−0x8(%ebp)
5     80483be: ja 8048414 <main+0x70>
6     80483c0: mov −0x8(%ebp),%eax
7     80483c3: shl $0x2,%eax
8     80483c6: mov 0x8048520(%eax),%eax
9     80483cc: jmp *%eax
10    80483ce: movl $0x80484f0,(%esp)
11    80483d5: call 80482d4 <puts@plt>
12    ...
13    8048406: movl $0x804850c,(%esp)
14    804840d: call 80482d4 <puts@plt>
15    8048412: jmp 8048420 <main+0x7c>
16    8048414: movl $0x8048513,(%esp)
17    804841b: call 80482d4 <puts@plt>
18    8048420: mov $0x0,%eax
19    ...
```

Hands on!

```
$ wget http://security.di.unimi.it/sicurezza1314/samples.tar.gz
```

Usando **solo** objdump:

1. `sampleA`: quali variabili (e di che tipo) sono usate dalla procedura `disass_me`?
2. `sampleB`: con quali parametri viene chiamata la procedura `disass_me`?
3. `sample(C|D|E)`: quali costrutti sono usati nelle varie procedure `disass_me`?

Vale tutto:

1. `sample_switch`: è possibile fare in modo che venga eseguito il `case 0`, *senza modificare il codice*? Se sì, come?

Seconda parte

- tecniche di disassembly
- per chi non l'avesse già fatto: **installare IDA Pro!**
  - versione freeware:
    `http://www.hex-rays.com/idapro/idadownfreeware.htm`