ELFy, obiekty i skrypty linkera

Paweł Kraszewski <root@linuxpedia.pl>

Jak zrobić najmniejszą aplikację*?

```
#include <stdio.h>

int main( int argc, char **argv )
{
    printf( "Hello world!\n" );
    return 0;
}
```

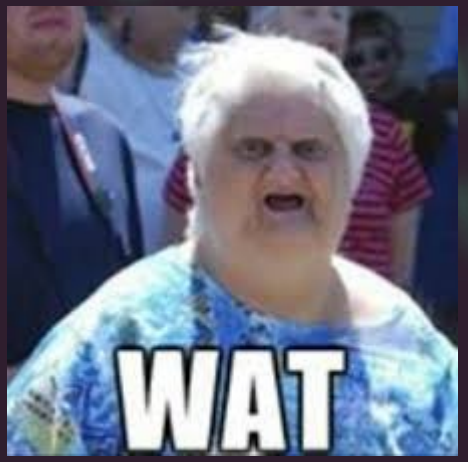
* Bez używania** asemblera

** Prawie

Jak zrobić najmniejszą aplikację?

```
> gcc -o main1 -O2 --static main1.c
> strip main1
> ls -al main1
```

```
-rwxr-xr-x 1 LwB LwB 844784 main1
```



```
> readelf -e main1
ELF Header:
  Magic:   7f 45 4c 46 02 01 01 03 00 00 00 00 00 00 00 00
  Class:                             ELF64
  Data:                              2's complement, little endian
  Version:                           1 (current)
  OS/ABI:                            UNIX - GNU
  ABI Version:                       0
  Type:                              EXEC (Executable file)
  Machine:                           Advanced Micro Devices X86-64
  Version:                           0x1
  Entry point address:               0x4009f0
  Start of program headers:          64 (bytes into file)
  Start of section headers:          842736 (bytes into file)
  Flags:                             0x0
  Size of this header:               64 (bytes)
  Size of program headers:           56 (bytes)
  Number of program headers:         6
  Size of section headers:           64 (bytes)
  Number of section headers:         32
  Section header string table index: 31


...
```

```
Section Headers:
  [Nr] Name              Type            Address          Off    Size   ES Flg Lk Inf Al
  [ 0]                   NULL            0000000000000000 000000 000000 00      0   0  0
  [ 1] .note.ABI-tag     NOTE            0000000000400190 000190 000020 00   A  0   0  4
  [ 2] .note.gnu.build-id NOTE            00000000004001b0 0001b0 000024 00   A  0   0  4
  [ 3] .rela.plt         RELA            00000000004001d8 0001d8 000108 18  AI  0  25  8
  [ 4] .init             PROGBITS        00000000004002e0 0002e0 000017 00  AX  0   0  4
  [ 5] .plt              PROGBITS        0000000000400300 000300 0000b0 00  AX  0   0 16
  [ 6] .text             PROGBITS        00000000004003b0 0003b0 09f967 00  AX  0   0 16
  [ 7] __libc_freeres_fn PROGBITS        000000000049fd20 09fd20 002529 00  AX  0   0 16
  [ 8] __libc_thread_freeres_fn PROGBITS        00000000004a2250 0a2250 0000e1 00  AX  0   0 16
  [ 9] .fini             PROGBITS        00000000004a2334 0a2334 000009 00  AX  0   0  4
  [10] .rodata           PROGBITS        00000000004a2340 0a2340 01c9a4 00   A  0   0 32
  [11] __libc_subfreeres PROGBITS        00000000004bece8 0bece8 000050 00   A  0   0  8
  [12] __libc_IO_vtables PROGBITS        00000000004bed40 0bed40 0006a8 00   A  0   0 32
  [13] __libc_atexit     PROGBITS        00000000004bf3e8 0bf3e8 000008 00   A  0   0  8
  [14] .stapsdt.base     PROGBITS        00000000004bf3f0 0bf3f0 000001 00   A  0   0  1
  [15] __libc_thread_subfreeres PROGBITS        00000000004bf3f8 0bf3f8 000008 00   A  0   0  8
  [16] .eh_frame         PROGBITS        00000000004bf400 0bf400 00aedc 00   A  0   0  8
  [17] .gcc_except_table PROGBITS        00000000004ca2dc 0ca2dc 0000c1 00   A  0   0  1
  [18] .tdata            PROGBITS        00000000006caeb8 0caeb8 000020 00 WAT  0   0  8
  [19] .tbss             NOBITS          00000000006caed8 0caed8 000030 00 WAT  0   0  8
  [20] .init_array       INIT_ARRAY      00000000006caed8 0caed8 000010 08  WA  0   0  8
  [21] .fini_array       FINI_ARRAY      00000000006caee8 0caee8 000010 08  WA  0   0  8
  [22] .jcr              PROGBITS        00000000006caef8 0caef8 000008 00  WA  0   0  8
  [23] .data.rel.ro      PROGBITS        00000000006caf00 0caf00 0000e4 00  WA  0   0 32
  [24] .got              PROGBITS        00000000006cafe8 0cafe8 000008 08  WA  0   0  8
  [25] .got.plt          PROGBITS        00000000006cb000 0cb000 000070 08  WA  0   0  8
  [26] .data             PROGBITS        00000000006cb080 0cb080 001ad0 00  WA  0   0 32
  [27] .bss              NOBITS          00000000006ccb60 0ccb50 001898 00  WA  0   0 32
  [28] __libc_freeres_ptrs NOBITS          00000000006ce3f8 0ccb50 000030 00  WA  0   0  8
  [29] .comment          PROGBITS        0000000000000000 0ccb50 00002d 01  MS  0   0  1
  [30] .note.stapsdt     NOTE            0000000000000000 0ccb80 000f04 00      0   0  4
  [31] .shstrtab         STRTAB          0000000000000000 0cda84 00016b 00      0   0  1

…
```

```
Key to Flags:
  W (write), A (alloc), X (execute), M (merge), S (strings), I (info),
  L (link order), O (extra OS processing required), G (group), T (TLS),
  C (compressed), x (unknown), o (OS specific), E (exclude),
  l (large), p (processor specific)

Program Headers:
  Type           Offset   VirtAddr           PhysAddr           FileSiz  MemSiz   Flg Align
  LOAD           0x000000 0x0000000000400000 0x0000000000400000 0x0ca39d 0x0ca39d R E 0x200000
  LOAD           0x0caeb8 0x00000000006caeb8 0x00000000006caeb8 0x001c98 0x003570 RW  0x200000
  NOTE           0x000190 0x0000000000400190 0x0000000000400190 0x000044 0x000044 R   0x4
  TLS            0x0caeb8 0x00000000006caeb8 0x00000000006caeb8 0x000020 0x000050 R   0x8
  GNU_STACK      0x000000 0x0000000000000000 0x0000000000000000 0x000000 0x000000 RW  0x10
  GNU_RELRO      0x0caeb8 0x00000000006caeb8 0x00000000006caeb8 0x000148 0x000148 R   0x1

 Section to Segment mapping:
  Segment Sections...
   00     .note.ABI-tag .note.gnu.build-id .rela.plt .init .plt .text __libc_freeres_fn
__libc_thread_freeres_fn .fini .rodata __libc_subfreeres __libc_IO_vtables __libc_atexit
.stapsdt.base __libc_thread_subfreeres .eh_frame .gcc_except_table
   01     .tdata .init_array .fini_array .jcr .data.rel.ro .got .got.plt .data .bss
__libc_freeres_ptrs
   02     .note.ABI-tag .note.gnu.build-id
   03     .tdata .tbss
   04
   05     .tdata .init_array .fini_array .jcr .data.rel.ro .got
```

I co teras?

Sprawdzimy plik obiektowy

```
> gcc -c -O2 main1.c
> objdump -s main1.o

main1.o:     file format elf64-x86-64

Contents of section .rodata.str1.1:
 0000 48656c6c 6f20776f 726c6421 00        Hello world!.
Contents of section .text.startup:
 0000 488d3d00 00000048 83ec08e8 00000000  H•=....H........
 0010 31c04883 c408c3                      1.H....
Contents of section .comment:
 0000 00474343 3a202855 62756e74 7520362e  .GCC: (Ubuntu 6.
 0010 332e302d 31327562 756e7475 32292036  3.0-12ubuntu2) 6
 0020 2e332e30 20323031 37303430 3600      .3.0 20170406.
Contents of section .eh_frame:
 0000 14000000 00000000 017a5200 01781001  .........zR..x..
 0010 1b0c0708 90010000 14000000 1c000000  ................
 0020 00000000 17000000 004b0e10 4b0e0800  .........K..K...
```

Sprawdzimy plik obiektowy

```
> objdump -d -Mintel main1.o

main.o:     file format elf64-x86-64

Disassembly of section .text.startup:

0000000000000000 <main>:
   0:   48 8d 3d 00 00 00 00    lea    rdi,[rip+0x0]
                                # 7 <main+0x7>
   7:   48 83 ec 08             sub    rsp,0x8
   b:   e8 00 00 00 00          call   10 <main+0x10>
  10:   31 c0                   xor    eax,eax
  12:   48 83 c4 08             add    rsp,0x8
  16:   c3                      ret
```

Sprawdzimy plik obiektowy

```
> objdump -tr main1.o

main1.o:     file format elf64-x86-64

SYMBOL TABLE:
0000000000000000 l    df *ABS*  0000000000000000 main1.c
0000000000000000 l    d  .text  0000000000000000 .text
0000000000000000 l    d  .data  0000000000000000 .data
0000000000000000 l    d  .bss   0000000000000000 .bss
0000000000000000 l    d  .rodata.str1.1 0000000000000000 .rodata.str1.1
0000000000000000 l    d  .text.startup  0000000000000000 .text.startup
0000000000000000 l    d  .note.GNU-stack        0000000000000000 .note.GNU-stack
0000000000000000 l    d  .eh_frame      0000000000000000 .eh_frame
0000000000000000 l       .rodata.str1.1 0000000000000000 .LC0
0000000000000000 l    d  .comment       0000000000000000 .comment
0000000000000000 g     F .text.startup  0000000000000017 main
0000000000000000         *UND*  0000000000000000 _GLOBAL_OFFSET_TABLE_
0000000000000000         *UND*  0000000000000000 puts


RELOCATION RECORDS FOR [.text.startup]:
OFFSET           TYPE              VALUE
0000000000000003 R_X86_64_PC32     .LC0-0x0000000000000004
000000000000000c R_X86_64_PLT32    puts-0x0000000000000004


RELOCATION RECORDS FOR [.eh_frame]:
OFFSET           TYPE              VALUE
0000000000000020 R_X86_64_PC32     .text.startup
```

Biblioteka standardowa

- „`puts`” jest częścią biblioteki standardowej
- Biblioteka standardowa jest WIEEELKA
- `puts` to w skrócie kombinacja `write` i `strlen`.
- To może tak zastąpić?

Take #2

```
#include <unistd.h>

const char MSG[] = "Hello world!\n";

int main( int argc, char **argv )
{
    write(1,MSG,sizeof(MSG));
    return 0;
}
```

Take #2

```
> gcc -o -O2 main2 --static main2.c
> strip main2
> ls -al main2

-rwxr-xr-x 1 LwB LwB 844784  main2
```

Zaglądamy

```
> gcc -c -O2 main2.c
> objdump -s main2.o

main2.o:     file format elf64-x86-64

Contents of section .text.startup:
 0000 488d3500 00000048 83ec08ba 0e000000  H.5....H........
 0010 bf010000 00e80000 000031c0 4883c408  ..........1.H...
 0020 c3                                   .
Contents of section .rodata:
 0000 48656c6c 6f20776f 726c6421 0a00      Hello world!..
Contents of section .comment:
 0000 00474343 3a202855 62756e74 7520362e  .GCC: (Ubuntu 6.
 0010 332e302d 31327562 756e7475 32292036  3.0-12ubuntu2) 6
 0020 2e332e30 20323031 37303430 3600      .3.0 20170406.
Contents of section .eh_frame:
 0000 14000000 00000000 017a5200 01781001  .........zR..x..
 0010 1b0c0708 90010000 14000000 1c000000  ................
 0020 00000000 21000000 004b0e10 550e0800  ....!....K..U...
```

Zaglądamy

```
> objdump -d -Mintel main2.o

main2.o:     file format elf64-x86-64


assembly of section .text.startup:

0000000000000 <main>:
0:   48 8d 35 00 00 00 00    lea    rsi,[rip+0x0]
                             # 7 <main+0x7>
7:   48 83 ec 08             sub    rsp,0x8
b:   ba 0e 00 00 00          mov    edx,0xe
0:   bf 01 00 00 00          mov    edi,0x1
5:   e8 00 00 00 00          call   1a <main+0x1a>
a:   31 c0                   xor    eax,eax
c:   48 83 c4 08             add    rsp,0x8
0:   c3                      ret
```

Zaglądamy

```
> objdump -tr main2.o

main2.o:     file format elf64-x86-64

SYMBOL TABLE:
0000000000000000 l    df *ABS*  0000000000000000 main2.c
0000000000000000 l    d  .text  0000000000000000 .text
0000000000000000 l    d  .data  0000000000000000 .data
0000000000000000 l    d  .bss   0000000000000000 .bss
0000000000000000 l    d  .text.startup  0000000000000000 .text.startup
0000000000000000 l    d  .rodata        0000000000000000 .rodata
0000000000000000 l    d  .note.GNU-stack        0000000000000000 .note.GNU-stack
0000000000000000 l    d  .eh_frame      0000000000000000 .eh_frame
0000000000000000 l    d  .comment       0000000000000000 .comment
0000000000000000 g     F .text.startup  0000000000000021 main
0000000000000000 g     O .rodata        000000000000000e MSG
0000000000000000         *UND*  0000000000000000 _GLOBAL_OFFSET_TABLE_
0000000000000000         *UND*  0000000000000000 write


RELOCATION RECORDS FOR [.text.startup]:
OFFSET           TYPE              VALUE
0000000000000003 R_X86_64_PC32     MSG-0x0000000000000004
0000000000000016 R_X86_64_PLT32    write-0x0000000000000004


RELOCATION RECORDS FOR [.eh_frame]:
OFFSET           TYPE              VALUE
0000000000000020 R_X86_64_PC32     .text.startup
```

Biblioteka standardowa #2

Co to jest funkcja `write`?

- Jest to tzw *cienki wrapper* wywołujący kernelowy syscall `sys_write`.

To może pozbyć się biblioteki standardowej i bezpośrednio wywołać `sys_write`? Jak wywołać syscalla w C?

- Za pomocą funkcji biblioteki standardowej `syscall(…)`

Oh, wait...

No dobra... a bez libc?

```
const char MSG[] = "Hello world!\n";
#define __NR_write 1

static int inline my_write(int fd, const void *buf, int size)
{
    int ret;
    asm volatile
    (
        "syscall"
        : "=a" (ret)
        : "0"(__NR_write), "D"(fd), "S"(buf), "d"(size)
        : "cc", "rcx", "r11", "memory"
    );
    return ret;
}

int main( int argc, char **argv )
{
    my_write(1,MSG,sizeof(MSG));
    return 0;
}
```

No dobra... a bez libc?

```
> gcc -o main3 -O2 --static main3.c
> strip main3
> ls -al main3

-rwxr-xr-x 1 LwB LwB 844784  main3
```

Zaglądamy

```
> gcc -c -O2 main3.c
> objdump -s main3.o

main3.o:     file format elf64-x86-64

Contents of section .text.startup:
 0000 b8010000 00ba0e00 0000488d 35000000  ..........H.5...
 0010 0089c70f 0531c0c3                    .....1..
Contents of section .rodata:
 0000 48656c6c 6f20776f 726c6421 0a00      Hello world!..
Contents of section .comment:
 0000 00474343 3a202855 62756e74 7520362e  .GCC: (Ubuntu 6.
 0010 332e302d 31327562 756e7475 32292036  3.0-12ubuntu2) 6
 0020 2e332e30 20323031 37303430 3600      .3.0 20170406.
Contents of section .eh_frame:
 0000 14000000 00000000 017a5200 01781001  .........zR..x..
 0010 1b0c0708 90010000 14000000 1c000000  ................
 0020 00000000 18000000 00000000 00000000  ................
```

Zaglądamy

```
> objdump -dMintel main3.o

main3.o:     file format elf64-x86-64


Disassembly of section .text.startup:

0000000000000000 <main>:
   0: b8 01 00 00 00          mov    eax,0x1
   5: ba 0e 00 00 00          mov    edx,0xe
   a: 48 8d 35 00 00 00 00    lea    rsi,[rip+0x0]
                                # 11 <main+0x11>
  11: 89 c7                   mov    edi,eax
  13: 0f 05                   syscall
  15: 31 c0                   xor    eax,eax
  17: c3                      ret
```

Zaglądamy

```
> objdump -tr main3.o

main3.o:     file format elf64-x86-64

SYMBOL TABLE:
0000000000000000 l    df *ABS*  0000000000000000 main3.c
0000000000000000 l    d  .text  0000000000000000 .text
0000000000000000 l    d  .data  0000000000000000 .data
0000000000000000 l    d  .bss 0000000000000000 .bss
0000000000000000 l    d  .text.startup 0000000000000000 .text.startup
0000000000000000 l    d  .rodata  0000000000000000 .rodata
0000000000000000 l    d  .note.GNU-stack 0000000000000000 .note.GNU-stack
0000000000000000 l    d  .eh_frame  0000000000000000 .eh_frame
0000000000000000 l    d  .comment 0000000000000000 .comment
0000000000000000 g     F .text.startup 0000000000000018 main
0000000000000000 g     O .rodata  000000000000000e MSG


RELOCATION RECORDS FOR [.text.startup]:
OFFSET           TYPE              VALUE
000000000000000d R_X86_64_PC32     MSG-0×0000000000000004


RELOCATION RECORDS FOR [.eh_frame]:
OFFSET           TYPE              VALUE
0000000000000020 R_X86_64_PC32     .text.startup
```

Ok, ale...

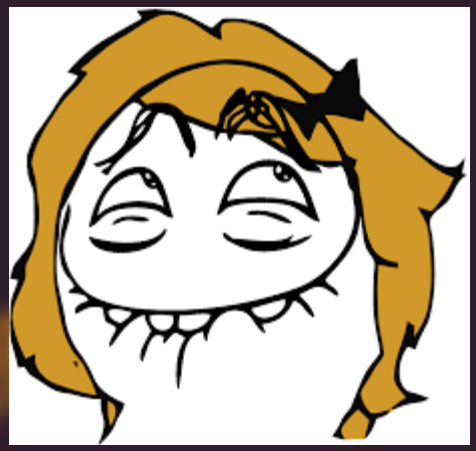
- No dobrze, nasza aplikacja *nie wywołuje* biblioteki standardowej – to skąd ten rozmiar?
- Nasza aplikacja *jest wywoływana* przez bibliotekę standardową, a konkretnie przez jej część nazywaną *runtimem*.
- Jak myślicie, skąd `main` ma argumenty `argc` i `argv`? I ciągle zapominany argument `env`? (Tak, `main` ma 3 argumenty a nie 2...)
- To pozbyć się runtime'a?

No dobra... a bez libc?

```
const char MSG[] = "Hello world!\n";
#define __NR_write 1


static int inline my_write(int fd, const void *buf, int size)
{
    int ret;
    asm volatile
    (
        "syscall"
        : "=a" (ret)
        : "0"(__NR_write), "D"(fd), "S"(buf), "d"(size)
        : "cc", "rcx", "r11", "memory"
    );
    return ret;
}

void _start()
{
    my_write(1,MSG,sizeof(MSG));
}
```

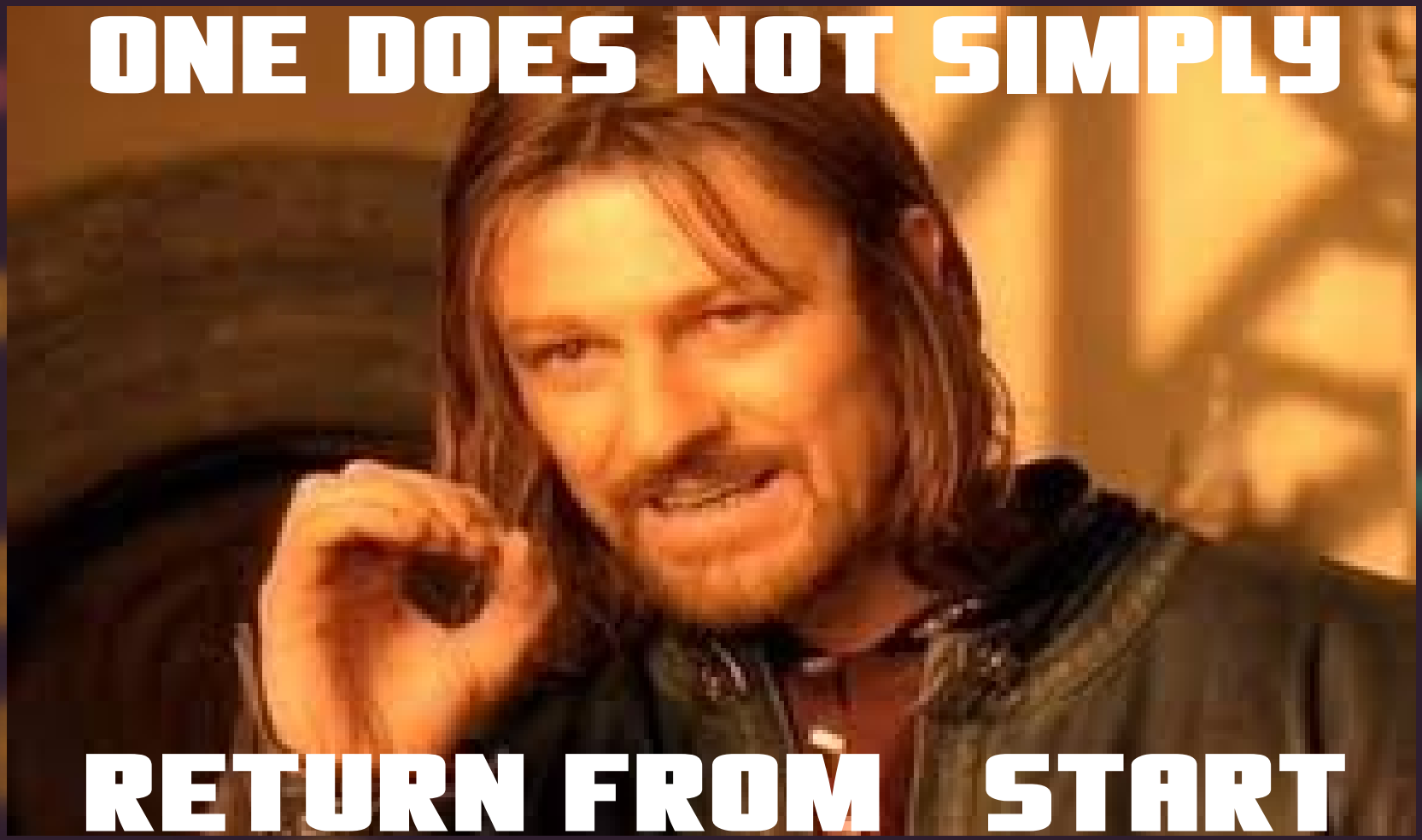
Take #4

```
> gcc -nostdlib --static -O2 -o main4 main4.c
> strip main4
> ls -al main4

-rwxr-xr-x 1 LwB LwB   920  main4
```



Auć!

```
> ./main4
Hello world!
zsh: segmentation fault (core dumped)
```



```
const char MSG[] = "Hello world!\n";
#define __NR_write 1
#define __NR_exit 60

static int inline my_write(int fd, const void *buf, int size)
{
    int ret;
    asm volatile
    (
        "syscall"
        : "=a" (ret)
        : "0"(__NR_write), "D"(fd), "S"(buf), "d"(size)
        : "cc", "rcx", "r11", "memory"
    );
    return ret;
}

static void __attribute__((noreturn)) my_exit(int rc)
{
    asm volatile ( "syscall" :: "a"(__NR_exit), "D"(rc) : );
    __builtin_unreachable();
}


void __attribute__((noreturn)) _start()
{
    my_write(1,MSG,sizeof(MSG));
    my_exit(0);
}
```

Auć!

```
> gcc -nostdlib --static -O2 -o main5 main5.c
> strip main5
> ./main5
Hello world!
> ls -al main5
-rwxr-xr-x 1 LwB LwB 928 kwi 17 15:48 main5
```

Program z exit-em jest mniej awanturujący się

928 bajtów to ciągle dużo, jak na program, który prawie nic nie robi...

Pokaż ELFie co masz w środku...

```
> readelf -SlW main5
There are 7 section headers, starting at offset 0×1e0:

Section Headers:
  [Nr] Name              Type            Address          Off    Size   ES Flg Lk Inf Al
  [ 0]                   NULL            0000000000000000 000000 000000 00      0   0  0
  [ 1] .note.gnu.build-i NOTE            00000000004000e8 0000e8 000024 00   A  0   0  4
  [ 2] .text             PROGBITS        0000000000400110 000110 00001f 00  AX  0   0 16
  [ 3] .rodata           PROGBITS        0000000000400130 000130 00000e 00   A  0   0  8
  [ 4] .eh_frame         PROGBITS        0000000000400140 000140 000030 00   A  0   0  8
  [ 5] .comment          PROGBITS        0000000000000000 000170 00002d 01  MS  0   0  1
  [ 6] .shstrtab         STRTAB          0000000000000000 00019d 00003f 00      0   0  1

Key to Flags:
  W (write), A (alloc), X (execute), M (merge), S (strings), I (info),
  L (link order), O (extra OS processing required), G (group), T (TLS),
  C (compressed), x (unknown), o (OS specific), E (exclude),
  l (large), p (processor specific)
Elf file type is EXEC (Executable file)
Entry point 0×400110
There are 3 program headers, starting at offset 64

Program Headers:
  Type           Offset   VirtAddr           PhysAddr           FileSiz  MemSiz   Flg Align
  LOAD           0×000000 0×0000000000400000 0×0000000000400000 0×000170 0×000170 R E 0×200000
  NOTE           0×0000e8 0×00000000004000e8 0×00000000004000e8 0×000024 0×000024 R   0×4
  GNU_STACK      0×000000 0×0000000000000000 0×0000000000000000 0×000000 0×000000 RW  0×10

 Section to Segment mapping:
  Segment Sections...
   00     .note.gnu.build-id .text .rodata .eh_frame
   01     .note.gnu.build-id
   02
```

Tak naprawdę potrzebujemy tylko .text i .rodata ...

Skrypty linkera

```
> cat main5.ld

OUTPUT_FORMAT("elf64-x86-64", "elf64-x86-64", "elf64-x86-64")
OUTPUT_ARCH(i386:x86-64)

ENTRY(_start);

SECTIONS
{
  PROVIDE (__executable_start =
                        SEGMENT_START("text-segment", 0×400000));
  . = SEGMENT_START("text-segment", 0×400000) + SIZEOF_HEADERS;
  .text   : { *(.text*); *(.rodata*); }

  /DISCARD/ :
  {
    *(.comment*)
    *(.eh_frame*)
    *(.note.gnu.build-id*)
  }
}
```

Skrypty linkera

```
> ld -T main5.ld -o main5 main5.o
> strip main5
> ls -al main5
-rwxr-xr-x 1 LwB LwB 432  main5
> ./main5
Hello world!
```

Skrypty linkera

```
> readelf -WSl main5
There are 3 section headers, starting at offset 0×f0:

Section Headers:
  [Nr] Name              Type            Address          Off    Size   ES Flg Lk Inf Al
  [ 0]                   NULL            0000000000000000 000000 000000 00      0   0  0
  [ 1] .text             PROGBITS        00000000004000b0 0000b0 00002e 00  AX  0   0 16
  [ 2] .shstrtab         STRTAB          0000000000000000 0000de 000011 00      0   0  1
Key to Flags:
  W (write), A (alloc), X (execute), M (merge), S (strings), I (info),
  L (link order), O (extra OS processing required), G (group), T (TLS),
  C (compressed), x (unknown), o (OS specific), E (exclude),
  l (large), p (processor specific)

Elf file type is EXEC (Executable file)
Entry point 0×4000b0
There are 2 program headers, starting at offset 64

Program Headers:
  Type      Offset   VirtAddr           PhysAddr           FileSiz  MemSiz   Flg Align
  LOAD      0×000000 0×0000000000400000 0×0000000000400000 0×0000de 0×0000de R E 0×200000
  GNU_STACK 0×000000 0×0000000000000000 0×0000000000000000 0×000000 0×000000 RW  0×10

 Section to Segment mapping:
  Segment Sections...
   00     .text
   01
```

Skrypty linkera

```
> objdump -dMintel -s main5

main5:     file format elf64-x86-64

Contents of section .text:
 4000b0 b8010000 00ba0e00 0000488d 350f0000  ..........H.5...
 4000c0 0089c70f 0531ffb8 3c000000 0f056690  .....1..<.....f.
 4000d0 48656c6c 6f20776f 726c6421 0a00      Hello world!..

Disassembly of section .text:

00000000004000b0 <.text>:
  4000b0:b8 01 00 00 00        mov    eax,0x1
  4000b5:ba 0e 00 00 00        mov    edx,0xe
  4000ba:48 8d 35 0f 00 00 00  lea    rsi,[rip+0xf]        # 0x4000d0
  4000c1:89 c7                 mov    edi,eax
  4000c3:0f 05                 syscall
  4000c5:31 ff                 xor    edi,edi
  4000c7:b8 3c 00 00 00        mov    eax,0x3c
  4000cc:0f 05                 syscall
  4000ce:66 90                 xchg   ax,ax
  4000d0:48                    rex.W
  4000d1:65 6c                 gs ins BYTE PTR es:[rdi],dx
  4000d3:6c                    ins    BYTE PTR es:[rdi],dx
  4000d4:6f                    outs   dx,DWORD PTR ds:[rsi]
  4000d5:20 77 6f              and    BYTE PTR [rdi+0x6f],dh
  4000d8:72 6c                 jb     0x400146
  4000da:64 21 0a              and    DWORD PTR fs:[rdx],ecx
```

To wszystko

Udało się zejść z rozmiarem pliku wykonywalnego z 844784 bajtów do 432 bajtów z zachowaniem pełnej (acz niewielkiej) funkcjonalności.

Co straciliśmy (ale można dopisać własne wersje):

- Biblitekę standardową, a z nią dobroci typu `printf`, `atexit` czy `malloc/free`
- Możliwość pracy na `float/double`
- Przy wykorzystaniu g++ - dużą część funkcjonalności C++ (wyjątki, konstruktory/destruktory, new/delete, STL)
- `pthready`