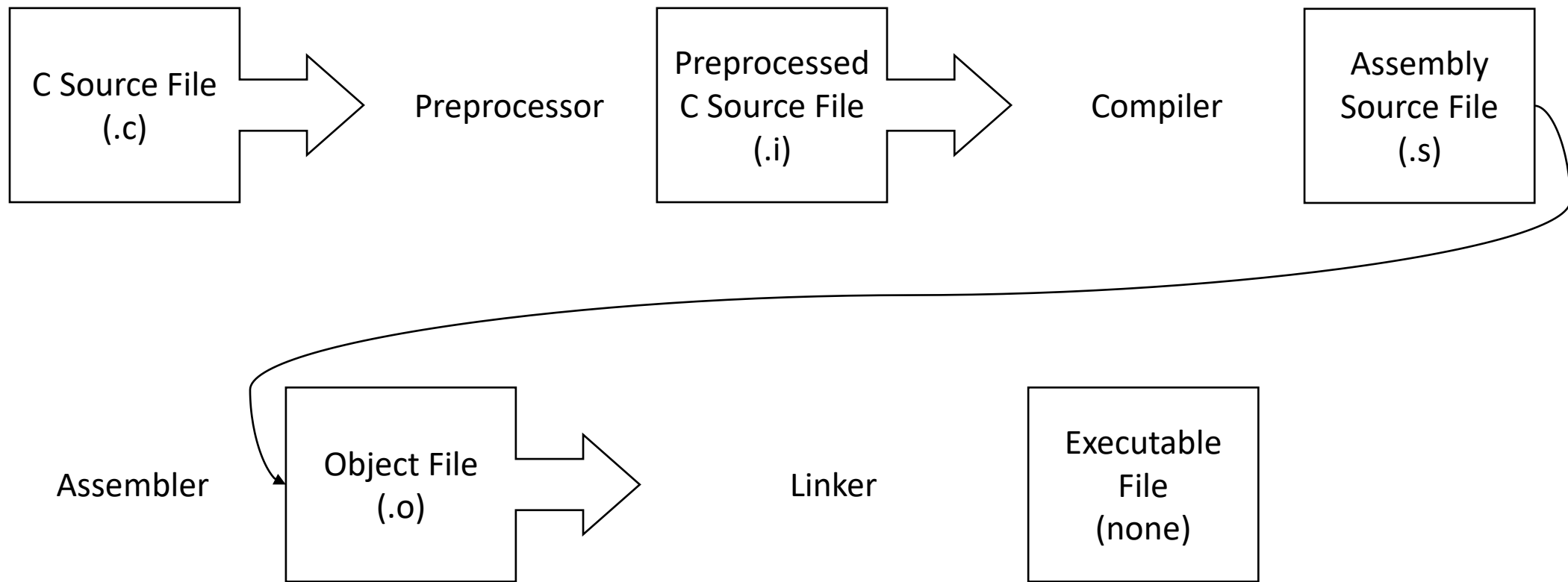


C Build Process

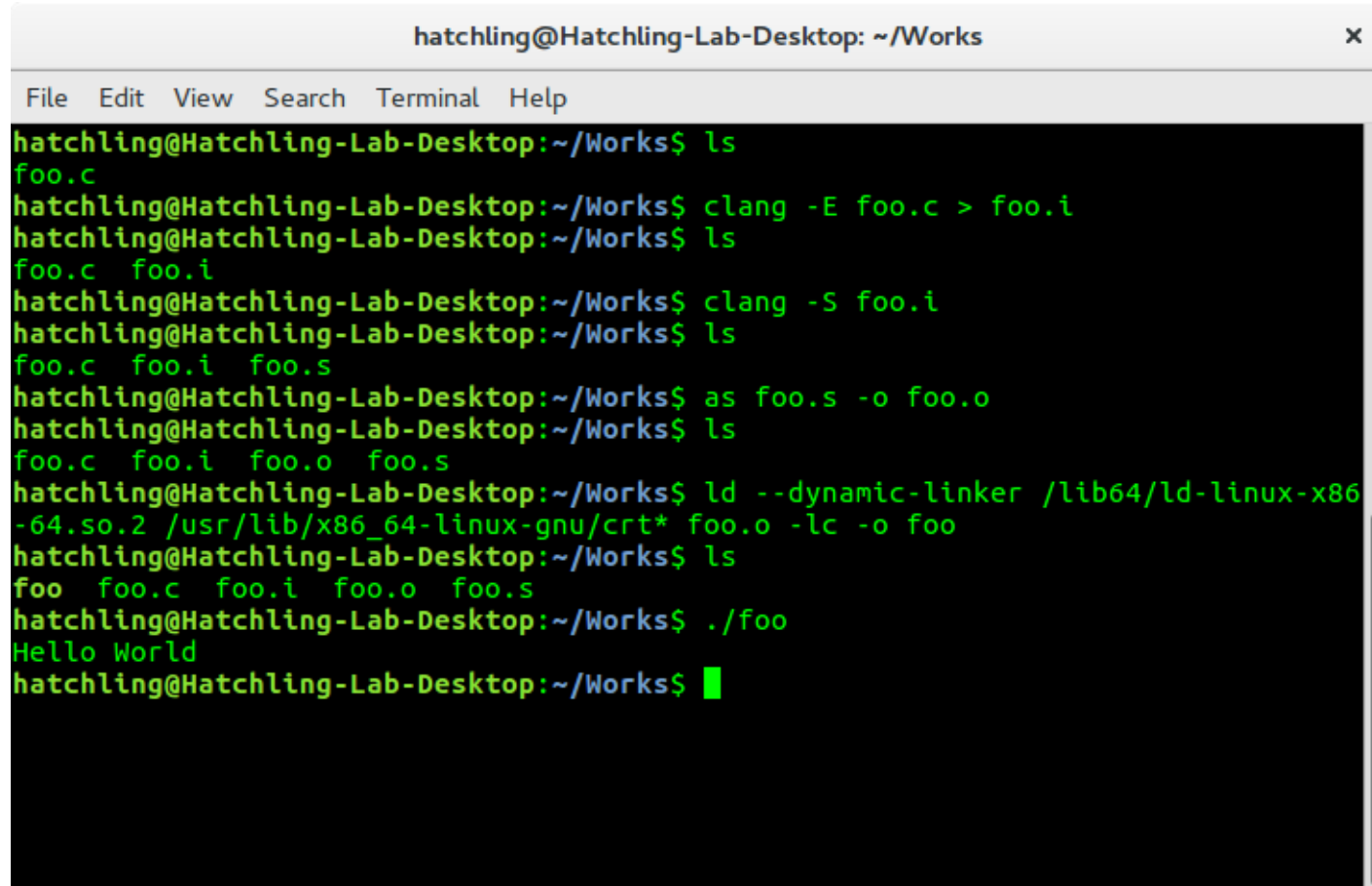
Content

- Model
- Preprocessor
- Compiler
- Assembler
- Linker

Model (Executable and Linkable Format)

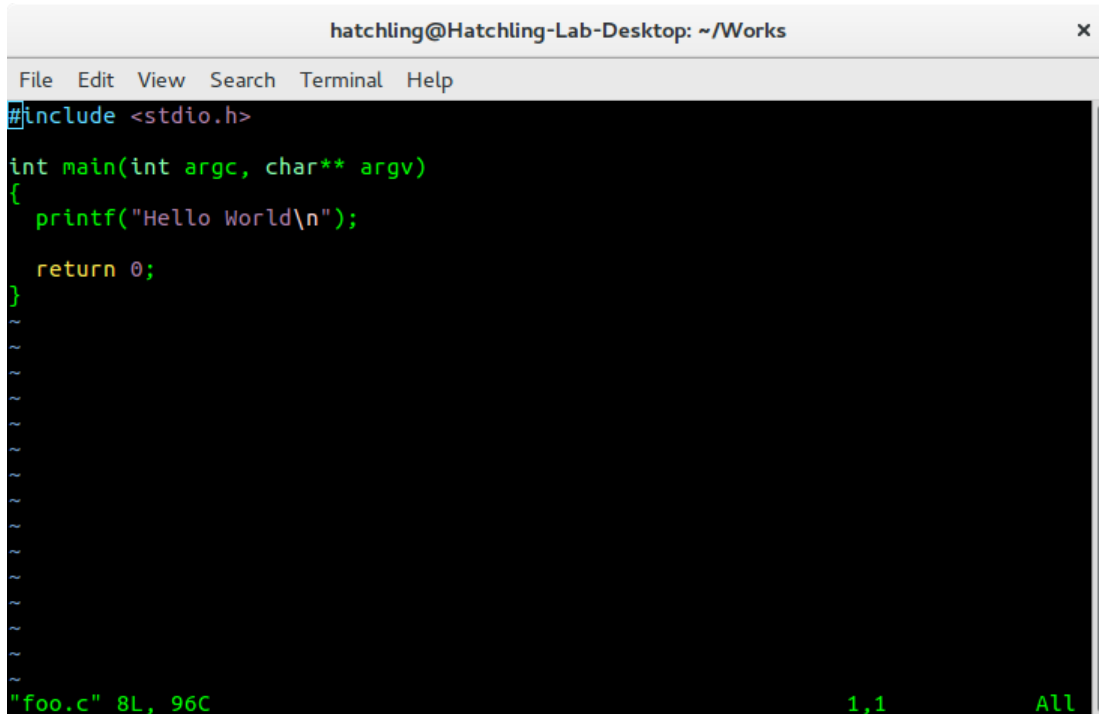


Model (Executable and Linkable Format)



```
hatchling@Hatchling-Lab-Desktop: ~/Works
File Edit View Search Terminal Help
hatchling@Hatchling-Lab-Desktop:~/Works$ ls
foo.c
hatchling@Hatchling-Lab-Desktop:~/Works$ clang -E foo.c > foo.i
hatchling@Hatchling-Lab-Desktop:~/Works$ ls
foo.c  foo.i
hatchling@Hatchling-Lab-Desktop:~/Works$ clang -S foo.i
hatchling@Hatchling-Lab-Desktop:~/Works$ ls
foo.c  foo.i  foo.s
hatchling@Hatchling-Lab-Desktop:~/Works$ as foo.s -o foo.o
hatchling@Hatchling-Lab-Desktop:~/Works$ ls
foo.c  foo.i  foo.o  foo.s
hatchling@Hatchling-Lab-Desktop:~/Works$ ld --dynamic-linker /lib64/ld-linux-x86
-64.so.2 /usr/lib/x86_64-linux-gnu/crt* foo.o -lc -o foo
hatchling@Hatchling-Lab-Desktop:~/Works$ ls
foo  foo.c  foo.i  foo.o  foo.s
hatchling@Hatchling-Lab-Desktop:~/Works$ ./foo
Hello World
hatchling@Hatchling-Lab-Desktop:~/Works$
```

Preprocessor



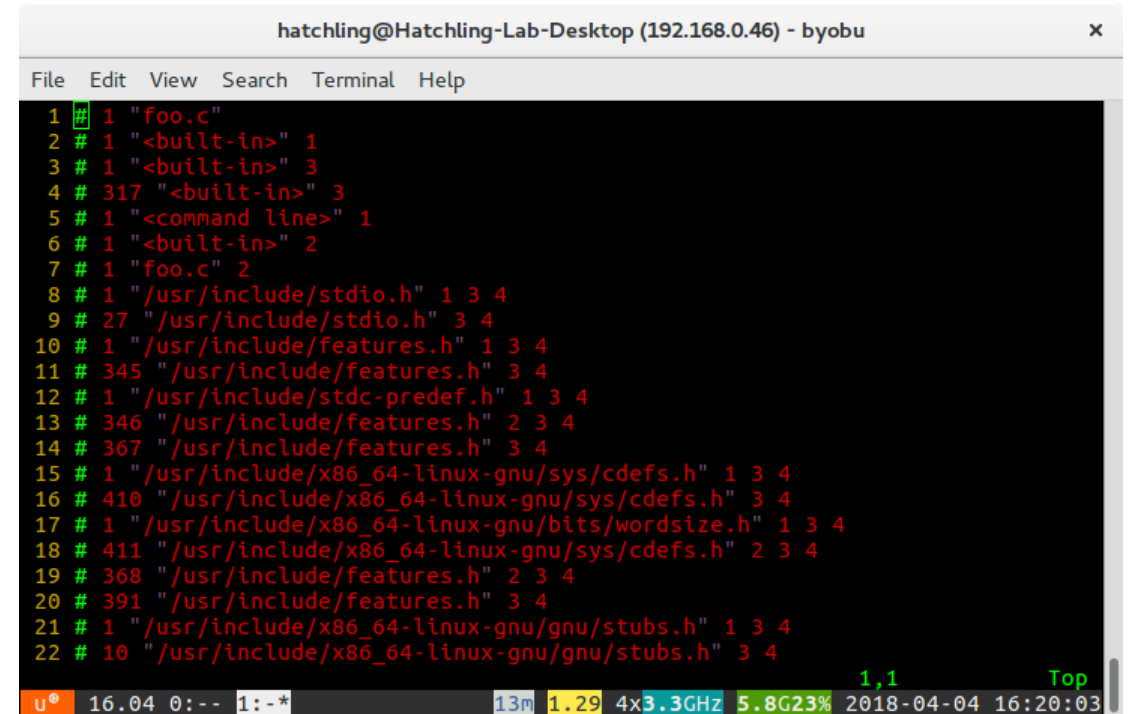
A screenshot of a text editor window titled "hatchling@Hatchling-Lab-Desktop: ~/Works". The editor shows a C source code file named "foo.c". The code is as follows:

```
#include <stdio.h>

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

The status bar at the bottom indicates the file is "foo.c" with 8 lines and 96 characters. The cursor is at line 1, column 1.

C Source code(foo.c)



A screenshot of a text editor window titled "hatchling@Hatchling-Lab-Desktop (192.168.0.46) - byobu". The editor shows the preprocessed C source code file named "foo.i". The code is as follows:

```
1 # 1 "foo.c"
2 # 1 "<built-in>" 1
3 # 1 "<built-in>" 3
4 # 317 "<built-in>" 3
5 # 1 "<command line>" 1
6 # 1 "<built-in>" 2
7 # 1 "foo.c" 2
8 # 1 "/usr/include/stdio.h" 1 3 4
9 # 27 "/usr/include/stdio.h" 3 4
10 # 1 "/usr/include/features.h" 1 3 4
11 # 345 "/usr/include/features.h" 3 4
12 # 1 "/usr/include/stdc-predef.h" 1 3 4
13 # 346 "/usr/include/features.h" 2 3 4
14 # 367 "/usr/include/features.h" 3 4
15 # 1 "/usr/include/x86_64-linux-gnu/sys/cdefs.h" 1 3 4
16 # 410 "/usr/include/x86_64-linux-gnu/sys/cdefs.h" 3 4
17 # 1 "/usr/include/x86_64-linux-gnu/bits/wordsize.h" 1 3 4
18 # 411 "/usr/include/x86_64-linux-gnu/sys/cdefs.h" 2 3 4
19 # 368 "/usr/include/features.h" 2 3 4
20 # 391 "/usr/include/features.h" 3 4
21 # 1 "/usr/include/x86_64-linux-gnu/gnu/stubs.h" 1 3 4
22 # 10 "/usr/include/x86_64-linux-gnu/gnu/stubs.h" 3 4
```

The status bar at the bottom shows system information: "u 16.04 0:-- 1:-* 13m 1.29 4x3.3GHz 5.8G23% 2018-04-04 16:20:03". The cursor is at line 1, column 1.

Preprocessed C Source code(foo.i)

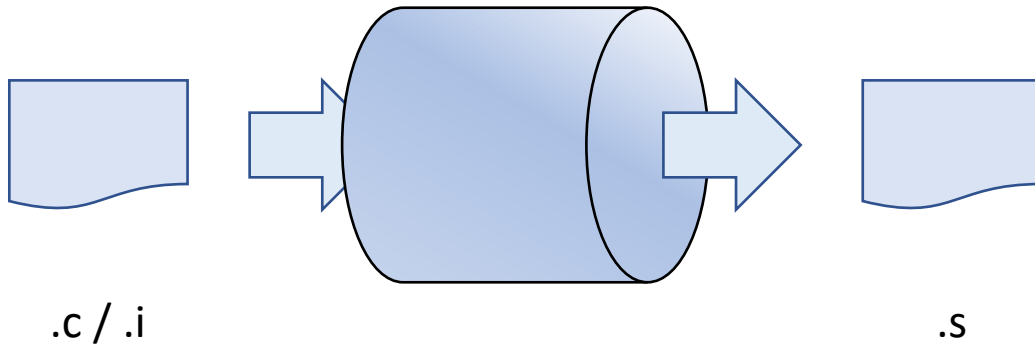
Preprocessor

```
hatchling@Hatchling-Lab-Desktop (192.168.0.46) - byobu
File Edit View Search Terminal Help
714 extern FILE *popen (const char *__command, const char *__modes) ;
715
716
717
718
719
720 extern int pclose (FILE *__stream);
721
722
723
724
725
726 extern char *ctermid (char *__s) __attribute__ ((__nothrow__ ));
727 # 912 "stdio.h"
728 extern void flockfile (FILE *__stream) __attribute__ ((__nothrow__ ));
729
730
731
732 extern int ftrylockfile (FILE *__stream) __attribute__ ((__nothrow__ )) ;
733
734
735 extern void funlockfile (FILE *__stream) __attribute__ ((__nothrow__ ));
735,1 Bot
u 16.04 0:-* 1:-* 15m 1.18 4x2.8GHz 5.8G23% 2018-04-04 16:21:59
```

VS.

```
hatchling@Hatchling-Lab-Desktop (192.168.0.46) - byobu
File Edit View Search Terminal Help
723
724
725
726
727 extern char *ctermid (char *__s) __attribute__ ((__nothrow__ ));
728 # 912 "/usr/include/stdio.h" 3 4
729 extern void flockfile (FILE *__stream) __attribute__ ((__nothrow__ ));
730
731
732
733 extern int ftrylockfile (FILE *__stream) __attribute__ ((__nothrow__ )) ;
734
735
736 extern void funlockfile (FILE *__stream) __attribute__ ((__nothrow__ ));
737 # 2 "foo.c" 2
738
739 int main(int argc, char** argv)
740 {
741     printf("Hello World\n");
742
743     return 0;
744 }
744,1 Bot
u 16.04 0:-* 1:-* 15m 1.30 4x3.3GHz 5.8G23% 2018-04-04 16:22:13
```

Compiler



```
.text
.file "foo.i"
.globl main
.align 16, 0x90
.type main,@function

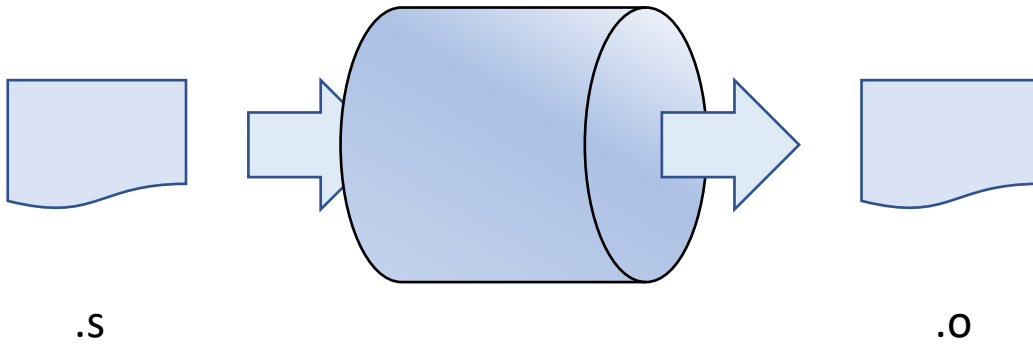
main:                                     # @main
.cfi_startproc
# BB#0:
pushq %rbp
.Ltmp0:
.cfi_def_cfa_offset 16
.Ltmp1:
.cfi_offset %rbp, -16
movq %rsp, %rbp
.Ltmp2:
.cfi_def_cfa_register %rbp
subq $32, %rsp
movabsq $.L.str, %rax
movl $0, -4(%rbp)
movl %edi, -8(%rbp)
movq %rsi, -16(%rbp)
movq %rax, %rdi
movb $0, %al
callq printf
xorl %ecx, %ecx
movl %eax, -20(%rbp)           # 4-byte Spill
movl %ecx, %eax
addq $32, %rsp
popq %rbp
retq

.Lfunc_end0:
.size main, .Lfunc_end0-main
.cfi_endproc

.type .L.str,@object          # @.str
.section .rodata.str1.1,"aMS",@progbits,1
.L.str:
.asciz "Hello World\n"
.size .L.str, 13

.ident "clang version 3.8.0-2ubuntu4 (tags/RELEASE_380/final)"
.section ".note.GNU-stack","",@progbits
```

Assembler



```
hatchling@Hatchling-Lab-Desktop (192.168.0.46) - byobu
File Edit View Search Terminal Help
00000000: 7f45 4c46 0201 0100 0000 0000 0000 0000 .ELF.....
00000010: 0100 3e00 0100 0000 0000 0000 0000 0000 ..>.....
00000020: 0000 0000 0000 0000 c802 0000 0000 0000 .....
00000030: 0000 0000 4000 0000 0000 4000 0d00 0a00 ....@....@....
00000040: 5548 89e5 4883 ec20 48b8 0000 0000 0000 UH..H.. H.....
00000050: 0000 c745 fc00 0000 0089 7df8 4889 75f0 ...E.....}.H.U.
00000060: 4889 c7b0 00e8 0000 0000 31c9 8945 ec89 H......1..E..
00000070: c848 83c4 205d c348 656c 6c6f 2057 6f72 .H.. 1.Hello Wor
00000080: 6c64 0a00 0063 6c61 6e67 2076 6572 7369 ld...clang versi
00000090: 6f6e 2033 2e38 2e30 2d32 7562 756e 7475 on 3.8.0-2ubuntu
000000a0: 3420 2874 6167 732f 5245 4c45 4153 455f 4 (tags/RELEASE_
000000b0: 3338 302f 6669 6e61 6c29 0000 0000 0000 380/final).....
000000c0: 1400 0000 0000 0000 017a 5200 0178 1001 .....zR..x..
000000d0: 1b0c 0708 9001 0000 1c00 0000 1c00 0000 .....
000000e0: 0000 0000 3700 0000 0041 0e10 8602 430d ....7....A....C.
000000f0: 0600 0000 0000 0000 0000 0000 0000 0000 .....
00000100: 0000 0000 0000 0000 0000 0000 0000 0000 .....
00000110: 0100 0000 0400 f1ff 0000 0000 0000 0000 .....
00000120: 0000 0000 0000 0000 0000 0000 0300 0100 .....
00000130: 0000 0000 0000 0000 0000 0000 0000 0000 .....
00000140: 0000 0000 0300 0300 0000 0000 0000 0000 .....
00000150: 0000 0000 0000 0000 0000 0000 0300 0400 .....
"foo.x" 97L, 6588C                                     1,1
u® 16.04 0: -* 12m 0.54 4x2.4GHz 5.8G22% 2018-04-04 17:09
```


Linker

```
hatchling@Hatchling-Lab-Desktop: ~/Works
File Edit View Search Terminal Help
hatchling@Hatchling-Lab-Desktop:~/Works$ ls
foo.c
hatchling@Hatchling-Lab-Desktop:~/Works$ clang -E foo.c > foo.i
hatchling@Hatchling-Lab-Desktop:~/Works$ ls
foo.c foo.i
hatchling@Hatchling-Lab-Desktop:~/Works$ clang -S foo.i
hatchling@Hatchling-Lab-Desktop:~/Works$ ls
foo.c foo.i foo.s
hatchling@Hatchling-Lab-Desktop:~/Works$ as foo.s -o foo.o
hatchling@Hatchling-Lab-Desktop:~/Works$ ls
foo.c foo.i foo.o foo.s
hatchling@Hatchling-Lab-Desktop:~/Works$ ld --dynamic-linker /lib64/ld-linux-x86
-64.so.2 /usr/lib/x86_64-linux-gnu/crt* foo.o -lc -o foo
hatchling@Hatchling-Lab-Desktop:~/Works$ ls
foo foo.c foo.i foo.o foo.s
hatchling@Hatchling-Lab-Desktop:~/Works$ ./foo
Hello World
hatchling@Hatchling-Lab-Desktop:~/Works$
```

Linker

- `main()` is not the entry point of program; `_start()` is
- `crt1.o`: contains `_start()`
- `crti.o`: contains prologue part of `__init()` and `__fini()`
- `crtn.o`: contains epilogue part of `__init()` and `__fini()`

Linker

```
hatchling@Hatchling-Lab-Desktop:~$ nm /usr/lib/x86_64-linux-gnu/crt1.o
0000000000000000 D __data_start
0000000000000000 W data_start
0000000000000000 R _IO_stdin_used
                U __libc_csu_fini
                U __libc_csu_init
                U __libc_start_main
                U main
0000000000000000 T _start
hatchling@Hatchling-Lab-Desktop:~$
```

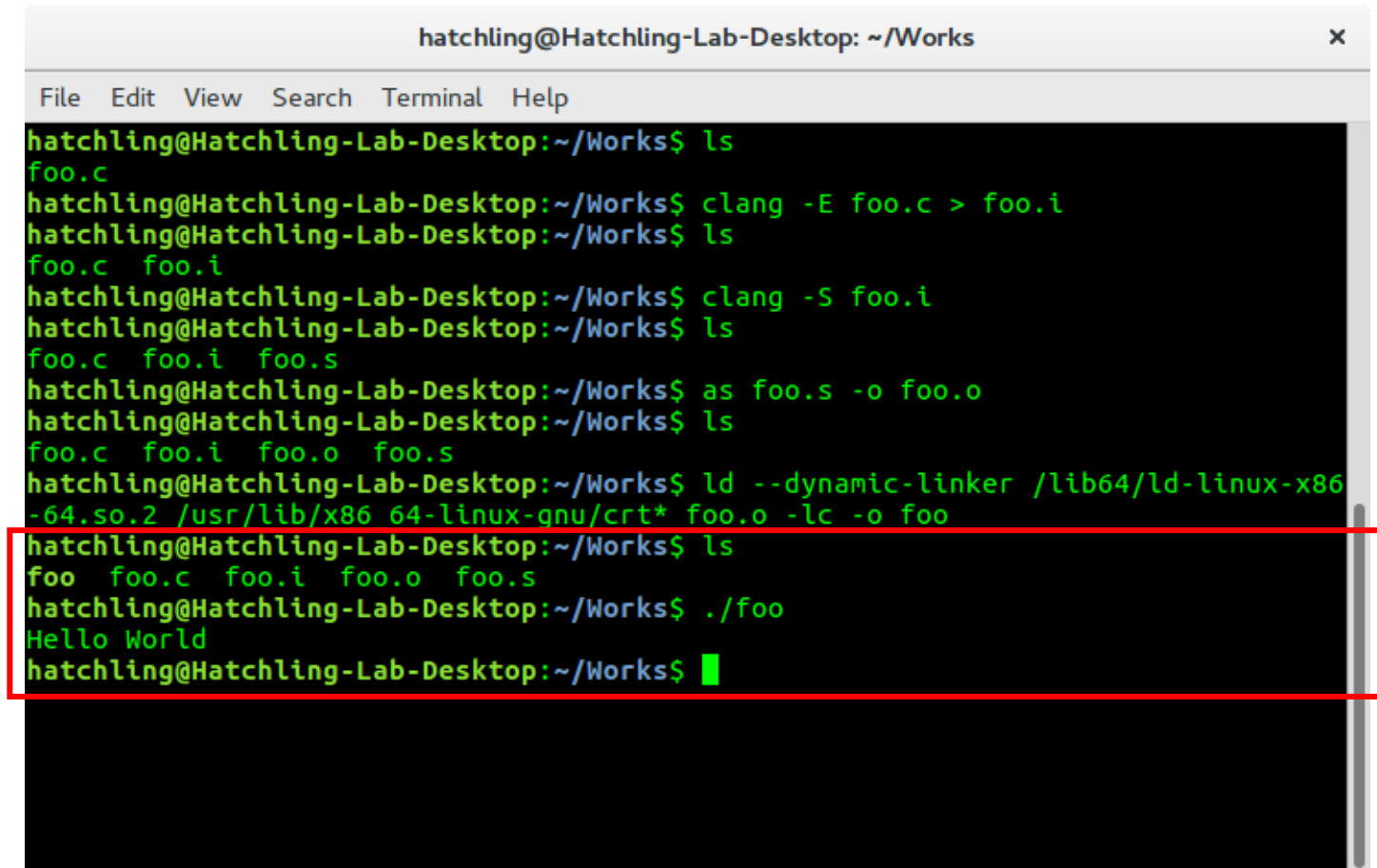
```
/* crt1.S puts a function prologue at the beginning of the .init and
   .fini sections and defines global symbols for those addresses, so
   they can be called as functions. The symbols _init and _fini are
   magic and cause the linker to emit DT_INIT and DT_FINI. */
```

```
/* crtn.S puts function epilogues in the .init and .fini sections
   corresponding to the prologues in crt1.S. */
```

Function prologue/epilogue

- Prologue
 - Appears at the beginning of a function
 - Prepares the stack and registers for use within the function
- Epilogue
 - Appears at the end of a function
 - Restores the stack and registers to previous state(before the function call)
- - Terms in assembly language programming

Executable



```
hatchling@Hatchling-Lab-Desktop: ~/Works
File Edit View Search Terminal Help
hatchling@Hatchling-Lab-Desktop:~/Works$ ls
foo.c
hatchling@Hatchling-Lab-Desktop:~/Works$ clang -E foo.c > foo.i
hatchling@Hatchling-Lab-Desktop:~/Works$ ls
foo.c foo.i
hatchling@Hatchling-Lab-Desktop:~/Works$ clang -S foo.i
hatchling@Hatchling-Lab-Desktop:~/Works$ ls
foo.c foo.i foo.s
hatchling@Hatchling-Lab-Desktop:~/Works$ as foo.s -o foo.o
hatchling@Hatchling-Lab-Desktop:~/Works$ ls
foo.c foo.i foo.o foo.s
hatchling@Hatchling-Lab-Desktop:~/Works$ ld --dynamic-linker /lib64/ld-linux-x86
-64.so.2 /usr/lib/x86_64-linux-gnu/crt* foo.o -lc -o foo
hatchling@Hatchling-Lab-Desktop:~/Works$ ls
foo foo.c foo.i foo.o foo.s
hatchling@Hatchling-Lab-Desktop:~/Works$ ./foo
Hello World
hatchling@Hatchling-Lab-Desktop:~/Works$
```