C 语言拾遗(1): 机制

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讲前提醒

PA0即将截止：

* 2022年9月18日23:59:59 (以此 deadline 计按时提交bonus)

PA1已悄悄发布：

* PA 1.1: 2022.9.25 (此为建议的不计分 deadline)
* PA 1.2: 2022.10.2 (此为建议的不计分 deadline)
* PA 1.3: 2022.10.9 23:59:59 (以此 deadline 计按时提交bonus)

本讲概述

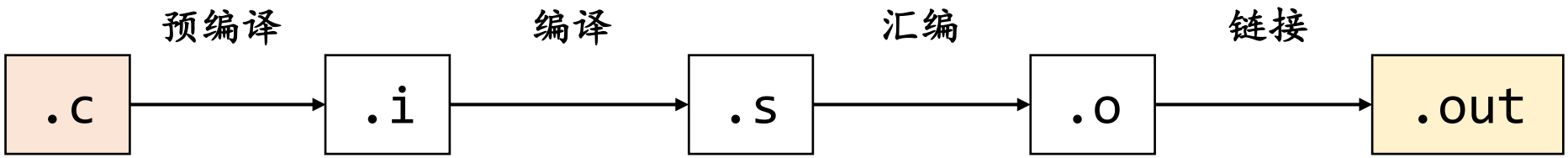
- 在IDE里，为什么按一个键，就能够编译运行?
  - 编译、链接
    - `.c` → 预编译 → `.i` → 编译 → `.s` → 汇编 → `.o` → 链接 → `a.out`
  - 加载执行
    - `./a.out`

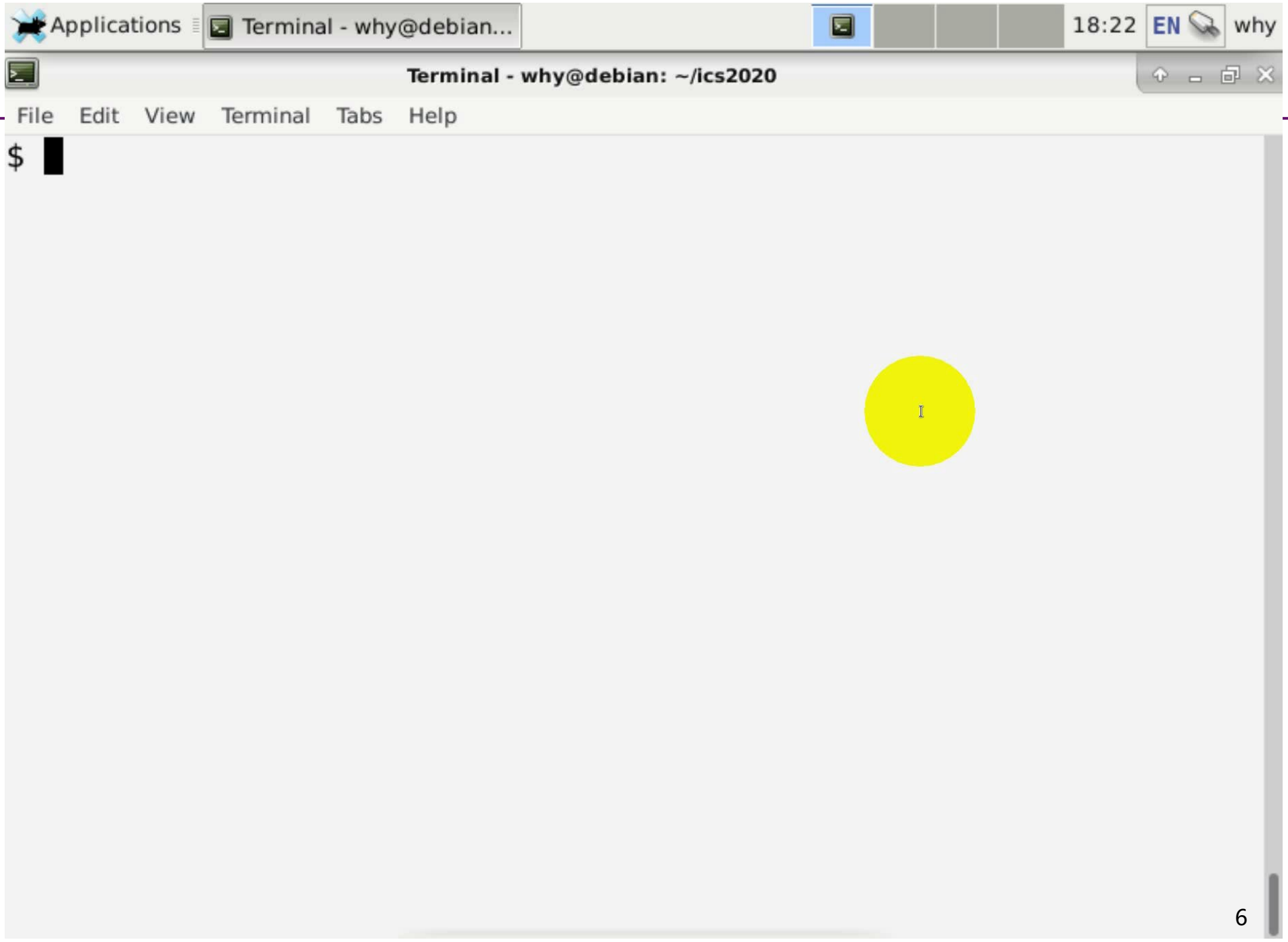
- 背后是通过调用命令行工具完成的
  - RTFM: `man gcc; gcc –help; tldr gcc`
    - 控制行为的三个选项: `-E, -S, -c`

- 本次课程
  - 预热：编译、链接、加载到底做了什么?
  - RTFSC时需要关注的C语言特性

IDE的一个键到底发生了什么?

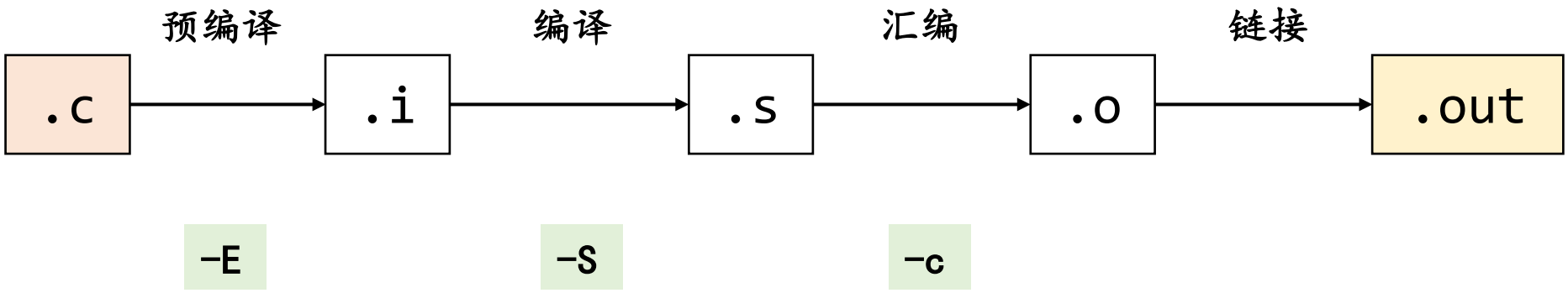
IDE的一个键到底发生了什么？




Applications
Terminal - why@debian...
18:22
EN
why
Terminal - why@debian: ~/ics2020
File Edit View Terminal Tabs Help
$


Applications
Terminal - why@debian...
18:37
EN
why
Terminal - why@debian: ~/ics2020
File Edit View Terminal Tabs Help
$

从源代码到可执行文件



进入C语言之前：预编译

```
#include
#define
#
##
#ifdef
```

#include指令

- 什么是#include?

- 怎么理解?


Applications
Terminal - why@debian...
18:51
EN
why
Terminal - why@debian: ~/ics2020
File Edit View Terminal Tabs Help
$

#include<>指令

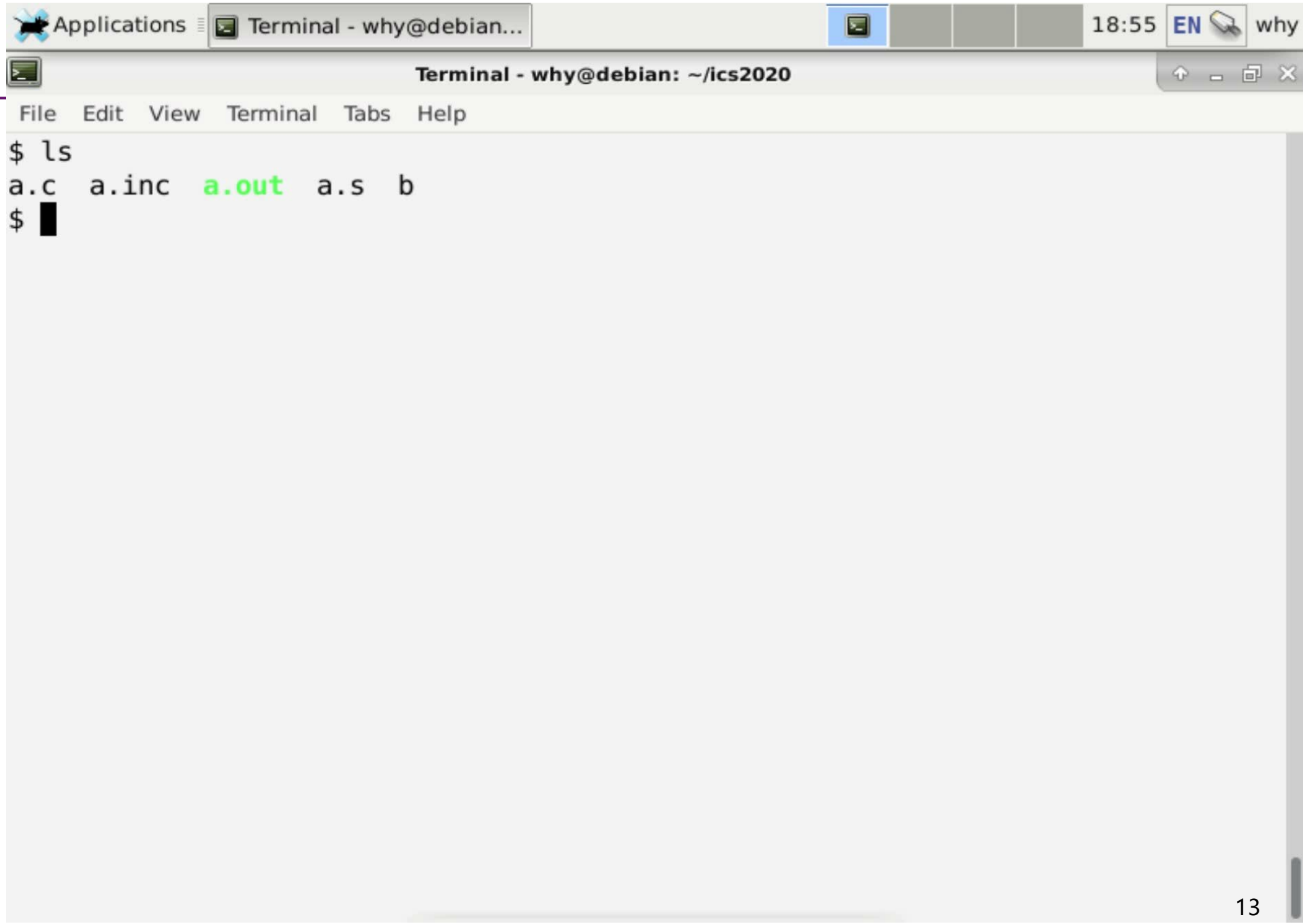
- 以下代码有什么区别?

```
#include <stdio.h>
#include “stdio.h”
```

- 为什么在没有安装库时会发生错误?

```
#include <SDL/SDL2.h>
```

- 你可能在书/阅读材料上了解过一些相关的知识
  - 但更好的办法是阅读命令的日志
  - `gcc --verbose a.c`


Applications
Terminal - why@debian...
18:55
EN
why
Terminal - why@debian: ~/ics2020
File Edit View Terminal Tabs Help
$ ls
a.c a.inc a.out a.s b
$

#include<>指令

```
#include "..." search starts here:
#include <...> search starts here:
 /usr/lib/gcc/x86_64-linux-gnu/8/include
 /usr/local/include
 /usr/lib/gcc/x86_64-linux-gnu/8/include-fixed
 /usr/include/x86_64-linux-gnu
 /usr/include
```

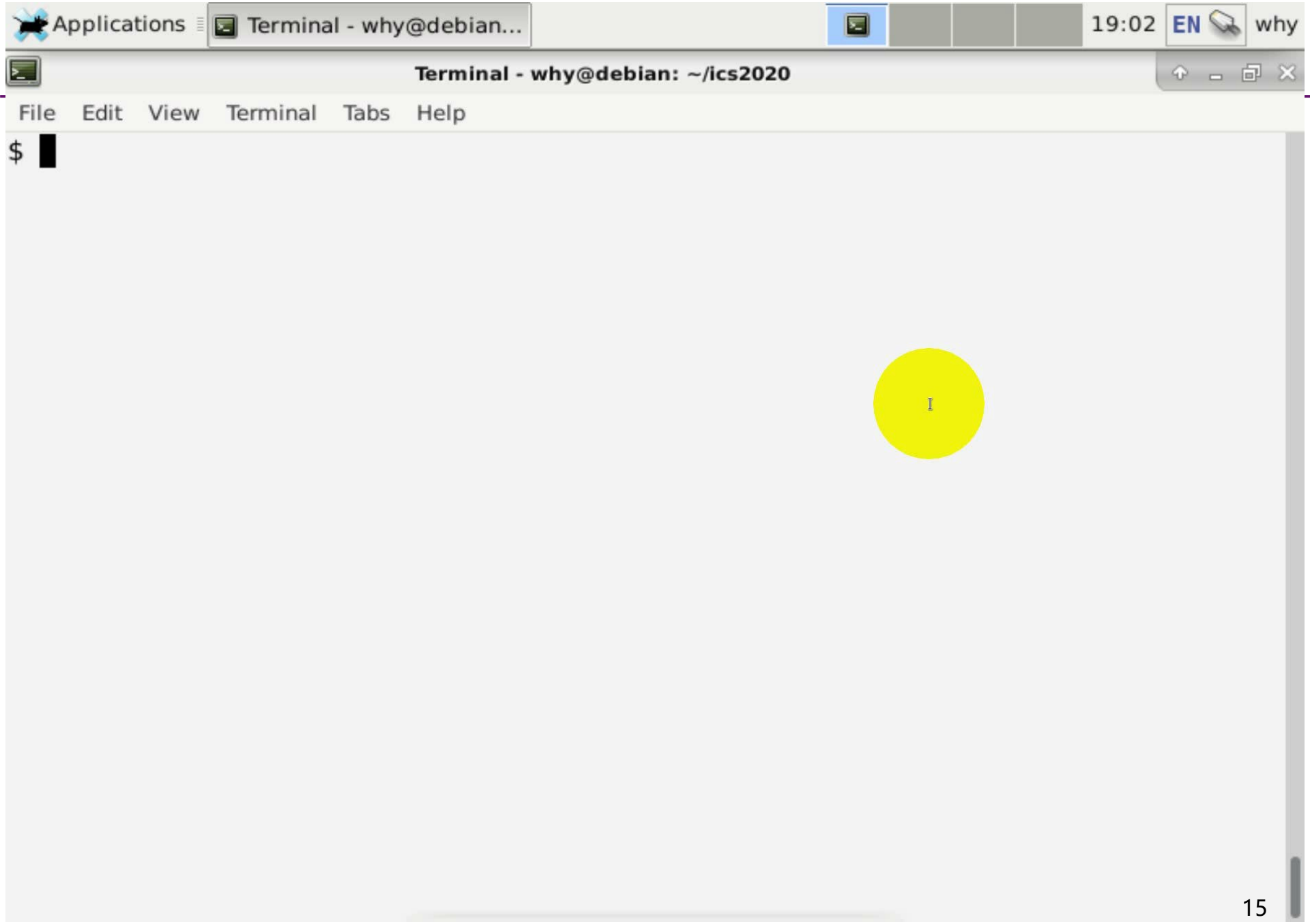
- 以下代码有什么区别?

```
#include <stdio.h>
#include “stdio.h”
```

- 为什么在没有安装库时会发生错误?

```
#include <SDL/SDL2.h>
```

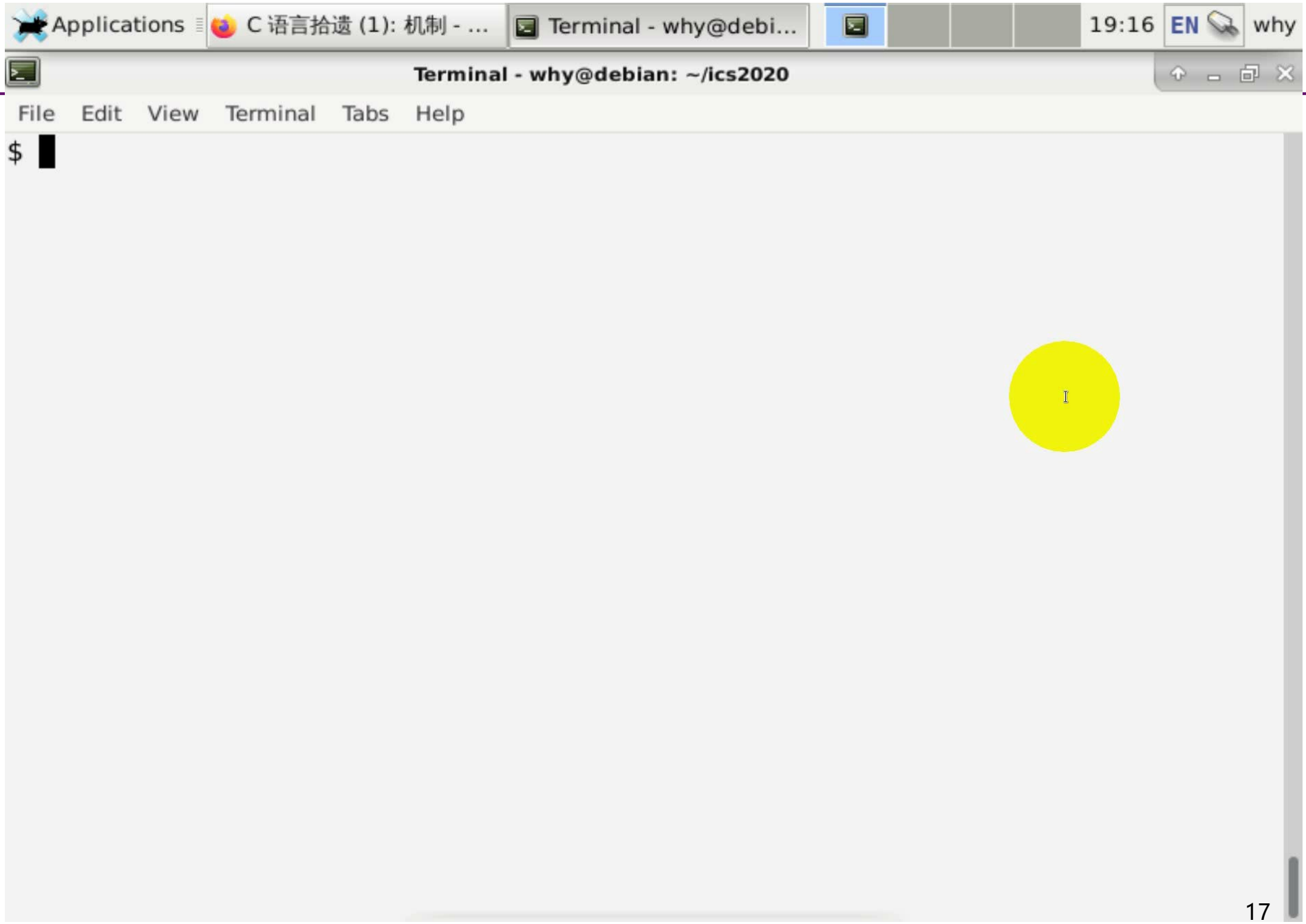
- 你可能在书/阅读材料上了解过一些相关的知识
  - 但更好的办法是阅读命令的日志
  - `gcc --verbose a.c`


Applications
Terminal - why@debian...
19:02
EN
why
Terminal - why@debian: ~/ics2020
File Edit View Terminal Tabs Help
$

有趣的预编译

- 以下代码会输出什么?
  - 为什么?

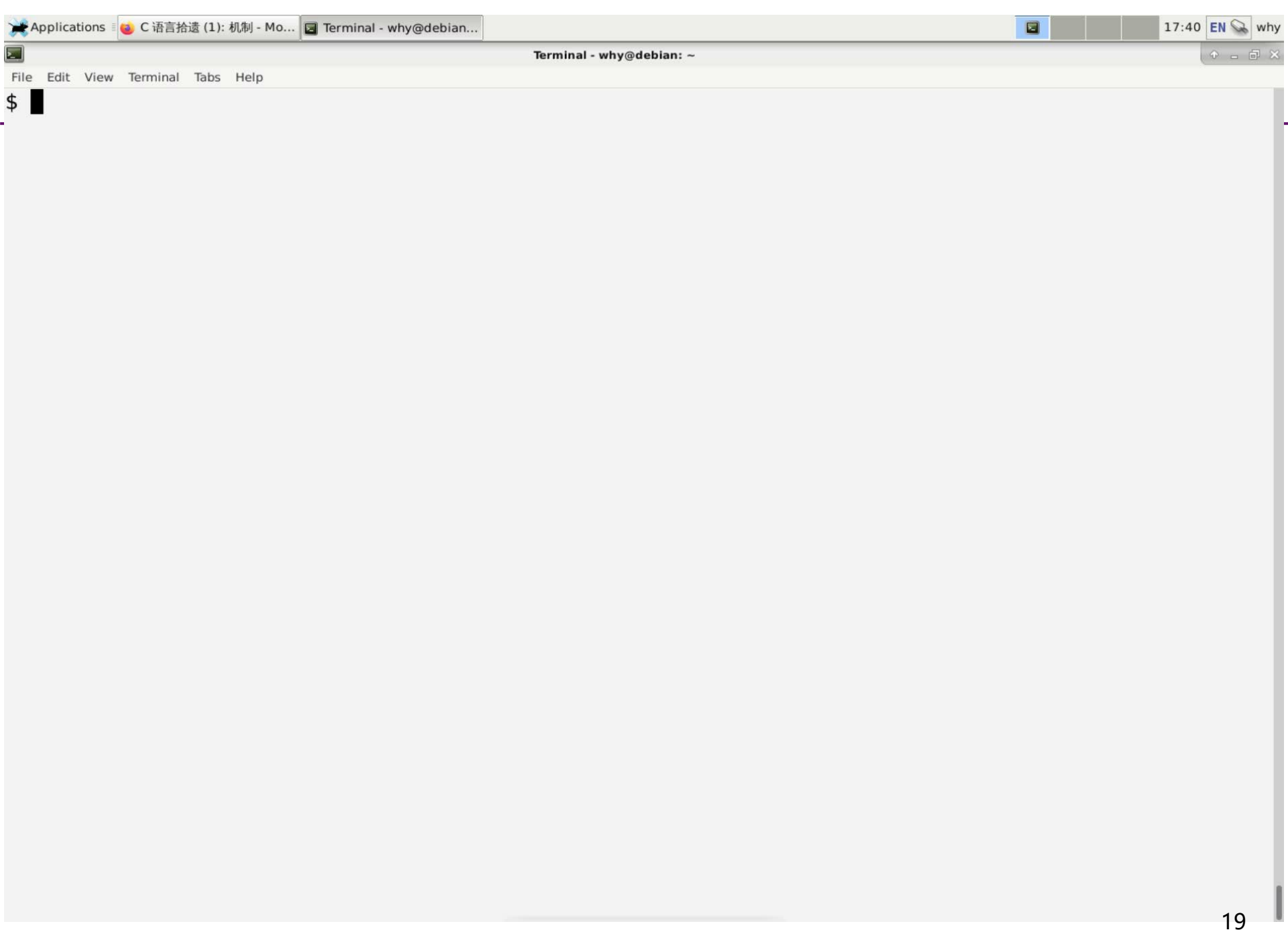
```c
#include <stdio.h>

int main() {
#if aa == bb
  printf("Yes\n");
#else
  printf("No\n");
#endif
}
```


Applications
C 语言拾遗 (1): 机制 - ...
Terminal - why@debi...
19:16
EN
why
Terminal - why@debian: ~/ics2020
File Edit View Terminal Tabs Help
$

宏定义与展开

- 宏展开：通过复制/粘贴改变代码的形态
  - #include →粘贴文件
  - aa, bb →粘贴符号
- 知乎问题：如何搞垮一个OJ?

```
#define A "aaaaaaaaaa"
#define TEN(A) A A A A A A A A A A
#define B TEN(A)
#define C TEN(B)
#define D TEN(C)
#define E TEN(D)
#define F TEN(E)
#define G TEN(F)
int main() { puts(G);}
```


Applications
C 语言拾遗 (1): 机制 - Mo...
Terminal - why@debian...
17:40
EN
why
Terminal - why@debian: ~
File Edit View Terminal Tabs Help
$

宏定义与展开

- 如何躲过Online Judge的关键字过滤?

```
#define SYSTEM sys ## tem
```

宏定义与展开

- 如何毁掉一个身边的同学?

```
#define true (__LINE__ % 2 != 0)
```

File Edit View Terminal Tabs Help

```
1  #define true (__LINE__ % 2 != 0)
2
3  #include <cstdio>
4
5  int main(){
6      if (true) printf("yes %d\n",__LINE__);
7      if (true) printf("yes %d\n",__LINE__);
8      if (true) printf("yes %d\n",__LINE__);
9      if (true) printf("yes %d\n",__LINE__);
10     if (true) printf("yes %d\n",__LINE__);
11     if (true) printf("yes %d\n",__LINE__);
12     if (true) printf("yes %d\n",__LINE__);
13     if (true) printf("yes %d\n",__LINE__);
14     if (true) printf("yes %d\n",__LINE__);
15     if (true) printf("yes %d\n",__LINE__);
16     if (true) printf("yes %d\n",__LINE__);
17     if (true) printf("yes %d\n",__LINE__);
18     if (true) printf("yes %d\n",__LINE__);
19     if (true) printf("yes %d\n",__LINE__);
20     if (true) printf("yes %d\n",__LINE__);
21 }
```

```
$ g++ a.c
$ ./a.out
yes 7
yes 9
yes 11
yes 13
yes 15
yes 17
yes 19
```

宏定义与展开

```
#define s ((((((((((((( 0
#define _ * 2)
#define X * 2 + 1)
static unsigned short stopwatch[] = {
  s _ _ _ _ _ X X X X X _ _ _ X X _ ,
  s _ _ _ X X X X X X X X _ X X X ,
  s _ _ X X X _ _ _ _ _ X X X _ X X ,
  s _ X X _ _ _ _ _ _ _ _ _ X X _ _ ,
  s X X _ _ _ _ _ _ _ _ _ _ X X _ ,
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  s _ _ X X X _ _ _ _ _ X X X _ _ _ ,
  s _ _ _ X X X X X X X X _ _ _ _ ,
  s _ _ _ _ _ X X X X X _ _ _ _ _ _ , };
```

宏定义与展开

```
#define s ((((((((((((((( 0
#define _ * 2)
#define X * 2 + 1)
static unsigned short stopwatch[] = {
  s _ _ _ _ _ X X X X X _ _ _ X X _ ,
  s _ _ _ X X X X X X X X X _ X X X ,
  s _ _ X X X _ _ _ _ _ X X X _ X X ,
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  s X X _ _ _ _ _ X _ _ _ _ _ X X _ ,
  s X X _ _ _ _ _ X _ _ _ _ _ X X _ ,
  s _ X X _ _ _ _ X _ _ _ _ X X _ _ ,
  s _ _ X X X _ _ _ _ _ X X X _ _ _ ,
  s _ _ _ X X X X X X X X X _ _ _ _ ,
  s _ _ _ _ _ X X X X X _ _ _ _ _ _ , };
```

gcc -E a.c

```
static unsigned short stopwatch[] = {
  ((((((((((((((( 0 * 2) * 2) * 2) * 2) * 2) * 2 + 1) * 2 + 1) * 2 + 1) * 2 + 1) * 2 + 1) * 2) * 2
) * 2) * 2 + 1) * 2 + 1) * 2) ,
  ((((((((((((((( 0 * 2) * 2) * 2) * 2 + 1) * 2 + 1) * 2 + 1) * 2 + 1) * 2 + 1) * 2 + 1) * 2 + 1)
* 2 + 1) * 2 + 1) * 2) * 2 + 1) * 2 + 1) * 2 + 1) ,
  ((((((((((((((( 0 * 2) * 2) * 2 + 1) * 2 + 1) * 2 + 1) * 2) * 2) * 2) * 2) * 2) * 2 + 1) * 2 + 1
) * 2 + 1) * 2) * 2 + 1) * 2 + 1) ,
  ((((((((((((((( 0 * 2) * 2 + 1) * 2 + 1) * 2) * 2) * 2) * 2) * 2) * 2) * 2) * 2) * 2 + 1) *
 2 + 1) * 2) * 2) ,
  ((((((((((((((( 0 * 2 + 1) * 2 + 1) * 2) * 2) * 2) * 2) * 2) * 2) * 2) * 2) * 2) * 2) * 2 +
 1) * 2 + 1) * 2) ,
  ((((((((((((((( 0 * 2 + 1) * 2 + 1) * 2) * 2 + 1) * 2 + 1) * 2 + 1) * 2 + 1) * 2 + 1) * 2) * 2)
* 2) * 2) * 2) * 2 + 1) * 2 + 1) * 2) ,
  ((((((((((((((( 0 * 2 + 1) * 2 + 1) * 2) * 2) * 2) * 2) * 2) * 2 + 1) * 2) * 2) * 2) * 2) * 2) *
 2 + 1) * 2 + 1) * 2) ,
  ((((((((((((((( 0 * 2 + 1) * 2 + 1) * 2) * 2) * 2) * 2) * 2) * 2 + 1) * 2) * 2) * 2) * 2) * 2) *
 2 + 1) * 2 + 1) * 2) ,
  ((((((((((((((( 0 * 2) * 2 + 1) * 2 + 1) * 2) * 2) * 2) * 2) * 2 + 1) * 2) * 2) * 2) * 2) * 2 +
1) * 2 + 1) * 2) * 2) ,
  ((((((((((((((( 0 * 2) * 2) * 2 + 1) * 2 + 1) * 2 + 1) * 2) * 2) * 2) * 2) * 2) * 2 + 1) * 2 + 1
) * 2 + 1) * 2) * 2) * 2) ,
  ((((((((((((((( 0 * 2) * 2) * 2) * 2 + 1) * 2 + 1) * 2 + 1) * 2 + 1) * 2 + 1) * 2 + 1) * 2 + 1)
```

```
$ ./a.out
1990
8183
14395
24588
49158
57094
49414
49414
24844
14392
8176
1984
```

X-Macros

- 宏展开：通过复制/粘贴改变代码的形态
  - 反复粘贴，直到没有宏可以展开为止

- 例子：X-macro

```
$ ./a.out
Hello, Tom!
Hello, Jerry!
Hello, Tyke!
Hello, Spike!
```

```
#define NAMES(X) \
   X(Tom) X(Jerry) X(Tyke) X(Spike)

int main() {
   #define PRINT(x) puts("Hello, " #x "!");
   NAMES(PRINT)
}
```

```
   PRINT(TOM) PRINT(Jerry) PRINT(Tyke) PRINT(Spike)
```

X-Macros

```
#define NAMES(X) \
   X(Tom) X(Jerry) X(Tyke) X(Spike)

int main() {
   #define PRINT(x) puts("Hello, " #x "!");
   NAMES(PRINT)
   #define PRINT2(x) puts("Goodbye, " #x "!");
   NAMES(PRINT2)
}
```

```
$ ./a.out
Hello, Tom!
Hello, Jerry!
Hello, Tyke!
Hello, Spike!
Goodbye, Tom!
Goodbye, Jerry!
Goodbye, Tyke!
Goodbye, Spike!
```

```
PRINT(TOM) PRINT(Jerry) PRINT(Tyke) PRINT(Spike)
```

```
PRINT2(TOM) PRINT2(Jerry) PRINT2(Tyke) PRINT2(Spike)
```

有趣的预编译

- 发生在实际编译之前
  - 也称为元编程（meta-programming）
    - Gcc的预处理器同样可以处理汇编代码
    - C++中的模板元编程；Rust中的macros；…

- Pros
  - 提供灵活的用法（X-macros）
  - 接近自然语言的写法

- Cons
  - 破坏可读性IOCCC、程序分析（补全）、……

```
#define L (
int main L ) { puts L "Hello, World" ); }
```

编译与链接

(先行剧透本学期的主要内容)

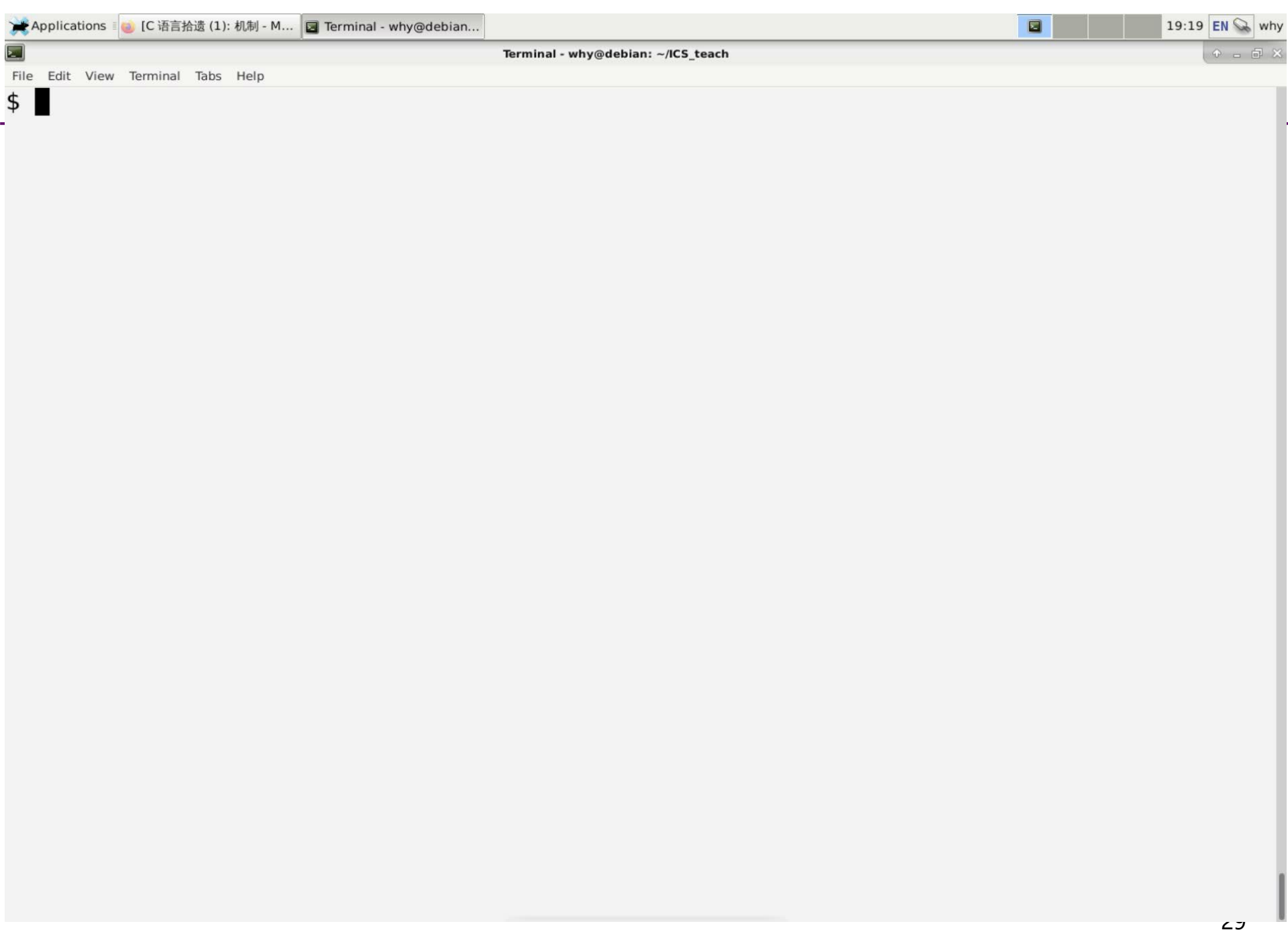
编译、链接

.c → 预编译 → .i → 编译 → .s → 汇编 → .o → 链接 → .out

编译

- 一个不带优化的简易（理想）的编译器
  - C代码中的连续一段总能找到对应的一段连续的机器指令
    - 这就是为什么大家会觉得C是高级的汇编语言！

```
int foo(int n) {
   int sum = 0;
   for (int i = 1; i <= n; i++) {
       sum += i;
   }
   return sum;
}
```


Applications
[C 语言拾遗 (1): 机制 - M...
Terminal - why@debian...
19:19
EN
why
Terminal - why@debian: ~/ICS_teach
File Edit View Terminal Tabs Help
$

编译

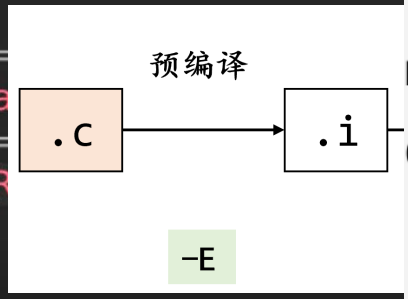
- 一个不带优化的简易（理想）的编译器
  - C代码中的连续一段总能找到对应的一段连续的机器指令
    - 这就是为什么大家会觉得C是高级的汇编语言！

```
int foo(int n) {
   int sum = 0;
   for (int i = 1; i <= n; i++) {
       sum += i;
   }
   return sum;
}
```

a.c到a.s到a.o

a.s

```
foo:
    n = ARG-1
    sum = 0
    i = 1
    goto    .L2
.L3:
    tmp = i
    sum += tmp
    i += 1
.L2:
    tmp =
    compa
    if(<=
    RETUR

    ret
```



a.c

```
int foo(int n) {
  int sum = 0;
  for (int i = 1; i <= n; i++) {
    sum += i;
  }
```

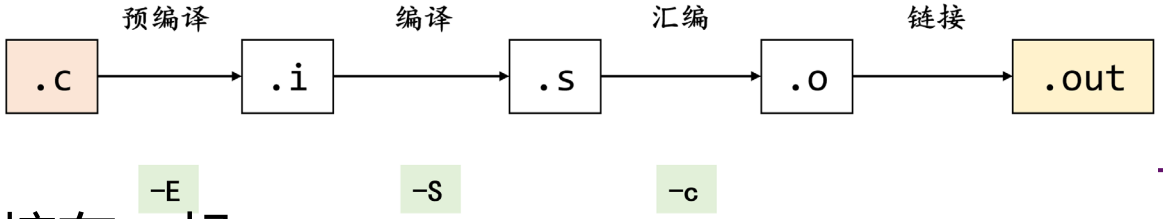
```
$ gcc -c a.c
$ objdump -d a.o

a.o:     file format elf64-x86-64


Disassembly of section .text:

0000000000000000 <foo>:
```

a.o

```
   0:   55                          push   %rbp
   1:   48 89 e5                    mov    %rsp,%rbp
   4:   89 7d ec                    mov    %edi,-0x14(%rbp)
   7:   c7 45 fc 00 00 00 00        movl   $0x0,-0x4(%rbp)
   e:   c7 45 f8 01 00 00 00        movl   $0x1,-0x8(%rbp)
  15:   eb 0a                       jmp    21 <foo+0x21>
  17:   8b 45 f8                    mov    -0x8(%rbp),%eax
  1a:   01 45 fc                    add    %eax,-0x4(%rbp)
  1d:   83 45 f8 01                 addl   $0x1,-0x8(%rbp)
  21:   8b 45 f8                    mov    -0x8(%rbp),%eax
  24:   3b 45 ec                    cmp    -0x14(%rbp),%eax
  27:   7e ee                       jle    17 <foo+0x17>
  29:   8b 45 fc                    mov    -0x4(%rbp),%eax
  2c:   5d                          pop    %rbp
  2d:   c3                          retq
```

没有main还不能运行

链接



- 将多个二进制目标代码拼接在一起
  - C中称为编译单元（compilation unit）

a.c

```c
int foo(int n) {
    int sum = 0;
    for (int i = 1; i <= n; i++) {
        sum += i;
    }
    return sum;
}
```

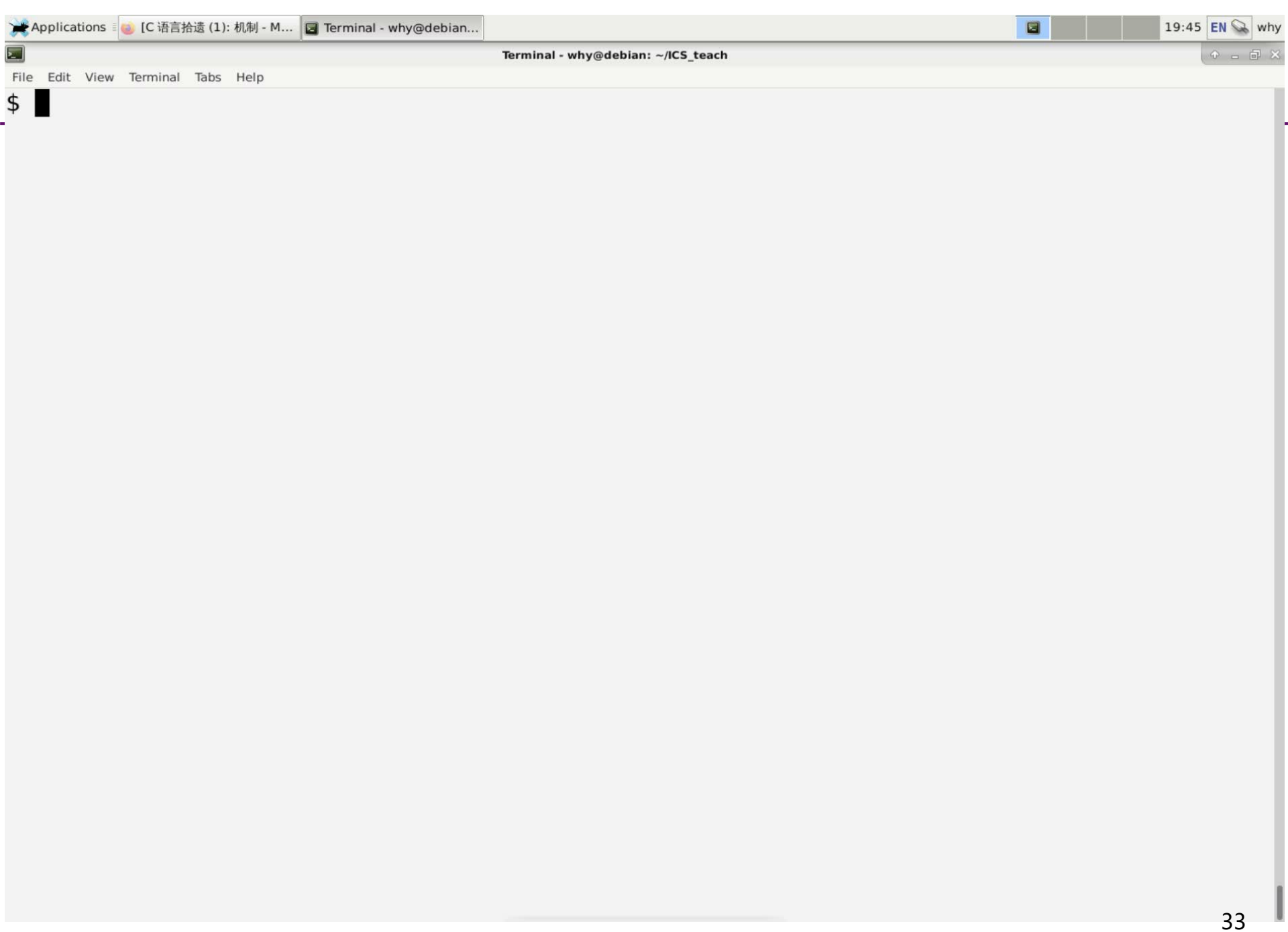
b.c

```c
#include <stdio.h>
int foo(int n);
int main(){
    printf("%d\n"),foo(100));
}
```

gcc -c a.c → a.o

gcc -c b.c → b.o

链接 ↔ ?


Applications
[C 语言拾遗 (1): 机制 - M...
Terminal - why@debian...
19:45
EN
why
Terminal - why@debian: ~/ICS_teach
File Edit View Terminal Tabs Help
$

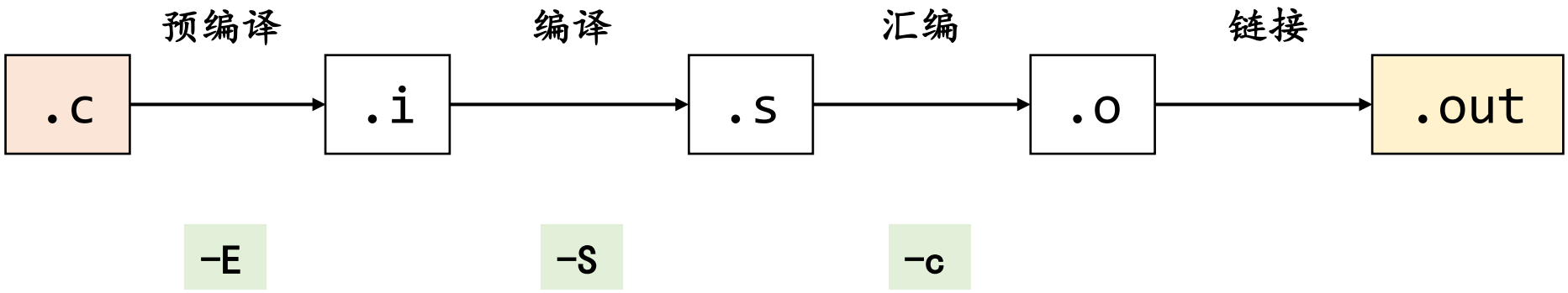
链接

- 将多个二进制目标代码拼接在一起
  - C中称为编译单元（compilation unit）
  - 甚至可以链接C++，rust，…代码

```
extern "C" {
   int foo() { return 0; }
}

int bar() { return 0; }
```

```
$ g++ -c a.cc
$ objdump -d a.o

a.o:     file format elf64-x86-64


Disassembly of section .text:

0000000000000000 <foo>:
   0:   55                      push   %rbp
   1:   48 89 e5                mov    %rsp,%rbp
   4:   b8 00 00 00 00          mov    $0x0,%eax
   9:   5d                      pop    %rbp
   a:   c3                      retq

000000000000000b <_Z3barv>:
   b:   55                      push   %rbp
   c:   48 89 e5                mov    %rsp,%rbp
   f:   b8 00 00 00 00          mov    $0x0,%eax
  14:   5d                      pop    %rbp
  15:   c3                      retq
```

从源代码到可执行文件



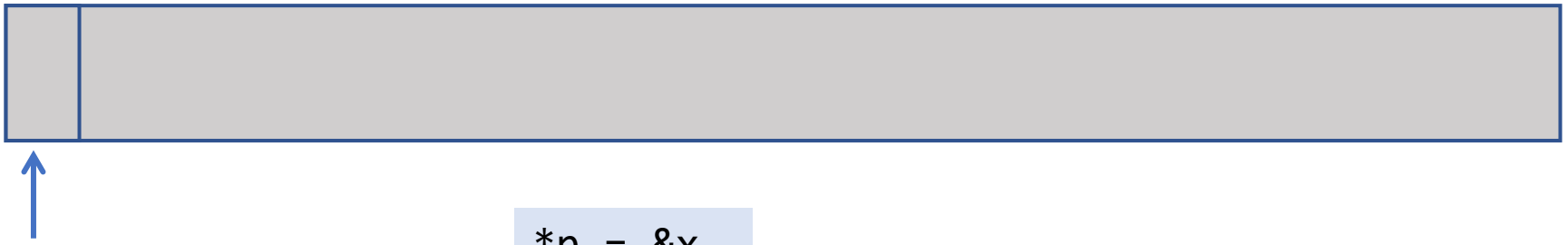
加载：进入C语言的世界

C程序执行的两个视角

- 静态：C 代码的连续一段总能对应到一段连续的机器指令
- 动态：C 代码执行的状态总能对应到机器的状态
  - 源代码视角
    - 函数、变量、指针……
  - 机器指令视角
    - 寄存器、内存、地址……

- 两个视角的共同之处：内存
  - 代码、变量 (源代码视角) = 地址 + 长度 (机器指令视角)
  - (不太严谨地) 内存 = 代码 + 数据 + 堆栈
  - 因此理解 C 程序执行最重要的就是内存模型

内存

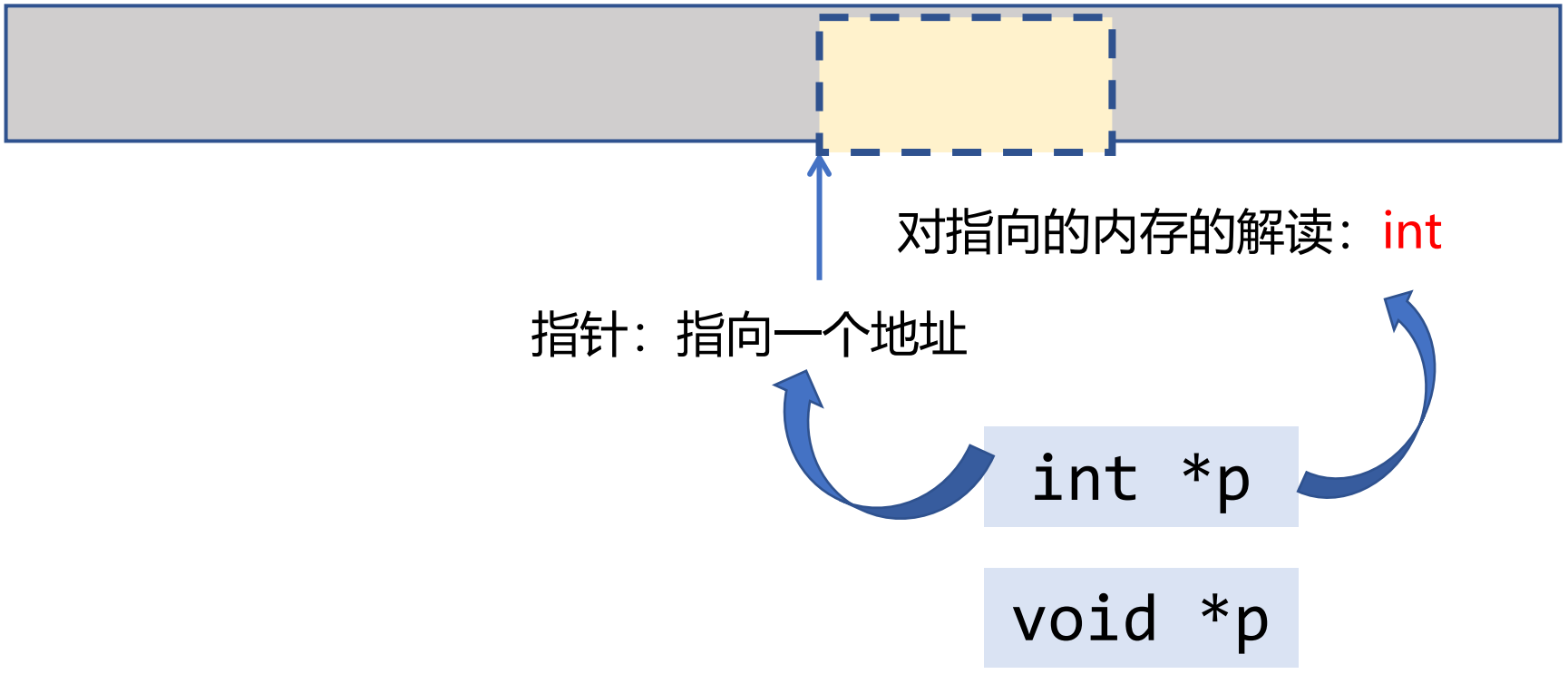


x=1 ⟶

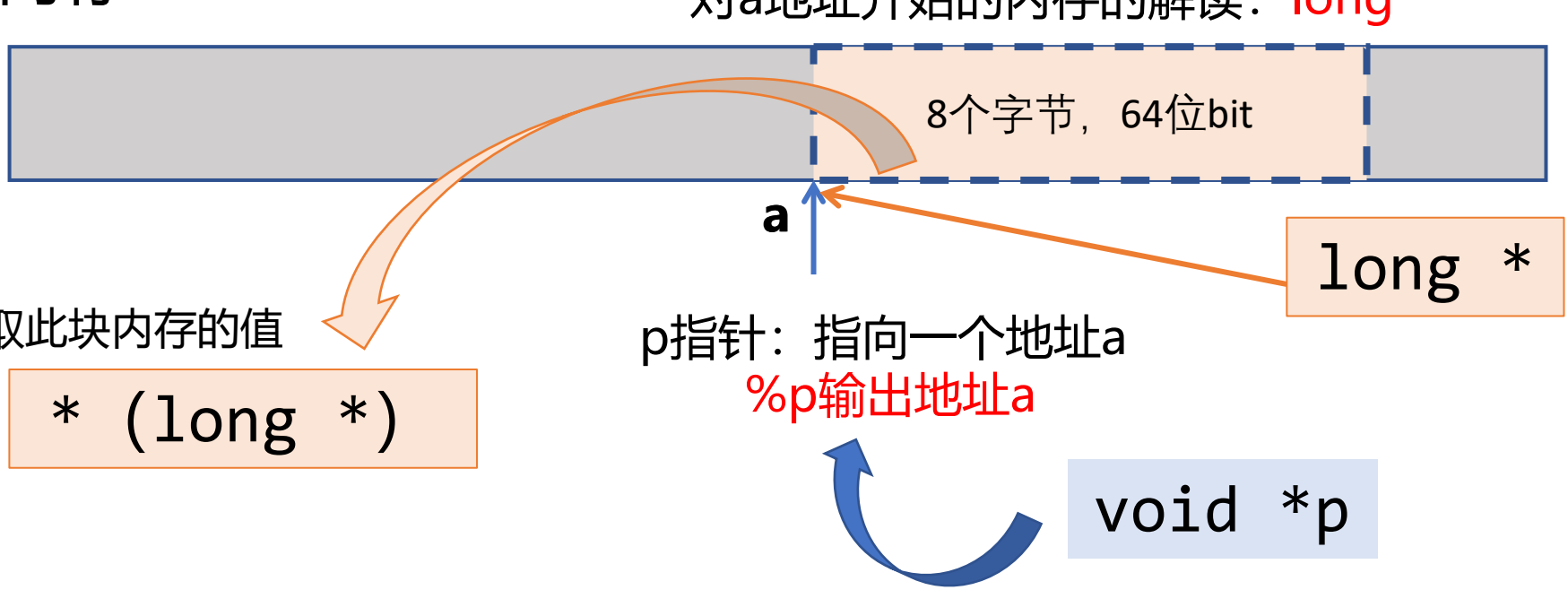
```
*p = &x
*p = 1
```

```
int main(int argc, char *argv[]) {
   int *p = (void *) 1;    //OK
   *p = 1;    //Segmentation fault
   }
```

内存



内存




```
void printptr(void *p) {
   printf("p = %p; *p = %016lx\n", p, *(long *)p);
}
```

指向的内存解读为long输出

输出指针指向的地址

以16位16进制数格式输出：16*4=64bit

main, argc和argv

- 一切皆可取地址!

```
void printptr(void *p) {
    printf("p = %p; *p = %016lx\n", p, *(long *)p);
}
int x;
int main(int argc, char *argv[]) {
    printptr(main); // 代码
    printptr(&main);
    printptr(&x); // 数据
    printptr(&argc); // 堆栈
    printptr(argv);
    printptr(&argv);
    printptr(argv[0]);
}
```

指向的地址处内存解读为long输出16位16进制

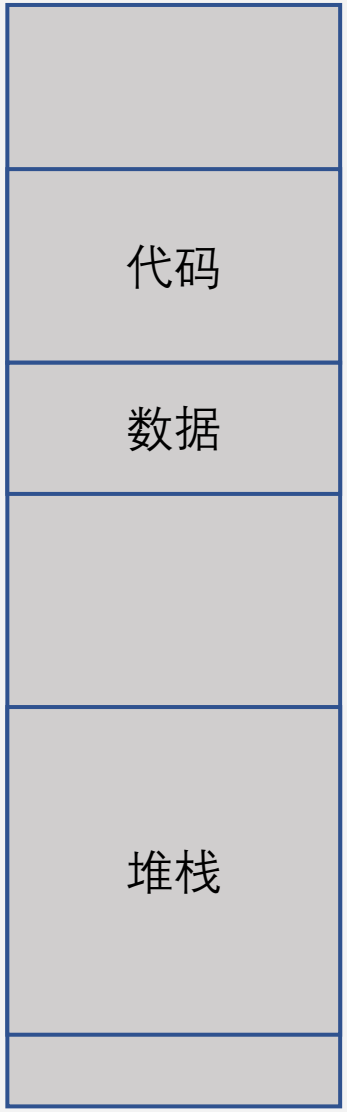
输出指针指向的地址

Applications Terminal - why@debian... 11:07 EN why

Terminal - why@debian: ~

File Edit View Terminal Tabs Help

$



C Type System

- 类型：对一段内存的解读方式
  - 非常汇编：没有class，polymorphism，type traits，……
  - C里的所有的数据都可以理解成地址（指针）+类型（对地址的解读）

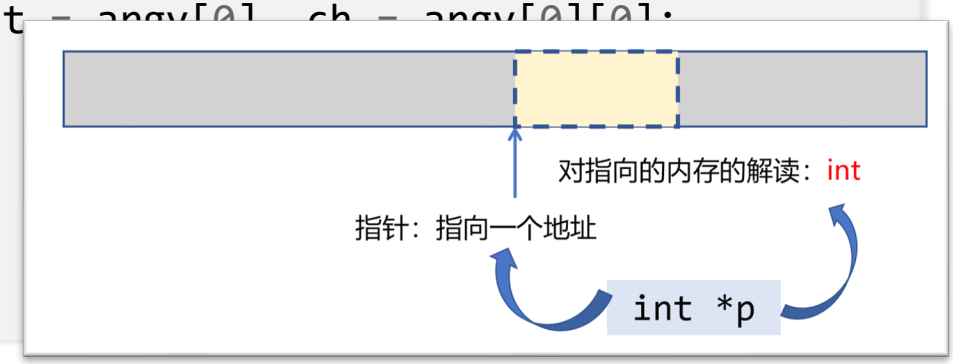
- 例子（是不是感到学到了假了C语言）

```
int main(int argc, char *argv[]) {
   int (*f)(int, char *[]) = main;
   if (argc != 0) {
       char ***a = &argv, *first = argv[0], ch = argv[0][0];
       printf("arg = \"%s\"; ch = '%c'\n", first, ch);
       assert(***a == ch);
       f(argc - 1, argv + 1);
   }
}
```

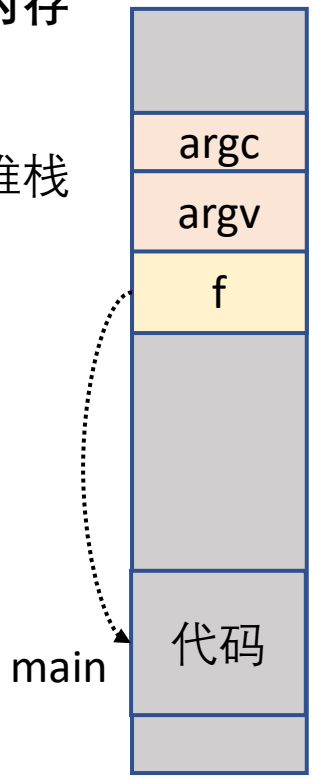
```
$ ./a.out 1 2 3 hello
arg = "./a.out";  ch = '.'
arg = "1";  ch = '1'
arg = "2";  ch = '2'
arg = "3";  ch = '3'
arg = "hello";  ch = 'h'
```

```
int main(int argc, char *argv[]) {
    int (*f)(int, char *[]) = main;
    if (argc != 0) {
        char ***a = &argv, *first = argv[0], ch = argv[0][0];
        printf("arg = \"%s\"; ch
        assert(***a == ch);
        f(argc - 1, argv + 1);
    }
}
```

函数指针f



内存



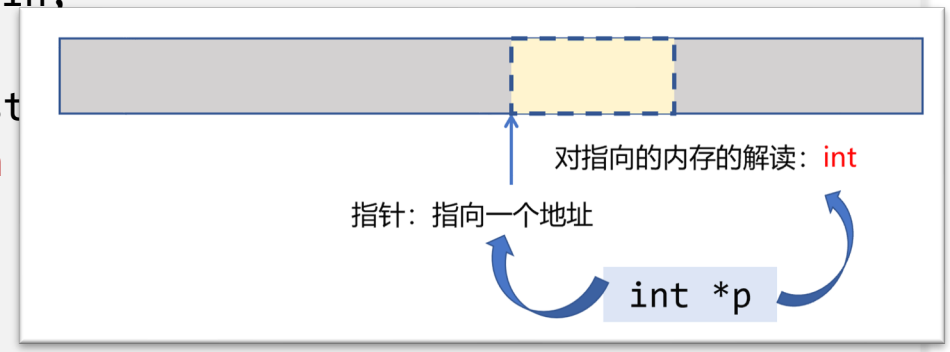
char *argv[] ➔ char **argv ➔ (char *)*argv

4字节

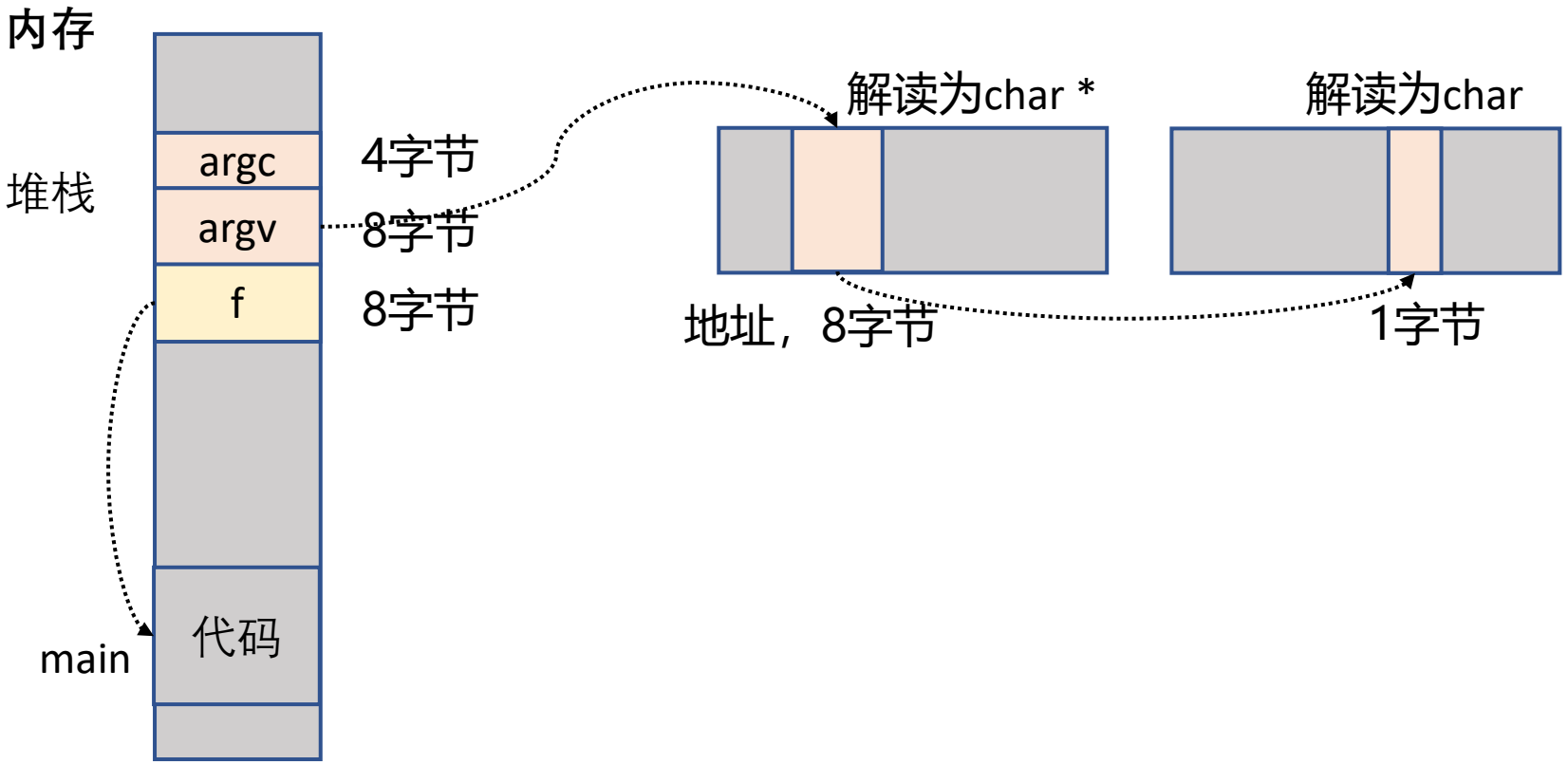
? **指针，存储地址，64位机器，8字节**

? **指针，存储地址，64位机器，8字节**

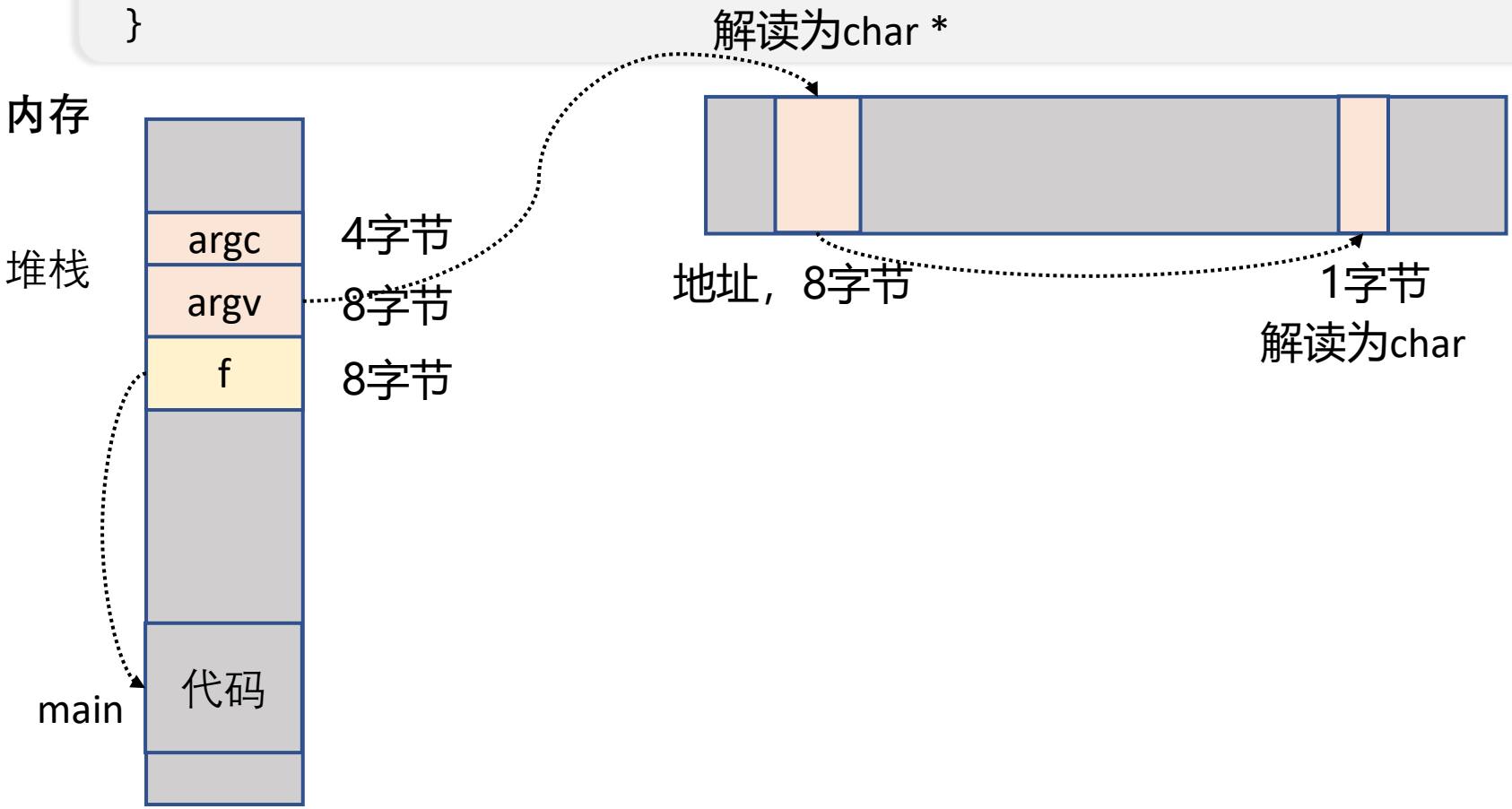
```c
int main(int argc, char *argv[]) {
    int (*f)(int, char *[]) = main;
    if (argc != 0) {
        char ***a = &argv, *first
        printf("arg = \"%s\"; ch
        assert(***a == ch);
        f(argc - 1, argv + 1);
    }
}
```



char *argv[] ➔ char **argv ➔ (char *)*argv



```
int main(int argc, char *argv[]) {
    int (*f)(int, char *[]) = main;
    if (argc != 0) {
        char ***a = &argv, *first = argv[0], ch = argv[0][0];
        printf("arg = \"%s\"; ch = '%c'\n", first, ch);
        assert(***a == ch);
        f(argc - 1, argv + 1);
    }
}
```



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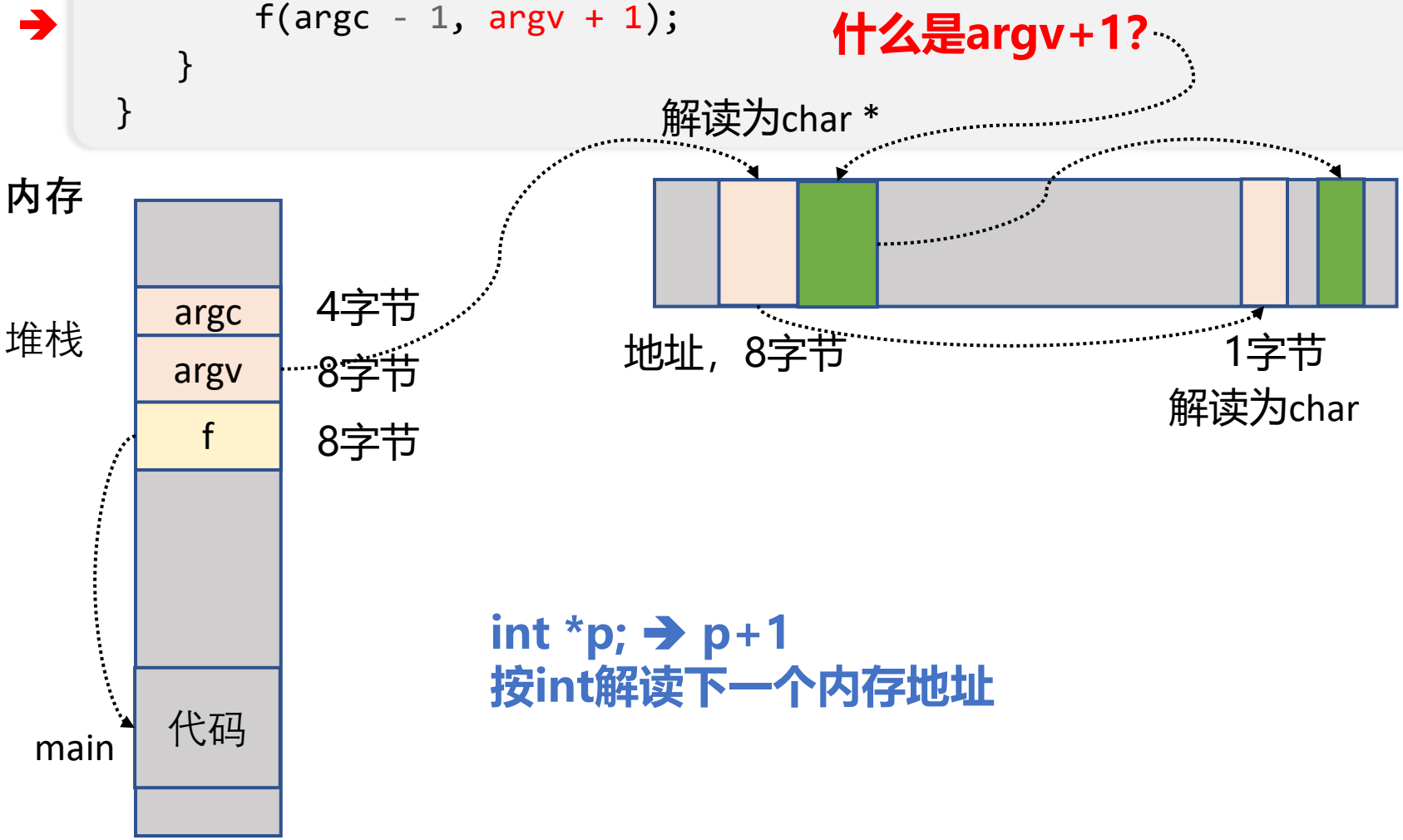
    if (argc != 0) {
        char ***a = &argv, *first = argv[0], ch = argv[0][0];
        printf("arg = \"%s\"; ch = '%c'\n", first, ch);
        assert(***a == ch);
        f(argc - 1, argv + 1);
    }
}
```



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    int (*f)(int, char *[]) = main;
    if (argc != 0) {
        char ***a = &argv, *first = argv[0], ch = argv[0][0];
        printf("arg = \"%s\"; ch = '%c'\n", first, ch);
        assert(***a == ch);
        f(argc - 1, argv + 1);
    }
}
```
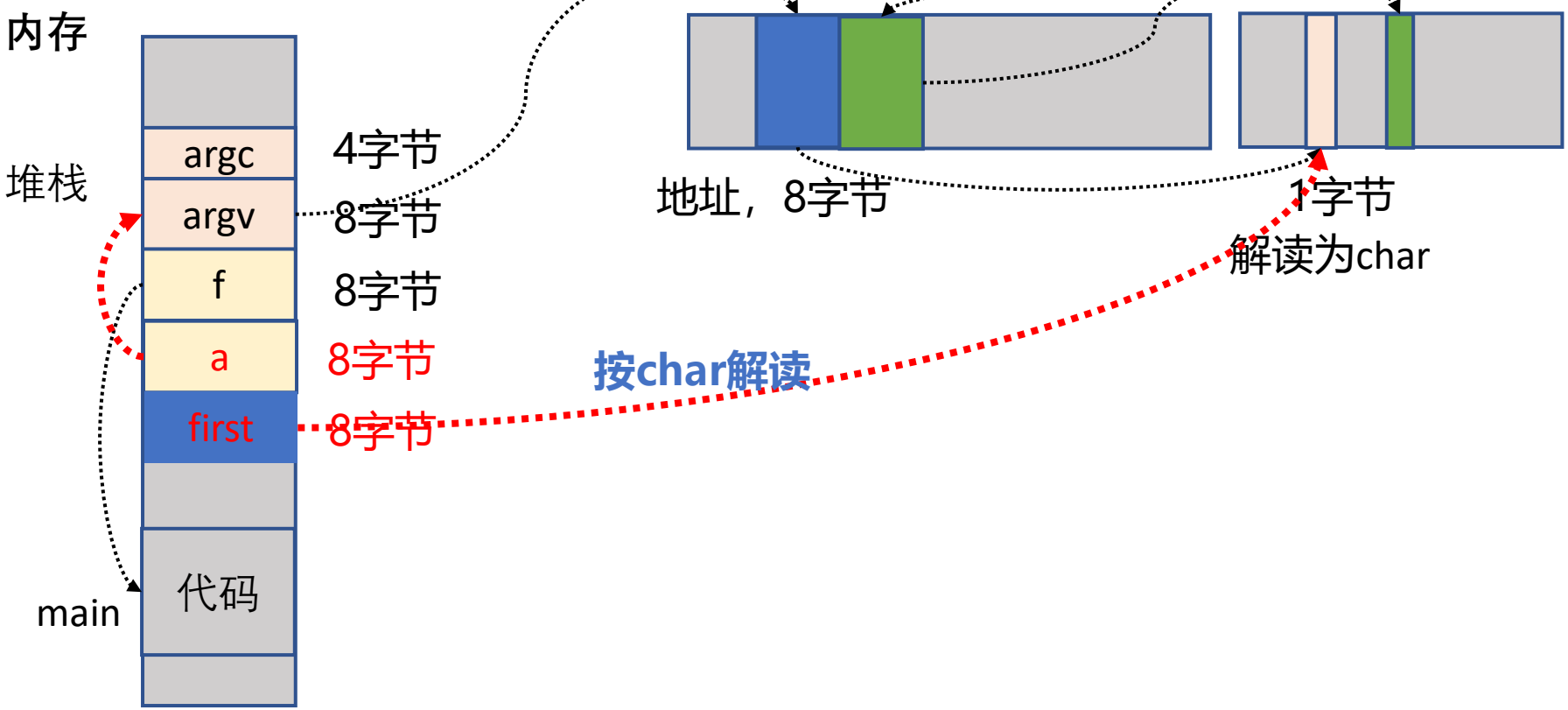
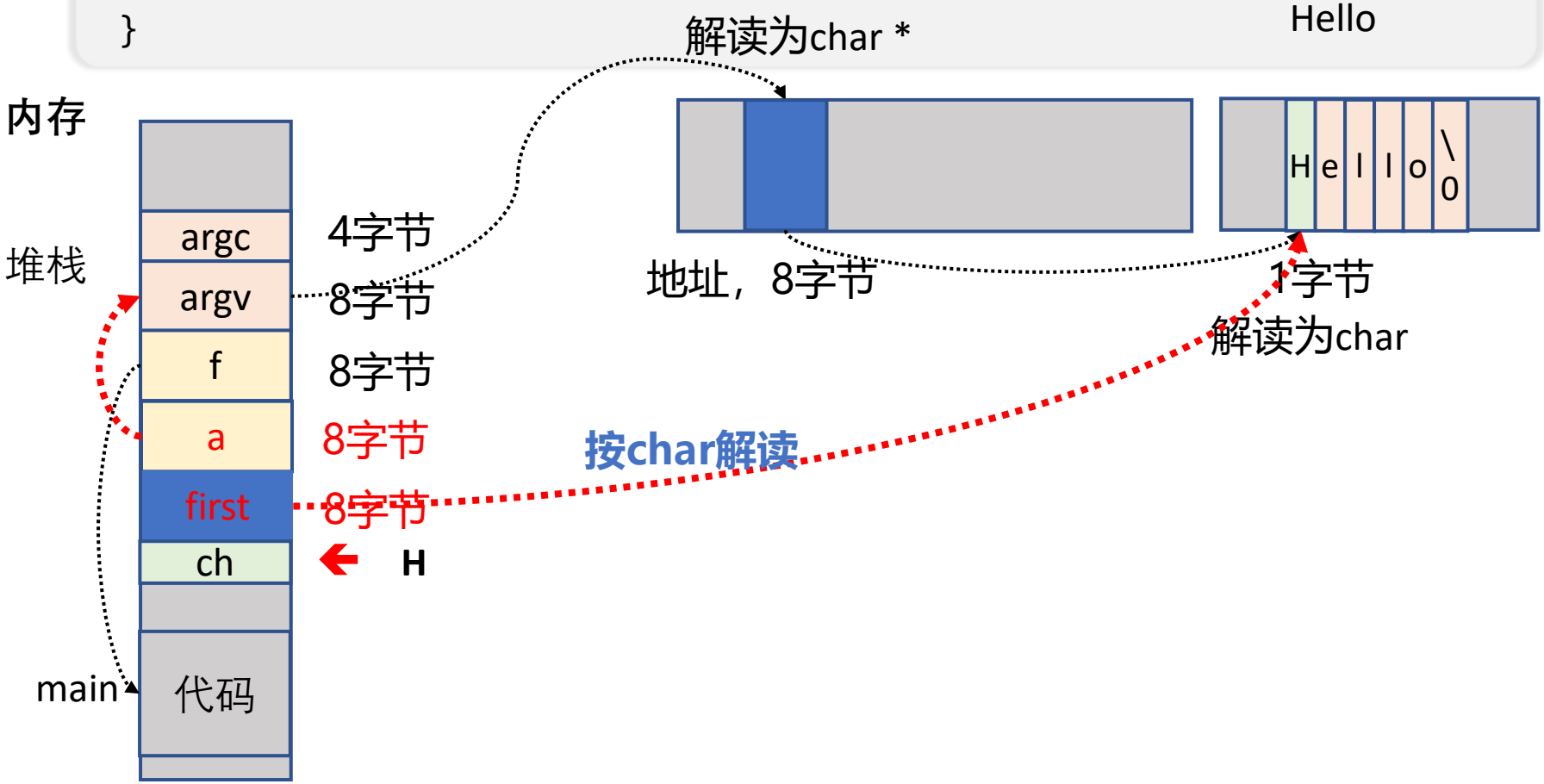



```c
int main(int argc, char *argv[]) {
    int (*f)(int, char *[]) = main;
    if (argc != 0) {
        char ***a = &argv, *first = argv[0], ch = argv[0][0];
        printf("arg = \"%s\"; ch = '%c'\n", first, ch);
        assert(***a == ch);
        f(argc - 1, argv + 1);
    }
}
```



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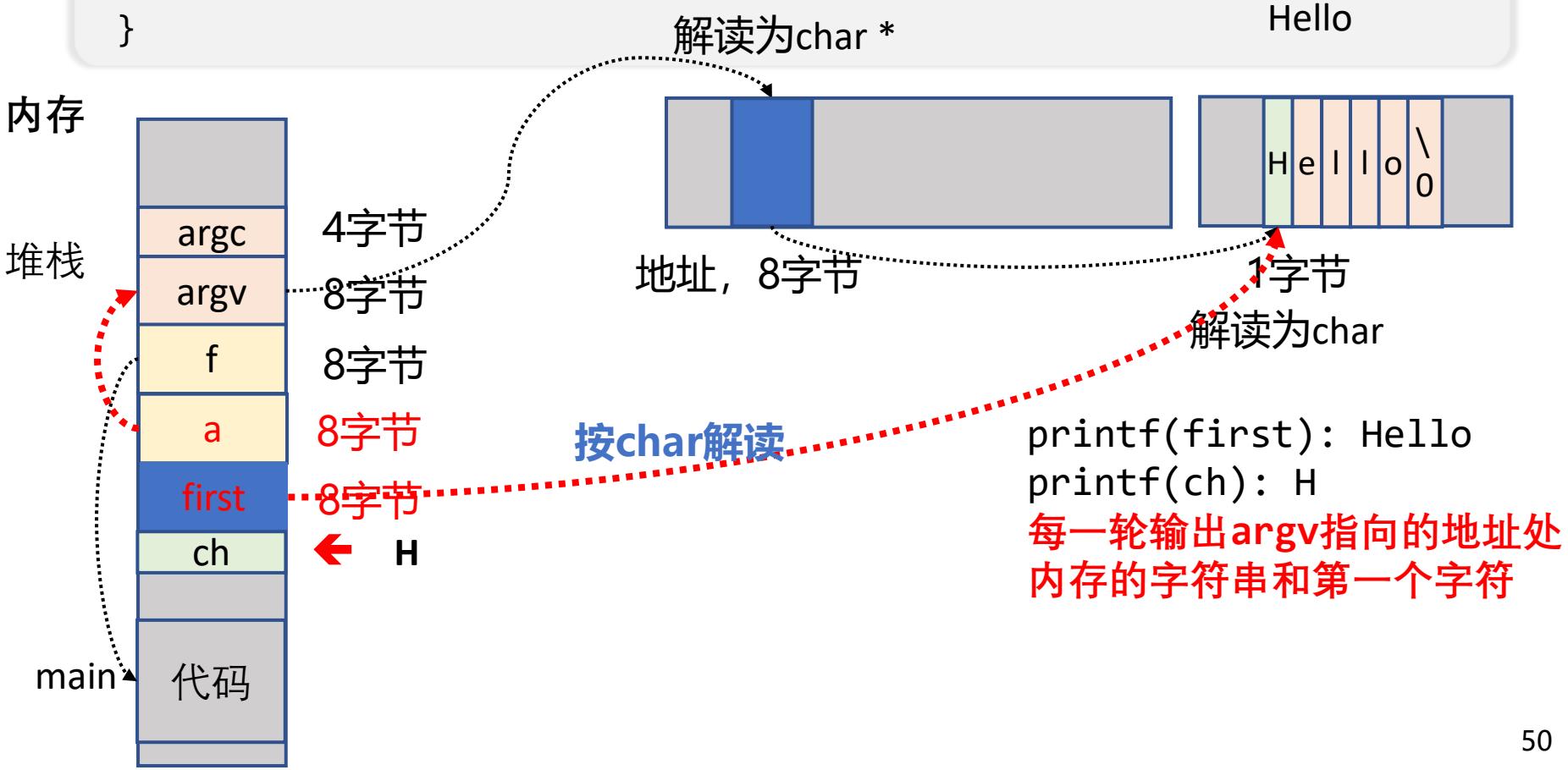
    if (argc != 0) {
        char ***a = &argv, *first = argv[0], ch = argv[0][0];
        printf("arg = \"%s\"; ch = '%c'\n", first, ch);
        assert(***a == ch);
        f(argc - 1, argv + 1);
    }
}
```



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int main(int argc, char *argv[]) {
    int (*f)(int, char *[]) = main;
    if (argc != 0) {
        char ***a = &argv, *first = argv[0
        printf("arg = \"%s\"; ch = '%c'\n'
        assert(***a == ch);
        f(argc - 1, argv + 1);
    }
}
```
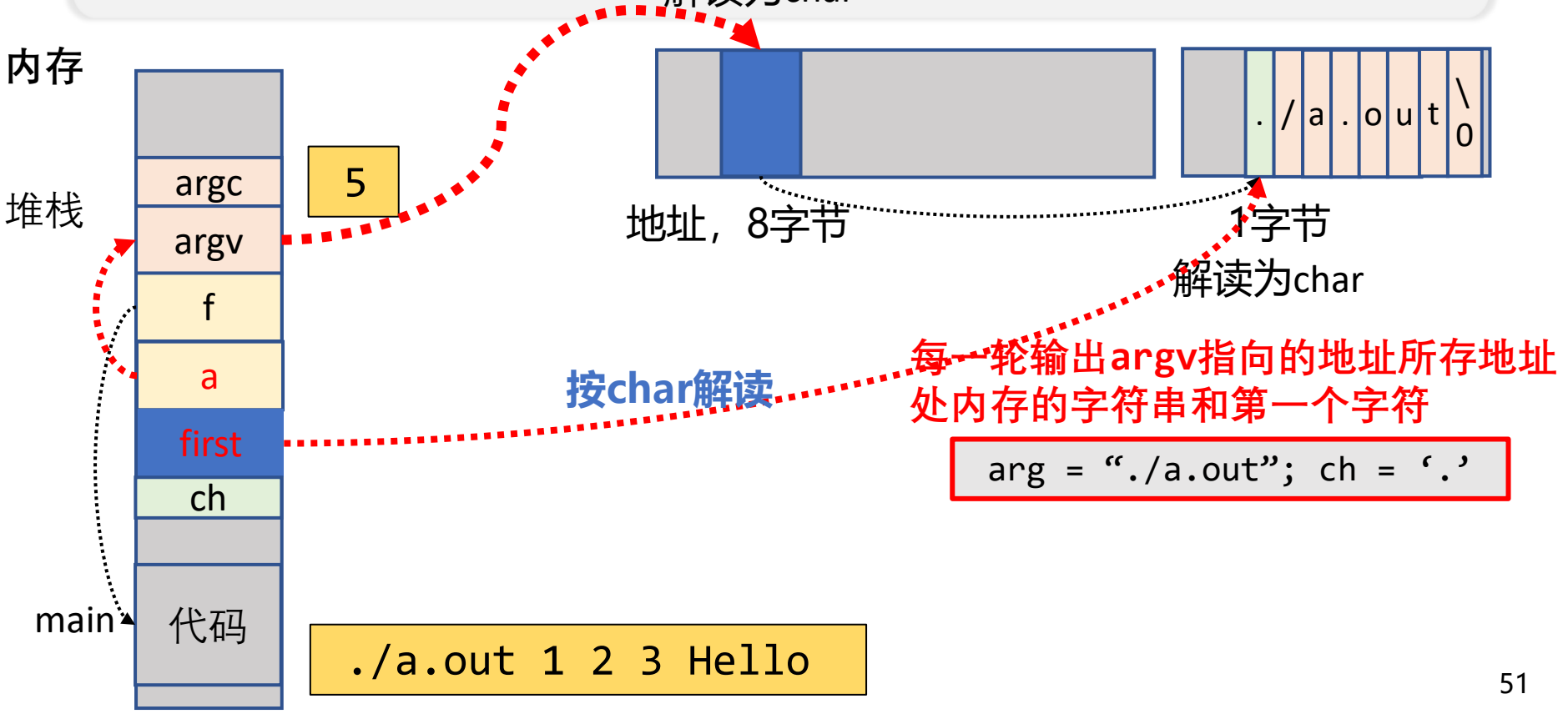

```
$ ./a.out 1 2 3 hello
arg = "./a.out";  ch = '.'
arg = "1";  ch = '1'
arg = "2";  ch = '2'
arg = "3";  ch = '3'
arg = "hello";  ch = 'h'
```

Hello



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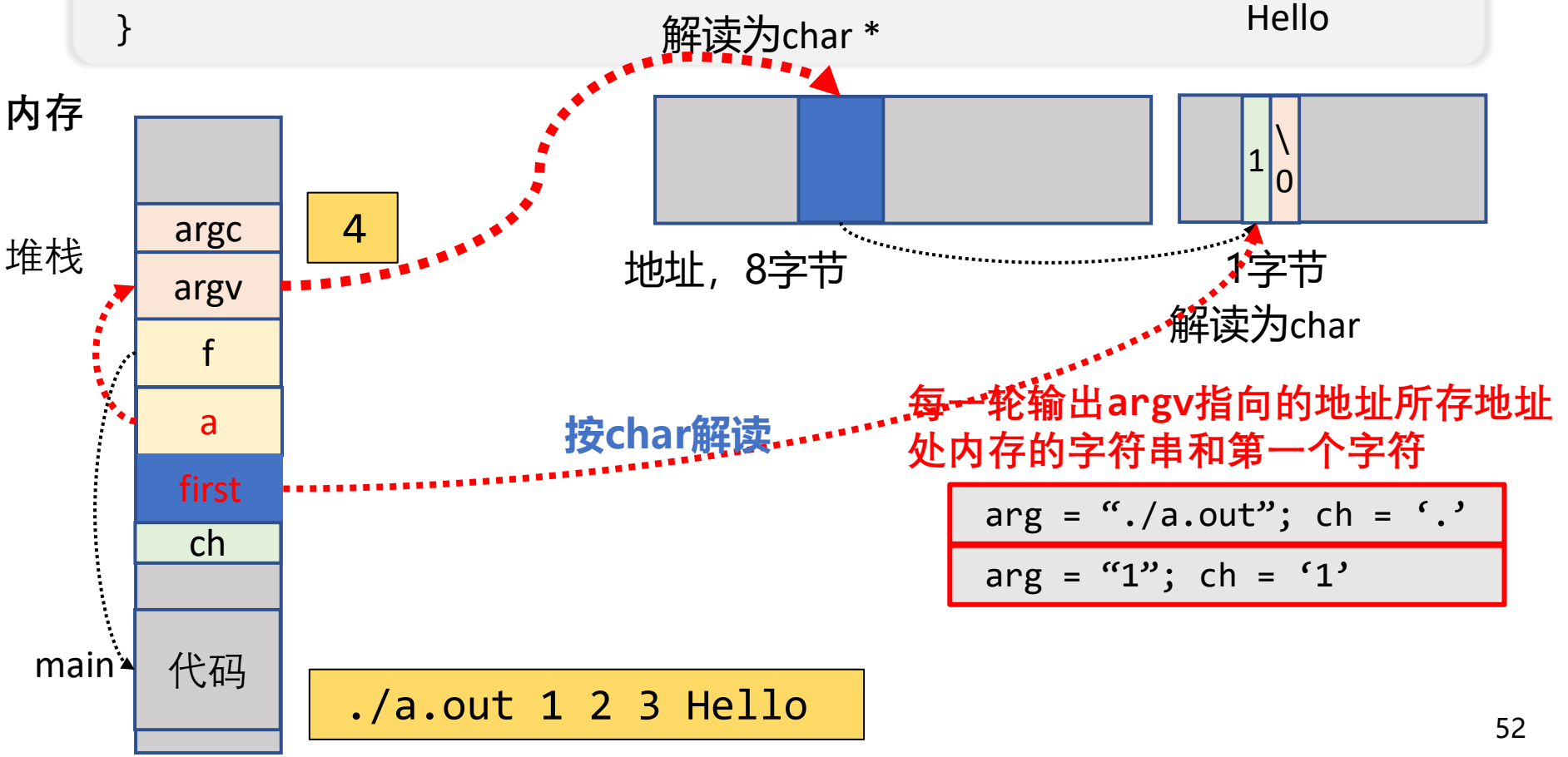
arg = "3";  ch = '3'
arg = "hello";  ch = 'h'
```

Hello



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    int (*f)(int, char *[]) = main;
    if (argc != 0) {
        char ***a = &argv, *first = argv[0
        printf("arg = \"%s\"; ch = '%c'\n'
        assert(***a == ch);
        f(argc - 1, argv + 1);
    }
}
```
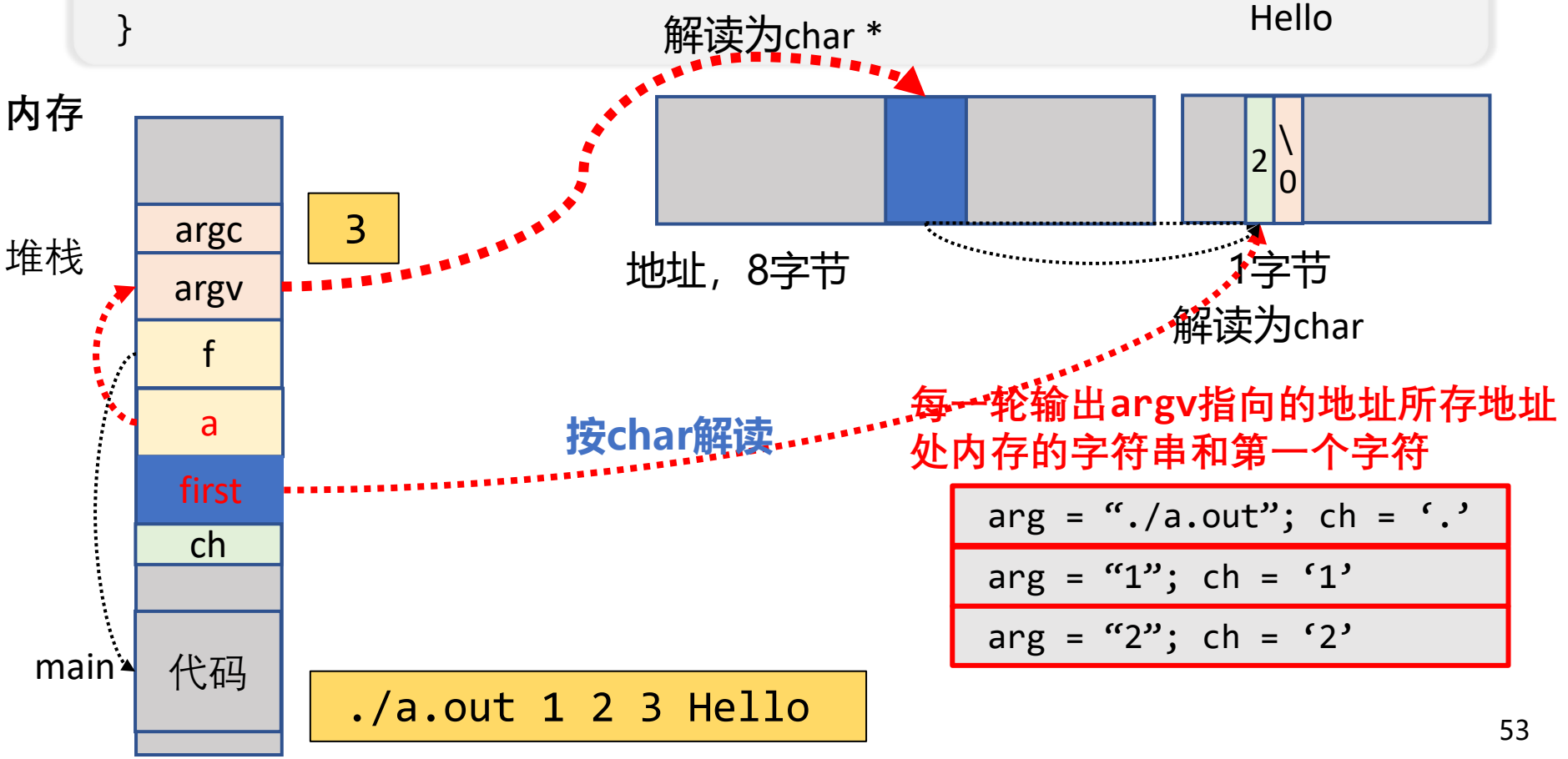

```
$ ./a.out 1 2 3 hello
arg = "./a.out";  ch = '.'
arg = "1";  ch = '1'
arg = "2";  ch = '2'
arg = "3";  ch = '3'
arg = "hello";  ch = 'h'
```

Hello



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    int (*f)(int, char *[]) = main;
    if (argc != 0) {
        char ***a = &argv, *first = argv[0
        printf("arg = \"%s\"; ch = '%c'\n'
        assert(***a == ch);
        f(argc - 1, argv + 1);
    }
}
```

```
$ ./a.out 1 2 3 hello
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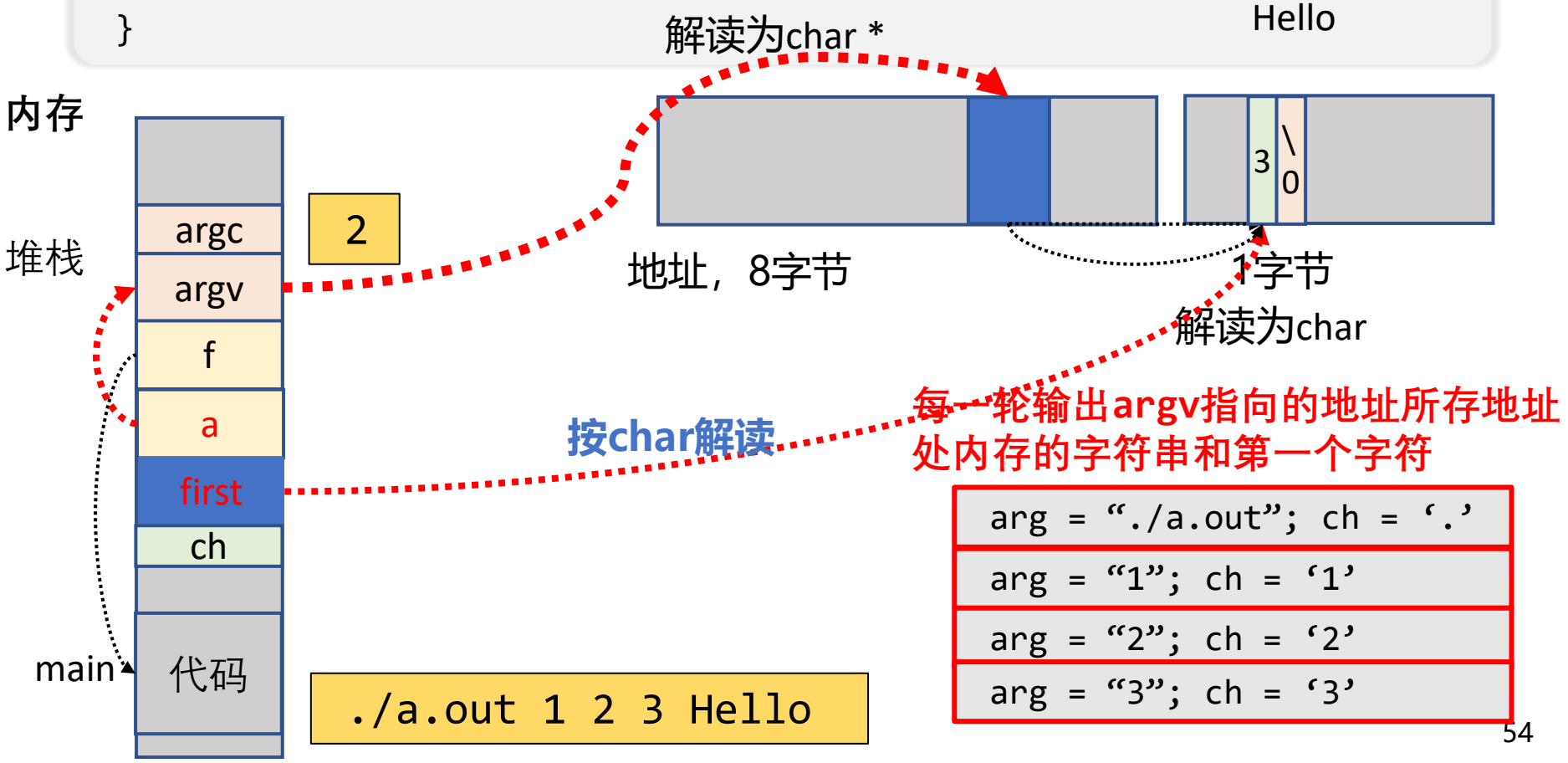
arg = "1";  ch = '1'
arg = "2";  ch = '2'
arg = "3";  ch = '3'
arg = "hello";  ch = 'h'
```

Hello



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    int (*f)(int, char *[]) = main;
    if (argc != 0) {
        char ***a = &argv, *first = argv[0
        printf("arg = \"%s\"; ch = '%c'\n'
        assert(***a == ch);
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}
```

```
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arg = "1";  ch = '1'
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arg = "3";  ch = '3'
arg = "hello";  ch = 'h'
```
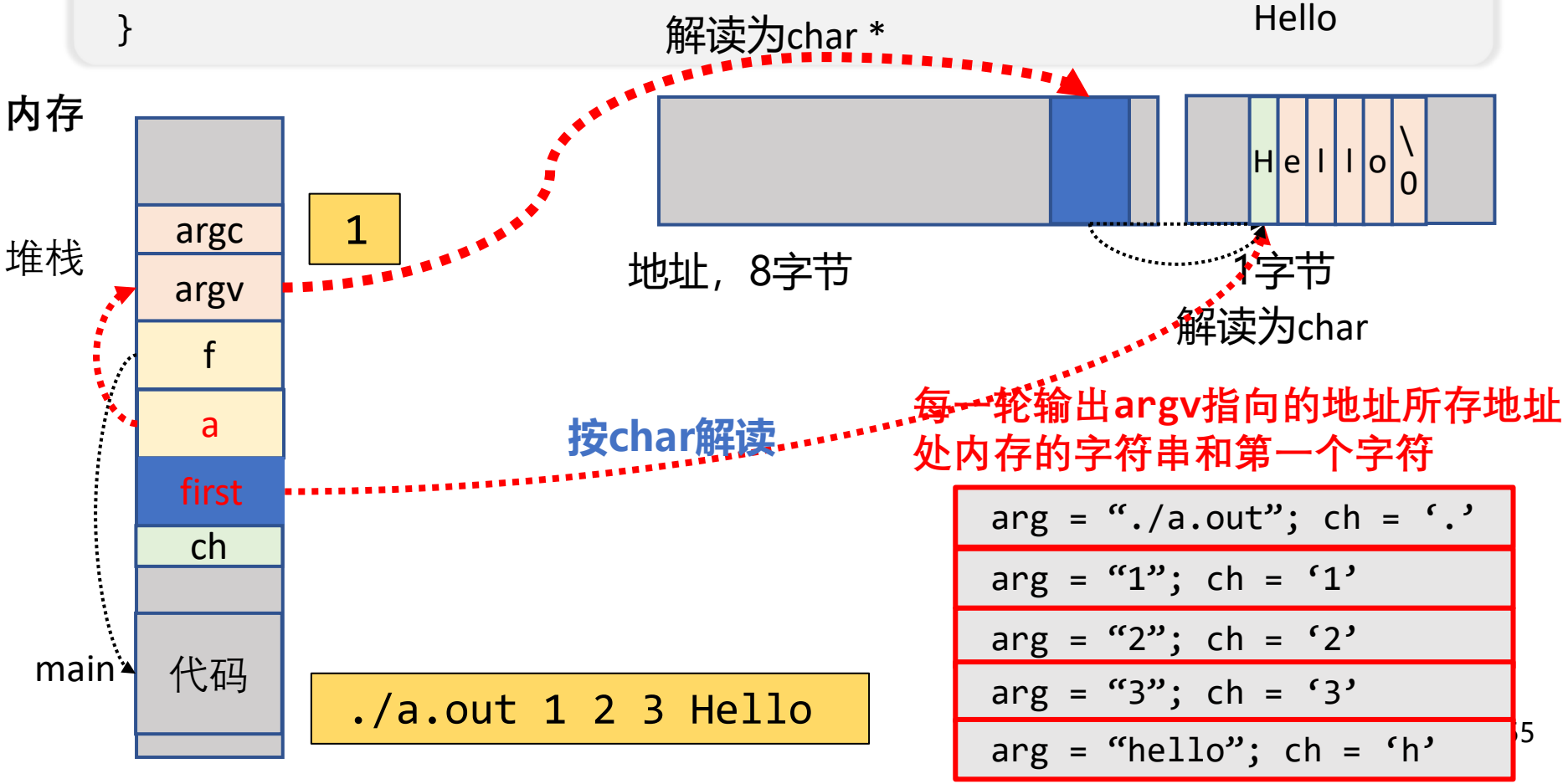
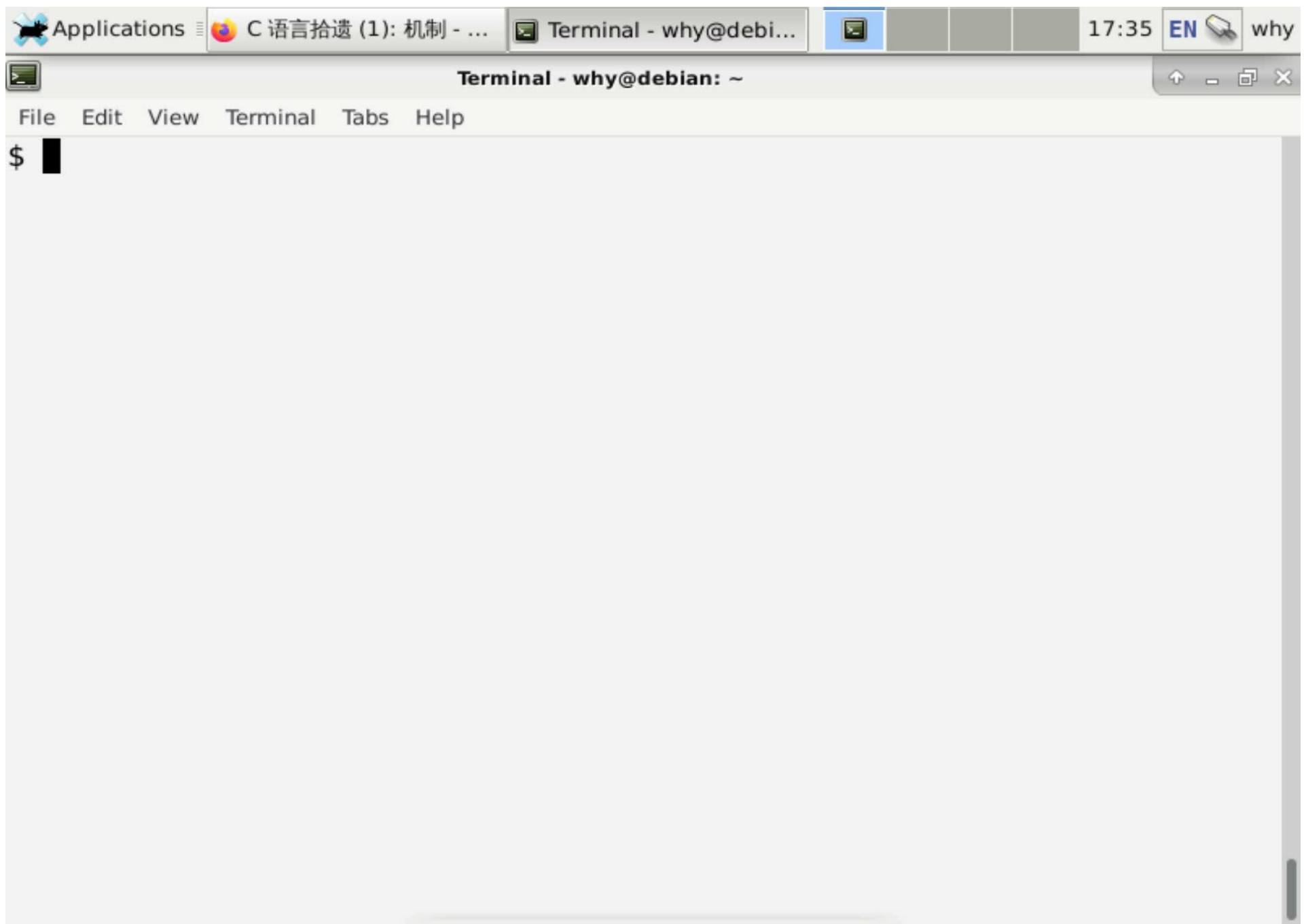

Hello




Applications
C 语言拾遗 (1): 机制 - ...
Terminal - why@debi...
17:35
EN
why
Terminal - why@debian: ~
File Edit View Terminal Tabs Help
$

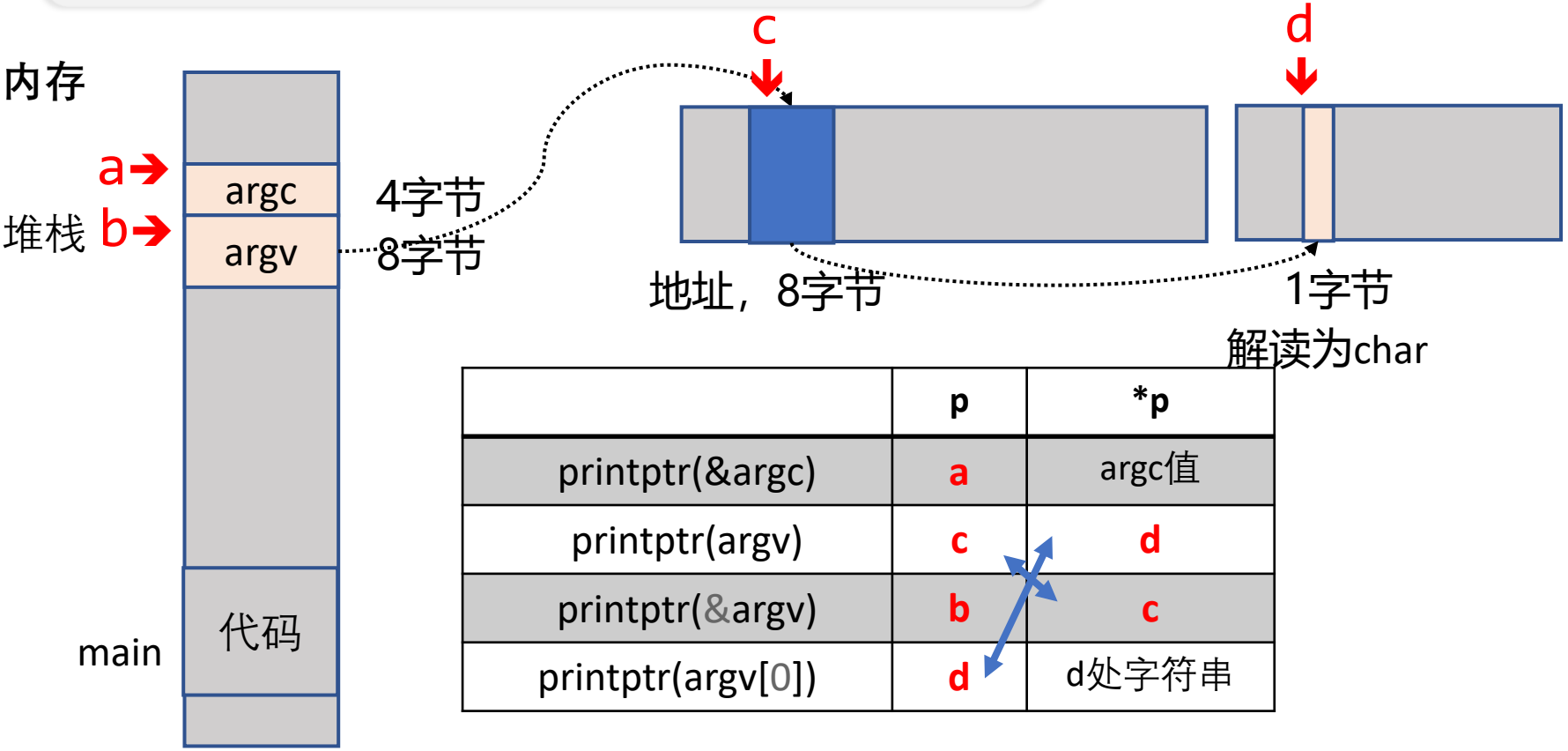
```
void printptr(void *p) {
   printf("p = %p; *p = %016lx\n", p, *(long *)p);
}
int x;
int main(int argc, char *argv[]) {
   printptr(main); // 代码
   printptr(&main);
   printptr(&x); // 数据
   printptr(&argc); // 堆栈
   printptr(argv);
   printptr(&argv);
   printptr(argv[0]);
}
```

指向的地址处内存解读为long输出16位16进制

输出指针指向的地址

```
$ ./a.out
p = 0x563afd3cf163;   *p = 10ec8348e5894855
p = 0x563afd3cf163;   *p = 10ec8348e5894855
p = 0x563afd3d2034;   *p = 0000000000000000
p = 0x7ffcada0761c;   *p = fd3cf1d000000001
p = 0x7ffcada07708;   *p = 00007ffcada084fe
p = 0x7ffcada07610;   *p = 00007ffcada07708
p = 0x7ffcada084fe;   *p = 0074756f2e612f2e
```

地址xx，地址xx内存的内容



	p	*p
printptr(&argc)	a	argc值
printptr(argv)	c	d
printptr(&argv)	b	c
printptr(argv[0])	d	d处字符串

从main函数开始执行

- 标准规定C程序从main开始执行
  - （思考题：谁调用的main？进程执行的第一条指令是什么？）

```
int main(int argc, char *argv[]);
```

  - argc (argument count): 参数个数
  - argv (argument vector): 参数列表（NULL结束）

  - ls –al
    - argc = 2, argv = ["ls", "-al", NULL]

End.

- C语言简单（在可控时间成本里可以精通）
- C语言通用（大量系统是C语言编写的）
- C语言实现对底层机器的精准控制（鸿蒙）
- 推荐阅读：The Art of Readable Code