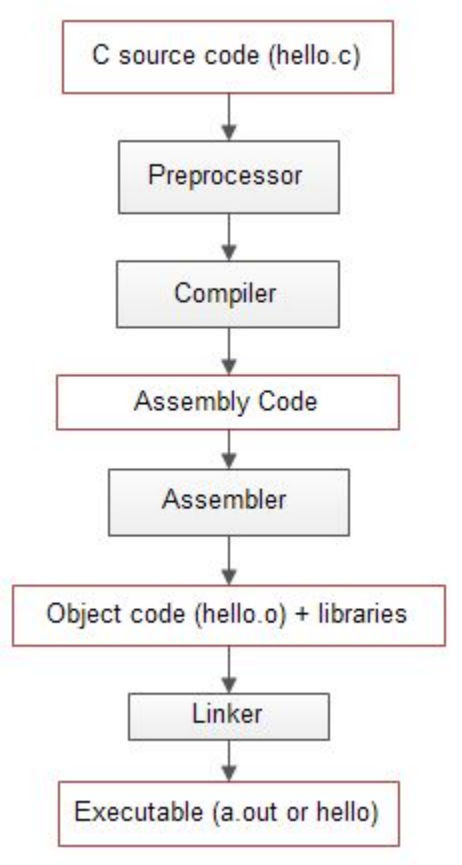
ILLINOIS TECH

College of Computing

Introduction to Binary Analysis

Yue Duan

What is binary



C source code (hello.c)

Preprocessor

Compiler

Assembly Code

Assembler

Object code (hello.o) + libraries

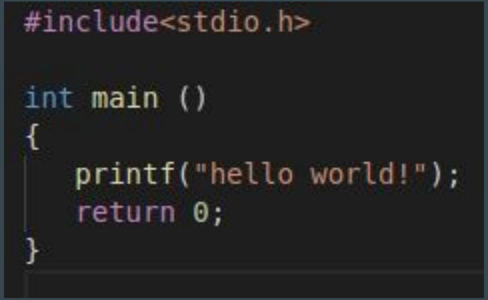
Linker

Executable (a.out or hello)

Binary:

- no source code
- 0s and 1s
- usually no debug symbol

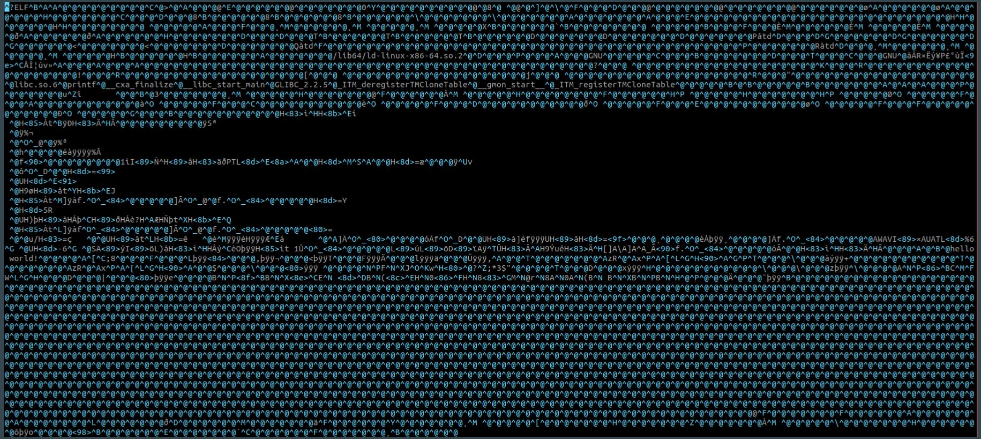
What is binary



```
#include<stdio.h>

int main ()
{
    printf("hello world!");
    return 0;
}
```

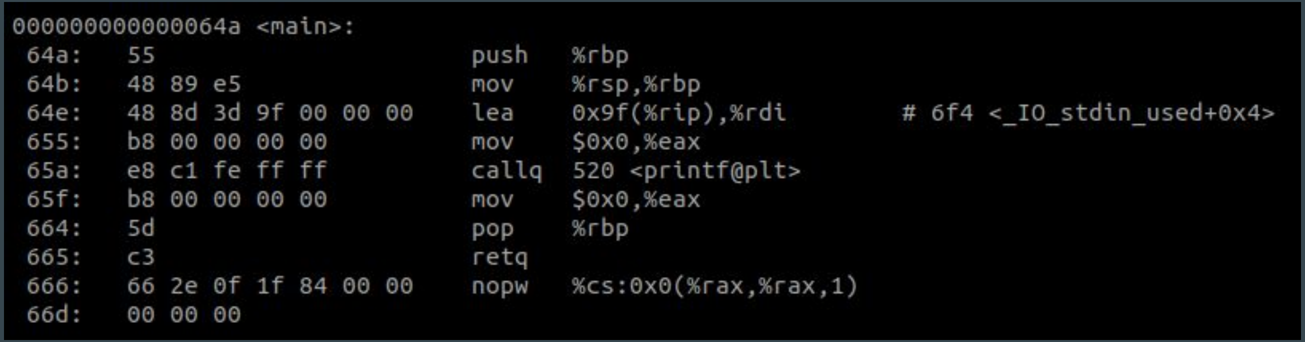
Compiler, assembler, linker



```
 ^@H<85>Àt^BÿÐH<83>Ä^HÃ^@^@^@^@^@^@^@^@ÿ5ª
 ^@ÿ%¬
 ^@^O^_@^@ÿ%ª
 ^@h^@^@^@^@éàÿÿÿÿ%Â
 ^@f<90>^@^@^@^@^@^@^@1íI<89>Ñ^H<89>âH<83>äðPTL<8d>^E<8a>^A^@^@H<8d>^M^S^A^@^@H<8d>=æ^@^@^@ÿ^Uv
 ^@ô^O^_D^@^@H<8d>=<99>
 ^@UH<8d>^E<91>
 ^@H9øH<89>åt^YH<8b>^EJ
 ^@H<85>Àt^M]ÿàf.^O^_<84>^@^@^@^@^@]Ã^O^_@^@f.^O^_<84>^@^@^@^@^@H<8d>=Y
 ^@H<8d>5R
 ^@UH)þH<89>åHÁþ^CH<89>ðHÁè?H^AÆHÑþt^XH<8b>^E^Q
 ^@H<85>Àt^L]ÿàf^O^_<84>^@^@^@^@^@]Ã^O^_@^@f.^O^_<84>^@^@^@^@^@<80>=
```

What is binary

Disassembler

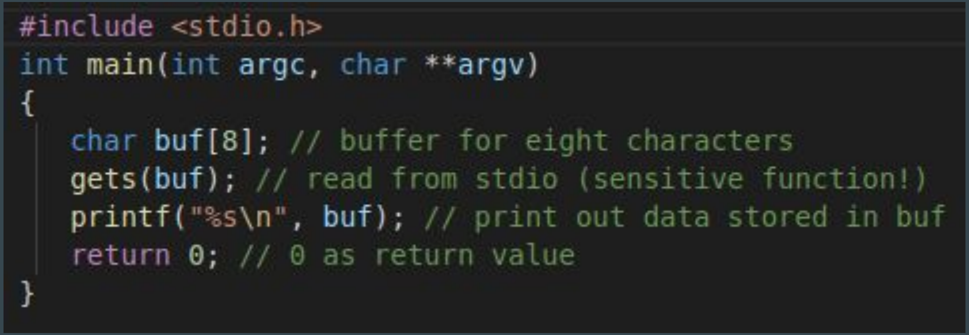


```
0000000000000064a <main>:
 64a:   55                      push   %rbp
 64b:   48 89 e5                mov    %rsp,%rbp
 64e:   48 8d 3d 9f 00 00 00    lea    0x9f(%rip),%rdi        # 6f4 <_IO_stdin_used+0x4>
 655:   b8 00 00 00 00          mov    $0x0,%eax
 65a:   e8 c1 fe ff ff          callq  520 <printf@plt>
 65f:   b8 00 00 00 00          mov    $0x0,%eax
 664:   5d                      pop    %rbp
 665:   c3                      retq
 666:   66 2e 0f 1f 84 00 00    nopw   %cs:0x0(%rax,%rax,1)
 66d:   00 00 00
```

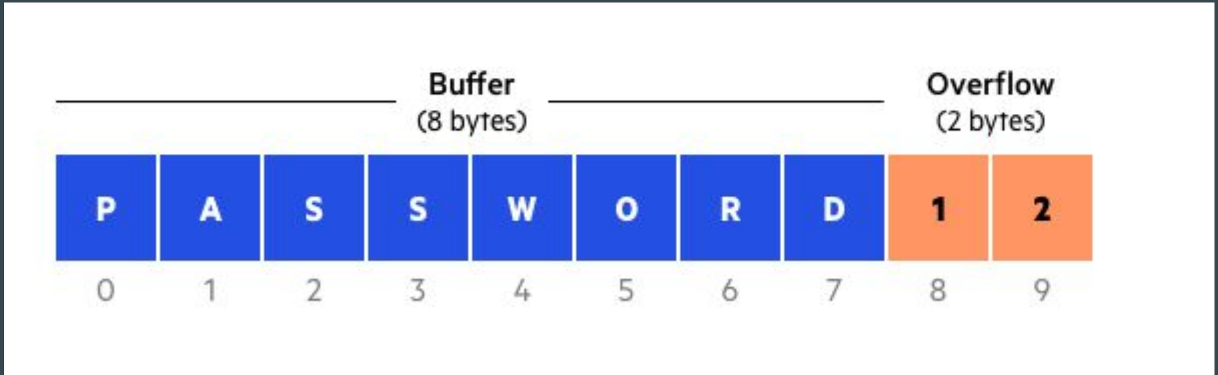
What could possibly go wrong?

- Vulnerabilities
    - Buffer overflow
    - Format string
    - Integer overflow
    - Race condition
    - Dangling pointer
    - Etc
- Malware
    - Info stealer
    - Rootkits
    - etc

Buffer Overflow



```c
#include <stdio.h>
int main(int argc, char **argv)
{
    char buf[8]; // buffer for eight characters
    gets(buf); // read from stdio (sensitive function!)
    printf("%s\n", buf); // print out data stored in buf
    return 0; // 0 as return value
}
```

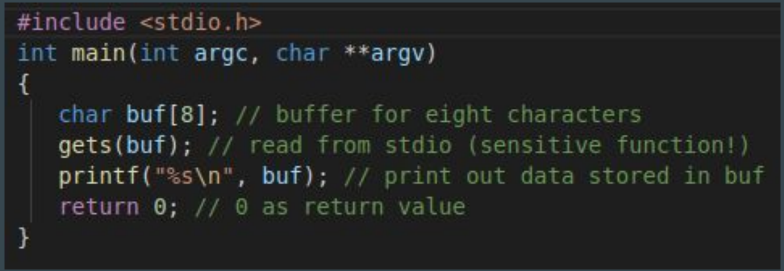


Buffer
(8 bytes)

Overflow
(2 bytes)

P	A	S	S	W	O	R	D	1	2
0	1	2	3	4	5	6	7	8	9

Buffer Overflow



```c
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int main(int argc, char **argv)
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    printf("%s\n", buf); // print out data stored in buf
    return 0; // 0 as return value
}
```
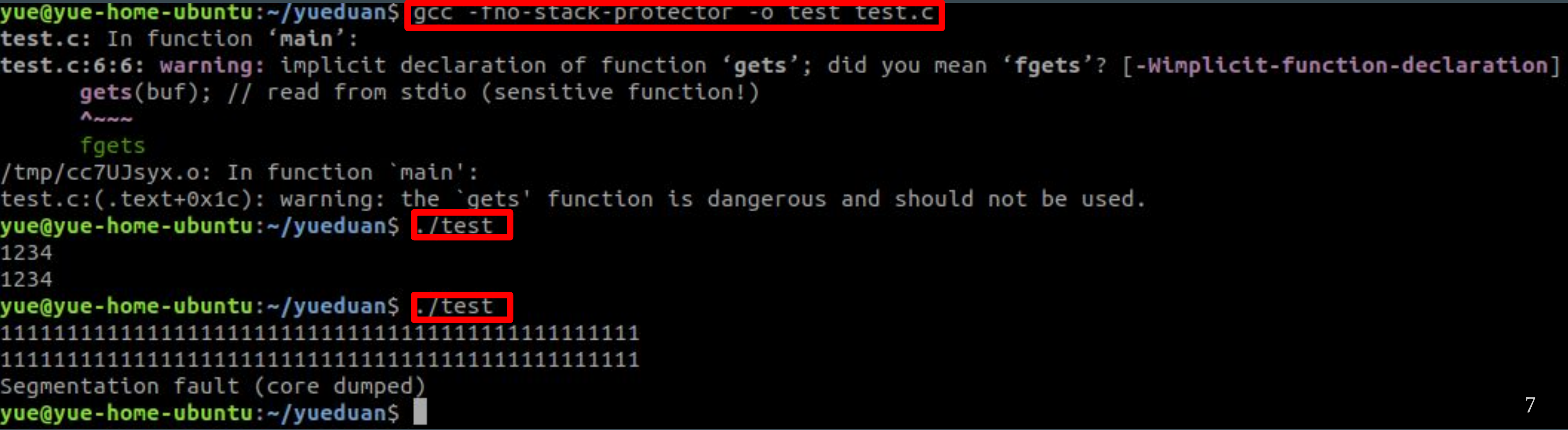
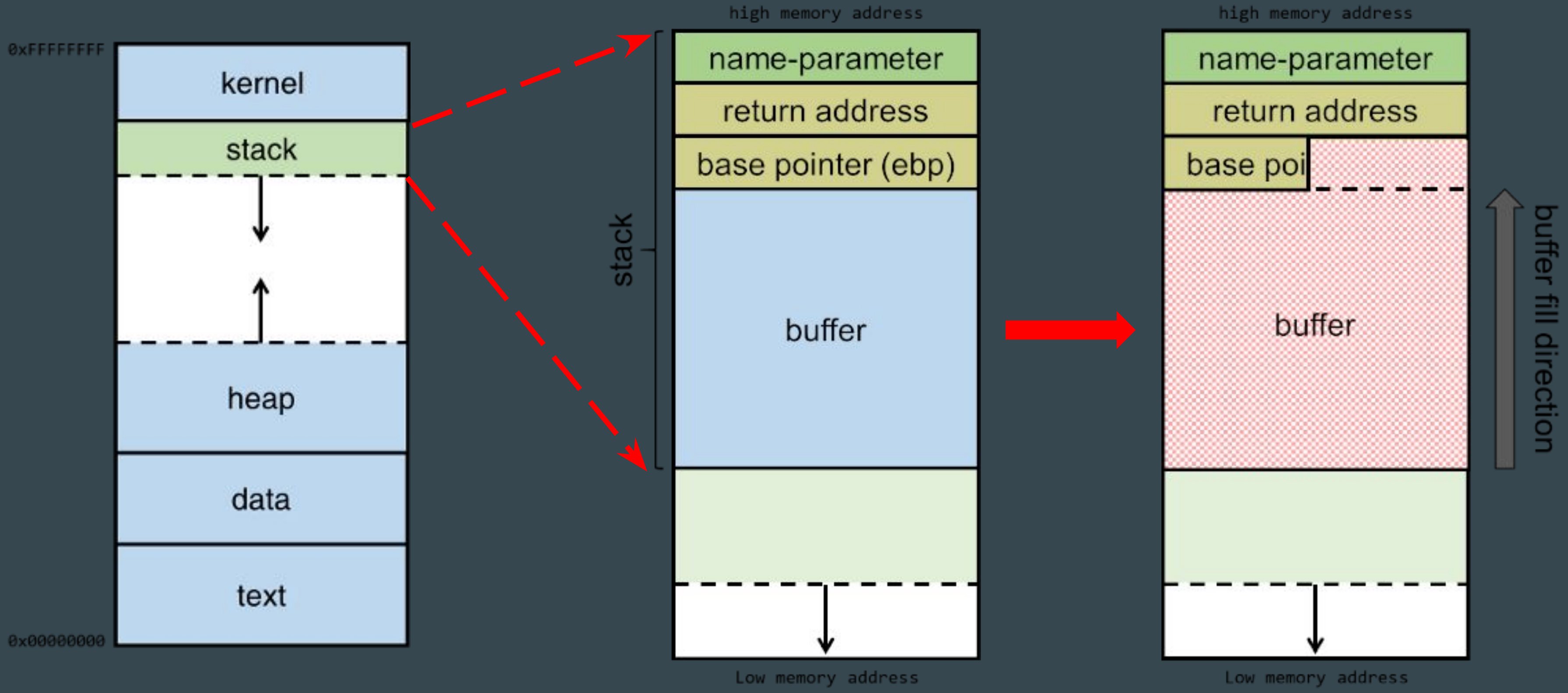
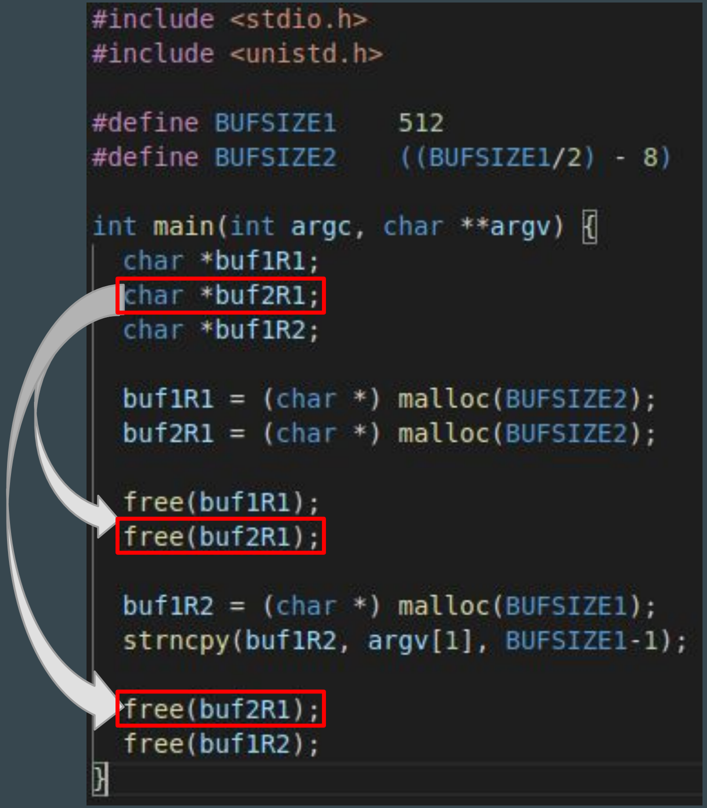



```
yue@yue-home-ubuntu:~/yueduan$ gcc -fno-stack-protector -o test test.c
test.c: In function ‘main’:
test.c:6:6: warning: implicit declaration of function ‘gets’; did you mean ‘fgets’? [-Wimplicit-function-declaration]
      gets(buf); // read from stdio (sensitive function!)
      ^~~~
      fgets
/tmp/cc7UJsyx.o: In function `main':
test.c:(.text+0x1c): warning: the `gets' function is dangerous and should not be used.
yue@yue-home-ubuntu:~/yueduan$ ./test
1234
1234
yue@yue-home-ubuntu:~/yueduan$ ./test
111111111111111111111111111111111111111111111111
111111111111111111111111111111111111111111111111
Segmentation fault (core dumped)
yue@yue-home-ubuntu:~/yueduan$ 
```

Buffer Overflow



double-free



```
#include <stdio.h>
#include <unistd.h>

#define BUFSIZE1    512
#define BUFSIZE2    ((BUFSIZE1/2) - 8)

int main(int argc, char **argv) {
  char *buf1R1;
  char *buf2R1;
  char *buf1R2;

  buf1R1 = (char *) malloc(BUFSIZE2);
  buf2R1 = (char *) malloc(BUFSIZE2);

  free(buf1R1);
  free(buf2R1);

  buf1R2 = (char *) malloc(BUFSIZE1);
  strncpy(buf1R2, argv[1], BUFSIZE1-1);

  free(buf2R1);
  free(buf1R2);
}
```

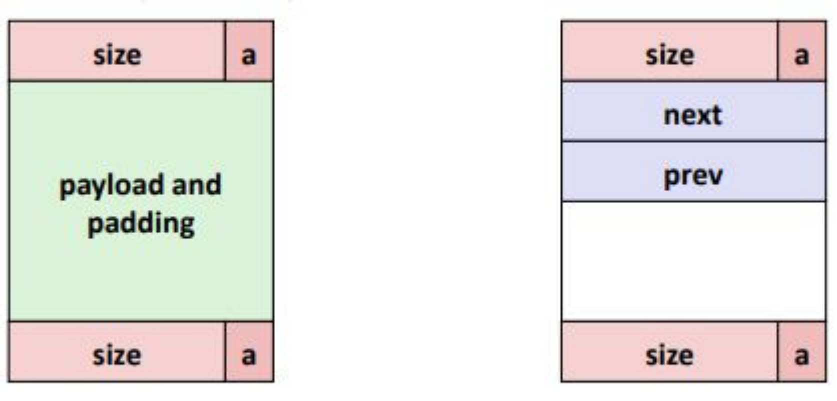
- Calling free() twice on the same value can lead to memory leak.
- When a program calls free() twice with the same argument, the program’s memory management data structures become corrupted and could allow a malicious user to write values in arbitrary memory spaces.

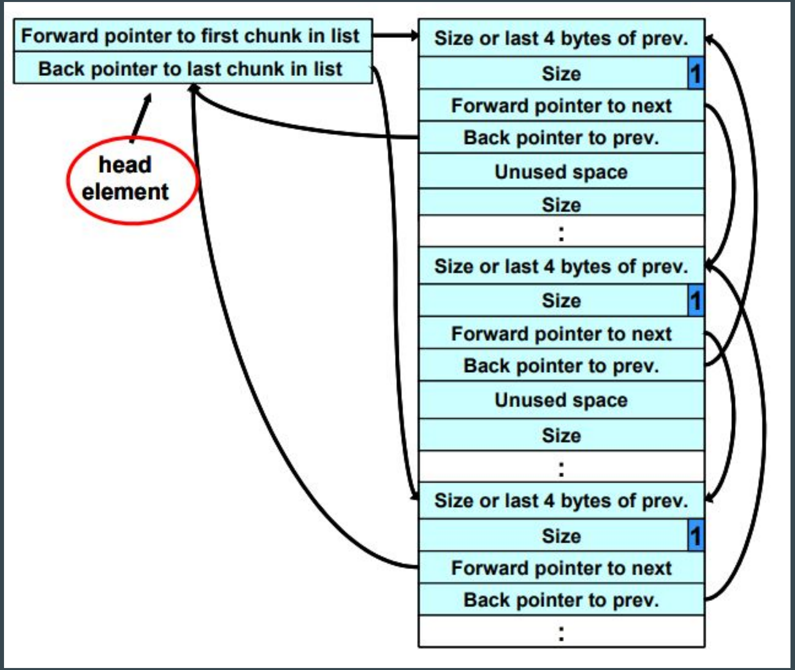
double-free

- Free chunks (memory chunks called by free()) are organized into circular double-linked lists (called bins)

Allocated chunk

free chunk

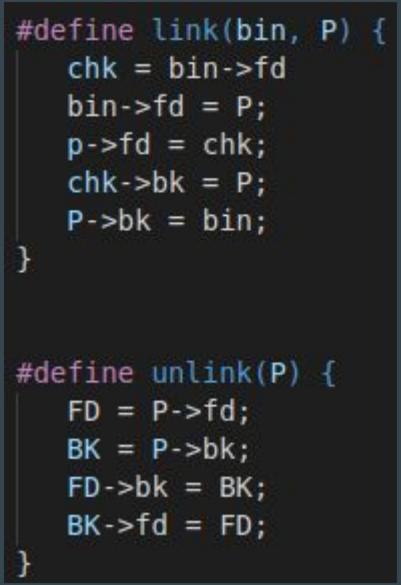




double-free

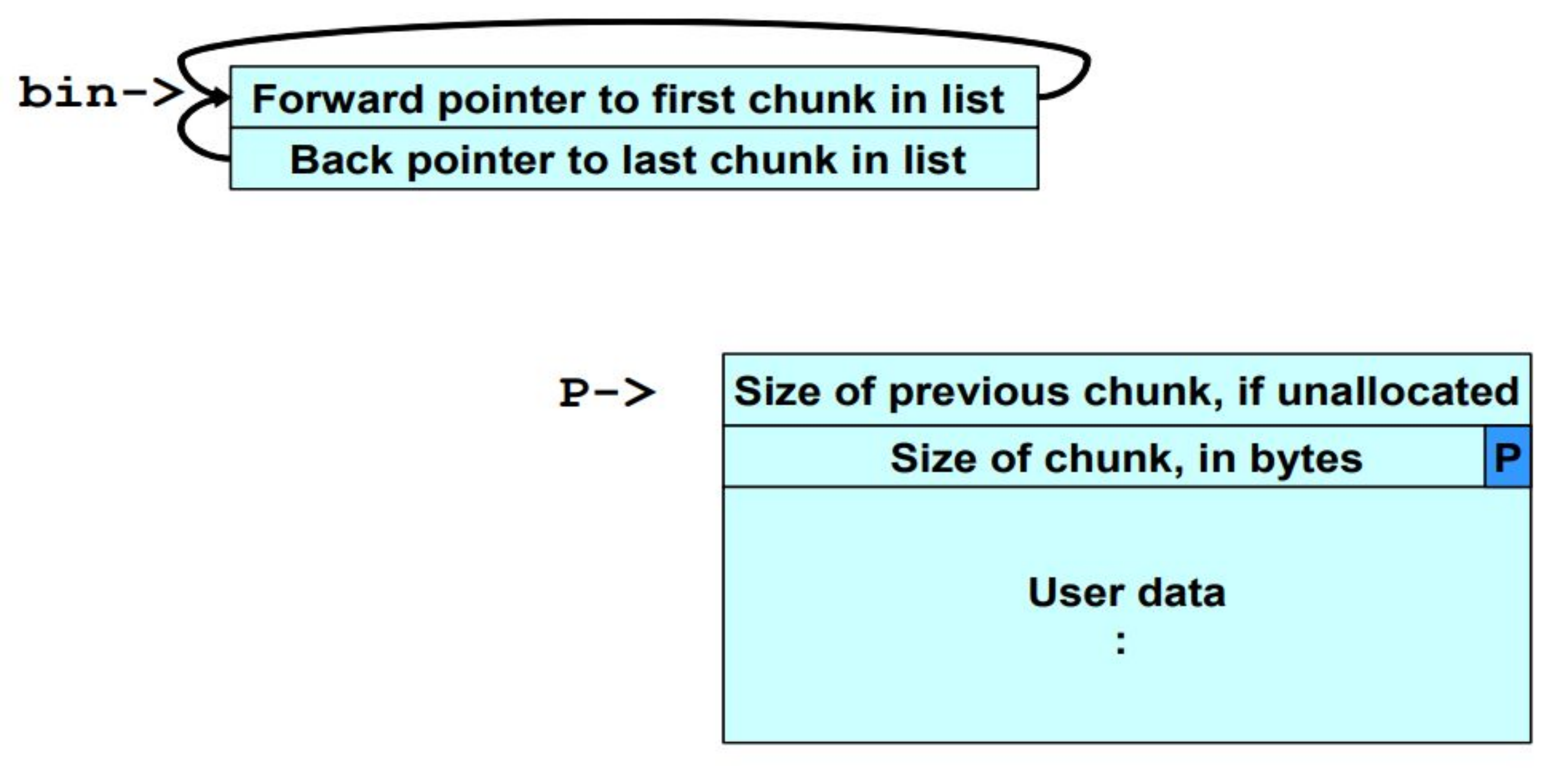
- link(): add chunk to the free list

- unlink(): remove chunk from the free list



```
#define link(bin, P) {
    chk = bin->fd
    bin->fd = P;
    p->fd = chk;
    chk->bk = P;
    P->bk = bin;
}


#define unlink(P) {
    FD = P->fd;
    BK = P->bk;
    FD->bk = BK;
    BK->fd = FD;
}
```

double-free



bin->

Forward pointer to first chunk in list

Back pointer to last chunk in list

P->

Size of previous chunk, if unallocated

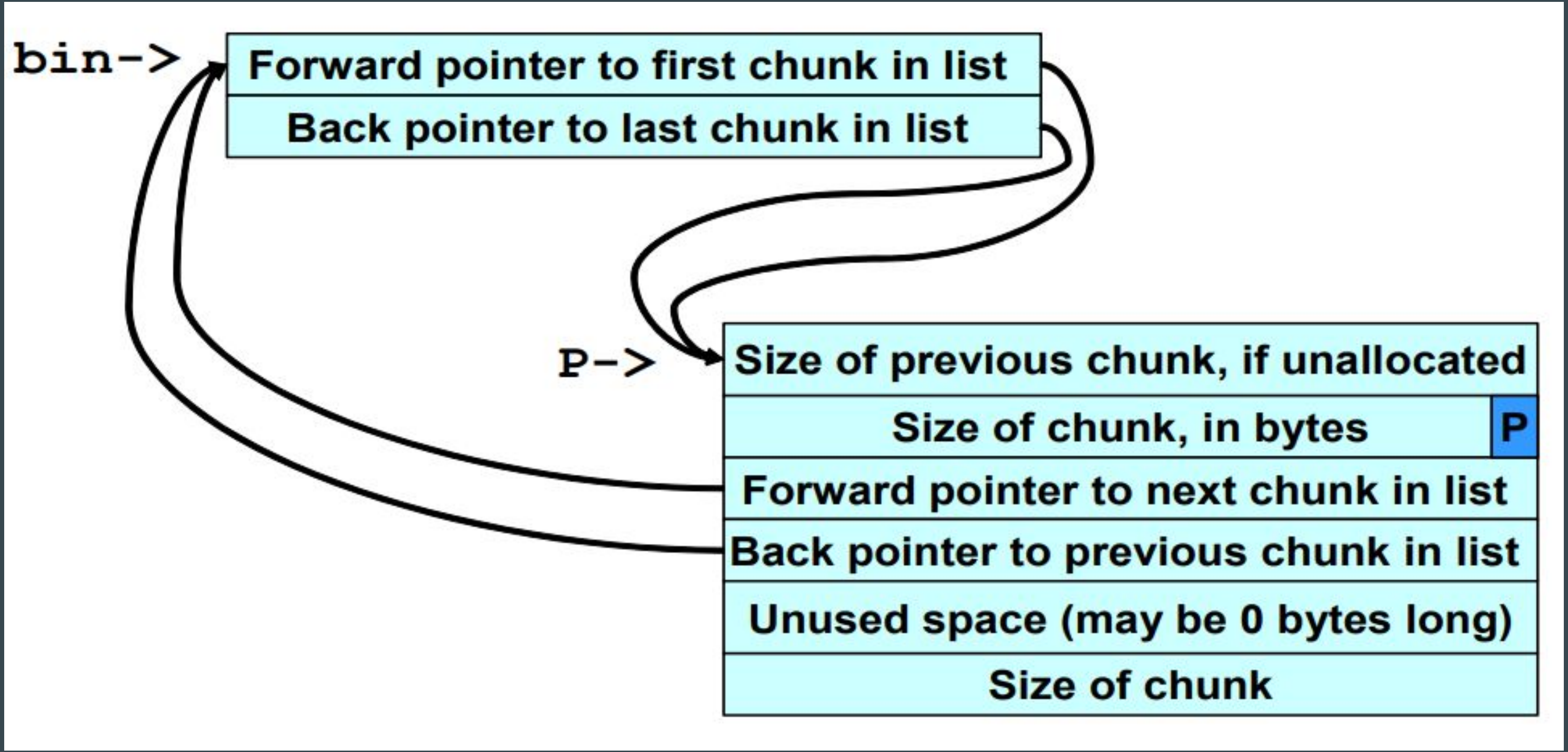
Size of chunk, in bytes

P

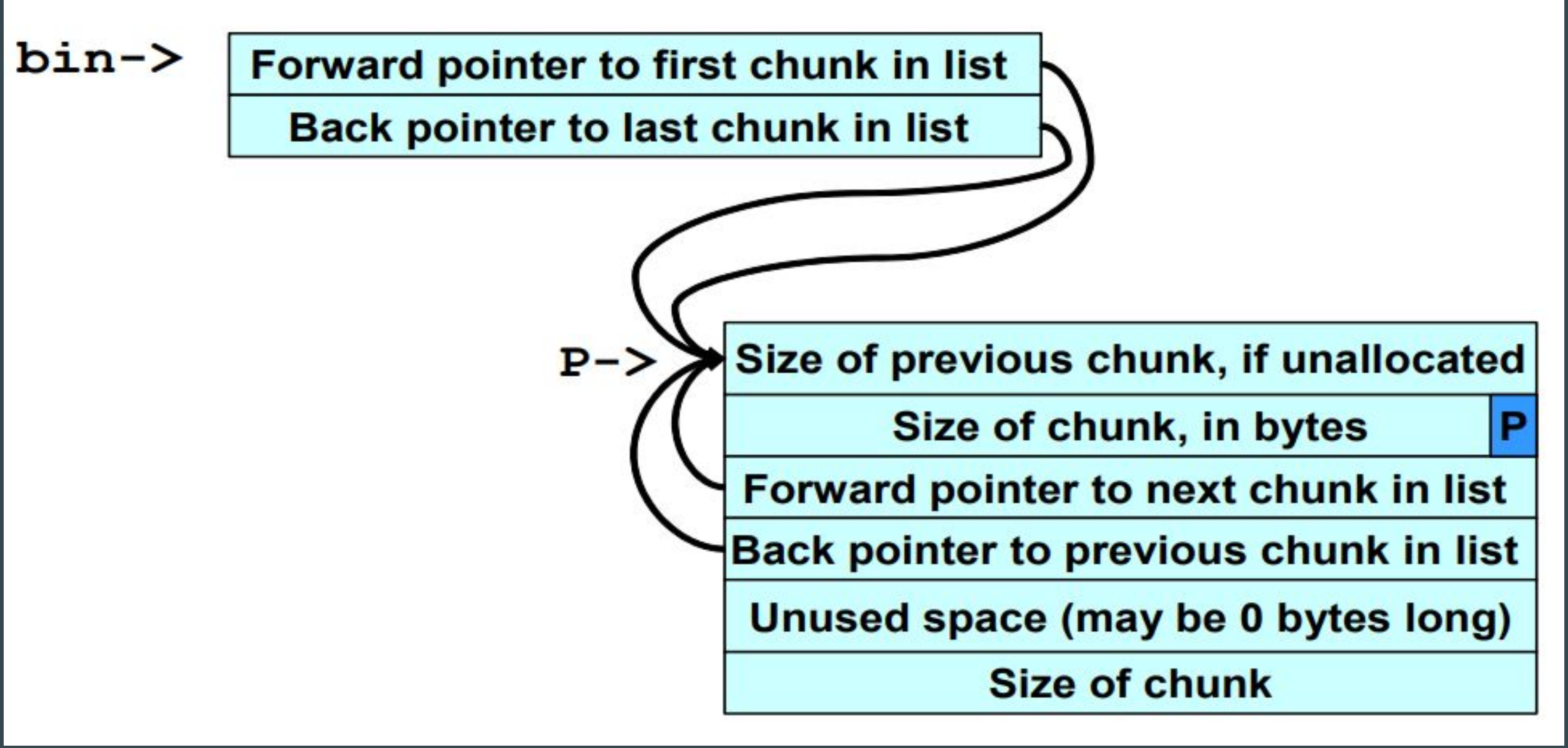
User data

:

after first call to free()

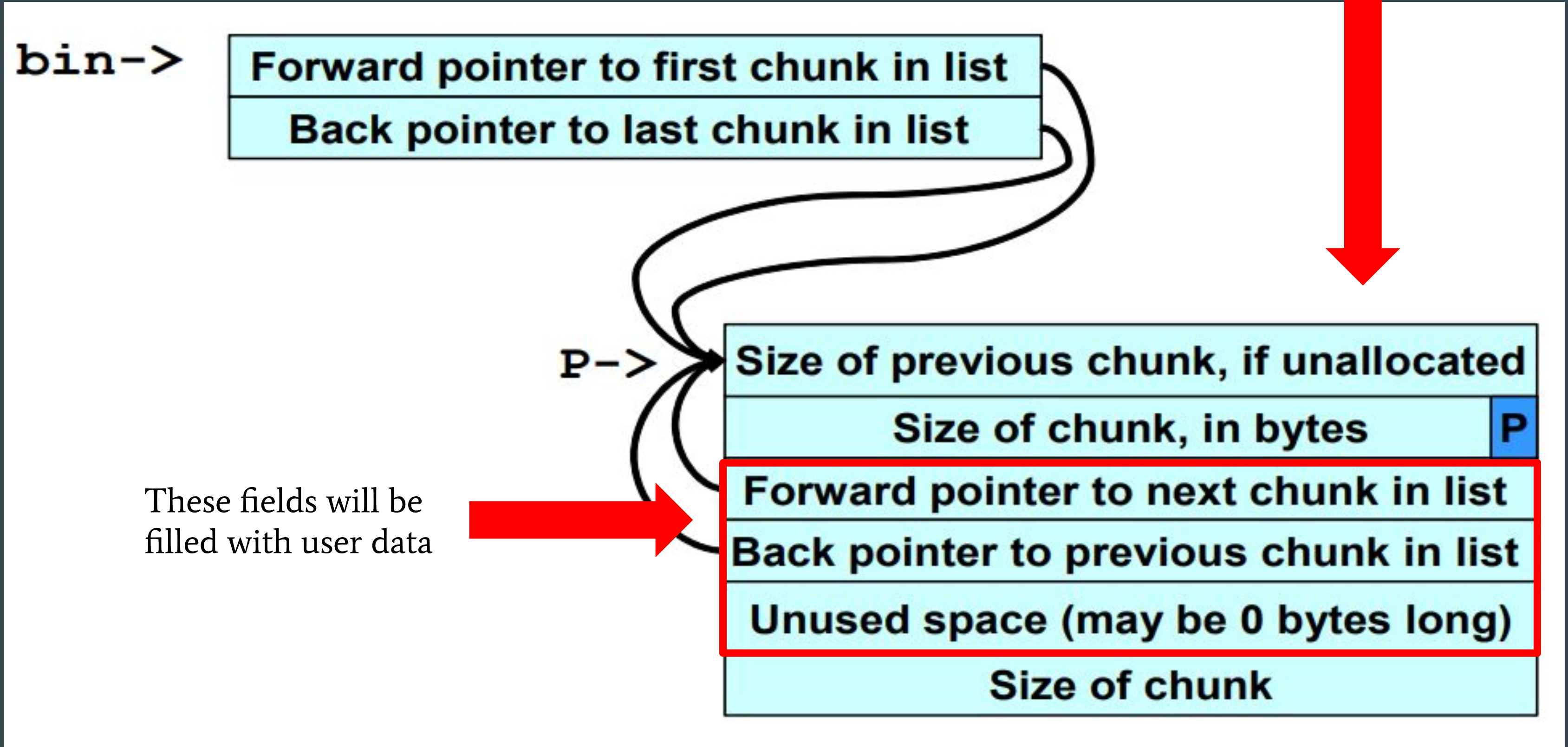

bin->
Forward pointer to first chunk in list
Back pointer to last chunk in list
P->
Size of previous chunk, if unallocated
Size of chunk, in bytes
P
Forward pointer to next chunk in list
Back pointer to previous chunk in list
Unused space (may be 0 bytes long)
Size of chunk

after second call to free()


bin->
Forward pointer to first chunk in list
Back pointer to last chunk in list
P->
Size of previous chunk, if unallocated
Size of chunk, in bytes
P
Forward pointer to next chunk in list
Back pointer to previous chunk in list
Unused space (may be 0 bytes long)
Size of chunk

Then if a malloc() is called

This chunk will still be here. Why?



Forward pointer to first chunk in list

Back pointer to last chunk in list

Size of previous chunk, if unallocated

Size of chunk, in bytes

Forward pointer to next chunk in list

Back pointer to previous chunk in list

Unused space (may be 0 bytes long)

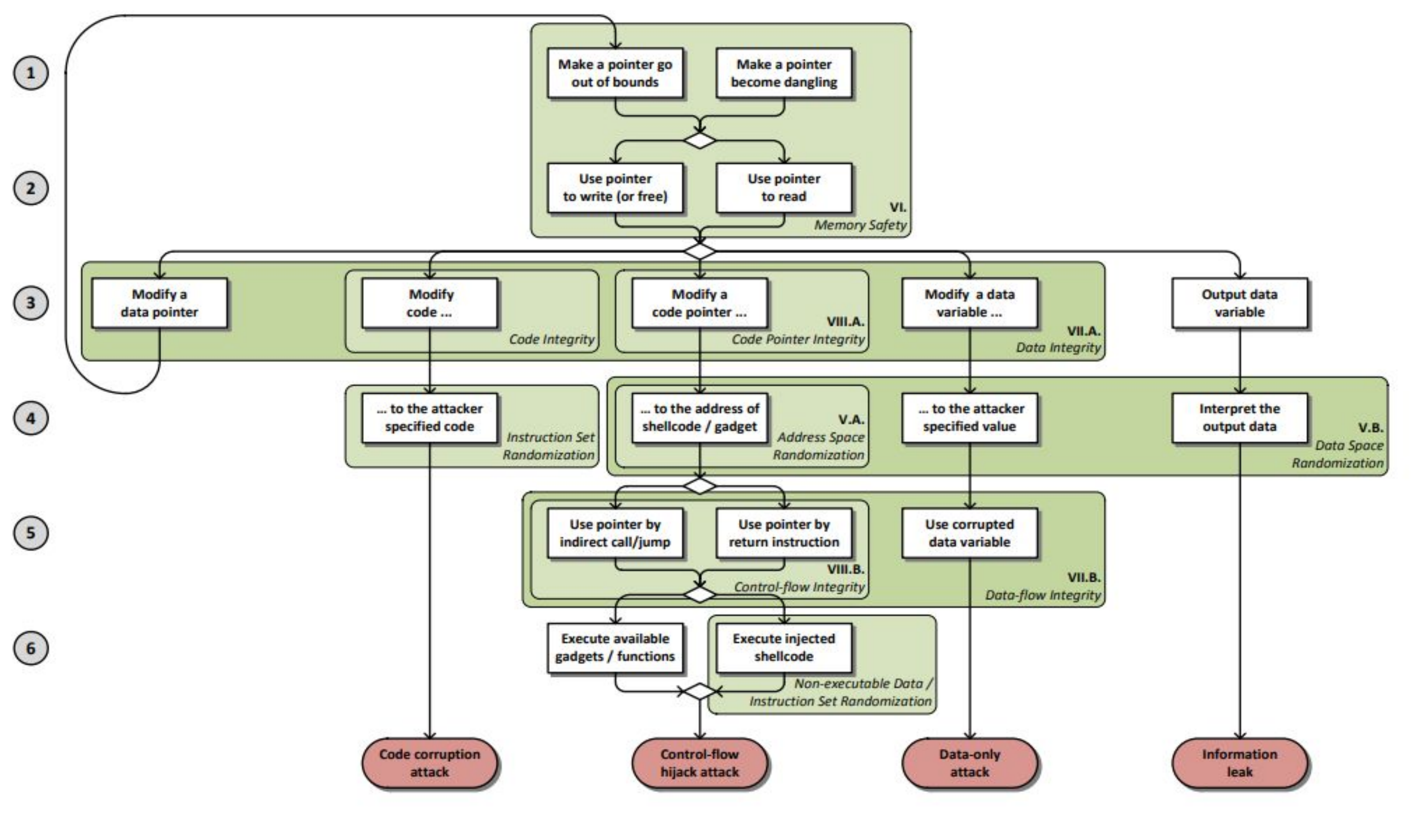
Size of chunk

These fields will be filled with user data

What if another malloc() is called?

What will happen?

Binary Analysis: vulnerability


1
2
3
4
5
6
Make a pointer go out of bounds
Make a pointer become dangling
Use pointer to write (or free)
Use pointer to read
VI.
Memory Safety
Modify a data pointer
Modify code ...
Code Integrity
Modify a code pointer ...
VIII.A.
Code Pointer Integrity
Modify a data variable ...
VII.A.
Data Integrity
Output data variable
... to the attacker specified code
Instruction Set Randomization
... to the address of shellcode / gadget
V.A.
Address Space Randomization
... to the attacker specified value
Interpret the output data
V.B.
Data Space Randomization
Use pointer by indirect call/jump
Use pointer by return instruction
VIII.B.
Control-flow Integrity
Use corrupted data variable
VII.B.
Data-flow Integrity
Execute available gadgets / functions
Execute injected shellcode
Non-executable Data / Instruction Set Randomization
Code corruption attack
Control-flow hijack attack
Data-only attack
Information leak

Binary Analysis: vulnerability

- How to detect vulnerabilities within binaries
    - Static approaches
        - Good code coverage
        - False positive
        - Disassembling can be hard
    - Dynamic approaches
        - Limited code coverage
    - Code search

- How to exploit vulnerabilities?
    - Automatic exploit generation

Binary Analysis: malware analysis

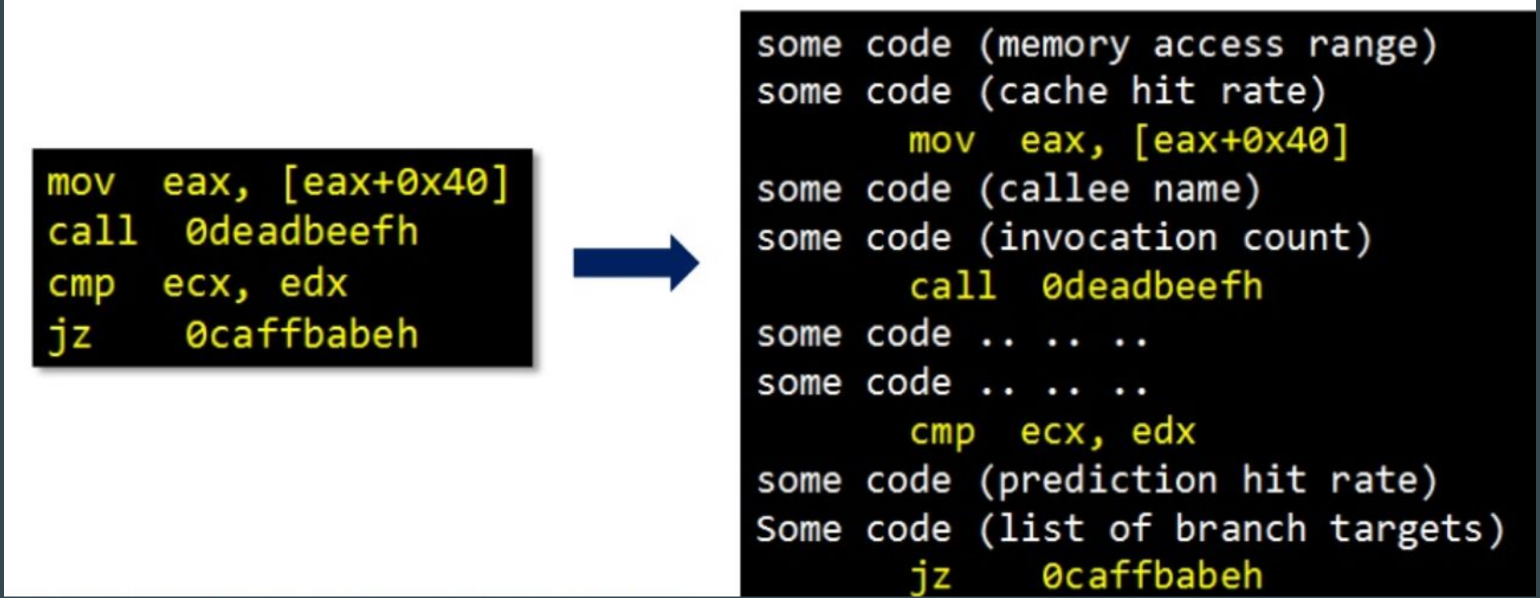
- Static approaches
  - Usually do not work well
  - Packing techniques

- Dynamic approaches
  - Dynamic code instrumentation
  - Whole-system emulation
  - Taint analysis
  - Anti-debugging techniques

Binary Analysis: malware analysis

Dynamic code instrumentation:

- Insert code during execution and change the behavior of original code



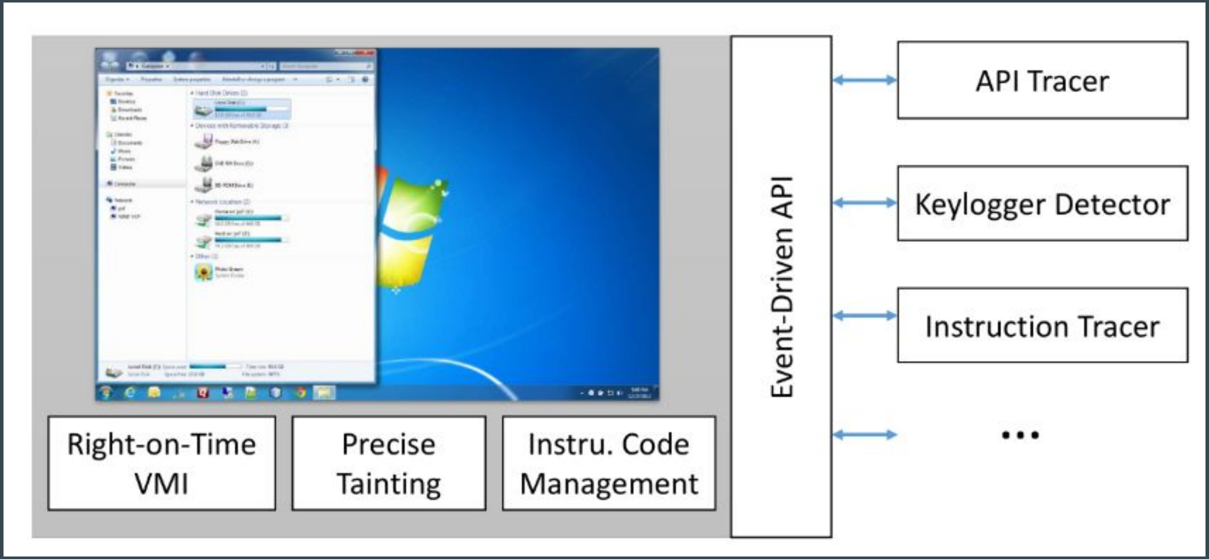
```
mov   eax, [eax+0x40]
call   0deadbeefh
cmp   ecx, edx
jz     0caffbabeh
```

```
some code (memory access range)
some code (cache hit rate)
       mov   eax, [eax+0x40]
some code (callee name)
some code (invocation count)
       call   0deadbeefh
some code .. .. ..
some code .. .. ..
       cmp   ecx, edx
some code (prediction hit rate)
Some code (list of branch targets)
       jz     0caffbabeh
```

Binary Analysis: malware analysis

Whole-system emulation:

- Run malware within the VM
- Observe behaviors from the outside
- Demo



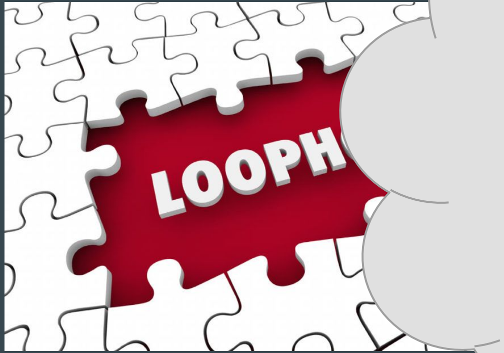
Binary Analysis: defense mechanisms

- StackGuard

- Control-flow integrity

- Data-flow integrity

Binary analysis: code search



How do you find a known vulnerability in 1,000,000 programs?

Question?