Cyber Security

Software security

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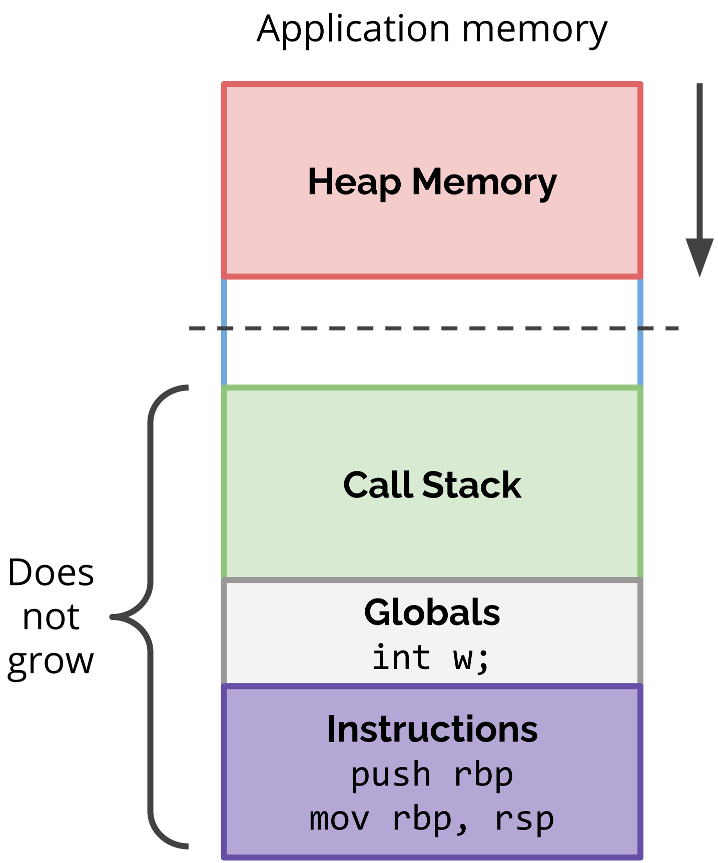
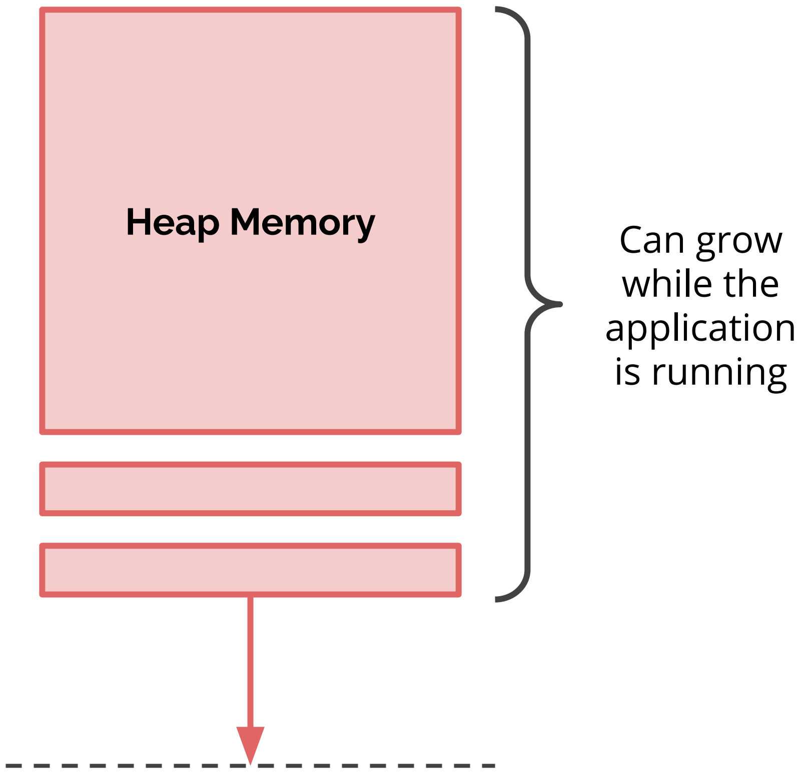
Recap


Application memory
Heap Memory
Call Stack
Globals
int w;
Instructions
push rbp
mov rbp, rsp
Does
not
grow


Heap Memory
Can grow
while the
application
is running

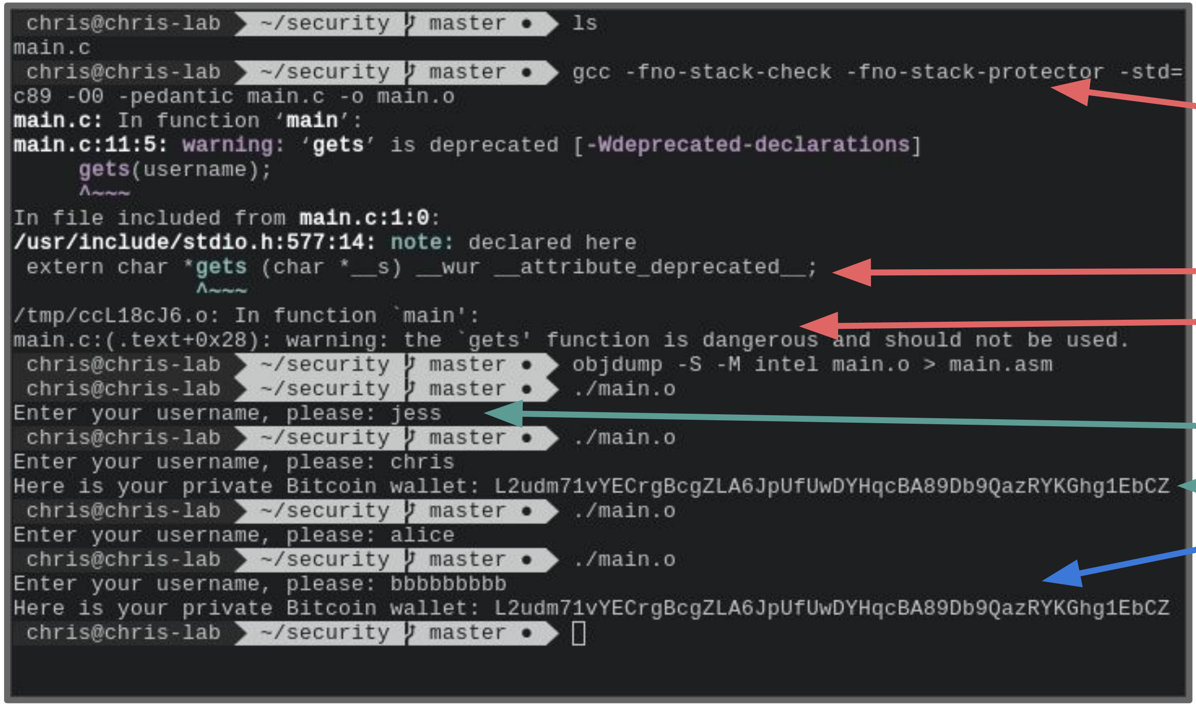
Buffer Overflows

- When writing data to a buffer, you overrun into adjacent memory locations
- Often results in a crash, but sometimes can be exploited for other malicious behaviour, such as gaining elevated privileges
- Can occur on the stack:
  - **Stack smashing**
- Can occur on the heap:
  - **Heap overflow**

Buffer Overflows

```
#include <stdio.h>

int main ()
{
   int allow;
   char username[8];

   allow = 0;

   printf("Enter your username, please: ");
   gets(username);

   if (strcmp(username, "chris") == 0)
       allow = 1;

   if (allow)
       printf("Here is your private Bitcoin wallet: L2udm71vYECrgBcgZLA6JpUfUwDYHqcBA89Db9QazRYKGhg1EbCZ\n");

   return 0;
}
```

Buffer Overflows



```
chris@chris-lab  ~/security  master ●  ls
main.c
chris@chris-lab  ~/security  master ●  gcc -fno-stack-check -fno-stack-protector -std=
c89 -O0 -pedantic main.c -o main.o
main.c: In function 'main':
main.c:11:5: warning: 'gets' is deprecated [-Wdeprecated-declarations]
     gets(username);
     ^~~~
In file included from main.c:1:0:
/usr/include/stdio.h:577:14: note: declared here
 extern char *gets (char *__s) __wur __attribute_deprecated__;
              ^~~~
/tmp/ccL18cJ6.o: In function `main':
main.c:(.text+0x28): warning: the `gets' function is dangerous and should not be used.
chris@chris-lab  ~/security  master ●  objdump -S -M intel main.o > main.asm
chris@chris-lab  ~/security  master ●  ./main.o
Enter your username, please: jess
chris@chris-lab  ~/security  master ●  ./main.o
Enter your username, please: chris
Here is your private Bitcoin wallet: L2udm71vYECrgBcgZLA6JpUfUwDYHqcBA89Db9QazRYKGhg1EbCZ
chris@chris-lab  ~/security  master ●  ./main.o
Enter your username, please: alice
chris@chris-lab  ~/security  master ●  ./main.o
Enter your username, please: bbbbbbbbb
Here is your private Bitcoin wallet: L2udm71vYECrgBcgZLA6JpUfUwDYHqcBA89Db9QazRYKGhg1EbCZ
chris@chris-lab  ~/security  master ● 
```

Lots of modern checks

- Using a patched gcc which forces stack protection by default
- Deprecated APIs
- Helpful warnings

- `jess` can't login
- `chris` <u>can</u> login
- .. but so can $\underbrace{\textbf{bbbbbbbb}}_{8}$**b**

Buffer Overflows

```
000000000000072a <main>:
72a:    55                      push   rbp
72b:    48 89 e5                mov    rbp,rsp
72e:    48 83 ec 10             sub    rsp,0x10
732:    c7 45 fc 00 00 00 00    mov    DWORD PTR [rbp-0x4],0x0
739:    48 8d 3d d8 00 00 00    lea    rdi,[rip+0xd8]
740:    b8 00 00 00 00          mov    eax,0x0
745:    e8 a6 fe ff ff          call   5f0 <printf@plt>
74a:    48 8d 45 f4             lea    rax,[rbp-0xc]
74e:    48 89 c7                mov    rdi,rax
751:    e8 ba fe ff ff          call   610 <gets@plt>
756:    48 8d 45 f4             lea    rax,[rbp-0xc]
75a:    48 8d 35 d5 00 00 00    lea    rsi,[rip+0xd5]
761:    48 89 c7                mov    rdi,rax
764:    e8 97 fe ff ff          call   600 <strcmp@plt>
769:    85 c0                   test   eax,eax
76b:    75 07                   jne    774 <main+0x4a>
76d:    c7 45 fc 01 00 00 00    mov    DWORD PTR [rbp-0x4],0x1
774:    83 7d fc 00             cmp    DWORD PTR [rbp-0x4],0x0
778:    74 0c                   je     786 <main+0x5c>
77a:    48 8d 3d bf 00 00 00    lea    rdi,[rip+0xbf]
781:    e8 5a fe ff ff          call   5e0 <puts@plt>
786:    b8 00 00 00 00          mov    eax,0x0
78b:    c9                      leave
78c:    c3                      ret
78d:    0f 1f 00                nop    DWORD PTR [rax]
```

```c
#include <stdio.h>

int main ()
{
    int allow;
    char username[8];

    allow = 0;

    printf("Enter your username, please: ");
    gets(username);

    if (strcmp(username, "chris") == 0)
        allow = 1;

    if (allow)
        printf("Here is your private Bitcoin wallet: ...");

    return 0;
}
```

Buffer Overflows

```
000000000000072a <main>:
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764:   e8 97 fe ff ff          call   600 <strcmp@plt>
769:   85 c0                   test   eax,eax
76b:   75 07                   jne    774 <main+0x4a>
76d:   c7 45 fc 01 00 00 00    mov    DWORD PTR [rbp-0x4],0x1
774:   83 7d fc 00             cmp    DWORD PTR [rbp-0x4],0x0
778:   74 0c                   je     786 <main+0x5c>
77a:   48 8d 3d bf 00 00 00    lea    rdi,[rip+0xbf]
781:   e8 5a fe ff ff          call   5e0 <puts@plt>
786:   b8 00 00 00 00          mov    eax,0x0
78b:   c9                      leave
78c:   c3                      ret
78d:   0f 1f 00                nop    DWORD PTR [rax]
```

16 byte stack frame

```c
#include <stdio.h>

int main ()
{
   int allow;
   char username[8];

   allow = 0;

   printf("Enter your username, please: ");
   gets(username);

   if (strcmp(username, "chris") == 0)
       allow = 1;

   if (allow)
       printf("Here is your private Bitcoin wallet: ...");

   return 0;
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Buffer Overflows

```
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751:   e8 ba fe ff ff          call   610 <gets@plt>
756:   48 8d 45 f4             lea    rax,[rbp-0xc]
75a:   48 8d 35 d5 00 00 00    lea    rsi,[rip+0xd5]
761:   48 89 c7                mov    rdi,rax
764:   e8 97 fe ff ff          call   600 <strcmp@plt>
769:   85 c0                   test   eax,eax
76b:   75 07                   jne    774 <main+0x4a>
76d:   c7 45 fc 01 00 00 00    mov    DWORD PTR [rbp-0x4],0x1
774:   83 7d fc 00             cmp    DWORD PTR [rbp-0x4],0x0
778:   74 0c                   je     786 <main+0x5c>
77a:   48 8d 3d bf 00 00 00    lea    rdi,[rip+0xbf]
781:   e8 5a fe ff ff          call   5e0 <puts@plt>
786:   b8 00 00 00 00          mov    eax,0x0
78b:   c9                      leave
78c:   c3                      ret
78d:   0f 1f 00                nop    DWORD PTR [rax]
```

```c
#include <stdio.h>

int main ()
{
   int allow;
   char username[8];

   allow = 0;

   printf("Enter your username, please: ");
   gets(username);

   if (strcmp(username, "chris") == 0)
       allow = 1;

   if (allow)
       printf("Here is your private Bitcoin wallet: ...");

   return 0;
}
```

Buffer Overflows

```
000000000000072a <main>:
72a:   55                      push   rbp
72b:   48 89 e5                mov    rbp,rsp
72e:   48 83 ec 10             sub    rsp,0x10
732:   c7 45 fc 00 00 00 00    mov    DWORD PTR [rbp-0x4],0x0
739:   48 8d 3d d8 00 00 00    lea    rdi,[rip+0xd8] # 818
740:   b8 00 00 00 00          mov    eax,0x0
745:   e8 a6 fe ff ff          call   5f0 <printf@plt>
74a:   48 8d 45 f4             lea    rax,[rbp-0xc]
74e:   48 89 c7                mov    rdi,rax
751:   e8 ba fe ff ff          call   610 <gets@plt>
756:   48 8d 45 f4             lea    rax,[rbp-0xc]
75a:   48 8d 35 d5 00 00 00    lea    rsi,[rip+0xd5] # 836
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774:   83 7d fc 00             cmp    DWORD PTR [rbp-0x4],0x0
778:   74 0c                   je     786 <main+0x5c>
77a:   48 8d 3d bf 00 00 00    lea    rdi,[rip+0xbf] # 840
781:   e8 5a fe ff ff          call   5e0 <puts@plt>
786:   b8 00 00 00 00          mov    eax,0x0
78b:   c9                      leave
78c:   c3                      ret
78d:   0f 1f 00                nop    DWORD PTR [rax]
```

Pointers to string data

```c
#include <stdio.h>

int main ()
{
   int allow;
   char username[8];

   allow = 0;

   printf("Enter your username, please: ");
   gets(username);

   if (strcmp(username, "chris") == 0)
       allow = 1;

   if (allow)
       printf("Here is your private Bitcoin wallet: ...");

   return 0;
}
```

Buffer Overflows

```
000000000000072a <main>:
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76b:   75 07                   jne    774 <main+0x4a>
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774:   83 7d fc 00             cmp    DWORD PTR [rbp-0x4],0x0
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```

.text (code segment) stores program instructions
.data segment stores global variables, static local variables
.rodata read-only data segment stores static constants

```
chris@chris-lab  ~/security  master ●  objdump -s -j .rodata main.o

main.o:     file format elf64-x86-64

Contents of section .rodata:
 0810 01000200 00000000 456e7465 7220796f  ........Enter yo
 0820 75722075 7365726e 616d652c 20706c65  ur username, ple
 0830 6173653a 20006368 72697300 00000000  ase: .chris.....
 0840 48657265 20697320 796f7572 20707269  Here is your pri
 0850 76617465 20426974 636f696e 2077616c  vate Bitcoin wal
 0860 6c65743a 204c3275 646d3731 76594543  let: L2udm71vYEC
 0870 72674263 675a4c41 364a7055 66557744  rgBcgZLA6JpUfUwD
 0880 59487163 42413839 44623951 617a5259  YHqcBA89Db9QazRY
 0890 4b476867 31456243 5a00               KGhg1EbCZ.
chris@chris-lab  ~/security  master ● 
```

There are a few other segments
try **`objdump -s main.o`**

Buffer Overflows

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000000000000072a <main>:
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739:   48 8d 3d d8 00 00 00    lea    rdi,[rip+0xd8] # 818
740:   b8 00 00 00 00          mov    eax,0x0
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761:   48 89 c7                mov    rdi,rax
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781:   e8 5a fe ff ff          call   5e0 <puts@plt>
786:   b8 00 00 00 00          mov    eax,0x0
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78c:   c3                      ret
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```

`.text` (code segment) stores program instructions
`.data` segment stores global variables, static local variables
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 0870 72674263 675a4c41 364a7055 66557744  rgBcgZLA6JpUfUwD
 0880 59487163 42413839 44623951 617a5259  YHqcBA89Db9QazRY
 0890 4b476867 31456243 5a00               KGhg1EbCZ.
chris@chris-lab  ~/security  master ●
```

There are a few other segments try **`objdump -s main.o`**

Buffer Overflows

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761:   48 89 c7               mov    rdi,rax
764:   e8 97 fe ff ff         call   600 <strcmp@plt>
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76b:   75 07                  jne    774 <main+0x4a>
76d:   c7 45 fc 01 00 00 00   mov    DWORD PTR [rbp-0x4],0x1
774:   83 7d fc 00            cmp    DWORD PTR [rbp-0x4],0x0
778:   74 0c                  je     786 <main+0x5c>
77a:   48 8d 3d bf 00 00 00   lea    rdi,[rip+0xbf] # 840
781:   e8 5a fe ff ff         call   5e0 <puts@plt>
786:   b8 00 00 00 00         mov    eax,0x0
78b:   c9                     leave
78c:   c3                     ret
78d:   0f 1f 00               nop    DWORD PTR [rax]
```

```c
#include <stdio.h>

int main ()
{
   int allow;
   char username[8];

   allow = 0;

   printf("Enter your username, please: ");
   gets(username);

   if (strcmp(username, "chris") == 0)
       allow = 1;

   if (allow)
       printf("Here is your private Bitcoin wallet: ...");

   return 0;
}
```

Buffer Overflows

```
000000000000072a <main>:
72a:   55                      push   rbp
72b:   48 89 e5                mov    rbp,rsp
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77a:   48 8d 3d bf 00 00 00    lea    rdi,[rip+0xbf] # 840
781:   e8 5a fe ff ff          call   5e0 <puts@plt>
786:   b8 00 00 00 00          mov    eax,0x0
78b:   c9                      leave
78c:   c3                      ret
78d:   0f 1f 00                nop    DWORD PTR [rax]
```
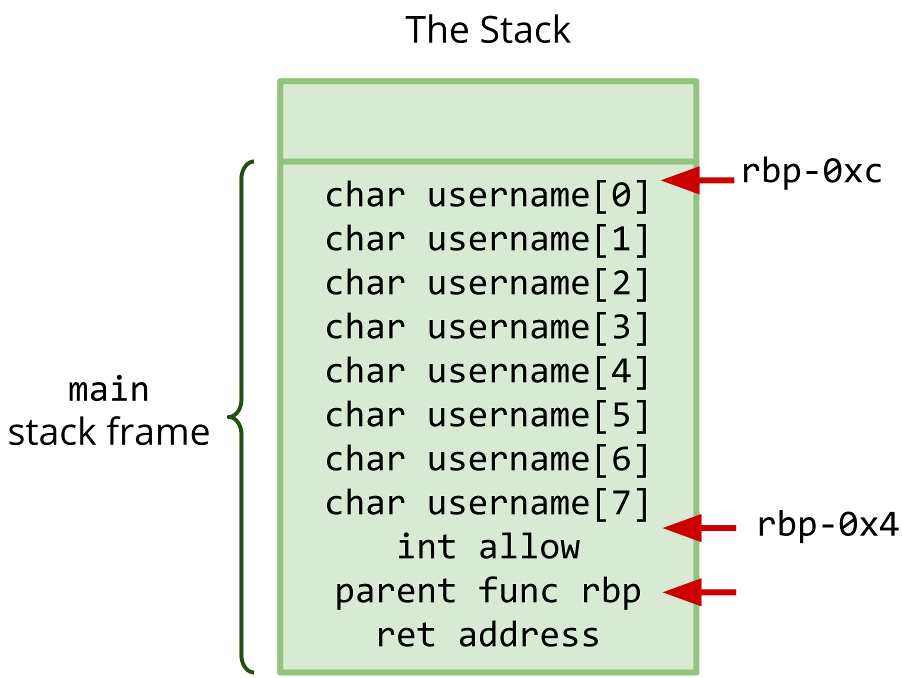

```c
#include <stdio.h>

int main ()
{
    int allow;
    char username[8];

    allow = 0;

    printf("Enter your username, please: ");
    gets(username);

    if (strcmp(username, "chris") == 0)
        allow = 1;

    if (allow)
        printf("Here is your private Bitcoin wallet: ...");

    return 0;
}
```

Buffer Overflows

Before calling **gets**, this is what the stack looks like:

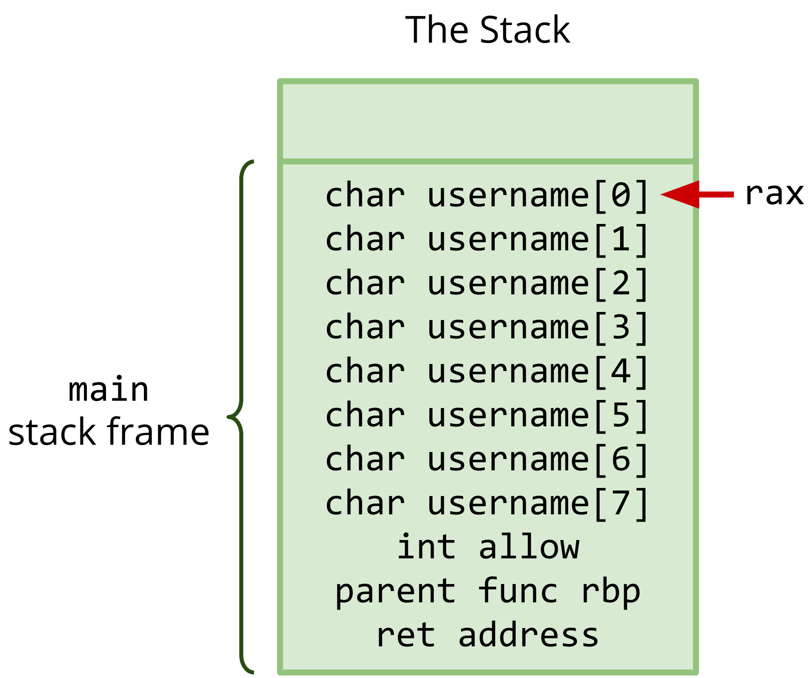
```c
#include <stdio.h>

int main ()
{
    int allow;
    char username[8];

    allow = 0;

    printf("Enter your username, please: ");
    gets(username);

    if (strcmp(username, "chris") == 0)
        allow = 1;

    if (allow)
        printf("Here is your private Bitcoin wallet: ...");

    return 0;
}
```



Buffer Overflows

gets then fetches data into the address specified by **rax** without considering the bounds of the buffer it is putting it into…

```c
#include <stdio.h>

int main ()
{
   int allow;
   char username[8];

   allow = 0;

   printf("Enter your username, please: ");
   gets(username);

   if (strcmp(username, "chris") == 0)
       allow = 1;

   if (allow)
       printf("Here is your private Bitcoin wallet: ...");

   return 0;
}
```



Buffer Overflows

For example: "**`jess`**"

```c
#include <stdio.h>

int main ()
{
    int allow;
    char username[8];

    allow = 0;

    printf("Enter your username, please: ");
    gets(username);

    if (strcmp(username, "chris") == 0)
        allow = 1;

    if (allow)
        printf("Here is your private Bitcoin wallet: ...");

    return 0;
}
```

main stack frame

The Stack	ASCII	Decimal
char username[0]	j	106
char username[1]	e	101
char username[2]	s	115
char username[3]	s	115
char username[4]	�	0
char username[5]	�	0
char username[6]	�	0
char username[7]	�	0
int allow	0	0
parent func rbp		-231
ret address		-532

Buffer Overflows

What about the string: “**abcd1234f**”

```c
#include <stdio.h>

int main ()
{
   int allow;
   char username[8];

   allow = 0;

   printf("Enter your username, please: ");
   gets(username);

   if (strcmp(username, "chris") == 0)
       allow = 1;

   if (allow)
       printf("Here is your private Bitcoin wallet: ...");

   return 0;
}
```

main stack frame

The Stack	ASCII	Decimal
char username[0]	�	0
char username[1]	�	0
char username[2]	�	0
char username[3]	�	0
char username[4]	�	0
char username[5]	�	0
char username[6]	�	0
char username[7]	�	0
int allow	0	0
parent func rbp		-231
ret address		-532

Buffer Overflows

What about the string: "**abcd1234f**"

```c
#include <stdio.h>

int main ()
{
   int allow;
   char username[8];

   allow = 0;

   printf("Enter your username, please: ");
   gets(username);

   if (strcmp(username, "chris") == 0)
       allow = 1;

   if (allow)
       printf("Here is your private Bitcoin wallet: ...");

   return 0;
}
```

main stack frame

The Stack	ASCII	Decimal
char username[0]	a	97
char username[1]	�	0
char username[2]	�	0
char username[3]	�	0
char username[4]	�	0
char username[5]	�	0
char username[6]	�	0
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   if (allow)
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   return 0;
}
```

main stack frame

The Stack	ASCII	Decimal
char username[0]	a	97
char username[1]	b	98
char username[2]	�	0
char username[3]	�	0
char username[4]	�	0
char username[5]	�	0
char username[6]	�	0
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   if (allow)
       printf("Here is your private Bitcoin wallet: ...");

   return 0;
}
```

main stack frame

The Stack	ASCII	Decimal
char username[0]	a	97
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char username[2]	c	99
char username[3]	�	0
char username[4]	�	0
char username[5]	�	0
char username[6]	�	0
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       allow = 1;

   if (allow)
       printf("Here is your private Bitcoin wallet: ...");

   return 0;
}
```

main
stack frame

The Stack	ASCII	Decimal
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char username[1]	b	98
char username[2]	c	99
char username[3]	d	100
char username[4]	�	0
char username[5]	�	0
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   if (allow)
       printf("Here is your private Bitcoin wallet: ...");

   return 0;
}
```

main
stack frame

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char username[0]	a	97
char username[1]	b	98
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char username[3]	d	100
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        printf("Here is your private Bitcoin wallet: ...");

    return 0;
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```

main
stack frame

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char username[2]	c	99
char username[3]	d	100
char username[4]	1	49
char username[5]	2	50
char username[6]	�	0
char username[7]	�	0
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   allow = 0;

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   gets(username);

   if (strcmp(username, "chris") == 0)
       allow = 1;

   if (allow)
       printf("Here is your private Bitcoin wallet: ...");

   return 0;
}
```

main stack frame

The Stack	ASCII	Decimal
char username[0]	a	97
char username[1]	b	98
char username[2]	c	99
char username[3]	d	100
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int main ()
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    gets(username);

    if (strcmp(username, "chris") == 0)
        allow = 1;

    if (allow)
        printf("Here is your private Bitcoin wallet: ...");

    return 0;
}
```

main
stack frame

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char username[0]	a	97
char username[1]	b	98
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char username[3]	d	100
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int main ()
{
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    char username[8];

    allow = 0;

    printf("Enter your username, please: ");
    gets(username);

    if (strcmp(username, "chris") == 0)
        allow = 1;

    if (allow)
        printf("Here is your private Bitcoin wallet: ...");

    return 0;
}
```

main stack frame

The Stack	ASCII	Decimal
char username[0]	a	97
char username[1]	b	98
char username[2]	c	99
char username[3]	d	100
char username[4]	1	49
char username[5]	2	50
char username[6]	3	51
char username[7]	4	52
int allow	f	102
parent func rbp		-231
ret address		-532

Buffer Overflows

What about the string: "**abcd1234f**"

We can write over the **`allow`** variable data

```c
#include <stdio.h>

int main ()
{
    int allow;
    char username[8];

    allow = 0;

    printf("Enter your username, please: ");
    gets(username);

    if (strcmp(username, "chris") == 0)
        allow = 1;

    if (allow)
        printf("Here is your private Bitcoin wallet: ...");

    return 0;
}
```

main
stack frame

The Stack	ASCII	Decimal
char username[0]	a	97
char username[1]	b	98
char username[2]	c	99
char username[3]	d	100
char username[4]	1	49
char username[5]	2	50
char username[6]	3	51
char username[7]	4	52
int allow	**f**	**102**
parent func rbp		-231
ret address		-532

Buffer Overflows

At this point, allow is now: **102**

```c
#include <stdio.h>

int main ()
{
    int allow;
    char username[8];

    allow = 0;

    printf("Enter your username, please: ");
    gets(username);

    if (strcmp(username, "chris") == 0)
        allow = 1;

    if (allow)
        printf("Here is your private Bitcoin wallet: ...");

    return 0;
}
```

main stack frame

The Stack	ASCII	Decimal
char username[0]	a	97
char username[1]	b	98
char username[2]	c	99
char username[3]	d	100
char username[4]	1	49
char username[5]	2	50
char username[6]	3	51
char username[7]	4	52
int allow	**f**	**102**
parent func rbp		-231
ret address		-532

Buffer Overflows

String check fails, allow is still: **102**

```c
#include <stdio.h>

int main ()
{
   int allow;
   char username[8];

   allow = 0;

   printf("Enter your username, please: ");
   gets(username);

   if (strcmp(username, "chris") == 0)
       allow = 1;

   if (allow)
       printf("Here is your private Bitcoin wallet: ...");

   return 0;
}
```

main
stack frame

The Stack	ASCII	Decimal
char username[0]	a	97
char username[1]	b	98
char username[2]	c	99
char username[3]	d	100
char username[4]	1	49
char username[5]	2	50
char username[6]	3	51
char username[7]	4	52
int allow	f	**102**
parent func rbp		-231
ret address		-532

Buffer Overflows

`if` statement passes (anything that is not zero is a true value in an **`if`**)

```c
#include <stdio.h>

int main ()
{
    int allow;
    char username[8];

    allow = 0;

    printf("Enter your username, please: ");
    gets(username);

    if (strcmp(username, "chris") == 0)
        allow = 1;

    if (allow)
        printf("Here is your private Bitcoin wallet: ...");

    return 0;
}
```

main stack frame

The Stack	ASCII	Decimal
char username[0]	a	97
char username[1]	b	98
char username[2]	c	99
char username[3]	d	100
char username[4]	1	49
char username[5]	2	50
char username[6]	3	51
char username[7]	4	52
int allow	f	**102**
parent func rbp		-231
ret address		-532

Protection against Buffer Overflows

- Detect and abort before malicious behaviour occurs:

```
 chris@chris-lab  ~/security  master ●  gcc -fstack-protector -std=c89 -O0 -pedantic main.c -o m
n.o
main.c: In function ‘main’:
main.c:11:5: warning: ‘gets’ is deprecated [-Wdeprecated-declarations]
     gets(username);
     ^~~~
In file included from main.c:1:0:
/usr/include/stdio.h:577:14: note: declared here
 extern char *gets (char *__s) __wur __attribute_deprecated__;
              ^~~~
/tmp/ccyFWBuE.o: In function `main':
main.c:(.text+0x48): warning: the `gets' function is dangerous and should not be used.
 chris@chris-lab  ~/security  master ●  ./main.o
Enter your username, please: abcd1234f
*** stack smashing detected ***: <unknown> terminated
[1]    4063 abort (core dumped)  ./main.o
 ✘ chris@chris-lab  ~/security  master ● 
```

Nice!

Protection against Buffer Overflows

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

int main ()
{
   int allow;
   char* username;
   allow = 0;
   username = malloc(8 * sizeof(*username));
   if (!username)
       return 1;

   printf("Enter your username, please: ");

   fgets(username, 8, stdin);
   strtok(username, "\n");

   if (strcmp(username, "chris") == 0)
       allow = 1;

   free(username);
   if (allow)
       printf("Here is your private Bitcoin wallet: L2udm71vYECrgBcgZLA6JpUfUwDYHqcBA89Db9QazRYKGhg1EbCZ\n");
   return 0;
}
```

Use heap memory

Do proper bounds checking (no more than 8 characters)

Protection against Buffer Overflows

- Using heap memory and **`fgets`**

```
 chris@chris-lab  ~/security  master ●  ls
main.c
 chris@chris-lab  ~/security  master ●  gcc -std=c89 -O0 -pedantic main.c -o main.o
 chris@chris-lab  ~/security  master ●  ./main.o
Enter your username, please: jess
 chris@chris-lab  ~/security  master ●  ./main.o
Enter your username, please: this-is-a-really-long-username-example
 chris@chris-lab  ~/security  master ●  ./main.o
Enter your username, please: chris
Here is your private Bitcoin wallet: L2thi71sYEConBeiZLA6JsU0UcDYHhrBA89Do9QnoRYtGri1ggCeZr
 chris@chris-lab  ~/security  master ● 
```

No warnings

No overflow

Other common functions vulnerable to overflow

Some more potentially dangerous system calls…

- `gets` - read line from stdin
- `strcpy` - copies string src dst
- `strcat` - appends string src dst
- `sprintf` - write data to string buffer
- `scanf` - read data from stdin
- `sscanf` - read data from string
- `fscanf` - read data from stream
- `vfscanf` - read from stream to args
- `realpath` - returns absolute path
- `getenv` - get environment string
- `getpass` - gets a password

… and lots more in many languages…

Heartbleed: A Buffer Over-read

Buffer over-read vulnerability in OpenSSL

- Open source code that handles a large proportion of the world's secured web traffic
  - Traffic between you and banks
  - Private emails
  - Social networks
- Clients send heartbeats to servers (are you alive?)
- Server responds with data
- A particular version of OpenSSL didn’t check for over-read
- Each heartbeat could reveal 64k of application memory
  - Lots of sensitive data leaked
  - Big websites request password resets following heartbleed
    - Reddit, Github, Bitbucket, Mojang, Amazon AWS, Pinterest, Tumblr, ...

Stack Smashing

- So we can overwrite memory. What else can we do?

The Stack	ASCII	Decimal
char username[0]	a	97
char username[1]	b	98
char username[2]	c	99
char username[3]	d	100
char username[4]	1	49
char username[5]	2	50
char username[6]	3	51
char username[7]	4	52
int allow	**f**	**102**
parent func rbp		-231
ret address		-532

main
stack frame

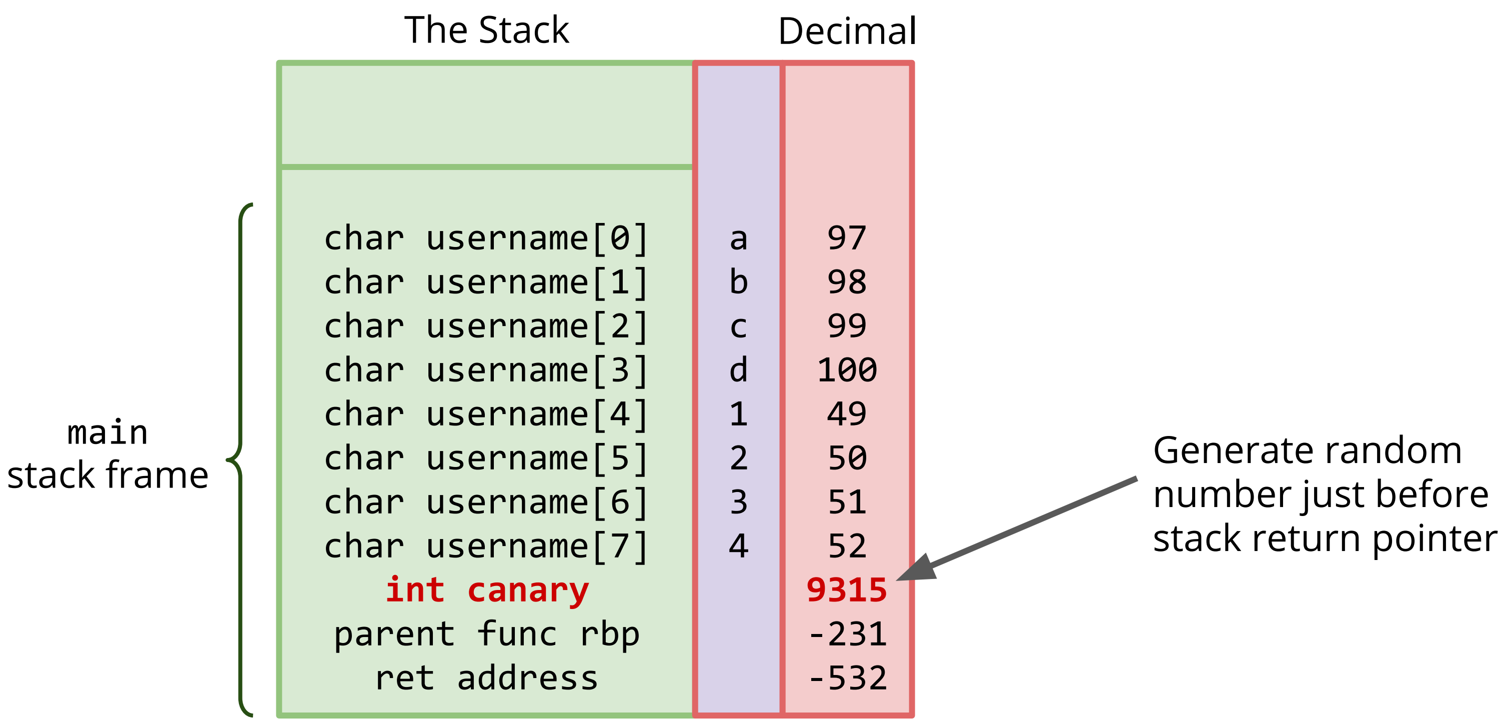
What if we kept going until we reached here?

Choose where we want to jump to...

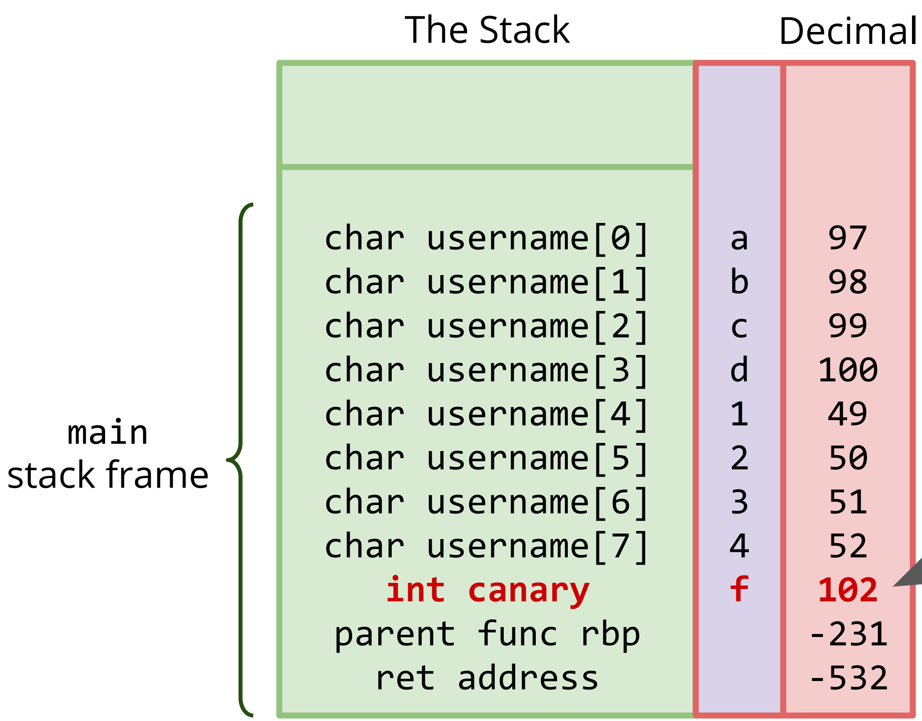
Stack Smashing

- What if we jumped to somewhere else where we had malicious code?
    - If we can use this on a program that has higher privilege than our self, we can jump to **deployed shellcode** for that **level of privilege**.
    - Shell code is executable code inserted as a payload for insertion attacks.
- Countermeasures:
    - Check buffer lengths
    - Use heap memory
    - Use ASLR, on the fly randomization of memory to make buffer flow attacks more difficult to implement.
        - Similar concept of making the operating system less predictable and much harder to do these kinds of attacks.
        - Has been bypassed using side-channel attacks (2017)
    - Use a canary
- We can do *similar* things on the heap

Canary Value



Canary Value



After writing to buffer, check if value is same as randomly generated value:

102 != 9315

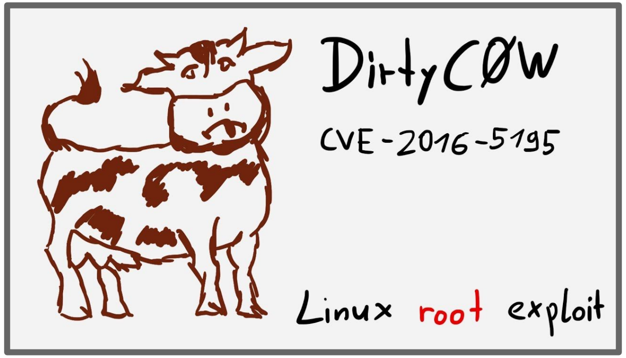
...this has been tampered with, exit!

Heap Smashing and NOP slides

- Heap memory rarely contains pointers that influence control flow
  - Needs to be combined as part of larger attack
  - Has been used in practice in some popular software
    - Internet Explorer
    - VLC multimedia player
    - Adobe Acrobat
    - Adobe Flash
- Heap sprays
  - Attempts to put a certain sequence of bytes at a predetermined location in the memory by allocating large blocks on the processes heap and filling the bytes in these blocks with specific values.
  - NOP slides (NOP sleds)
    - “Move onto next instruction” - put loads of x90’s followed by your shell code. Then your return address is likely to hit one and slide to the malicious code.

Race Condition Attacks

- Occur when multiple processes or threads operate on shared data.
- Attacks occur in many different situations:
  - Typically developers perform two or more steps but forget that hackers can **do something malicious in the gap** between the steps
- Popular example, **Dirty Cow**



Exploits copy-on-write (CoW) functionality in OS to gain root (quite easy to do).

- Two processes may read same physical memory.
- If one tries to write, the OS makes a copy.
- Dirty cow map sensitive files that you want to modify, invokes CoW, opens two threads which interfere and allow you to write over sensitive file.

Timing Attacks

```
bool check_password(string real, string guess)
{
   for (int i=0; i<16; ++i)
       if (real[i] != guess[i])
           return false;
   return true;
}
```

You would typically need 96^{16} guesses to bruteforce

= 52,040,292,466,647,269,602,037,015,248,896

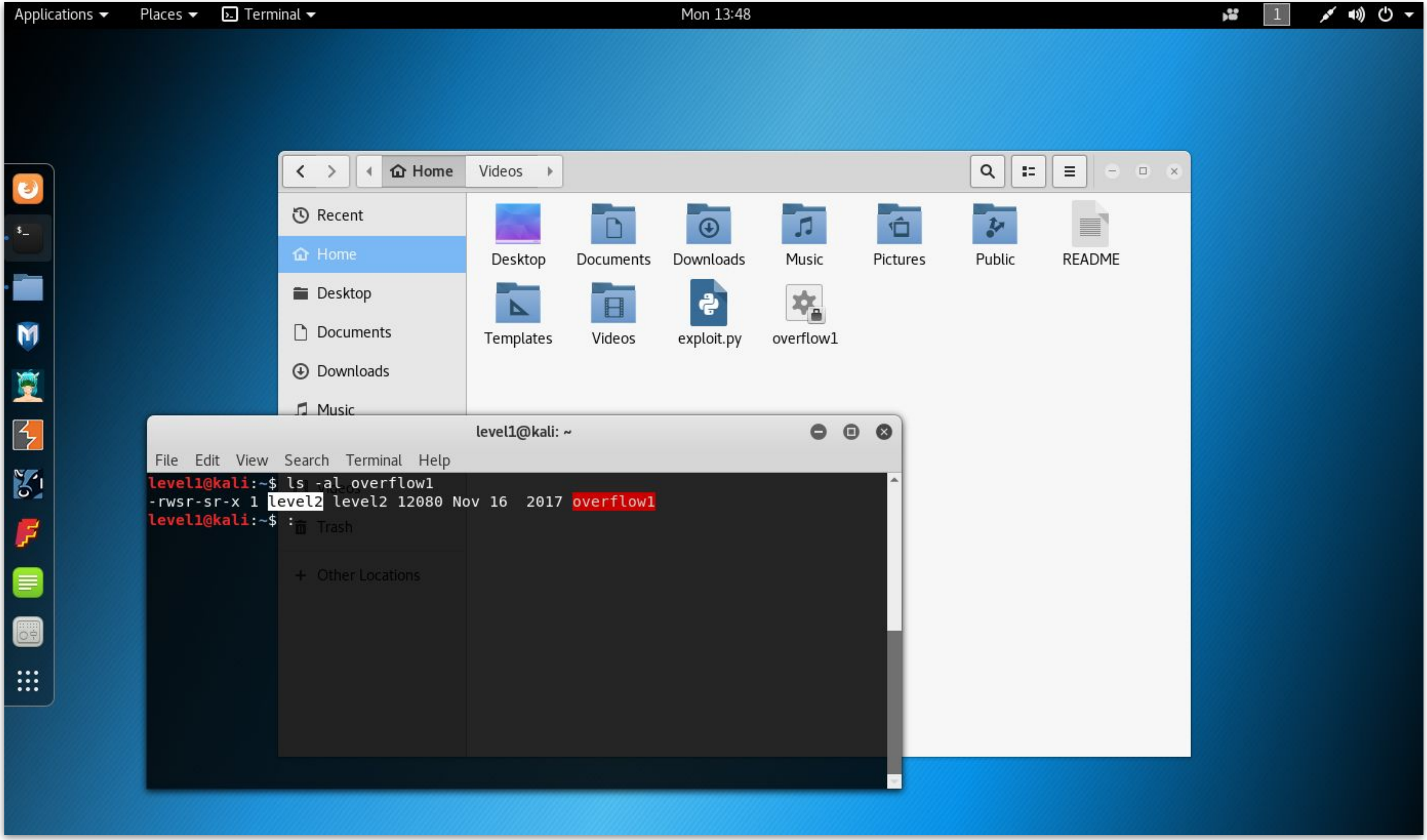
However if you accurately time application, it finishes at different times

Timing attack:

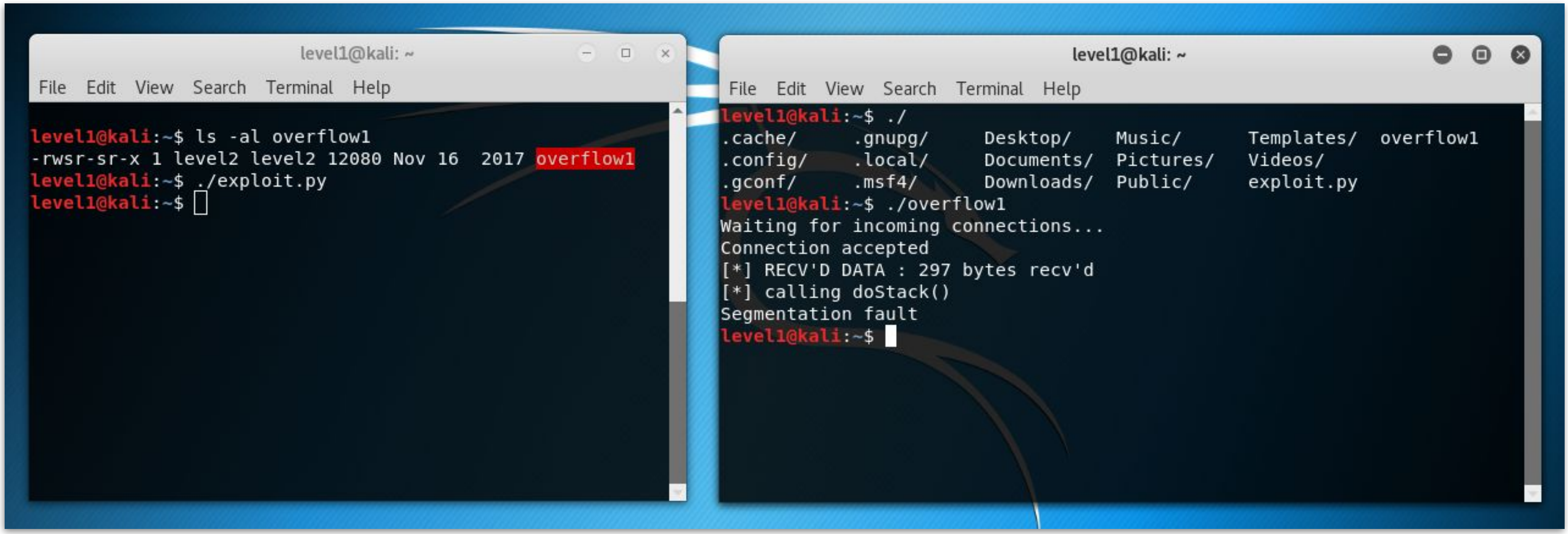
1. Try each of 96 chars for first letter in a random 16-length string.
   - Find which character takes longest to return false.
2. Move on to next character, and repeat

Would only take 96 * 16 guesses = maximum of **1,536** attempts to brute force

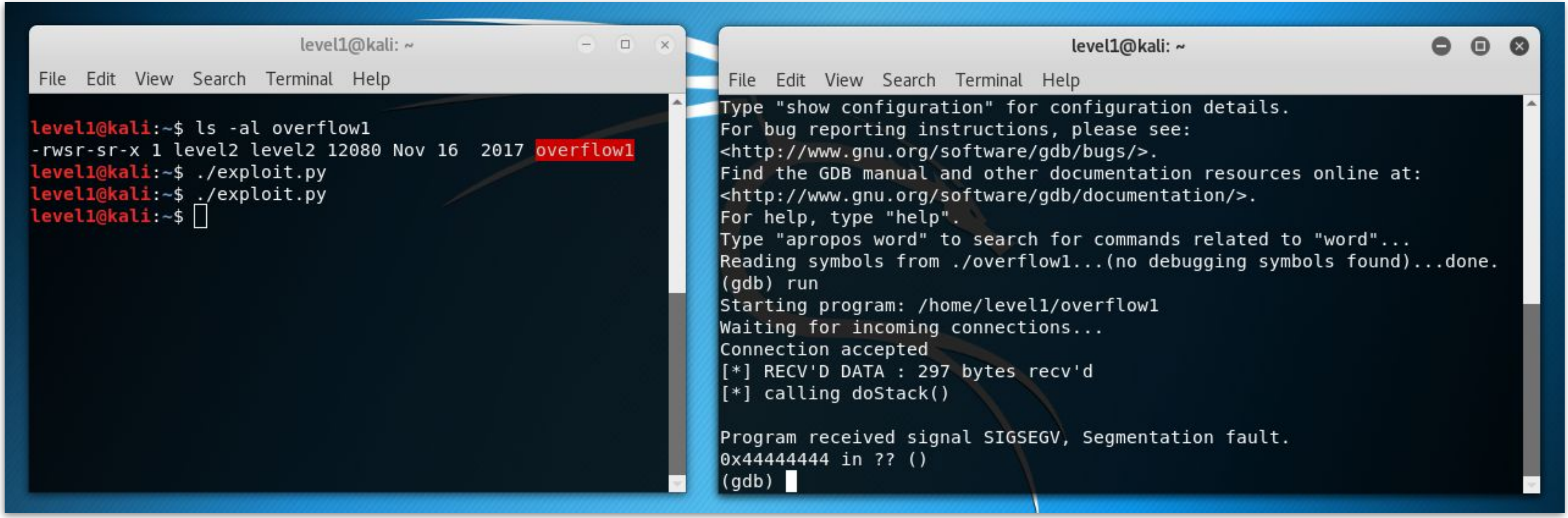
Metasploit Example



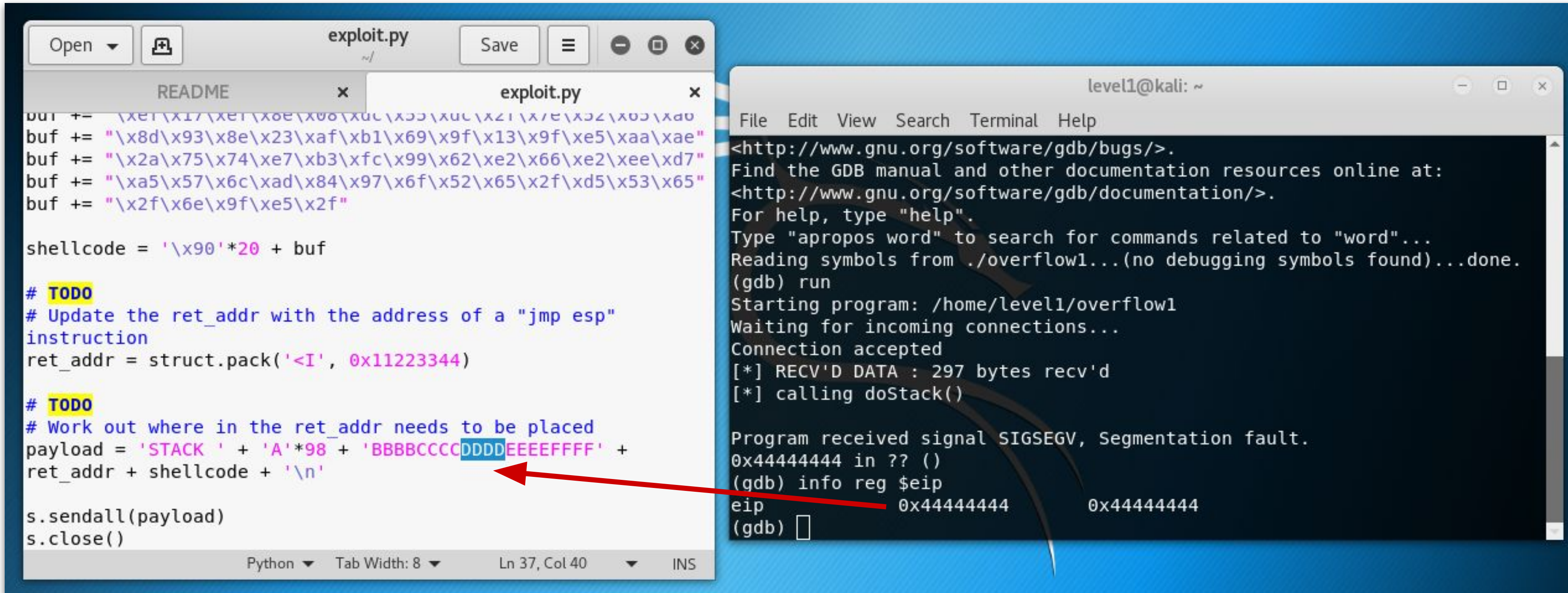
Metasploit Example



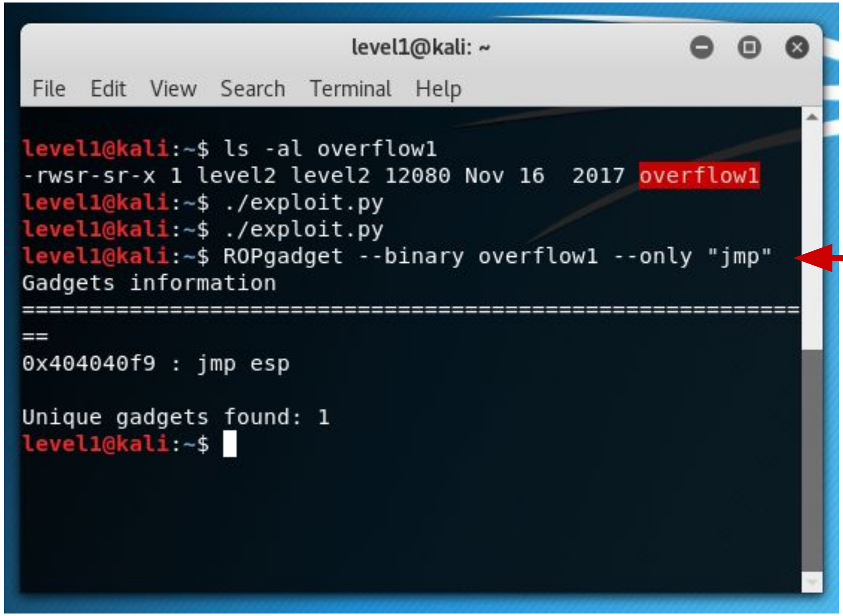
Metasploit Example



Metasploit Example

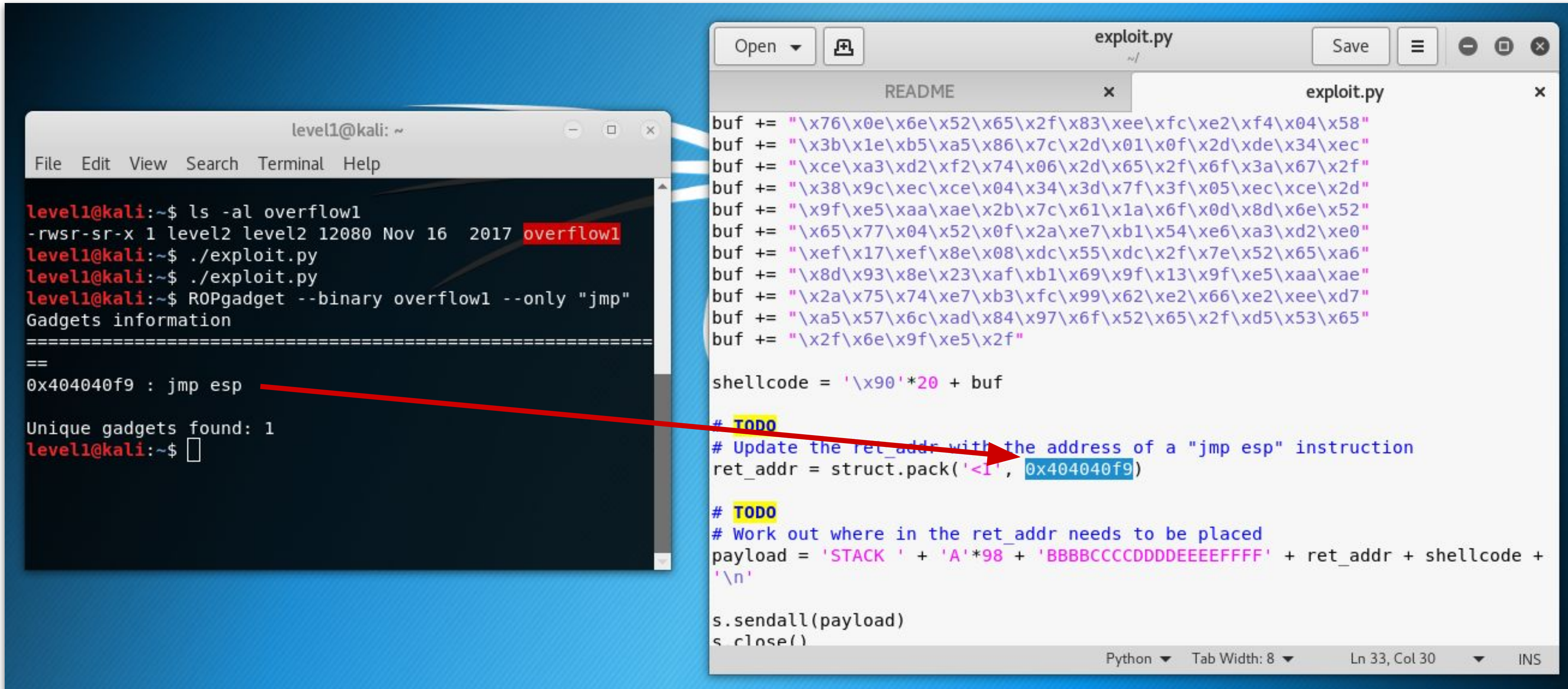


Metasploit Example



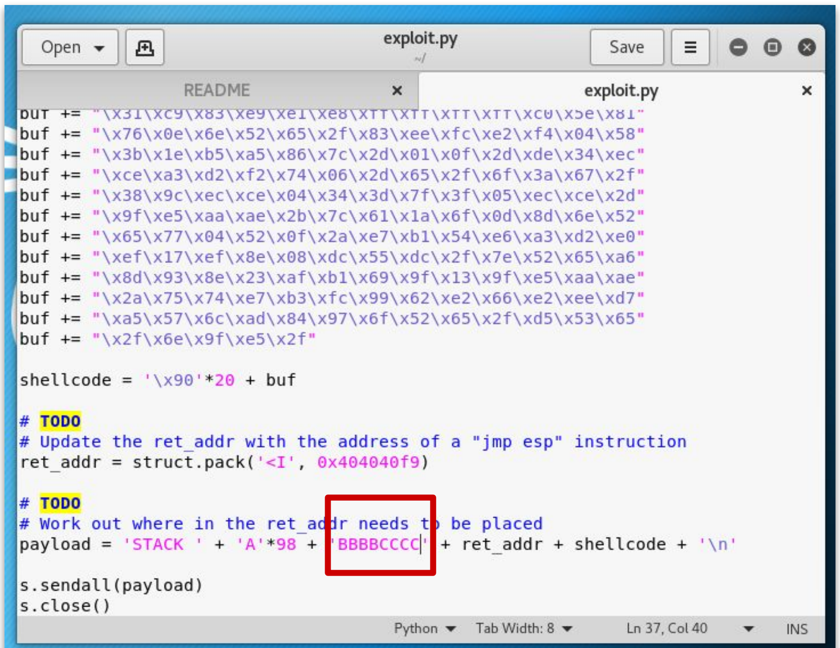
Search for **`jmp`** instructions

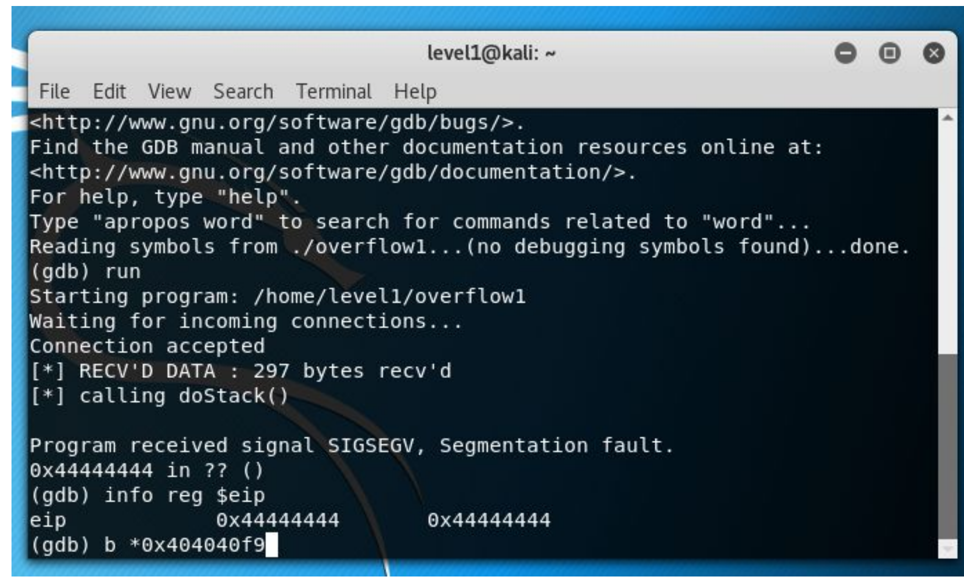
Metasploit Example



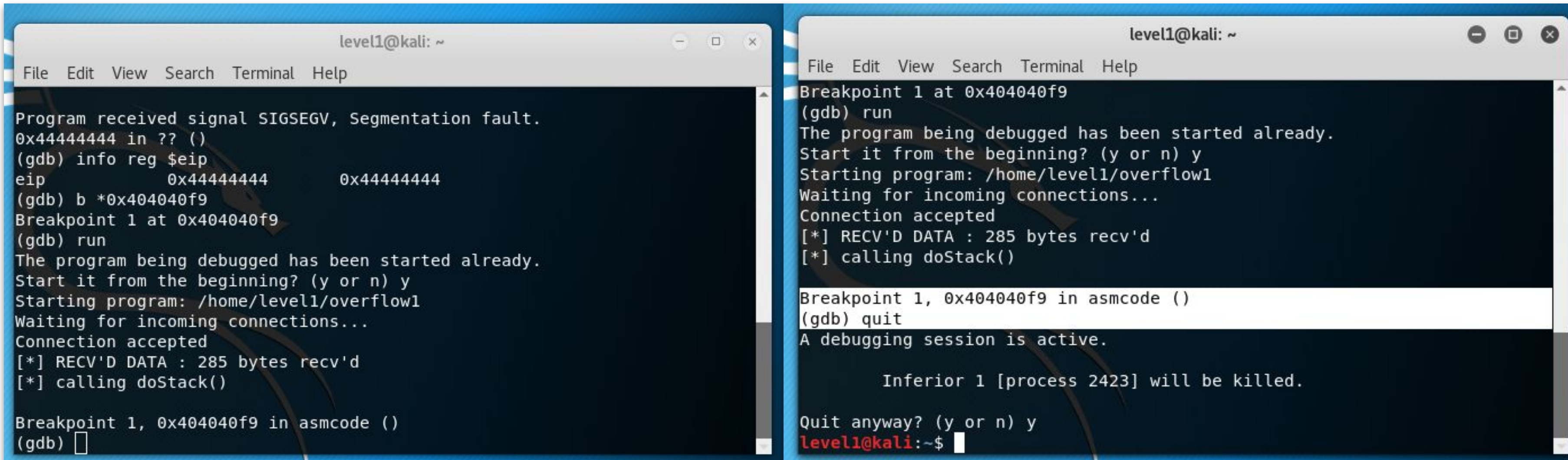
Metasploit Example

0x44 = ‘D’

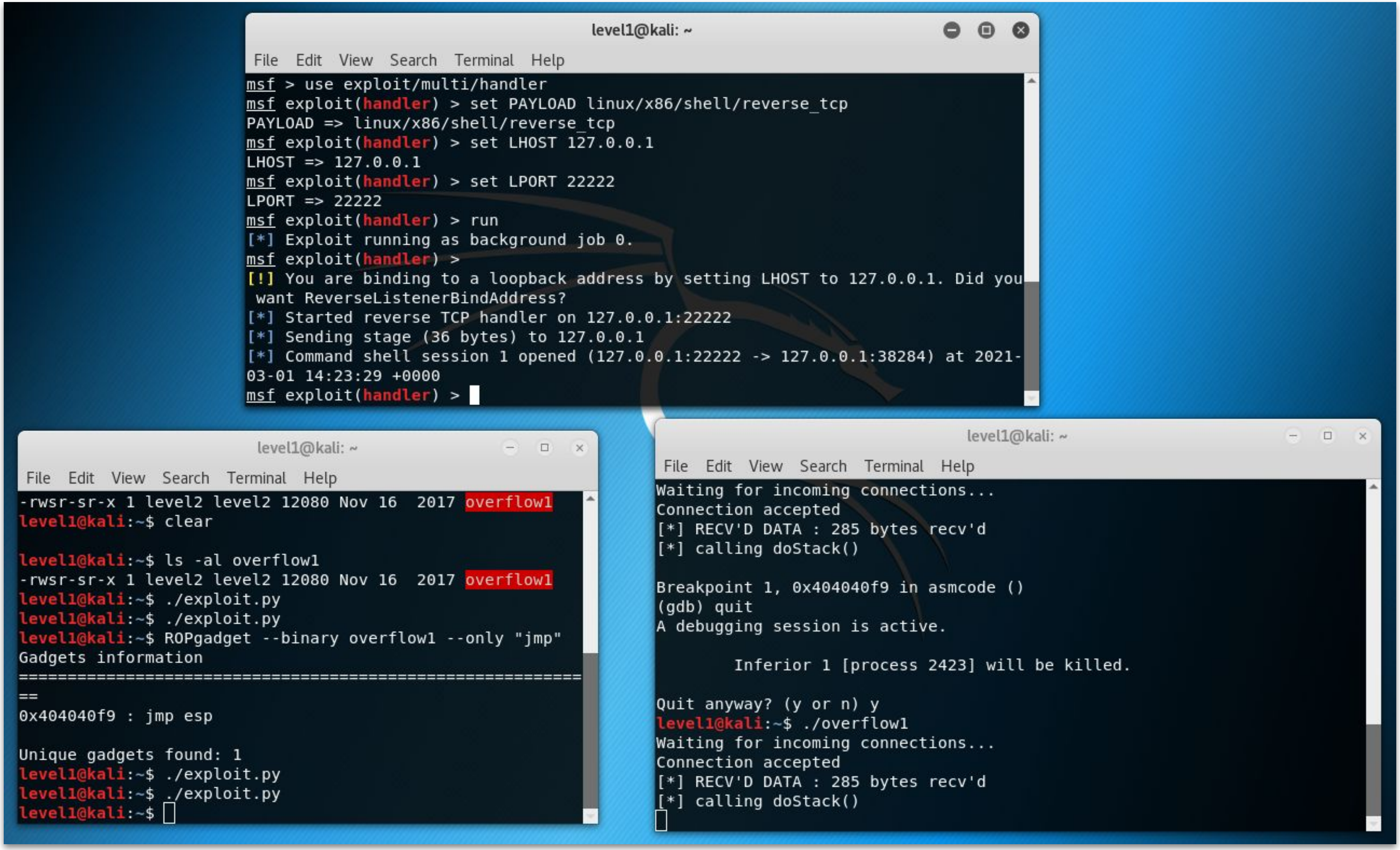




Metasploit Example

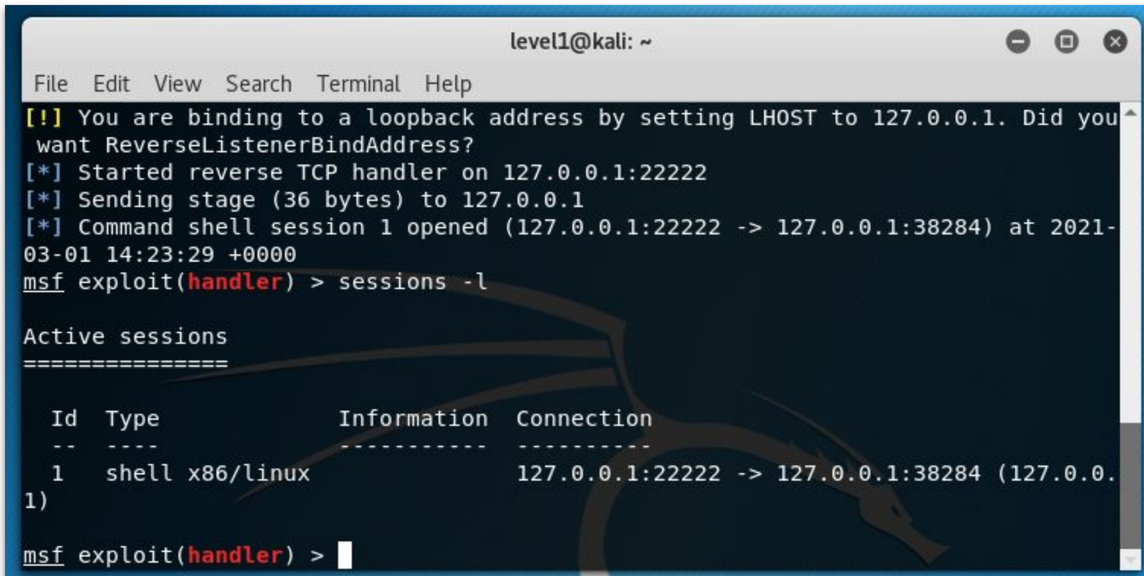


Metasploit Example



Metasploit Example

…and now you've got a shell running at the permission of level 2
`cat /home/level2/flag.txt` to get the level 2 login password



Thanks to SRM for helping prepare this lab material