Hacking in C

Attacks, part I

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A short recap

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- Code segment (or `.text`) for (read-only) program code
- `.data` and `.bss` for global and static variables

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  - Grows downwards, i.e., function call decreases stack pointer
  - Also contains return addresses, function arguments, (frame pointer)
  - Managed *automatically*, data is non-persistent
  - Stack overflow: exceeding maximum stack size (e.g., massive recursion)

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  - Managed *automatically*, data is non-persistent
  - Stack overflow: exceeding maximum stack size (e.g., massive recursion)
- Heap for persistent or large data
  - Request heap space with `malloc`
  - Resize requested memory with `realloc`
  - Always check whether returned pointer is `NULL`!
  - Free heap space using `free`
  - Heap is managed by the programmer
  - Many possible problems: danging pointers, double-free, memory leaks. . .

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- Example usage:

```
int *p = calloc(1000, sizeof(int));
if(p == NULL) exit(-1);
```

- Request space for 1000 integers

`malloc` vs. `calloc`

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  - `int *p = calloc(nelems,sizeof(int));`?
- Multiplication `nelems*sizeof(int)` can overflow!
- Result: successful allocation, but of *much less* memory!
- Another difference:
  - `malloc` doesn't guarantee you that you can *use* the memory you requested
  - Linux optimistically grants you the memory
  - Later *access* to this memory may still fail
  - `calloc` gives you memory that is actually "backed" by the OS

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- One solution: maintain a table of all malloc'ed addresses and space
- Other solution: write information just before the pointer

Reading and manipulating data

- Situation so far: program itself may do “weird” things in its own memory space
- “Weird” things means: **undefined behavior**
- Easiest case: program crashes (segmentation fault)
- More scary case: leak data (out of bounds read)

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- Remember: All of this is allowed by the C specification!

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- Examples of software accepting attacker input:
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- **Is there any program that only receives trustworthy input?**

Format-string attacks

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- This is after 25 years of people programming in C!
- Allow an attacker to
  - read data from the stack (and heap)
  - manipulate data in memory
- Vulnerable code (typically) fairly easy to spot
- These attacks *should* be history by now
- Still, great first example for malicious-input attacks

A simple `main`

```
#include<stdio.h>

extern long f(long *x);

int main(int argc, char* argv[])
  long pincode = 1234;
  printf (argv [1]);
  return f(&pincode);
}
```

- The program prints the first command line argument
- The call to `f()` is so that gcc doesn't optimize `pincode` away

argc and argv

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  - `(void)`
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- `char **argv` and `char *argv[]` are equivalent
- `char **` is a pointer to a pointer to `char`
- Can also see it as an array of strings
- Contains the command-line arguments:
  - `argv[0]` is the name of the program
  - `argv[1]` is the first argument
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- argc contains the length of the argv array
- Without any command-line argument, argc == 1

Arguments passing, the “easy” way

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- Answer: It depends ;-)
- `printf` has variable number of arguments
- For each % in the first argument, expect one more argument
- (To print a percent sign, use %% in the first printf argument)

Arguments passing, the “easy” way

- Let’s call our program with `./formatstring "%x"`
- What does the program print?
- Answer: It depends ;-)
- `printf` has variable number of arguments
- For each % in the first argument, expect one more argument
- (To print a percent sign, use %% in the first printf argument)
- `printf` finds one `%x`, looks for second argument
- Traditionally (x86) arguments are passed through the stack
- On x86, we would get the top 4 bytes of the stack

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- Major change in function-call ABI: pass up to 6 arguments through registers:
  - First argument passed through `rdi`
  - Second argument passed through `rsi`
  - ...
- `printf` will look for second argument in `rsi`
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- Output (on AMD64) is the content of `rsi`
- What happens if we run
  `./formatstring "%p %p %p %p %p %p %p %p %p"`?

Format strings

- A *format string* is a string containing control parameters
- Control parameters start with `%`
- Functions like `printf` (or `snprintf`) interpret those control parameters
- Look in additional arguments for values to replace them
- Short recap:
  - `%d` prints integer in decimal
  - `%x` prints integer in hexadecimal
  - `%p` prints a pointer
  - `%s` prints a string

Leaking data with format strings

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- What happens if we use `str == "%s"`?
- Print memory from address in `rdi` up to first zero byte
- Use multiple `%s` to print memory at multiple locations

Corrupting data with format strings

- So far we can use format-string attacks “only” to *read* data
- Consider the following code program:

```
int main(int argc, char *argv[])
{
  int len;
  printf("How long is %s?\n%n", argv[1], &len);
  printf("%d\n", len-14);
  return 0;
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- What happens if we feed `"Hello World!%n"` to:

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int main(int argc, char* argv[])
  printf (argv [1]);
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- Answer (on AMD64): Write 12 to the address in `rsi`
- Can choose arbitrary values by feeding in longer strings

Evil formatstrings (summary)

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- Assumption is that attacker controls the format string
- Typically:
  - format string sits somewhere on the stack
  - Same location that will be used by `printf` for arguments
- Can *choose* address to write to with `%n`
- Depends on where the actual format-string is sitting in memory

The first format-string attack

- Discovered by Tymm Twillman when auditing ProFTPD (1999)
- First ftp to vulnerabable host, login (anonymous)

  ```
  ftp> ls aaaXXXX%u%u%u%u%u%u%u%u%u%u%u%u%u%u%u%u%u%u
       %u%u%u%u%u%u%u%u%u%u%u%u%u%u%u%u%u%u%653300u%n
  ```

- replace the X's with the characters with ASCII values 0xdc,0x4f,0x07,0x08 consecutively
- See http://seclists.org/bugtraq/1999/Sep/328

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```

"The a's at the beginning are just for alignment, the `%u`*'s to skip bytes in the stack, the* `%653300u` *is to increment the # of bytes that have been "output", and the* `%n` *stores that value (whose LSBs have now flipped over to 0) to the location pointed to by the current "argument" – which just happens to point right after the a's in this string. The bytes that replace the X's are the address where proftpd keeps the current user ID..."*

Getting rid of format-string attacks

- Vulnerable pattern:

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printf(str);
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- Safe pattern:

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printf("%s", str);
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- Compilers find such patterns and warn about them
- Need compiler flags (e.g., `-Wall`)
- Much more subtle if format string is not known at compile time
- Could ask a user: how would you like your output formatted
- Static (compile-time) analysis has no chance here
- Need to carefully validate user input!

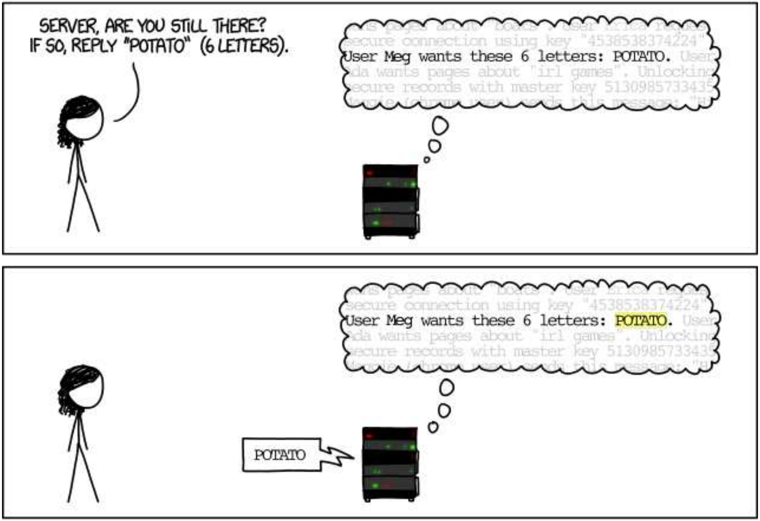
Buffer Overflows

No bounds checking – what could go wrong?

- April 7, 2014, OpenSSL discloses "Heartbleed" bug
- Heartbleed allows remote attacker to read out OpenSSL memory
- Content typically includes cryptographic keys, passwords, etc.
- Bug was in OpenSSL for more than 3 years
- Introduced on December 31, 2010
- First bug with a logo
- Major media coverage
- Initiated major changes in OpenSSL

Underlying problem: Out of bounds array access in OpenSSL

How Heartbleed works



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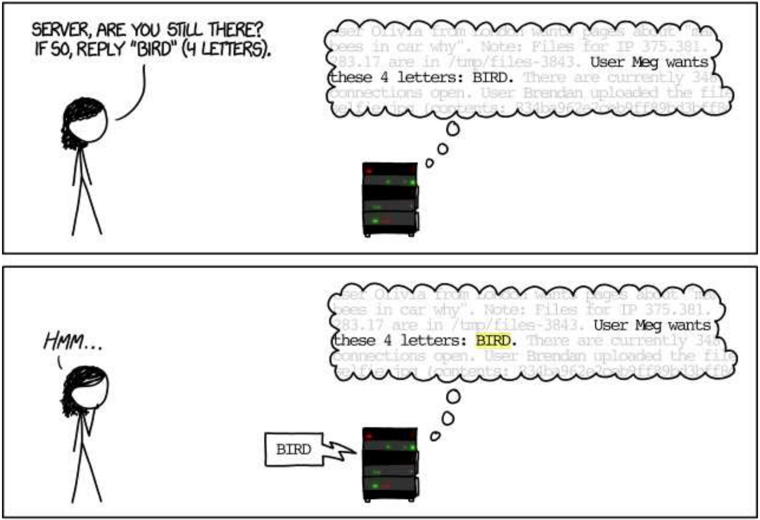

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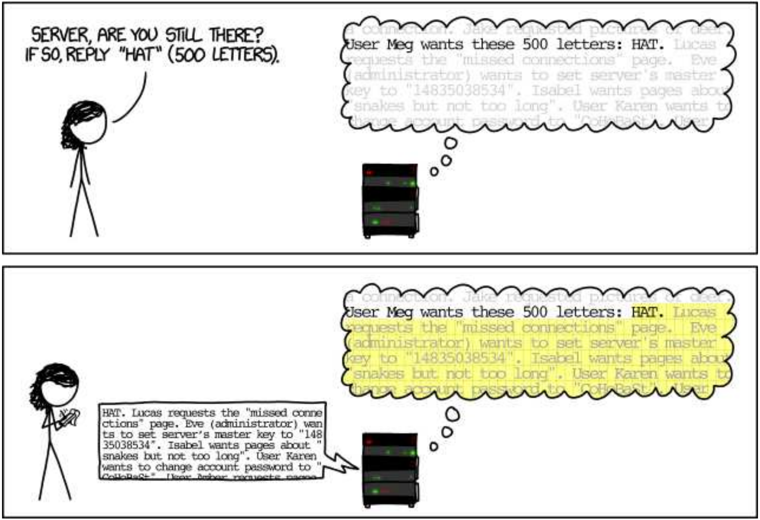

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- Fix by checking `offset + packet_size <= 65525`

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- CVE-2016-1409: IPv6 ping of death against Cisco's IOS, IOS XR, IOS XE, and NX-OS software