Secure Programming

Buffer Overflows

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Learning objectives

- Understand the definition of a buffer overflow
- Learn the importance of buffer overflows
- Know how buffer overflows happen
- Know how to handle strings safely with regular "C" functions
- Learn safer ways to manipulate strings and buffers

Buffer Overflows

- a.k.a. "Buffer Overrun"
- A buffer overflow happens when a program attempts to read or write data outside of the memory allocated for that data
  - Usually affects buffers of fixed size
- Special case of memory management and input validation

An Important Vulnerability Type

- Most Common (over 60% of CERT advisories)
- Well understood
- Easy to avoid in principle
  - Dont use "C" family languages, or be thorough
  - Can be tricky (off-by-one errors)
  - Tedious to do all the checks properly
    - Temptation: "I don't need to because I control this data and I *know* that it will never be larger than this"
      - Until a hacker figures out how to change it

Example Overflow

```
char B[10];
B[10] = x;
```

- Array starts at index zero
- So [10] is 11th element
- One byte outside buffer was referenced
- Off-by-one errors are common and can be exploitable!

Other Example

```
function do_stuff(char * a) {
        char b[100];
    ...
        strcpy(b, a); // (dest, source)
    ...
    }
```

- What is the size of the string located at “a”?
- Is it even a null-terminated string?
- What if it was "`strcpy(a, b);`" instead?
  - What is the size of the buffer pointed to by "a"?

What happens when memory outside a buffer is accessed?

- If memory doesn't exist:
  - Bus error
- If memory protection denies access:
  - Segmentation fault
  - General protection fault
- If access is allowed, memory next to the buffer can be accessed
  - Heap
  - Stack
  - Etc...

Real Life Example: efingerd.c, v. 1.6.2

```
int get_request (int d, char buffer[], u_short len) {
      u_short i;
      for (i=0; i< len; i++) {
      ...
      }
      buffer[i] = '\0';
      return i;
   }
```

- What is the value of "i" at the end of the loop?
- Which byte just got zeroed?
- It's tricky even if you try to get things right...

Real Life Example: efingerd.c, v. 1.5

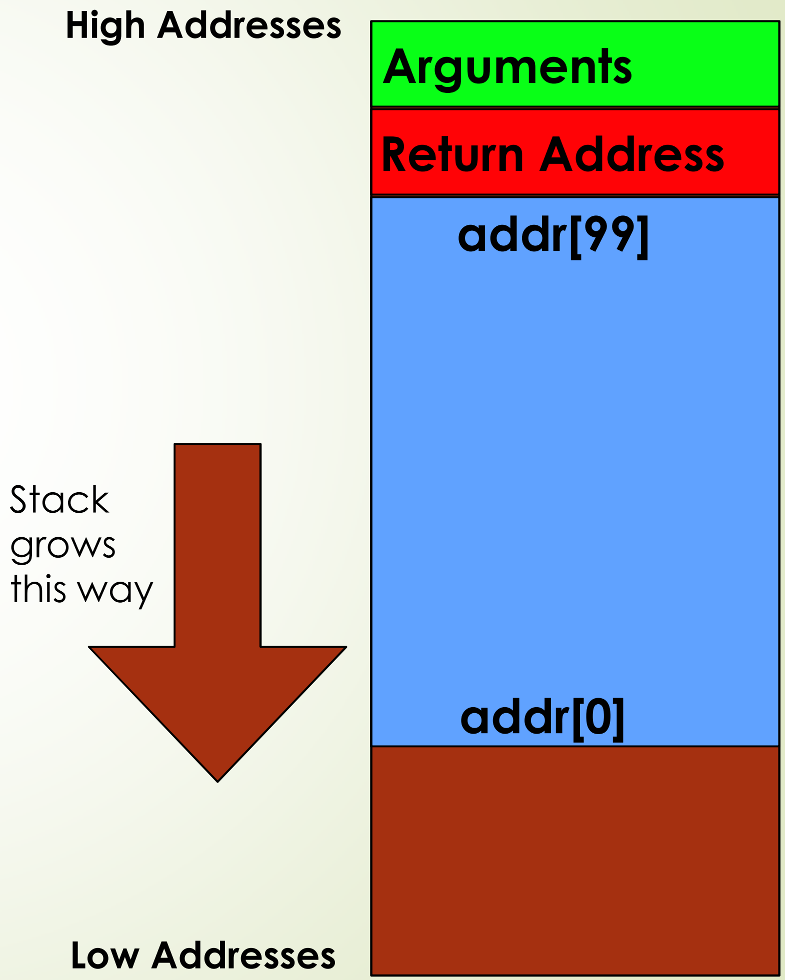
- CAN-2002-0423

```
static char *lookup_addr(struct in_addr in) {
    static char addr[100];
    struct hostent *he;
    he = gethostbyaddr(...)
    strcpy (addr, he->h_name);
    return addr;
}
```

- How big is `he->h_name`?
- Who controls the results of `gethostbyaddr`?
- How secure is DNS? Can you be tricked into looking up a maliciously engineered value?

A Typical Stack Exploit

- The stack contains:
  - Parameters (arguments) to function
  - Return Address
  - Local variables
  - Anything pushed on the stack
- addr[100+] overwrites the return address
- addr[0] typically contains exploit code
- Return address is chosen to point at exploit code!



Fundamental "C" Problems

- You can't know the length of buffers just from a pointer
  - Partial solution: pass the length as a separate argument
- "C" string functions aren't safe
  - No guarantees that the new string will be null-terminated!
  - Doing all checks completely and properly is tedious and tricky

Strlen

- What happens when you call strlen on an improperly terminated string?
- Strlen scans until a null character is found
  - Can scan outside buffer if string is not null-terminated
  - Can result in a segmentation fault or bus error
- Strlen is not safe to call!
  - Unless you positively know that the string is null-terminated...
    - Are all the functions you use ***guaranteed*** to return a null-terminated string?

Strcpy

```
char * strcpy(char * dst, const char * src);
```

- How can you use strcpy safely?
  - Set the last character of src to NULL
    - According to the size of the buffer pointed to by src or a size parameter passed to you
    - Not according to strlen(src)!
    - Wide char array: sizeof(src)/sizeof(src[0]) -1 is the index of the last element
  - Check that the size of the src buffer is smaller than or equal to that of the dst buffer
  - Or allocate dst to be at least equal to the size of src

Strncpy

```
char * strncpy(char * dst, const char * src, size_t len);
```

- "len" is maximum number of characters to copy
  - What is the correct value for len?
    - If dst is an array, `sizeof(dst)`
- What if src is not NULL-terminated?
  - Don't want to read outside of src buffer
  - What is the correct value for "len" given that?
    - Spare one character for NULL byte
      - `MIN(sizeof(dst), sizeof(src)) - 1`
- Other issue: "dst" is NULL-terminated only if less than "len" characters were copied!
  - All calls to strncpy must be followed by a NULL-termination operation

Question Answer

- What's wrong with this function?

```
function do_stuff(char * a) {
    char b[100];
...
    strncpy(b, a, strlen(a));
...
}
```

- The string pointed to by could be larger than the size of "b"!

Question Answer

- What's wrong with this function?

```
function do_stuff(char * a) {
    char *b;
     ...
    b = malloc(strlen(a)+1);
    strncpy(b, a, strlen(a));
     ...
}
```

- Are you absolutely certain that the string pointed to by "a" is NULL-terminated?

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Corrected Efinger.c (v.1.6)

- sizeof is your friend, when you can use it (if an array)

```
static char addr[100];
he = gethostbyaddr(...);
if (he == NULL)
   strncpy(addr, inet_ntoa(in), sizeof(addr));
else
   strncpy(addr, he->h_name, sizeof(addr));
```

- What is still wrong?

Corrected Efinger.c (v.1.6)

- Notice that the last byte of addr is not zeroed, so this code can produce non-NULL-terminated strings!

```
static char addr[100];
he = gethostbyaddr(...);
if (he == NULL)
    strncpy(addr, inet_ntoa(in), sizeof(addr));
else
    strncpy(addr, he->h_name, sizeof(addr));
```

Strcat

```
char * strcat(char * s, const char * append);
```

- String pointed to by "append" is added at the end of the string contained in buffer "s"
- No check for size!
  - Need to do all checks beforehand
  - Example with arrays:
    - ```
      if (sizeof(s)-strlen(s)-1 >= strlen(append))
          strcat(s, append);
      ```
- Need to trust that "s" and "append" are NULL-terminated
  - Or set their last byte to NULL before the checks and call
      ```

Strncat

```
char * strncat(char * s, const char * append,
size_t count);
```

- No more than "count" characters are added, and then a NULL is added
- Correct call is complex:
  - `strncat(s, append, sizeof(s)-strlen(s)-1)`
    - Not a great improvement on strcat, because you still need to calculate correctly the count
      - And then figure out if the string was truncated
- Need to trust that "s" and "append" are NULL-terminated
  - Or set their last byte to NUL before the checks and call

Strlcat

```
size_t strlcat(char *dst, const char *src, size_t size);
```

- Call semantics are simple:
  - `strlcat(dst, src, dst_len);`
  - If an array:
    - `strlcat(dst, src, sizeof(dst));`
- Safety: safe even if dst is not properly terminated
  - Won't read more than size characters from dst when looking for the append location
- Not safe if src is not properly terminated!
  - If dst is large and the buffer for src is small, then it could cause a segmentation fault or bus error, or copy confidential values

Issues with Truncating Strings

- Subsequent operations may fail or open up vulnerabilities
  - If string is a path, then it may not refer to the same thing, or be an invalid path
- Truncation means you weren't able to do what you wanted
  - You should handle that error instead of letting it go silently

Truncation Detection

- Truncation detection was simplified by `strlcpy` and `strlcat`, by changing the return value
  - The returned value is the size of what would have been copied if the destination had an infinite size
    - if the returned value is larger than the destination size, truncation occurred
    - Source still needs to be NULL-terminated
    - Inspired by `snprintf` and `vsprintf`, which do the same
- However, it still takes some consideration to make sure the test is correct:
  - ```
    if (strlcpy(dest, src, sizeof(dest)) >=
    sizeof(dest)) goto toolong;
    ```
    ```

Multi-Byte Character Encodings

- Handling of strings using variable-width encodings or multi-byte encodings is a problem
  - e.g., UTF-8 is 1-4 bytes long
- How long is the string?
  - In bytes
  - In characters
- Overflows are possible if size checks do not properly account for character encoding!
- .NET: System.String supports UTF-16
  - Strings are immutable - no overflow possible there!

Safestr

- Free library for safe string operations:
  - https://manned.org/safestr/20fb981d

- Features:
  - Works on UNIX and Windows
  - Buffer overflow protection
  - String format protection

- Limitations and differences:
  - Does not handle multi-byte characters
  - License: binaries must reproduce a copyright notice
  - NULL characters have no special meaning
  - Must use their library functions all the time (but conversion to regular "C" strings is easy)

Microsoft Strsafe

- Null-termination guaranteed
- Option for using either number of characters or bytes (for Unicode character encoding), and disallowing the other
- Option to treat truncation as a fatal error
- Define behavior upon error
  - Output buffer set to "" or filled
- Option to prevent information leaks
  - Pad rest of buffer
- However, correct calculations still needed
  - e.g., wcsncat requires calculating the remaining space in the destination string...

Future Microsoft

- Visual Studio 2005 have a new series of safe string manipulation functions
  - strcpy_s()
  - strncpy_s()
  - strncat_s()
  - strlen_s()
  - etc...

- Visual Studio 2005 (as of Beta 1) by default issues deprecation warnings on strcpy, strncpy, etc… Say goodbye to your old friends, they're too dangerous!

Other Unsafe Functions: sprintf family

```
int sprintf(char *s, const char *format, /* args*/ ...);
```

- Buffer "s" can be overflowed

```
int snprintf(char *s, size_t n, const char *format,
/* args*/ ...);
```

- Does not guarantee NULL-termination of s on some platforms (Microsoft, Sun)
- MacOS X: NULL-termination guaranteed
- Which is it on the server? Check with "`man snprintf`"

```
int vsprintf(char * str, const char * format, va_list
ap);
```

- Buffer "str" can be overflowed

Gets, fgets

```
char *gets(char *str);
```

- Buffer "str" can be overflowed

```
char *fgets(char * str, int size, FILE * stream);
```

- Buffer "str" is not NULL-terminated if an I/O error occurs
- If an error occurs, returns NULL
- If end-of-file occurs before any characters are read, returns NULL also (and buffer is unchanged)
- Callers must use feof(3) and ferror(3) to determine which occurred.

Conclusion

- Buffer sizes should be passed as a parameter with every pointer
  - Applies to other buffer manipulations besides strings
- Need simple truncation detection

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Preventing Buffer Overflows Without Programming

- Idea: make the heap and stack non-executable
  - Because many buffer overflow attacks aim at executing code in the data that overflowed the buffer
- Doesn't prevent "return into libc" overflow attacks
  - Because the return address of the function on the stack points to a standard "C" function (e.g., "system"), this attack doesn't execute code on the stack
- e.g., ExecShield for Fedora Linux (used to be RedHat Linux)

Canaries on a Stack

- Add a few bytes containing special values between variables on the stack and the return address.
- Before the function returns, check that the values are intact.
  - If not, there's been a buffer overflow!
    - Terminate program
- If the goal was a Denial-of-Service then it still happens
  - At least the machine is not compromised
- If the canary can be read by an attacker, then a buffer overflow exploit can be made to rewrite them
  - e.g., see string format vulnerabilities

Canary Implementations

- StackGuard
- Stack-Smashing Protector (SSP)
  - Formerly ProPolice
  - gcc modification
  - Used in OpenBSD
  - http://www.trl.ibm.com/projects/security/ssp/
- Windows: /GS option for Visual C++ .NET
- These can be useful when testing too!

Protection Using Virtual Memory Pages

- Page: A chunk (unit) of virtual memory
- POSIX systems have three permissions for each page.
  - PROT_READ
  - PROT_WRITE
  - PROT_EXEC
- Idea: manipulate and enforce these permissions correctly to defend against buffer overflows
  - Make injected code non-executable

Windows Execution Protection

- "NX" (No Execute)
- Windows XP service pack 2 feature
  - Somewhat similar to POSIX permissions
- Requires processor support
  - AMD64
  - Intel Itanium

Buffer Overflow Lab

- Create your own safe version of the strlen, strcpy, strcat
  - Name them mystrlen, mystrcpy and mystrcat
  - Pass buffer sizes for each pointer argument
  - Return 0 if successful, and 1 if truncation occurred
    - Other error codes if you wish
  - Make your implementation pass all test cases
    - int mystrlen(const char *s, size_t s_len);
      - In this case, return the string length, not zero or one.
    - int mystrcpy(char * dst, const char * src, size_t dst_len, size_t src_len);
    - int mystrcat(char * s, const char * append, size_t s_len, size_t a_len);

Things to Ponder

- What about 0 as source size? Error or not?
- What if "s" is NULL?
- What about overlapping buffers? Undefined everytime, or only in certain cases?
- What if reach the end in mystrlen?
- How efficient to make it -- how many passes at source string are made?
- What to check first?
- Reuse mystrlen within mystrcpy or mystrcat?
- Compare your implementations to strl*, strsafe, safestr, str*_s.