Vulnerability Assessment and Secure Coding Practices for Middleware

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Surprise Quiz

- One small function per problem
- Find as many potential vulnerabilities as you can (there may be more than one)
- Assume:
  - pointer arguments are never NULL  
  - strings are always NULL terminated
- After each, we will discuss the answers
Problem 2

/* Safely Exec program: drop privileges to user uid and group gid, and use chroot to restrict file system access to jail directory. Also, don’t allow program to run as a privileged user or group */

1. void ExecUid(int uid, int gid, char *jailDir,
2. char *prog, char *const argv[])
3. {
4.   if (uid == 0 || gid == 0) {
5.     FailExit("ExecUid: root uid or gid not allowed");
6.   }
7.   chroot(jailDir); /* restrict access to this dir */
8.   setuid(uid);     /* drop privs */
9.   setgid(gid);
10.  fprintf(LOGFILE, "Execvp of %s as uid=%d gid=%d\n",
11.       prog, uid, gid);
12.  fflush(LOGFILE);
13.  execvp(prog, argv);
14. }

Part 2 Roadmap

• Part 1: Vulnerability assessment process
  – Buffer overflows
  – Injections
  – Integer
  – Race conditions
  – Privileges
  – Command line
  – Environment
  – Denial of service
  – General engineering
  – Compiler warnings

• Part 2: Secure coding practices
  – Introduction
  – Handling errors
  – Numeric parsing
  – Missing error detection
  – ISO/IEC 24731
  – Variadic functions
Discussion of the Practices

- Description of vulnerability
- Signs of presence in the code
- Mitigations
- Safer alternatives

Handling Errors

- If a call can fail, always check for errors
  optimistic error handling (i.e. none) is bad
- Error handling strategies:
  - Handle locally and continue
  - Cleanup and propagate the error
  - Exit the application
- All APIs you use or develop, that can fail, must be able to report errors to the caller
- Using exceptions forces error handling
Numeric Parsing Unreported Errors

- **atoi, atol, atof, scanf family (with %u, %i, %d, %x and %o specifiers)**
  - Out of range values **results in unspecified behavior**
  - Non-numeric input **returns 0**
  - Use **strtol, strtoul, strtoll, strtoull, strtof, strtod, strtold** which allow error detection

Missing Error Detection

- **strcat, strcpy, strncat, strncpy, gets, getpass, getwd, scanf** (using **%s** or **% [...] without width specified**)
  - **Never use these**
  - Unable to report if buffer would overflow (not enough information present)
  - Safer alternatives exist
ISO/IEC 24731
Extensions for the C library: Part 1, Bounds Checking Interface
- Functions to make the C library safer
- Meant to easily replace existing library calls with little or no other changes
- Aborts on error or optionally reports error
- Very few unspecified behaviors
- All updated buffers require a size param
  - http://www.open-std.org/jtcl/sc22/wg14

Buffer Overflows
- Description
  - Accessing locations of a buffer outside the boundaries of the buffer
- Common causes
  - C-style strings
  - Array access and pointer arithmetic in languages without bounds checking
  - Off by one errors
  - Fixed large buffer sizes (make it big and hope)
  - Decoupled buffer pointer and its size
    - If size unknown overflows are impossible to detect
    - Require synchronization between the two
    - Ok if size is implicitly known and every use knows it (hard)
Why Buffer Overflows are Dangerous

• An overflow overwrites memory adjacent to a buffer
• This memory could be
  – Unused
  – Code
  – Program data that can affect operations
  – Internal data used by the runtime system
• Common result is a crash
• Specially crafted values can be used for an attack

Buffer Overflow of User Data Affecting Flow of Control

```c
char id[8];
int validId = 0; /* not valid */

id validId
gets(id); /* reads "evillogin"*/

id validId
    e v i l l o g i 110

/* validId is now 110 decimal */
if (IsValid(id)) validId = 1; /* not true */
if (validId) /* is true */
{DoPrivilegedOp();} /* gets executed */
```
Buffer Overflow Danger Signs: Missing Buffer Size

- **gets, getpass, getwd, and scanf family** (with `%s` or `%[…]%` specifiers without width)
  - Impossible to use correctly: size comes solely from user input
  - Alternatives

<table>
<thead>
<tr>
<th>Unsafe</th>
<th>Safe</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>gets(s)</code></td>
<td><code>fgets(s, sLen, stdin)</code></td>
</tr>
<tr>
<td><code>getcwd(s)</code></td>
<td><code>getwd(s, sLen)</code></td>
</tr>
<tr>
<td><code>scanf(&quot;%s&quot;, s)</code></td>
<td><code>scanf(&quot;%100s&quot;, s)</code></td>
</tr>
</tbody>
</table>

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**strcat, strcpy, sprintf, vsprintf**

- Impossible for function to detect overflow
  - Destination buffer size not passed
- Difficult to use safely w/o pre-checks
  - Checks require destination buffer size
  - Length of data formatted by printf
  - Difficult & error prone
  - Best incorporated in the function

**Proper usage: concat s1, s2 into dst**

```c
If (dstSize < strlen(s1) + strlen(s2) + 1)
    ERROR("buffer overflow");
strcpy(dst, s1);
strcat(dst, s2);
```
Buffer Overflow Danger Signs: Difficult to Use and Truncation

- **strncat**(dst, src, n)
  - n is the maximum number of chars of src to append (trailing null also appended)
  - can overflow if n \( \geq (\text{dstSize} - \text{strlen}(\text{dst})) \)
- **strncpy**(dst, src, n)
  - Writes n chars into dst, if strlen(src) \(< n\), it fills the other n-strlen(src) chars with 0's
  - If strlen(src) \( \geq n\), dst is not null terminated

- Truncation detection not provided
- Deceptively insecure
  - Feels safer but requires same careful use as strcat

Safer String Handling: C-library functions

- **snprintf**(buf, bufSize, fmt, ...)** and \vsnprintf**
  - Truncation detection possible
    (result \( \geq \) bufSize implies truncation)
  - Can be used as a safer version of strcpy and strcat

**Proper usage: concat s1, s2 into dst**

\[
\text{r} = \text{snprintf}(\text{dst}, \text{dstSize}, "\%s\%s", \text{s1}, \text{s2});
\]
\[
\text{If} \ (\text{r} \geq \text{dstSize})
\]
\[
\{ \text{ERROR("truncation")}; \}
\]
Injection Attacks

- **Description**
  - A string constructed with user input, that is then interpreted by another function, where the string is not parsed as expected
    - Command injection (in a shell)
    - Format string attacks (in printf/scanf)
    - SQL injection
    - Cross-site scripting or XSS (in HTML)

- **General causes**
  - Allowing metacharacters
  - Not properly quoting user data if metacharacters are allowed

SQL Injections

- **User supplied values used in SQL command must be validated, quoted, or prepared statements must be used**

- **Signs of vulnerability**
  - Uses a database mgmt system (DBMS)
  - Creates SQL statements at run-time
  - Inserts user supplied data directly into statement without validation
SQL Injections: attacks and mitigations

• Dynamically generated SQL without validation or quoting is vulnerable

```php
$u = "' drop table t --";
$sth = $dbh->do("select * from t where u = '$u'");
```

Database sees 2 statements:
```
select * from t where u = ' ' drop table t --'
```

• Use prepared statements to mitigate

```php
$sth = $dbh->do("select * from t where u = :u", $u);
```

– SQL statement template and value sent to database
– No mismatch between intention and use
**Integer Vulnerabilities**

- **Description**
  - Many programming languages allow silent loss of integer data without warning due to
    - Overflow
    - Truncation
    - Signed vs. unsigned representations
  - Code may be secure on one platform, but silently vulnerable on another, due to different underlying integer types.

- **General causes**
  - Not checking for overflow
  - Mixing integer types of different ranges
  - Mixing unsigned and signed integers

**Integer Danger Signs**

- Mixing signed and unsigned integers
- Converting to a smaller integer
- Using a built-in type instead of the API’s typedef type
- However built-ins can be problematic too: `size_t` is unsigned, `ptrdiff_t` is signed
- Assigning values to a variable of the correct type before data validation (range/size check)
Race Conditions

• Description
  – A race condition occurs when multiple threads of control try to perform a non-atomic operation on a shared object, such as
    • Multithreaded applications accessing shared data
    • Accessing external shared resources such as the file system

• General causes
  – Threads or signal handlers without proper synchronization
  – Non-reentrant functions (may have shared variables)
  – Performing non-atomic sequences of operations on shared resources (file system, shared memory) and assuming they are atomic

File System Race Conditions

• A file system maps a path name of a file or other object in the file system, to the internal identifier (device and inode)
• If an attacker can control any component of the path, multiple uses of a path can result in different file system objects

• Safe use of path
  – eliminate race condition
    • use only once
    • use file descriptor for all other uses
  – verify multiple uses are consistent
**File System Race Examples**

- **Check properties of a file then open**
  
  **Bad:** access or stat \(\rightarrow\) open
  
  **Safe:** open \(\rightarrow\) fstat

- **Create file if it doesn’t exist**
  
  **Bad:** if stat fails \(\rightarrow\) creat(fn, mode)
  
  **Safe:** open(fn, O_CREAT|O_EXCL, mode)

  - Never use O_CREAT without O_EXCL
  
  - Better still use safefile library

  

  James A. Kupsch and Barton P. Miller, “How to Open a File and Not Get Hacked,” 2008 Third International Conference on Availability, Reliability and Security (ARES), Barcelona, Spain

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**Race Condition Temporary Files**

- **Temporary directory (/tmp) is a dangerous area of the file system**
  
  - Any process can create a directory entry there
  
  - Usually has the sticky bit set, so only the owner can delete their files

- **Ok to create *true temporary files* in /tmp**
  
  - Create using mkstemp, unlink, access through returned file descriptor
  
  - Storage vanishes when file descriptor is closed

- **Safe use of /tmp directory**
  
  - create a secure directory in /tmp
  
  - use it to store files
Race Condition Examples

• Your Actions
  
  ```
  s = strdup("/tmp/zXXXXXX")
  tempnam(s)
  // s now "/tmp/zRANDOM"
  
  f = fopen(s, "w+")
  // writes now update
  // /etc/passwd
  ```

  **Safe Version**
  
  ```
  fd = mkstemp(s)
  f = fdopen(fd, "w+")
  ```

  **Attackers Action**
  
  ```
  link = "/etc/passwd"
  file = "/tmp/zRANDOM"
  symlink(link, file)
  ```

Not Dropping Privilege

• Description
  
  – When a program running with a privileged status (running as root for instance), creates a process or tries to access resources as another user

• General causes
  
  – Running with elevated privilege
  – Not dropping all inheritable process attributes such as uid, gid, euid, egid, supplementary groups, open file descriptors, root directory, working directory
  – not setting close-on-exec on sensitive file descriptors
Not Dropping Privilege: chroot

- **chroot** changes the root directory for the process, files outside cannot be accessed
- Only root can use **chroot**
- Need to **chdir("/")** to somewhere underneath the new root directory, otherwise relative pathnames are not restricted
- Need to recreate all support files used by program in new root: /etc, libraries, ...

Insecure Permissions

- Set **umask** when using **mkstemp** or **fopen**
  - File permissions need to be secure from creation to destruction
- Don’t write sensitive information into insecure locations (directories need to have restricted permission to prevent replacing files)
- Executables, libraries, configuration, data and log files need to be write protected
Insecure Permissions

• If a file controls what can be run as a privileged, users that can update the file are equivalent to the privileged user

File should be:
  – Owned by privileged user, or
  – Owned by administrative account
    • No login
    • Never executes anything, just owns files

• DBMS accounts should be granted minimal privileges for their task

Trusted Directory

• A trusted directory is one where only trusted users can update the contents of anything in the directory or any of its ancestors all the way to the root

• A trusted path needs to check all components of the path including symbolic links referents for trust

• A trusted path is immune to TOCTOU attacks from untrusted users

• safefile library
  – http://www.cs.wisc.edu/mist/safefile
  – Determines trust based on trusted users & groups
Command Line

• Description
  – Convention is that \texttt{argv[0]} is the path to the executable
  – Shells enforce this behavior, but it can be set to anything if you control the parent process

• General causes
  – Using \texttt{argv[0]} as a path to find other files such as configuration data
  – Process needs to be setuid or setgid to be a useful attack

Environment

• List of (name, value) string pairs
• Available to program to read
• Used by programs, libraries and runtime environment to affect program behavior

• Mitigations:
  – Clean environment to just safe names & values
  – Don’t assume the length of strings
  – Avoid PATH, LD_LIBRARY_PATH, and other variables that are directory lists used to look for execs and libs
General Software Engineering

- Don’t trust *user data*
  - You don’t know where that data has been
- Don’t trust your own *client* software either
  - It may have been modified, so always revalidate data at the server.
- Don’t trust your operational configuration either
  - If your program can test for unsafe conditions, do so and quit
- Don’t trust your own code either
  - Program *defensively* with checks in high and low level functions
- **KISS** - Keep it simple, stupid
  - Complexity kills security, its hard enough assessing simple code

Let the Compiler Help

- Turn on compiler warnings and fix problems
- Easy to do on new code
- Time consuming, but useful on old code
- Use lint, multiple compilers
  - **-Wall** is not enough!
    - Many useful warning including security related warnings such as format strings and integers
Books


Questions?

http://www.cs.wisc.edu/mist