Vulnerability Assessment and Secure Coding Practices for Middleware

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CERN, Geneva, Switzerland
December 7, 2009

This research funded in part by Department of Homeland Security grant FA8750-10-2-0030 (funded through AFRL). Past funding has been provided by NATO grant CLG 983049, National Science Foundation grant OCI-0844219, the National Science Foundation under contract with San Diego Supercomputing Center, and National Science Foundation grants CNS-0627501 and CNS-0716460.

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

```c
/* 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   */

void ExecUid(int uid, int gid, char *jailDir,
             char *prog, char *const argv[])
{
  if (uid == 0 || gid == 0)  {
    FailExit("ExecUid: root uid or gid not allowed");
  }

  chroot(jailDir);  /* restrict access to this dir */

  setuid(uid);      /* drop privs */
  setgid(gid);

  fprintf(LOGFILE, "Execvp of %s as uid=%d gid=%d\n",
                   prog, uid, gid);
  fflush(LOGFILE);

  execvp(prog, argv);
}
```


Part 2 Roadmap

- Part 1: Vulnerability assessment process
- Part 2: Secure coding practices
  - Introduction
  - Handling errors
  - Numeric parsing
  - Missing error detection
  - ISO/IEC 24731
  - Variadic functions
  - Buffer overflows
  - Injections
  - Integer
  - Race conditions
  - Privileges
  - Command line
  - Environment
  - Denial of service
  - General engineering
  - Compiler warnings

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

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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)

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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

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

id								validId			
								\0	\0	\0	\0

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

id								validId			
e	v	i	l	l	o	g	i	110 n	\0	\0	\0

```
/* 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

Unsafe	Safe
`gets(s)`	`fgets(s, sLen, stdin)`
`getcwd(s)`	`getwd(s, sLen)`
`scanf("%s", s)`	`scanf("%100s", s)`

`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

```
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 >=(dstSize-strlen(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)>=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 >= bufSize` implies truncation)
  - Can be used as a safer version of `strcpy` and `strcat`

Proper usage: concat s1, s2 into dst

```
r = snprintf(dst, dstSize, "%s%s",s1, s2);
If (r >= dstSize)
      {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

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

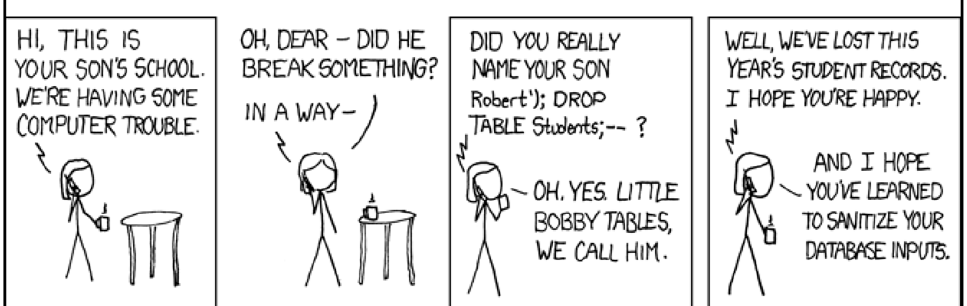
Database sees 2 statements:

```
select * from t where u = ' '; drop table t --'
```

- Use prepared statements to mitigate

```
$sth = $dbh->do("select * from t where 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

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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

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File System Race Examples

- Check properties of a file then open
  - Bad: `access` or `stat` ➔ `open`
  - Safe: `open` ➔ `fstat`
- Create file if it doesn't exist
  - Bad: if `stat` fails ➔ `creat(fn, mode)`
  - Safe: `open(fn, O_CREAT|O_EXCL, mode)`
  - Never use `O_CREAT` without `O_EXCL`
  - Better still use safefile library
    - http://www.cs.wisc.edu/mist/safefile
      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

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**

time

Attackers Action

```
s=strdup("/tmp/zXXXXXX")
tempnam(s)
// s now "/tmp/zRANDOM"
```

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

```
f = fopen(s, "w+")
// writes now update
// /etc/passwd
```

Safe Version

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


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 `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 `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!

  gcc: **-Wall, -W, -O2, -Werror, -Wshadow, -Wpointer-arith, -Wconversion, -Wcast-qual, -Wwrite-strings, -Wunreachable-code** and many more
  - Many useful warning including security related warnings such as format strings and integers

Books

- Viega, J. & McGraw, G. (2002). *Building Secure Software: How to Avoid Security Problems the Right Way*. Addison-Wesley.
- Seacord, R. C. (2005). *Secure Coding in C and C++.* Addison-Wesley.
- Seacord, R. C. (2009). *The CERT C Secure Coding Standard*, Addison-Wesley.
- McGraw, G. (2006). *Software security: Building Security In*. Addison-Wesley.
- Dowd, M., McDonald, J., & Schuh, J. (2006). *The Art of Software Assessment: Identifying and Preventing Software Vulnerabilities*. Addison-Wesley.

Questions?

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