Vulnerability Assessment and Secure Coding Practices for Middleware

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Part 2 Roadmap

- **Part 1: Vulnerability assessment process**
- **Part 2: Secure coding practices**
  - **Introduction**
  - **Handling errors**
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  - **Environment**
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  - **Memory allocators**
  - **General engineering**
  - **Compiler warnings**

Vulnerability Types

- 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
- When error is detected
  - Handle locally and continue
  - Cleanup and propagate the error
  - Exit the application
- All APIs you use, or develop, that can fail need to be able to report errors to the caller
- Using exceptions forces error handling

Numeric Parsing
No Error Indication

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

Correct Numeric Parsing

```
char *endptr;
long longVal;

errno = 0;              /* clear to detect all errs */
longVal = strtol(s, &endptr, 10);
if (errno == ERANGE)
   {ERROR("overflow");}
if (endptr == 0)        /* errno is EINVAL */
   {ERROR("non-numeric");}
if (errno != 0)
   {ERROR("other error");}
if (*endptr != '\0')   /* parse ok, optional errors */
   {ERROR("non-numeric at end");}
if (isspace(*s))
   {ERROR("space at beginning");}
```

Correct Numeric Parsing in C++

- iostream inserter's
  - Type safe
  - All errors set stream to failed (test with `!is`)
  - Use `istringstream` to parse a string

```
istringstream is("123 87.32");
is >> i >> f;
if (!is) {ERROR("parse error");
```

- Boost's `lexical_cast<T>(s)`
  - http://www.boost.org
  - Throw's `bad_lexical_cast` exception on failure

Missing Error Detection

- `strcat`, `strcpy`, `strncat`, `strncpy`, `gets`, `getpass`, `getwd`, `scanf` (with `%s` or `%[…]`, without width specified)
  - Unable to report if buffer would overflow (not enough information present)
  - Only secure in rare case where files or strings are verified for secure values before use
  - Never use these

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
- http://www.open-std.org/jtcl/sc22/wg14

ISO/IEC 24731: Run-time Constraints

- Property of the arguments that must be true at call time
- Violations handled by callback
  - default is to abort
- Common run-time constraints
  - `rsize_t` parameter type
    - size of the buffer or amount to copy
    - violation if `size > RSIZE_MAX`
    - catches large size caused by integer overflow
  - Buffer pointers not `NULL`
  - `dst` buffer too small for operation
    - usually a violation (`snprintf` truncates)

Variadic Functions

- C functions that can take a variable number of parameters
- Not type safe
- Common variadic functions
  - `printf`, `scanf`, `syslog` families
    - never take the format string from the user
    - use compile time constants for format string
    - use compiler warnings
    - in C++, use iostreams instead
  - `execl` family
  - `open` with `O_CREAT` (3rd argument is the mode)

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
- Usual sign 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;
if (validId)
   {DoPrivilegedOp();} /* gets executed */
```

C-style String Design Flaws

- Null terminated array of characters
- Represented by a pointer to this array
- Not a proper type, just a convention
- Only language support is string literals
  - Initialize a char array
  - Create array containing a constant string literal
- Problems
  - Null may be missing
  - Pointers are difficult to use correctly
  - Size of buffer is kept externally from pointer if at all
  - Many common operations are expensive
  - Can't have a string with a null in it

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)`

Buffer Overflow Danger Signs:
scanf family

- Max field can not be taken from an argument
  - `*` width suppresses assignment
- `%nc` does not null terminate
- `%ns` and `%n[…]` require a buffer of size *n*+1
- Requires manual coordination of format string, number and types of arguments, and result

Example: 3 items must be coordinated

```
char big[100], small[10];
int r, j;
r = scanf("%99s %9s %d", big, small, &j);
If (r == EOF) ERROR("EOF")
If (r != 3) ERROR("bad line");
```

strcat, strcpy, sprintf, vsprintf

- Impossible for function to detect overflow
  - Destination buffer size not passed
- Difficult to use safely w/o preflight 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
  - `n` is not a static value, same check required 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`**
  - Officially doesn't exist until C99 standard

Proper usage: concat s1, s2 into dst

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

Safer String Handling:
BSD's strlcpy and strlcat

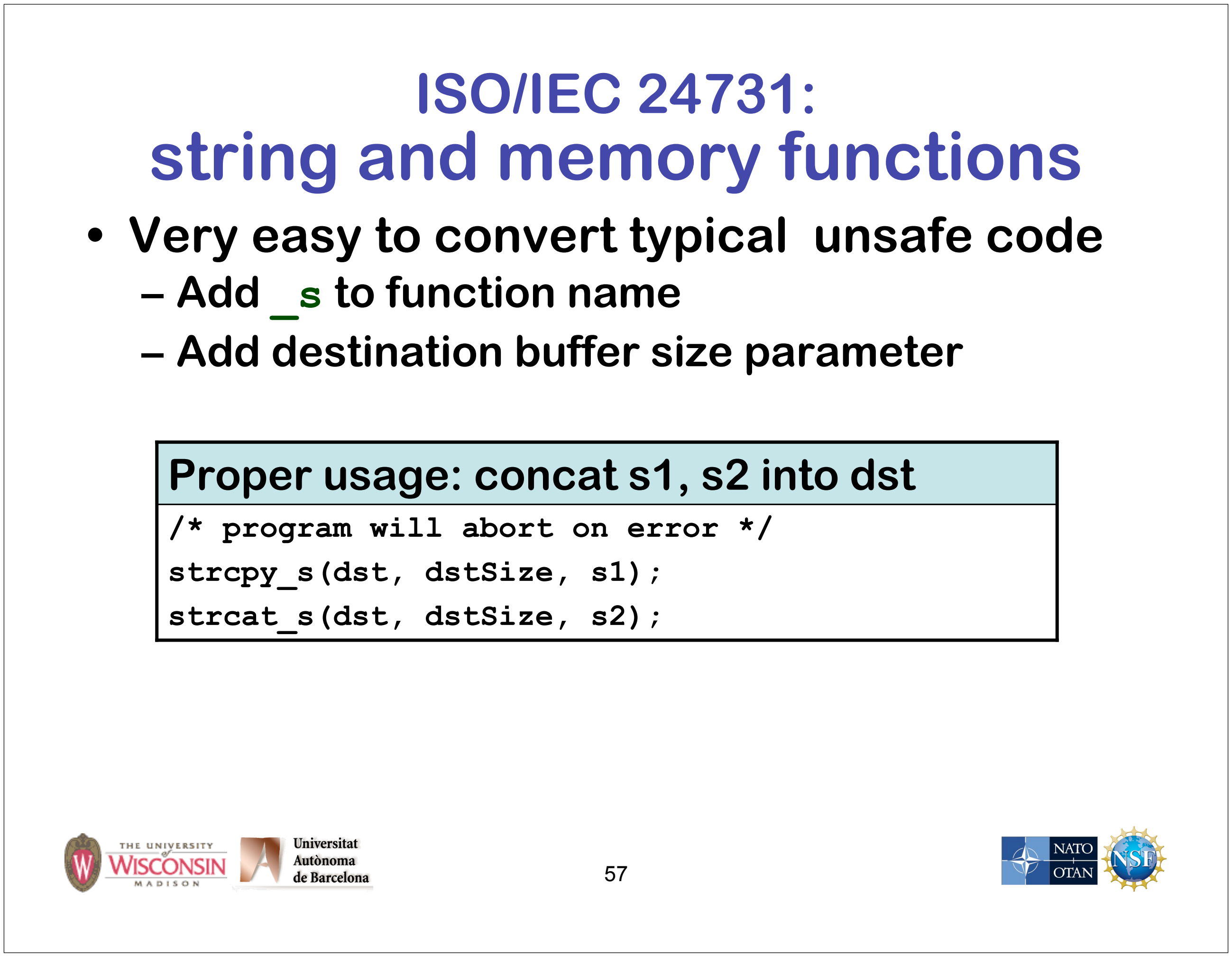
- **strlcpy**(dst, src, size) **and** **strlcat**(dst, src, size)
  - **size** is always the size of the **dst** buffer
  - Returns number of chars required
  - **result >= size** indicates truncation
  - dst always null terminated, except strlcat where dst is not terminated
  - Can read outside src if not null-terminated
  - Not universally implemented (not in linux)

Safer String Handling:
BSD's strlcpy and strlcat

Proper usage: concat s1, s2 into dst

```
/* safe to just check errors at last call */
(void)strlcpy(dst, s1, dstSize);

r = strlcat(dst, s2, dstSize)
if (r >= dstSize)  {
      if (r == dstSize && dst[r] != '\0')  {
            /* this should not happen as
               strlcpy will always terminate */
            ERROR("unterminated dst");
      }  else  {
            ERROR("truncation");
      }
}
```

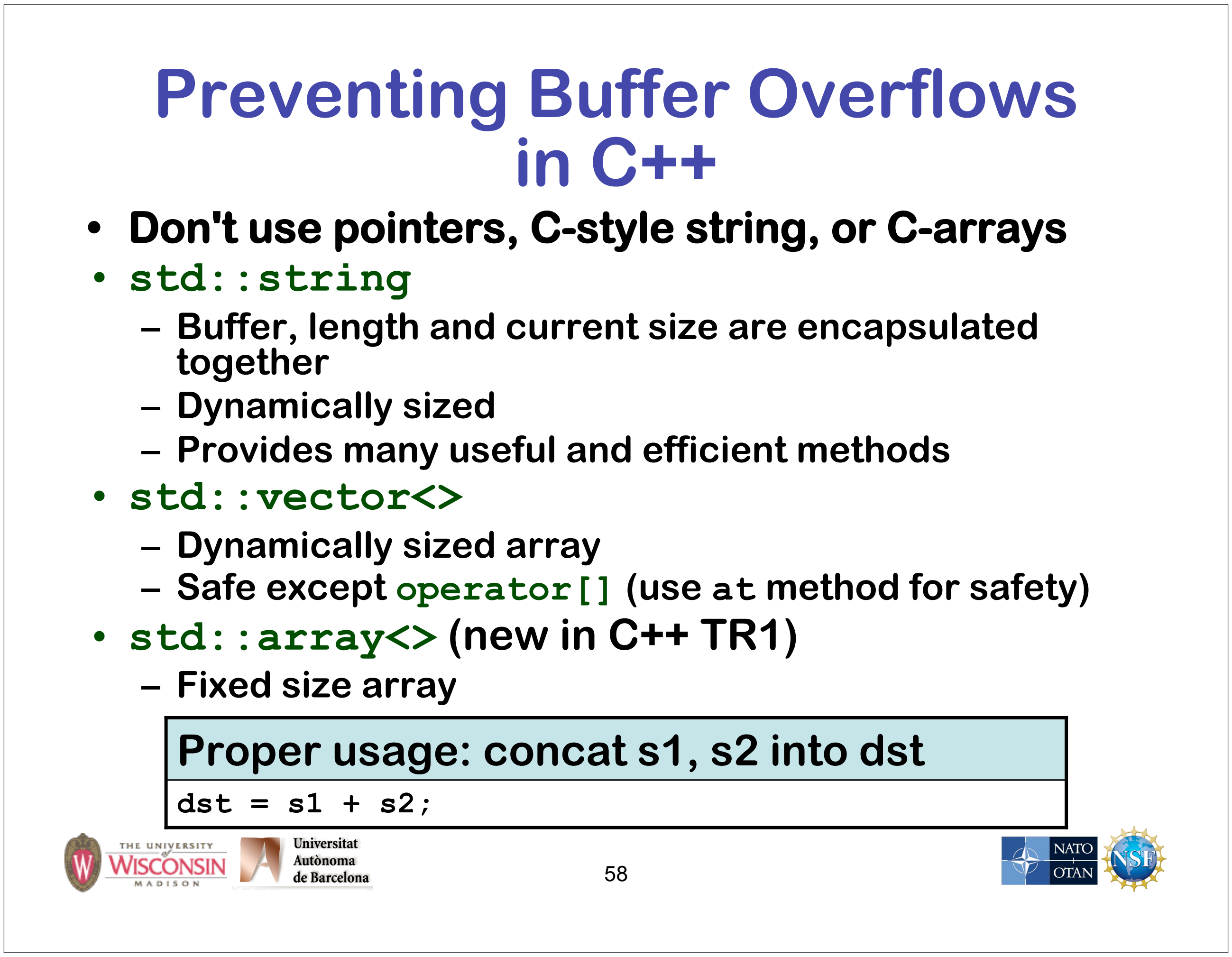


ISO/IEC 24731: string and memory functions

- Very easy to convert typical unsafe code
  - Add _s to function name
  - Add destination buffer size parameter

Proper usage: concat s1, s2 into dst

```
/* program will abort on error */
strcpy_s(dst, dstSize, s1);
strcat_s(dst, dstSize, s2);
```



Preventing Buffer Overflows in C++

- **Don't use pointers, C-style string, or C-arrays**
- `std::string`
  - Buffer, length and current size are encapsulated together
  - Dynamically sized
  - Provides many useful and efficient methods
- `std::vector<>`
  - Dynamically sized array
  - Safe except `operator[]` (use `at` method for safety)
- `std::array<>` (new in C++ TR1)
  - Fixed size array

Proper usage: concat s1, s2 into dst

```
dst = s1 + s2;
```

Potential Problems with C++ Strings

- System call and libraries expect C-strings
  - `c_str` method will return a constant C-string pointer
  - Valid only until string is modified
  - Nulls are allowed
    - Truncated at first null when converted to C-string
    - If tests are done on C++-string and used as a C-string these may be different
    - Same problem in other languages such as Perl
- Denial of service if length not restricted

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)
  - Uses SQL commands created at run-time
- Do not use SQL fragments from user
  - create parsable language
  - securely translate to limited SQL

SQL Injection Attacks

- Dynamically generated SQL without validation or quoting is vulnerable

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

- Quoting values is safe if done correctly

```
$u = " \\'; drop table t --";    # perl eats one \
$u =~ s/'/''/g;                  # quote (' -> '')
$sth = $dbh->do("select * from t where u = '$u'")
--  select * from t where u = ' \''; drop table t --'
```

- What is correctly? Previous example is correct in standard SQL, but incorrect in systems that allow \-escapes

SQL Injection Mitigations

- Best to use prepared statements

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

- Use library functions to perform quoting

```
$sth = $dbh->do("select * from t where u = "
                 . $dbh->quote($u))
```

- Other SQL safe practices
  - Views can be used to limit access to data
  - Stored procedures can help, but not if they dynamically create and execute SQL
  - Restrict rights of database account to minimum required

Command Injections

- User supplied data used to create a string that is the interpreted by command shell such as `/bin/sh`
- Signs of vulnerability
  - Use of `popen`, or `system`
  - `exec` of a shell such as `sh`, or `csh`
- Usually done to start another program
  - That has no C API
  - Out of laziness

Command Injection Mitigations

- Check user input for metacharacters
- Quote those that can't be eliminated or rejected
  - replace single quotes with the four characters, `'\''`, and enclose each argument in single quotes
- Beware of program argument injections, allowing arguments to begin with `"-"` can be dangerous
- Use `fork`, drop privileges and `exec` for more control
- Avoid if at all possible
- Use C API if exists

Perl Command Injection Danger Signs

- `open(F, $filename)`
  - Filename is a tiny language besides opening
    - Open files in various modes
    - Can start programs
    - dup file descriptors
  - If `$userFile` is `"rm -rf /|"`, you probably won't like the result
  - Use separate mode version of open to eliminate vulnerability

Perl Command Injection Danger Signs

- Vulnerable to shell interpretation

```
open(C, "$cmd|")         open(C, "-|", $cmd)
open(C, "|$cmd")         open(C, "|-", $cmd)
`$cmd`                   qx/$cmd/
system($cmd)
```

- Safe from shell interpretation

```
open(C, "-|", @argList)
open(C, "|-", @cmdList)
system(@argList)
```

Eval Injections

- A string formed from user supplied input that is used as an argument that is interpreted by the language running the code
- Usually allowed in scripting languages such as Perl, shells, and SQL
- In Perl `eval($s)` and `s/$pat/$replace/ee`
  - `$s` and `$replace` are evaluated as perl code

Format String Injections

- User supplied allowed to create format strings in `scanf` or `printf`
- `printf(userData)` is insecure
  - `%n` can be used to write memory
  - large field width values can be used to create a denial of service attack
  - Safe to use `printf("%s", userData)` or `fputs(userData, stdout)`
- `scanf(userData, …)` allows arbitrary writes to memory pointed to by stack values
- ISO/IEC 24731 does not allow `%n`

Directory Traversal

- Description
  - When user data is used to create a pathname to a file system object that is supposed to be restricted to a particular set of paths or path prefixes, but which the user can circumvent
- General causes
  - Not checking for path components that are empty, `"."` or `".."`
  - Not creating the canonical form of the pathname (there is an infinite number of distinct strings for the same object)
  - Not accounting for symbolic links

Directory Traversal Mitigation

- Use `realpath` or something similar to create canonical pathnames
- Use the canonical pathname when comparing filenames or prefixes
- If using prefix matching to check if a path is within directory tree, also check that the next character in the path is the directory separator or `'\0'`

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
- `size_t` is unsigned, `ptrdiff_t` is signed
- Using a built-in type instead of the API's typedef type
- Not assigning values to a variable of the correct type before data validation, so the validated value is not the same as the value used

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
  - Using threads without proper synchronization including non-thread (non-reentrant) safe functions
  - Performing non-atomic sequences of operations on shared resources (file system, shared memory) and assuming they are atomic
  - Signal handlers

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 other uses
  - verify multiple uses are consistent

Race Conditions Checking File Properties

- Use the path to check properties of a file, and then open the file (also called time of check, time of use TOCTOU)
  - `access` followed by `open`
    - Safe to just set the effective ids and then just open the file
  - `stat` followed by `open`
    - Safe to `open` the file and then `fstat` the file descriptor

Race Condition File Attributes

- Using the path to create or open a file and then using the same path to change the ownership or mode of the file
  - Best to create the file with the correct owner, group, and mode at creation
  - Otherwise the file should be created with restricted permissions and then changed to less restrictive using `fchown` and `fchmod`
  - If created with lax permissions there is a race condition between the attacker opening the file and permissions being changed

Race Condition Creating a File

- Want to atomically check if file exists and create if not, or fail if it exists
- Common solution is to check if file exists with `stat`, then `open` if it doesn't
- Open a file or create it if does not exist
  - `creat(fname, mode)`
    `open(fname, O_CREAT|O_WRONLY|O_TRUNC, mode)`
- Must use `O_CREAT|O_EXCL` to get desired property
- Never use `O_CREAT` without `O_EXCL`

Race Condition Creating a File

- open also fails if the last component of the path is a symbolic link when using O_CREAT|O_EXCL
- fopen never uses O_EXCL
  - Only use for read mode
  - For append or write modes use open and fdopen to create a FILE* from a file descriptor
- C++ iostreams never use O_EXCL
  - No standard way to get iostream from fd
  - Use use non-standard extension
  - Use library that can create a stream from a fd, such as http://www.boost.org/libs/iostream

Safely Create or Open a File

- If you want to open or create like O_CREAT without O_EXCL use the following:

```
f = open(fname, O_CREAT|O_EXCL|O_RDWR, mode);
if (f == -1 && errno == EEXIST)  {
   f = open(fname, O_RDWR)
}
```

- 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
  - Does the above and much more

Race Condition Temporary Files

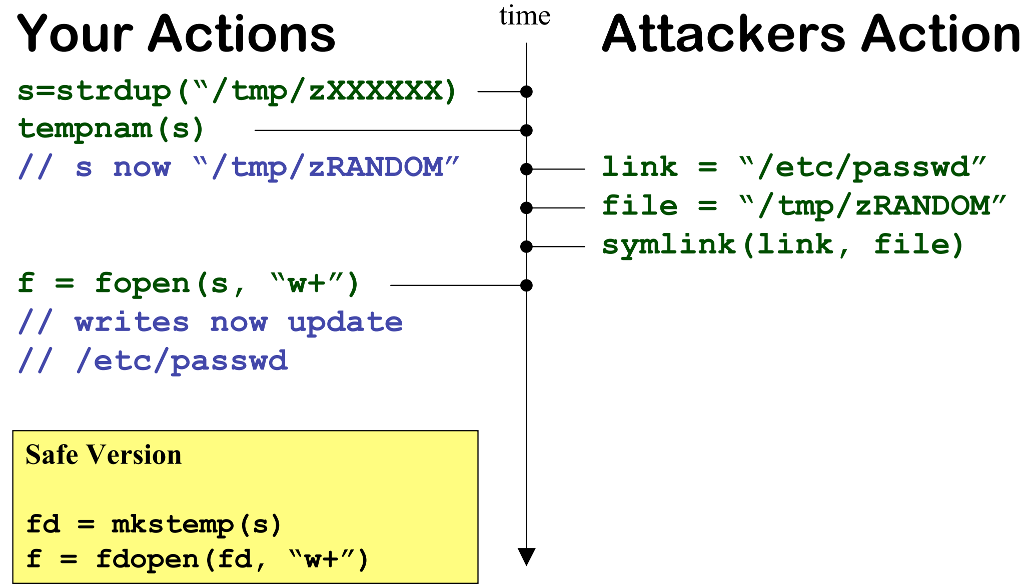
- Temporary directory (`/tmp`) is the bad part of town for the file system
- Any process can create a file there
- Usually has the sticky bit set, so only the owner can delete their files
- Ok to create true temporary files here
  - Created, immediately deleted, and only accessed through the original 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 Temporary Files

- `mktemp`, `tmpnam`, or `tempnam`, then `open`
  - Return filename that does not exist
  - a race condition exists if `O_EXCL` is not used
- Use `mkstemp` which returns the filename and a file descriptor to the opened file (use `umask` to restrict privileges)
- To create a directory use `mkdtemp` if available or the following:

```
for (int j = 0; j < 10; ++j)  {
    strcpy(path, template);
    if (mktemp(path) == NULL)  {ERROR("mktemp failed");}
    if (mkdir(path) != -1 || errno != EEXIST)  {
           break;
    }
}
```

Race Condition Examples



- Your Actions

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


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

Attackers Action

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

Safe Version

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

Non-canonical Forms

- If one value can be encoded in multiple different forms they must be converted to a unique canonical form before comparison
  - Paths: use (device, inode) pair, or convert to a canonical form using realpath
  - Usernames and groups: use uid and gid
  - utf: convert to utf-32 or canonical form
  - HTML & URL encoded: decode
  - Case insensitive: convert to all lower (some languages lose info if converted to upper)

Non-canonical Forms

- In weakly typed language, such as a shell or Perl, where a value can be a number or string use the correct comparison operator
  - Comparing numbers lexically is bad
    - `"100" le "2"`
    - `"000" ne "0"`
  - Comparing strings numerically is bad
    - `"111111" > "9sdflkj"`
    - `"000" == "0abc"`
    - `"xyz" == "abc"`

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
  - Owned by privileged user
  - 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

- Description
  - A program's environment is a list of strings that a program is allowed to interpret. Libraries are also allowed to use the environment to alter their behavior. Since changes to the environment can alter the execution of a program, library code, and spawned programs, the environment must be carefully controlled.
- General causes
  - Not sanitizing the environment
  - Allowing user input to alter the environment
  - Not fully specified as to what happens when multiple values with the same name, or value without '=' in it

Environment Mitigation

- Record needed values of the environment, sanitize them, clear the environment, add only necessary values, discard others
- Don't make assumptions about size of values
- Don’t allow code from the user to set environment
- Use `execle` or `execve` to start a process with user supplied environment variables
- Use `setenv` instead of `putenv`

Environment Mitigation

- `PATH`: list of directories to search for executables given as just a name
  - Only used by `execlp` and `execvp`
  - Use `execle` or `execve` and full paths
  - Set `PATH` to something safe `/bin:/usr/bin`
- `LD_LIBRARY_PATH`: list of directories to search for shared libraries, could be used to inject a library into your process
- Many others

Denial of Service

- Description
  - Programs becoming unresponsive due to over consumption of a limited resource or unexpected termination.
- General causes
  - Not releasing resources
  - Crash causing bugs
  - Infinite loops or data causing algorithmic complexity to consume excessive resources
  - Failure to limit data sizes
  - Failure to limit wait times
  - Leaks of scarce resources (memory, file descriptors)

Information Leaks

- Description
  - Inadvertent divulgence of sensitive information
- General causes
  - Reusing buffers without completely erasing
  - Providing extraneous information that an adversary may not be able to otherwise obtain
    - Generally occurs in error messages
    - Give as few details as possible
    - Log full details to a database and return id to user, so admin can look up details if needed

Information Leaks

- General causes (cont.)
  - Timing attacks where the duration of the operation depends on secret information
  - Lack of encryption when using observable channels
  - Allowing secrets on devices where they can't be erased such as swap space (use `mlock`) or backups

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
- 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

Let the Perl Compiler Help

- `-w` - produce warning about suspect code and runtime events
- `use strict` - fail if compile time
- `use Fatal` - cause built-in function to raise an exception on error instead of returning an error code
- `use diagnostics` - better diagnostic messages

Perl Taint Mode

- Taint mode (-T) prevents data from untrusted sources from being used in dangerous ways
- Untrusted sources
  - Data read from a file descriptor
  - Command line arguments
  - Environment
  - User controlled fields in password file
  - Directory entries
  - Link referents
  - Shared memory
  - Network messages
- Environment sanitizing required for `exec`
  - `IFS PATH CDPATH ENV BASH_ENV`

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