Secure Programming II
“I’m paranoid, but am I paranoid enough?”
**Special Techniques for Secure Programs**

- Buffer overflows are bad in any case
- Some problems are only a risk for security-sensitive programs
- But what is a “security-sensitive program”?
- A security-sensitive program is one that runs with one set of permissions and accepts input from someone with different (especially lesser) permissions
- Includes most network servers and privileged programs, and many system daemons
Privileged Programs Are More Sensitive

- Anyone on the local machine can invoke them
- Many environmental influences that can be controlled by the invoker
- On the other hand, network daemons can be accessed remotely
Macro Injection Attacks

- Suppose a program is querying an SQL database based on valid userID and query string:

\[
\text{sprintf(buf, "select where user=\"\%s\" && query=\"\%s\"", uname, query);}
\]

- What if \text{query} is

\[
\text{foo" || user="root}
\]

- The actual command passed to SQL is

\[
\text{select where user="uname" && query = "foo" || user="root"}
\]

- This will retrieve records it shouldn’t have
What Was Wrong with That Slide?
Did You Notice?

• I wrote `sprintf` instead of `snprintf`
• I was mostly trying to save room on a complex slide
• I was also curious to see who’d notice...
SQL Injection Attacks

(From http://xkcd.com/327/)

Hi, this is your son’s school. We’re having some computer trouble.

Oh, dear — did he break something? In a way—

DID YOU REALLY NAME YOUR SON Robert'); DROP TABLE Students; -- ?

Well, we’ve lost this year’s student records. I hope you’re happy.

And I hope you’ve learned to sanitize your database inputs.
Injection Attacks

- Injection attacks (usually against SQL) are the most common security failure we see today
- Most web servers are front ends for database systems; if programmers are careless about how this is done, there’s trouble
- The risk comes from some other program parsing a string and executing it—and the string may do dangerous things
- Stored SQL procedures are much safer—there’s no parsing involved
More Generally

• If you invoke an external program, be aware of its parsing rules
• Especially serious for languages like Shell, Perl, and Python, where data can be converted to statements and executed
• Example: what delimits different arguments to the shell?
• Blank, tab, newline? Why?
IFS

- The shell variable IFS lists the delimiters used when parsing command lines
- If you can change it, you can control the shell’s parsing
- (The exact effects are subtle, because of the risks of just accepting it blindly—know your semantics!)
Other Sensitive Environment Variables

- **PATH** Search path for finding commands
  - If “.” is first, you’ll execute a command in the current directory. What if it’s booby-trapped?
  - Secure programs should always use absolute paths or reset **PATH**

- **ENV** With some shells, a file to execute on startup

- **LD_LIBRARY_PATH** The search path for shared libraries

- **LD_PRELOAD** Extra modules loaded at runtime

Some of these are disabled for setUID programs, to minimize the risks
Search Paths

- What directories do programs come from? Components of programs?
- (Important for correctness as well as security—complex issue for Multics, in the 1960s.): which version of a library routine do you get?
- Choices: program specification, user specification, system directories, current directory, location of base program, location of data file, probably more
File Descriptors

- Normally, file descriptor 0 is stdin, 1 is stdout, and 2 is stderr
- The `open()` system call allocates the first available file descriptor, starting from 0
- Suppose you close fd 1, then invoke a setUID program that will open some sensitive file for output
- Anything it prints to stdout will overwrite that file
- Similar tricks for fd 0
Some Other Inherited Attributes

current directory
root directory  see \texttt{chroot()}
resource limits  see \texttt{getrlimit()}
umask
timers  see \texttt{getitimer()}
signal mask
open files  See the \texttt{FIOCLEX} option to \texttt{ioctl}
Current uid
Effective uid
Process Creation on Windows

- The `CreateProcess` call creates processes on Windows
- Executing a new program is part of the process creation mechanism
- 10 parameters control the program to be executed, window creation, priority, security attributes, file inheritance, and much more
- The Windows call does more for you, but is it simpler?
- Do programmers have a better understanding of what is inherited, and the implications of those things?
Why Do These Matter?

- Will such a program misbehave?
- Will it core dump after having read a sensitive file? (Some systems prevent core dumps of setUID programs.)
- If the program terminates prematurely, will it leave some crucial resource locked?
Access Control

- Some privileged programs need to read or write user-specified files
- Example: local mailer, as we saw last week
- Other examples: web server (remote), lpr (setUID)
- Very tricky...
Remote Access Control

- Don’t want to offer all system files to, say, web users
- Operating system doesn’t help—too many files are world-readable
- Web server must implement its own access control
- Several different levels
Filename Parsing

- User supplies pathname; application must check for validity
- Administrator specifies list of accessible files and/or directories
- Sometimes, wildcards—*, ?, and more—are permitted
- Application must parse supplied filename
- Remarkably difficult
The “..” Problem

- Attackers try to get at other files
- Simplest attack: put .. in the path
- http://example.com/../../etc/passwd
- The .. can occur later:
  - http://example.com/a/b/../../etc/passwd
- If directory /dir is legal, what about /dir/../../dir/file? Do you want to count levels?
- Watch out for /dir///../../file—replicated /’s counts as a single one
- Note that /foo..bar/bletch is legal
Application Syntax Issues

- Applications can have their own weird syntax
- Example: in URLs, %%xx can specify two hex digits for the character. %2F is the same as /
- When is that expanded?
- How is /foo%2F..%2Fetc/passwd processed?
Unicode

- Standard for representing (virtually) all of the world’s scripts
  - There are proposals for Klingon and Tengwar (“Elvish”) codepoints
- Many problems!
- Some symbols look the same, but have different values: ordinary /—technically called “solidus”—is U+002F, but U+2044, “fraction slash”, looks the same
- “Combining characters” and “grapheme joiners” make life even more complicated. Thus, á can be U+00C1 or the two-character sequence U+0041,U+0301
- Comparison rules have to be application-dependent—and watch out for false visual equivalences; these have already been used for attacks, especially with Cyrillic domain names
Cyrillic Homograph Attack on “Paypal”

<table>
<thead>
<tr>
<th>Glyph</th>
<th>Unicode value in Cyrillic</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>U+0420</td>
</tr>
<tr>
<td>a</td>
<td>U+0430</td>
</tr>
<tr>
<td>y</td>
<td>U+0443</td>
</tr>
<tr>
<td>p</td>
<td>U+0440</td>
</tr>
<tr>
<td>a</td>
<td>U+0430</td>
</tr>
<tr>
<td>l</td>
<td>U+006C (ASCII)</td>
</tr>
</tbody>
</table>
Operating Systems Don’t Have Such Problems

- Conceptually, you’re trying to permit certain subtrees.
- The application is trying to map a string into a subtree
- The OS has one mapping function; the application has another
- The OS doesn’t care about the tree structure for access control; it uses its own mechanisms
- The OS stores permissions with the data; no separate parse is needed
File Access by SetUID Programs

- Some commands—`lpr`, for example—need to write to restricted places, but also read users’ files
- Need permissions to write to spool directory; need user permissions to read users’ files
- How can this be done?
First Attempt: Access() System Call

```c
if (access(file, R_OK) == 0) {
    fd = open(file, O_RDONLY);
    ret = read(fd, buf, sizeof buf);
    ....
}
else {
    perror(file);
    return -1;
}
```

What’s wrong?
Several Problems

- Only useful if setUID root—other UIDs can’t open read-protected files.
- (I didn’t check the return code on the `open()` call . . .)
- Race conditions
- Generic name: TOCTTOU (Time of Check to Time of Use)
Race Conditions

- There is a window between the `access()` call and the `open()` call
- The attack program can create a link to a readable file, invoke `lpr` in the background, then remove the link and replace it with a link to a protected file
- The probability of success is low but not zero—and the attacker only has to win once
Temporary Files

- The same attack can happen on files in /tmp
- The standard C library subroutine \texttt{mktemp()} is vulnerable to this
- Alternatives: \texttt{mkstemp()} or \texttt{mktemp()} with the \texttt{O_CREAT | O_EXCL} flags to \texttt{open()}
- Caution: if \texttt{open()} is used that way, generate a new template if EEXIST is returned
Shedding SetUID

- A setUID program can give up and then regain its setUID status:
  ```c
  save_uid = geteuid();
  seteuid(getuid());
  fd = open(file, O_RDONLY);
  seteuid(save_uid);
  ```

- Better alternative: run unprivileged most of the time, but assume setUID status only when doing privileged operations

⚠️ But—watch for SIGINT, buffer overflows; injected code can reassume privileges, too
Use a Subprocess

- Fork, and have a non-privileged subprocess open the user’s files
- Option 1: copy the file contents to the parent process over a pipe—safe but slow
- Option 2: send the file descriptor via `sendmsg()`/`recvmsg()` over a Unix-domain socket
Issues with Message-Passing Systems

- File-opening permissions
- Authentication
- Other issues?
Opening Files

- How does the server open a private file? Two ways...
- The client opens the file and passes the open file descriptor
- The client sends some sort of access right—a capability—to the server

Note: a file descriptor is a form of capability, but can’t be used over a network
Authentication

- Who is allowed to send messages to the server?
- How does the server know the client’s identity?
- Two solutions: support from the OS or cryptographic authentication
  - Think System V Shared Memory
  - Cryptographic authentication works over a network
Other Issues?

- The buggy code problem doesn’t go away
- It’s very similar to the network security problem; it hasn’t been solved, either
The Fundamental Problem

- The real issue: interaction
- To be secure, a program must minimize interactions with the outside
- All interactions must be controlled
RASQ

- RASQ: Relative Attack Surface Quotient
- Microsoft metric of how vulnerable an application is
- Roughly speaking, it measures how many input channels it has
- Must reduce RASQ
Not All Channels Are Equal

- Some channels are easier to exploit
- Some are more accessible to attackers
- Some have a bad track record
RASQ Examples

• Weak ACLs on shared files: .9—names are generally known; easy to attack remotely

• Weak ACLs on local files: .2—only useful to attacker after initial compromise

• Open sockets: 1.0—potential target
Generic Defenses

• Better OS

• What’s a secure OS? One that makes it easy to write security-sensitive programs

• Most don’t qualify...
Minimize Chances for Mistakes

- Eliminate unnecessary interactions
- Example: per-process or per-user `/tmp`
- Avoid error-prone primitives (i.e., minimize the chances of *comprehension* mistakes)
- Tight specification of input and environment—and check that it’s all true