

Secure programming

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SECURITY



- **Why bother at all?**
 - The Internet is not a secure place. Many people try to crack systems, and the network infrastructure is inherently insecure
- **How secure is secure?**
 - No computer can be ever totally secure
 - Security needs vary from case to case (e.g., your home computer vs. your bank's)
 - The more secure your system is, the more intrusive security becomes. You need to decide when your system will still be usable, and yet secure for your purposes
- **But wait, what does this have to do with this course?**
 - Just an introduction to the matter at hand
 - The point is, your servers should lay as good a basis as possible for secure computers
 - If your server is crackable, then so is the machine it runs on; even if the server is installed improperly, the risks should be minimized

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SECURITY ISSUES



- **Risks:** An intruder may subvert the server, e.g., make it read or write files, delete critical data, or execute arbitrary code
- **Threats:** Several types of intruders:
 - The Curious wants to see what you have in there
 - The Malicious wants to bring down your system
 - The High-Profile Intruder cracks your system for boasting rights
 - The Borrowers wants to use resources you pay for (e.g., bandwidth)
 - The Leapfrogger wants to use your system to attack others
 - The Competition
- **Vulnerabilities:** what are the security holes in the system
 - This is where you, the programmer of servers, come in: to minimize these
 - If the system is full of vulnerabilities it will eventually go down (and bring your server down too), but do not let your server be the cause

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UNPRIVILEGED SERVERS



Vulnerabilities are greatly minimized if your server runs unprivileged

- A program inherits not only the open descriptors, but also the user it belongs to
- However, a server is usually launched by the init system, which is run for obvious reasons as `root` (user ID 0)
- Root privileges are also needed at startup
- Once the startup is complete very few servers need root privileges
- Therefore as soon as you can you should **drop root privileges**, i.e., change the user ID your program runs under to something else than 0:
`setuid(non-privileged-uid);`
- Group privileges are also important, and thus they should be dropped too:
`setgid(non-privileged-gid);`
- This is arguably the biggest security improvement of them all
- Typically, servers launch as `root` but then switch to special user IDs, created just for them and which have the minimum amount of privileges

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- Servers should change the current working directory to a safe directory
- Even so, nothing prevents them to write to any other directory: all they have to do is to provide full paths to the files they want to access
- Sometimes you cannot do anything about it (whenever the server **must** access files all over the place)
- But sometimes your server needs files that are all located in a specific subtree of your file system
- If this is the case, then you should confine your server to that subtree
 - `chroot(dir);`
 - The effect: **dir** becomes the **root directory** of your server
 - For instance, after your program does `chroot("/var/lib/shfd")`, it will view the file `"/var/lib/shfd/shfd.log"` as `"/shfd.log"`
 - A file which is someplace else (say, `"/etc/passwd"`) is simply inaccessible
- Once you go into a “chroot jail” you can not get back (not even as root)
- Arguably the second biggest security improvement, but difficult to implement
 - All the shared libraries necessary for running the program must be available in the chroot jail



- Some system calls have no effect if run unprivileged; they include `chroot`, `setgid`, and `setuid`
- A non-root program cannot bind to ports below 1024
- So your server must run as root at the very beginning, just to issue these calls and/or open its ports
- As a consequence, once your server drops root privileges, it cannot get them back
- In other words, the proper sequence of calls is:


```
chdir("/var/lib/shfd");
chroot("/var/lib/shfd");
// open master socket on port below 1024
setgid(99);
setuid(99);
```
- Of course, there are cases when you have to run your server as root all the way (and perhaps also outside any chroot jail)
 - Then the potential of harm is huge
 - You should be extra careful when programming such a server



- Some inputs are from untrustable users, so those inputs must be validated (filtered) before being used
 - You should **determine what is legal** and reject anything that does not match that definition
 - Example of illegal strings: `" . "`, anything starting with `/`, control characters (too small ASCII values) and/or characters with the high bit set (too large ASCII values)
 - But validate, **do not do the reverse** (do not identify what is illegal and write code to reject those cases)!
- **Strings:** identify the legal characters or legal patterns and reject anything not matching that form
 - A character sequence may have special meaning to the program's internal storage format (e.g., a slash in the name of a file); check for these
- **Numbers:** limit all numbers to the minimum (often zero) and maximum allowed values



- Input includes but is not limited to command line arguments, environment variables, and things received from a client
 - Use text input as much as you can (easier to check)
- Limit the maximum character length (and minimum length if appropriate)
 - Be sure to not lose control when such lengths are exceeded
- Tests should usually be centralized in one place so that the validity tests can be easily examined for correctness later
- Make sure that your validity test is actually correct
 - This is particularly a problem when checking input that will be used by another program
 - These tests may have subtle errors, producing the **deputy problem** (the checking program makes different assumptions than the program that actually uses the data)



- While parsing user input, it is a good idea to temporarily drop all privileges, or even create separate processes
 - This is especially true if the parsing task is complex, or if the programming language does not protect against buffer overflows (e.g., C and C++)
- **Validate command line arguments**
 - Attackers can send just about any kind of data through a command line (through calls such as `execve`)
 - You must definitely validate the command line inputs
 - In particular, never trust the name of the program reported by `argv[0]` (an attacker can set it to any value including NULL)
- **Validate file descriptors**
 - Do not assume that any file descriptor is opened and points to anything in particular
 - Better close them all and reopen what is needed (a matter of resource management but also of security!)



- **Validate file names**
 - Reject “globing” characters (*, ?) whenever possible
 - If you must glob, do so in a separate process, with limits on resources
 - Filter dangerous file names, including:
 - Names beginning with a dash
 - Names with control characters (especially newlines) in them
 - Names containing spaces
 - Names containing characters with special meaning to the system and the programming language (e.g., <, ", ;, etc.)
- **Validate file content**
 - If a program takes directions from a file, the file must be considered suspect unless only trusted users can control its content (meaning: untrusted users cannot modify the file, its directory, or any of its ancestor directories)
 - If the file is suspect, make sure that the inputs from the file are protected as described in other places (taking data from a file is not an excuse)



<http://xkcd.com/327>

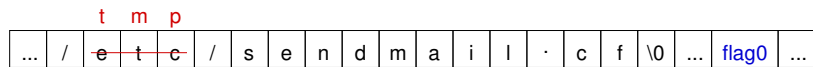


- This is a very common and very dangerous security flaw
- When allocating data (e.g., an array), validate the size
 - It should be **positive**
- When accessing data in an array, validate the index
 - It should be within the array size, **and** positive
- When copying stuff, check for bounds **and** for the format of the output;
 - Especially important for strings
 - Use “safe” functions (e.g., `snprintf` instead of `sprintf`, `strncpy` instead of `strcpy`)
 - **But** do not forget that you may thus lose the terminating null byte!
- Avoid dangling pointers at all cost
 - Set deleted pointers to 0, and check before accessing the content of any pointer

THE PERRILS OF BUFFER OVERFLOW: A REAL-WORLD EXAMPLE



- Sendmail debug flags: `-dflag,value`
 - “`sendmail -d8,100 ...`” sets flag number 8 to value 100
- Name of config file (`/etc/sendmail.cf`) also stored in memory (before the flags)
 - `/etc/sendmail.cf` gives the path to `/bin/mail`
- Sendmail checked for maximum flag numbers, but not for positiveness
- Integer larger than 2^{31} considered negative by C on 32-bit machines
- `sendmail -d4294967269,117 -d4294967270,110 -d4294967271,113` changes “etc” to “tmp” in the name of the config file



- Attacker then creates `/tmp/sendmail.cf` which claims local mailer is `/bin/sh`
 - debug call gives root shell!

RACE CONDITIONS



- Simple code gone wrong:

```
void incr() {
    x++;
}
```

 - Three instructions (load `x`, increment register, store result), possibly executed in an interleaved manner → fails when called from multiple threads
 - Result depends on the interleaving = **race condition**
- Use synchronization primitives judiciously
- But also keep in mind that abusing critical regions can unboundedly decrease response time
- Choose carefulness instead of critical regions as much as possible, but do choose critical regions whenever applicable
- Race conditions can also happen because of **signal handlers!**

RACE CONDITIONS CAN BE VERY SUBTLE



- Innocent code (typical producer-consumer system):

Blue thread	Red thread
<code>x = ...;</code>	<code>while (!done) {}</code>
<code>done = true;</code>	<code>... = x;</code>
- ... Except that the compiler might obligingly break it for you!
 - Indeed, any optimization flag passed to the compiler might cause it to notice that `done` is not modified inside the loop
 - So the red thread might become `tmp = done; while (!tmp) {}`
 - ...or even `tmp = done; if (!tmp) while (true) {}`
 - Even if you don't pass any optimization flags the hardware might still optimize
 - This rather than CPU load is the reason why **busy loops in user space are evil**

RACE CONDITIONS (CONT'D)



- Many system calls are not **thread safe** (also called **reentrant**), that is, they can lead to race conditions when used concurrently
- Many such system calls have a “reentrant” variant (identified by the `_r` suffix), which is
 - Thread safe, but also
 - Harder to use and usually less efficient
- Use the reentrant variant whenever concurrent calls are possible, but use the normal variant when race conditions cannot happen
 - Tokenize a string which is a **local** (stack) variable → use `strtok`
 - Tokenize a string which is a **global** or **heap** variable → use `strtok_r`



- **Least privilege.** Each user and program should operate using the **fewest privileges possible**, thus limiting the damage from an accident, error, or attack
- **Economy of mechanism/Simplicity.** The design of the protection system should be simple and small as possible; interfaces should be **minimal, narrow, and non-bypassable**; trust should be minimized
- **Open design.** The protection mechanism must not depend on attacker ignorance; the mechanism should be public, depending on the secrecy of relatively few (and easily changeable) items like passwords or private keys
- **Complete mediation.** Every access attempt must be checked; position the mechanism so it cannot be subverted; for instance, in a client-server model the **server** must do all access checking
- **Fail-safe defaults.** The default should be denial of service
- **Separation of privilege.** Ideally, access should depend on more than one condition, so that defeating one protection system won't enable complete access
- **Least common mechanism.** Minimize the amount and use of shared mechanisms (e.g. use of the `/tmp` or `/var/tmp` directories)
- **Psychological acceptability/Easy to use.** The human interface must be designed for ease of use so users will routinely and automatically use the protection mechanisms correctly



- This is just a brief incursion into security issues
- Other things that have strong impact on security:
 - Environment variables (they are very dangerous)
 - Random number generators
 - Etc.
- For more details about secure programming, take a look at <http://www.faqs.org/docs/Linux-HOWTO/Secure-Programs-HOWTO.html> and the references therein
- An instructive tutorial on buffer overflow exploitation: <http://www.cs.wright.edu/~tkprasad/courses/cs781/alephOne.html>