Programming Secure Applications for Unix-like Systems

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Introduction

- Contents: Lessons learned on how to write secure applications, based on past exploits (lots of detail)
  - Not how to break into software
  - Not how to configure existing software/systems
- Secure applications have inputs from untrusted users (setuid/setgid, daemon, web app, viewer,…)
  - Some recommendations don't apply to some app types
- My goal: Make software *secure* from attackers
  - Open Source Software *not* immune (sendmail, wu-ftpd)
  - People can't do it if they don't know how
  - Please, teach others this material!

First: What are Your Security Requirements?

- What is your security environment?
  - What threats, and how severe? Who's not trusted? What assumptions? What environment (platforms, network)? What organizational policies? What assets?
- What are your product's security objectives?
  - Confidentiality ("can't read")
  - Integrity ("can't change")
  - Availability ("works continuously")
  - Others: Privacy ("doesn't reveal"), Audit, …
- What functions and assurance measures are needed?
- Common Criteria useful checklist of requirements

Abstract View of a Program

1. Validate all Input

Program

2. Avoid Buffer Overflow
3. Program Internals/ Design Approach
6. Language-Specific Issues
7. Special Topics

5. Send Info Back Judiciously

4. Carefully Call Out to Other Resources

Validate All Input: General

- Validate *all* input from untrusted sources
- Determine what's legal, reject non-matches
  - Don't do the reverse (check for just illegal values); "there's always another illegal value"
  - Use known illegal values to test validators
- Limit maximum character length
- Next: Various data types & input sources

Validate All Input: Strings and Numbers

- Watch out for special characters
  - Control characters, including linefeed, ASCII NUL
  - Metacharacters for shell, SQL, etc. (e.g., *, ?,\, ",…)
  - Internal storage delimiters (e.g., tab, comma, <, :)
  - Make sure encodings (e.g., UTF-8, URL encoding) are legal & decoded results are legal
  - Don’t over-decode (i.e., don’t decode more than once “unnecessarily”)
- Numbers: check min & max; min often 0

Validate All Input: War Story (Check Minimums!)

- Sendmail debug flags: -d*flag*,*value*
  - Sendmail –d8,100 sets flag #8 to value 100
  - Name of config file (/etc/sendmail.cf) stored in data segment before flag array; that file gives /bin/mail path
  - Sendmail checked for max but ***not*** min flag numbers, since input format doesn't allow negative numbers
  - int >= 2^{31} considered negative by C on 32-bit hosts
  - Sendmail –d4294967269,117 –d4294967270,110 –d4294967271,113 changed "etc" to "tmp"
  - Attacker creates /tmp/sendmail.cf which claims local mailer is /bin/sh; debug call gives root shell to attacker

tmp

…	/	~~e~~	~~t~~	~~c~~	/	s	e	n	d	m	a	i	l	.	c	f	\0	…	flag0	…

Validate All Input: Other Data Types

- Email addresses: Complex, see RFCs 2822 & 822
- Filenames:
  - If possible, omit "/", newline, leading ".".
  - Omit "../" from legal pattern
  - Where possible, don't glob (*, ?, [], maybe {})
- Cookies: Check if domain is correct
- HTML: Prevent cross-site malicious posting, takeover of format (limit tags & attributes)
- URIs/URLs: Validate first; will it be cross-posted?
- Locale: [A-Za-z][A-Za-z0-9_,+@\-\.=]*

Validate All Input: Consider All Data Sources

- Command line:
  - Don't trust any value of command line if attacker can set them – including argv[0]
- Environment Variables:
  - Environment variables inherited; could they be from an attacker, even indirectly?
  - Local attacker can set ***anything***, even undocumented variables with effects on the shell or other programs
  - Some variables may be set more than once; this may circumvent checking
  - Only solution: Extract and erase at trust boundary

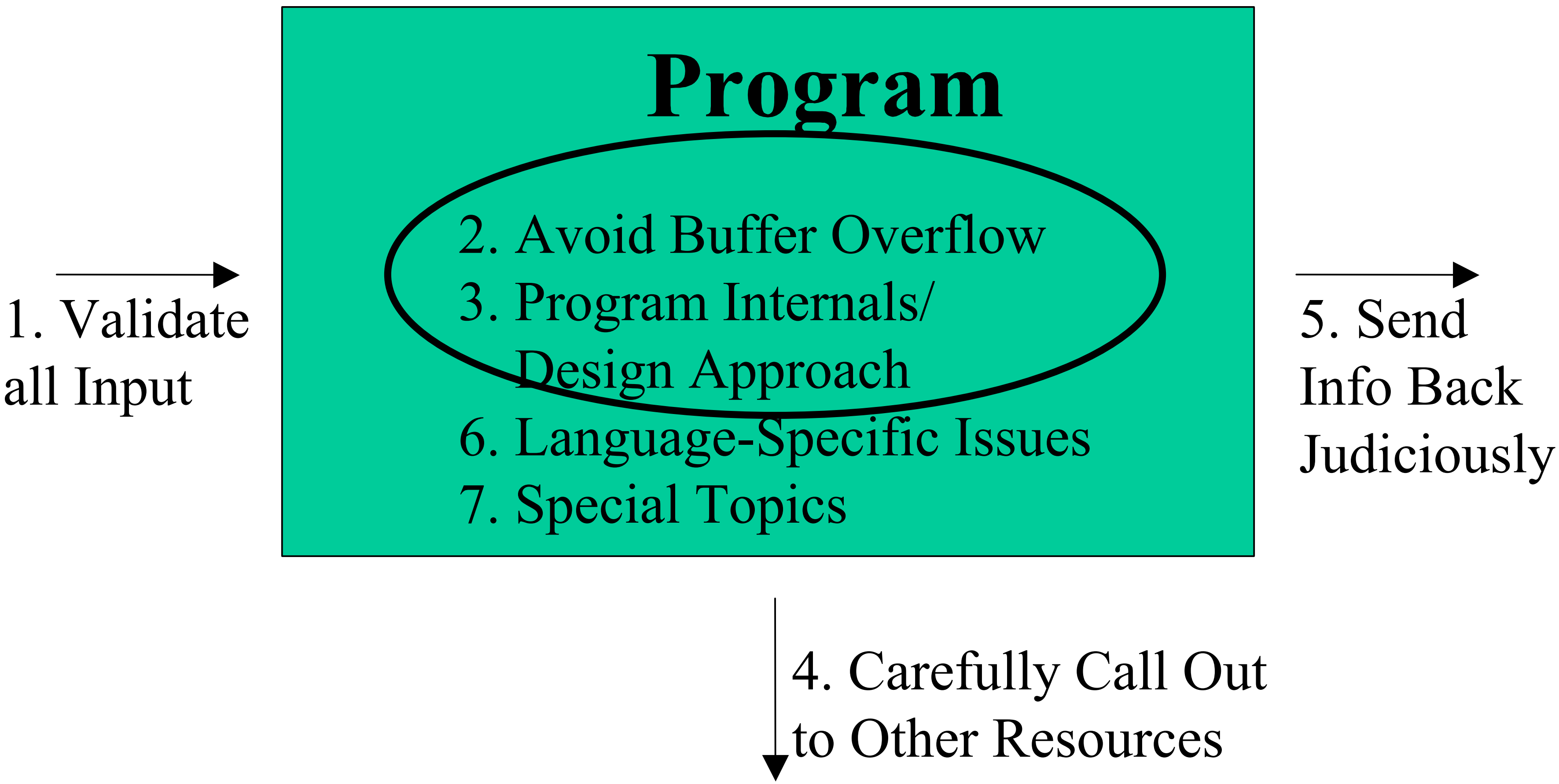
Validate All Input: Consider All Data Sources

- File Descriptors:
  - (setuid/setgid) Don’t assume stdin/stdout/stderr are open!
- File Contents:
  - Don’t trust files that can be controlled by untrusted users (e.g., configuration files)
- Cookies & HTML form data:
  - Users can set them to arbitrary values; if you care, include authenticators and check them
- Other input: current directory, signals, memory maps, System V IPC, the umask, filesystem

Validate All Input: Miscellaneous

- Web applications: Limit GET commands
  - Ignore/verify GET commands if it's not just a simple query (e.g., changing data, transferring money, signing up/committing something)
  - It may be a maliciously created cross-posted link, possibly on your own site
- Limit Valid Input Time/Load Level

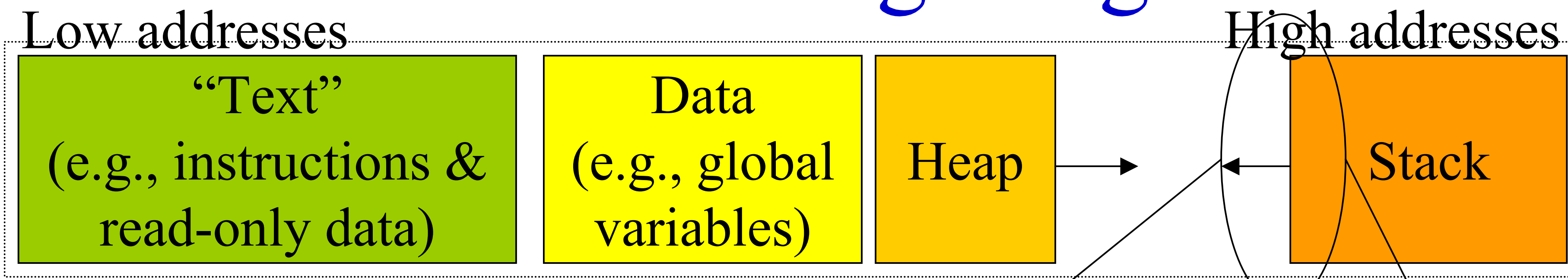
Abstract View of a Program



Avoid Buffer Overflow: The Problem

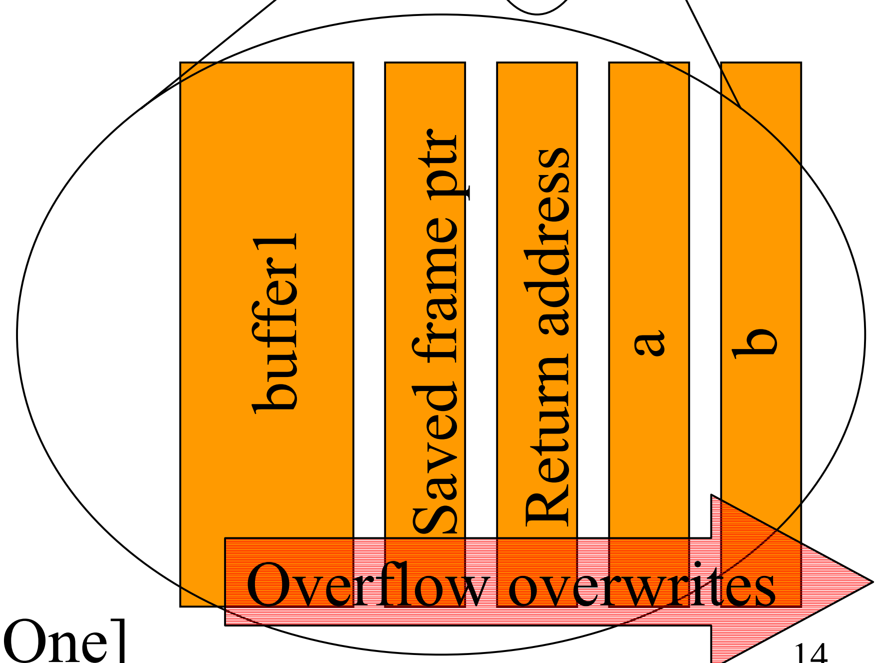
- Buffer Overflow
  - Occurs when an attacker can cause data (usually characters) to be written outside a buffer's boundaries (usually past its end), overwriting previous values
  - If buffer is on the stack, also called "stack overflow" or "smashing the stack"; can change the return address and provide code you'd like it to return to and run
  - Possible because C/C++/asm don't autocheck bounds
  - Often allows attackers to modify data and/or force arbitrary code to run
  - Common : More than half of all CERT advisories 1998-1999; 2/3 said leading cause in 1999 Bugtraq survey

Avoid Buffer Overflow: Stack Smashing Diagram




```
void function(int a, int b) {
  char buffer1[5];
  /* imagine we're here */
}

void main() {
  function(1, 2);
}
```



[Aleph One]

Avoid Buffer Overflow: War Story

- Wu-ftpd realpath vulnerability (<2.4.2)
  - Realpath() canonicalizes pathname (eliminating “/../”..)
  - Realpath() implementation internally used fixed-length buffer and didn’t prevent length from being exceeded
  - Attacker with ftp write access could create arbitrarily long path (e.g., mkdir AAA…; cd AAA…; then repeat)
  - At end of path, attacker created filename with return address and machine code to run (e.g., “run shell”)
  - When ftpd called realpath() to find real path, instead of returning, the function ran arbitrary code supplied by the attacker (e.g. root shell)

Avoid Buffer Overflow: The Solution

- Avoid or carefully use risky functions
  - gets(), strcpy(), strcat(), *sprintf(), *scanf(%s)..
- Alternatives: fixed-length vs. dynamic
- Choose an approach, e.g.:
  - Standard C fixed-length: strncpy(), strncat(), snprintf()
  - Standard C dynamic length: malloc(), …
  - Strlcpy/strlcat (fixed): easier to use than strncpy
  - Libmib (dynamic, separate library, rename if modify)
  - C++ std::string (not when converted to char*)

Program Internals/ Design Approach (1 of 6)

- Secure the Interface ("can't circumvent it")
  - Simple, narrow, non-bypassable; avoid macro langs
- Minimize privileges
  - Minimize privileges granted (setgid not setuid, run as special user/group not root, restrictive file permissions, limit/remove debug requests, limit writers)
  - Permanently give up privilege as soon as possible (e.g., open TCP/IP port, then drop completely)
  - Minimize time privilege active
  - Minimize the modules given the privilege: break program up to do so
  - Consider using FSUID, chroot, resource limiting

Program Internals / Design Approach (2 of 6)

- Use safe defaults
  - Install as secure, then let users weaken security if necessary after initial installation
  - *Never* install a working "default" password
  - Install programs owned by root and non-writeable by others (inhibits viruses)
- Load initialization values safely (e.g., /etc)
- "Fail safe": stop processing the request if surprising errors or input problems occur

Program Internals / Design Approach (3 of 6)

- Avoid race conditions
  - Occur when multiple processes interfere with each other; an attacker may be able to exploit it
  - Races can be between secure program processes, or with an attacker's process
  - Don't use access() to check if it's okay and then open(); after the access() things may change!

Is X a normal file owned by user U?

Make X a symbolic link to /etc/passwd

Append text to X

Program Internals / Design Approach (4 of 6)

- Watch out for temporary files in shared directories (common race condition)
  - /tmp and /var/tmp are shared by all; attackers can often exploit this, e.g., by adding symlinks or their files
  - If possible, move to unshared locations (e.g., ~)
  - Shared directories must be sticky: test first
  - Repeatedly (1) create "random" filename, (2) open using (O_CREAT|O_EXCL) and minimal privileges, (3) stop on success; NFSv2 requires more magic
  - Use fd's; reopening with same name vulnerable
  - tmpfile(3) unsafe on some, tmpnam(3) often unsafe

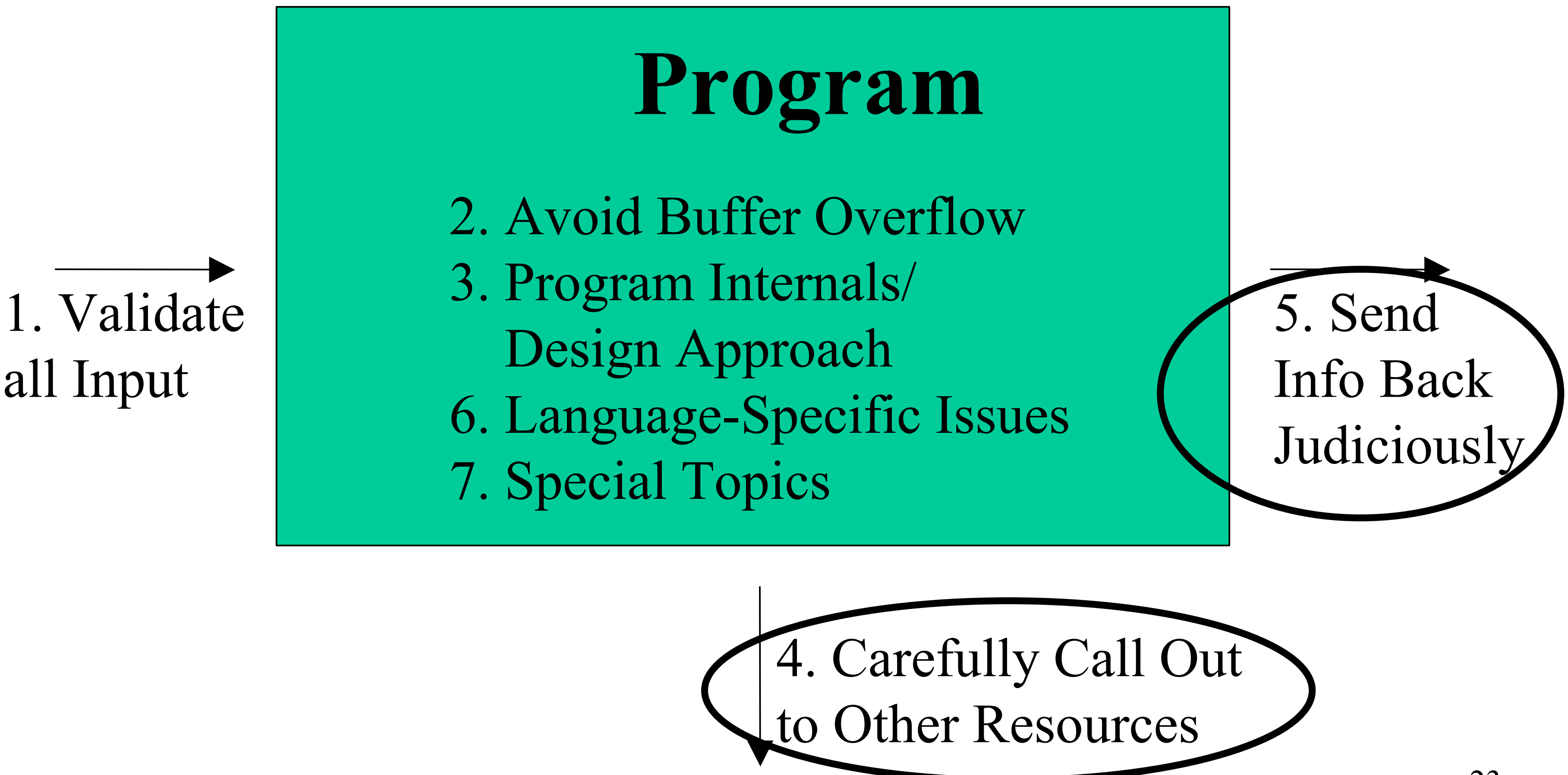
Program Internals / Design Approach (5 of 6)

- Trust only trustworthy channels
  - “From” IP addresses & email sources can be forged
  - DNS entries come from external entities
- Prevent Cross-site Malicious Content
  - Filter, or encode
- Counter Semantic Attacks
  - http://www.bloomberg.com@badguy.com
  - Confirm oddities, give more visual cues

Program Internals / Design Approach (6 of 6)

- Follow good security principles (S&S), e.g.:
  - Keep it simple
  - Open design: Encourage others to review it!
  - Complete mediation: Check every access. If it’s client/server, server has to re-check everything
  - Fail-safe defaults: Deny by default
  - Make it easy/acceptable to use: “no urine tests”

Abstract View of a Program



Calling Out to Other Resources

- Call only safe library routines
  - If they're not portably safe, write your own
- Limit call parameters to valid values
- Escape/forbid shell metacharacters before calling shell; indeed, avoid calling the shell!
  - & ; ` ' \ " | * ? ~ < > ^ ( ) [ ] { } $ \n \r
  - Whitespace are parameter separators – problem?
  - Other possible problems include: #, !, -, ASCII NUL
  - Shell often called indirectly (popen, system, exec[lv]p)
- Escape/forbid other tools' metacharacters (SQL)

Calling Out to Other Resources

- Call only interfaces intended for programs
  - Avoid calling mail, mailx, ed, vi, emacs; they all have exotic interactive escape mechanisms (~, :, !)
  - If you *do* use them, learn their escape mechanisms first and prevent them
- Check all system & library call returns
- Encrypt sensitive information
  - E.G., use SSL/TLS for private data over Internet
  - Encrypt data on disk if it's especially critical

Output Judiciously

- Minimize feedback
  - Log failures - don’t explain them to untrusted users
  - Don’t send program version numbers
- Handle disk full/unresponsive recipient
- Control data formatting (“format strings”)
  - WRONG: printf(stringFromUntrustedUser);
  - RIGHT: printf(“%s”, stringFromUntrustedUser);
  - Attacker may use %n (writes *into* variables), select “parameters” to output arbitrary stack values, etc.
  - Currently a *major* problem

Output Judiciously: War Story

- PHP $<$ 4.0.3 error logging format string:
  - If error logging enabled, php_syslog function called with user-provided data
  - Php_syslog called printf, using that data as the format string (!)
  - Attacker could cause process to overwrite its stack variables with arbitrary data
  - Allowed remote attacker to “take over” PHP process (usually with web server’s privileges)

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Language-Specific Comments

- Perl:
  - Enable –w (warn) and –T (taint) options
  - Use 3-parameter open() to disable excessive magic (man perlopentut for more)
  - “use strict”
- Python:
  - Check uses of exec, eval, execfile, compile
  - Function input is very dangerous
    - Don’t use it for untrusted input; use e.g., raw_input
  - Don't use rexec or Bastion

Language-Specific Comments

- Shell (sh, csh)
  - Don't use them for setuid/setgid; nonportable
  - Avoid using for secure programs unless heavily protected; too many ways to exploit
    - Filenames with whitespace, control chars, beginning with "-"
    - Magic environment variables (e.g., IFS, ENV)
  - Trusted programs okay if *all* input from trusted sources
- PHP
  - Set register_globals to "off"
  - Use PHP 4.1.0+ and use $_REQUEST for external data
  - Filter data used by fopen()

Language-Specific Comments

- C/C++
  - Make types as strict as possible
    - Use enum, unsigned where appropriate
    - Watch out for char; signedness varies
  - Turn on all warnings, and resolve them
  - Use gcc __attribute__ extension to mark functions that use format strings
  - Remember buffer overflow issues!

Special Topics

- Random Numbers: use /dev/(u?)random
- Don’t send passwords “in the clear” over Internet
- Web Authentication of Users
  - For intranets, use intranet authentication system (e.g., Kerberos)
  - Web basic authentication is in the clear – avoid it
  - Currently client-side certificates are poorly supported, so for many, use “Fu’s approach” to authenticate web users (see document for details). Uses passwords over encrypted link, returns a temp cookie used for authentication. Not ideal, but it’s practical for most sites

Special Topics

- Protect Secrets (passwords, keys) in user memory
  - Disable core dumps via ulimit; perhaps mmap to prevent swapping out the data; don't use immutable strings to store passwords; erase quickly once used
- Use existing *unpatented* crypto algorithms and protocols; don't invent your own
  - SSL/TLS, SSH, IPSec, OpenPGP (GnuPG), Kerberos
  - AES or Triple-DES (*not* in ECB mode-use CBC), RSA
  - For hashing, move from MD5 to SHA-1
  - For integrity checking or MAC, use HMAC-SHA-1
- Have "development" branch (gives time to audit)

Tools

- Source Code Scanners
  - Flawfinder, RATS, LCLint, cqual

```
Flawfinder version 1.21, © 2001-2002 David A. Wheeler
Test.c:32 [5] (buffer) gets:
 Does not check for buffer overflows. Use fgets() instead.
...
```

- Run random tests to try to crash
  - BFBTester

Conclusions

- Do it right! Avoid well-known problems:
  - Validate all input: Is it all legal?
  - Avoid buffer overflow
  - Structure program: Minimize privileges, avoid race conditions
  - Carefully call out: Shell/SQL metacharacters, check all system call return values
  - Reply judiciously: Minimize feedback, format strings
- You'll avoid >95% of reported vulnerabilities
- Be paranoid. They really *are* trying to get you
- See: http://www.dwheeler.com/secure-programs

Backup Material

Why Do Programmers Write Insecure Programs?

- "How to write secure programs" is almost *never* taught in schools, even though it's critical
  - This is criminal! This should be a CS/SE requirement
  - Teach at college & to developers in high school too
- Few books on the topic
- Unnecessarily hard to write secure code in C
- Consumers don't select products based on their real security-so real security isn't provided
- Security costs more (in $, time, installation effort)

What's Open Source Software/Free Software?

- Software licensed in a way giving the freedom to:
  - (0) run the program, for any purpose
  - (1) study how the program works, and adapt it to your needs (requires access to the source code)
  - (2) redistribute copies so you can help your neighbor
  - (3) improve the program & release your improvements to the public, so that the whole community benefits
- "Open Source Software" often emphasizes belief in better results (e.g., higher reliability & security)
- "Free Software" emphasizes freedom for users
- See http://www.dwheeler.com/oss_fs_refs.html

Is Open Source/Free Software Good for Security?

- Some claim OS/FS gives more info to crackers
  - But crackers can disassemble & don't need source code to attack. Transparency helps the "good guys" more
- OS/FS *can* be better over time
  - After "good guys" have found/fixed problems
- But many caveats:
  - People have to actually review the code
  - Reviewers must know how to find insecure code
  - Problems found must be fixed, distributed, applied

Hacker, Cracker, Attacker: These Words Have Meanings

- Hacker: One who enjoys exploring the details of programmable systems & stretching their abilities; enjoys programming; (or) an expert or enthusiast*
- Cracker: One who breaks security on a system*
- Attacker: One who attacks a system
- Note the distinctions:
  - **Not all hackers are crackers** (e.g., white hats)
  - Not all crackers are hackers (e.g., script kiddies)
  - Not all attackers are crackers (e.g., DoS attacks)
- The media often don't get it

* The New Hacker's Dictionary (The Jargon File), ed. Eric S. Raymond

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