Outline

Programming failures

Buffer overflows

Race conditions

Permissions and Access Control

Poor randomness

Confidentiality leaks

Building in security: design and guidelines
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Programming and Security

The relationship between programming and security may be viewed in at least a couple of ways.

**Programming Securely** To develop code in a secure manner so that the code itself is not a vulnerability that can be exploited by an attacker.

**Programming Security** To develop code for security-specific functions such as encryption, digital signatures, firewalls, etc.

Of course, the second may be required for the first.

In this lecture, we consider Programming Securely.
Choose security

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▶ The **penetrate and patch** approach to fixing security problems in mass market systems is badly flawed, e.g.
  ▶ patches often do not get applied
  ▶ patches often fix only symptoms, not cause
  ▶ patches cause version explosion, compatibility nightmare

▶ Much better to eliminate security bugs at outset!
Vulnerabilities at CERT/CC

- The **CERT Coordination Center**
  [http://www.cert.org](http://www.cert.org) at Carnegie Mellon University is a reporting centre for Internet security problems. They provide technical advice, recommended responses, identifying trends.
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**Example statistics:**

<table>
<thead>
<tr>
<th>Year</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008[Q1-3]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vulnerabilities:</td>
<td>3784</td>
<td>3780</td>
<td>5990</td>
<td>8064</td>
<td>7236</td>
<td>6058</td>
</tr>
</tbody>
</table>

The no. 1 category of vulnerabilities (over 50% up to 2004, at least) was the **buffer overflow**. More recently, with the rise of web applications written in higher-level languages, it has been taken over by **cross-site scripting** and **SQL injection**.
Categories of programming failure

1. buffer overflow (inadequate input validation)
2. race conditions
3. access control mistakes
4. poor randomness
5. confidentiality leaks

The following slides review each category.

- There are many check lists and emerging standard requirements for security checking, e.g. the **CWE/SANS Top 25** at http://cwe.mitre.org/top25/.

- Perhaps the single most important piece of advice for programming secure applications: **check your inputs!**
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A few overflow vulnerabilities

splitvt, syslog, mount/umount, sendmail, lpr, bind, 
gethostbyname(), modstat, cron, login, sendmail again, the query 
CGI script, newgrp, AutoSofts RTS inventory control system, host, 
talkd, getopt(), sendmail yet again, FreeBSD s crt0.c, WebSite 1.1, 
rlogin, term, ffbconfig, libX11, passwd yppasswd nispasswd, imapd, 
ipop3d, SuperProbe, lpd, xterm, eject, lpd again, host, mount, the 
NLS library, xlock, libXt and further X11R6 libraries, talkd, fdformat, 
eject, elm, cxterm, ps, fbconfig, metamail, dtterm, df, an entire 
range of SGI programs, ps again, chkey, libX11, suidperl, libXt 
again, lquerylv, getopt() again, dtaction, at, libDtSvc, eeprom, lpr 
yet again, smbmount, xlock yet again, MH-6.83, NIS+, ordist, xlock 
again, ps again, bash, rdist, login/scheme, libX11 again, sendmail 
for Windows NT, wm, wwwcount, tgetent(), xdat, termcap, portmir, 
writesrv, rcp, opengroup, telnetd, rlogin, MSIE, eject, df, statd, at 
again, rlogin again, rsh, ping, traceroute, Cisco 7xx routers, 
xscreensaver, passwd, deliver, cidentd, Xserver, the Yapp 
conferencing server, …
A few overflow vulnerabilities – continued

multiple problems in the Windows95/NT NTFTP client, the Windows War and Serv-U FTP daemon, the Linux dynamic linker, filter (part of elm-2.4), the IMail POP3 server for NT, pset, rpc.nisd, Samba server, ufsrestore, DCE secd, pine, dslip, Real Player, SLMail, socks5, CSM, Proxy, imapd (again), Outlook Express, Netscape Mail, mutt, MSIE, Lotus Notes, MSIE again, libauth, login, iwsh, permissions, unfsd, Minicom, nslookup, zpop, dig, WebCam32, smbclient, compress, elvis, lha, bash, jidentd, Tooltalk, ttodbserver, dbadmin, zgv, mountd, pcnfs, Novell Groupwise, mscreen, xterm, Xaw library, Cisco IOS, mutt again, ospf_monitor, sdtdm_convert, Netscape (all versions), mpg123, Xprt, klogd, catdoc, junkbuster, SerialPOP, and rdist

- It’s frustrating that such a basic programming error can have such an enormous impact on software security, and doubly frustrating that it hasn’t been eliminated yet.
Source of buffer overflows

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- Overflows can corrupt other pieces of the program data and cause security bugs, or even execution of arbitrary code...
Smashing the stack for fun and profit

- Attack: exploit a program that uses a stack allocated buffer, by using a specially constructed longer-than-expected argument.
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The malicious argument overwrites all of the space allocated for the buffer, all the way to the return address location. This is altered to point back into the stack, somewhere in a “landing pad” of NOPs before the attack code (the “egg”). Typically the attack code executes a shell.
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- Similar attacks work on the heap.
Fixing buffer overflows

- **good programming** to check bounds when necessary
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  - Needs operating system support
    — Added in Windows XP SP2, Linux 2.6.8
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Attack: suspend mkdir process between 1 and 2, replace new directory with a link to a confidential file, e.g., /etc/passwd. Resume process; it then changes permissions on the critical file instead of the new directory.
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- General approaches to fixing:
  - use locks in multi-threaded programming (synchronized)
  - reduce time-of-check, time-of-use (TOCTOU)
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Building in security: design and guidelines
Many exploits have taken advantage of failure to follow the *principle of least privilege*.

Poor programming or inflexible OS permissions structures can lead to programs and users that are given more privileges than they need.

Typical pattern of attacking a system is using *escalation of privilege*:

1. **gain access as ordinary user**
2. **escalate permissions**
3. **do anything !!!**
Managing permissions

Two extreme views:

1. Most machines are single-user or single-application so user-level access controls don’t matter. Separation of users lies in application-level code and network security.

2. Trusted operating systems are vital, good security and strong access control mechanisms must be built-in to the lowest level.
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The first view was originally argued by vendors such as Microsoft and the second view was typical of the military. Nowadays, the second view is also being espoused by Microsoft and many other vendors (why?).
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- General strategy: **true random seed** + **cryptographically strong PRNG** if more bits needed. Secure PRNG passes statistical randomness properties and has property that an attacker cannot guess the next value in the sequence based on some history of previous values.
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- General strategy: true random seed + cryptographically strong PRNG if more bits needed. Secure PRNG passes statistical randomness properties and has property that an attacker cannot guess the next value in the sequence based on some history of previous values.
- How do we get the true random seed? Without a dedicated random source, we must rely on non-deterministic external environmental data...
Environmental sources of randomness

- Good sources [RFC1750]: disk-head seek times, keystrokes, mouse movements, memory paging behaviour, network status, interrupt arrival times, random electrical noise (e.g. /dev/audio). Best use several, combined with a hash.
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- Linux’s random kernel device uses an “entropy pool” and estimates the number of “true” random bits in the pool. Adding random data into pool recharges entropy; reading random bytes removes entropy. Strong random device /dev/random can return no more bits than are in the pool. Less secure device /dev/urandom returns unbounded amount of cryptographically strong numbers.
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  - Other defences beyond realm of software.
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Security design principles

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4. **Open design** — the design should not be secret. Decouple protection mechanisms from protection keys; no security-by-obscurity.
5. **Separation of privilege** — require two keys rather than one. Once the mechanism is locked, two distinct owners can be made responsible for the keys. Implementation of ADTs uses this idea.
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Two further principles from physical security: **work factor** (comparison of cost of circumvention with the resources of an attacker) and **compromise recording** (make mechanisms tamper-evident).
Granularity of security provision

The hardware level has *fine grained* access controls. At higher levels, we implement increasingly user-oriented security policies. Reliability of each level depends on levels below, and increasingly complex implementations.

- **hardware**
  - firmware
  - OS kernel
  - OS services
  - middleware
  - applications

**machine-oriented**

**increasing complexity**

**decreasing reliability**

**human-oriented**
Programming principles

General principles for security programming emerge from case history of security vulnerabilities.

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3. **Use cryptography carefully.** Avoid predictable keys, small key spaces (choose cryptographic PRNGs and good seeds); be careful with key management (use secure locations, clear memory).

4. **Program defensively.** Beware data that comes from outside, and be aware of vulnerabilities introduced by relying on external programs. Try to minimise those vulnerabilities.
Some C coding guidelines (incomplete!)

- Check **all input arguments** for *validity*. Since C is not strongly typed, the validity of types should be checked. Semantical checks should also be performed: e.g., if input is an executable file, should check that the file is indeed executable and user has execute permission for file.
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- Check error return values. Essential because C doesn’t implement an exception mechanism.

- Don’t keep secret information in memory of unprivileged programs; it may be possible to interrupt the program and cause it to dump core.
Some C coding guidelines (incomplete!)

- Check **all input arguments** for **validity**. Since C is not strongly typed, the validity of types should be checked. Semantical checks should also be performed: e.g., if input is an executable file, should check that the file is indeed executable and user has execute permission for file.
- Never use **scanf**; use **fgetc** (similarly, avoid **printf**, etc). In general, avoid routines which do not **check buffer boundaries**. Perform bounds checking on every array index when in any doubt.
- Check **error return values**. Essential because C doesn’t implement an exception mechanism.
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- Consider **logging** UIDs, file accesses, etc..
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- **Strip binaries** (strings can reveal a lot!).
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- Take care with **root permissions**: beware of setuid programs, avoid setuid scripts, never open a file as root. If you need setuid root, give it up as soon as possible. Better to use ad-hoc user-names.
References


Recommended Reading
The short book Graff and van Wyk, or an equivalent, Chapters 1, 2, 5 of Wheeler.