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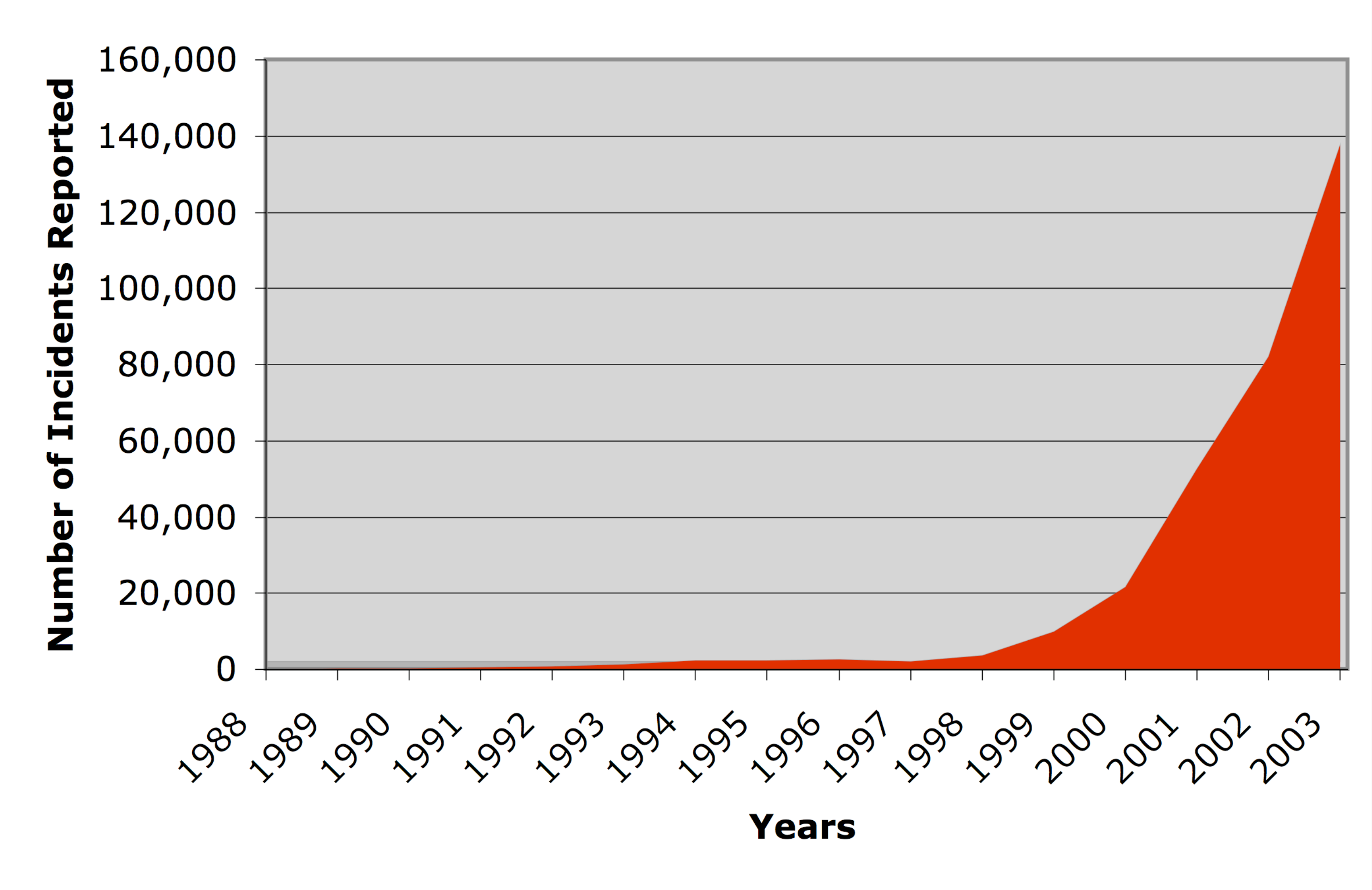
# Developing Secure Software

EECE 412

Session 21

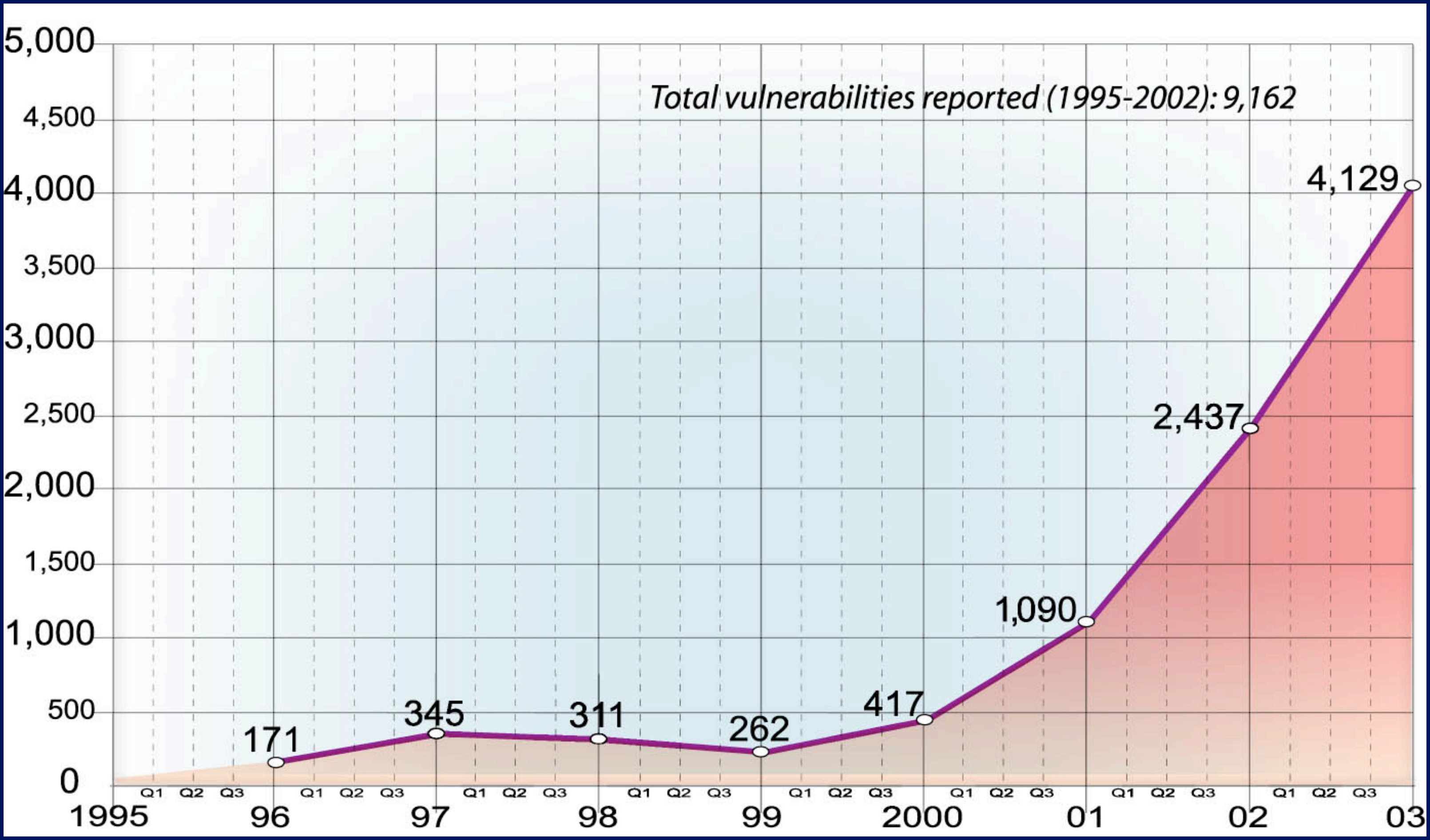
# What’s cell phones, ATMs, air traffic control systems, emergency service systems, healthcare equipment, and PDAs have in common?

# Internet security incidents reported to CERT



Security break-ins are all too prevalent

# Vulnerability Report Statistics



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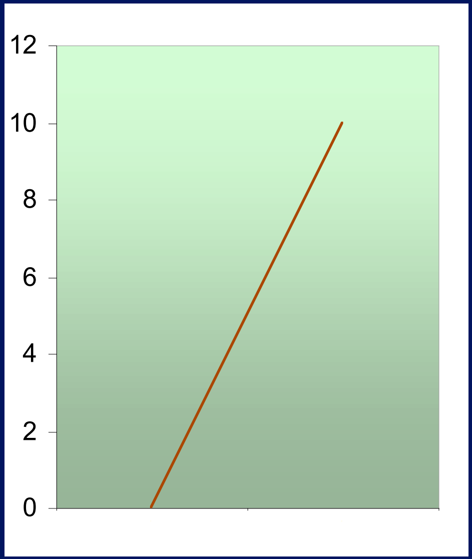
# Why are there so many vulnerabilities in software?

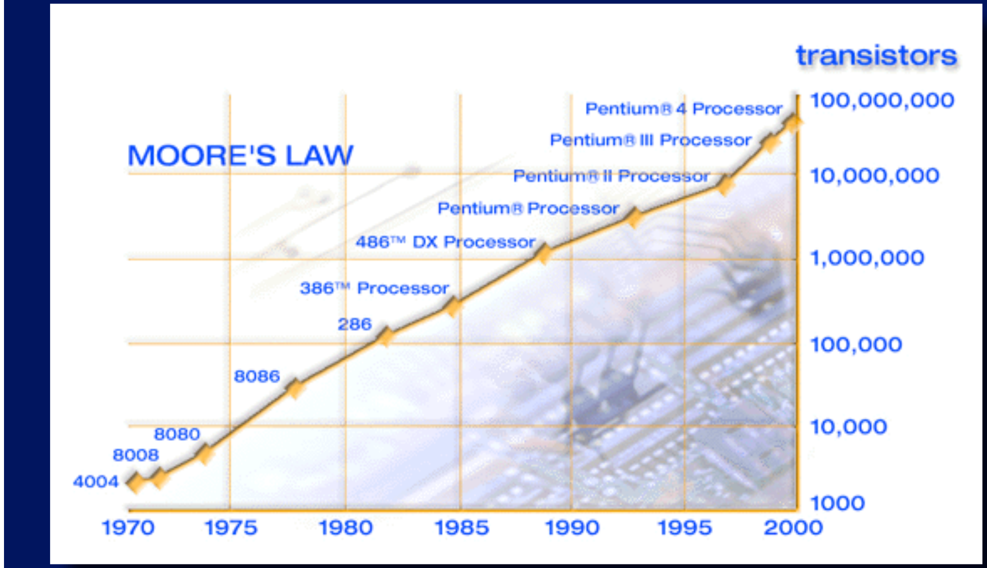
# What will happen in a moment?

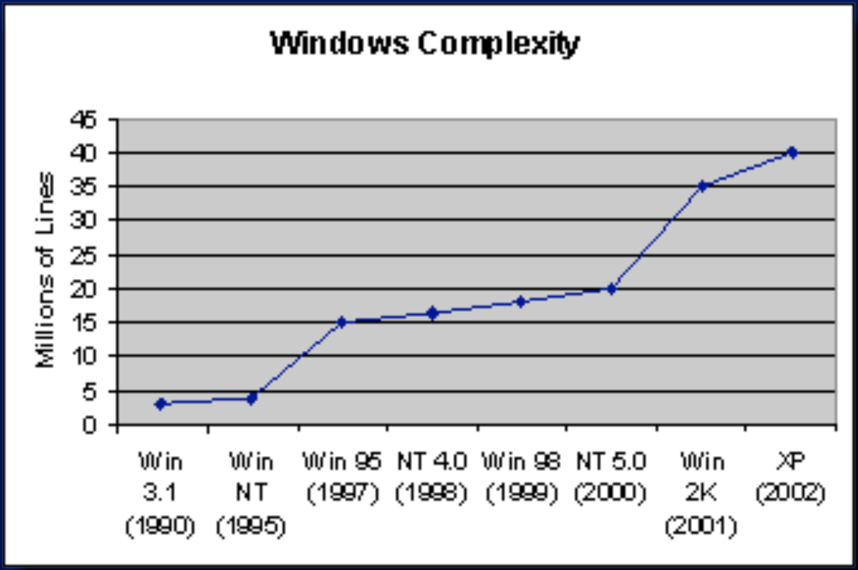


What makes simple mechanical systems predictable?

- Linearity (or, piecewise linearity)
- Continuity (or, piecewise continuity)
- Small, low-dimensional statespaces

Systems with these properties are
(1) easier to analyze, and (2) easier to test.



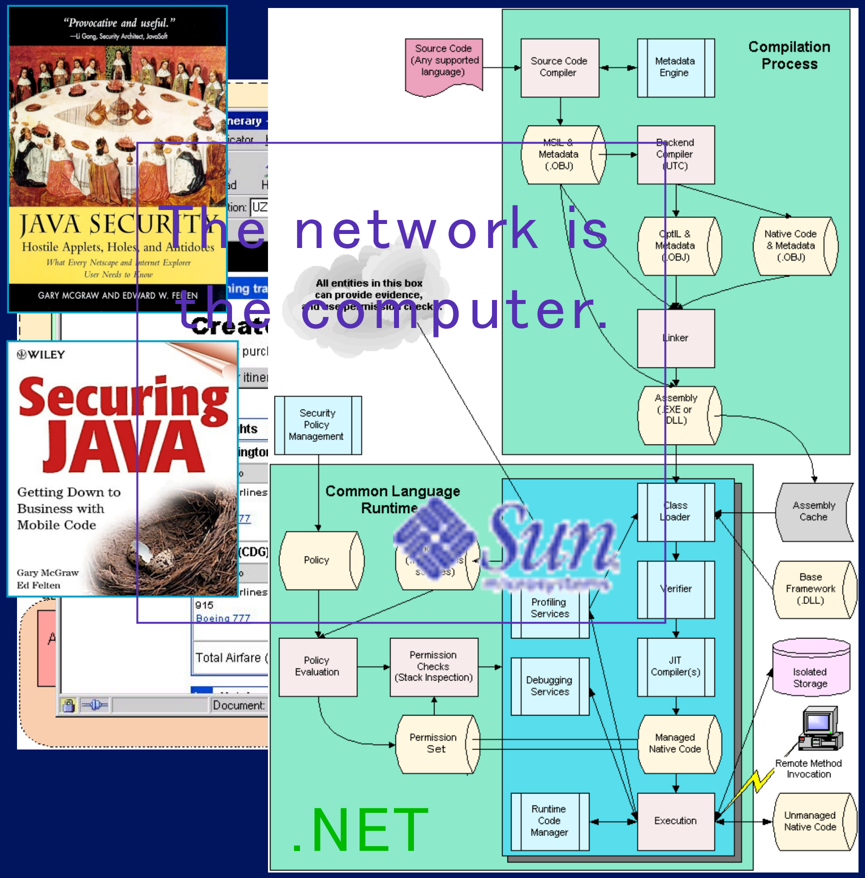


- Computers enable highly complex systems
- Software is taking advantage of this
  - Highly non-linear behavior; large, high-dim. state spaces

# Other software properties make security difficult

## The Trinity of Trouble

- **Connectivity**
  - The Internet is everywhere and most software is on it
- **Complexity**
  - Networked, distributed, mobile, feature-full
- **Extensibility**
  - Systems evolve in unexpected ways and are changed on the fly



The network is the computer.

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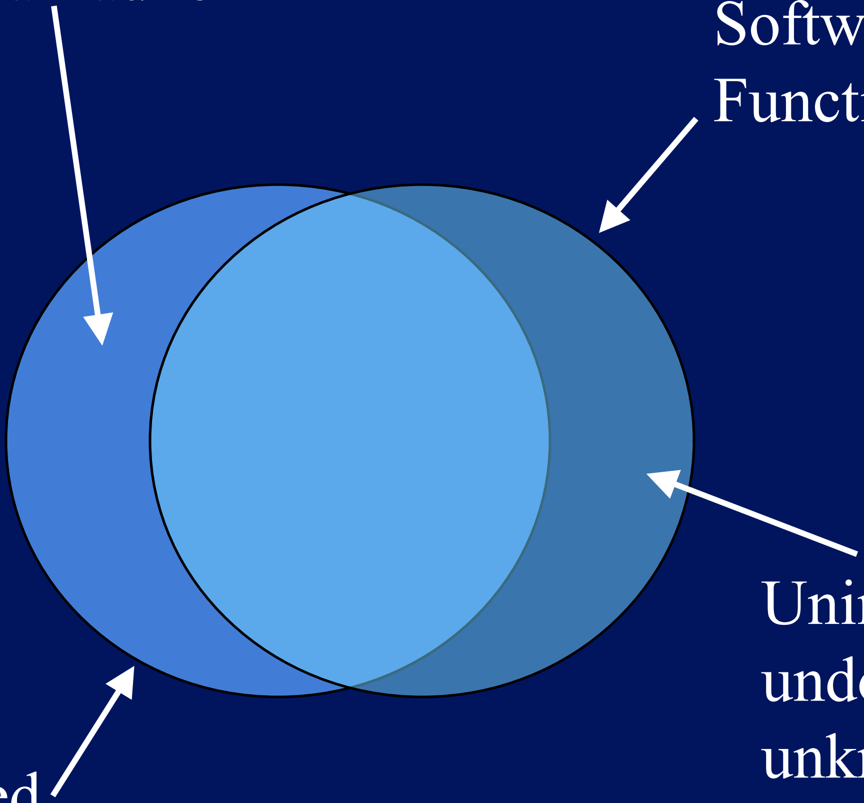
# How Are Security Bugs Different?

# When is a security bug not like a bug?

- Traditional non-security bugs -- often defined as a violation of a specification.
- Security bugs -- additional behavior, not originally intended
  - Meanwhile, it is doing what it is supposed to do
  - Traditional techniques not good at finding
  - Even in inspections, tend to look for
    - missing behavior
    - incorrect behavior
  - Neglect to look for ... undesirable side-effects

# Intended vs. Implemented Behavior



Traditional faults

Actual
Software
Functionality

Unintended,
undocumented,
unknown
functionality

Intended
Functionality

# Traditional faults

- Incorrect
  - Supposed to do A but did B instead

- Missing
  - Supposed to do A *and* B but did only A.

# Security Bugs

- Side effects
  - Supposed to do A, and it did.
  - In the course of doing A, it *also* did B
- Monitoring for side effects and their impact on security can be challenging
  - Side effects can be subtle and hidden
  - Examples: file writes, registry entries, extra network packets with unencrypted data

# Security problems are complicated

## Implementation Flaws

- Buffer overflow
  - String format
- Race conditions
  - TOCTOU (time of check to time of use)
- Unsafe environment variables
- Unsafe system calls
  - System()
- Untrusted input problems

## Design Flaws

- Misuse of cryptography
- Compartmentalization problems in design
- Privileged block protection failure (DoPrivilege())
- Catastrophic security failure (fragility)
- Type safety confusion error
- Insecure auditing
- Broken or illogical access control
- Method over-riding problems (subclass issues)

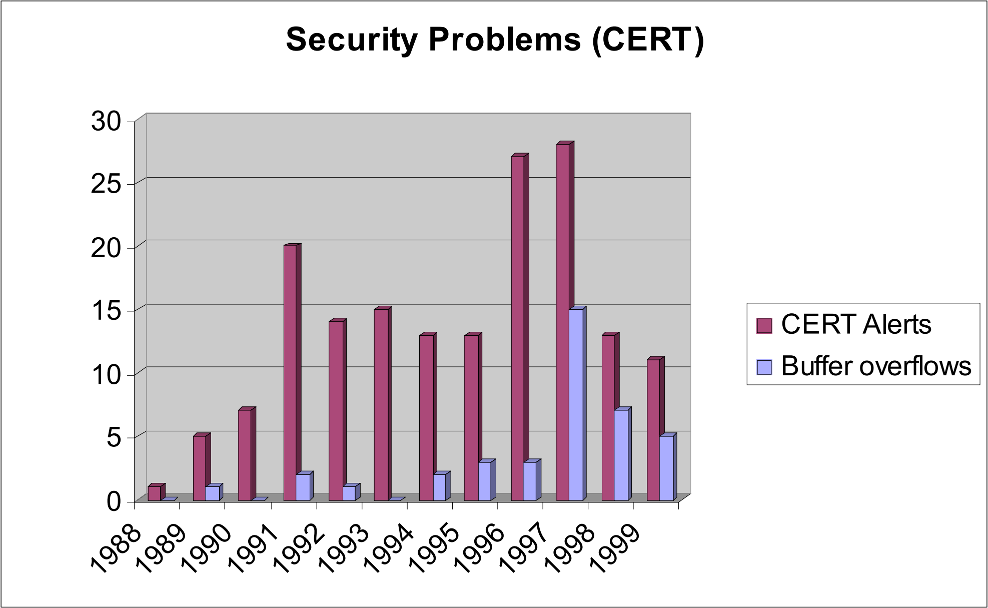
Which ones are more frequent?

# The BUG: buffer overflow

- Overwriting the bounds of data objects
- Allocate some bytes, but the language doesn't care if you try to use more
  - `char x[12 ];`

    `x[12 ] = ‘\0’;`
- Why was this done? Efficiency!

The most pervasive security problem today



# How Buffer Overflow Works

Adopted from the material by
Dave Hollinger

# The Problem

```
void foo(char *s) {
  char buf[10];
  strcpy(buf,s);
  printf(“buf is %s\n”,s);
}
…
foo(“thisstringistolongforfoo”);
```

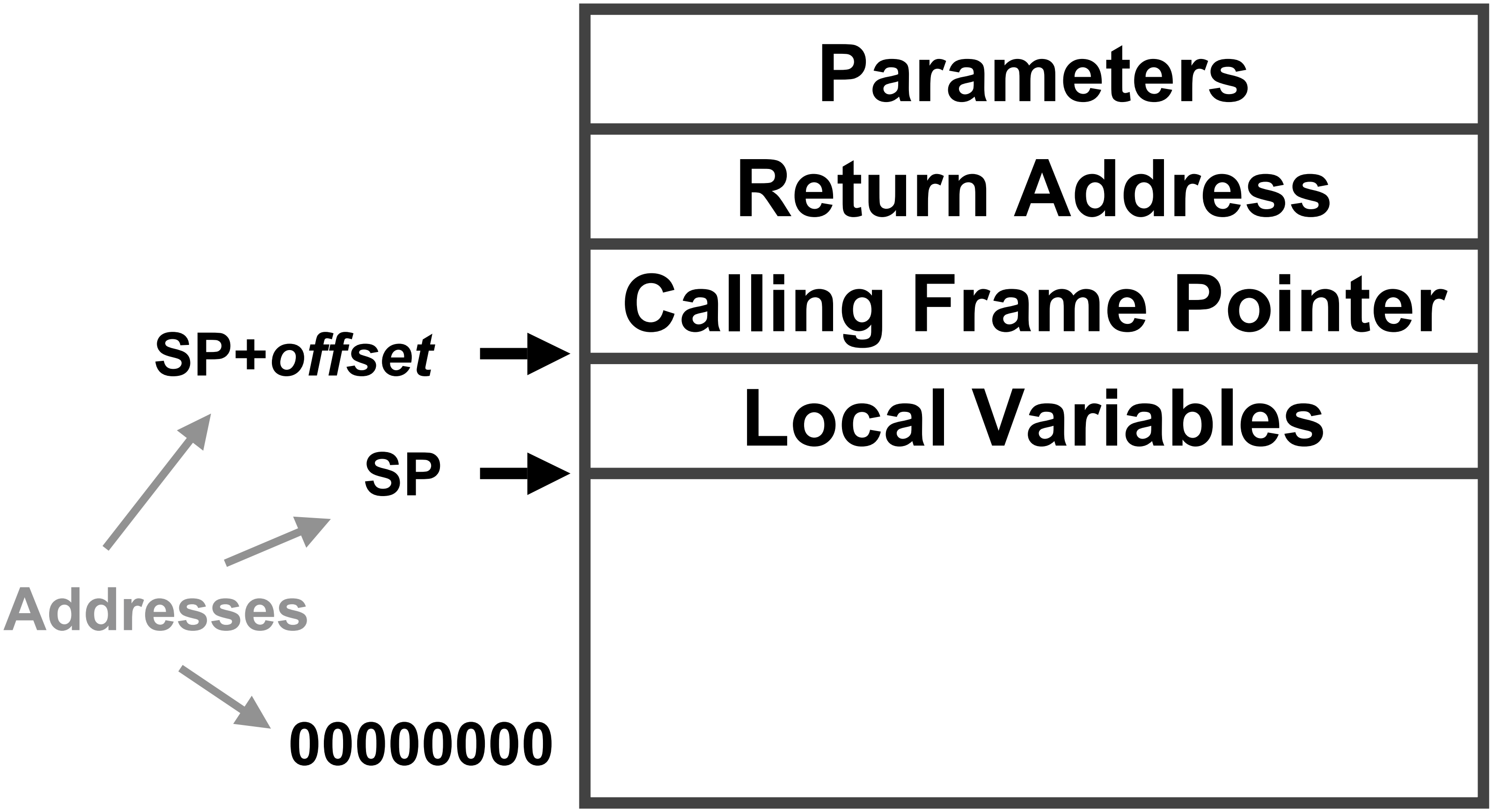
# Exploitation

- The general idea is to give programs (servers) very large strings that will overflow a buffer.

- For a server with sloppy code – it’s easy to crash the server by overflowing a buffer.

- It’s sometimes possible to actually make the server do whatever you want (instead of crashing).

# A Stack Frame



# Sample Stack

18

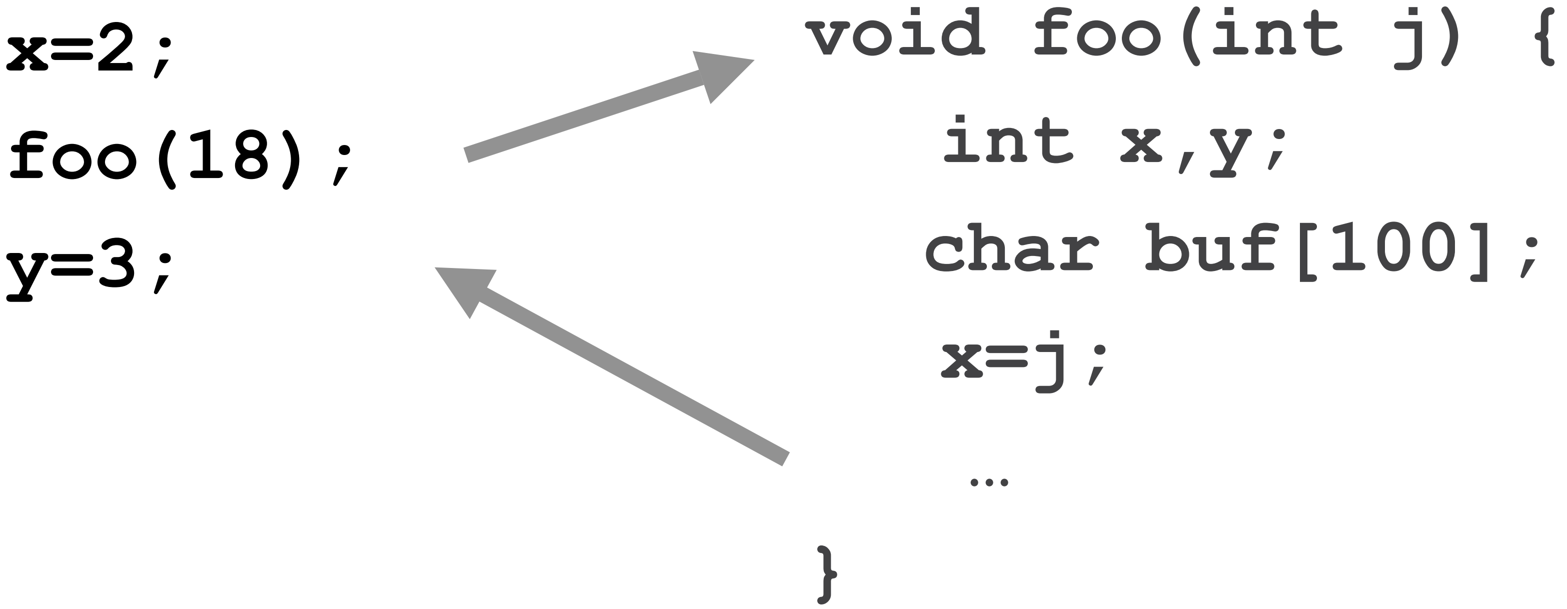
addressof(y=3) *return address*

saved stack pointer

y

x

buf

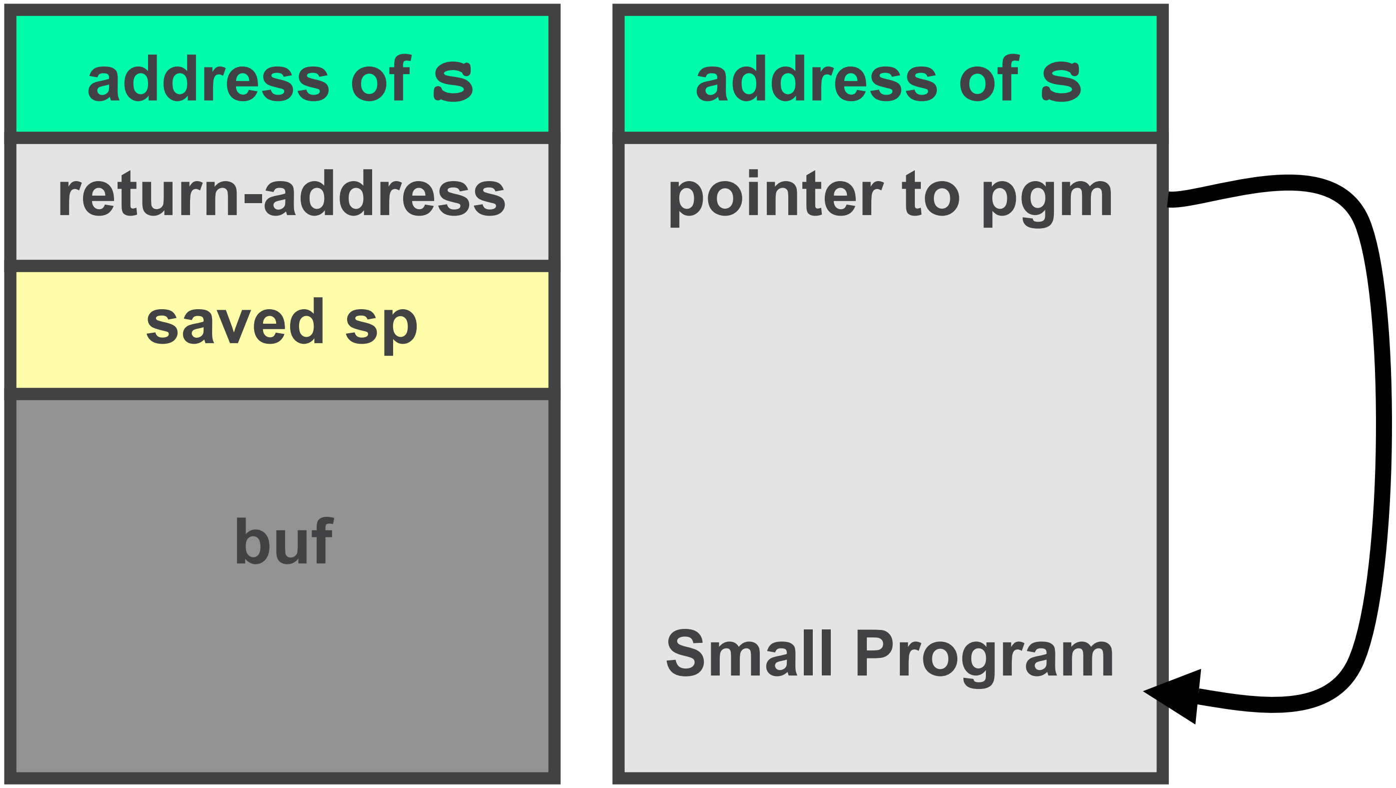


```
x=2;
foo(18);
y=3;
```

```
void foo(int j) {
    int x,y;
   char buf[100];
    x=j;
     …
}
```

# Before and After

```
void foo(char *s) {
     char buf[100];
     strcpy(buf,s);
     …
```



# Building the small program

- Typically, the small program stuffed in to the buffer does an **`exec()`** .

- Sometimes it changes the password db or other files…

# **exec()** example

```
#include <stdio.h>

char *args[] = {"/bin/ls", NULL};

void execls(void) {
  execv("/bin/ls",args);
  printf(“I’m not printed\n");
}
```

# A Sample Program/String

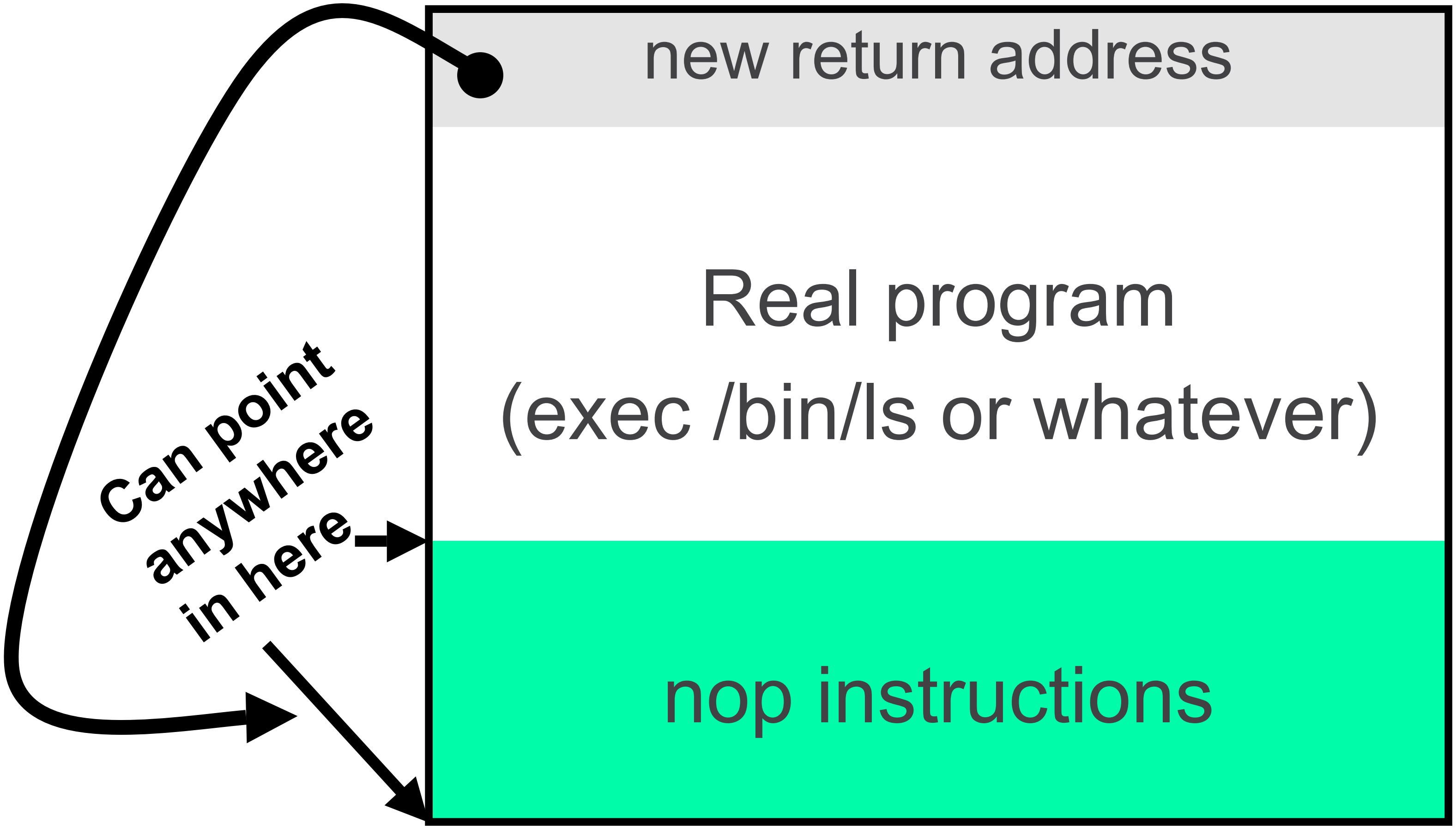
- Does an exec() of /bin/ls:

```
unsigned char cde[] =
"\xeb\x1f\x5e\x89\x76\x08\x31\xc0”
“\x88\x46\x07\x89\x46\x0c\xb0\x0b"
"\x89\xf3\x8d\x4e\x08\x8d\x56\x0c”
“\xcd\x80\x31\xdb\x89\xd8\x40\xcd"
"\x80\xe8\xdc\xff\xff\xff/bin/ls";
```

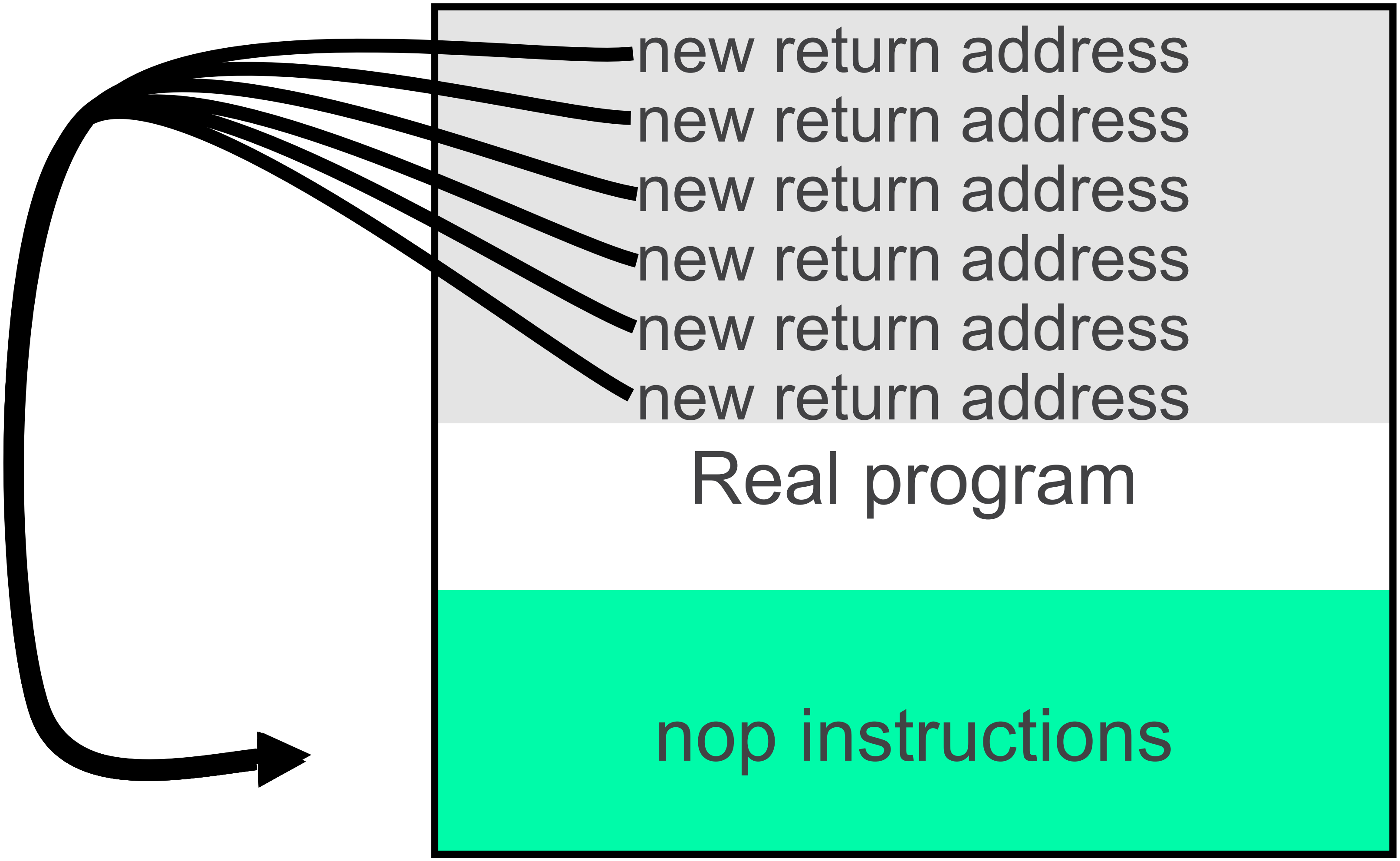
# Sample Overflow Program

```
unsigned char cde[] = "\xeb\x1f\…

void tst(void) {
  int *ret;
  ret = (int *)&ret+2; // pointer arith!
  (*ret) = (int) cde;  //change ret addr
}

int main(void) {
  printf("Running tst\n");
  tst();
  printf("foo returned\n");
}
```

# Using NOPs


new return address
Real program
(exec /bin/ls or whatever)
Can point anywhere in here
nop instructions

# Estimating the Location



# vulnerable.c

```
void foo( char *s ) {
  char name[200];
  strcpy(name,s);
  printf("Name is %s\n",name);
}
int main(void) {
  char buf[2000];
  read(0,buf,2000);
  foo(buf);
}
```

# Pervasive C problems lead to bugs

- Calls to watch out for

| Instead of: | Use: |
|---|---|
| gets(buf) | fgets(buf, size, stdin) |
| strcpy(dst, src) | strncpy(dst, src, n) |
| strcat(dst, src) | strncat(dst, src, n) |
| sprintf(buf, fmt, a1,…) | snprintf(buf, fmt, a1, n1,…) (where available) |
| *scanf(…) | Your own parsing |

- Hundreds of such calls
- Use static analysis to find these problems
  - ITS4, SourceScope
- Careful code review is necessary

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# How to Develop Secure Software?

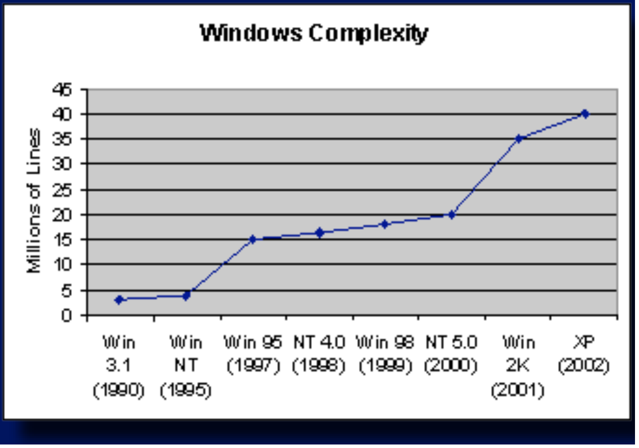
# Some Guidelines

1. Reduce the number of all defects by order of magnitude
2. Build security in your development process from beginning
3. Practice principles of designing secure systems
4. Know how systems can be compromised
5. Develop and use guidelines and checklists
6. Choose safer languages, VMs, OSs, etc.
7. Provide tool support

# Why Software Quality is Important?

According to CERT/CC:

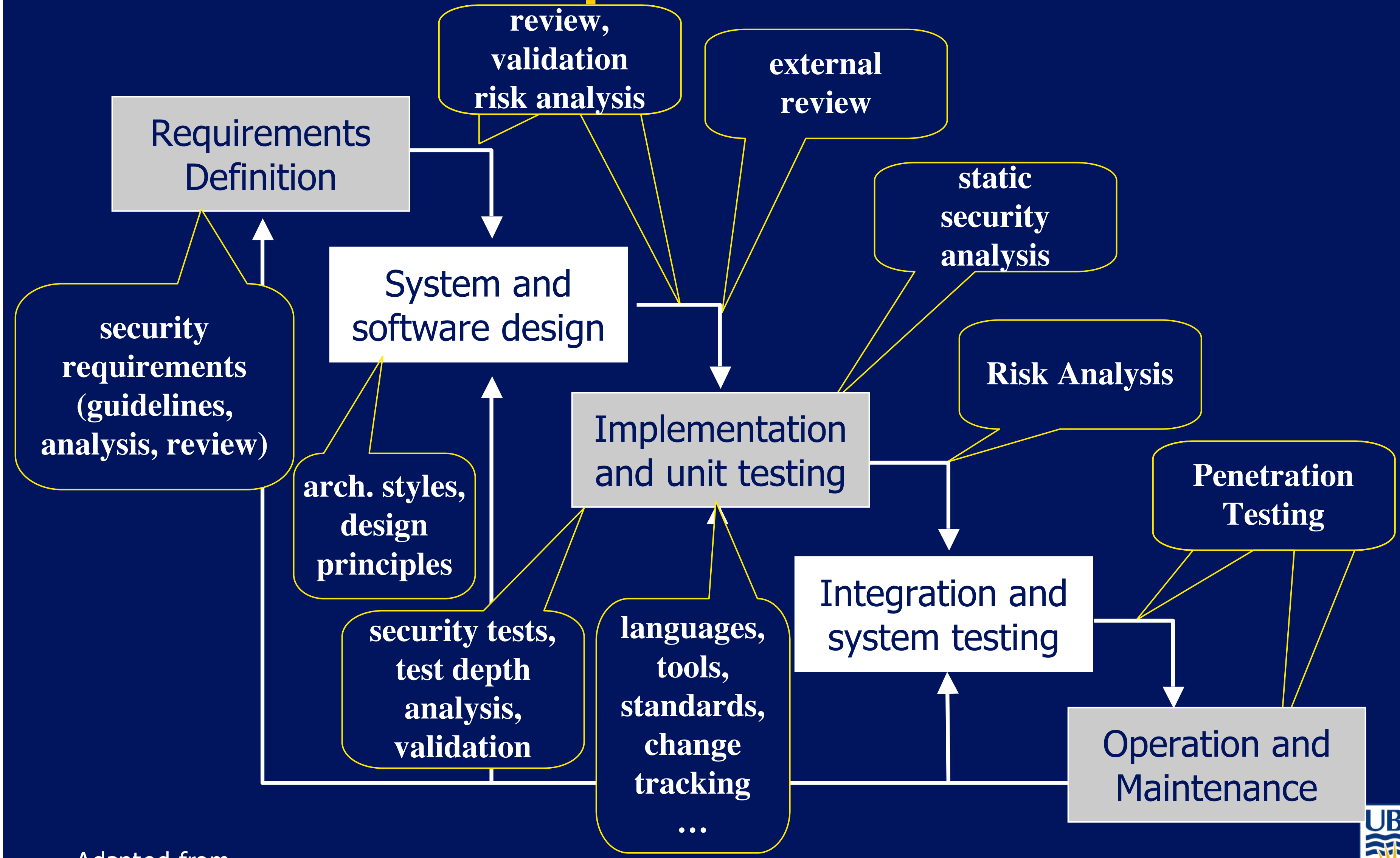
- over 90% of software security vulnerabilities are caused by known software defect types
- most software vulnerabilities arise from common causes
  - top ten account for 75% of vulnerabilities
- One design or implementation defect is injected for every 7 to 10 lines of new and changed code produced
  - Even if 99% is removed,
    1/1K left (40K defects in Win XP)



# 1. Produce Quality Software

- Use well structured effective processes
  - e.g., Capability Maturity Model (CMM), *-CMM
- Use precise requirements and specifications
  - Formal methods
    - e.g., Praxis Critical Systems approach
      - 0.75-0.04 defects/KLOC
    - CleanRoom
      - 0.08 defects/KLOC

# 2. Build Security into Development Process



Adapted from
D. Verdon and G. McGraw, "Risk analysis in software design," *IEEE Security & Privacy*, vol. 2, no. 4, 2004, pp. 79-84.

# Follow Best Practices

- These best practices should be applied throughout the lifecycle
- Tendency is to "start at the end" (penetration testing) and declare victory
  - Not cost effective
  - Hard to fix problems
- Start as early as possible

- Abuse cases
- Security requirements analysis
- Architectural risk analysis
- Risk analysis at design
- External review
- Test planning based on risks
- Security testing (malicious tests)
- Code review with static analysis tools

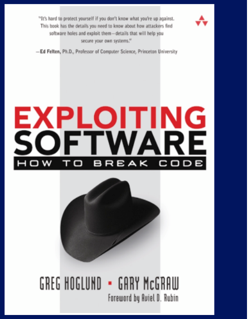
# 3. Practice principles of designing secure systems

Principles of Designing Secure Systems

1. Least Privilege
2. Fail-Safe Defaults
3. Economy of Mechanism
4. Complete Mediation
5. Open Design
6. Separation of Privilege
7. Least Common Mechanism
8. Psychological Acceptability
9. Defense in depth
10. Question assumptions

# 4. Know How Systems Can Be Compromised

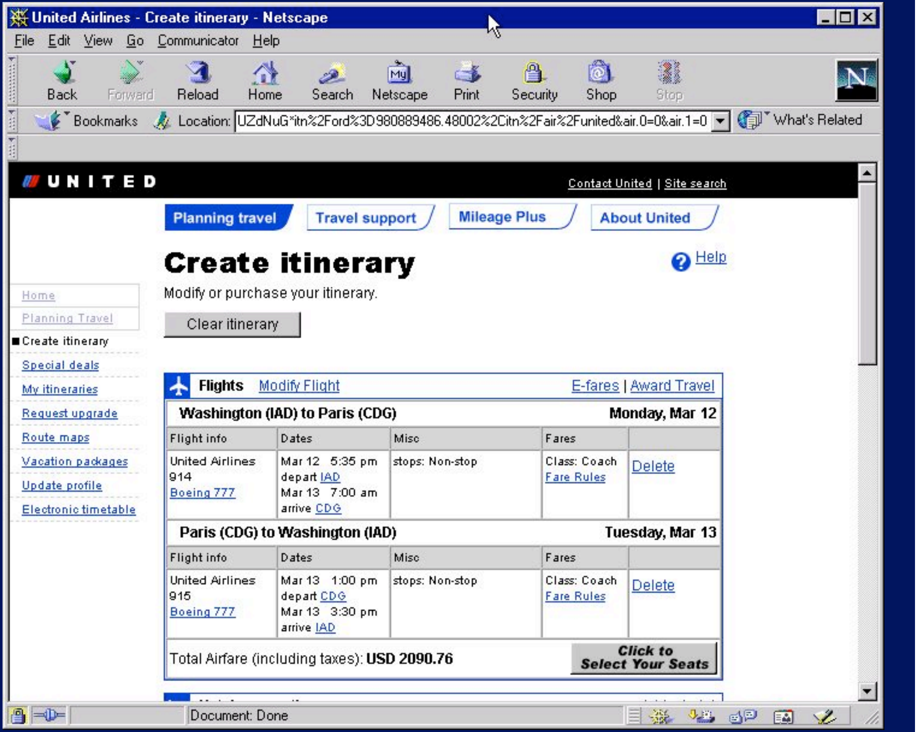
1. Make the Client Invisible
2. Target Programs That Write to Privileged OS Resources
3. Use a User-Supplied Configuration File to Run Commands That Elevate Privilege
4. Make Use of Configuration File Search Paths
5. Direct Access to Executable Files
6. Embedding Scripts within Scripts
7. Leverage Executable Code in Nonexecutable Files
8. Argument Injection
9. Command Delimiters
10. Multiple Parsers and Double Escapes
11. User-Supplied Variable Passed to File System Calls
12. Postfix NULL Terminator
13. Postfix, Null Terminate, and Backslash
14. Relative Path Traversal
15. Client-Controlled Environment Variables
16. User-Supplied Global Variables (DEBUG=1, PHP Globals, and So Forth)
17. Session ID, Resource ID, and Blind Trust
18. Analog In-Band Switching Signals (aka “Blue Boxing”)
19. Attack Pattern Fragment: Manipulating Terminal Devices
20. Simple Script Injection
21. Embedding Script in Nonscript Elements
22. XSS in HTTP Headers
23. HTTP Query Strings
24. User-Controlled Filename
25. Passing Local Filenames to Functions That Expect a URL
26. Meta-characters in E-mail Header
27. File System Function Injection, Content Based
28. Client-side Injection, Buffer Overflow
29. Cause Web Server Misclassification
30. Alternate Encoding the Leading Ghost Characters
31. Using Slashes in Alternate Encoding
32. Using Escaped Slashes in Alternate Encoding
33. Unicode Encoding
34. UTF-8 Encoding
35. URL Encoding
36. Alternative IP Addresses
37. Slashes and URL Encoding Combined
38. Web Logs
39. Overflow Binary Resource File
40. Overflow Variables and Tags
41. Overflow Symbolic Links
42. MIME Conversion
43. HTTP Cookies
44. Filter Failure through Buffer Overflow
45. Buffer Overflow with Environment Variables
46. Buffer Overflow in an API Call
47. Buffer Overflow in Local Command-Line Utilities
48. Parameter Expansion
49. String Format Overflow in syslog()


"It's hard to protect yourself if you don't know what you're up against. This book has the details you need to know about how attackers find software holes and exploit them—details that will help you secure your own systems."

—Ed Felten, Ph.D., Professor of Computer Science, Princeton University

# Attack pattern examples

- Exploit race condition
- Provide unexpected input
- Bypass input validation



UZdNuG*itn%2Ford%3D980889486.48002%2Citn%2Fair%2Funited&air.0=0&air.1=0

## Create itinerary

Modify or purchase your itinerary.

**Washington (IAD) to Paris (CDG)** — **Monday, Mar 12**

| Flight info | Dates | Misc | Fares | |
|---|---|---|---|---|
| United Airlines 914<br>Boeing 777 | Mar 12 5:35 pm<br>depart IAD<br>Mar 13 7:00 am<br>arrive CDG | stops: Non-stop | Class: Coach<br>Fare Rules | Delete |

**Paris (CDG) to Washington (IAD)** — **Tuesday, Mar 13**

| Flight info | Dates | Misc | Fares | |
|---|---|---|---|---|
| United Airlines 915<br>Boeing 777 | Mar 13 1:00 pm<br>depart CDG<br>Mar 13 3:30 pm<br>arrive IAD | stops: Non-stop | Class: Coach<br>Fare Rules | Delete |

Total Airfare (including taxes): **USD 2090.76**

# 5. Develop Guidelines and Checklists

Example from Open Web Application Security Project (www.owasp.org):

- Validate Input and Output
- Fail Securely (Closed)
- Keep it Simple
- Use and Reuse Trusted Components
- Defense in Depth
- Security By Obscurity Won't Work
- Least Privilege: provide only the privileges absolutely required
- Compartmentalization (Separation of Privileges)
- No homegrown encryption algorithms
- Encryption of all communication must be possible
- No transmission of passwords in plain text
- Secure default configuration
- Secure delivery
- No back doors

# Secure Programming How-Tos

- David Wheeler's Secure Programming for Linux and UNIX How-To
  - http://www.dwheeler.com/secure-programs
- Secure UNIX Programming FAQ
  - http://www.whitefang.com/sup/secure-faq.html
- OWASP (Open Web Application Security Project) Guide
  - http://www.owasp.org
- Etc... (Google "secure programming")

# 6. Choose Safer Languages, VMs, OSs, etc.

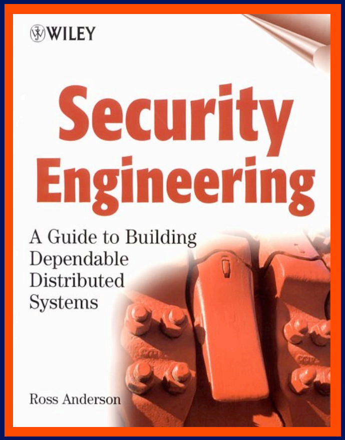
- C or C++?
- Java or C++?
- Managed C++ or vanilla C++?
- .NET CLR or JVM?
- Windows XP or Windows 2003?
- Linux/MacOS/Solaris or Windows?

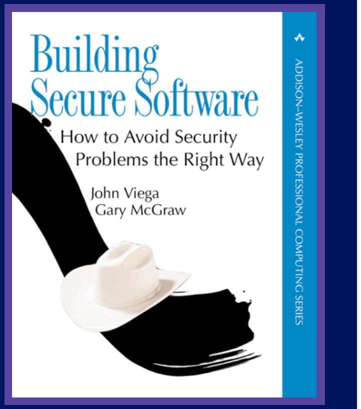
# 7. Make Developers' Life Easier: Give Them Good Tools

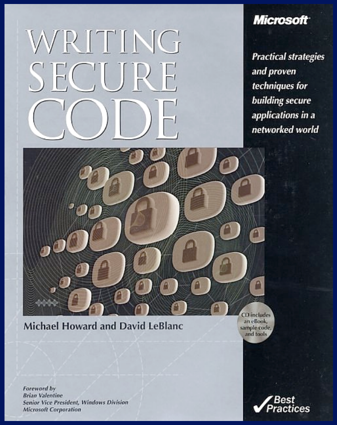
- automated tools for formal methods
  - http://www.comlab.ox.ac.uk/archive/formal-methods.html
- code analysis tools
  - RATS http://www.securesw.com/rats
  - Flawfinder http://www.dwheeler.com/flawfinder
  - ITS4 http://www.cigital.com/its4
  - ESC/Java http://www.niii.kun.nl/ita/sos/projects/escframe.html
  - PREfast, PREfix, SLAM www.research.microsoft.com
  - Fluid http://www.fluid.cmu.edu
  - JACKPOT research.sun.com/projects/jackpot
  - Many more …

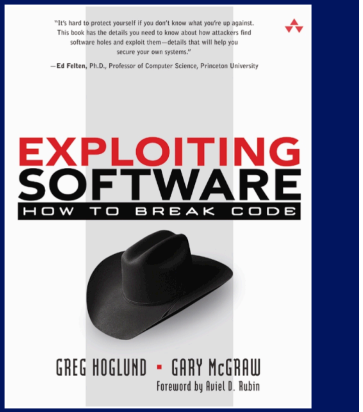
# Relevant Books

- High Level
  - Secure Coding, Principles and Practices (M.G. Graff and K.R. Van Wyk 2003)
- Technical
  - Secure Programming Cookbook (J. Viega and M. Messier)
  - Writing Secure Code, 2nd Edition (Howard and Leblanc)




Building Secure Software
How to Avoid Security Problems the Right Way
John Viega
Gary McGraw
ADDISON-WESLEY PROFESSIONAL COMPUTING SERIES


WRITING SECURE CODE
Microsoft
Practical strategies and proven techniques for building secure applications in a networked world
Michael Howard and David LeBlanc
CD includes an e-Book, sample code, and tools
Foreword by Brian Valentine Senior Vice President, Windows Division Microsoft Corporation
Best Practices


"It's hard to protect yourself if you don't know what you're up against. This book has the details you need to know about how attackers find software holes and exploit them—details that will help you secure your own systems."
—Ed Felten, Ph.D., Professor of Computer Science, Princeton University
EXPLOITING SOFTWARE
HOW TO BREAK CODE
GREG HOGLUND • GARY McGRAW
Foreword by Aviel D. Rubin

# Free Relevant Books

- Improving Web Application Security: Threats and Countermeasures Roadmap
  - J.D. Meier, Alex Mackman, Michael Dunner, Srinath Vasireddy, Ray Escamilla and Anandha Murukan
    Microsoft Corporation
  - MSDN Library, June 2003
  - http://msdn.microsoft.com/library/default.asp?url=/library/en-us/dnnetsec/html/ThreatCounter.asp