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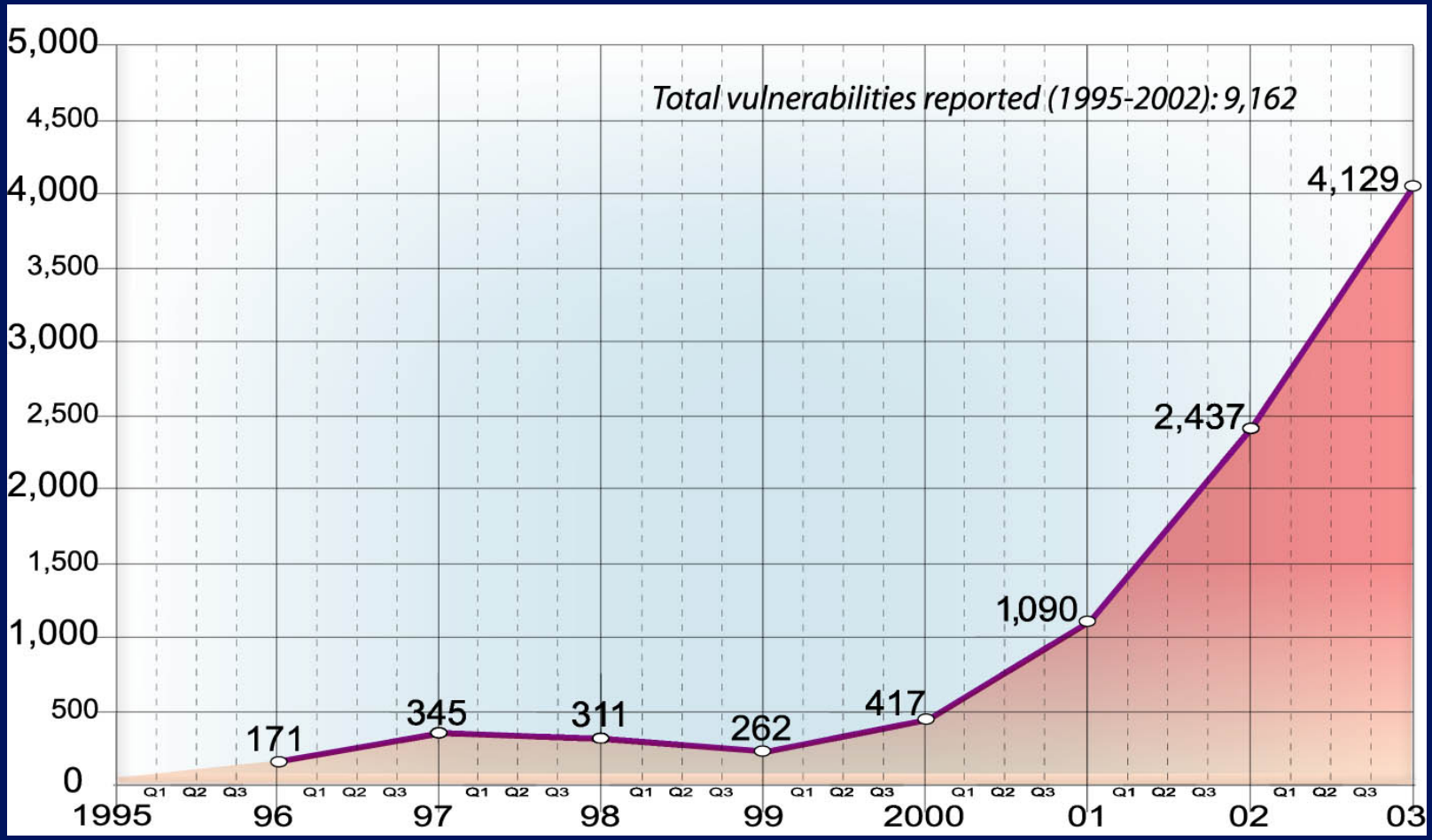
Developing Secure Software

Vulnerability Report Statistics



Outline

- Why developing secure software is hard?
- How are security bugs different?
- How does buffer overflow work?
- Guidelines for developing secure software

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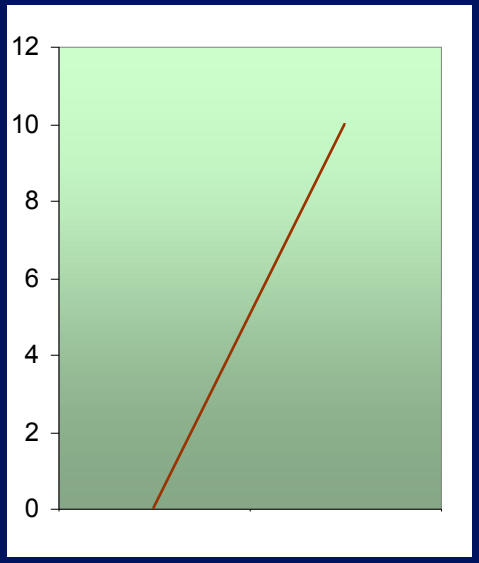
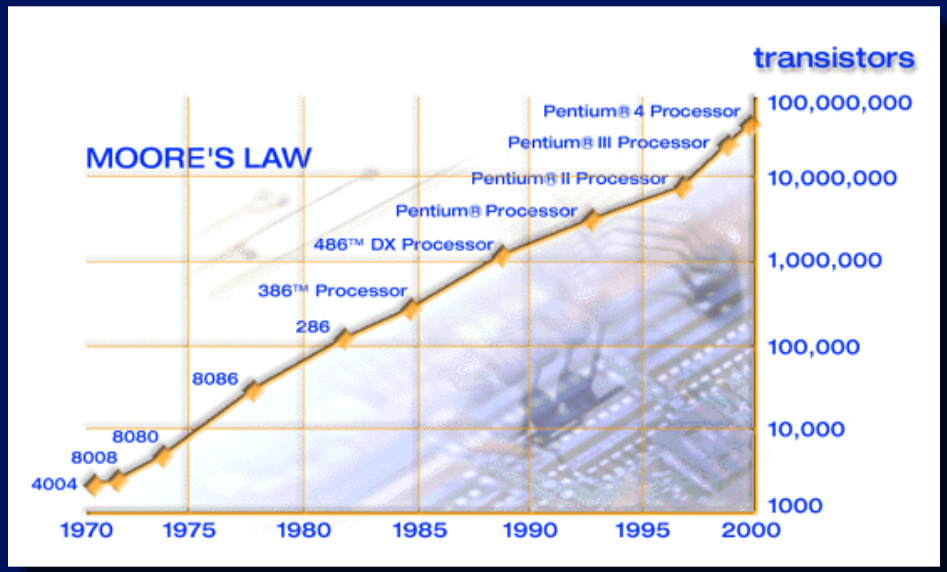
Why are there so many vulnerabilities in software?

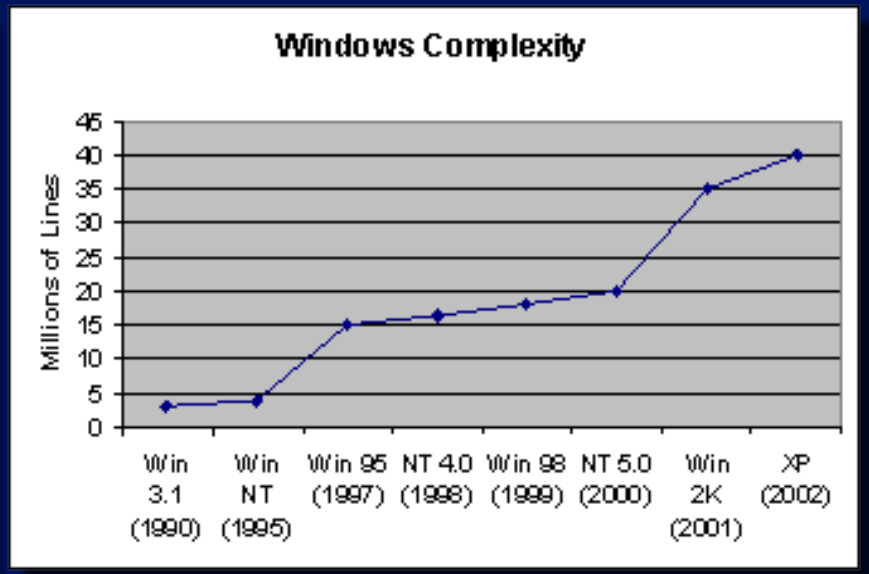


What makes simple mechanical systems predictable?

- 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

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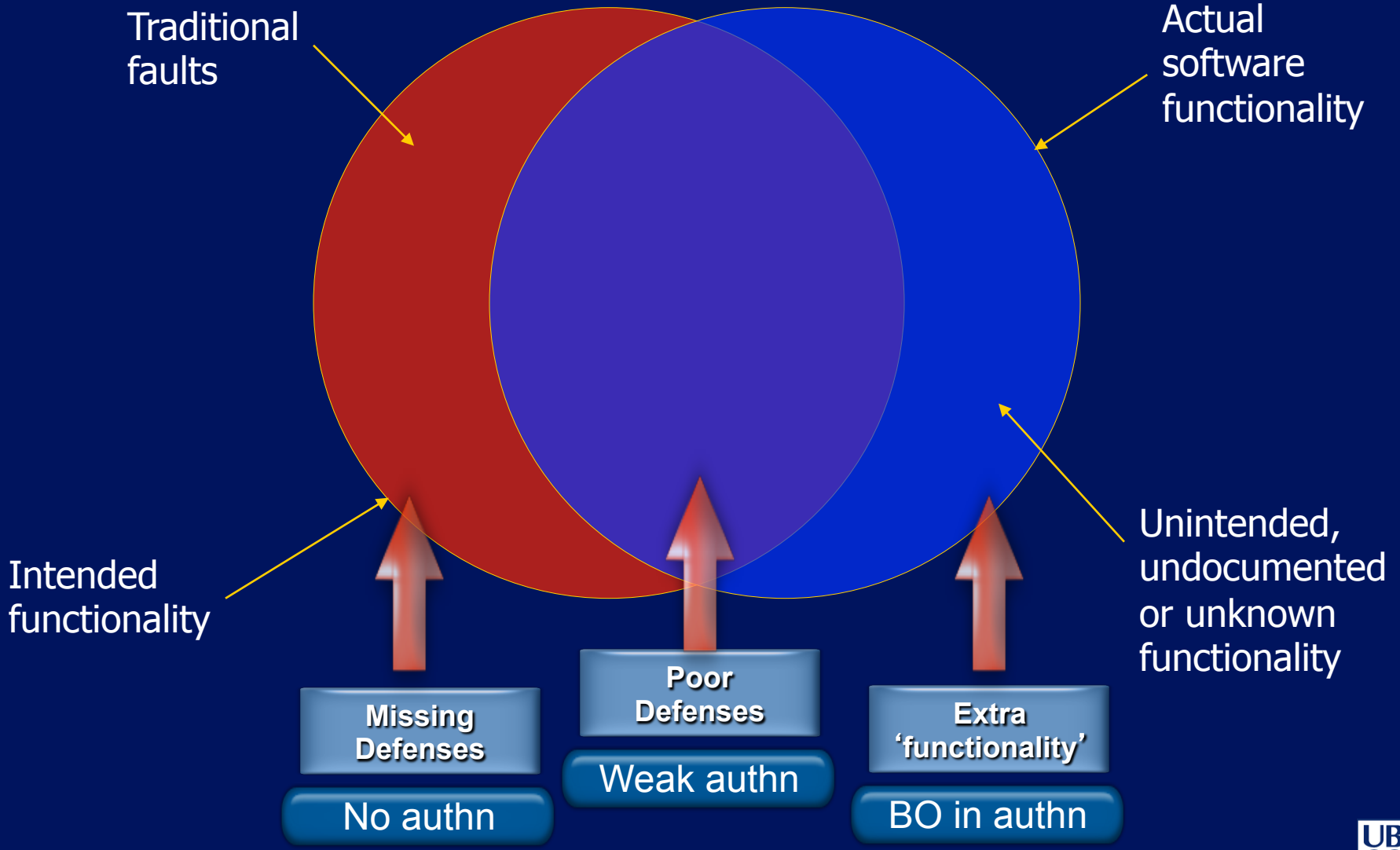
How Are Security Bugs Different?

Intended vs. Implemented Behavior



Traditional faults

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

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?

How Buffer Overflow Works

Adopted from the material by
Dave Hollinger

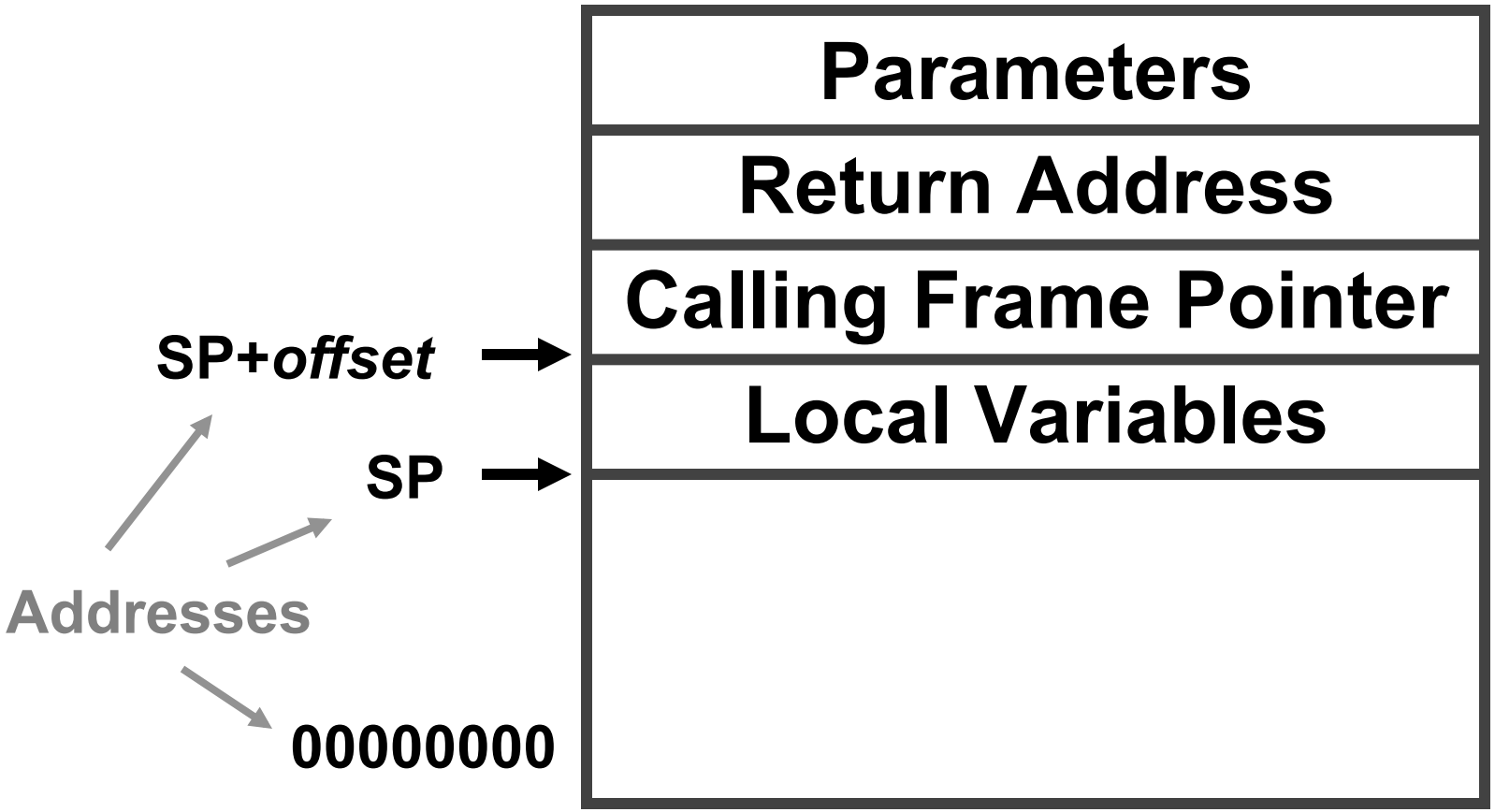
The Problem

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

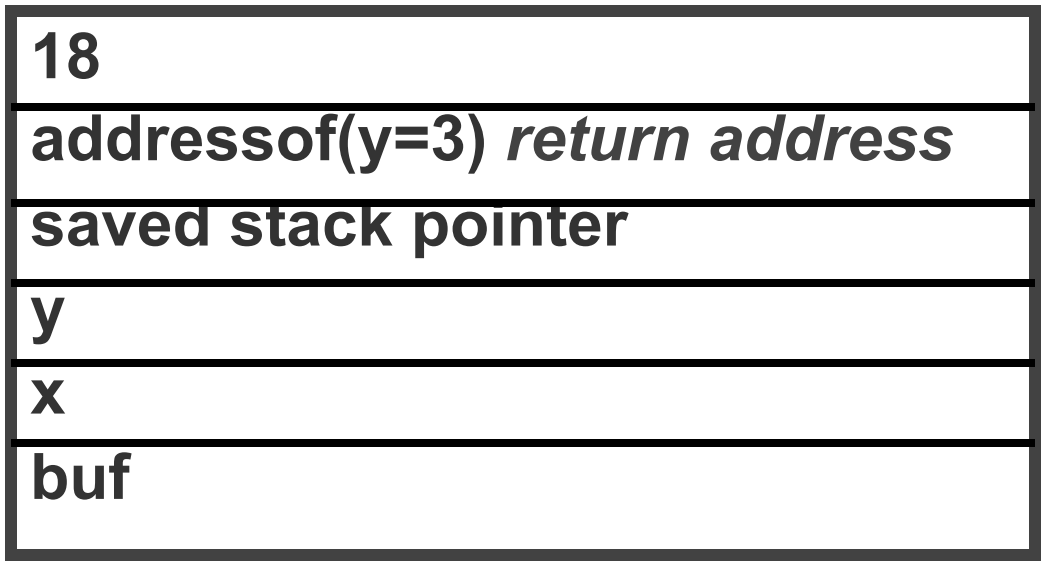
Exploitation

- 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

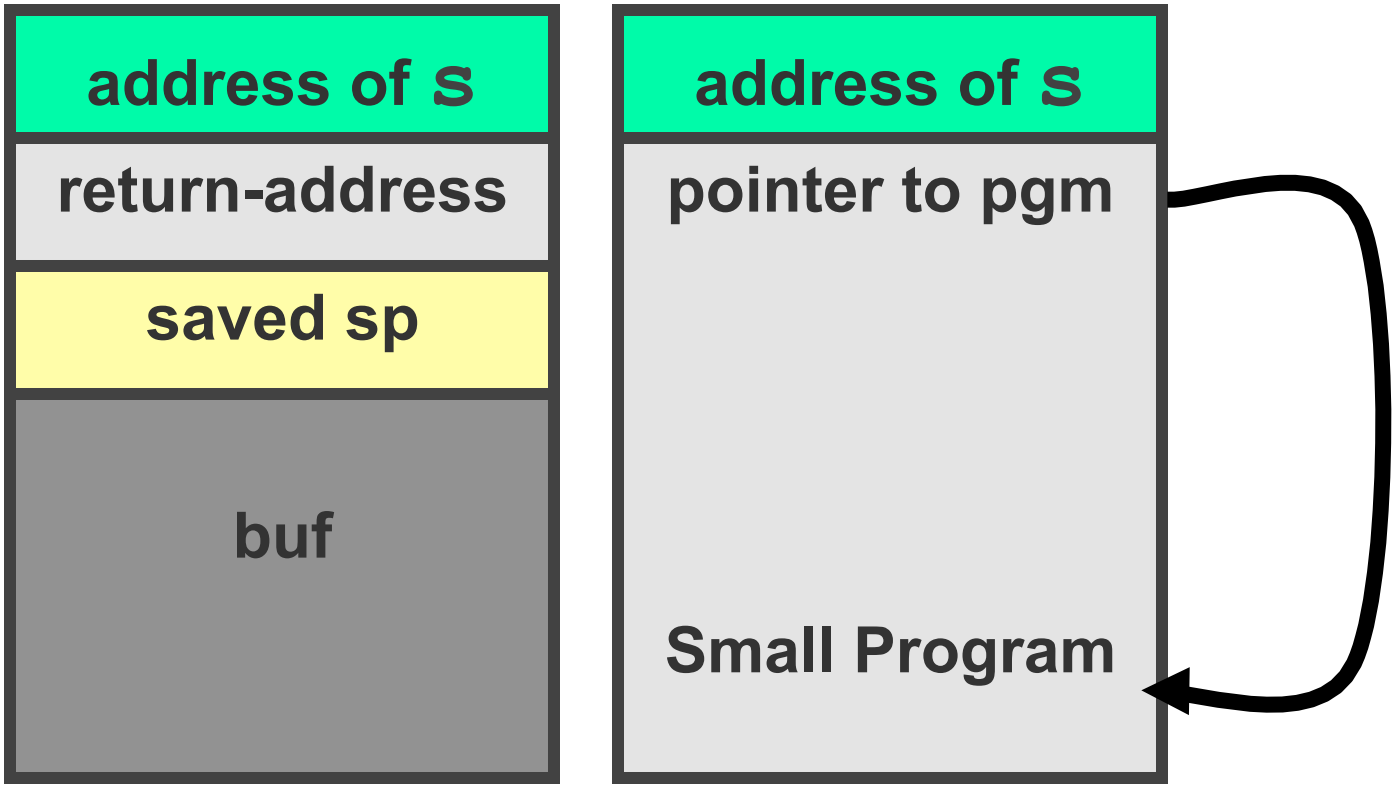



```
x=2;
foo(18);
y=3;
```

```
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

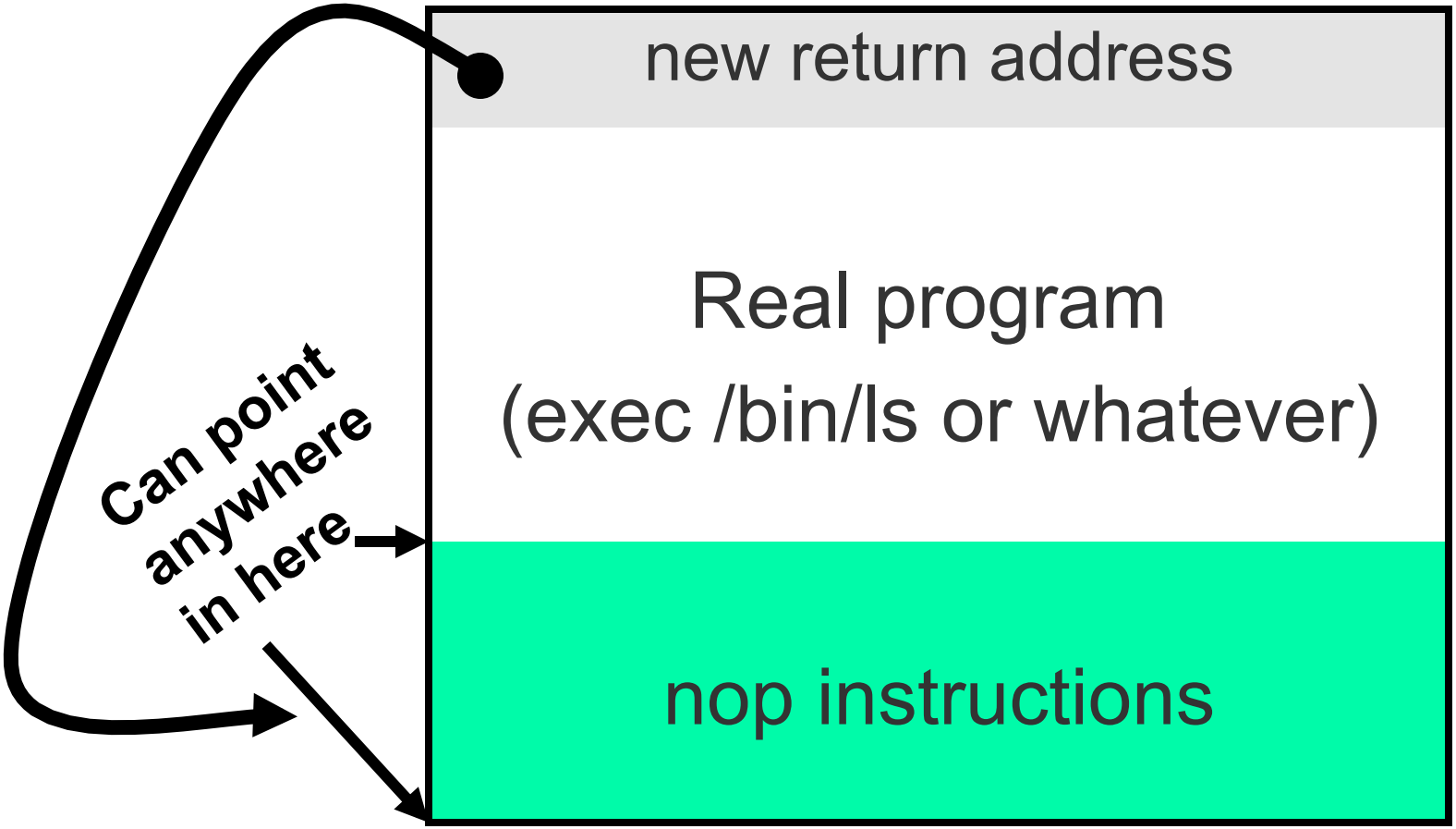
Does an exec() of /bin/ls:

```
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";
```

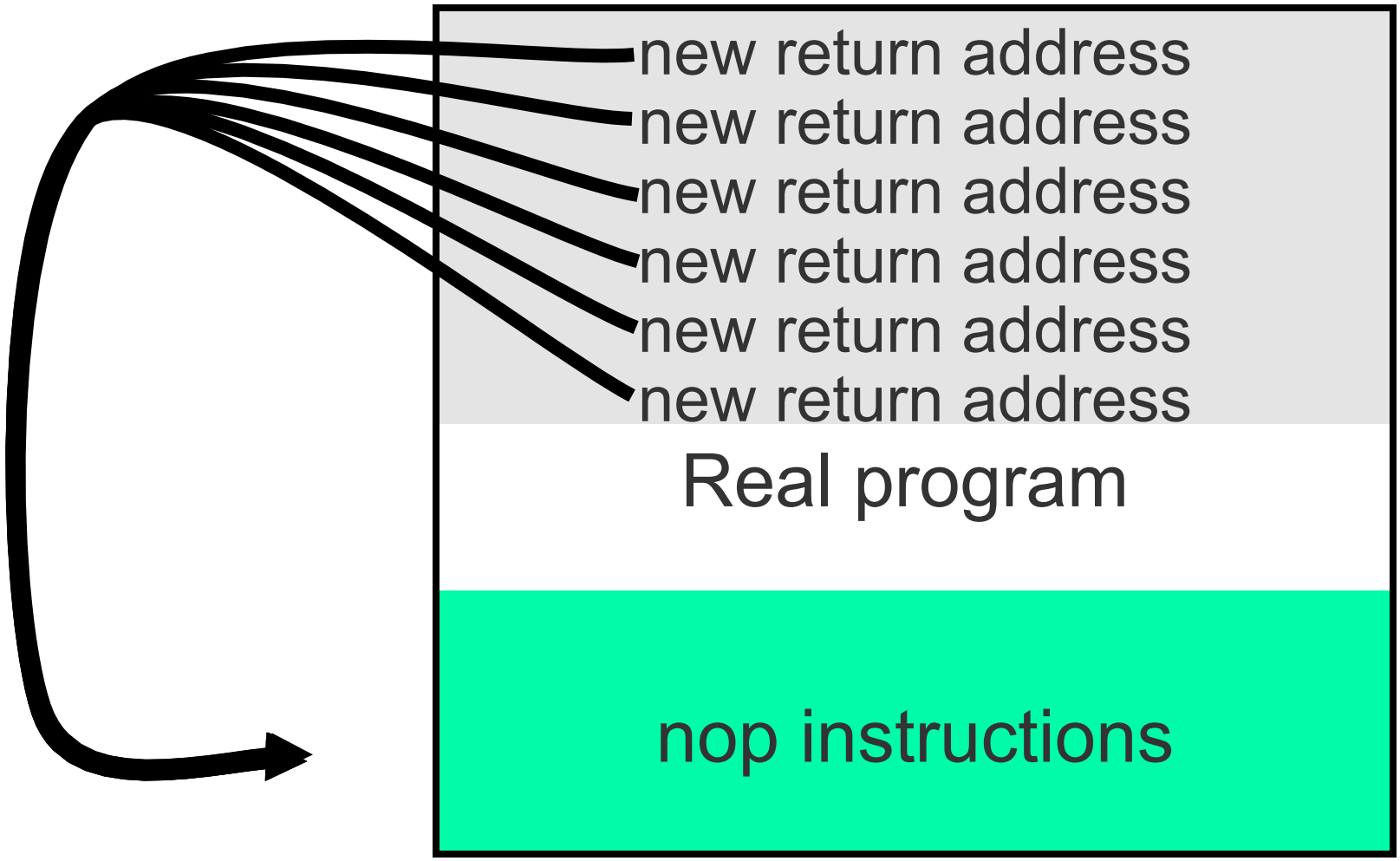
Sample Overflow Program

```
unsigned char cde[] = "\xeb\x1f\…

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

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);
}
```

Properties of Control Flow Exploits

- Computation
  - The attacker wishes to perform
    - Shellcode (machine code)
- Control flow
  - Disrupts regular control flow of the program
  - Commonly transfers control to the shellcode

Techniques for Preventing Buffer Overflow Attacks

- Write or Execute, but not both
  - No program segment loaded into memory is both writable and executable
- Address Space Layout Randomization (ASLR)
  - Prevents an attacker from predicting information needed for correctly changing information flow towards the desirable computation

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?

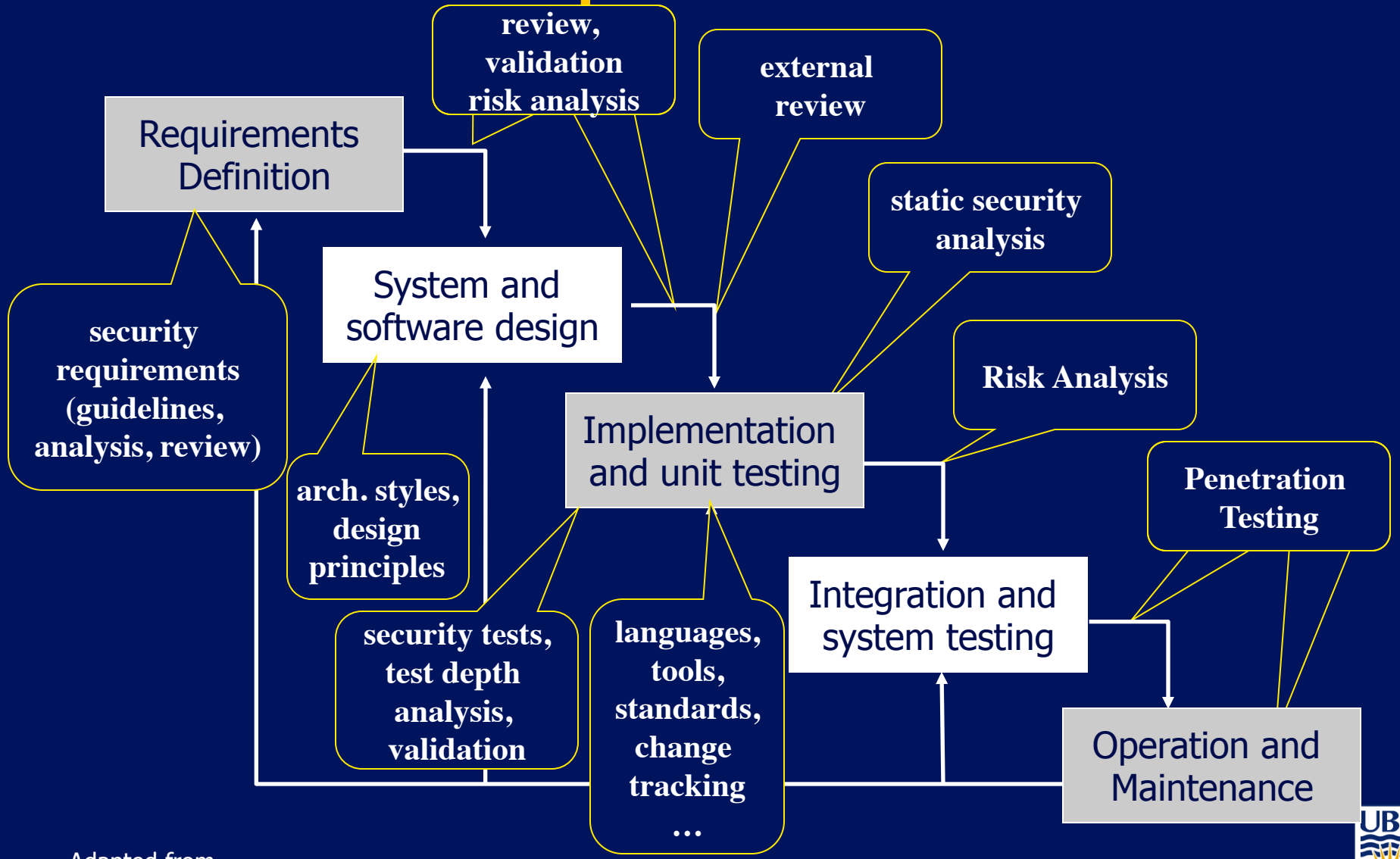
Guidelines

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

1. Produce Quality Software

- Use well structured effective processes
  - e.g., Capability Maturity Model (CMM), *-CMM
- Use precise requirements and specifications

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

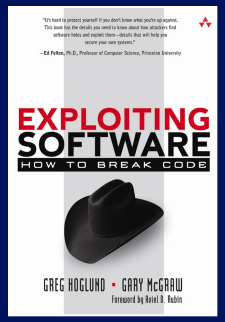
3. Practice principles of designing secure systems

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()



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

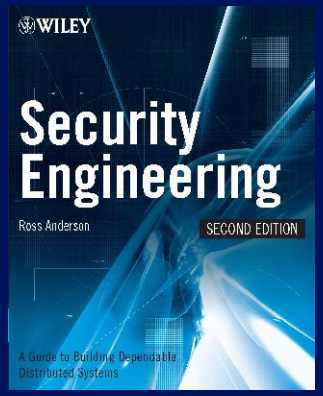
6. Choose Safer Languages, VMs, OSs, etc.

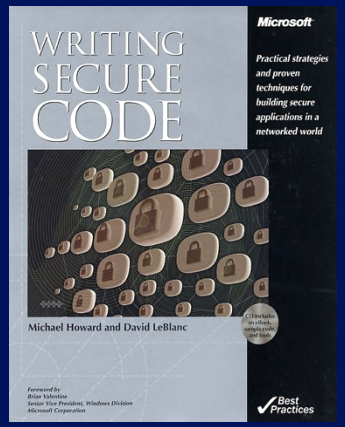
- C or C++?
- Java or C++?
- Managed C++ or vanilla C++?
- .NET CLR or JVM?
- Windows XP or Windows 2003?
- Linux/MacOS/Solaris or Windows?

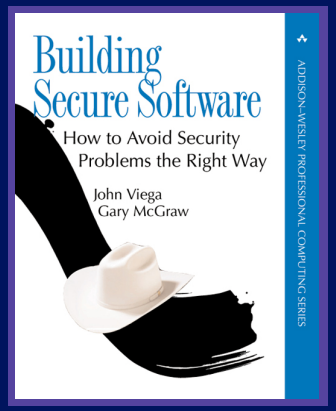
7. Make Developers' Life Easier: Give Them Good Tools

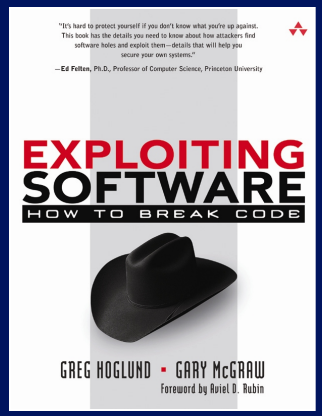
- automated tools for formal methods
  - http://www.comlab.ox.ac.uk/archive/formal-methods.html
- code analysis tools
  - RATS http://www.securesw.com/rats
  - Flawfinder http://www.dwheeler.com/flawfinder
  - ITS4 http://www.cigital.com/its4
  - ESC/Java http://www.niii.kun.nl/ita/sos/projects/escframe.html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

Relevant Books









and many more …

module summary

- developing secure software is hard because it's
  - nonlinear, large, extensible, complex, has side-effects, networked
- security bugs are different because they are undocumented side-effects
- buffer overflow works through overriding return address and replacing data with code
- guidelines for developing secure software

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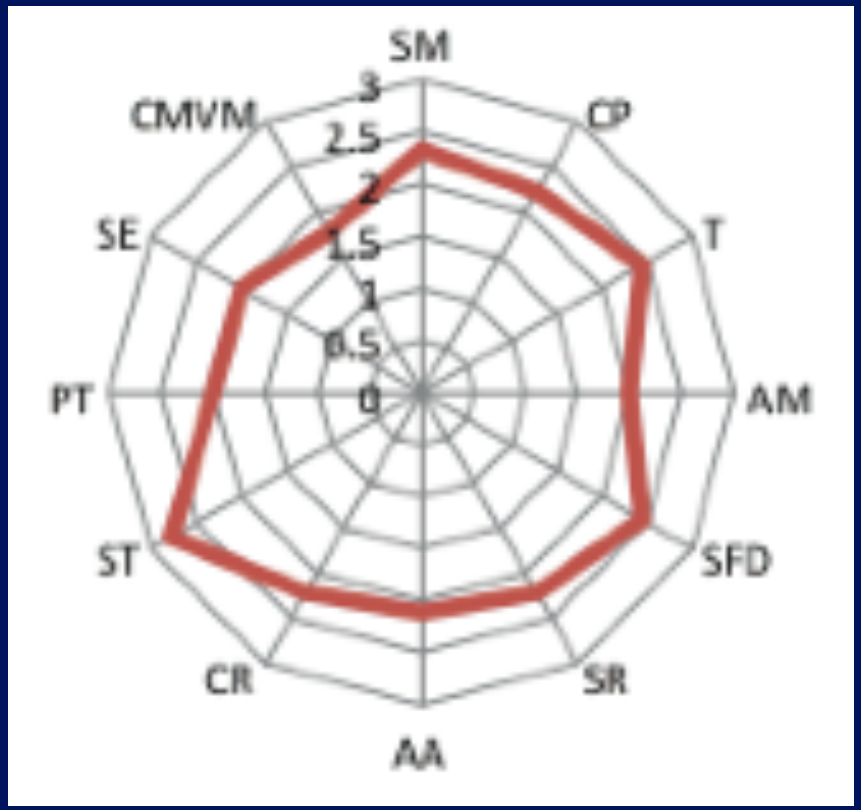
Case Study:
Build Security In Maturity Model

BSIMM

- Framework derived from SAMM Beta
- Based on collected data from 9 large firms

Governance	Intelligence	SSDL Touchpoints	Deployment
Strategy and Metrics	Attack Models	Architecture Analysis	Penetration Testing
Compliance and Policy	Security Features and Design	Code Review	Software Environment
Training	Standards and Requirements	Security Testing	Configuration Management and Vulnerability Manage-ment



Source: "Building Security In Maturity Model" by Gary McGraw, Brian Chess, Sammy Migues