Software Security

Introduction

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Admin

- Most course material will be on

  http://www.cs.ru.nl/~erikpoll/ss

  but some things will be in Brightspace

- Keep track of Brightspace announcements
  - If you do not log into Brightspace regularly, have these announcements forwarded to your email

Goals of this course

- **How** does security typically fail in software?

- **Why** does software often fail?

  What are the underlying root causes?

- **What** are ways to make software more secure?

  incl. principles, methods, tools & technologies

  - incl. practical experience with some of these

Focus more on defence than on offense

Practicalities: prerequisites

- Introductory security course
  - TCB (Trusted Computing Base),
    CIA (Confidentiality, Integrity, Availability),
    Authentication, ...

- Basic programming skills, in particular
  - C(++) or assembly/machine code
    - eg. `malloc()`, `free()`, `*(p++)`, `&x`
      `strings in C using char*`
  - Java or some other typed OO language
    - eg. `public`, `final`, `private`, `protected`, `Exceptions`
  - bits of PHP and JavaScript

The kind of C(++) code you will see next week

```
char* copy_and_print(char* string)  {
      char* b = malloc(strlen(string));
      strcpy(b,string); // copy string to b
      printf("The string is %s.", b);
      free(b);
      return(b);
}
int sum_using_pointer_arithmetic(int a[])  {
      int sum = 0;
      int *pointer = a;
      for (int i=0; i<4; i++ ){
          sum = sum + *pointer;
          pointer++; }
      return sum;
}
```

The kind of Java code you will see next month

```
public int sumOfArray(int[] pin)
    throws NullPointerException,
           ArrayIndexOutOfBoundsException      {
     int sum = 0;
     for (int i=0; i<4; i++ ){
          sum = sum + a[i];
     }
     return sum;
}
```

The kind of OO Java code you will see next month

```
final class A implements Serializable {
  public final static int SOME_CONSTANT = 2;
  private B b1;
  public  B b2;

  protected A ShallowClone(Object o)
        throws ClassCastException      {
      a = new(A);
      x.b1 = ( (A) o).b1; // cast o to class A
      x.b2 = ( (A) o).b2;
      return a;
  }
}
```

Exam material

- Slides + reading material available at
  http:///www.cs.ru.nl/~erikpoll/ss
- Mandatory reading:
  - my lecture notes, on 2 topics
  - 2 CyBok book chapters
  - some articles

  I'll be updating this as we go along

Not exam material

Join the student CTF group if you're interested in the practical side of security

The Risky.Biz podcast to keep up with weekly security news

Not exam material

Next week Thursday:

OWASP Netherlands meet-up

See https://owasp.org/www-chapter-netherlands/#div-upcoming

You can also register for the (low-traffic) OWASP-NL mailing list

Practicalities: form & examination

- 2-hrs lecture every week
  - read associated papers & ask questions!
- project work
  - PREfast for C++ (individual or in pairs)
  - group project (with 4 people) on fuzzing
  - exercise on web site sanitisations
  - project on static analysis with Semmle (individual or in pairs)
- written exam

Bonus point for group project, computed as `(grade-6)/4`

Today

- Organisational stuff

- What is "software security"?
- The problem of software insecurity
- The causes of the problem
- The solution to the problem
- Security concepts

Motivation

Quiz

Why can websites, servers, browsers, laptops, mobile phones, wifi access points, network routers, mobile phones, cars, pacemakers, the electricity grid, uranium enrichment facilities, … be hacked?

Because they contain 

When it comes to cyber security
software is not our Achilles heel
but our Achilles *body*

'Achilles only had an Achilles heel, I have an entire Achilles body'

- Woody Allen

Why a course on software security?

- **Software is a MAJOR source of security problems and plays MAJOR role in providing security**

  Software is *the* weakest link in the security chain, with the possible exception of 'the human factor'

- **Software security does not get much attention**
  - **in other security courses, or**
  - **in programming courses,**

  or indeed, in much of the security literature!

How do computer systems get hacked?

By attacking

- **software**

- **humans**

Or: the interaction between software & humans

- crypto
- hardware
- …

Fairy tales

Many discussions about security begin with Alice and Bob

How can Alice communicate securely with Bob,
when Eve can modify or eavesdrop on the communication?

This is an interesting problem,
but it is *not* the biggest problem

The *really big* problem

Alice & her computer are communicating with *another computer*

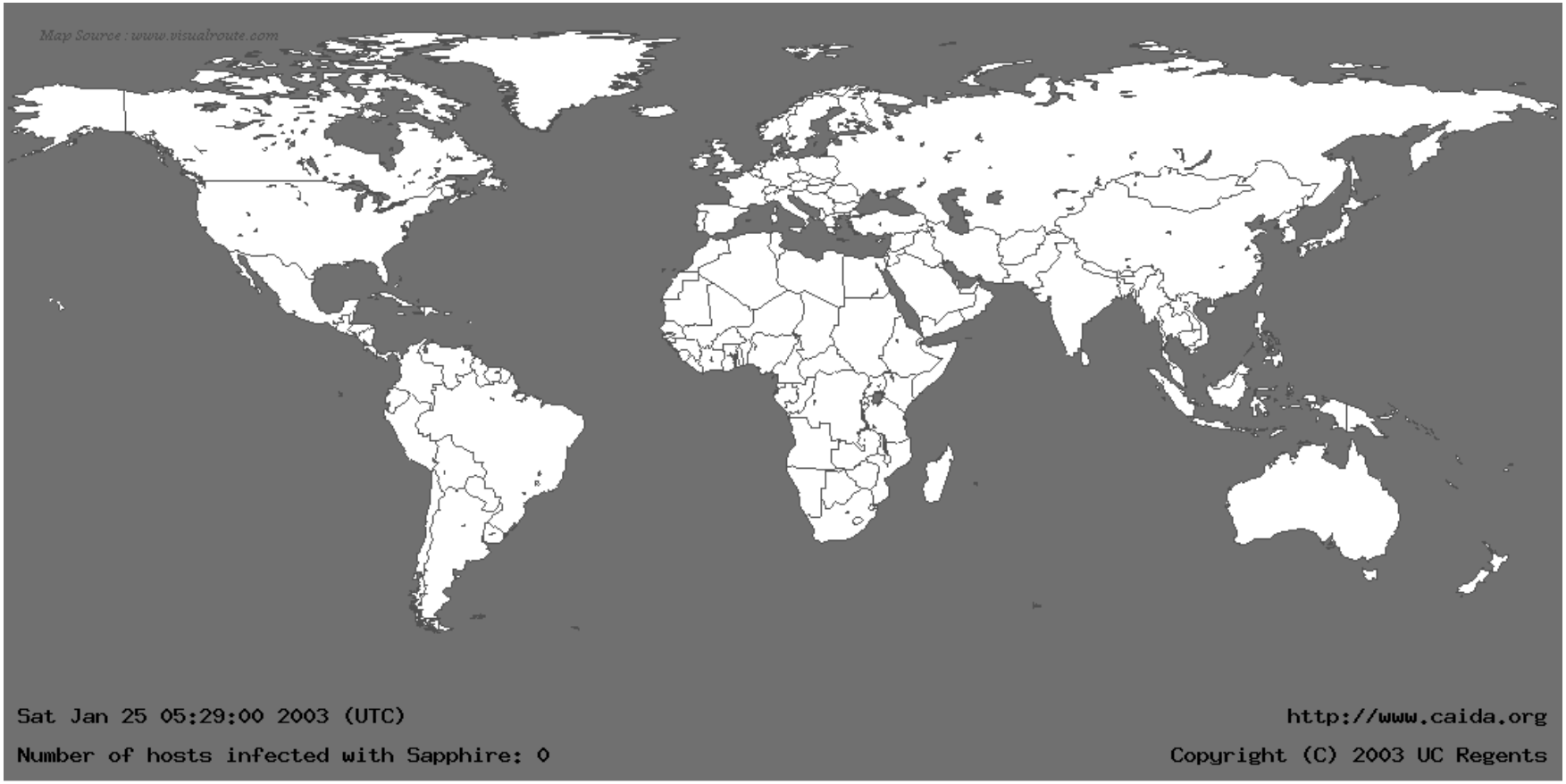
How to prevent Alice's computer from getting *hacked*?

Or how to detect this? And then react ?

Solving earlier problem, securing the communication, does *not* help!

The problem

25th January 2003, 5:29 AM



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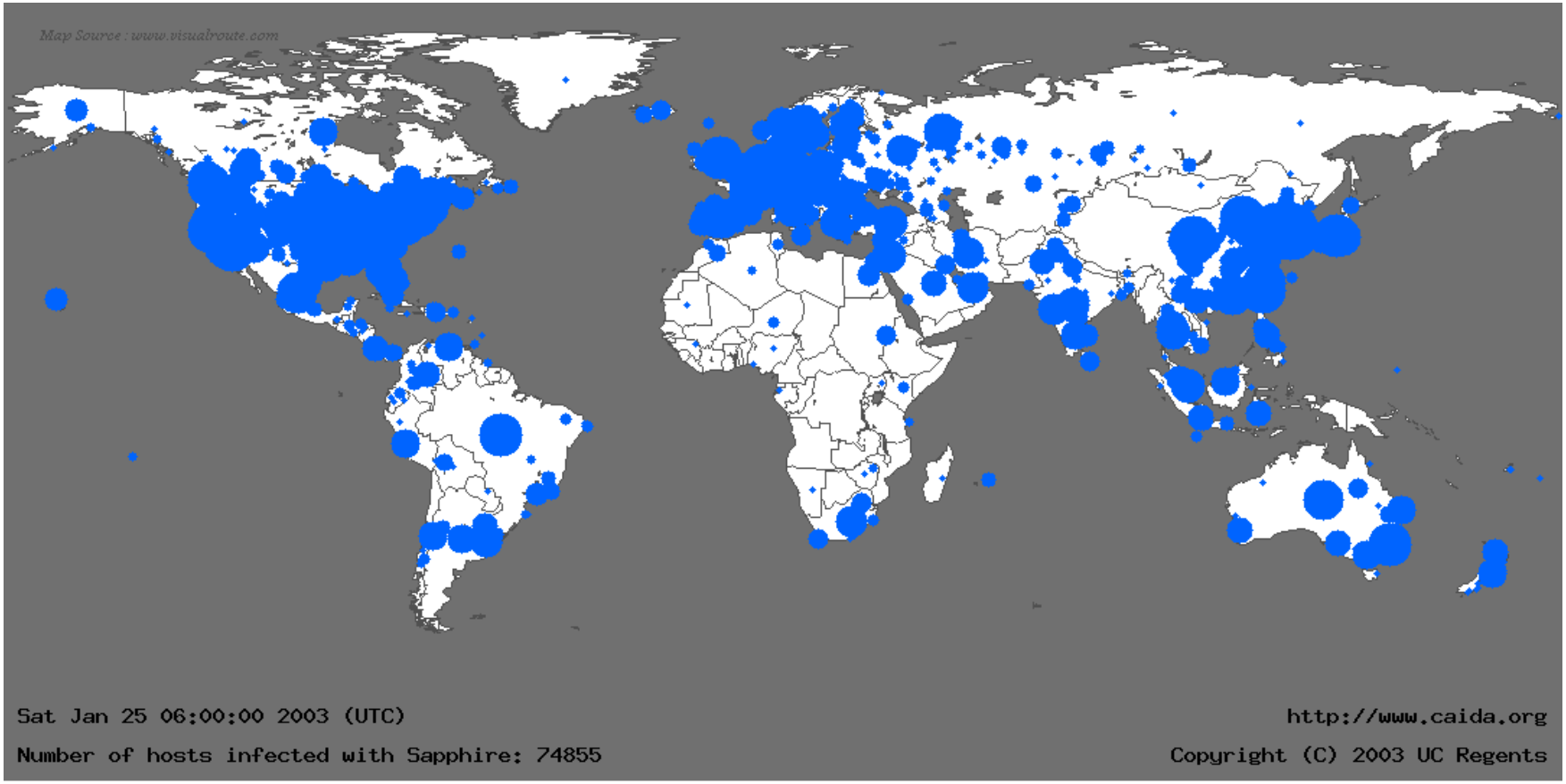
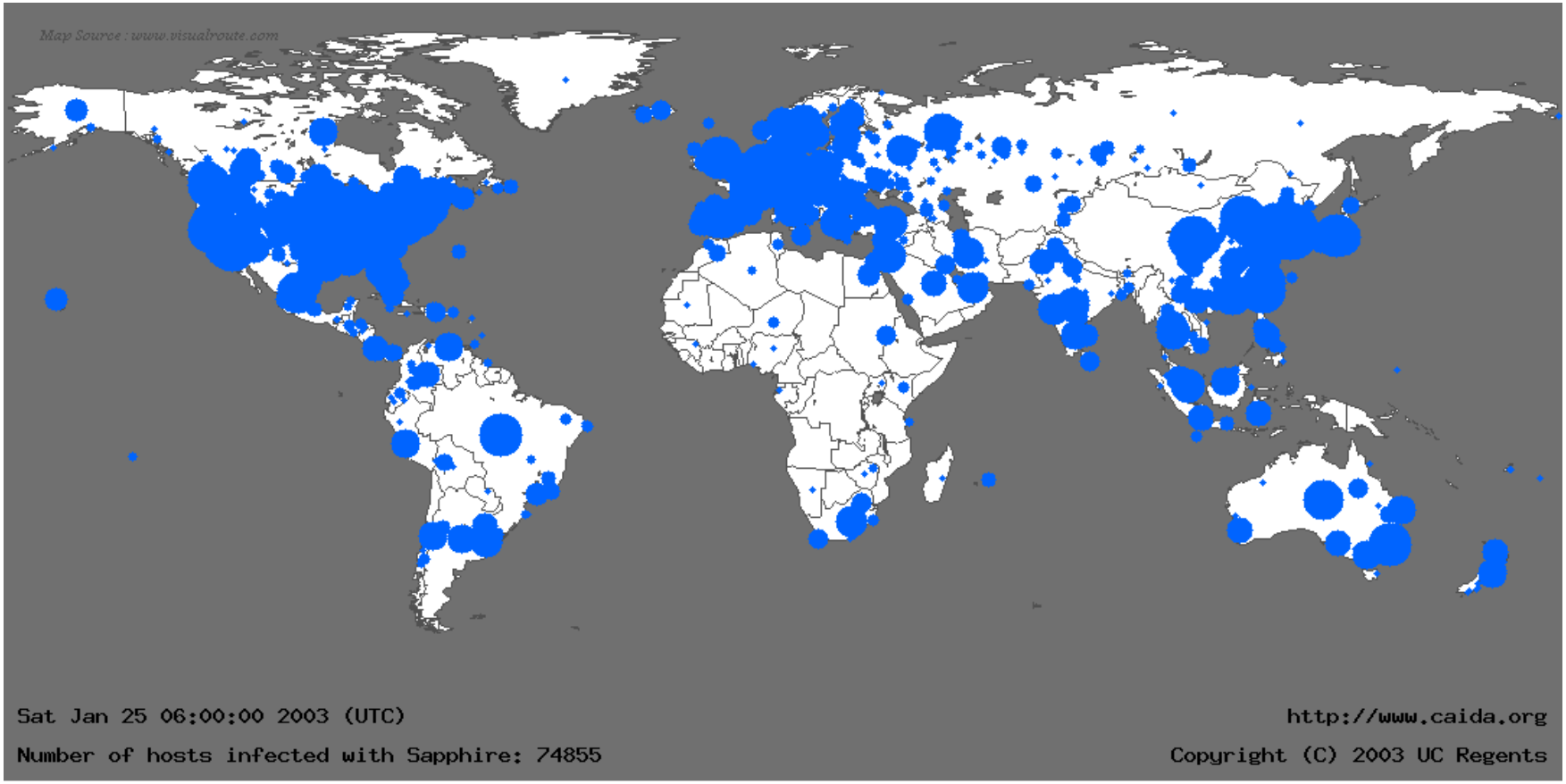


Slammer Worm



From *The Spread of the Sapphire/Slammer Worm*, by David Moore et al.

Security problems nowadays

To get an impression of the problem, have a look at

US-CERT bulletins

https://us-cert.cisa.gov/ncas/bulletins

CVE (Common Vulnerability Enumeration)

https://cve.mitre.org/cve/

NIST's vulnerability database

https://nvd.nist.gov/vuln/search

Or subscribe to the CVE twitter feed

https://twitter.com/cvenew

Changing nature of attackers

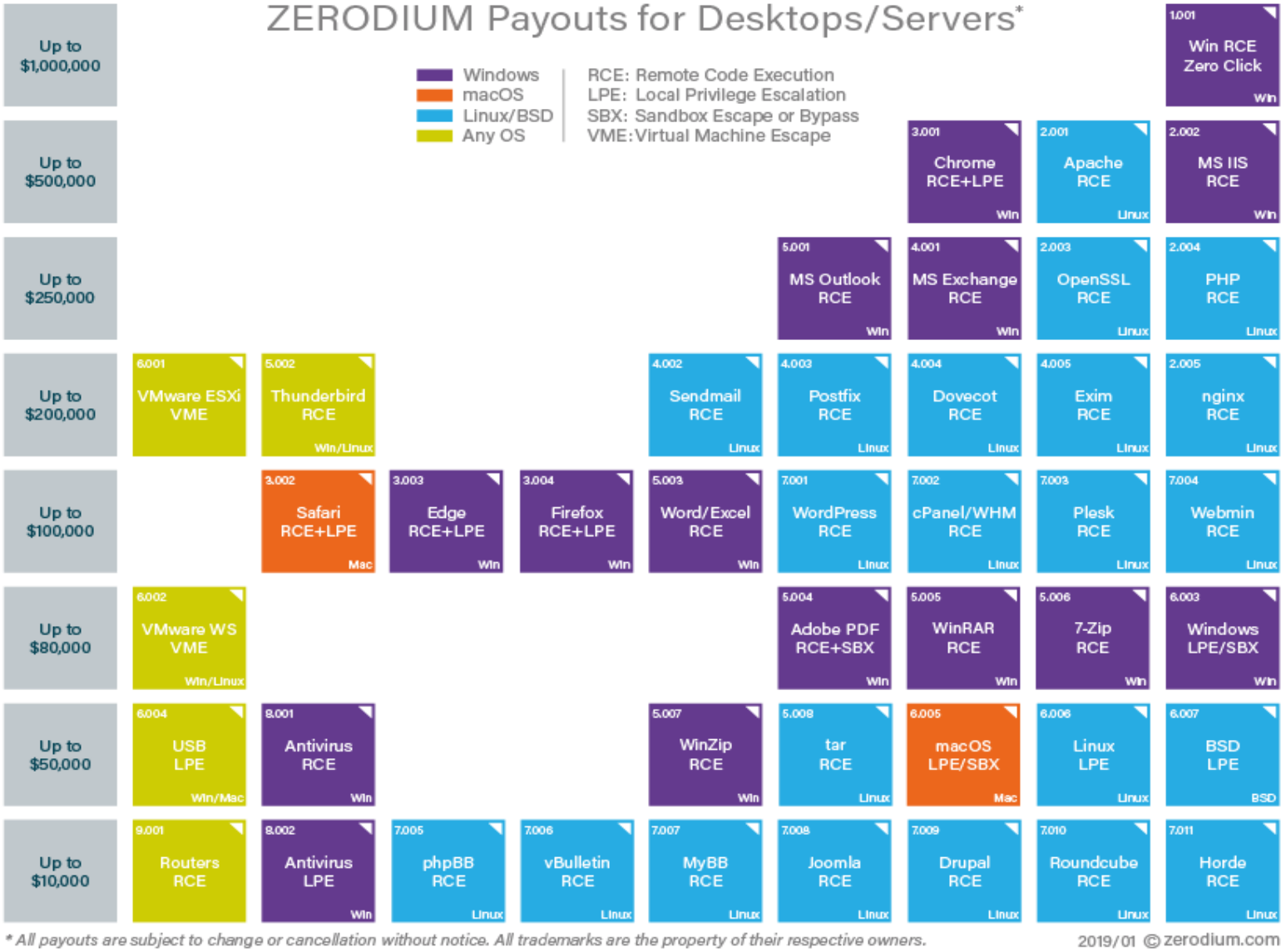
Traditionally, hackers were amateurs motivated by 'fun'

- by script kiddies & more skilled hobbyists
- NB if you like that, join the RU-CTF team!

Nowadays hackers are professional:

- cyber criminals
  - with lots of money & (hired) expertise
  - Important game changers: ransomware & bitcoin
- state actors
  - with even more money & in-house expertise
- hackers for hire
  - like NSO group, Zerodium, …

Prices for 0days



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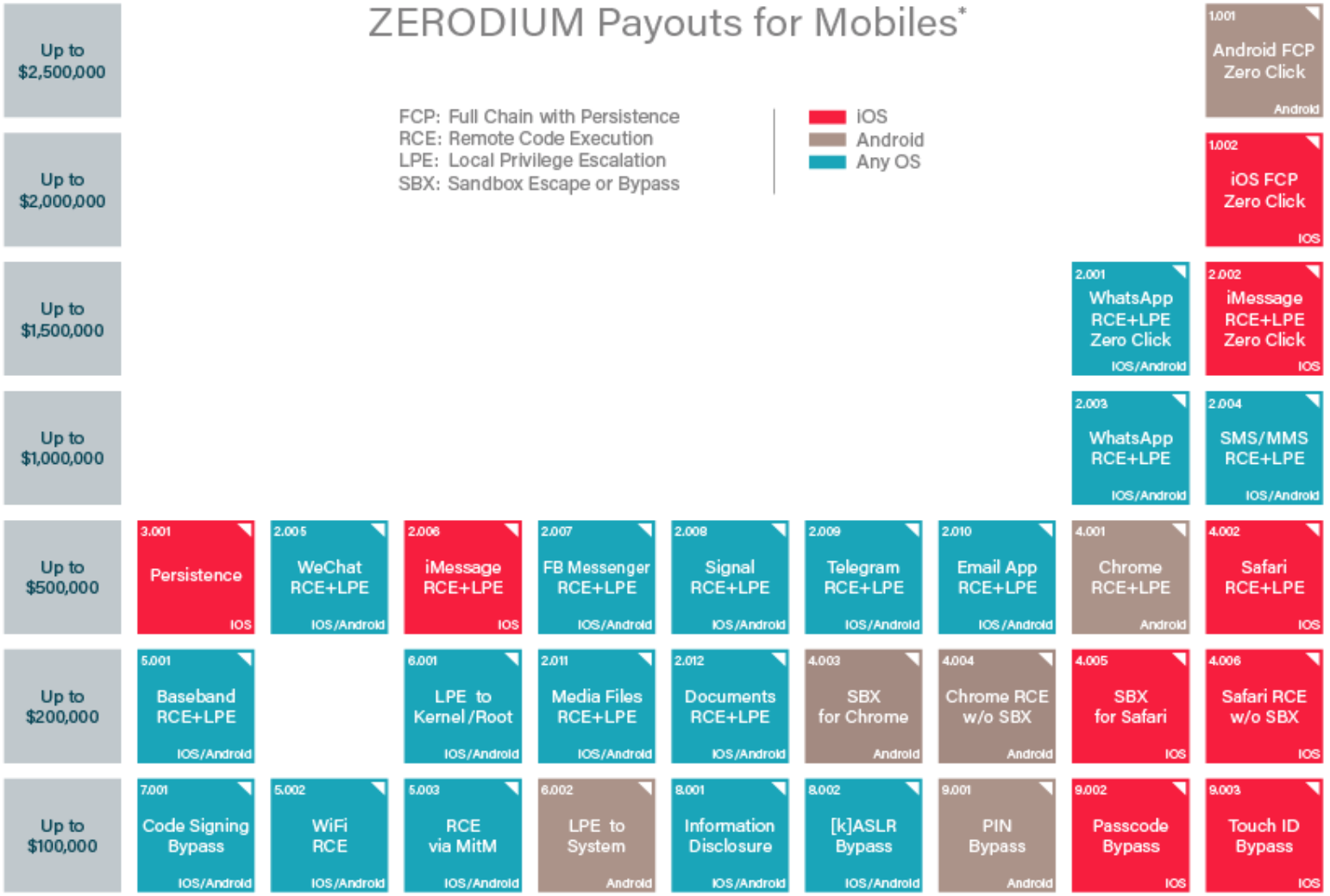
Prices for 0days



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Apple & Google payouts

Google Offers $1.5M Bug Bounty for Android 13 Beta

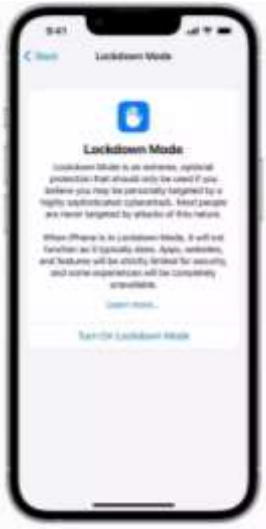
The security vulnerability payout set bug hunters rejoicing, but claiming the reward is much, much easier said than done.

Tara Seals
Managing Editor, News, Dark Reading

May 02, 2022

Apple will pay you $2 million if you can break its new 'Lockdown Mode'

By Joe Wituschek published July 07, 2022



Software security: crucial facts

- *There are no silver bullets!*

  Firewalls, crypto, or special security features do not magically solve all problems

  - "if you think your problem can be solved by cryptography, you do not understand cryptography and you do not understand your problem" [Bruce Schneier]

- Security is emergent property of entire system
  - like quality
  - or maybe: property of the ongoing process?

- Security should be - but hardly ever is - integral part of the design, right from the start

security software ≠ software security

Adding security software can make a system more secure

i.e. software specifically for security, such as

- TLS, IPSEC, firewall, VPN, …
- AV (AntiVirus), WAF (Web Application Firewall)
- access control, with eg 2FA, logging, monitoring, …
- NIDS (Network Intrusion Detection System)
- EDR (Endpoint Detection and Response)
- RASP (Runtime Application Self-Protection)
- …

But *all* software must be secure, not just the security software

- That buffer overflow in your PDF viewer can still be exploited…
- Adding security software may *add* software bugs and make things less secure:

Check out https://cve.mitre.org/cgi-bin/cvekey.cgi?keyword=firewall

https://cve.mitre.org/cgi-bin/cvekey.cgi?keyword=VPN

Root causes

Quick audience polls

- *Did you ever take a course on C(++) programming ?*
- *Were you taught C(++) as a first programming language?*
- *Did this these courses*
  - *warn about buffer overflows?*
  - *explain how to avoid them?*

Major causes of problems are

- **lack of awareness**
- **lack of knowledge**
- **irresponsible teaching of dangerous programming languages**

Quick audience poll

- *Did you ever build a web-application?*
  - *in which programming languages?*
- *Do you know the secure way of doing a SQL query in this language (to prevent SQLi)?*

Major causes of problems are

- **lack of awareness**
- **lack of knowledge**

More root causes: security vs fuctionality

Primary goal of software is providing functionality & services

Managing associated risks is a secondary concern

- There is often a trade-off/conflict between
  - security
  - functionality, convenience, speed , …

  where security typically looses out

- Users are likely to complain about missing or broken functionality, but not about insecurity

Functionality vs security: Lost battles?

- Operating systems (OSs)
  - with huge OS, with huge attack surface
- Programming languages
  - with easy to use, efficient, but very insecure and error-prone mechanisms
- Web browsers
  - with JavaScript, and Web APIs to access microphone, web cam, location, …
- Email clients
  - which handle with all sorts of formats & attachments

Functionality vs security : PHP

"After writing PHP forum software for three years now, I've come to the conclusion that it is basically impossible for normal programmers to write secure PHP code.

It takes far too much effort. ....

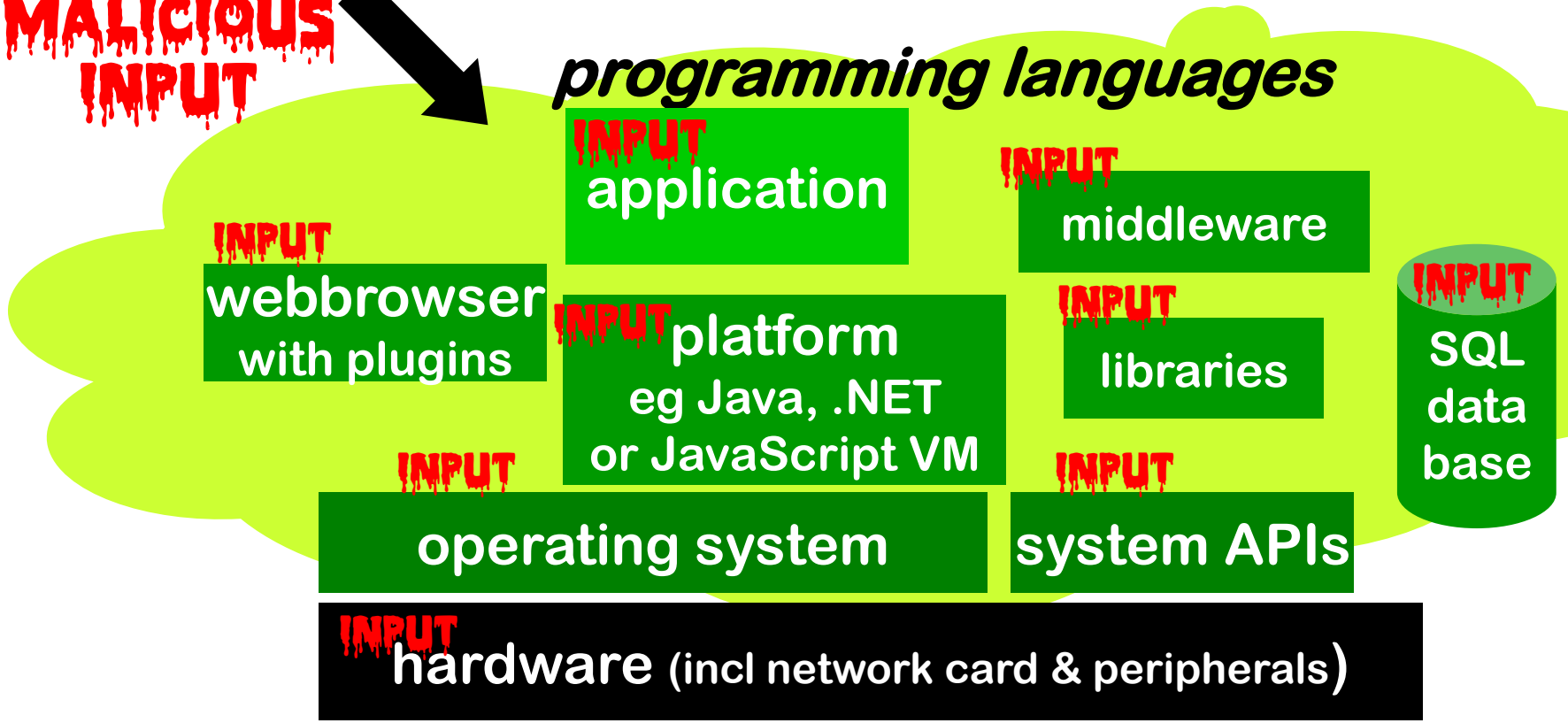
PHP's raison d'etre is that it is simple to pick up and make it do something useful. ...."

[Source http://www.greebo.cnet/?p=320]

More root causes: Weakness in depth

***complex input languages**, for interpretable* or *executable* input, eg pathnames, XML, JSON, jpeg, mpeg, xls, pdf...

MALICIOUS INPUT



Weakness in depth

Software

- runs on a huge, complicated infrastructure
  - HW, OS, platforms, web browser, lots of libraries & APIs, …
- is built using complicated languages
  - *programming* languages
    and *input* languages (SQL, HTML, XML, mp4, …)
- using various tools
  - compilers, IDEs, pre-processors, dynamic code downloads

All of these may have security holes, or may make the introduction of security holes very easy & likely

Recap

Problems are due to

- lack of awareness
  - of threats, but also of what should be protected
- lack of knowledge
  - of potential security problems, but also of solutions
- people choosing functionality over security
- compounded by complexity
  - software written in complex languages, using large complex APIs, and running on complex platforms

Types of software security problems

Weaknesses vs vulnerabilities

Terminology can be messy & confusing

security weakness, flaw, vulnerability, bug, error, coding defect, ..

Important distinction:

1. (potential) security weaknesses

   Things that could go wrong & could be better

2. (real) security vulnerabilities

   Flaws that can actually be exploited by an attacker

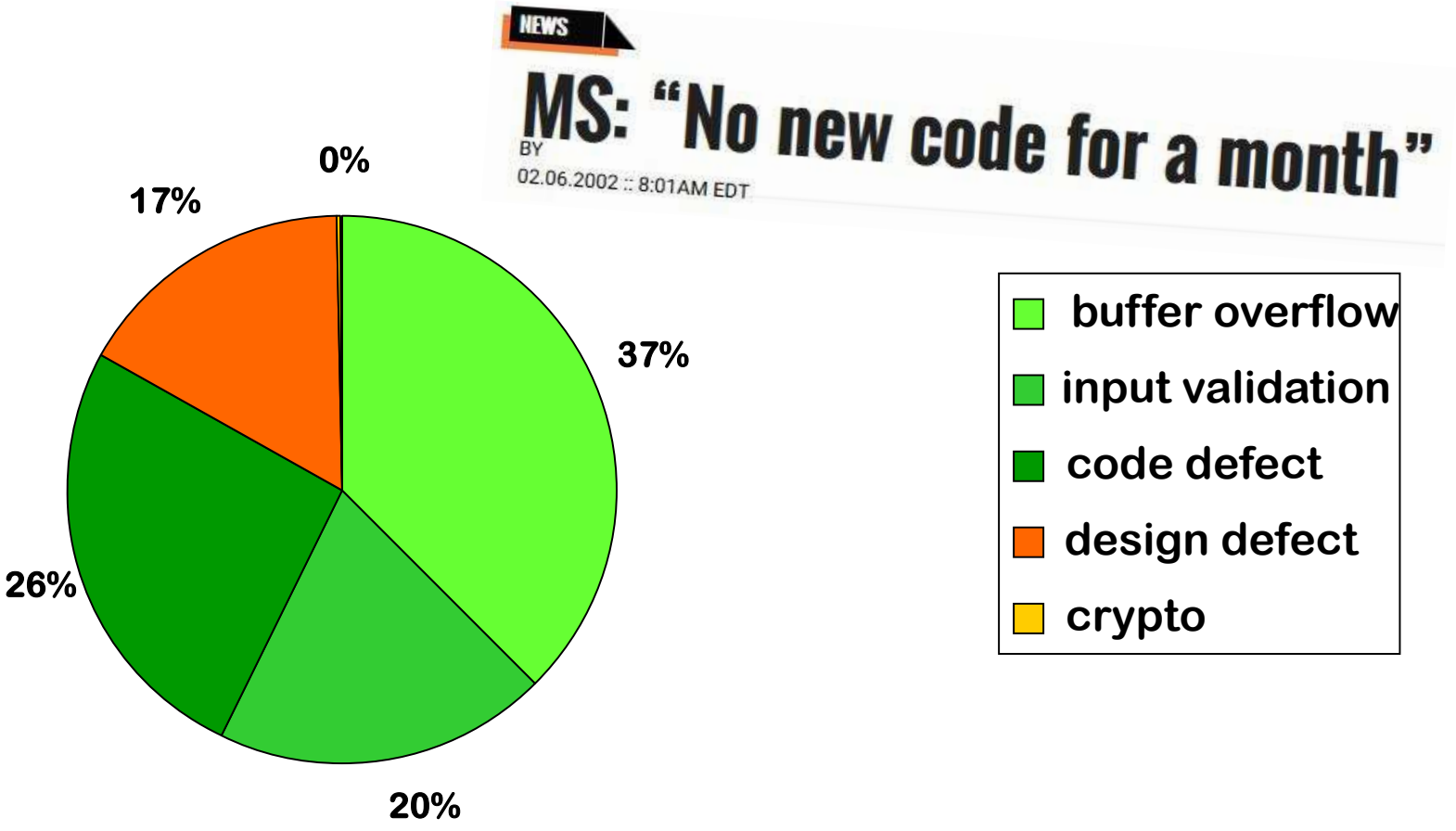
   Requires flaw to be

   accessible: attacker has to be able to get at it

   exploitable: attacker has to be able to do some damage with it

Eg by turning off Wifi and BlueTooth on my laptop,
many vulnerabilities become weaknesses

Typical software security flaws



Flaws found in Microsoft's first security bug fix month (2002)

'Levels' at which security flaws can arise

1. Design flaws
   introduced *before* coding
2. Implementation flaws aka bugs aka code-level defects
   introduced *during* coding

As a rule of thumb, coding & design flaws equally common

Vulnerabilities can also arise on other levels

3. Configuration flaws
4. Unforeseen consequences of the *intended functionality*
   - eg. spam: not enabled by flaws, but by features!

Types of implemention flaws

2a. Flaws that can be understood by looking at program itself

Eg. typos, < instead of <= …, mistake in the program logic with wrongly nested if-statements, …

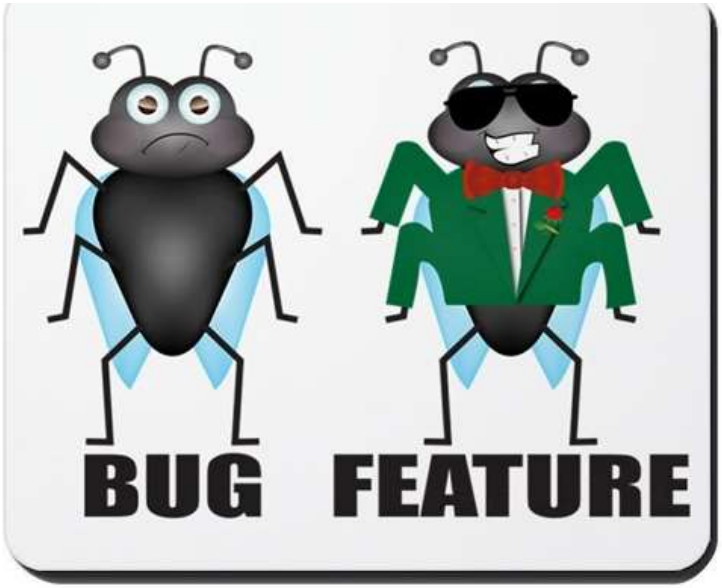
2b. Problems in the interaction with the underlying platform or other systems and services, eg

- memory corruption in C(++) code
- SQL injection in program that uses an SQL database
- XSS, CSRF, SSI, XXE, …. in web-applications
- Deserialisation attacks in many programming languages
- …

Bug vs features, yet again

Attacks can not only exploit bugs, but also features

Eg: SQL injection uses a feature of the back-end database



The dismal state of software security

The *bad* news

people keep making the same mistakes

The *good* news

people keep making the same mistakes

…… so we can do something about it!

"Every upside has its downside" [Johan Cruijff]

Spot the security flaws!

```
int balance;

void decreaseBankBalance(int amoun
 { if (balance <= amount)
        { balance = balance - amount; }
   else { println("Insufficient funds\n"); }
 }

void increaseBankBalance(int amount)
 { balance = balance + amount;
 }
```

<= should be >=

what if amount is negative?

what if this sum is too large for an `int`?

Different kinds of implementation flaws

what if amount is negative?

1. Lack of input validation

   Maybe this is a design flaw? We could decide not use signed integers..

   Root cause: IMPLICIT ASSUMPTION

<= should be >=

2. Logic error

what if sum is too large for a 64 bit `int`?

3. Problem in interaction with underlying platform

   'Lower level' than the flaws above

   Root cause: BROKEN ABSTRACTION

Security in the Software Development Life Cycle (SDLC)

[Material cover in CyBok chapter on Secure Software Lifecycle by Laurie Williams, see course web page]

How can we make software secure?

We do *not* know how to do this!

Even if we formally verify software, we may

- **miss security properties that need to be verified**
- **make implicit assumptions**
- **overlook attack vectors**
- **…**

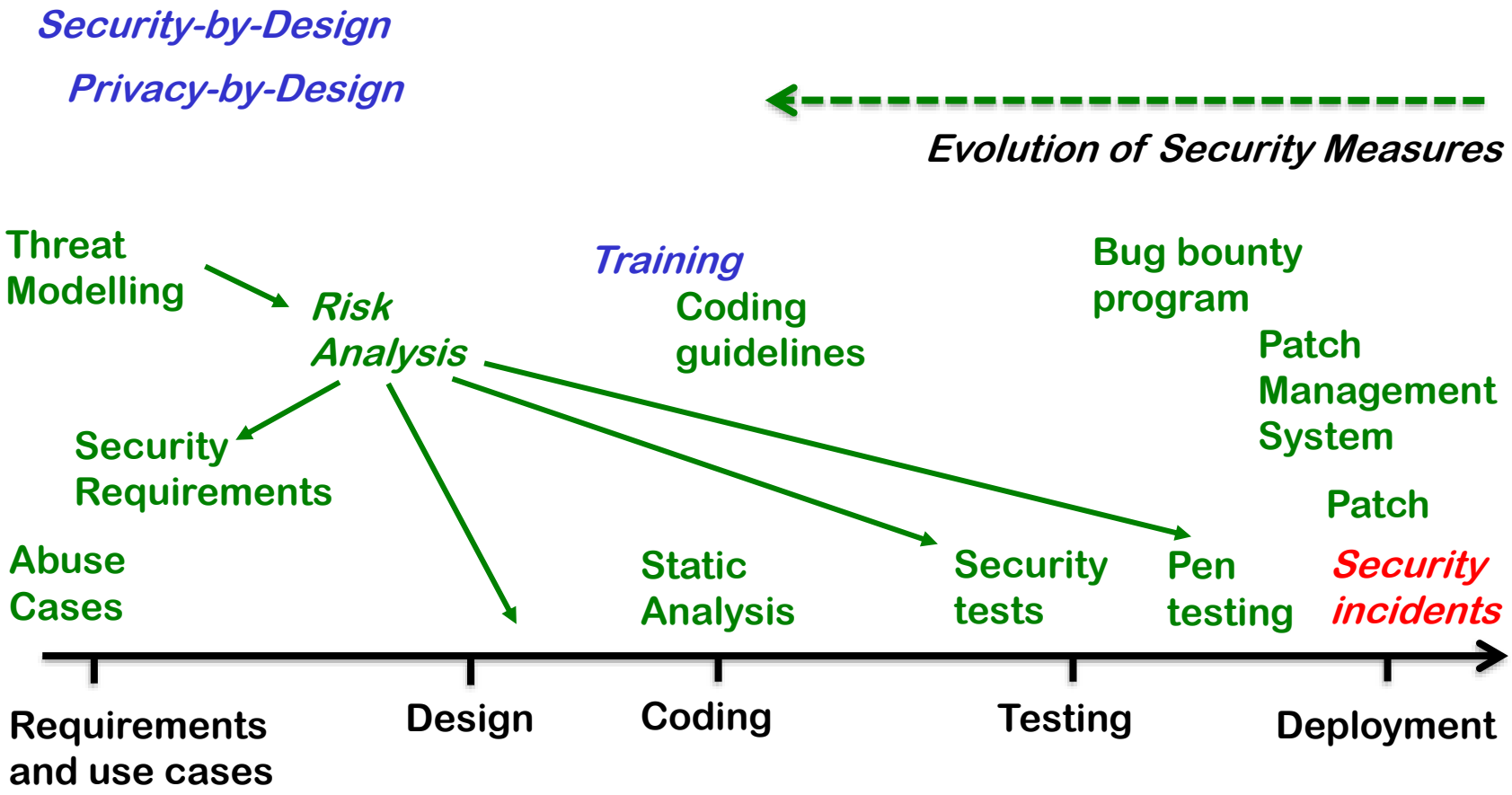
How can we make software *more* secure?

We *do* know how to do this!

- Knowledge about standard mistakes is crucial
  - These depends on programming language, "platform", APIs/technologies used, type of application
  - There is LOTS of info available on this nowadays

- But this is not enough: security to be taken into account from the start, *throughout* the software development life cycle
  - Several ideas, best practices, methodologies to do this

Security in Software Development Lifecycle



"Shifting left"

Organisations always begin tackling security at the *end* of the SDLC, and then slowly evolve to tackle it earlier

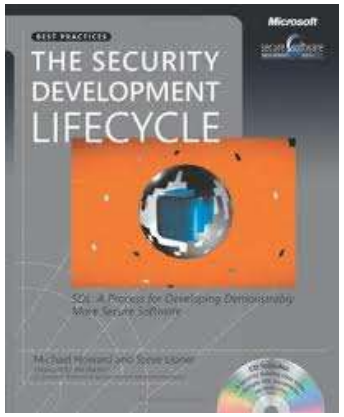
1. First, do nothing
2. Some security issue is discovered:
   a) Still do nothing, if there's no (economic) incentive
   b) Or: patch
3. If this happens often: update mechanism for regular patching
4. Do security testing: eg. hire pen-testers or bug bounty program
5. Use static analysis tools when coding
6. Give security training to programmers
7. Think of abuse cases, and develop security tests for them
8. Think about security *before* you start coding, eg with security architecture review
9. …

DAST, SAST

Security people keep inventing 4 letter new acronyms

- DAST
  - Dynamic Application Security Testing
  - ie. testing
- SAST
  - Static Application Security Testing
  - ie. static analysis
- IAST
  - Interactive Application Security Testing
  - manual pen-testing
- RASP
  - Run-time Application Security Protection
  - ie. monitoring

Methodologies for secure software development



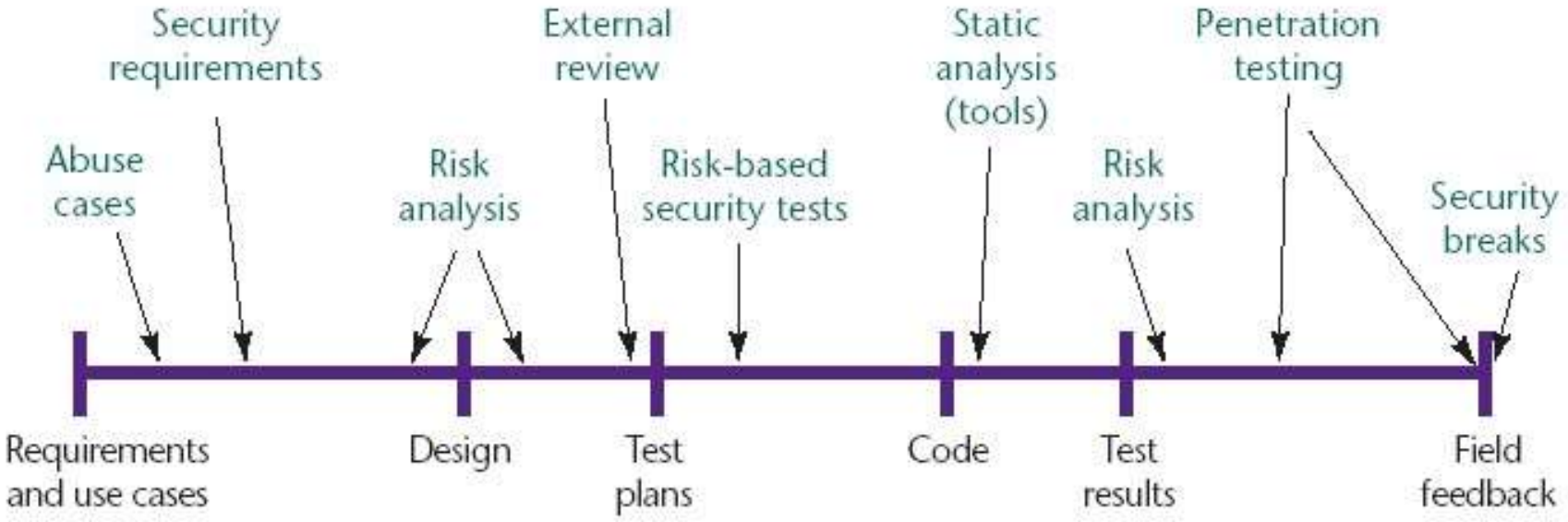
- **Microsoft SDL**
  with extension for Secure DevOps (DevSecOps)
- **BSIMM**
- Open SAMM (Software Assurance Maturity Model)
- Gary McGraw's Touchpoints
- OWASP SAMM
- Grip op SSD (Secure Software Development)
  Ongoing initiative by Dutch government organisations
  https://www.cip-overheid.nl/en/category/products/secure-software/
- …

These come with best practices, checklists, methods for assessments, roadmaps for improvement, …

Microsoft's SDL Optimisation Model

Security in the software development life cycle

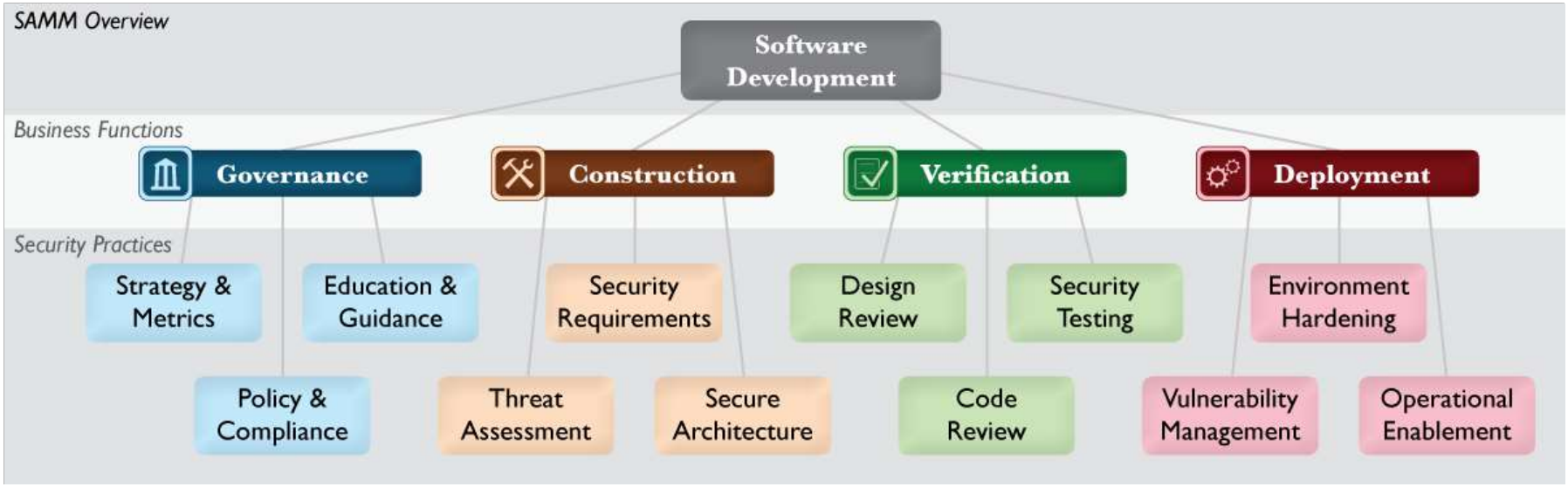
McGraw's Touchpoints



[Source: Gary McGraw, *Software security*, Security & Privacy Magazine, IEEE, Vol 2, No. 2, pp. 80-83, 2004.]

OpenSAMM

With 4 business functions and 12 security practices



BSIMM (Building Security In Maturity Model)

Framework to compare your software security efforts with other organisations

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

Based on data collected from large enterprises

https://www.bsimm.com/framework/

BSIMM: comparing your security maturity

But first…

Crucial first steps in any security discussion!

1. What are your security requirements?

   What does it mean for the system to be secure?

2. What is your attacker model?

   Against what does the system have to be secure?

   - Attack surface / attack vectors
   - Attacker's motivations & capabilities
   - What are your security assumptions ?
     - Including: what is the TCB (Trusted Computing Base) ?

Any discussion of security without answering these questions is *meaningless*

Aka threat modelling using eg Microsoft STRIDE or MITRE ATT&CK

Security requirements

a) 'This application cannot be hacked'

- generic default requirement ☺
- vague & not actionable ☹
- negative security model

b) More specific security requirements

- In terms of Confidentiality, Integrity and Availability (CIA)
- Or, usually better, in terms of Access Control
  (i.e. Authentication & Authorisation)
- Not just Prevention but also Detection & Reaction/Response
- positive security model

prevention vs detection & reaction

prevention vs detection & reaction

- Prevention seems to be *the* way to ensure security, but detection & response often more important and effective
  - Eg. breaking into a house with large windows is trivial; despite this absence of prevention, detection & reaction still provides security against burglars
  - Most effective security requirement for most persons and organisations: make good back-ups, so that you can recover after an attack
- *NB don't ever be tempted into thinking that good prevention makes detection & reaction superfluous.*
- Hence important security requirements include
  - being able to do monitoring
  - having logs for auditing and forensics
  - having someone actually inspecting the logs
  - ...

For you to read & do

1. To read: CyBok chapter on Secure Software Lifecycle

2. To do: check out
   a) CVEs in latest US-CERT bulletin
   b) recent CVEs for your web-browser & PDF viewer
   c) how their CVSS score was

3. To do: brush up on you C(++) knowledge