5. Introduction to Software Security

Computer Security Courses @ POLIMI

Prof. Carminati & Prof. Zanero

Software security fundamentals

Good **software engineering**: meet requirements

- **Functional** requirements
  - Software must do what it is designed for.
- **Non-functional** requirements
  - Usability
  - Safety
  - *Security*
- Creating *inherently secure* applications is a fundamental, yet often unknown, skill for a good developer or software engineer.
  - Creating secure software is *hard*.
  - Proof: see next slides.

Software has Vulnerabilities

Software should implement the **specifications**

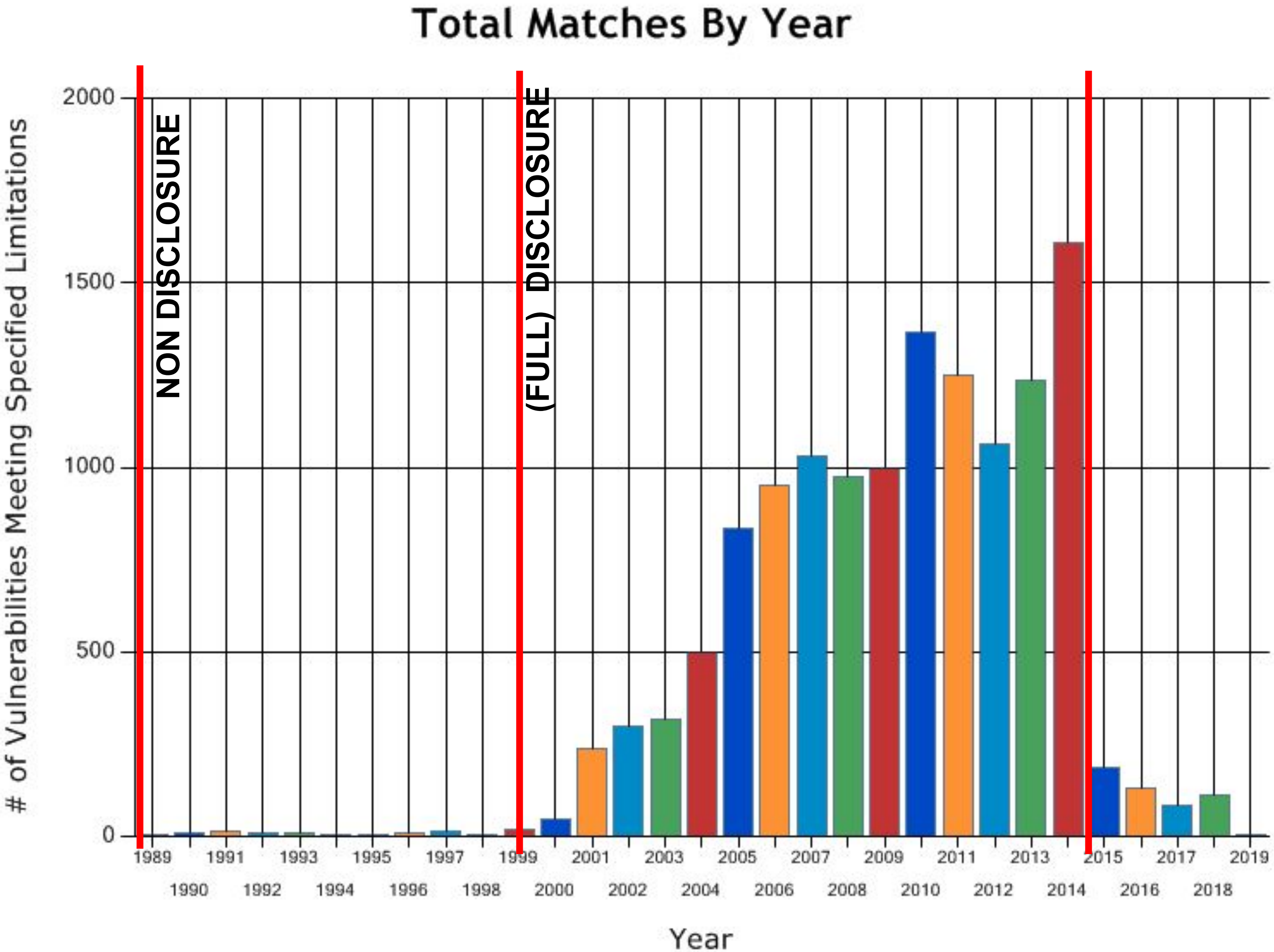
- Unmet specification == *software bug*
- Unmet *security* specification == *vulnerability*

A way to leverage a vulnerability to violate the CIA is called *exploit*.

- Vulnerability != exploit.

Life of a vulnerability

Known Software Vulnerabilities



Source: NIST' National Vulnerability Database

The Early Days of Disclosure

Subject: Comments on the dvwssr.dll vulnerability threads

From: Iván Arce

Date: **2000-04-18** 1:25:52

I do not intend to go further down the full disclosure vs. mediated release of information discussion here, however [Microsoft’s handler’s] post on NTBugtraq regarding CORE's work requires some clarifications on our side.

[...]

If someone yells 'FIRE' and that appears to be reasonable, I'd would be very careful in my methodology and editorial policies before yelling "NOT TRUE! NOT TRUE! EVERYTHING IS FINE!".

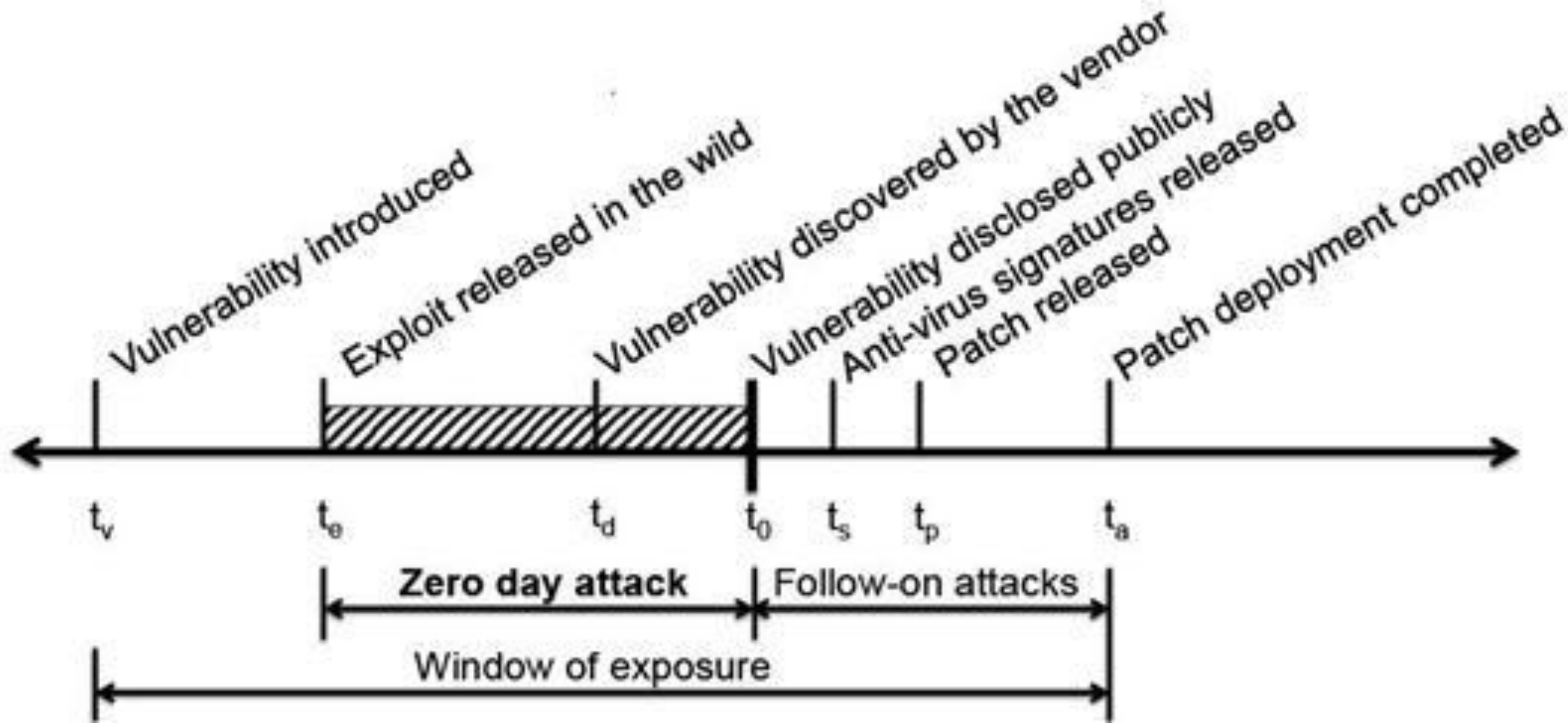
[...]

Excuse me if I’m being rude, but **I’m shocked by the fact that our company is being questioned because we found a bug.**

http://www.s0ftpj.org/bfi/online/bfi10/BFi10-02.html

http://marc.info/?l=vuln-dev&m=95602682515862&w=2

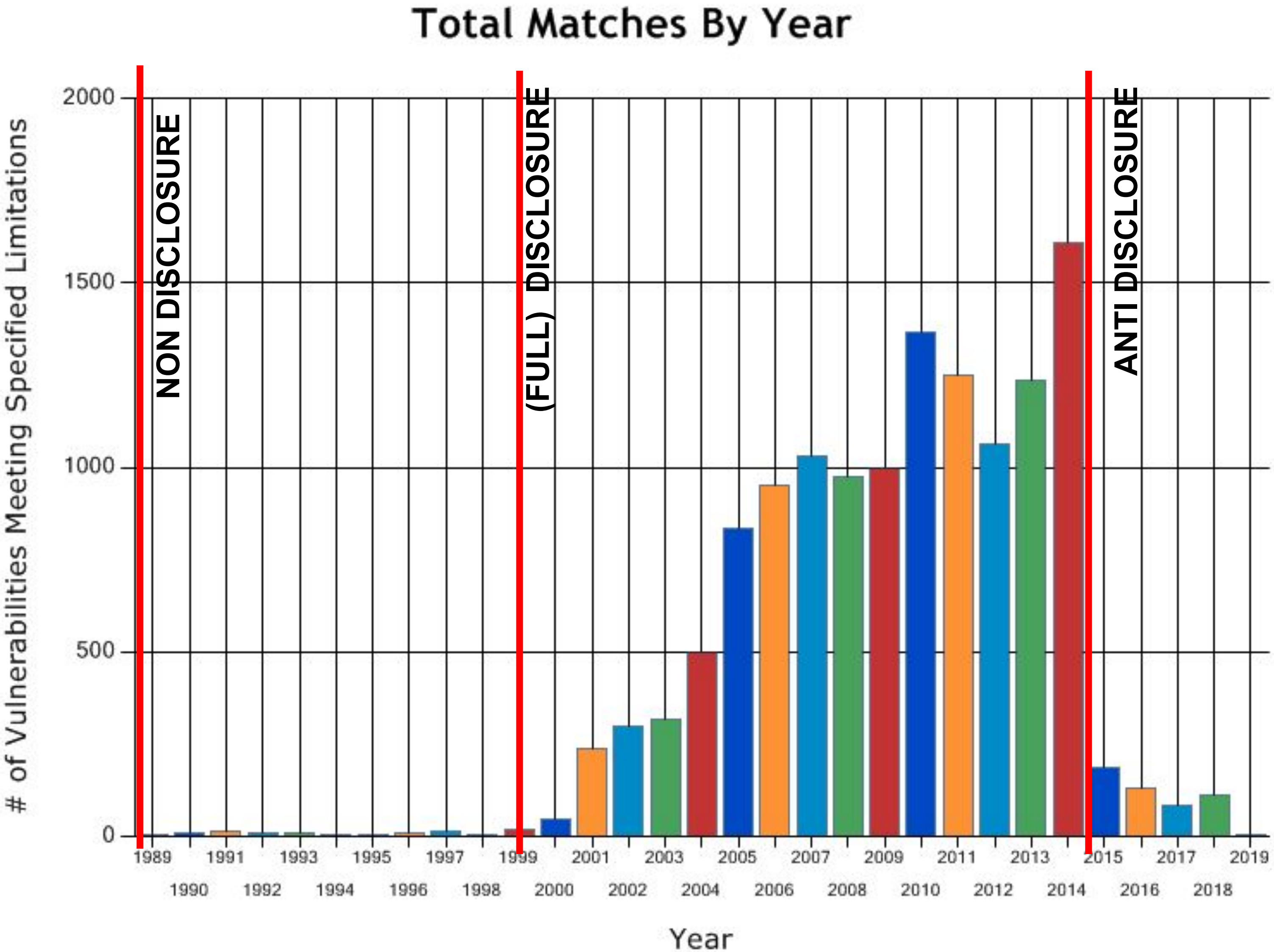
The (full) Disclosure Vuln. Lifecycle



Leyla Bilge, Tudor Dumitras, [Before We Knew It: An Empirical Study of Zero-Day Attacks In The Real World](), ACM CCS 2012.

The Black Hat Parties

Known Software Vulnerabilities



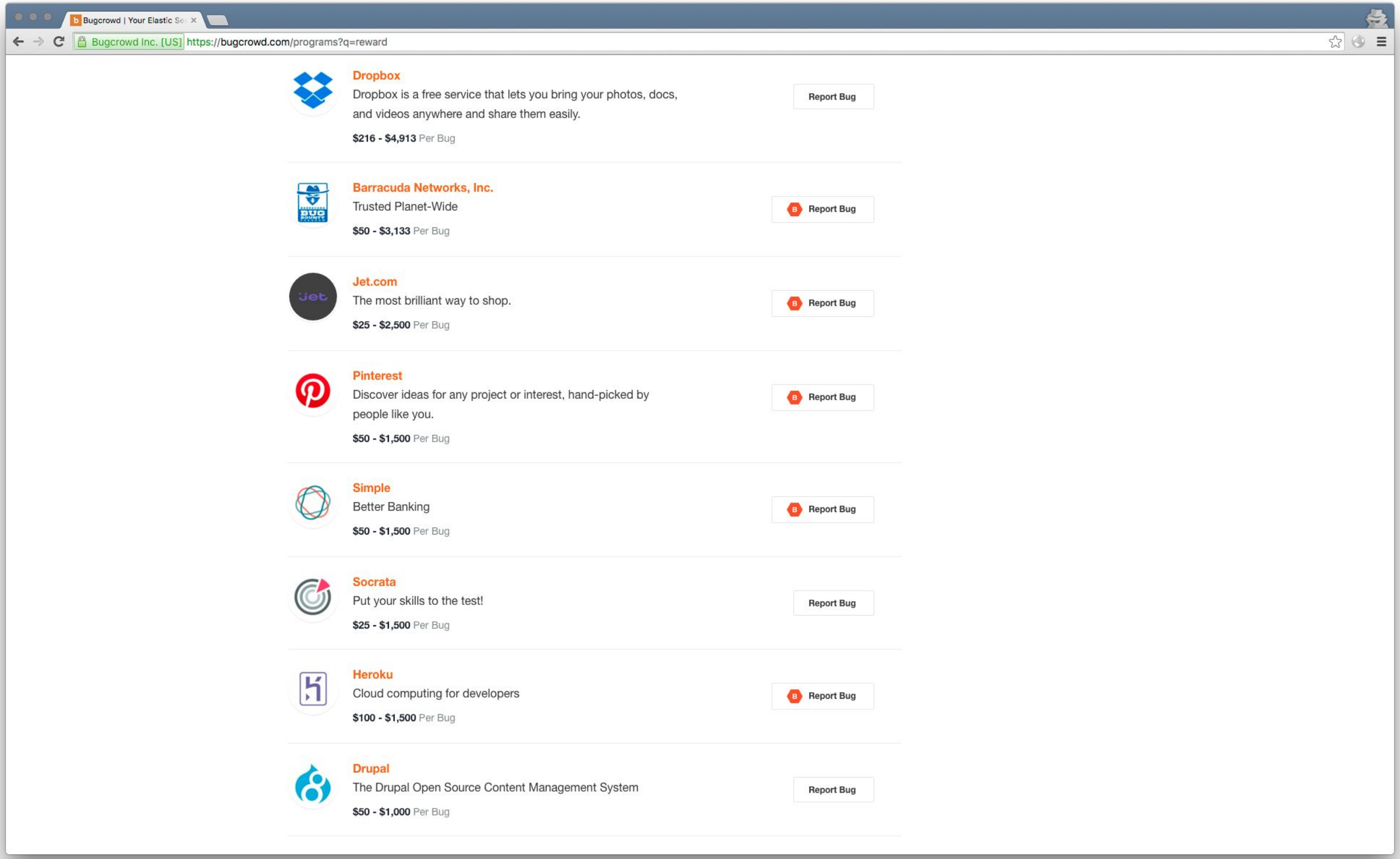
Source: NIST' National Vulnerability Database


NO MORE FREE BUGS

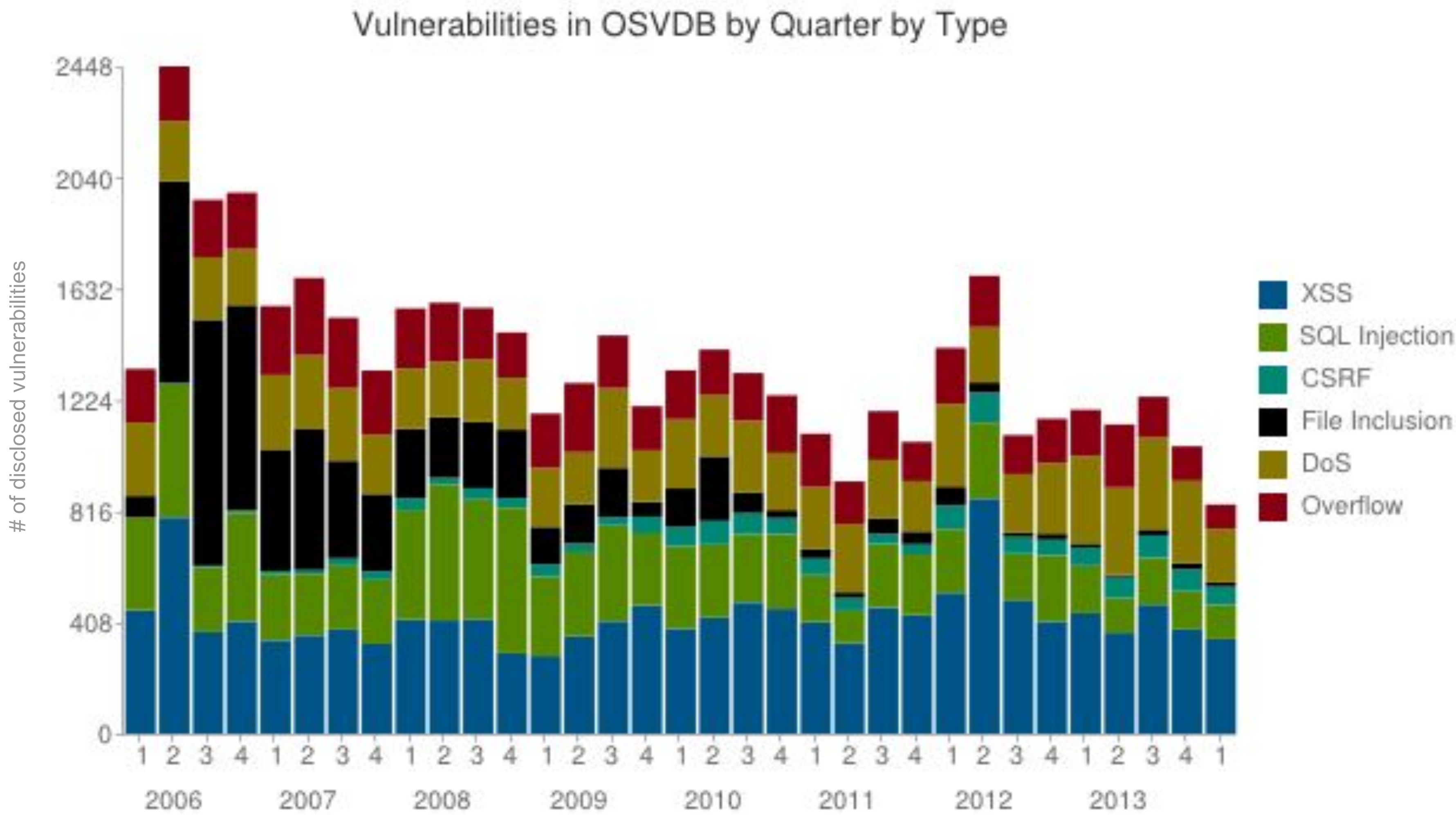
Black Market of Exploits

Bug Bounties

More Bug Bounties (bugcrowd.com)



Known Software Vulnerabilities (2)



[Source: Open Source Vulnerability Database](#) [CLOSED]

Vulnerability and Exploit Example

Processes in UNIX-like systems.

Vulnerability and Exploit Example (1)

Every file has a *owner* (user):

```
[bar@localhost]$ ls -la executable
 -rwxr-xr-x 1 foo group 41836 2012-10-14 19:19 executable
```

Real UID (RUID): real *owner* of a process.

```
[bar@localhost]$ ./executable   #Darwin Kernel 13.1.0
[bar@localhost]$ ps -a -x -o user,pid,cmd
 USER  PID     COMMAND
 bar    18299   ./executable
```

The RUID could differ from the owner.

Normally: RUID == Effective UID (EUID).

Vulnerability and Exploit Example (2)

Saved **set-user-ID** (SUID) can be used to change the EUID at runtime.

```
[root@localhost]# chmod u+s executable
[root@localhost]# ls -la executable
 -rwsr-xr-x 1 foo group 41836 2012-10-14 19:19 executable
```

Now the executable's SUID is "foo".

```
[bar@localhost]$ ./executable
[bar@localhost]$ ps -a -x -o user,pid,cmd
 USER PID    COMMAND
 foo    18299  ./executable
```

"bar" == real UID != EUID == "foo".

Vulnerability and Exploit Example (3)

```
#include <unistd.h>
#include <stdio.h>

int main(int argc, const char *argv[])
{
    printf("RUID %d EUID %d", getuid(), geteuid());
    return 0;
}
```

Vulnerability and Exploit Example (3)

```
#include <unistd.h>
#include <stdio.h>

int main(int argc, const char *argv[])
{
    printf("RUID %d EUID %d", getuid(), geteuid());
    return 0;
}

[foo@localhost]$ gcc -o executable -c executable.c
[foo@localhost]$ sudo su -                    # become root
[root@localhost]# chown root                     # change the owner
[root@localhost]# chmod +s executable     # set the SUID root bit
[root@localhost]# exit                           # get back to foo
[foo@localhost]$ ls -la executable           # check the flags
 -rwsr-xr-x 1 root group 41836 2012-10-14 19:19 executable
```

Vulnerability and Exploit Example (4)

```
[foo@localhost]$ ./executable
RUID 501 Effective 0                         # 501 is foo's UID - 0 is root's UID
```

Vulnerability and Exploit Example (4)

```
[foo@localhost]$ ./executable
RUID 501 Effective 0                         # 501 is foo's UID - 0 is root's UID

[foo@localhost]$ sudo -u root ./executable
RUID 0 Effective 0
```

Vulnerability and Exploit Example (4)

```
[foo@localhost]$ ./executable
RUID 501 Effective 0                          # 501 is foo's UID - 0 is root's UID

[foo@localhost]$ sudo -u root ./executable
RUID 0 Effective 0

[foo@localhost]$ vim executable.c             // let's add a privileged instruction
#include <unistd.h>
#include <stdio.h>

int main(int argc, const char *argv[])
{
    FILE * fp;
    char line[1024];

    printf("Real %d Effective %d", getuid(), geteuid());

    fp = fopen("/etc/secret", "r");           // /etc/secret can be read only by root
    while (!feof(fp)) {
        fgets(line, 1024, fp);
        puts(line);
    }
    fclose(fp);
    return 0;
}
```

Vulnerability and Exploit Example (4)

Programs are "SUID root" to allow them to execute privileged instructions.

```
[foo@localhost]$ ls -la /etc/secret
-rwx------  1 root  wheel  12 Mar 10 16:07 /etc/secret

[foo@localhost]$ ./executable
Real 501 Effective 0
s3cr3t inf0
```

Vulnerability and Exploit Example (5)

The EUID should be changed back once the privileged instructions are done.

```
#include <unistd.h>
#include <stdio.h>

int main(int argc, const char *argv[])
{
                    // execute as EUID ------------------------
    char line[1024];
    FILE * fp;

    printf("Real %d Effective %d\n", getuid(), geteuid());

    fp = fopen("/etc/secret", "r");
    fgets(line, 1024, fp);
    fclose(fp);

    setuid(501);    //execute as unprivileged user
    printf("Real %d Effective %d\n", getuid(), geteuid());

    puts(line);

    return 0;
}
```

Vulnerability and Exploit Example (5)

```
[foo@localhost]$ ./executable
Real 501 Effective 0
Real 501 Effective 501
s3cr3t inf0                                   # <- content of /etc/secret
```

Once we read the file, we release the privileges.

The subsequent instructions are executed with `foo`'s privileges.

General Idea (pseudocode)

<u>Vulnerable program</u>

```
EUID: RUID -> SUID
read(config)
r = parse(config)
IF r = OK do_things() ELSE
error("...")


[user@host]$ ./ex /etc/shadow


ERROR in file, line 1:
root:<password hash>: ...
```

The **`read(config)`** function prints the content of the file in the error message. This allows an unprivileged user to print the content of, e.g., the **`/etc/shadow`** file, which can be normally read only by privileged users.

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Fixed program

```
EUID: SUID -> RUID
read(config)  //low privs
EUID: RUID -> SUID
r = parse(config)
IF r = OK do_things() ELSE
error("...")
[user@host]$ ./ex /etc/shadow

Permission denied.
```

By acquiring higher privileges only after the file is read, the developer decreases the attack surface and effectively eliminates *this* specific vulnerability (there **may** be *other* vulnerabilities).

What else?

Could you spot the other vulnerability in the code snippet on the right?

General Idea (pseudocode)

(still) vulnerable program

```
EUID: SUID -> RUID
read(config)  //low privs
EUID: RUID -> SUID
r = parse(config)
IF r = OK do_things() ELSE
error("...")



[user@host]$ ./ex
carefully-crafted-file
```

Any bug in the `parse(config)` function would happen in a privileged portion of the code, therefore potentially allowing the attacker to perform actions

General Idea (pseudocode)

(still) vulnerable program

```
EUID: SUID -> RUID
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Any bug in the **`parse(config)`** function would happen in a privileged portion of the code, therefore potentially allowing the attacker to perform actions

Fixed program

```
EUID: SUID -> RUID
read(config)  //low privs
r = parse(config)
IF r = OK
    EUID: RUID -> SUID
    do_things()
    EUID: SUID -> RUID
ELSE error("...")
```

By acquiring the privileges as late as possible, and releasing them as soon as possible, the developer decreases further the attack surface (but there may still be *other* vulnerabilities in the "**`do_things()`**" part of code).

Vulnerability *vs.* Exploit (Examples)

The developer acquired the privileges before

`read(config)`

Invocation of the program with **`/etc/shadow`** as the first argument.

The developer acquired the privileges before

`parse(config)`

Invocation of the program on a specifically crafted file to exploit a vulnerability inside the configuration file

Key Issues in Secure Design / Principle of Secure Design (1)

Reduce **privileged** parts to a **minimum**.

KISS (Keep It **Simple**, Stupid).

Discard privileges definitively (i.e. SUID->RUID) as soon as possible

Open design: just as with Kerchoffs principle, the program must **not rely on obscurity** for security.

Concurrency and race conditions are **tricky**.

Key Issues in Secure Design / Principle of Secure Design (2)

Fail-safe and default deny.

Avoid the use of:
- shared resources (e.g. **`mktemp`**).
- unknown, untrusted libraries.

Filter the input and the output.

Do not write any crypto, password and secret management code: use trusted code that has been audited already.

Use trusted entropy sources such as **`/dev/urandom`**

Code Security by Example

We will see 4 main examples of (in)secure programming:

- Memory errors in **desktop applications**
  - Buffer overflow bugs
  - Format string bugs
- Code-injection bugs in **web applications**
  - SQL injection bugs
  - Cross site scripting bugs
  - CSRF

There are many other examples. We will just deal with a few cases.

Conclusion

Bug-free software **does not exist**.

Not all bugs lead to vulnerabilities.

Vulnerability-free software is difficult to achieve.

Vulnerabilities without a working exploit exist.

Be careful with the SUID permission bit.

Material

Section 7.5, 10.6 of D. Gollman, “Computer Security”, Wiley (3rd ed.).

"Advanced Linux Programming", chapter 10