5. Introduction to Software Security

Computer Security Courses @ POLIMI

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**

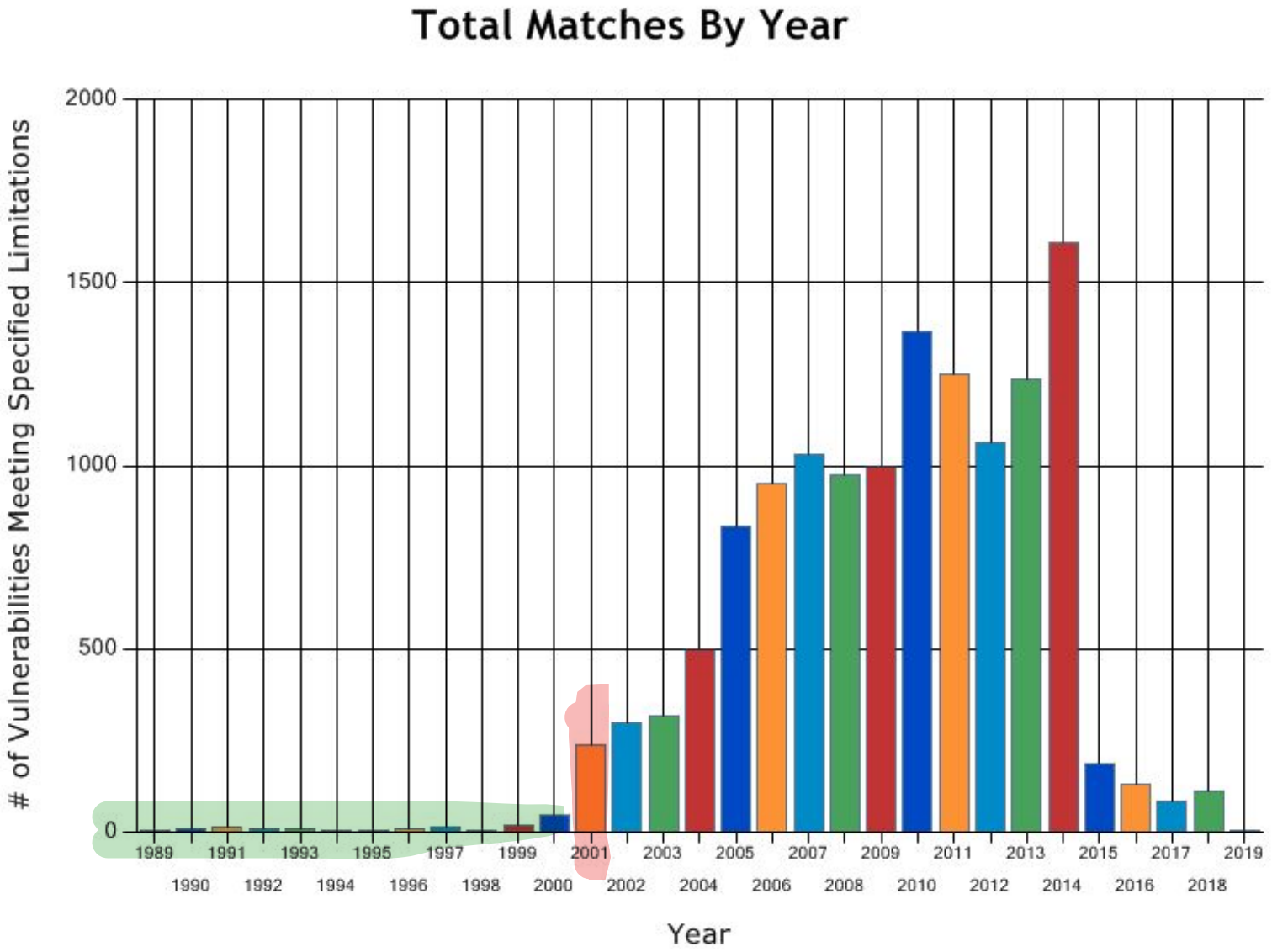
- Unmet specification == *software bug*
- Unmet *security* specification == *vulnerability*

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

- Vulnerability != exploit.

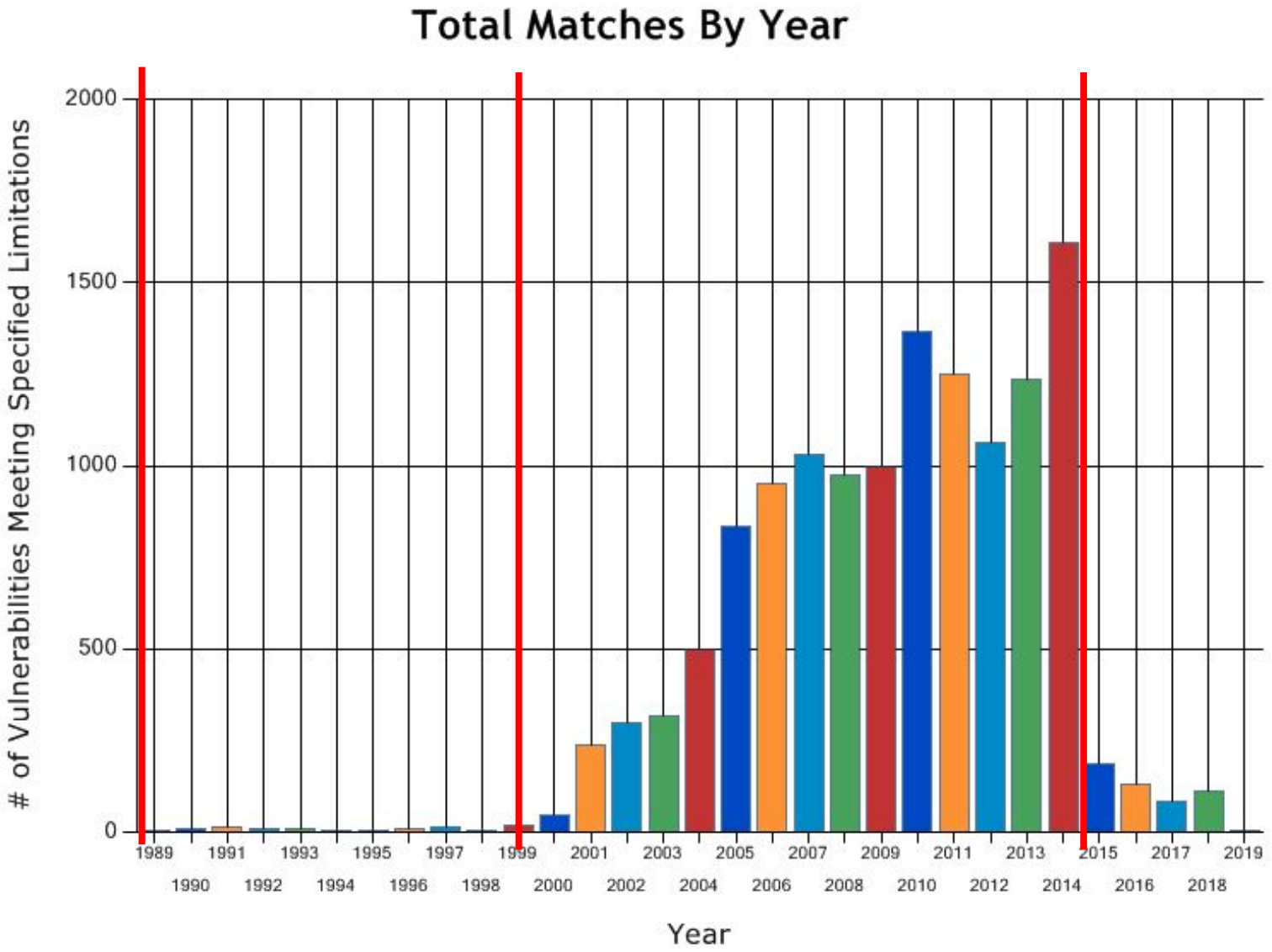
Life of a SW vulnerability

Known Software Vulnerabilities



Source: NIST' National Vulnerability Database

Known Software Vulnerabilities



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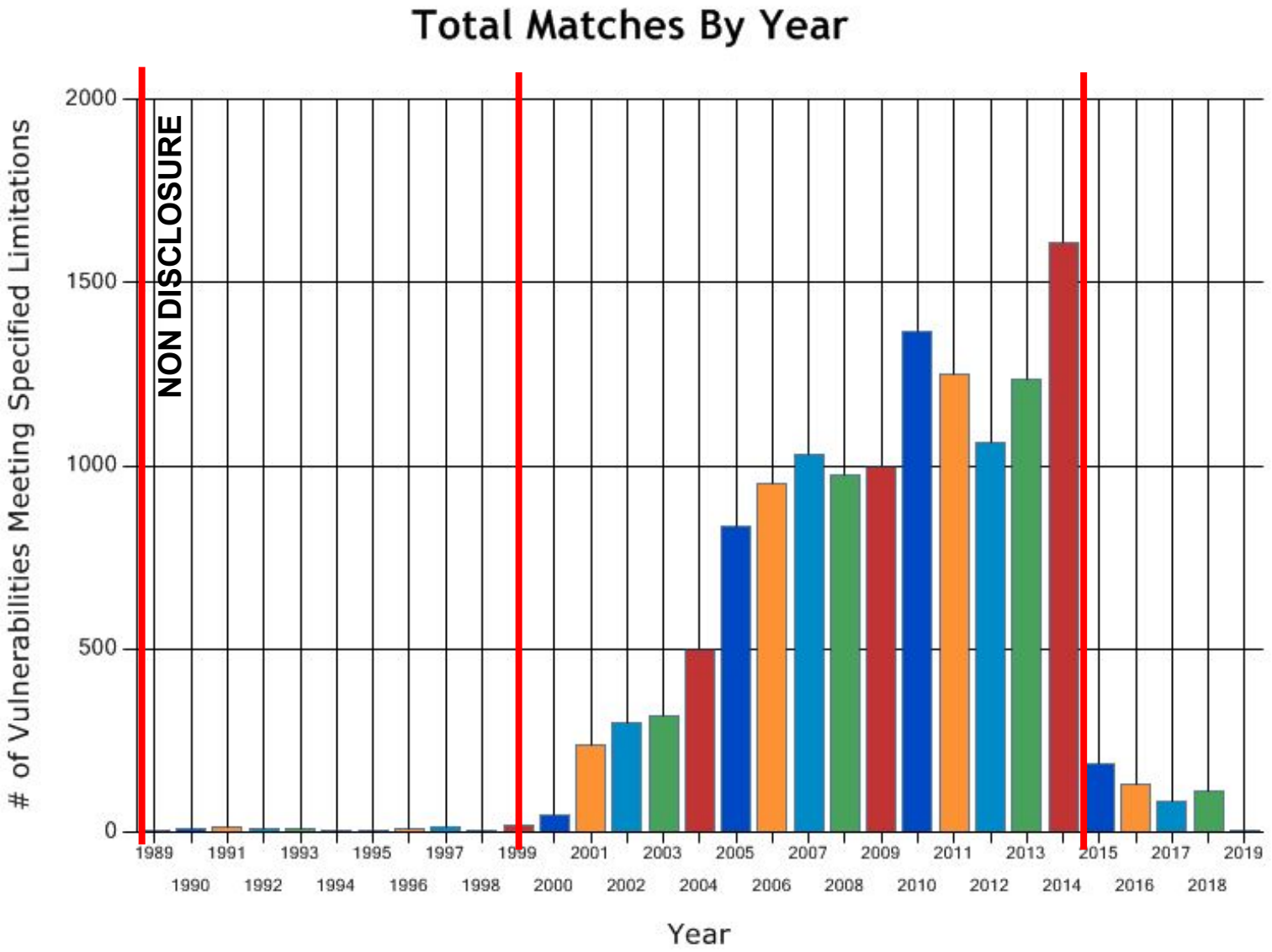
Known Software Vulnerabilities



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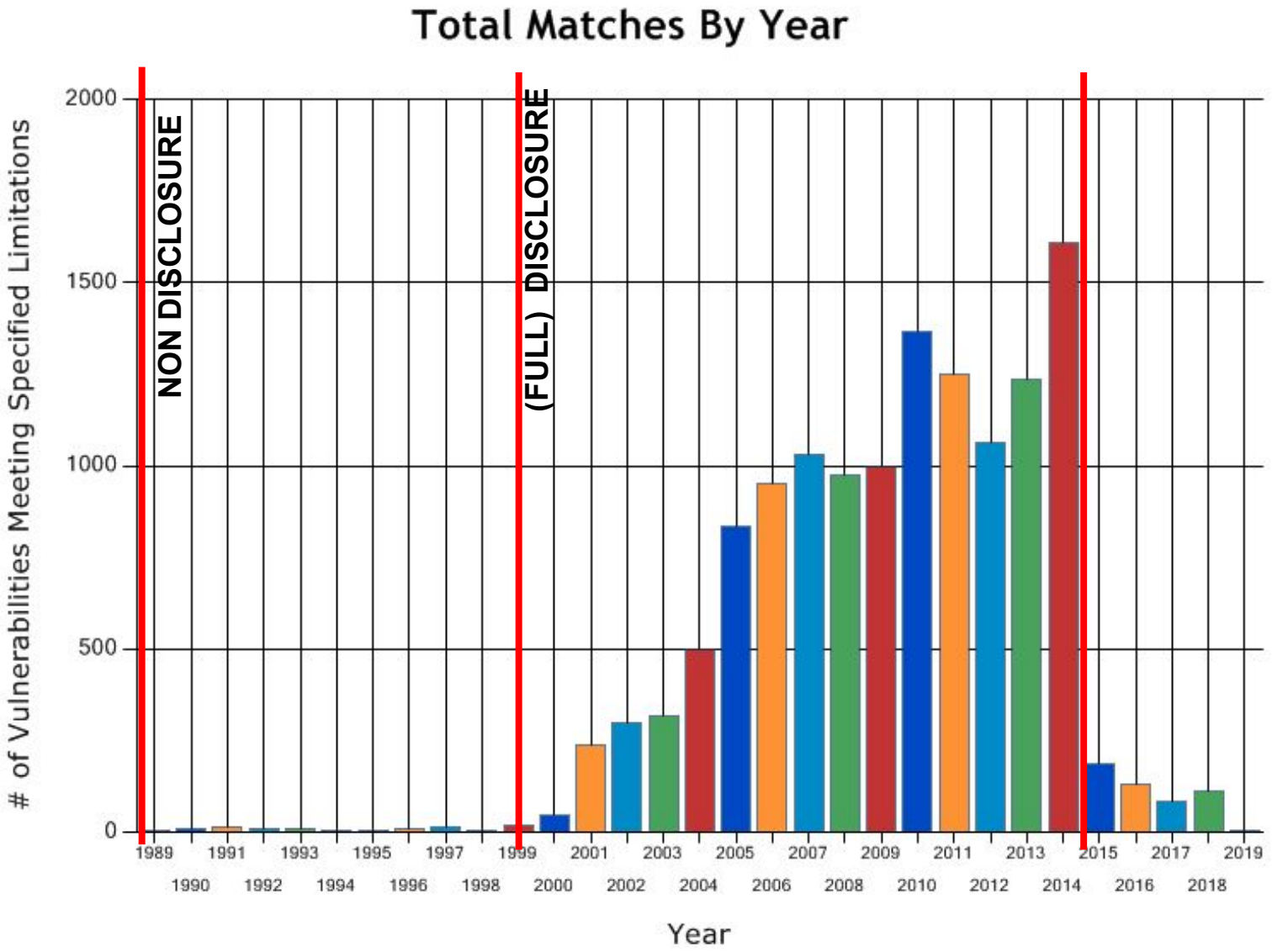
Known Software Vulnerabilities



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!".

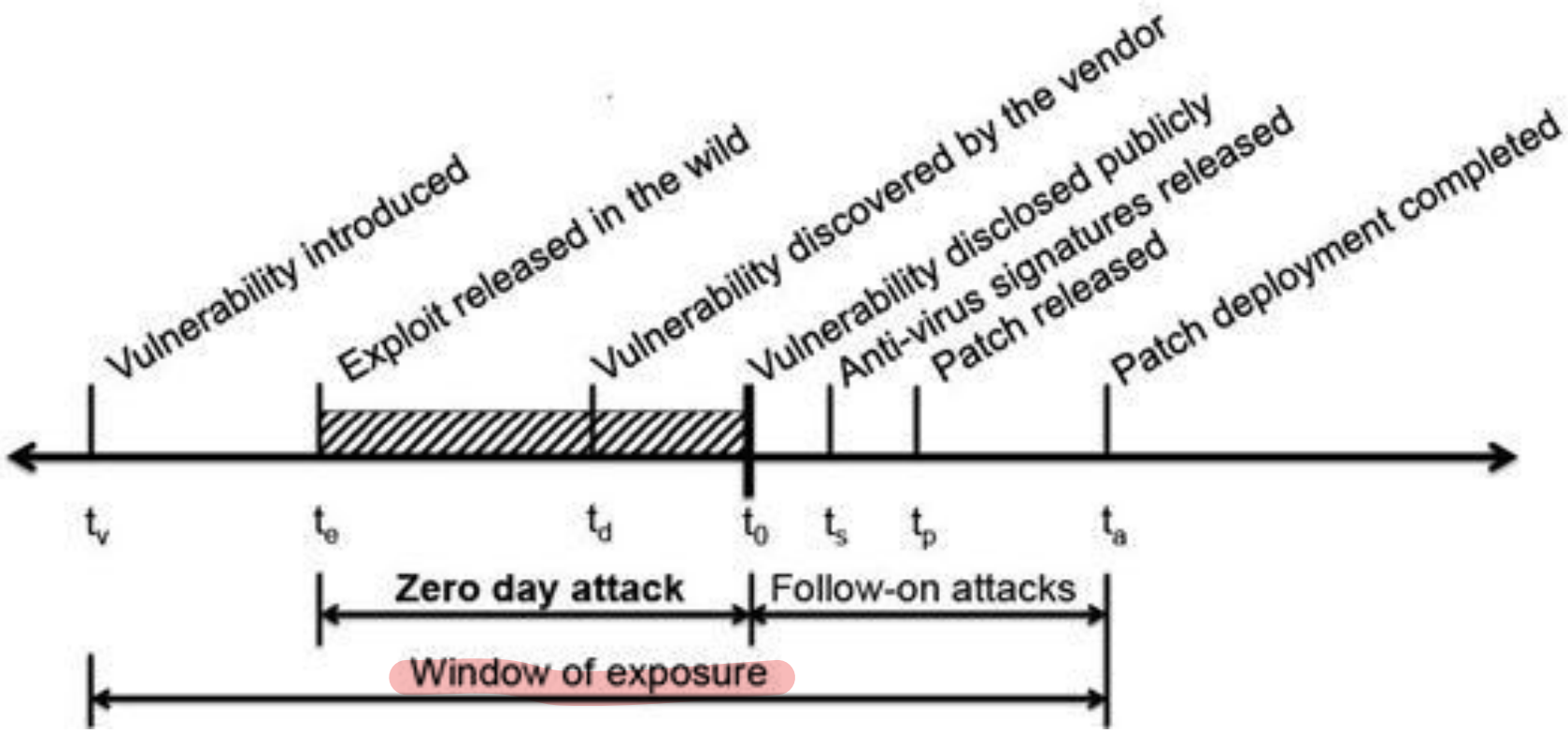
[...]

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

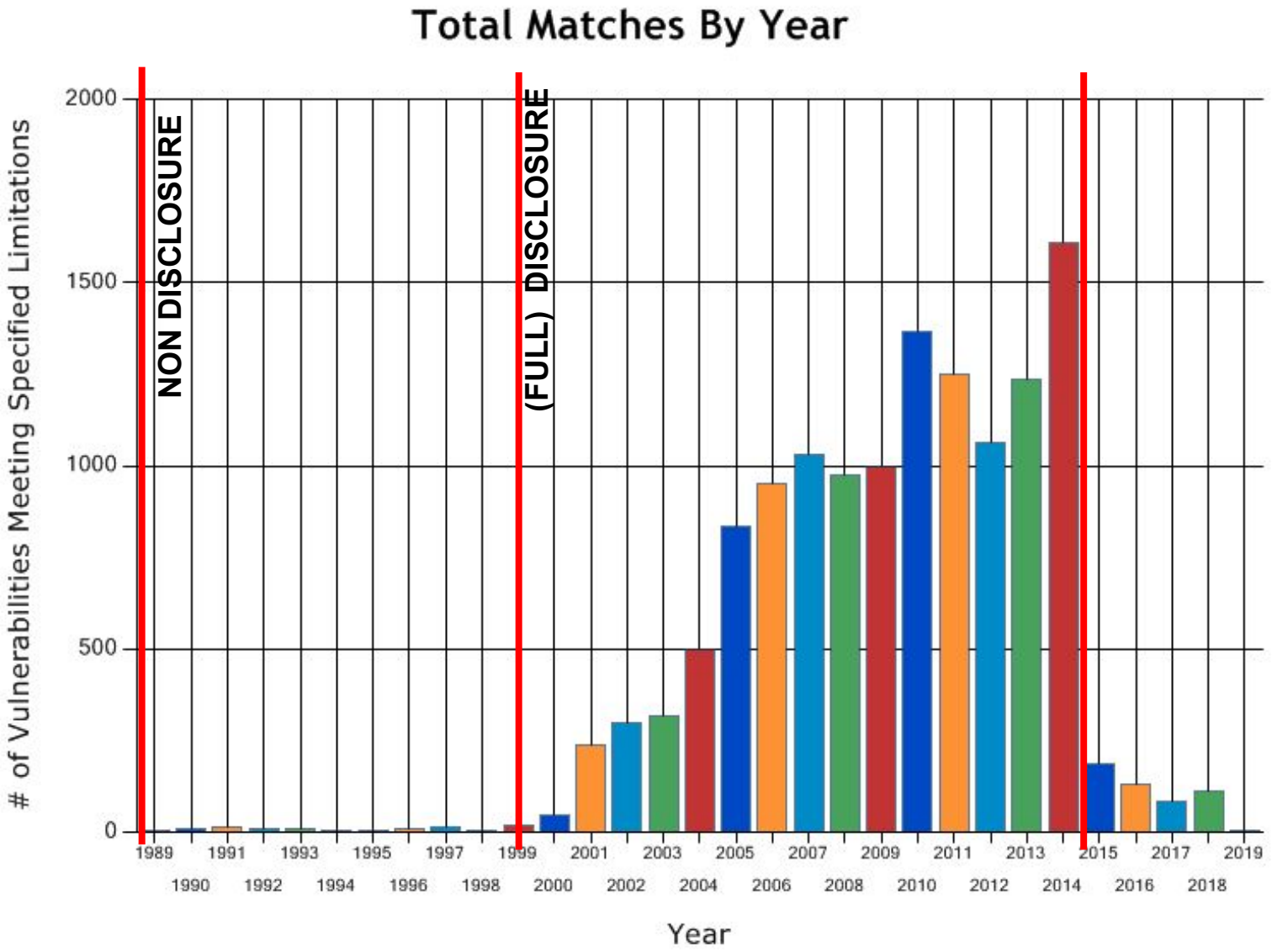
The (full) Disclosure Vuln. Lifecycle



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



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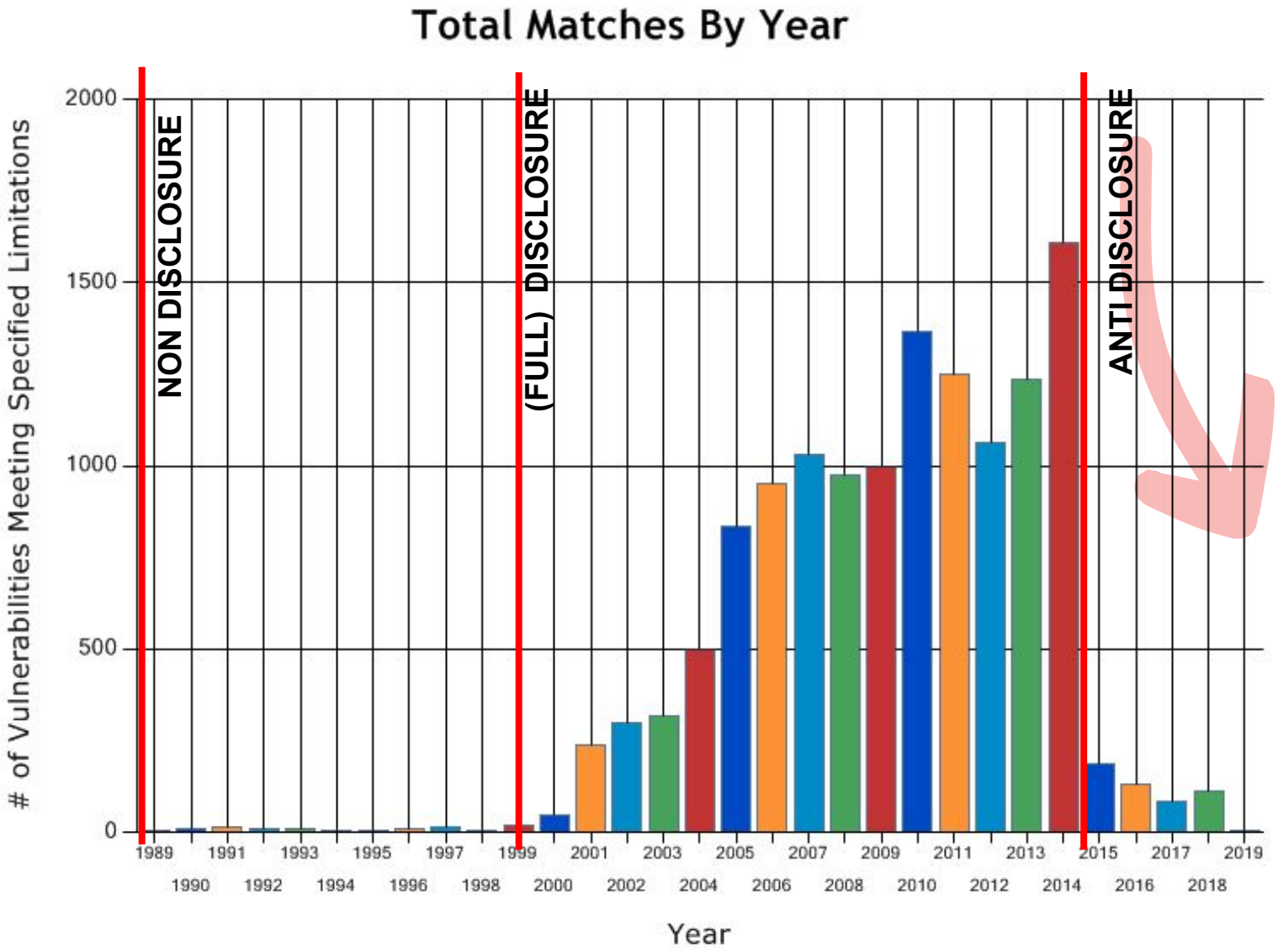
Known Software Vulnerabilities

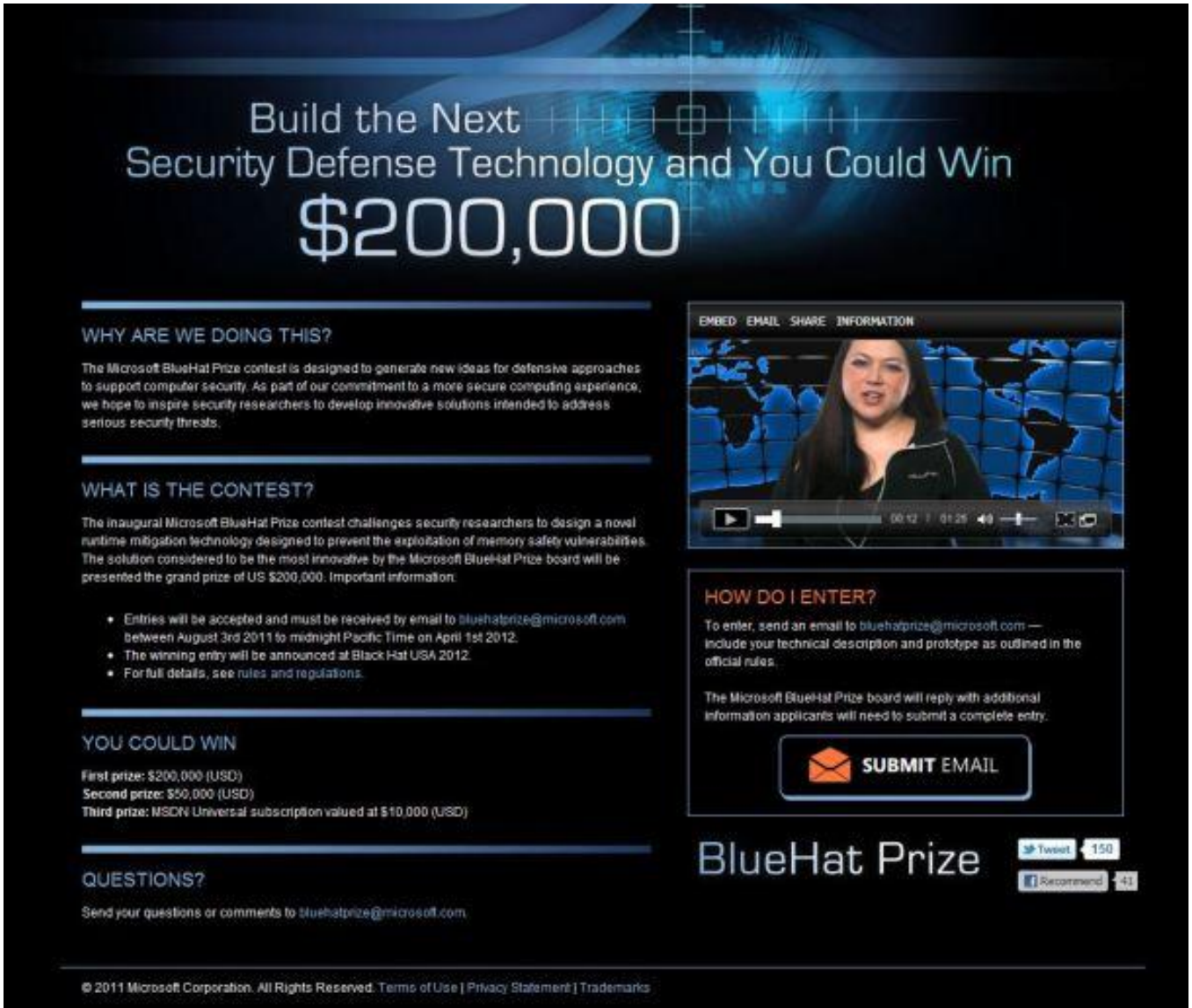


Source: NIST' National Vulnerability Database

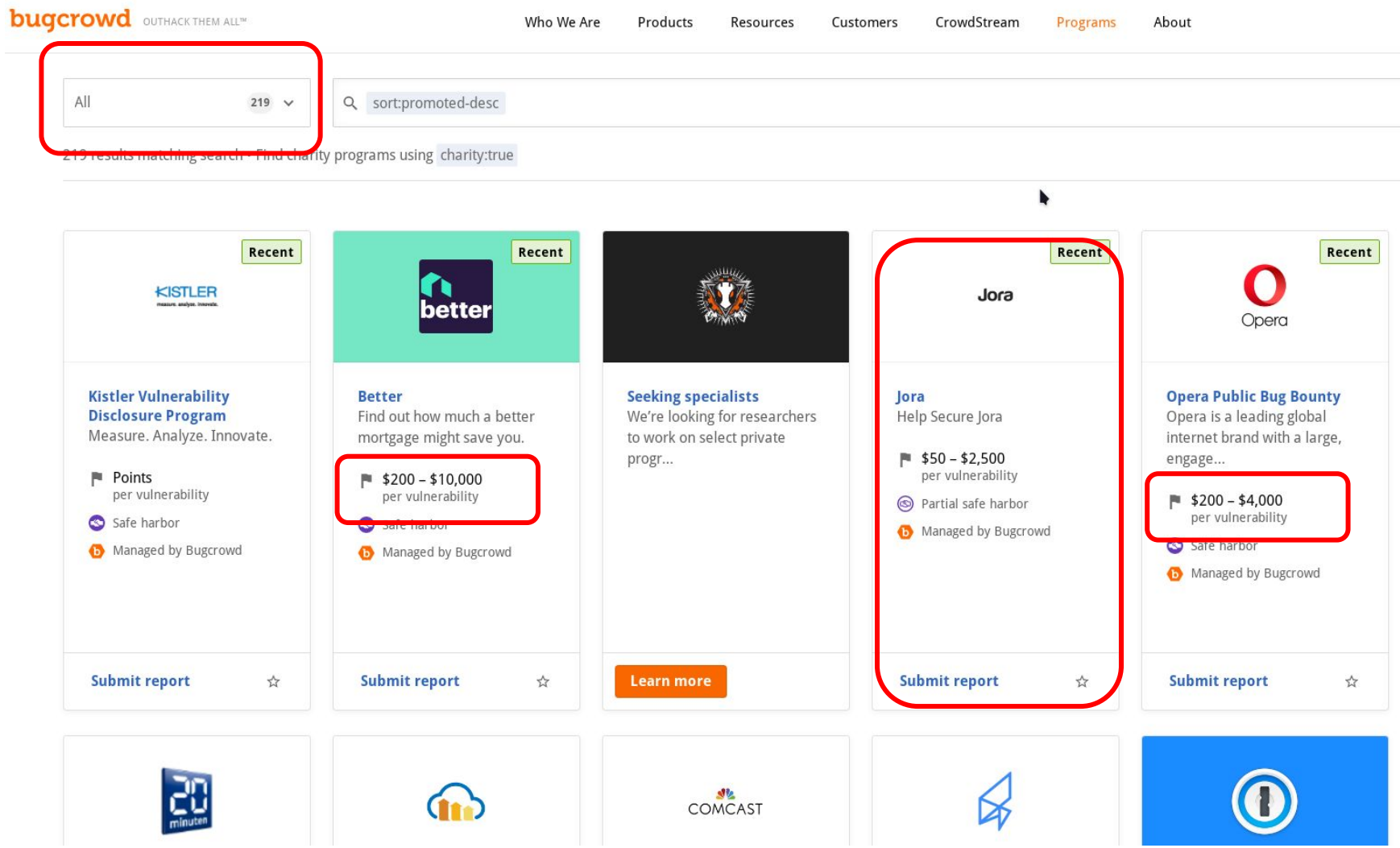

NO MORE BIKES
NO FREE BIKES

Black Market of Exploits

Bug Bounties



More Bug Bounties (bugcrowd.com)

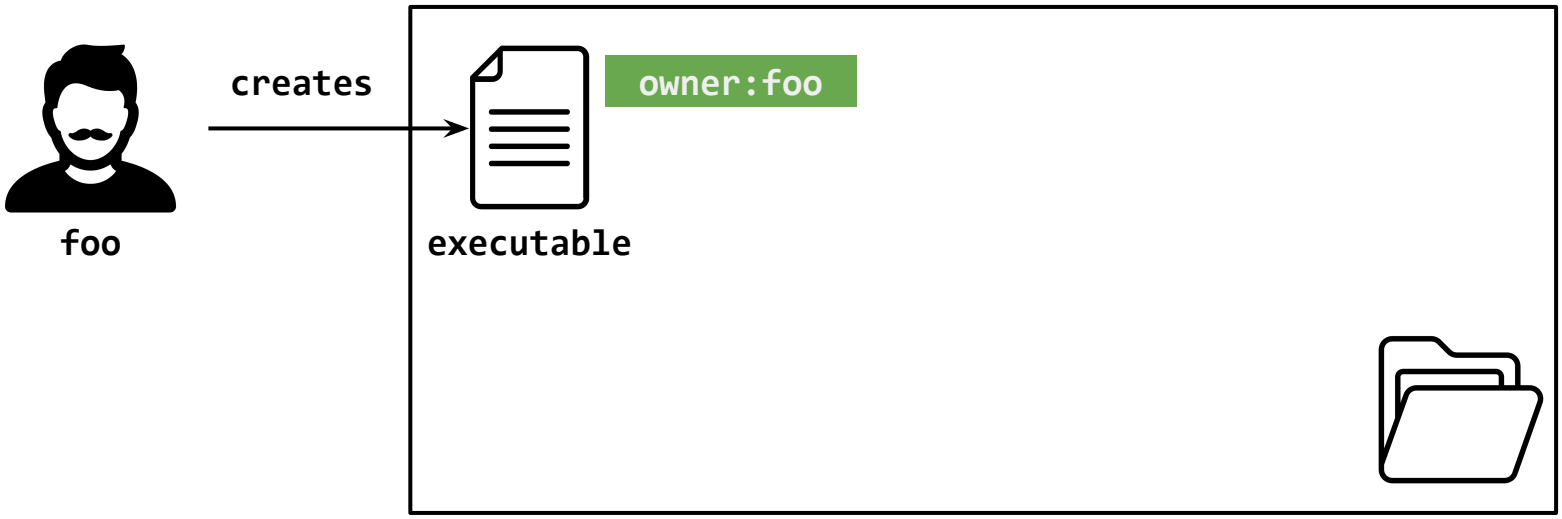


Vulnerability and Exploit Example

Processes in UNIX-like systems.

Vulnerability Example

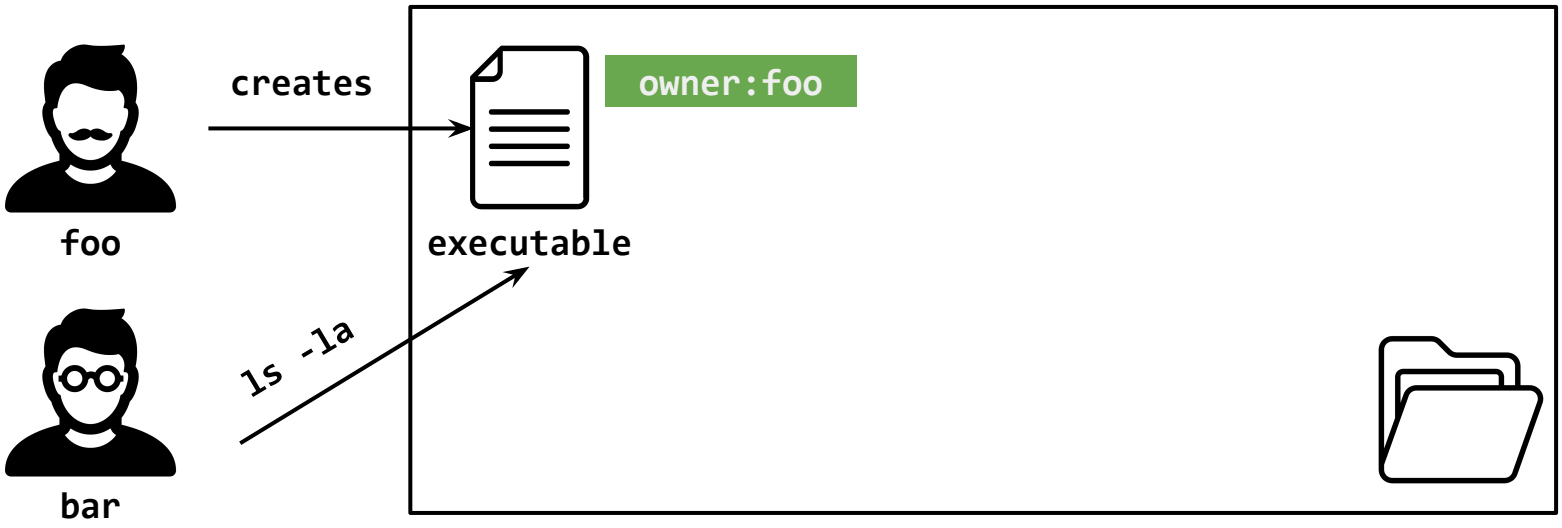
Every file has a *owner* (user):



Vulnerability Example

Every file has a *owner* (user):

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



Vulnerability Example

Every file has a *owner* (user):

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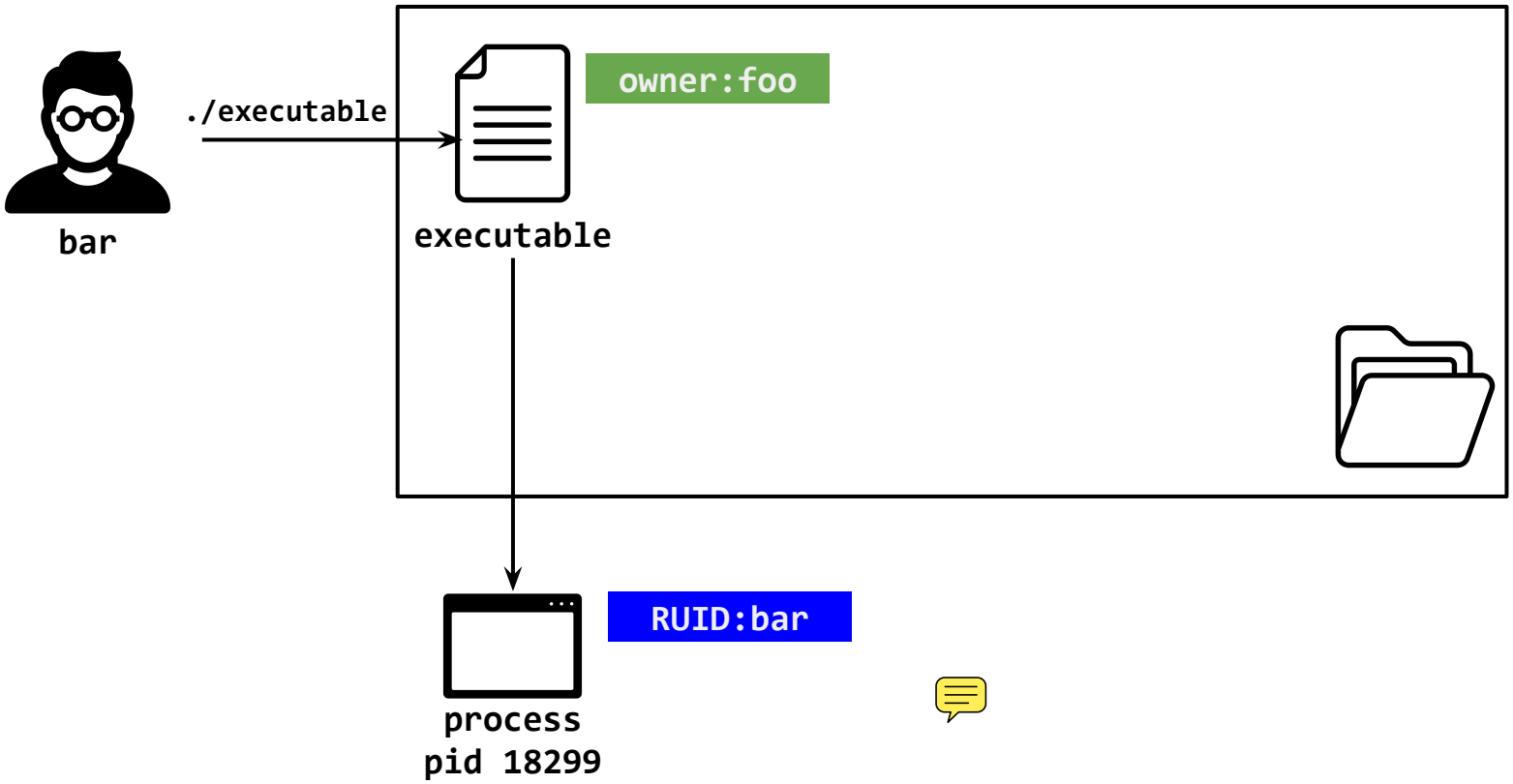
```

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.

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



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The RUID could differ from the owner.

Effective UID (**EUID**): UID for checking permissions

Vulnerability Example

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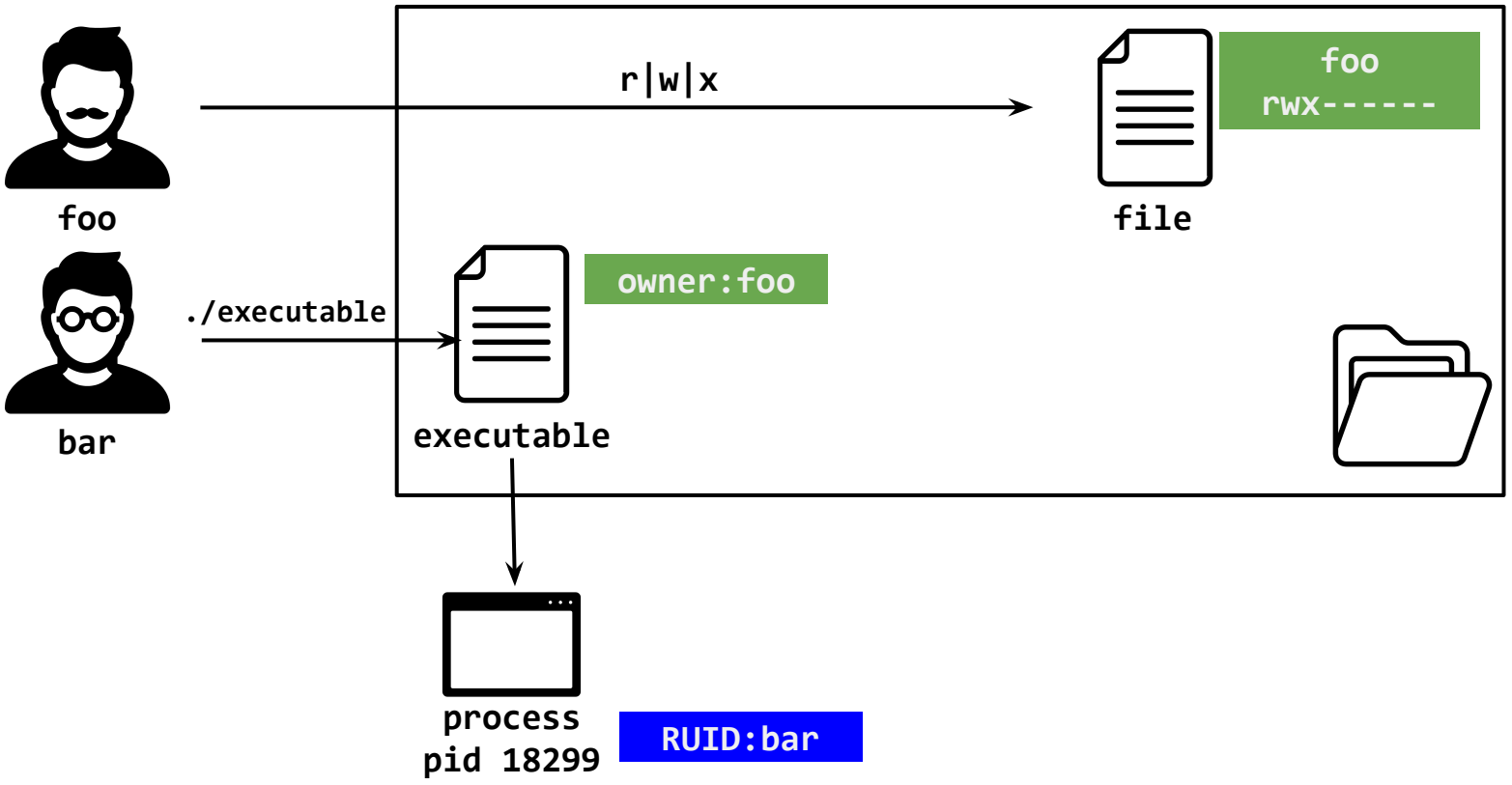
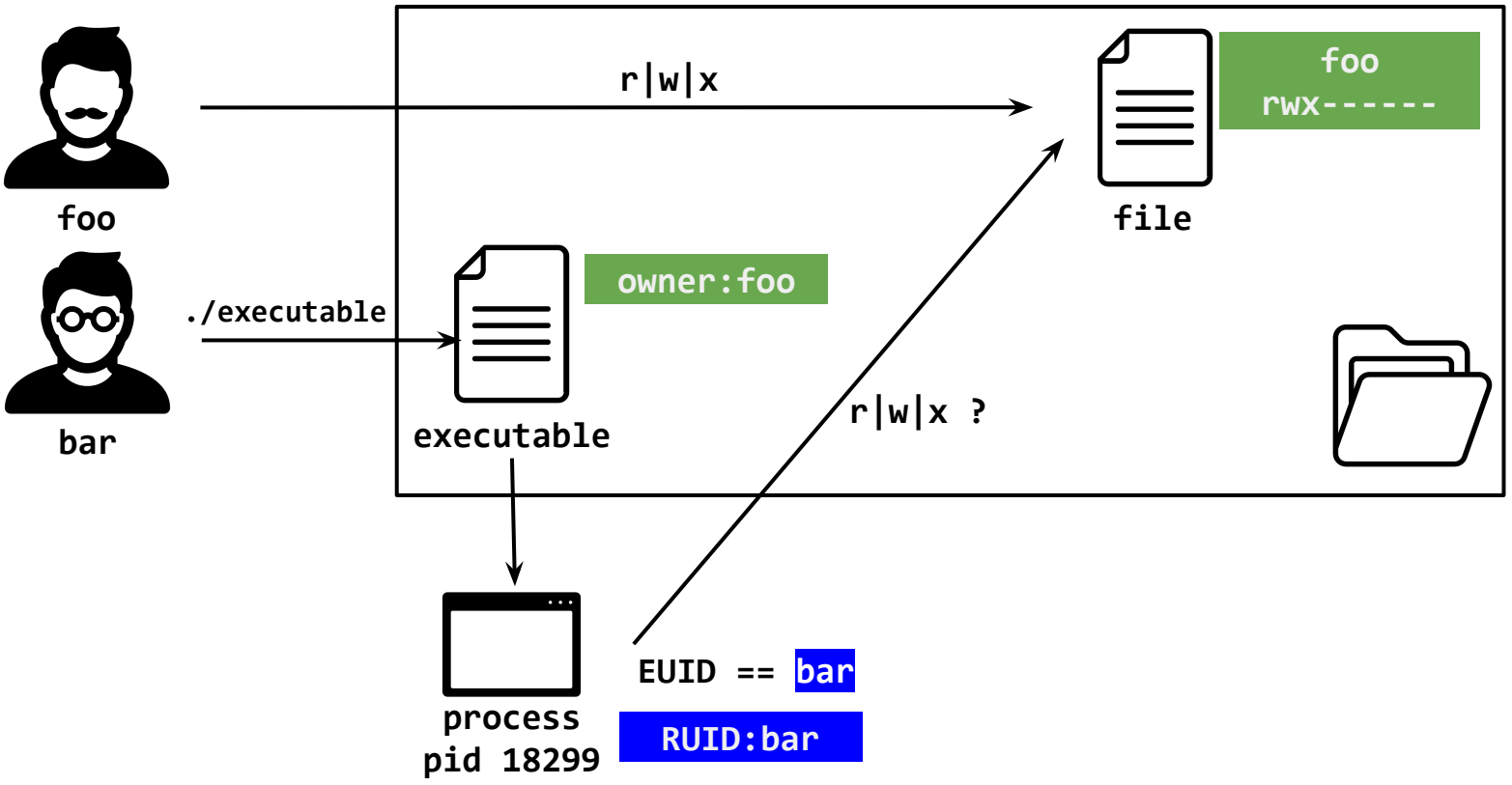
The RUID could differ from the owner.

Normally: RUID == Effective UID (EUID).

Effective UID (EUID): UID for checking permissions



Effective UID (EUID): UID for checking permissions



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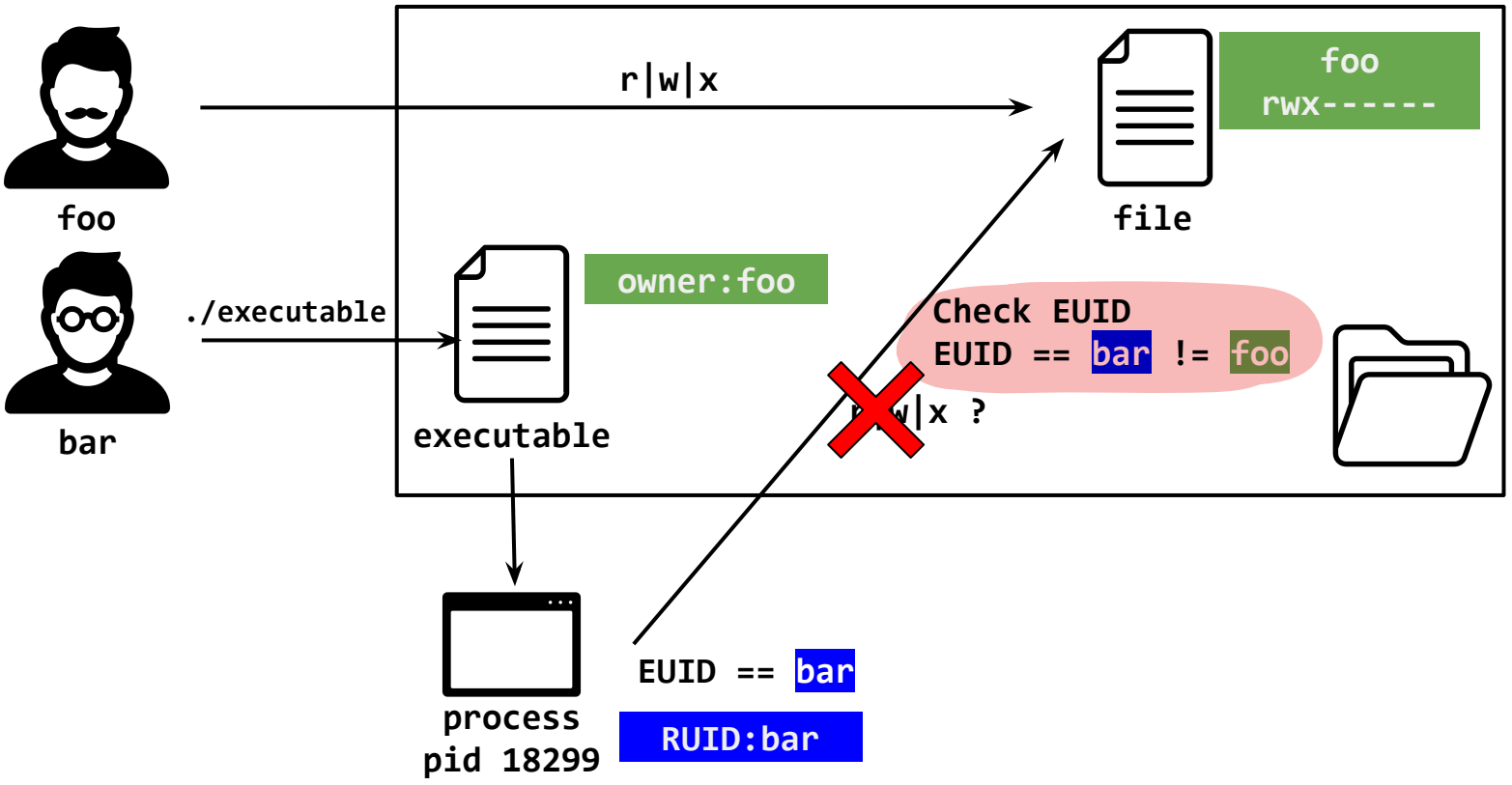
Effective UID (EUID): UID for checking permissions



Normally: RUID == Effective UID (EUID).

Vulnerability Example

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

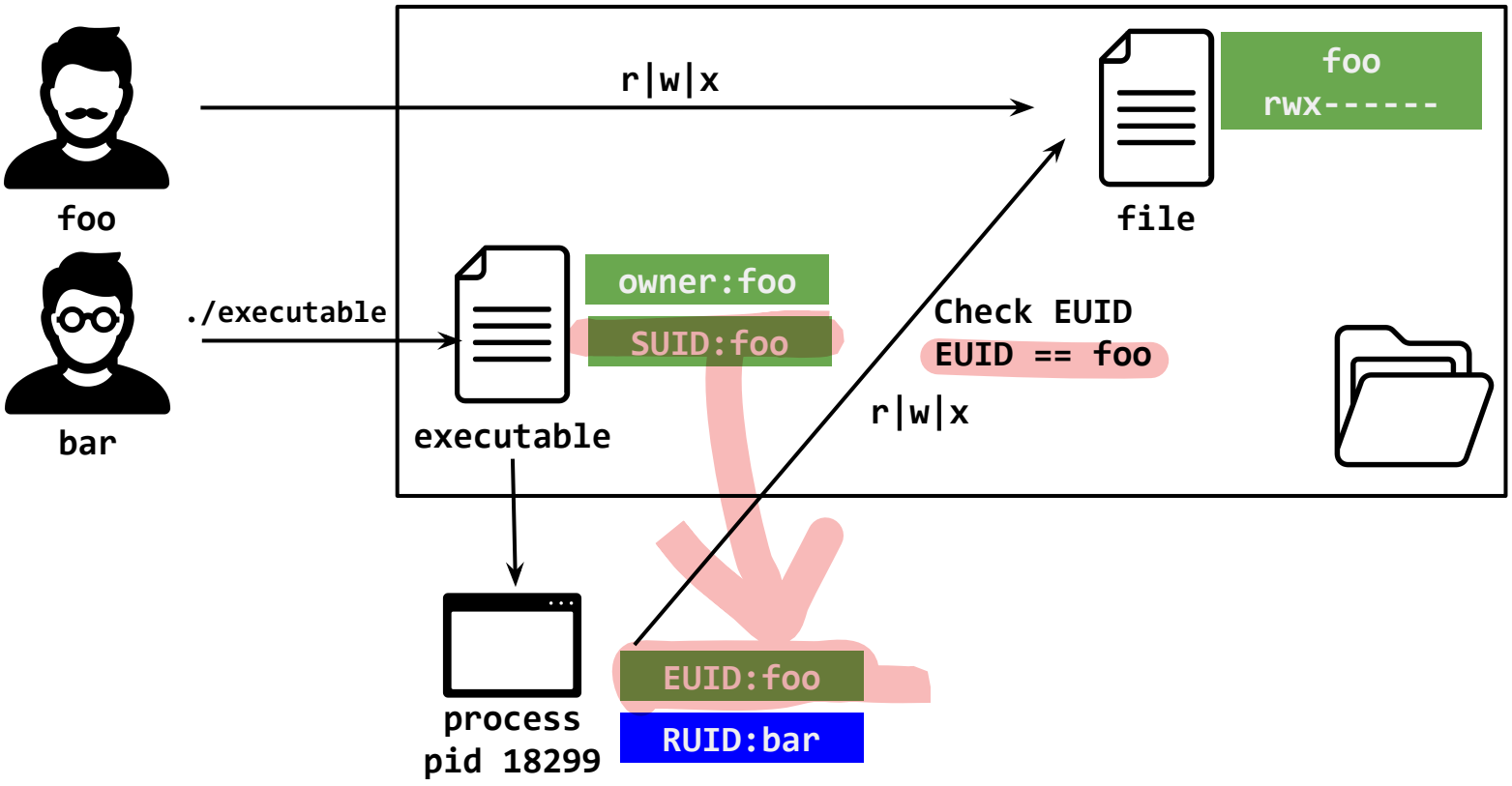
```
[root@localhost]# chmod u+s executable
[root@localhost]# ls -la executable
 -rwsr-xr-x 1 foo group 41836 2012-10-14 19:19 executable
```

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".

Now the executable's SUID is "foo".



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

Vulnerability Example

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

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

Vulnerability Example

```
#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 Example

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

Vulnerability Example

```
[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 Example

```
[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");
    while (!feof(fp)) {
        fgets(line, 1024, fp);
        puts(line);
    }
    fclose(fp);
    return 0;
}
```

Vulnerability Example (4)

Let's check the permission associated to `/etc/secret`

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

Vulnerability Example

```
[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 Example

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

[foo@localhost]$ ./executable
```

What happens if we execute the binary file now ?

Vulnerability Example

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
```

What if these programs have vulnerabilities or bugs ?

A serious issue....

```
#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 Example

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 Example

```
[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.

Vulnerability and Exploit

Vulnerable program (pseudocode)

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

The `read(config)` function prints the content of the file in the error message.

Vulnerability and Exploit

Vulnerable program

```
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.

Exploit patching

Vulnerable program

```
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>: ...
```

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.
```

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.

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("...")
```

General Idea (pseudocode)

(still) vulnerable program

```
EUID: SUID -> RUID
read(config)   //low privs
EUID: RUID -> SUID
r = parse(config)
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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
read(config)   //low privs
EUID: RUID -> SUID
r = parse(config)
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[user@host]$ ./ex
carefully-crafted-file
```

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("...")
```

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

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 Kerckhoffs 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 own cryptographic primitives, password, and secret management code: use trusted code that has been audited already.

Use trustworthy RNGs such as **`/dev/[u]random`**

Code Security by Example

We will see 5 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.

Code Security by Example

We will see various examples of (in)secure programming:

- 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