CSC 405
Linux Security

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We are done with machine code!

We are done with machine code!

for now…

Reason

$ █

Having access to the shell means you have full control over the system

Reason

$ █

Having access to the shell means you have full control over the system
Which means all we're ever trying to do is reach **THAT** again

Reason

And it means we have access to all the tools available to Linux

```
$ls
```

Having access to the shell means you have full control over the system
Which means all we're ever trying to do is reach **THAT** again

Reason

And it means we have access to all the tools available to Linux

```
$cd
 ls
```

Having access to the shell means you have full control over the system
Which means all we're ever trying to do is reach **THAT** again

Reason

And it means we have access to **all the tools** available to Linux

```
$rm -rf /
cd
ls
```

Having access to the shell means you have full control over the system
Which means all we're ever trying to do is reach **THAT** again

Reason

And it means we have access to **<u>all the tools</u>** available to Linux

```
$rm -rf /
```

This is also a friendly reminder that some of the control we gain in this class can break a system

(please remember to always test things out on your VMs)

Havi[...] e system

[...]ain

Linux

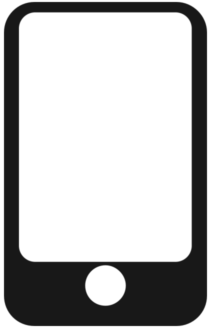
The most deployed operating system in the world

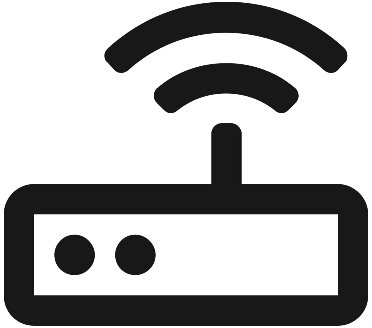
What are three devices that explain why?

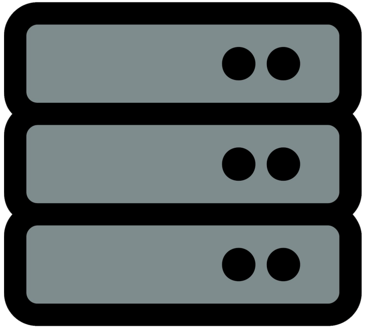
Linux

The most deployed operating system in the world

What are three devices that explain why?



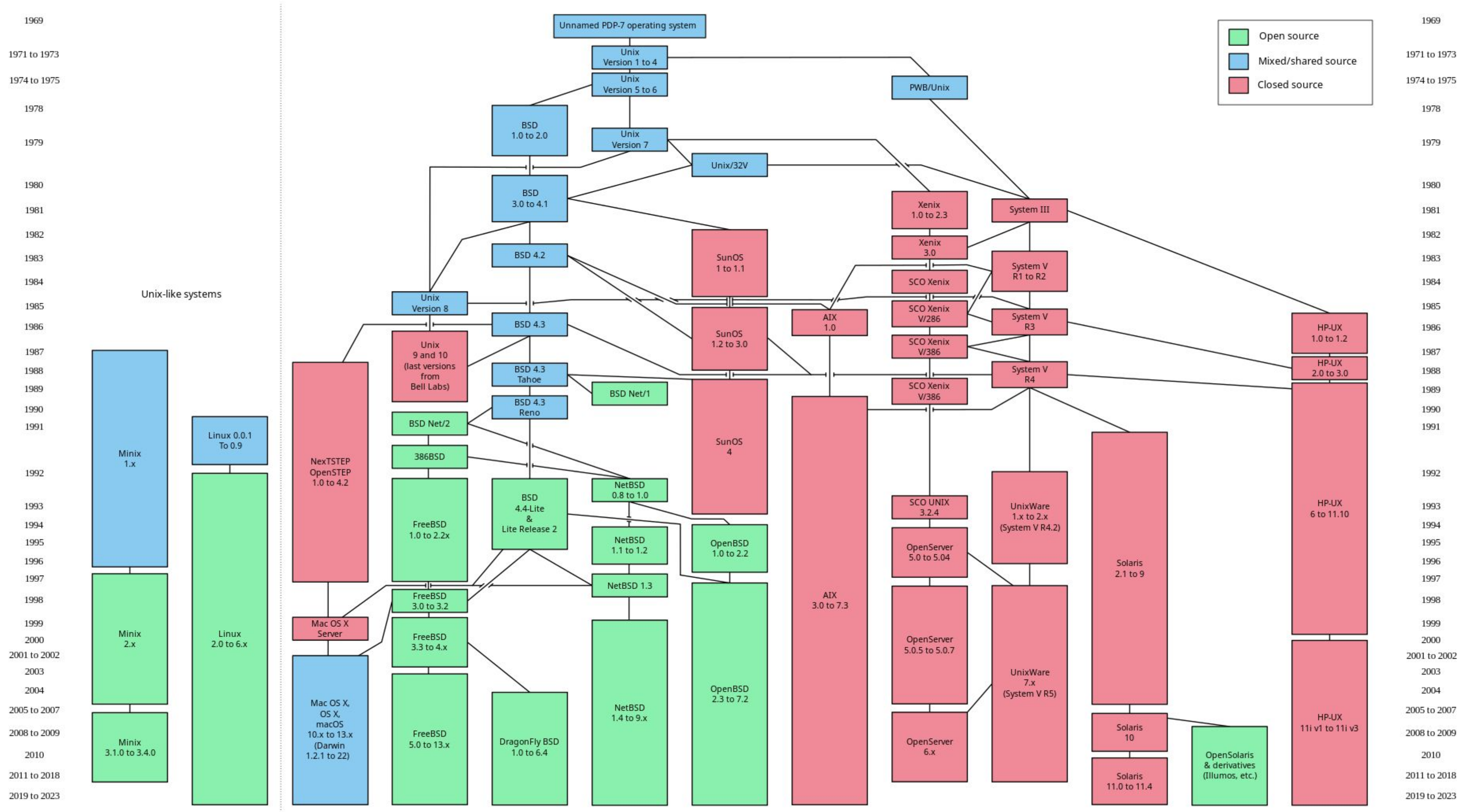




A History of Linux

In the beginning, there was UNIX®

An Open Group Standard



Open source
Mixed/shared source
Closed source
1969
1971 to 1973
1974 to 1975
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001 to 2002
2003
2004
2005 to 2007
2008 to 2009
2010
2011 to 2018
2019 to 2023
Unix-like systems
Minix 1.x
Minix 2.x
Minix 3.1.0 to 3.4.0
Linux 0.0.1 To 0.9
Linux 2.0 to 6.x
Unnamed PDP-7 operating system
Unix Version 1 to 4
Unix Version 5 to 6
Unix Version 7
Unix/32V
PWB/Unix
BSD 1.0 to 2.0
BSD 3.0 to 4.1
BSD 4.2
Unix Version 8
BSD 4.3
Unix 9 and 10 (last versions from Bell Labs)
BSD 4.3 Tahoe
BSD Net/1
BSD 4.3 Reno
BSD Net/2
386BSD
NexTSTEP OpenSTEP 1.0 to 4.2
Mac OS X Server
Mac OS X, OS X, macOS 10.x to 13.x (Darwin 1.2.1 to 22)
FreeBSD 1.0 to 2.2x
FreeBSD 3.0 to 3.2
FreeBSD 3.3 to 4.x
FreeBSD 5.0 to 13.x
BSD 4.4-Lite & Lite Release 2
DragonFly BSD 1.0 to 6.4
NetBSD 0.8 to 1.0
NetBSD 1.1 to 1.2
NetBSD 1.3
NetBSD 1.4 to 9.x
OpenBSD 1.0 to 2.2
OpenBSD 2.3 to 7.2
SunOS 1 to 1.1
SunOS 1.2 to 3.0
SunOS 4
AIX 1.0
AIX 3.0 to 7.3
Xenix 1.0 to 2.3
Xenix 3.0
SCO Xenix
SCO Xenix V/286
SCO Xenix V/386
SCO Xenix V/386
SCO UNIX 3.2.4
OpenServer 5.0 to 5.04
OpenServer 5.0.5 to 5.0.7
OpenServer 6.x
System III
System V R1 to R2
System V R3
System V R4
UnixWare 1.x to 2.x (System V R4.2)
UnixWare 7.x (System V R5)
Solaris 2.1 to 9
Solaris 10
Solaris 11.0 to 11.4
OpenSolaris & derivatives (Illumos, etc.)
HP-UX 1.0 to 1.2
HP-UX 2.0 to 3.0
HP-UX 6 to 11.10
HP-UX 11i v1 to 11i v3

Unix

- Started in 1969 at AT&T / Bell Labs
- Split into a number of popular branches
  - BSD, System V (commercial, AT&T), Solaris, HP-UX, AIX
- Inspired a number of Unix-like systems
  - Linux, Minix, macOS
- Standardization attempts
  - POSIX, Single Unix Specification (SUS), Filesystem Hierarchy Standard (FHS), Linux Standard Base (LSB), ELF

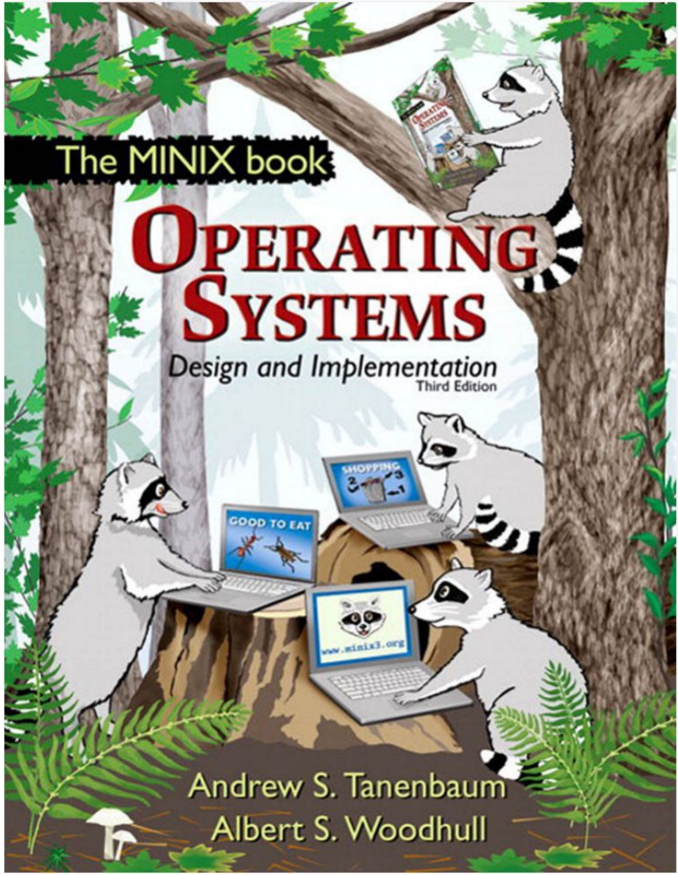
A History of Linux

Linus Torvalds

A History of Linux

Linus developed the first iteration of Linux while in college (~1987) coding in Minix and thought…

"there must be a better way"

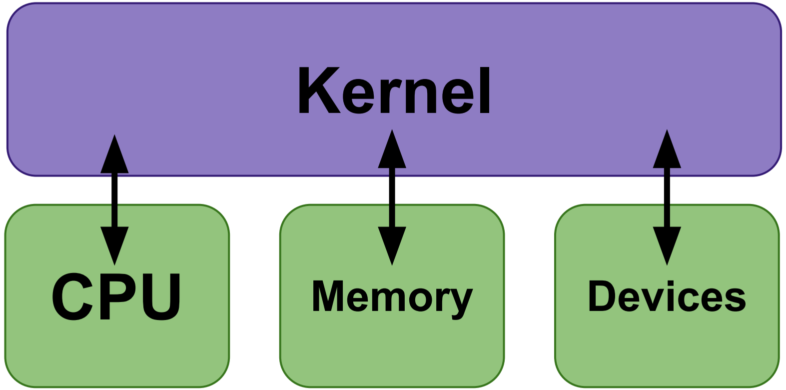


The Kernel

Core component to the operating system

Manages system resources

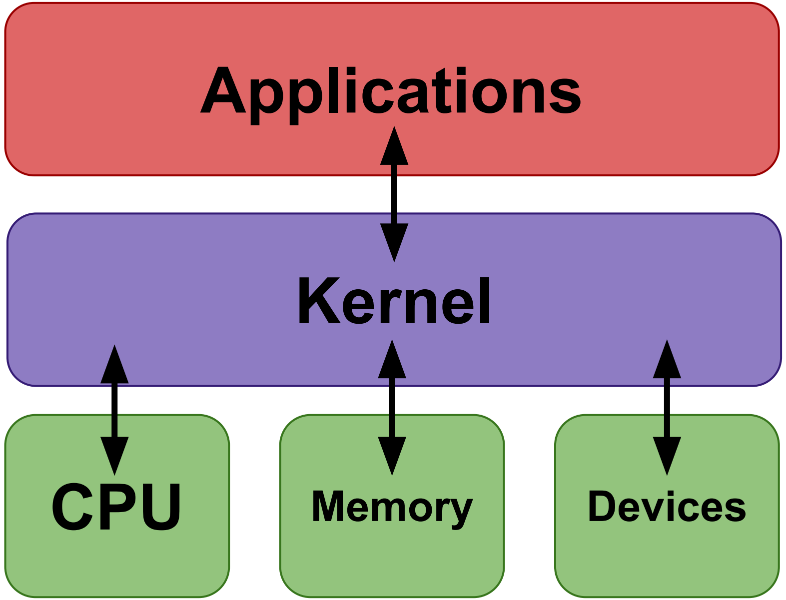
Provides essential services like scheduling, drivers, memory management, and **system calls**



The Kernel

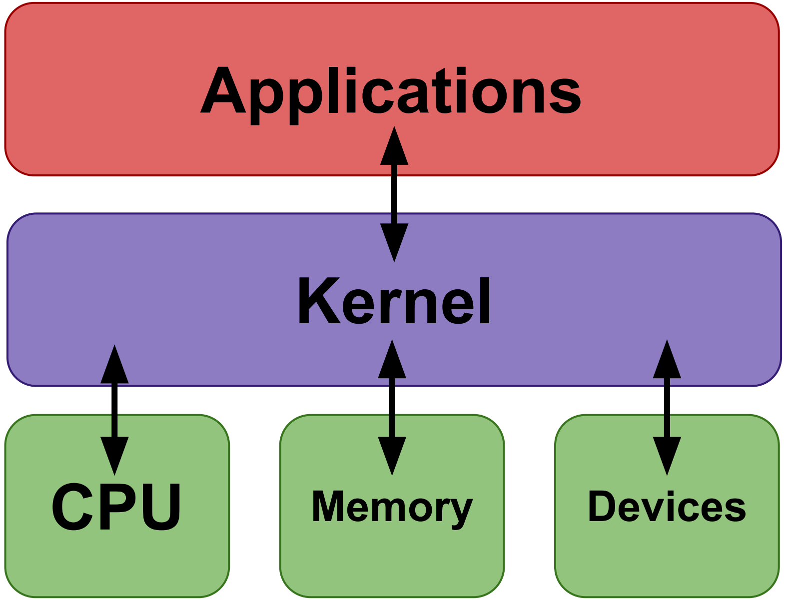
Serves as the bridge between software and hardware

Facilitates communication between them



The Kernel

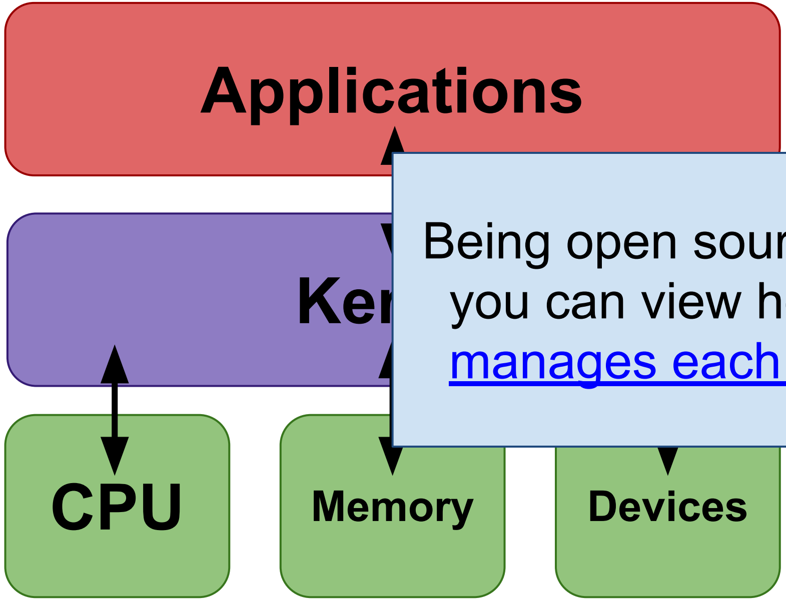
Linux for example is a collection of C binaries for handling the kernel



- grub
- kexec
- modprobe
- insmod
- rmmod
- lsmod
- depmod
- sysctl

The Kernel

Linux for example is a collection of C binaries for handling the kernel

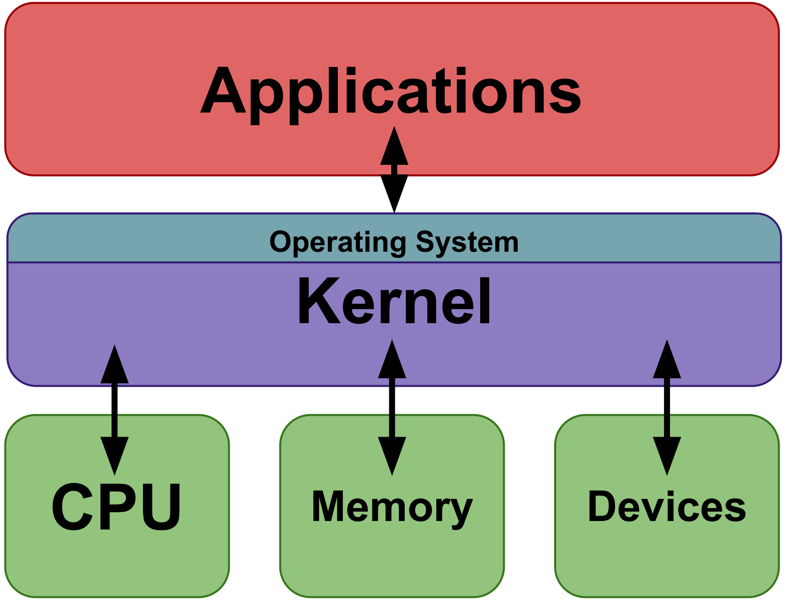


Being open source means you can view how Linux [manages each program]

- grub
- kexec
- modprobe
- insmod
- rmmod
- lsmod
- depmod
- sysctl

The Operating System

The operating system, on the other hand, is essentially built around the kernel to provide a user-friendly interface



Kernel vulnerabilities

<table>
<tr><th>#</th><th>CVE ID</th><th>CWE ID</th><th># of Exploits</th><th>Vulnerability Type(s)</th><th>Publish Date</th><th>Update Date</th><th>Score</th><th>Gained Access Level</th><th>Access</th><th>Complexity</th><th>Authentication</th><th>Conf.</th><th>Integ.</th><th>Avail.</th></tr>
<tr><td>1</td><td>CVE-2017-12762</td><td>119</td><td></td><td>Overflow</td><td>2017-08-09</td><td>2017-08-25</td><td>10.0</td><td>None</td><td>Remote</td><td>Low</td><td>Not required</td><td>Complete</td><td>Complete</td><td>Complete</td></tr>
<tr><td colspan="15">In /drivers/isdn/i4l/isdn_net.c: A user-controlled buffer is copied into a local buffer of constant size using strcpy without a length check which can cause a buffer overflow. This affects the Linux kernel 4.9-stable tree, 4.12-stable tree, 3.18-stable tree, and 4.4-stable tree.</td></tr>
<tr><td>2</td><td>CVE-2017-11176</td><td>416</td><td></td><td>DoS</td><td>2017-07-11</td><td>2017-08-07</td><td>10.0</td><td>None</td><td>Remote</td><td>Low</td><td>Not required</td><td>Complete</td><td>Complete</td><td>Complete</td></tr>
<tr><td colspan="15">The mq_notify function in the Linux kernel through 4.11.9 does not set the sock pointer to NULL upon entry into the retry logic. During a user-space close of a Netlink socket, it allows attackers to cause a denial of service (use-after-free) or possibly have unspecified other impact.</td></tr>
<tr><td>3</td><td>CVE-2017-8890</td><td>415</td><td></td><td>DoS</td><td>2017-05-10</td><td>2017-05-24</td><td>10.0</td><td>None</td><td>Remote</td><td>Low</td><td>Not required</td><td>Complete</td><td>Complete</td><td>Complete</td></tr>
<tr><td colspan="15">The inet_csk_clone_lock function in net/ipv4/inet_connection_sock.c in the Linux kernel through 4.10.15 allows attackers to cause a denial of service (double free) or possibly have unspecified other impact by leveraging use of the accept system call.</td></tr>
<tr><td>4</td><td>CVE-2017-7895</td><td>189</td><td></td><td></td><td>2017-04-28</td><td>2017-05-11</td><td>10.0</td><td>None</td><td>Remote</td><td>Low</td><td>Not required</td><td>Complete</td><td>Complete</td><td>Complete</td></tr>
<tr><td colspan="15">The NFSv2 and NFSv3 server implementations in the Linux kernel through 4.10.13 lack certain checks for the end of a buffer, which allows remote attackers to trigger pointer-arithmetic errors or possibly have unspecified other impact via crafted requests, related to fs/nfsd/nfs3xdr.c and fs/nfsd/nfsxdr.c.</td></tr>
<tr><td>5</td><td>CVE-2017-0648</td><td>264</td><td></td><td>Exec Code</td><td>2017-06-14</td><td>2017-07-07</td><td>9.3</td><td>None</td><td>Remote</td><td>Medium</td><td>Not required</td><td>Complete</td><td>Complete</td><td>Complete</td></tr>
<tr><td colspan="15">An elevation of privilege vulnerability in the kernel FIQ debugger could enable a local malicious application to execute arbitrary code within the context of the kernel. This issue is rated as High due to the possibility of a local permanent device compromise, which may require reflashing the operating system to repair the device. Product: Android. Versions: Kernel-3.10. Android ID: A-36101220.</td></tr>
<tr><td>6</td><td>CVE-2017-0605</td><td>264</td><td></td><td>Exec Code</td><td>2017-05-12</td><td>2017-05-19</td><td>9.3</td><td>None</td><td>Remote</td><td>Medium</td><td>Not required</td><td>Complete</td><td>Complete</td><td>Complete</td></tr>
<tr><td colspan="15">An elevation of privilege vulnerability in the kernel trace subsystem could enable a local malicious application to execute arbitrary code within the context of the kernel. This issue is rated as Critical due to the possibility of a local permanent device compromise, which may require reflashing the operating system to repair the device. Product: Android. Versions: Kernel-3.10, Kernel-3.18. Android ID: A-35399704. References: QC-CR#1048480.</td></tr>
<tr><td>7</td><td>CVE-2017-0564</td><td>264</td><td></td><td>Exec Code</td><td>2017-04-07</td><td>2017-07-10</td><td>9.3</td><td>None</td><td>Remote</td><td>Medium</td><td>Not required</td><td>Complete</td><td>Complete</td><td>Complete</td></tr>
<tr><td colspan="15">An elevation of privilege vulnerability in the kernel ION subsystem could enable a local malicious application to execute arbitrary code within the context of the kernel. This issue is rated as Critical due to the possibility of a local permanent device compromise, which may require reflashing the operating system to repair the device. Product: Android. Versions: Kernel-3.10, Kernel-3.18. Android ID: A-34276203.</td></tr>
<tr><td>8</td><td>CVE-2017-0563</td><td>264</td><td></td><td>Exec Code</td><td>2017-04-07</td><td>2017-07-10</td><td>9.3</td><td>None</td><td>Remote</td><td>Medium</td><td>Not required</td><td>Complete</td><td>Complete</td><td>Complete</td></tr>
<tr><td colspan="15">An elevation of privilege vulnerability in the HTC touchscreen driver could enable a local malicious application to execute arbitrary code within the context of the kernel. This issue is rated as Critical due to the possibility of a local permanent device compromise, which may require reflashing the operating system to repair the device. Product: Android. Versions: Kernel-3.10. Android ID: A-32089409.</td></tr>
<tr><td>9</td><td>CVE-2017-0561</td><td>264</td><td></td><td>Exec Code</td><td>2017-04-07</td><td>2017-08-15</td><td>10.0</td><td>None</td><td>Remote</td><td>Low</td><td>Not required</td><td>Complete</td><td>Complete</td><td>Complete</td></tr>
<tr><td colspan="15">A remote code execution vulnerability in the Broadcom Wi-Fi firmware could enable a remote attacker to execute arbitrary code within the context of the Wi-Fi SoC. This issue is rated as Critical due to the possibility of remote code execution in the context of the Wi-Fi SoC. Product: Android. Versions: Kernel-3.10, Kernel-3.18. Android ID: A-34199105. References: B-RB#110814.</td></tr>
<tr><td>10</td><td>CVE-2017-0528</td><td>264</td><td></td><td>Exec Code Bypass</td><td>2017-03-07</td><td>2017-07-17</td><td>9.3</td><td>None</td><td>Remote</td><td>Medium</td><td>Not required</td><td>Complete</td><td>Complete</td><td>Complete</td></tr>
<tr><td colspan="15">An elevation of privilege vulnerability in the kernel security subsystem could enable a local malicious application to to execute code in the context of a privileged process. This issue is rated as High because it is a general bypass for a kernel level defense in depth or exploit mitigation technology. Product: Android. Versions: Kernel-3.18. Android ID: A-33351919.</td></tr>
</table>

Kernel vulnerabilities

<table>
<tr><th>#</th><th>CVE ID</th><th>CWE ID</th><th># of Exploits</th><th>Vulnerability Type(s)</th><th>Publish Date</th><th>Update Date</th><th>Score</th><th>Gained Access Level</th><th>Access</th><th>Complexity</th><th>Authentication</th><th>Conf.</th><th>Integ.</th><th>Avail.</th></tr>
<tr><td>1</td><td>CVE-2018-20961</td><td>415</td><td></td><td>DoS</td><td>2019-08-07</td><td>2019-08-27</td><td>10.0</td><td>None</td><td>Remote</td><td>Low</td><td>Not required</td><td>Complete</td><td>Complete</td><td>Complete</td></tr>
<tr><td colspan="15">In the Linux kernel before 4.16.4, a double free vulnerability in the f_midi_set_alt function of drivers/usb/gadget/function/f_midi.c in the f_midi driver may allow attackers to cause a denial of service or possibly have unspecified other impact.</td></tr>
<tr><td>2</td><td>CVE-2019-10125</td><td>94</td><td></td><td></td><td>2019-03-27</td><td>2019-06-14</td><td>10.0</td><td>None</td><td>Remote</td><td>Low</td><td>Not required</td><td>Complete</td><td>Complete</td><td>Complete</td></tr>
<tr><td colspan="15">An issue was discovered in aio_poll() in fs/aio.c in the Linux kernel through 5.0.4. A file may be released by aio_poll_wake() if an expected event is triggered immediately (e.g., by the close of a pair of pipes) after the return of vfs_poll(), and this will cause a use-after-free.</td></tr>
<tr><td>3</td><td>CVE-2019-11683</td><td>399</td><td></td><td>DoS Mem. Corr.</td><td>2019-05-02</td><td>2019-06-14</td><td>10.0</td><td>None</td><td>Remote</td><td>Low</td><td>Not required</td><td>Complete</td><td>Complete</td><td>Complete</td></tr>
<tr><td colspan="15">udp_gro_receive_segment in net/ipv4/udp_offload.c in the Linux kernel 5.x before 5.0.13 allows remote attackers to cause a denial of service (slab-out-of-bounds memory corruption) or possibly have unspecified other impact via UDP packets with a 0 payload, because of mishandling of padded packets, aka the "GRO packet of death" issue.</td></tr>
<tr><td>4</td><td>CVE-2019-11811</td><td>416</td><td></td><td></td><td>2019-05-07</td><td>2019-05-31</td><td>10.0</td><td>None</td><td>Remote</td><td>Low</td><td>Not required</td><td>Complete</td><td>Complete</td><td>Complete</td></tr>
<tr><td colspan="15">An issue was discovered in the Linux kernel before 5.0.4. There is a use-after-free upon attempted read access to /proc/ioports after the ipmi_si module is removed, related to drivers/char/ipmi/ipmi_si_intf.c, drivers/char/ipmi/ipmi_si_mem_io.c, and drivers/char/ipmi/ipmi_si_port_io.c.</td></tr>
<tr><td>5</td><td>CVE-2019-15292</td><td>416</td><td></td><td></td><td>2019-08-21</td><td>2019-09-02</td><td>10.0</td><td>None</td><td>Remote</td><td>Low</td><td>Not required</td><td>Complete</td><td>Complete</td><td>Complete</td></tr>
<tr><td colspan="15">An issue was discovered in the Linux kernel before 5.0.9. There is a use-after-free in atalk_proc_exit, related to net/appletalk/atalk_proc.c, net/appletalk/ddp.c, and net/appletalk/sysctl_net_atalk.c.</td></tr>
<tr><td>6</td><td>CVE-2019-15504</td><td>415</td><td></td><td></td><td>2019-08-23</td><td>2019-09-04</td><td>10.0</td><td>None</td><td>Remote</td><td>Low</td><td>Not required</td><td>Complete</td><td>Complete</td><td>Complete</td></tr>
<tr><td colspan="15">drivers/net/wireless/rsi/rsi_91x_usb.c in the Linux kernel through 5.2.9 has a Double Free via crafted USB device traffic (which may be remote via usbip or usbredir).</td></tr>
<tr><td>7</td><td>CVE-2019-15505</td><td>125</td><td></td><td></td><td>2019-08-23</td><td>2019-09-04</td><td>10.0</td><td>None</td><td>Remote</td><td>Low</td><td>Not required</td><td>Complete</td><td>Complete</td><td>Complete</td></tr>
<tr><td colspan="15">drivers/media/usb/dvb-usb/technisat-usb2.c in the Linux kernel through 5.2.9 has an out-of-bounds read via crafted USB device traffic (which may be remote via usbip or usbredir).</td></tr>
<tr><td>8</td><td>CVE-2019-15926</td><td>125</td><td></td><td></td><td>2019-09-04</td><td>2019-09-14</td><td>9.4</td><td>None</td><td>Remote</td><td>Low</td><td>Not required</td><td>Complete</td><td>None</td><td>Complete</td></tr>
<tr><td colspan="15">An issue was discovered in the Linux kernel before 5.2.3. Out of bounds access exists in the functions ath6kl_wmi_pstream_timeout_event_rx and ath6kl_wmi_cac_event_rx in the file drivers/net/wireless/ath/ath6kl/wmi.c.</td></tr>
<tr><td>9</td><td>CVE-2018-20836</td><td>416</td><td></td><td></td><td>2019-05-07</td><td>2019-05-08</td><td>9.3</td><td>None</td><td>Remote</td><td>Medium</td><td>Not required</td><td>Complete</td><td>Complete</td><td>Complete</td></tr>
<tr><td colspan="15">An issue was discovered in the Linux kernel before 4.20. There is a race condition in smp_task_timedout() and smp_task_done() in drivers/scsi/libsas/sas_expander.c, leading to a use-after-free.</td></tr>
<tr><td>10</td><td>CVE-2019-11815</td><td>362</td><td></td><td></td><td>2019-05-08</td><td>2019-06-07</td><td>9.3</td><td>None</td><td>Remote</td><td>Medium</td><td>Not required</td><td>Complete</td><td>Complete</td><td>Complete</td></tr>
<tr><td colspan="15">An issue was discovered in rds_tcp_kill_sock in net/rds/tcp.c in the Linux kernel before 5.0.8. There is a race condition leading to a use-after-free, related to net namespace cleanup.</td></tr>
</table>

Kernel Security Research is Active

Papers from USENIX Security 2023

- PhyAuth: Physical-Layer Message Authentication for ZigBee Networks
- Auditory Eyesight: Demystifying μs-Precision Keystroke Tracking Attacks on Unconstrained Keyboard Inputs
- Improving Logging to Reduce Permission Over-Granting Mistakes
- Know Your Cybercriminal: Evaluating Attacker Preferences by Measuring Profile Sales on an Active, Leading Criminal Market for User Impersonation at Scale

source: https://www.usenix.org/conference/usenixsecurity23/technical-sessions

Kernel Security is also Rapidly Changing

Rust will be added to Linux v6.1
- Compiles to machine code via rustc
- Provides stronger memory safety guarantees
- Performs comparable to C and C++

Aka, a lot of the most basic attacks may change

Users

Unix is **user-centric**

- no roles

Running code is **always linked** to a certain identity

- **security checks** and **access control** decisions are based on user identity

Users

User

– identified by username (**UID**), group name (**GID**)

```
amgaweda amgaweda 4.0K Jan 29 21:04 .
amgaweda amgaweda 4.0K Jan 29 21:03 ..
amgaweda amgaweda    0 Jan 29 21:04 example.txt
```

Users

User

- identified by username (**UID**), group name (**GID**)

```
amgaweda amgaweda 4.0K Jan 29 21:04 .
amgaweda amgaweda 4.0K Jan 29 21:03 ..
amgaweda amgaweda    0 Jan 29 21:04 example.txt
```

- typically authenticated by password (stored encrypted)

```
sudo cat /etc/shadow
...
amgaweda:$y$notOnYourLifeBubYoullNeverGuessBubbles:0:99999:7:::
```

Users

User

- identified by username (**`UID`**), group name (**`GID`**)
- typically authenticated by password (stored encrypted)

User **`root`**

```
root root 4.0K Apr 18  2022 boot
```

- superuser, system administrator
- special privileges (access resources, modify OS)
- **cannot decrypt user passwords**

Process Management

Process (**PID**)

- implements user-activity
- entity that executes a given piece of code
- has its own execution stack, memory pages, and file descriptors table
- separated from other processes using the virtual memory abstraction

htop

PID	USER	PRI	NI	VIRT	RES	SHR	S	CPU%	MEM%	TIME+	Command
1	root	20	0	2456	1864	1756	S	0.0	0.0	0:00.01	/init
4	root	20	0	2456	932	896	S	0.0	0.0	0:00.00	plan9 --
9	amgaweda	20	0	6180	5156	3396	S	0.0	0.0	0:00.11	-bash
163	amgaweda	20	0	5364	3780	3116	R	0.0	0.0	0:00.01	htop

Process Management

Thread

- separate stack and program counter
- share memory pages and file descriptor table
- processes are also executed through threads and have their own thread ids (**`LWP`**) and count (**`NLWP`**)

```
$ ps -eLf
UID         PID  PPID   LWP  C NLWP STIME TTY          TIME CMD
root          1     0     1  0    2 21:02 hvc0     00:00:00 /init
amgaweda      9     8     9  0    1 21:02 pts/0    00:00:00 -bash
amgaweda    164     9   164  0    1 21:24 pts/0    00:00:00 ps -eLf
```

Process Management

Process Attributes

- process ID (**`PID`**)
  - uniquely identified process
- user ID (**`UID`**)
  - ID of owner of process
- effective user ID (**`EUID`**)
  - ID used for permission checks (e.g., to access resources)
- saved user ID (**`SUID`**)
  - to temporarily drop and restore privileges
- lots of management information
  - scheduling, memory management, resource management

Process Management

Switching between IDs

- uid-setting system calls
- **`int setuid(uid_t uid)`**
- **`int seteuid(uid_t uid)`**
- **`int setresuid(uid_t ruid, uid_t euid, uid_t suid)`**

Can be tricky

- POSIX 1003.1:

  If the process has appropriate privileges, the setuid(newuid) function sets the real user ID, effective user ID, and the [saved user ID] to newuid.
- what are appropriate privileges?

  Solaris: **`EUID = 0`**; FreeBSD: **`newuid = EUID`**; Linux: **`SETUID`** capability

Sudo Change Time

- `user` logs in
  - their `UID` is set to a non-`root` value, indicating they have regular user permissions

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- `user` runs `date` to change the system time
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  - date is executed but the kernel checks the `EUID` of the process to see if it matches the users `UID`
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Sudo Change Time

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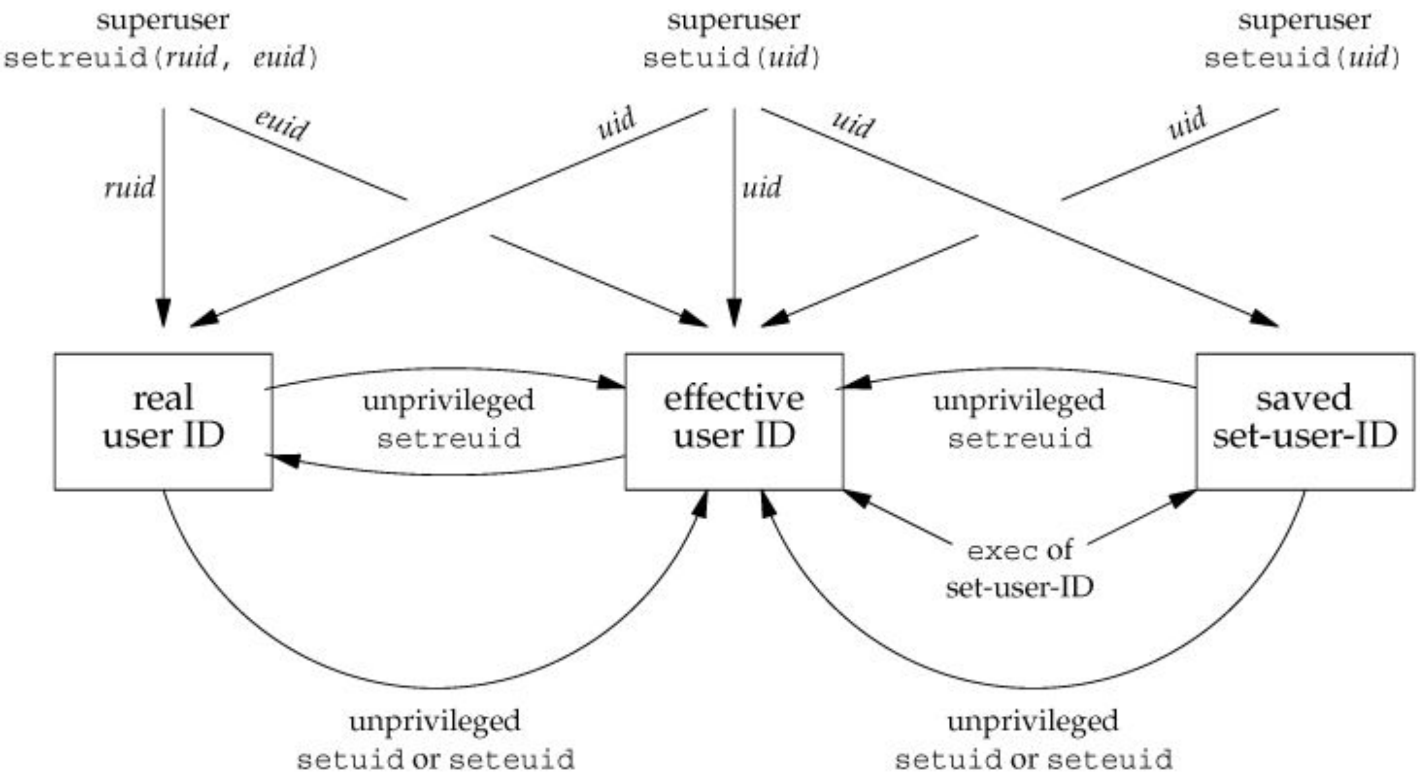
  - their **`UID`** is set to a non-**`root`** value, indicating they have regular user permissions
- **`user`** runs **`date`** to change the system time
  - Doing this requires escalated privileges (**`root`**)
  - date is executed but the kernel checks the **`EUID`** of the process to see if it matches the users **`UID`**
  - Since it doesn't, the process is halted
- **`user`** runs **`sudo date`**
  - **`sudo`** elevates the **`EUID`** of **`date`** to **`root`** temporarily, allowing it to change the time

Obligatory XKCD

Obligatory alt-text: https://xkcd.com/838/

Summary of all the Functions that Set the User IDs



source: http://poincare.matf.bg.ac.rs/~ivana/courses/ps/sistemi_knjige/pomocno/apue/APUE/0201433079/ch08lev1sec11.html

Early Example of Privilege Escalation

Bug in **`sendmail`** 8.10.1:

- call to **`setuid(getuid())`** to clear privileges (effective **`UID`** is **`root`**)
- on Linux, attacker could clear **`SETUID`** capability
- call clears **`EUID`**, but **`SUID`** remains root

Further reading

Setuid Demystified, Hao Chen, David Wagner, and Drew Dean
11th USENIX Security Symposium, 2002

User Authentication

How does a process get a user ID?

User Authentication

How does a process get a user ID?

Authentication

User Authentication

Passwords

- user passwords are used as keys for crypt() function
- uses SHA-512
- 8-byte “salt”
  - chosen from date, not secret
  - prevent same passwords to map onto same string
  - make dictionary attacks more difficult

```
sudo cat /etc/shadow
kali:$y$j9T$lR7REZ4XgU56yXNl9PFiN/$oI3B/OeQGXOoTb7opQ.azBMOgG2IM0neRj4MN3HCqQ.:19331:0:99999:7:::
```

User

SHA-512 encryption of "kali"

More on salting passwords in our Web Security lectures

User Authentication

Password Cracking

- dictionary attacks (try common passwords)
- rainbow tables (efficiently try common passwords)
- simple brute force (inefficiently try all passwords)

Password Crackers

- Crack
- JohnTheRipper

User Authentication

Shadow passwords

- password file is needed by many applications to map user ID to user names
- encrypted passwords are not

```
kali:$y$j9T$lR7REZ4XgU56yXNl9PFiN/$oI3B/OeQGXOoTb7opQ.azBMOgG2IM0neRj4MN3HCqQ.:19331:0:99999:7:::
```

`/etc/shadow`

- holds encrypted passwords
- account information
  - last change date (**19331**)
  - minimum change frequency (**0**, **99999**)
  - number of days before expiration (**7**)
- readable only by superuser and privileged programs
- SHA-512 hashed passwords (default on Ubuntu) to slow down guessing

User Authentication

Shadow passwords

- a number of other encryption / hashing algorithms were proposed
- blowfish, SHA-1, …

Other authentication means possible

- Linux PAM (pluggable authentication modules)
- Kerberos
- Active directory (Windows)

Group Model

Users belong to one or more **groups**

- primary group (stored in **`/etc/passwd`**)
- additional groups (stored in **`/etc/group`**)
- become group member with **`newgrp`**
- can also to set group password (none by default)

`/etc/group` (**groupname : password : group id : additional users**)

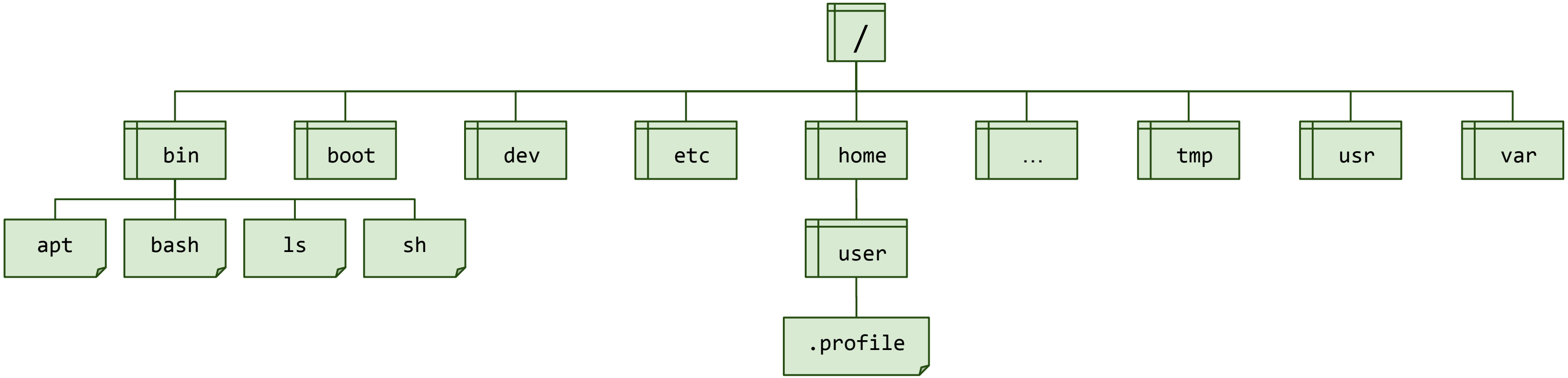
```
root:x:0:root
bin:x:1:root,bin,daemon
users:x:100:akaprav
```

Special group `wheel/sudo` (like on Ubuntu)

- protect `root` account by limiting user accounts that can perform `su`

File System

- File Hierarchy Tree - primary repository of information
  - directories contain file system objects (FSO)



- File system object
  - files, directories, symbolic links (shortcuts), sockets, device files
  - referenced by **`inode`** (index node)

Denial of Service through Inodes

```
#!/bin/bash

# Directory to create files in
target_dir="/tmp/exhaust_inodes"
mkdir -p $target_dir

# Loop to create one million small files
for i in {1..1000000}; do
    # Create a small file with a unique name, exhausting 1 inode
    echo "This is file $i" > "$target_dir/file_$i.txt"
done

# Wait for user input to keep files in place for inspection
# Could DOS processes waiting to creating files on the system
# if the script exhausts all available inodes, even if there
# is still disk space on the drive
read -p "Press any key to delete files and clean up..." -n 1 -r

# Clean up: Remove files and directory
rm -rf $target_dir
echo "Cleanup complete."
```

Do exercise **caution**, this is one of those "attack" scripts

We aren't responsible if you break your machine

`df -i` to see how many inodes your system has

File Permissions

Access Control

- permission bits
- `chmod, chown, chgrp, umask`
- permission structure:

```
      -       rwx     rwx     rwx       -
(file type) (user)  (group) (other) (sticky)
```

Type	r	w	x	s	t
File	read access	write access	execute	suid / sgid inherit id	sticky bit
Directory	list files	insert and remove files	stat / execute files, chdir	new files have dir-gid	files/dirs only delete-able by owner

File Permissions

Access Control

- permission bits
- `chmod, chown, chgrp, umask`
- permission structure:

```
      -          rwx      rwx      rwx
(file type)    (user)   (group)   (othe
```

s inherits the permissions of the binary owner

When you execute `passwd`, it inherits root permissions

Type	r	w	x	s	t
File	read access	write access	execute	suid / sgid inherit id	sticky bit
Directory	lis				

Find files w/ root setuid

```
find / -type f -perm /4000 -exec stat -c "%U %n" {} + | grep root
```

Find available binaries on the system

```
dpkg –get-resources
```

Sticky bit

No effect on files (on Linux)
When used on a directory, all the files in that directory will be modifiable **only by their owners**

What's a very common directory with sticky bit?

Sticky bit

No effect on files (on Linux)
When used on a directory, all the files in that directory will be modifiable **only by their owners**

What's a very common directory with sticky bit?

```
$ ls -ld /tmp
drwxrwxrwt 26 root root 69632 Sep  7 15:24 /tmp

$ ls -l
-rw-rw-r-- 1 username username 0 Sep  7 15:29 test

$ chmod +t test; ls -l
-rw-rw-r-t 1 username username 0 Sep  7 15:29 test
```

SUID Programs

Each process has real and effective user / group ID

- usually identical
- real IDs
  - determined by current user
  - authentication (login, `su`)
- effective IDs
  - determine the "rights" of a process
  - system calls (e.g., `setuid()`)
- `suid` / `sgid` bits
  - to start process with effective ID different from real ID
  - attractive target for attacker

Never use `suid` shell scripts (multiplying problems)

- many operating systems ignore the `setuid` attribute when applied to executable shell scripts
- you need to patch the kernel to enable it

File System

Shared resource

- susceptible to race condition problems

Time-of-Check, Time-of-Use (**TOCTOU**)

- common race condition problem
- problem:
  - Time-Of-Check ($\mathbf{t_1}$): validity of assumption **A** on entity **E** is checked
  - Time-Of-Use ($\mathbf{t_2}$): assuming **A** is still valid, **E** is used
  - Time-Of-Attack ($\mathbf{t_3}$): assumption **A** is invalidated

$$t_1 < t_3 < t_2$$

TOCTOU

- Steps to access a resource
  - obtain reference to resource
  - query resource to obtain characteristics
  - analyze query results
  - if resource is fit, access it

- Often occurs in Unix file system accesses
  - check permissions for a certain file name (e.g., using `access(2)`)
  - open the file, using the file name (e.g., using `fopen(3)`)
  - four levels of indirection (symbolic link - hard link - **`inode`** - file descriptor)

- Windows uses file handles and includes checks in the API `open` call

TOCTOU Example

```
/* access returns 0 on success */
if(!access(file, W_OK)) {
   f = fopen(file, "wb+");
   write_to_file(f);
} else {
   fprintf(stderr, "Permission denied \
                    when trying to open %s.\n", file);
}
```

W_OK: Flag meaning test for write permission.
access return value is 0 if the access is permitted

Application checks if a file is safe to write to, if so then writes to it.

TOCTOU Example

```c
/* access returns 0 on success */
if(!access(file, W_OK)) {
    f = fopen(file, "wb+");
    write_to_file(f);
} else {
    fprintf(stderr, "Permission denied \
                    when trying to open %s.\n", file);
}
```

W_OK: Flag meaning test for write permission.
access return value is 0 if the access is permitted

Application checks if a file is safe to write to, if so then writes to it.

```
$ touch dummy; ln -s dummy pointer
$ rm pointer; ln -s /etc/passwd pointer
```

Attack creates symbolic link to **dummy**
Application makes **access()** call on **dummy**
System says **dummy** is okay to write to

TOCTOU Example

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/* access returns 0 on success */
if(!access(file, W_OK)) {
   f = fopen(file, "wb+");
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                    when trying to open %s.\n", file);
}
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Application checks if a file is safe to write to, if so then writes to it.

```
$ touch dummy; ln -s dummy pointer
$ rm pointer; ln -s /etc/passwd pointer
```

Attack creates symbolic link to **dummy**
Application makes **access()** call on **dummy**
System says **dummy** is okay to write to

Before **fopen()** operation occurs, attacker deletes the symbolic link on **dummy** and creates it on **/etc/passwd**

TOCTOU Example

- **`setuid`** Scripts
  - **`exec()`** system call invokes **`seteuid()`** call prior to executing program
  - program is a script, so command interpreter is loaded first
  - program interpreted (with **`root`** privileges) is invoked on script name
  - attacker can replace script content between step 2 and 3

```
#!/bin/bash

# Check if the user has read permissions on sensitive_file
if [ -r "sensitive_file" ]; then
    echo "User has read permissions. Executing privileged operation..."
    # Perform privileged operation
    cat "sensitive_file"
else
    echo "User does not have read permissions. Operation aborted."
fi
```

TOCTOU Example

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  - **`exec()`** system call invokes **`seteuid()`** call prior to executing program
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    # Perform privileged operation
    cat "sensitive_file"
else
    echo "Use                                              borted."
fi
```

User triggers execution of script…

TOCTOU Example

- **`setuid`** Scripts
  - **`exec()`** system call invokes **`seteuid()`** call prior to executing program
  - program is a script, so command interpreter is loaded first
  - program interpreted (with **`root`** privileges) is invoked on script name
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```bash
#!/bin/bash

# Check if the user has read permissions on sensitive_file
if [ -r "sensitive_file" ]; then
    echo "User has read permissions. Executing privileged operation..."
    # Perform privileged operation
    cat "sensitive_file"
else
    echo
fi
```

But before execution, attacker creates a symbolic link named `sensitive_file` pointing to `/etc/passwd`

```
$ ln -s /etc/passwd sensitive_file
```

TOCTOU Example

- Directory operations
  - `rm` can remove directory trees, traverses directories depth-first
  - issues `chdir("..")` to go one level up after removing a directory branch
  - by relocating subdirectory to another directory, arbitrary files can be deleted

```bash
#!/bin/bash

# Create a temporary file
touch /tmp/example

# Check if the directory exists
if [ -f "/tmp/example" ]; then
  # Prompt the user before removing
  echo "File exists. Are you sure? (y/n)"
  read answer
  if [ "$answer" == "y" ]; then
    # Remove the file
    rm -rf /tmp/example
    echo "File removed."
  else
    echo "File not removed."
  fi
else
    echo "File does not exist."
fi
```

TOCTOU Example

- Directory operations
  - **rm** c… trave…
  - issue… up a…
  - by relocating subdirectory to another directory, arbitrary files can be deleted

After checking the file exists…
1. Attacker deletes **/tmp/example**
2. Creates a symbolic link **ln -s /etc /tmp/example**
3. Process proceeds to execute **rm -rf /etc**

```bash
#!/bin/bash

# Create a temporary file
touch /tmp/example

# Check if the directory exists
if [ -f "/tmp/example" ]; then
  # Prompt the user before removing
  echo "File exists. Are you sure? (y/n)"
  read answer
  if [ "$answer" == "y" ]; then
    # Remove the file
    rm -rf /tmp/example
    echo "File removed."
  else
    echo "File not removed."
  fi
else
    echo "File does not exist."
fi
```

TOCTOU Example

- Temporary files
  - commonly opened in `/tmp` or `/var/tmp`
  - often guessable file names
  - if the attacker can intercept the process between permission check and operation, and the `/tmp` file is trivially named, they may be able to manipulate it

Common Trivial Names:

- `cache.dat`
- `temp_file`
- `data.txt`
- `apache2.pid`
- `sshd.pid`

Temporary Files

- "Secure" procedure for creating temporary files
  - pick a prefix for your filename
  - generate **at least** `64` bits of high-quality randomness
  - `base64` encode the random bits
  - concatenate the prefix with the encoded random data
  - set **`umask`** appropriately (`0066` is usually good, readable/writable only by you)
  - use [`fopen(3)`] to create the file, opening it in the proper mode
  - delete the file immediately using [`unlink(2)`] (deletes file after you're done with it)
  - perform reads, writes, and seeks on the file as necessary
  - finally, close the file

Prevention

- Immutable bindings
  - rather than using the file's variable, operate on file descriptors (fstat)

```
int main() {
  ...
  int fd = open(filename, O_RDONLY);
  ...
  struct stat st;
  fstat(fd, &st)
  ...
  if (!S_ISREG(st.st_mode)) { ... }
  ...
  printf("File size: %ld bytes\n", st.st_size);
  close(fd);
  return 0;
}
```

Ensures that we're not attempting to word with a special file type (directory, symbolic link)

Prevention

- Use the `O_CREAT | O_EXCL` flags to create a new file with [open(2)]
  - be prepared to have the open call fail

```
int main() {
  ...
  int fd = open(filename, O_WRONLY | O_CREAT | O_EXCL, 0066);
  ...
  close(fd);
  return 0;
}
```

Automatically creates the file if it does not exist and fails if it does

Prevention

Series of papers on the access system call

Fixing races for fun and profit: how to use access(2)
D. Dean and A. Hu
Usenix Security Symposium, 2004

Fixing races for fun and profit: how to abuse atime
N. Borisov, R. Johnson, N. Sastry, and D. Wagner
Usenix Security Symposium, 2005

Portably Solving File TOCTTOU Races with Hardness Amplification
D. Tsafrir, T. Hertz, D. Wagner, and D.Da Silva
Usenix Conference on File and Storage Technologies (FAST), 2008

Locking

- Ensures exclusive access to a certain resource
- Used to circumvent accidental race conditions
  - advisory locking (processes need to cooperate)
  - not mandatory, therefore not secure
- Often, files are used for locking
  - portable (files can be created nearly everywhere)
  - “stuck” locks can be easily removed
- Simple method
  - create file using the `O_EXCL` flag

```
struct flock lock;

// Open or create a file
fd = open("example.txt",
          O_RDWR | O_CREAT,
          0666);

// Prepare lock structure
lock.l_type = F_WRLCK;  // Write lock
lock.l_whence = SEEK_SET;
lock.l_start = 0;
lock.l_len = 0;  // Lock entire file

// Try to acquire the lock
if (fcntl(fd, F_SETLK, &lock) == -1) {
  // error
}

// Do some operations

// Unlock the file
lock.l_type = F_UNLCK;
```

Shell

- Shell
  - one of the core Unix application
  - both a command language and programming language
  - provides an interface to the Unix operating system
  - rich features such as control-flow primitives, parameter passing, variables, and string substitution
  - communication between shell and spawned programs via redirection and pipes
  - different flavors
    - **bash** and **sh**, **tcsh** and **csh**, **ksh**, **zsh**

Shell Attacks

- Environment Variables
  - **$HOME** and **$PATH** can modify behavior of programs that operate with relative path names
  - **$IFS** – internal field separator
    - used to parse tokens
    - usually set to [**\t\n**] but can be changed to **"/"**
    - **"/bin/ls"** is parsed as **"bin ls"** calling bin locally
    - IFS now only used to split expanded variables
  - preserve attack (**/usr/lib/preserve** is **SUID**)
    - called **"/bin/mail"** when **vi** crashes to preserve file
    - change **IFS**, create **bin** as link to **/bin/sh**, **kill vi**

Used to be super common but IFS has been removed since actual use is rare

```
$ IFS=';' ./vulnerable_script.sh
Enter a filename:
/tmp/secret_file; ls /
```

```
IFS=$'\n'
ln -s /bin/sh
      /usr/lib/preserve/bin
vi /usr/lib/preserve/some_file
```

Shell Attacks

- Control and escape characters
  - can be injected into command string
  - modify or extend shell behavior
  - user input used for shell commands has to be rigorously sanitized
  - easy to make mistakes
  - classic examples are `';'` and `'&'`

```
find /some_path -name "filename.txt; ls /"
```

- Applications that are invoked via shell can be targets as well
  - increased vulnerability surface
- Restricted shell
  - invoked with `-r` or `rbash`
  - more controlled environment

Shell Attacks

- `system(char *cmd)`
  - function called by programs to execute other commands
  - invokes shell
  - executes string argument by calling `/bin/sh -c string`
  - makes binary program vulnerable to shell attacks
  - especially when user input is utilized

- `popen(char *cmd, char *type)`
  - forks a process, opens a pipe and invokes shell for cmd

File Descriptor Attacks

- SUID program (everyone uses, `root` permissions) opens file
- forks external process
  - sometimes under user control
- **`on-execute`** flag
  - if **`close-on-exec`** flag is not set, then new process inherits file descriptor
  - malicious attacker might exploit such weakness
- Linux Perl 5.6.0
  - **`getpwuid()`** leaves **`/etc/shadow`** opened (June 2002)
  - could attack this with Apache or `mod_perl`
  - web browsers and flash

Resource Limits

- File system limits
  - quotas
  - restrict storage blocks and number of inodes
  - hard limit
    - can never be exceeded (operation fails)
  - soft limit
    - can be exceeded temporarily
  - can be defined per mount-point
  - defend against resource exhaustion (denial of service)

```
#!/bin/bash

# Limit CPU time to 10 seconds
ulimit -t 10
# Limit virtual memory to 100 MB
ulimit -v 100000

# Infinite loop consumes CPU and memory
while true; do
    :
done
```

- Process resource limits
  - number of child processes, open file descriptors

Signals

Signal

- asynchronous notification; simple form of interrupt
- can happen anywhere for process in user space
- used to deliver segmentation faults, reload commands, …
- kill command

Signal handling

- process can install signal handlers
- when no handler is present, default behavior is used
  - ignore or kill process
- possible to catch all signals except SIGKILL (-9)

```bash
#!/bin/bash

# Start the vulnerable script in the background
./vulnerable_script.sh &

# Obtain the PID of the vulnerable script
pid=$!

# Wait for a few seconds to ensure the
vulnerable script is running
sleep 2

# Send a SIGINT signal to the vulnerable script
echo "Sending SIGINT signal to PID $pid..."
kill -2 $pid
```

Signals

- Security issues
  - code has to be re-entrant (code running, signal jump, then come back)
    - atomic modifications
    - no global data structures
  - race conditions
  - unsafe library calls, system calls
  - examples
    - wu-ftpd 2001, sendmail 2001 + 2006, stunnel 2003, ssh 2006
- Secure signals
  - write handler as simple as possible
  - block signals in handler

Shared Libraries

- Library
  - collection of object files
  - included into (linked) program as needed
  - code reuse

- Shared library
  - multiple processes share a single library copy
  - save disk space (program size is reduced)
  - save memory space (only a single copy in memory)
  - used by virtually all Unix applications (at least libc.so)
  - check binaries with **`ldd`**

Shared Libraries

- Static shared library
  - address binding at link-time
  - not very flexible when library changes
  - code is fast
- Dynamic shared library
  - address binding at load-time
  - uses procedure linkage table (PLT) and global offset table (GOT) to hold references to code
  - code is slower (redirection)
  - loading is slow (binding has to be done at run-time)
  - classic .so or .dll libraries
- PLT and GOT entries are very popular attack targets
  - buffer overflows

https://www.technovelty.org/linux/plt-and-got-the-key-to-code-sharing-and-dynamic-libraries.html

Shared Libraries

- Management
  - stored in special directories (listed in `/etc/ld.so.conf`)
  - manage cache with `ldconfig`

- Preload
  - override (substitute) with other version
  - use `/etc/ld.so.preload`
  - can also use environment variables for override
  - possible security hazard
  - now disabled for SUID programs (old Solaris vulnerability)

Advanced Security Features

- Address space protection
  - address space layout randomization (ASLR)
  - non-executable stack (based on NX bit or PAX patches)
- Mandatory access control extensions
  - SELinux/AppArmor
  - role-based access control extensions
  - capability support
- Miscellaneous improvements
  - hardened chroot jails
  - better auditing
- https://wiki.ubuntu.com/Security/Features

Security Zen - You Knew It Was Bound to Happen…

FORBES > INNOVATION > CYBERSECURITY

Google Update Reveals AI Will Read All Your Private Messages

Zak Doffman Contributor

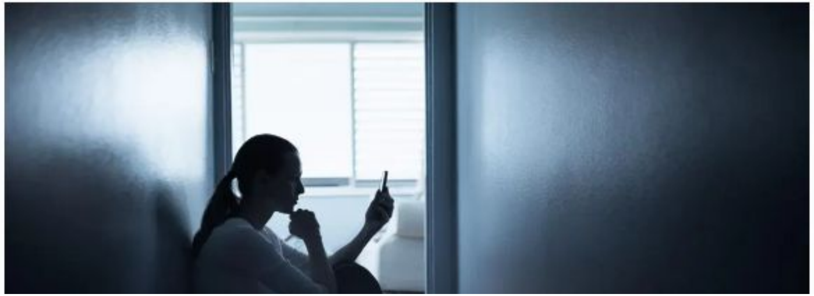
I cover security and surveillance

Follow

12

Jan 28, 2024, 09:26pm EST

Google has just unveiled a game-changing AI upgrade for Android. But it has a darker side. Google's AI will read and analyze your private messages, going back forever. So what does this mean for you, how do you maintain privacy, and when does it begin.



Source: [Google Update Reveals AI Will Read All Your Private Messages]