Why should you learn about the filesystem in 2026?

Gergely Kalman
OFTW, 2026

whoami

- my name is **Gergely** (**call me Greg**)
  - twitter: **@gergely_kalman**
  - I do bug bounties
  - full time in the **Apple Security Bounty** (**ASB**) program

My assumptions

- you are either a **student**
- or looking for a **career change**

Why should you listen

- Because I started bug bounties **4 years ago**
  - as a **burned-out programmer**
- managed to find a few **0days**
- was enough to **live comfortably**

You might have heard these

“Build your career”

“Climb the corporate ladder”

“Firm handshakes”

“Other boomer sh*t”

None of that works

- getting a job is **insanely difficult**
- especially:
  - getting a **good** one
  - if you have little to no **experience**
- to make matters worse...

The state of the industry

- the industry is going through a **“transformation”**
- **Nobody knows what will happen**
- but it doesn’t look great
  - We’re clearly in a bubble
  - AI might take our jobs
- feels like when fuzzing became mainstream

It’s a scary time

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What can you do?

- learn **objectively valuable** skills (research what these are)
- **demonstrate the skills** you already have (publish code, past research)
- **research opportunities** (what is valuable and **why**)
- **talk to people in your field** (they can become mentors or future coworkers)

A concrete example

- **hacking** was my choice of **objectively valuable skill**
  - might as well do something that I always wanted to...
- I researched this career
- I read a lot
- I practiced
- I eventually found Apple’s bug bounty program
- Let me explain bug bounties quickly...

Bugs and vulnerabilities

- all software has **bugs**
- some bugs are **vulnerabilities** (security bugs)
- **bug → vulnerability** if it's **exploitable**

Vulnerabilities are exploitable bugs

What are 0days?

- **0days** are vulnerabilities that are **not public**
  - unknown to the vendor and users
  - unpatched (obviously)
- Good ones are **rare** and **powerful** → **valuable** and **interesting**
- Finding them is **impressive:**
  - **You have something nobody else has**

Basically

bugs

vulnerabilities

0-days

Each 0day is unique

serious bug in niche software

useless bug in popular software

VS

serious bug in popular software

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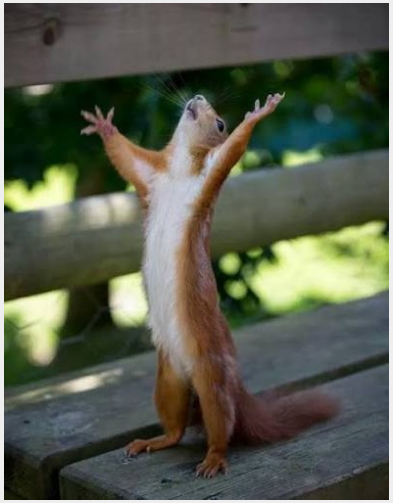
You mean they pay money?

Bug bounties

YES!

this is what a bug bounty is



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Unsolicited career advice

- **Let me suggest that you try bug bounties**
- Specifically the **ASB** (Apple Security Bounty)
  - everyone knows **Apple**
  - they **pay well***
  - program scope is **huge**

*: except when they unilaterally decide to nerf full TCC bypasses by ~84%

Being a bug hunter is cool

- **Be your own boss: pick when/how/what to attack**
- collect **bounties** and **CVEs**
- improve the life of **millions** if not **billions of people**
  - **macOS** is used by **~100 million people** (~1.2% of the world)
  - **iOS** is used by **1 billion people** (12% of the world)
- go to conferences (travel the world)

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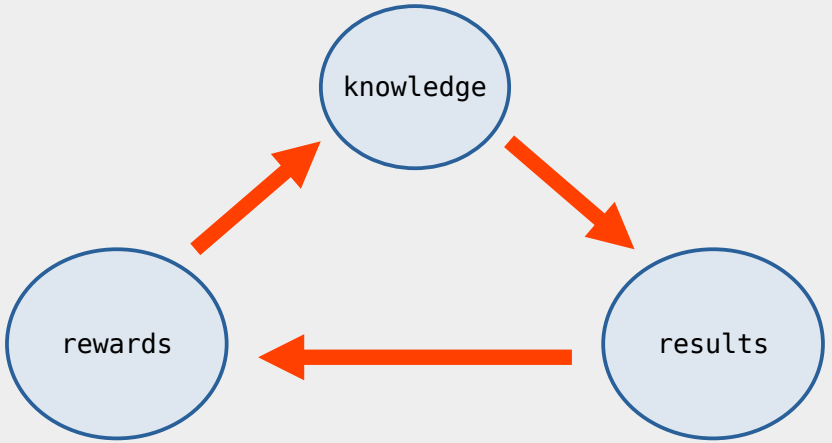
Not a sponsored talk

- **Apple did NOT pay me for this BTW**
- I’m telling you, because:
  - this **worked for me**
  - **people ask me about** it all the time
- IMO bug bounties are genuinely useful
  - it’s a 0-risk way to **improve your skills** and **profile**
  - **it’s a ton of fun**
  - **no job interview** or permission is required

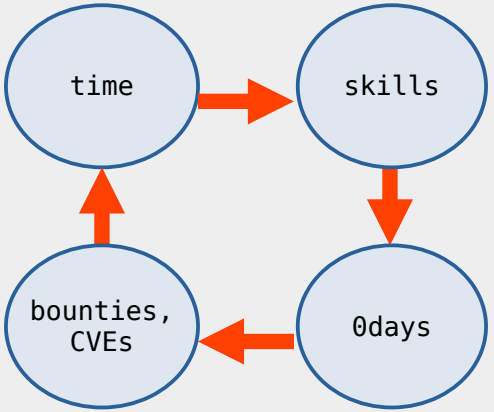
Universal game loop of a career

**Extremely simplified (and wrong),
but bear with me**



Translated to bug bounties

- more time spent → better skills
- better skills → more bugs
- more bugs found → more bounties and reputation
- more bounties and CVEs → more time you can/want to spend



Pitfalls

- time spent but no skills → **you're doing mindless work / relying on LLMs**
- skills but no 0days → **unlucky / underskilled / bad target selection**
- 0days but no bounties/CVEs → **report was bad / program is bad**
- bounties/CVEs but no time spent → **you are burned out / demotivated**

Let’s find 0days!

- my focus
  - **logic bugs**
  - **filesystem / file operation** bugs
- because files / file ops are:
  - **everywhere**
  - **hard to mitigate**
  - **fundamentally hard to get right**

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Recommendations for beginners

- also: this is **beginner-friendly**
  - patterns are easy to spot
  - attack paths are well mapped-out
- **Beginner**: Start with **soft targets** and **well-known attacks**
- **Advanced**: Graduate to more **hardened targets**
- **Expert**: Find **novel attack vectors / new bug classes**

How hard are file operations?

- well...

File ops are shockingly hard

no copy() syscall

“Everything is a file”

legacy filesystems

symlinks are hard to prevent

in-band signaling in file operations

. and .. are special

network filesystems

race conditions everywhere

POSIX permissions are incredibly complex

mountpoints can move

CWD is unintuitive

File ops are shockingly hard

no copy() syscall

case-insensitivity

reliance on extended attributes

“Everything is a file”

legacy filesystems

user sets fs options

user mounting

/.file, /.vol/

symlinks are hard to prevent

in-band signaling in file operations

firmlinks

sandbox_exec

union mounts

. and .. are special

user can change mount options at runtime

network filesystems

noowners

race conditions everywhere

applesingle/appledouble

in-band signaling: /..namedfork/rsrc

POSIX permissions are incredibly complex

(force) unmount

hardlinked directories

mountpoints can move

CWD is unintuitive

File ops are shockingly hard

- file operations are racy
- Access Control is complex
- path resolution is unintuitive
- users can mount (alter the FS graph)
- advanced protections are basically regex based
- attackers can deploy a ton of tricks

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Mitigation is impossible

- **you can’t:**
  - **break the API**
  - **rewrite everything**
  - **break with POSIX’s 40 year old traditions**
- **best you can do is to silo privileged programs**
  - not always feasible (/tmp/ files, shared files, etc…)
- more on this later...

Meeting the prerequisite

- we need at least **one controllable path segment**
  - **/Users/student/hello/legitimate.txt**
- this is enough because **parents can control the descendants**
  - write access, symlinks, mounts, inheriting permissions

Meeting the prerequisite

Example: **root** daemon writes to **/Users/student/hello/legitimate.txt**

→ **/Users/student/../../../../../../etc/sudoers.d/legitimate.txt**

→ **root write to /etc/sudoers.d/legitimate.txt**

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Meeting the prerequisite

- on **macOS** this is often a given
  - particularly with **entitled** apps
- most of the protections are not by-design
- circumvention is easy

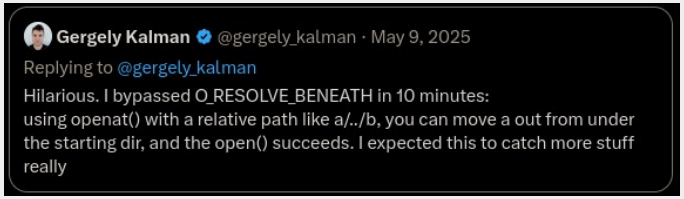
Apple’s mitigations

- Apple introduced **Launch Constraints**
  - You **can no longer directly execute most apps**
    - not really a protection against file operation issues...
- Apple reduced **TCC bypass** payouts by **83.6% (!)** last December
  - this upset **everyone**
    - hardly a mitigation as bad guys don’t care…
- You might have seen these guys:

```
O_NOFOLLOW_ANY                  ----------   1 root  admin     0 Jul 22 23:57 .file
O_RESOLVE_BENEATH               drwxr-xr-x   2 root  wheel    64 Jul 22 23:57 .nofollow
RENAME_NOFOLLOW_ANY             drwxr-xr-x   2 root  wheel    64 Jul 22 23:57 .resolve
```

Apple’s mitigations

- sure, there’s **O_RESOLVE_BENEATH**
  - **which I bypassed in this tweet:**



- and **O_NOFOLLOW_ANY** being put everywhere
  - which only works if you can break **POSIX** compatibility
    - 0% chance of this being merged upstream in portable codebases

Retrofitting security

- we know **retrofitting security is a bad idea**
- but this is what **Apple** is doing (and **AppArmor** and **SELinux**)
- **a commendable effort**
  - but extremely difficult to accomplish
  - mostly a clunky patchwork with slow gradual improvement
- **still better than doing nothing**

my targets in 2026

- ~~**macOS TCC bypass**~~
- **macOS LPE** (user → root)
- **macOS SIP bypass** (root to SIP-exempt root)
- **macOS App SBX** (sandboxed code exec to unsandboxed)
- **iOS: anything** (I can find)

Attack example: LPE

- the classic **POSIX** LPE
- **GOAL:** take control over an important file
  - /etc/sudoers, /etc/sudoers.d/*
  - /etc/cups/*
  - many others...
- **targets**: processes running as **root**
- **examples**: hijacked **chmod()** / **rename()** / **chown()** / **open()**
- there are many things to attack with this...

Attack example: SIP bypass

- bug in an Apple-signed installer package's scripts
- requires **root** access
- **GOAL:** control a process that is a descendant of **system_installd**
- **targets**: scripts in Apple-signed installers
- **examples**: script command injection, execution of a program you control, hijacking privileged file operations
  - make these do something useful

Attack example: App SBX

- Application Sandbox Escape
- **GOAL:** have a directory created without the quarantine flag
- **targets**: **XPC** endpoints reachable from the sandbox
- **examples**: **XPC** endpoint with an arbitrary dir create bug
- a simple dir **whatever.app** dir create is enough to break out
  - https://gergelykalman.com/CVE-2023-32364-a-macOS-sandbox-escape-by-mounting.html

Attack example: iOS

- **I’m out of depth here...**
  - but made partial progress
- **Grateful for any hints**
  - Suppose I have an arbitrary file write as root…
    - talk to me...

Attack surfaces in 2026

- lots of low-hanging fruit is gone
  - but **not nearly all**
- **XPC** (IPC) is still incredibly promising
- **LLM**s are actually decent at reading code
  - credit where credit’s due

Where to go from here?

- lots of good blogs
- lots of good talks
- I published a **lot about this**
- but it’s never enough...

Happy Hunting!

Thank you