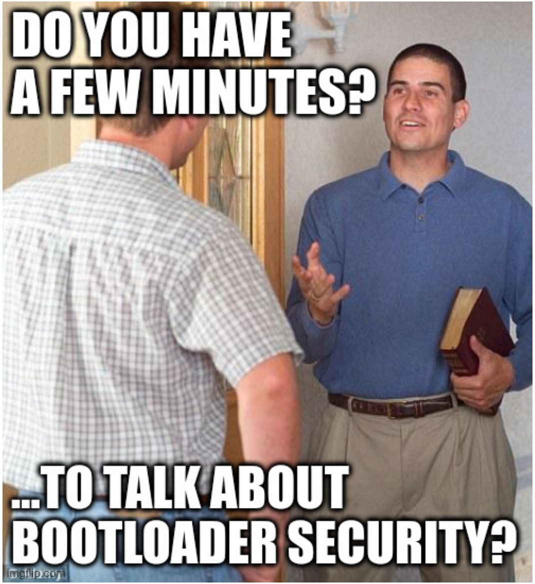
From Boot to Root

Richard Weinberger - sigma star gmbh

2024-11-11


DO YOU HAVE A FEW MINUTES?
...TO TALK ABOUT BOOTLOADER SECURITY?
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Richard Weinberger

- Co-founder of sigma star gmbh
- Linux kernel developer and maintainer
- Strong focus on Linux kernel, lowlevel components, virtualization, security, code audits

sigma star gmbh

- Software Development & Security Consulting
- Main areas: Embedded Systems, Linux Kernel & Security
- Contributions to Linux Kernel and other OSS projects

Bootloader 101

- Started by boot ROM (BIOS/UEFI on x86)
- On embedded systems, boot ROM is part of the SoC
- Bootloader loads operating system (the kernel)
- ±fancy UI and configuration

Get root On a Typical Linux System

- Edit bootloader config
- Add `init=/bin/sh` to kernel command line
- Solution: Lockdown bootloader (plus config!)

Bootloader Lockdown

- No way to change boot config
- No shell
- Input only from trusted sources or fully authenticated input
- Sounds easier than it is

Chain of Trust

- Boot ROM authenticates bootloader signature
- Bootloader authenticates OS kernel signagure
- OS kernel authenticates userspace
- Common on security focused systems (UEFI Secure Boot, etc.)
- Hello CRA (Cyber Resilience Act), hello NIS-2 (Network and Information Security)

The Weakest Link: The Bootloader

- Break the bootloader and control the rest of the system:
  - Start our own code
  - Extract secrets (key material)
  - Impersonate the device
  - Basically become root

U-Boot and Barebox

- Extremely common bootloaders for embdded Linux
- Load and authenticate files from a filesystem
- I started auditing their critical code paths

Critical Code Paths

- Config file parsing (AKA boot environment)
- Parsing other state, e.g. boot counter on EEPROM
- Loading boot files, kernel, device tree, ...
- Most inputs are authenticated
- The elephant in the room: filesystems

Filesystems at Boot Stage

- Data *on* the filesystems is authenticated
- The filesystem itself is *not*
- Filesystems drivers in bootloades:
  - Good enough to read a file
  - Not more
- Filesystems can get manipulated by an attacker

Vulnerability #1

- Integer overflow in ext4 symlink code
- Results in attacker driven out of bounds write
- Unauthenticated attacker can trigger it
- Both U-Boot and Barebox affected

```
static char *ext4fs_read_symlink(struct  ↲
    ext2fs_node *node)
{
...
   symlink = zalloc(le32_to_cpu(diro->inode  ↲
       .size) + 1);
   if (!symlink)
      return NULL;
...
}
```

Vulnerability #2

- Integer overflow in squashfs symlink code, like vulnerability #1.
- Results in attacker driven out of bounds write
- Unauthenticated attacker can trigger it
- Both U-Boot and Barebox affected
- Although they have different squashfs implementations

Vulnerability #3

- Stack overflow in squashfs symlink code
- Code follows symlinks recursively
- Results in attacker driven stack smashing
- Unauthenticated attacker can trigger it
- Only U-Boot affected

```
int sqfs_size(const char *filename, loff_t  ↲
     *size)
{
...
   switch (get_unaligned_le16(&base->  ↲
        inode_type)) {
...
   case SQFS_LSYMLINK_TYPE:
   symlink = (struct squashfs_symlink_inode  ↲
         *)ipos;
   resolved = sqfs_resolve_symlink(symlink,  ↲
         filename);
   ret = sqfs_size(resolved, size);
   free(resolved);

   break;
...
}
```

Vulnerability #4

- Multiple integer overflows in memory allocator
- You ask for N bytes but get much less
- Can get triggered by most filesystem drivers
- Unauthenticated attacker can trigger it
- Both U-Boot and Barebox affected
- They use Doug Lea’s Malloc, but broke it 25 years ago
- Bonus: Another integer overflow in their `sbrk()`
- Bonus #2: `ptrdiff_t` too small on x86_64, more overflows

```
#define request2size(req) \
 (((long)((req) + (SIZE_SZ +  ↲
      MALLOC_ALIGN_MASK)) < \
  (long)(MINSIZE + MALLOC_ALIGN_MASK)) ?  ↲
      MINSIZE : \
   (((req) + (SIZE_SZ + MALLOC_ALIGN_MASK))  ↲
        & ~(MALLOC_ALIGN_MASK)))

Void_t* mALLOc_impl(size_t bytes)
{
...
  if ((long)bytes < 0) return NULL;

  nb = request2size(bytes);  /* padded  ↲
      request size; */
...
}
```

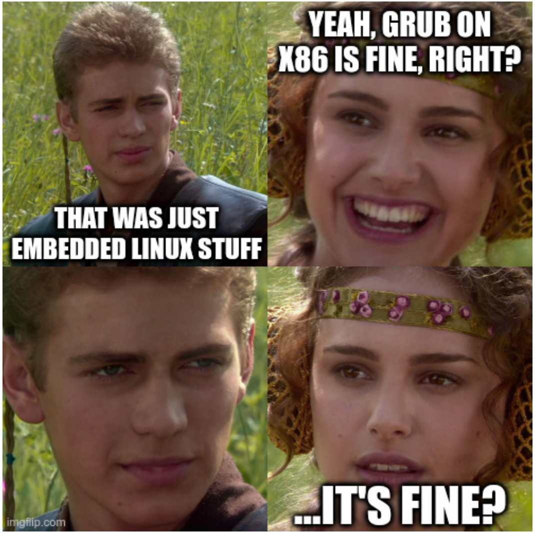
Outcome

- At least four beefy vulnerabilities that allow full compromise
- Sent bug reports and patches for all vulnerabilities, all merged
- Improved (fixed) U-Boot's ASAN integration

Just Update the Damn Bootloader?!

- Think of downgrade attacks!
- Attacker can always install the old vulnerable bootloader
- Mitigations:
  - Have a revoke list (hard!)
  - Have an authenticated version counter in hardware

What About Non-Embedded?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- CVE-2024-2312

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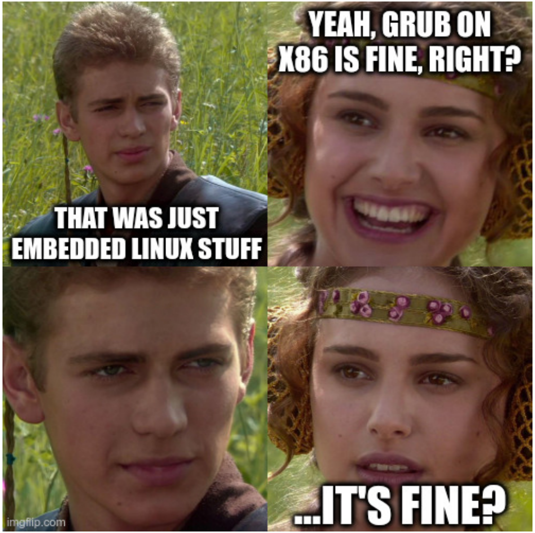
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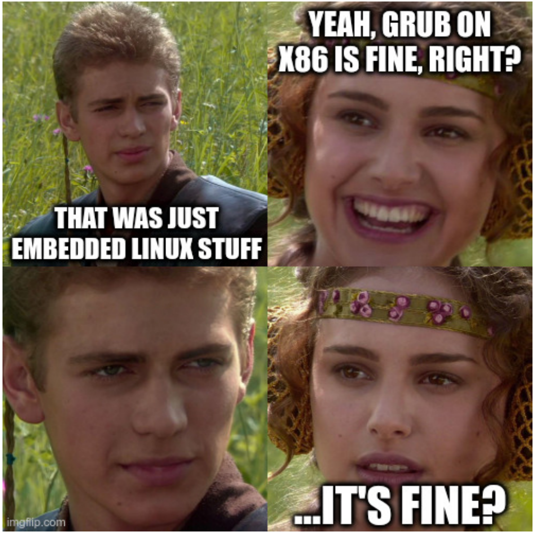
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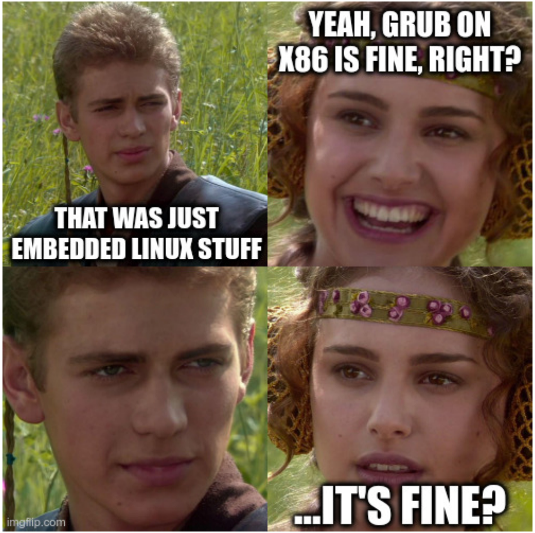
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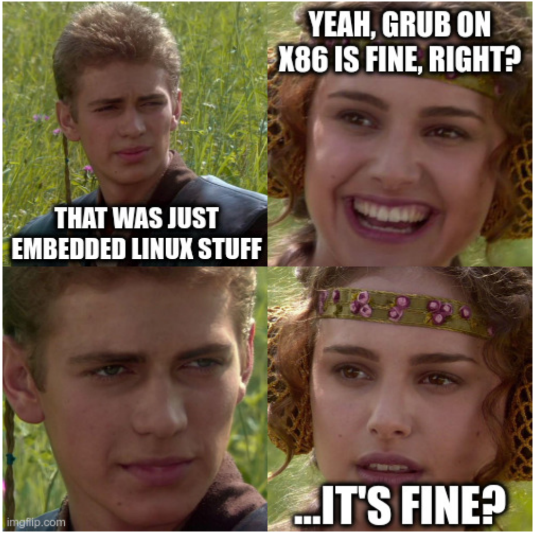
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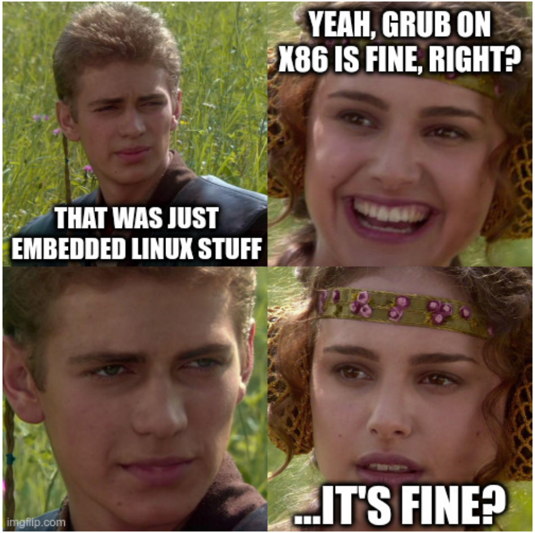
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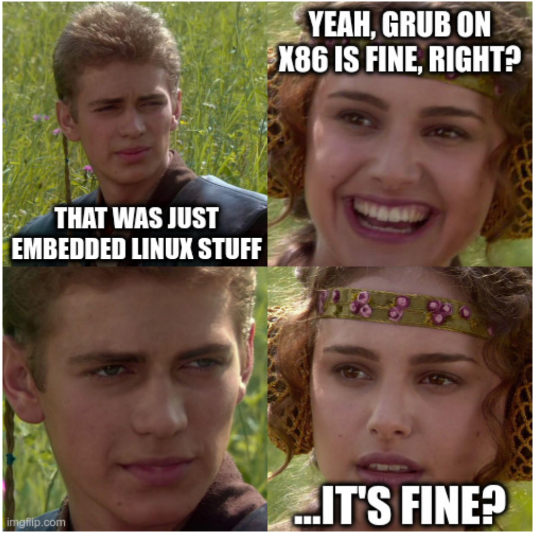
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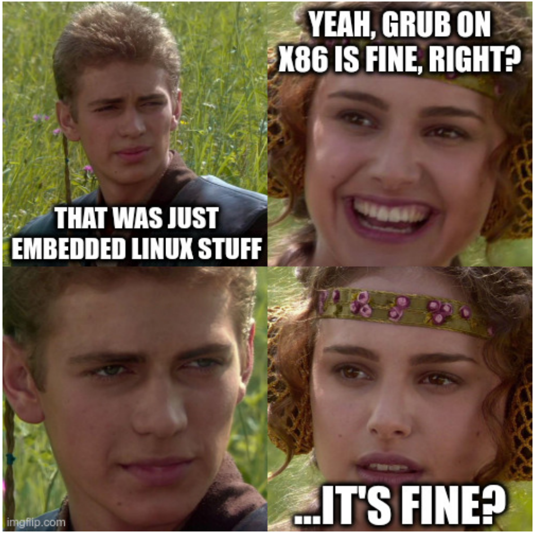
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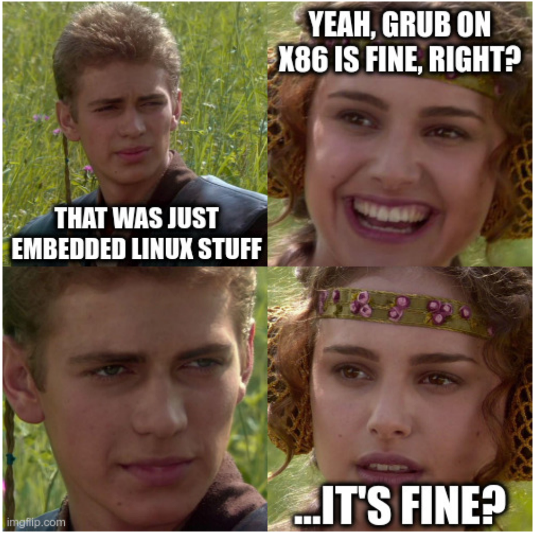
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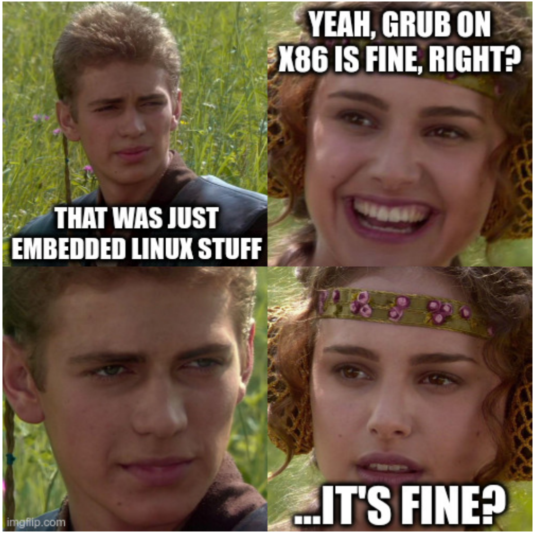
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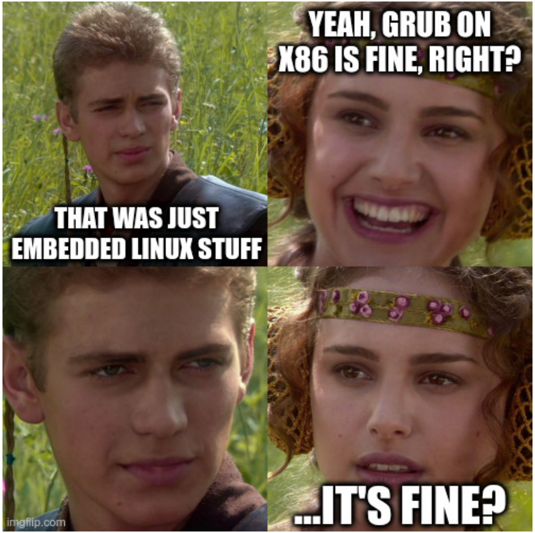
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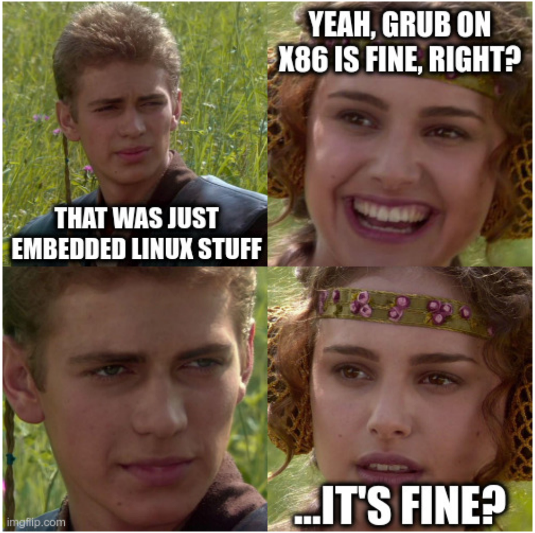
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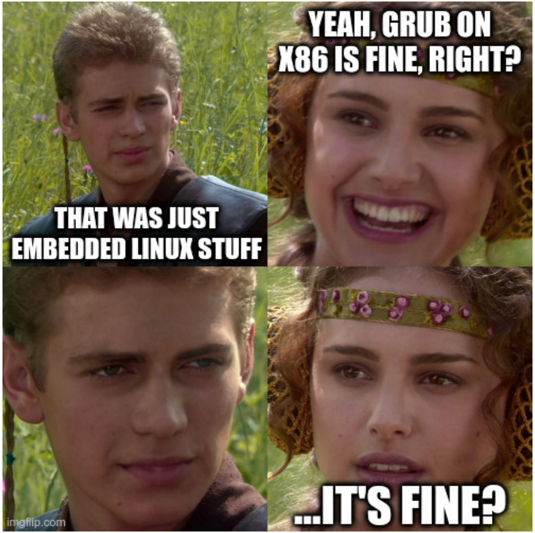
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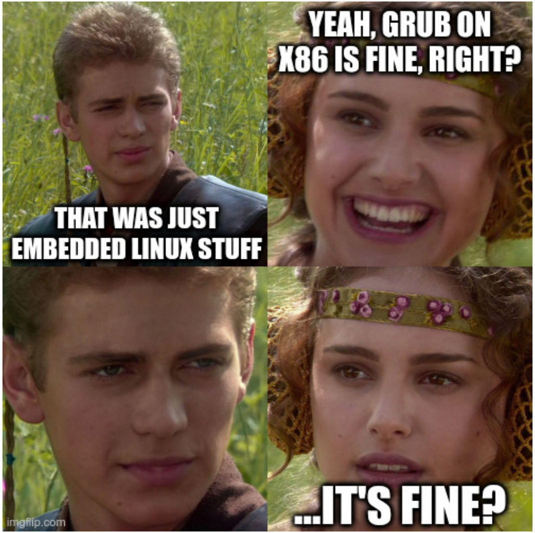
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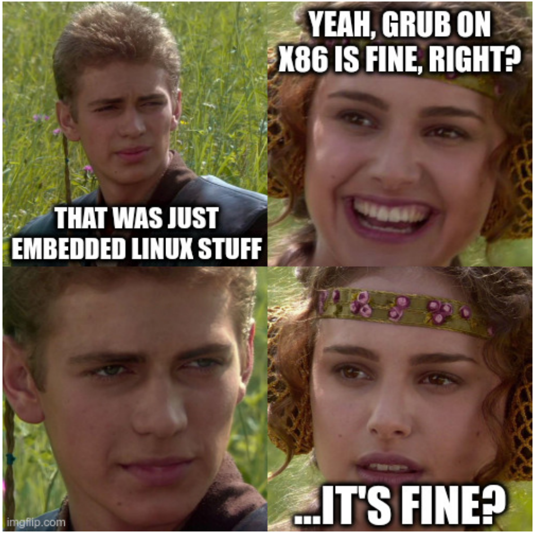
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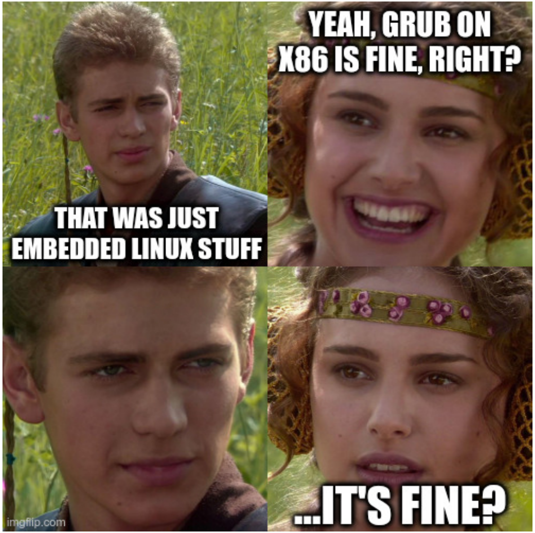
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Discussion: How to Improve the Situation?

- Reusing Linux implementations is hard
  - Needs a Linux VFS
  - Offer more than needed
  - Code size matters
- Toy implementations are always broken
- kexec is problematic on embedded systems
- Idea: Provide sane libfs{ext4, squashfs, ...} for bare metal
  - How to sync with Linux?
  - Funding?
  - What license?

FIN

Thank you!

Questions, Comments?

Richard Weinberger
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