ECE 471 – Embedded Systems
Lecture 25

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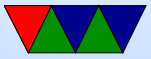
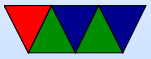
Announcements

- Don't forget HW#8
- Project ideas due Friday: even if you've told me about it, send an e-mail if you haven't yet (note this is worth points on your project grade)
- Midterms finally graded, will hand back Friday



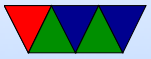
Quick Rundown of Project Topic Possibilities

- There's a list of possible projects and a link to past projects toward the end of the assignment pdf
- There's also a list of parts. Lots of sensors, displays, and other things available
- If you do want to borrow parts, give me a bit of warning as sometimes can take a bit to find it and make sure it's in working condition



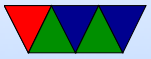
Trusted Firmware

- Firmware can be dangerous: runs below/outside of the Operating System, doesn't matter how secure your OS is if firmware compromised
- Can you trust your firmware to be not-evil?
- Evil Maid problem – what if someone breaks into your hotel room and replaces your firmware – could you tell?



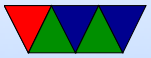
Firmware Danger Examples

- What if firmware reprogrammed on USB key to be evil?
- What if firmware on USB keyboard is evil? How would you know?
- What if hard-drive firmware reprogrammed
- Do you audit the firmware on your system?



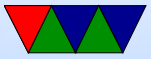
What could evil firmware do?

- USB keyboard, log keypresses, send key commands at 2am to open web browser and cut-and-paste data to evil website
- Disk could refuse to write certain values, or maybe just notice writing a spreadsheet and randomize numbers, etc
- USB key could look like 4GB storage but then later change its ID to a network card and send data
- USB chargers at airports / wall. Can you trust plugging into them?



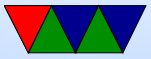
What can we do?

- Epoxy shut USB ports on computers?
- Some secure sites actually do that
- It's a real threat, viruses have spread over USB
  Sneaky people can drop USB keys in parking lots in hopes they'll be plugged in to see who owns it



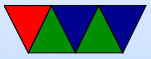
Can we solve this in Software?

- Instead of epoxying shut USB, just have OS ignore any USB ports?
- In theory you could do that. Which is cheaper/harder epoxying USB or else writing your own kernel (or convincing Microsoft) to disable USB?
- If OS is ignoring USB, are you safe?
- (Ignoring the possibility of a USB device with super-capacitors on board to explode your system)

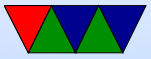


I/O Bus Access to System Internals

- Past DMA attacks with Firewire which could bypass OS and read/write memory
- What if hardware vendor for whatever reason talks to the USB device even though OS hasn't asked it to? It probably shouldn't, but how can you audit that? What about the firmware on the USB controller itself?
- The USB controller hooks up to a main CPU bus somehow, maybe over PCIe, maybe directly to CPU. It can potentially do lots of sneaky things.

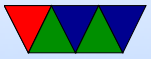


- Why would there even be a controller for USB? Well when you plug in has to negotiate power, speed, and other stuff too. Probably a microcontroller

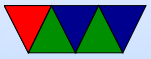


Firmware Paranoia

- It all depends how paranoid you want to be
- Even things like sandboxes and if you have all the code, can you *prove* the code is correct? That the compiler is trustworthy? This is actually a field of study, trying to prove code is correct. It's not trivial.
- Doesn't matter how good your software is if SW/HW compromised
- Can you analyze all 10 billion transistors in modern CPU?
- USB keyboard needs to work, even w/o OS

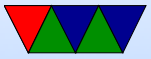


- Generally if someone has unrestricted physical access to your computer all bets are off



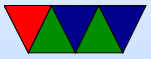
Signed Firmware

- Best you can do is trust it to be the same firmware released by your vendor (you still have to trust them)
- Use cryptographic signing. Hardware will only run code "signed" by a trusted entity.
- A signed firmware can run a signed bootloader which can run a signed operating system which can run signed apps



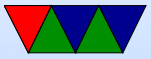
Reasons for Signed Firmware in Embedded Systems

- Cars – rules about emissions. Should people be allowed to hack system for better speed but more pollution?
- Wifi – can you change firmware to give you more wifi power and longer range but it interferes with other people's speeds?



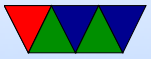
Signed Firmware Tradeoffs

- Downside: no longer general purpose, average person cannot run code they wrote unless they can get it signed
- Code still has to be well written. "jailbreaks" on phones and video game consoles are due to trusted code having bugs and then jumping into unsigned code.
- Walled gardens, restricted App stores (see Apple / EPIC lawsuit)
- Maybe makes sense if the firmware in your microwave locked down, but also might mean no one can ever fix it



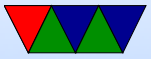
Will running Linux or homebrew software still be possible?

- Will you still be able to run Linux?
- Trust Microsoft to keep signing bootloader for us?

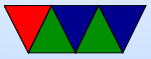


Signed Firmware on "General Purpose" Computers

- Hardware manufacturer has keys that only allow booting trusted signed boot firmware (UEFI)
  - Signed UEFI only allows booting trusted signed bootloader
  - Signed bootloader only allows booting trusted signed operating system
  - Signed operating system only allows signed device drivers

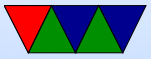


- Signed operating system only allows running signed apps



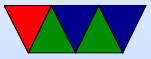
Already here in a lot of ways

- Get warnings if MacOS apps compiled/released by someone without a signature
- Windows 12 requiring hardware with TPM hardware
- Some smartphones and game systems have been here a while
- Linux on trusted hardware, Microsoft owns the keys and for now will sign a bootloader that will run Linux. Do we trust them?
- Efforts to ban “side-loading” software



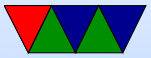
Right to Repair Laws

- People concerned that car repair and cell phone repair becoming impossible as the companies lock things down with microcontrollers so you can only use officially approved parts
- Actually tractors and farm equipment big deal too
- Maine Ballot initiative on this November 2023



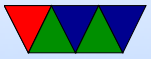
Firmware on Desktop/Laptop Systems

- What is the Pi GPU doing?
- What about the T2 processor on macs?
- New for ARMv8: ARM Trusted Firmware (ATF). Two standards, vendors have possibly made a mess of it already.
- Other platforms have it too. DRM to keep you from copying movies or video games.
- Windows 11 requiring TPM2 module



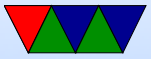
Firmware Hacking

- How can you figure out what the firmware is doing?
- Reverse engineering
- Looking for Security Issues
- Bypassing security measures

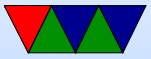


Firmware Weaknesses

- Encryption, but key has to live somewhere
  - If it's in ROM or RAM, can be dumped unless careful
  - Also might travel bus in open (original Xbox)
  - Decapping, people dissolve tops off chips and look at with microscope to see contents
- Glitching
  - If give improper power (too little/too much), temperature (too cold/too hot), noise/sparks, etc, can cause code to jump to places it shouldn't

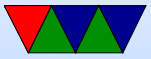


- Poor user code
  - Save game bugs popular cause of jailbreaks on consoles
  - Console code can be super tight but if you sign a game from a customer and it has a bug, all might be lost



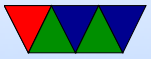
Firmware Countermeasure

- Encrypting everything (ROM, busses)
- Chips that self-destruct if opened
- Extra logic gates (work by profs here at UMaine)



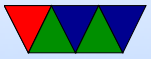
Embedded System Countermeasures

- Many embedded boards, like STM32, you can "blow the fuses" after programming so that you can't read out or re-flash ROM
- Recent news: locked down STM32 boards, but when debugger hooked up still shows address of interrupts. What if move interrupt table into protected code and trigger interrupt? Code appears as interrupt address?



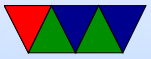
Why Lock Down Hardware

- Companies say it's for safety, security. Are there other reasons?
  - Profit. Can they lock you into one phone vendor? Lock you into one app store?
  - Secrecy. Don't want secrets of how their code works getting out.
  - "Piracy". Companies super worried you'll save video / music / games and then copy to your friends without paying for them. Digital Rights Management (DRM)



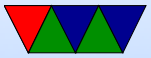
C string review

- String manipulation is famously horrible in C.
- There are many ways to get the "YES" and "t=24125" values out of the text file for HW#8.
- Any way you choose is fine.



C String Review

- This is tricky to get right
- It's relevant to Computer Security, the next topic we will cover

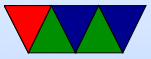


What is a C string? – essentially a hack

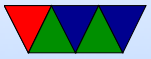
- A NUL (zero) (note: not NULL) terminated array
H	e	l	l	o	\0
- Note this is really:

0x48	0x65	0x6c	0x6c	0x6f	0x00
- Note in C, arrays are essentially just pointers
- Can statically declare: (compiler puts the 0 on end for you)

```
char string1[6]="Hello";
char string1[]="Hello";  // autosize
```

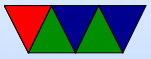


```
char *string2="Hello";
```



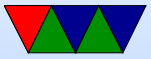
C String Review

- Many issues with array of bytes vs string, especially in other languages. Complicated if Unicode or UTF8. Windows / java and wchar (16-bit chars)
- You can use either pointer or array access to get a value (string[0] is the same as *string)
- Note that double quotes indicate a string, while single quotes indicate a single character



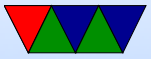
Upsides of C strings

- Fast and simple to deal with in assembly language
- Can quickly make short and cryptic functions to manipulate them
- ???



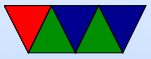
Downsides of C strings

- No way to tell the maximum size from the pointer
- Can only find out current size of string by iterating to find end
- The C library has a lot of helper functions, many of which are flawed in deep ways



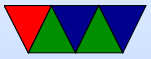
Other String Implementations

- Pascal-style strings, first byte is the length
  - Always know length, no need to strlen()
  - Maximum size (if 8-bit than max 256 chars)
- Higher level / object oriented languages (python, C++?) still have some sort of array of chars inside, but wrap it with extra info to provide safer access to things



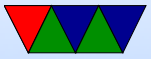
C string pitfalls – Writing off the End

- What happens when web form on your device's web interface asking "name" and you allocate 64 bytes but don't check, and someone types 4096 bytes
- What's the worst case?
- Crash your program?
- Corrupt data?
- Complete system compromise?



Can the C-library string functions save you?

- The standard strcpy(char *dst, char *src)
  - will happily go off the end if destination smaller than source
- strncpy(char *dst, char *src, int size)
  - added destination-size parameter, also pads dest with 0
  - NOTE: will leave off (!) the NUL terminator if not fit
- strlcpy(char *dst, char *src, int size)
  - always terminates destination



- if destination full, you lose a byte as it is silently truncated and last byte made NUL
- No error is indicated if this happens
- why a problem? example: say want to remove file.txt˜but got got truncated to file.txt instead?
- `https://lwn.net/Articles/507319/`

- Kernel has strscpy(char *dst, char *src, int size)
  - always returns valid string
  - returns a negative ERRNO on failure