It's assembler, Jim, *but not as we know it*!

Morgan Gangwere

DEF CON 26



Dedication

Never forget the
shoulders you stand on.

Thanks, Dad

whoami

Hoopy Frood

Been fiddling with Linux SOCs since I fiddled with an old TS-7200 EmbeddedARM board

I've used ARM for a lot of services: IRC, web hosting, etc.

I've built CyanogenMod/LineageOS, custom ARM images, etc.



A word of note

There are few concrete examples in this talk. I'm sorry.

This sort of work is

- One part science
- One part estimation
- Dash of bitter feelings towards others
- Hint of "What the *fuck* was that EE thinking?"

A lot comes from experience. I can point the way, but I cannot tell the future.

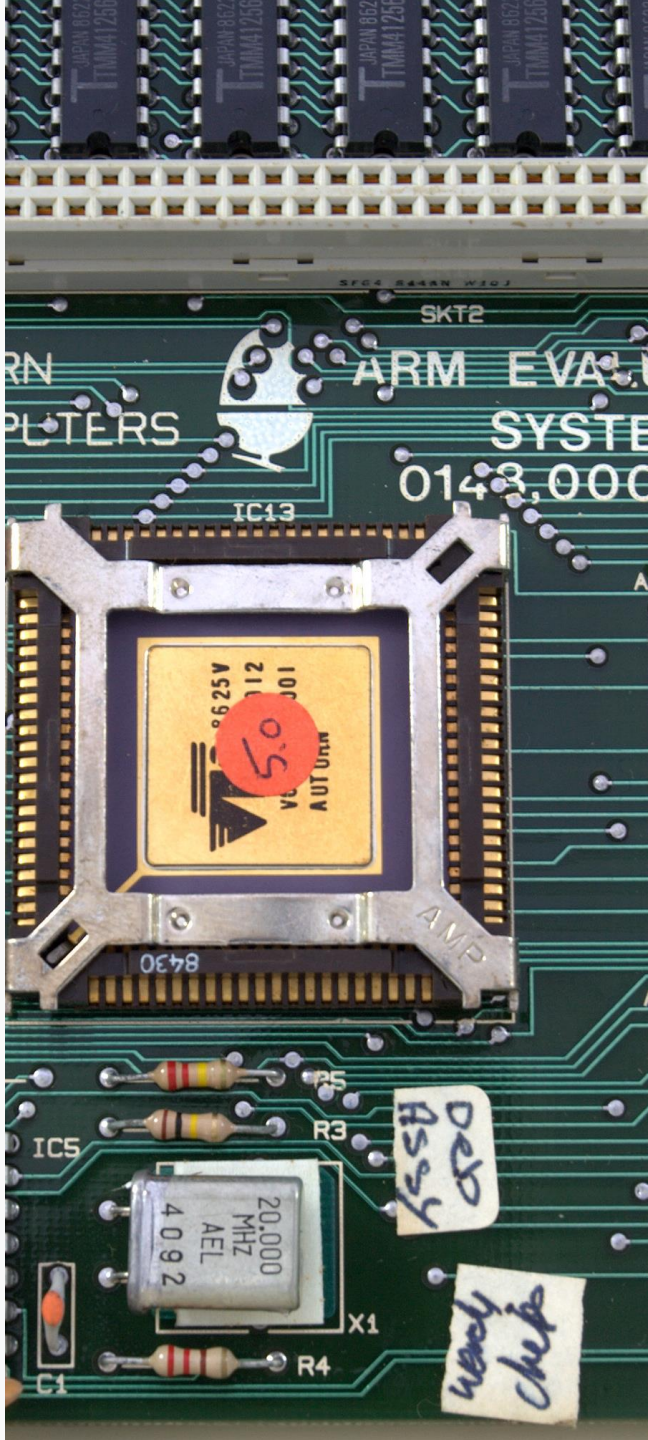
There's a lot of seemingly random things. Trust me, It'll make sense.

ARMed to the teeth

From the BBC to your home.

Short history of ARM

- Originally the Acorn RISC machine
- Built for the BBC Micro!
- Acorn changed hands and became ARM Holdings
- Acorn/ARM has never cut silicon!
- Fun fact: Intel has produced ARM-based chips (StrongARM and XSCale) and still sometimes does!
- The ISA hasn't changed *all that much.*




CenturyLink
POWER
DSL
INTERNET
ETHERNET
WIRELESS
CenturyLink
WPS
PK5001Z


Microsoft
9:50
Tuesday, 6 October


QNAP
STATUS
USB
LAN
TS-531X
POWER
COPY


Qualcomm
snapdragon
ASUS






SONY
α
7R
E-mount
SONY





Embedded Linux 101

Anatomy of an Embedded Linux device.

Fundamentally 3 parts

- Storage
- SoC/Processor
- RAM

Everything else? Bonus.

- PHYs on everything from I2C, USB to SDIO
- Cameras and Screens are via MIPI-defined protocols, CSI and DSI respectively

At one point, they all *look* mostly the same.

What is an SoC?

Several major vendors:

- Allwinner, Rockchip (China)
- Atheros, TI, Apple (US)
- Samsung (Korea)

80-100% of the peripherals and possibly storage is right there on die

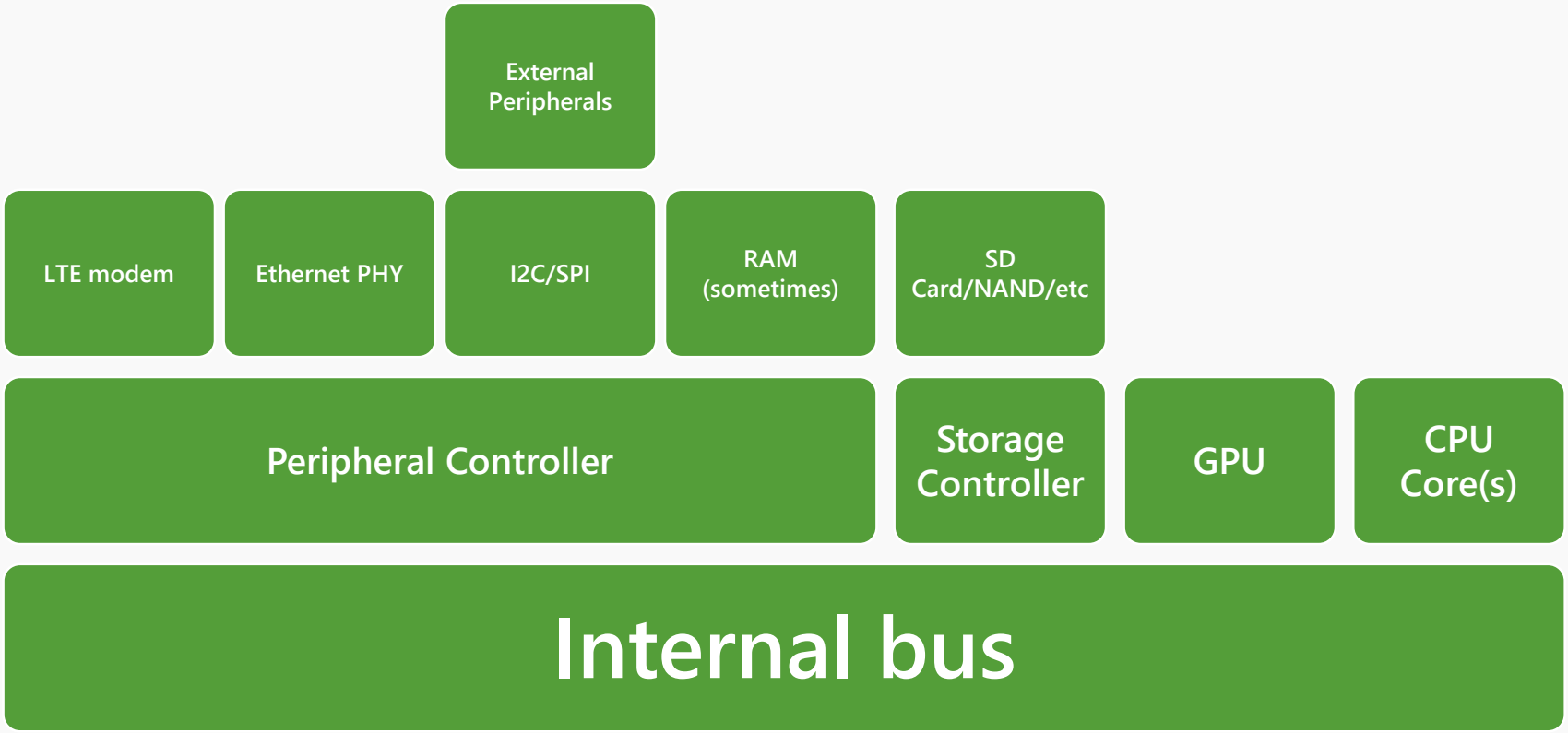
Becomes a “just add peripherals” design

- Some vendors include SoCs as a part of other devices, such as TI's line of DSPs with an ARM SoC used for video production hardware and the like.

In some devices, there may be multiple SoCs: A whole line of Cisco-owned Linux-based teleconferencing hardware has big banks of SoCs from TI doing video processing on the fly alongside a DSP.



What is an SoC?



3. BLOCK DIAGRAM

Figure 3-1 shows the block diagram of the R8.

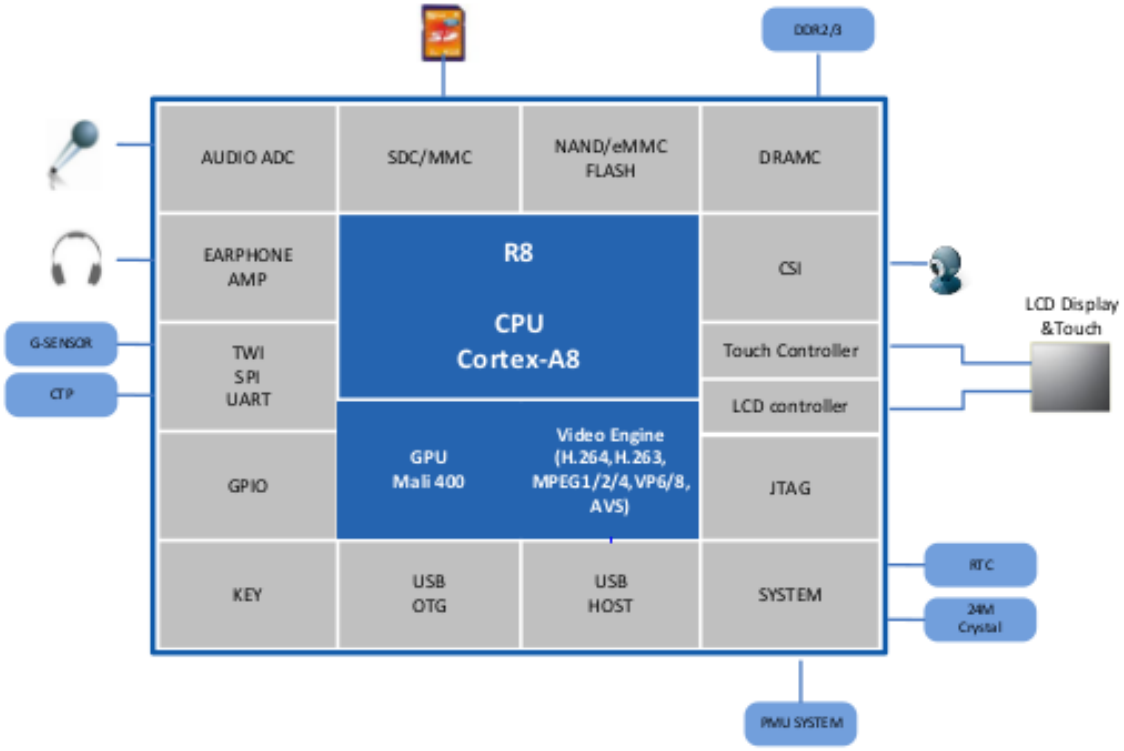
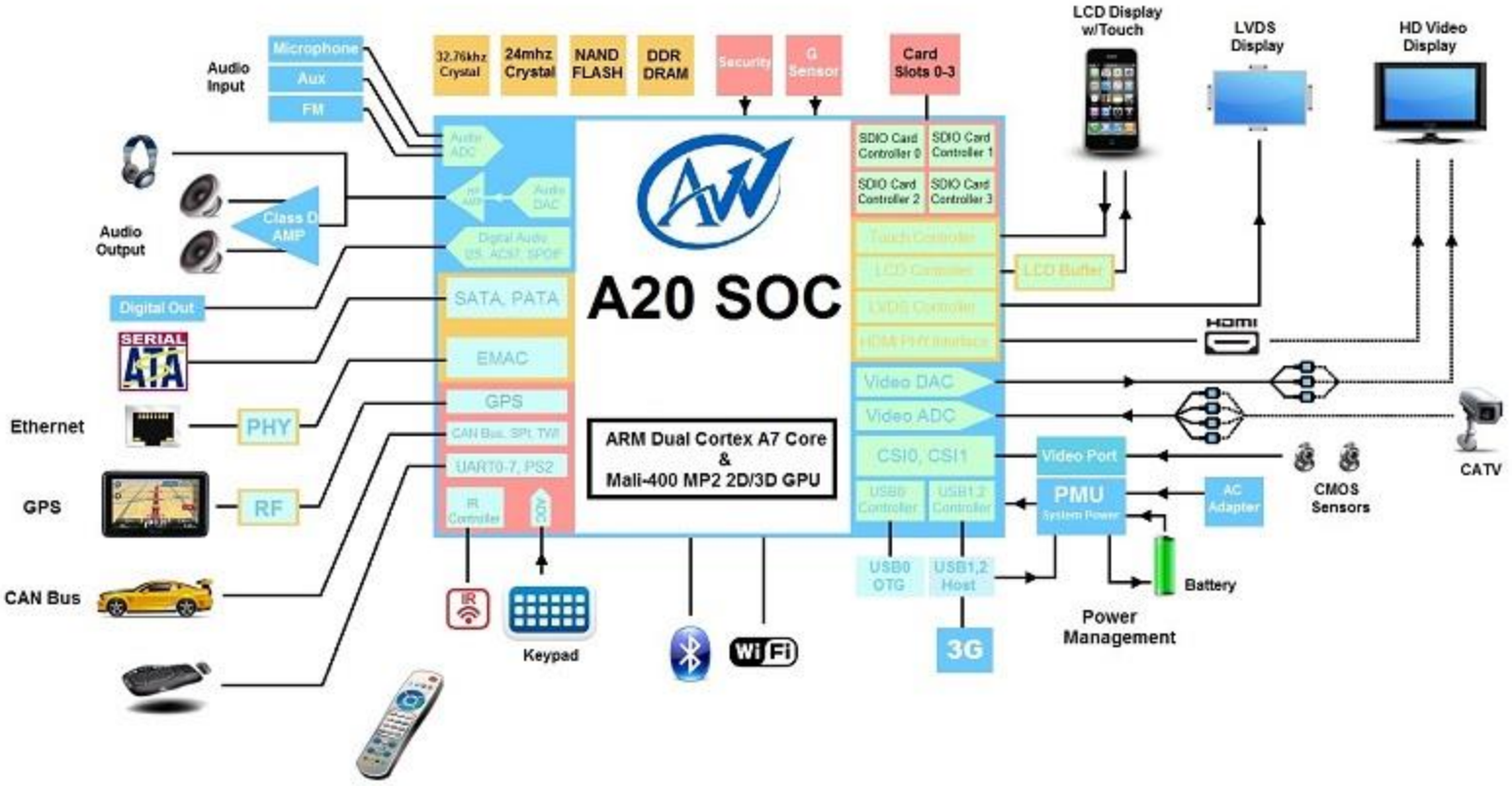
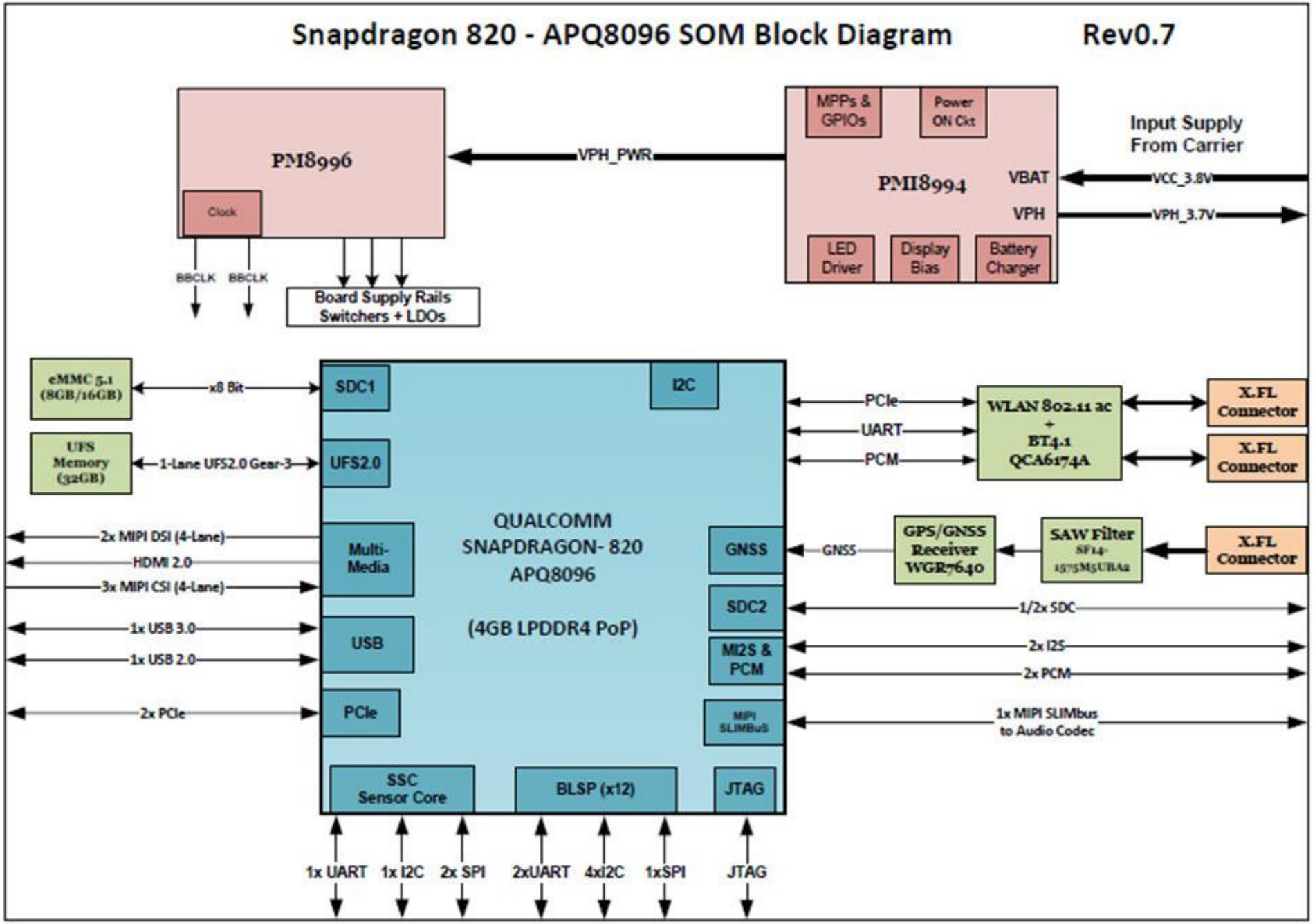
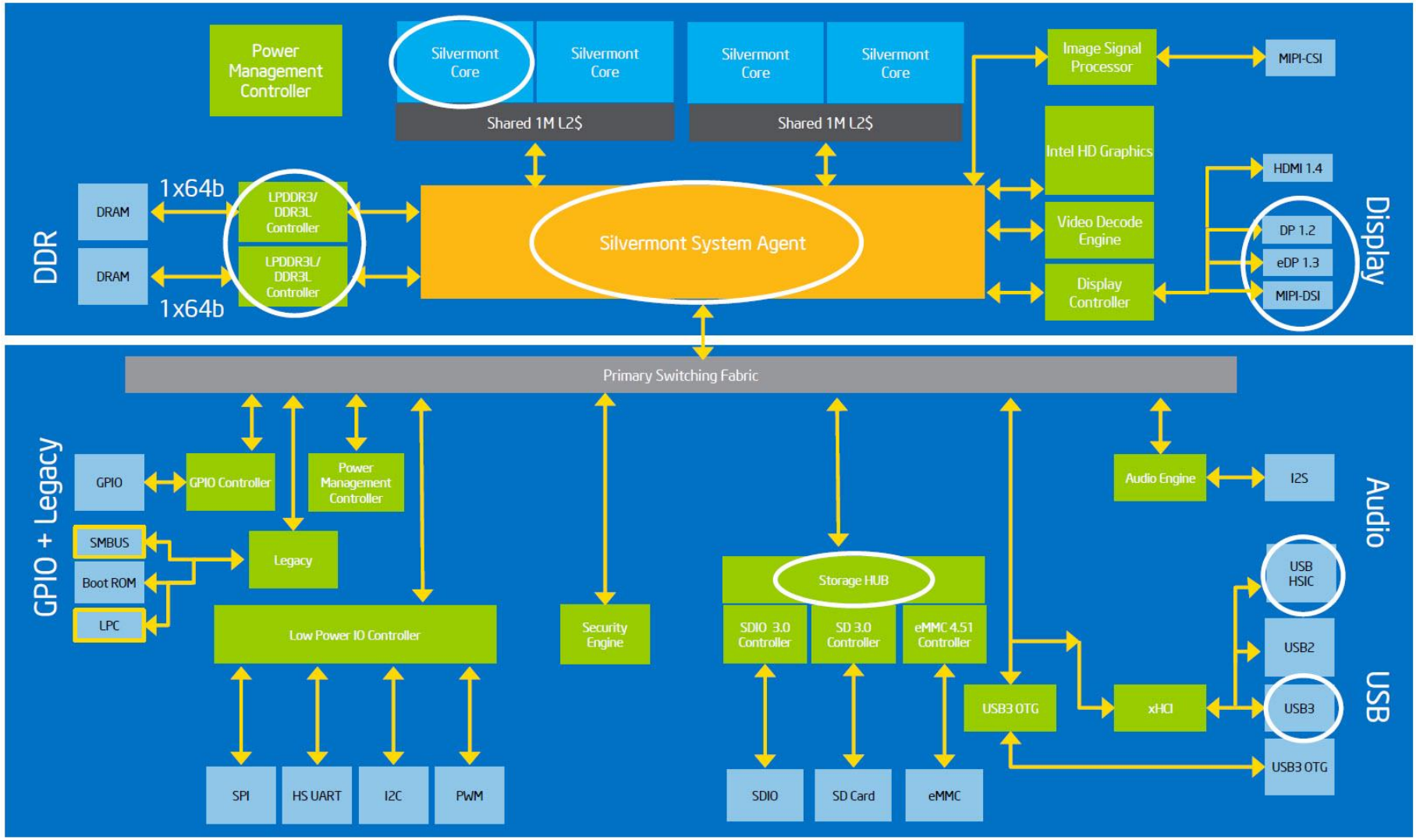


Figure 3-1. R8 Block Diagram


Audio Input
Microphone
Aux
FM
32.76khz Crystal
24mhz Crystal
NAND FLASH
DDR DRAM
Security
G Sensor
Card Slots 0-3
LCD Display w/Touch
LVDS Display
HD Video Display
Audio Output
Class D AMP
Digital Out
SERIAL ATA
Ethernet
PHY
GPS
RF
CAN Bus
SATA, PATA
EMAC
GPS
CAN Bus, SPI, TWI
UART0-7, PS2
IR Controller
A20 SOC
ARM Dual Cortex A7 Core
&
Mali-400 MP2 2D/3D GPU
SDIO Card Controller 0
SDIO Card Controller 1
SDIO Card Controller 2
SDIO Card Controller 3
LCD Buffer
HDMI
Video DAC
Video ADC
CSI0, CSI1
Video Port
CMOS Sensors
CATV
PMU
System Power
AC Adapter
Battery
Power Management
USB0 OTG
USB1,2 Host
3G
Keypad
Wi Fi


Snapdragon 820 - APQ8096 SOM Block Diagram
Rev0.7
PM8996
Clock
BBCLK
BBCLK
Board Supply Rails
Switchers + LDOs
VPH_PWR
MPPs & GPIOs
Power ON Ckt
PMI8994
VBAT
VPH
LED Driver
Display Bias
Battery Charger
Input Supply From Carrier
VCC_3.8V
VPH_3.7V
eMMC 5.1 (8GB/16GB)
x8 Bit
SDC1
I2C
UFS Memory (32GB)
1-Lane UFS2.0 Gear-3
UFS2.0
QUALCOMM SNAPDRAGON- 820 APQ8096
(4GB LPDDR4 PoP)
2x MIPI DSI (4-Lane)
HDMI 2.0
3x MIPI CSI (4-Lane)
Multi-Media
1x USB 3.0
1x USB 2.0
USB
2x PCIe
PCIe
SSC Sensor Core
BLSP (x12)
JTAG
1x UART
1x I2C
2x SPI
2xUART
4xI2C
1xSPI
JTAG
PCIe
UART
PCM
WLAN 802.11 ac + BT4.1 QCA6174A
X.FL Connector
X.FL Connector
GNSS
GNSS
GPS/GNSS Receiver WGR7640
SAW Filter
X.FL Connector
SDC2
1/2x SDC
MI2S & PCM
2x I2S
2x PCM
MIPI SLIMBuS
1x MIPI SLIMbus to Audio Codec

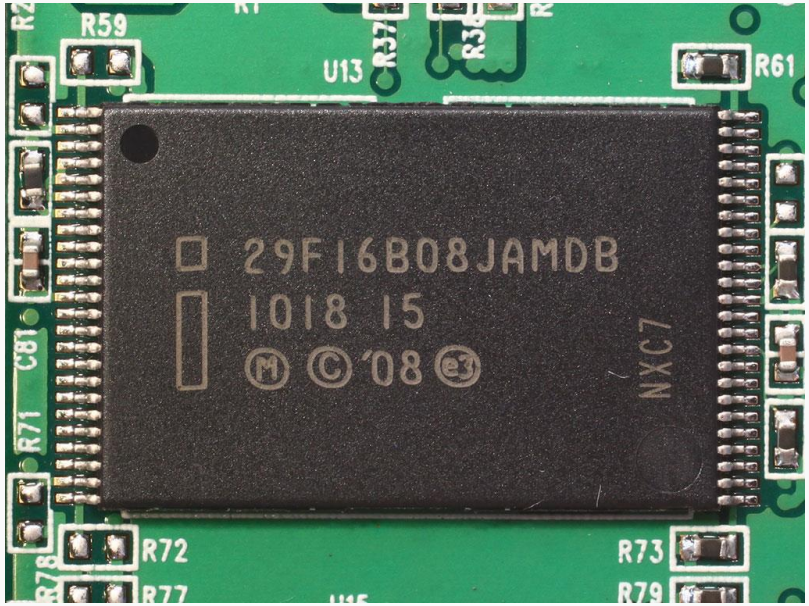
Bay Trail SOC Block Diagram



Storage

Two/Three common flavors

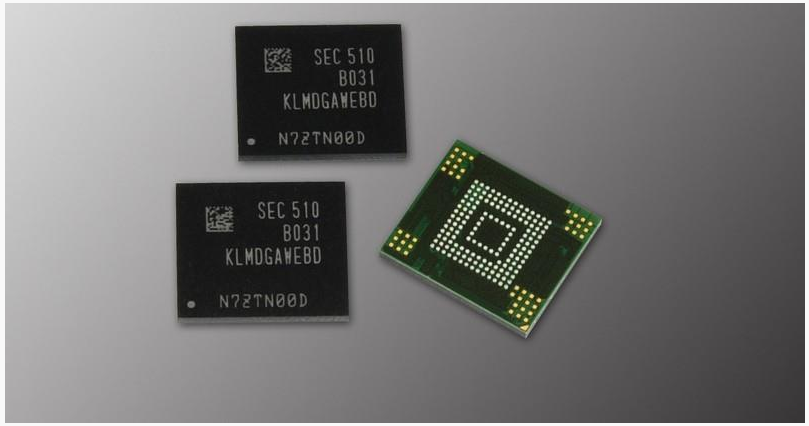
MTD (Memory Technology Device): Abstraction of flash pages to partitions



Storage

Two/Three common flavors

- MTD (Memory Technology Device): Abstraction of flash pages to partitions
- eMMC: Embedded MultiMedia Card



Storage

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- eMMC: Embedded MultiMedia Card, SPI SD card
- SD cards



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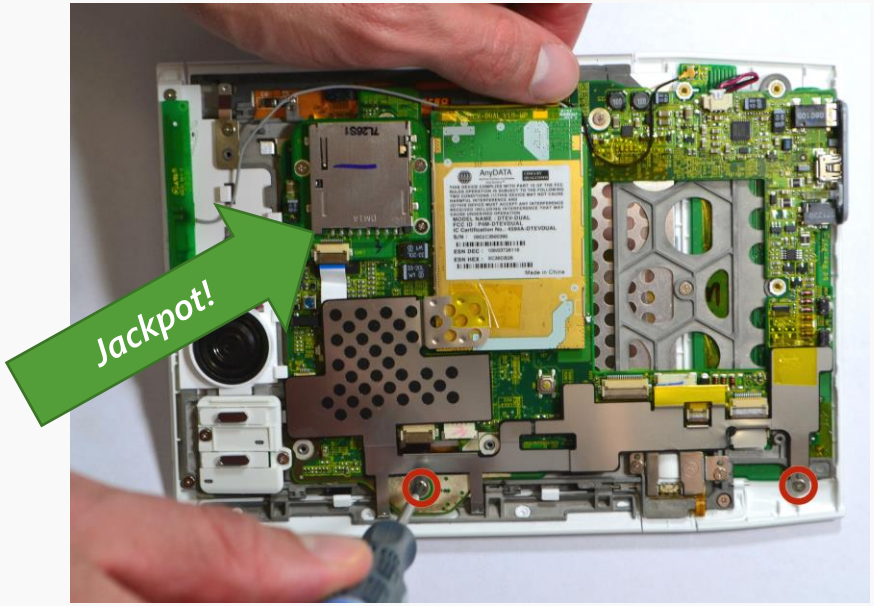


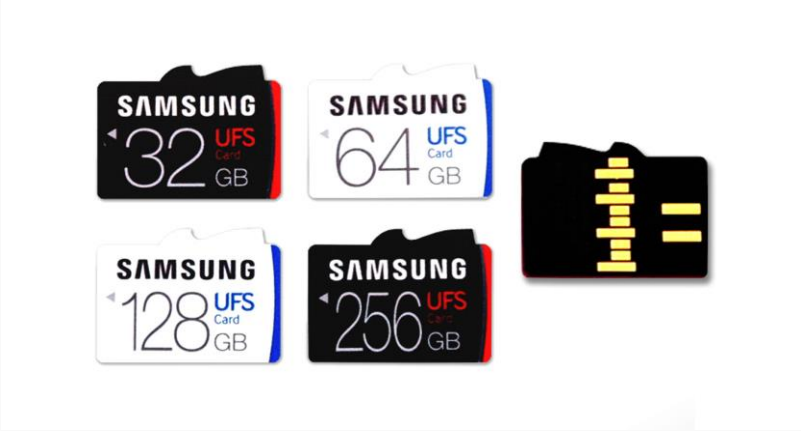
Storage

Two/Three common flavors

- MTD (Memory Technology Device): Abstraction of flash pages to partitions
- eMMC: Embedded MultiMedia Card, SPI SD card
- SD cards

Then there's UFS

- Introduced in 2011 for phones, cameras: High Bandwidth storage devices
- Uses a SCSI model, not eMMC's linear model



Variations

Some devices have a small amount of onboard Flash for the bootloader

- Commonly seen on phones, for the purposes of boostrapping everything else

Every vendor has different tools for pushing bits to a device and *they all suck*.

- Samsung has at least three for Android
- Allwinner based devices can be placed into FEL boot mode
- Fastboot on Android devices

RAM

- The art of cramming a lot in a small place
- Vendors are seriously tight-assed
- Can you cram everything in 8MB? Some routers do.
  - The WRT54G had 8M of RAM, later 4M
  - Modern SoCs tend towards 1GB, phones 4-6G
- In pure flash storage, ramfs might be used to expand on-demand files (http content)



Peripherals

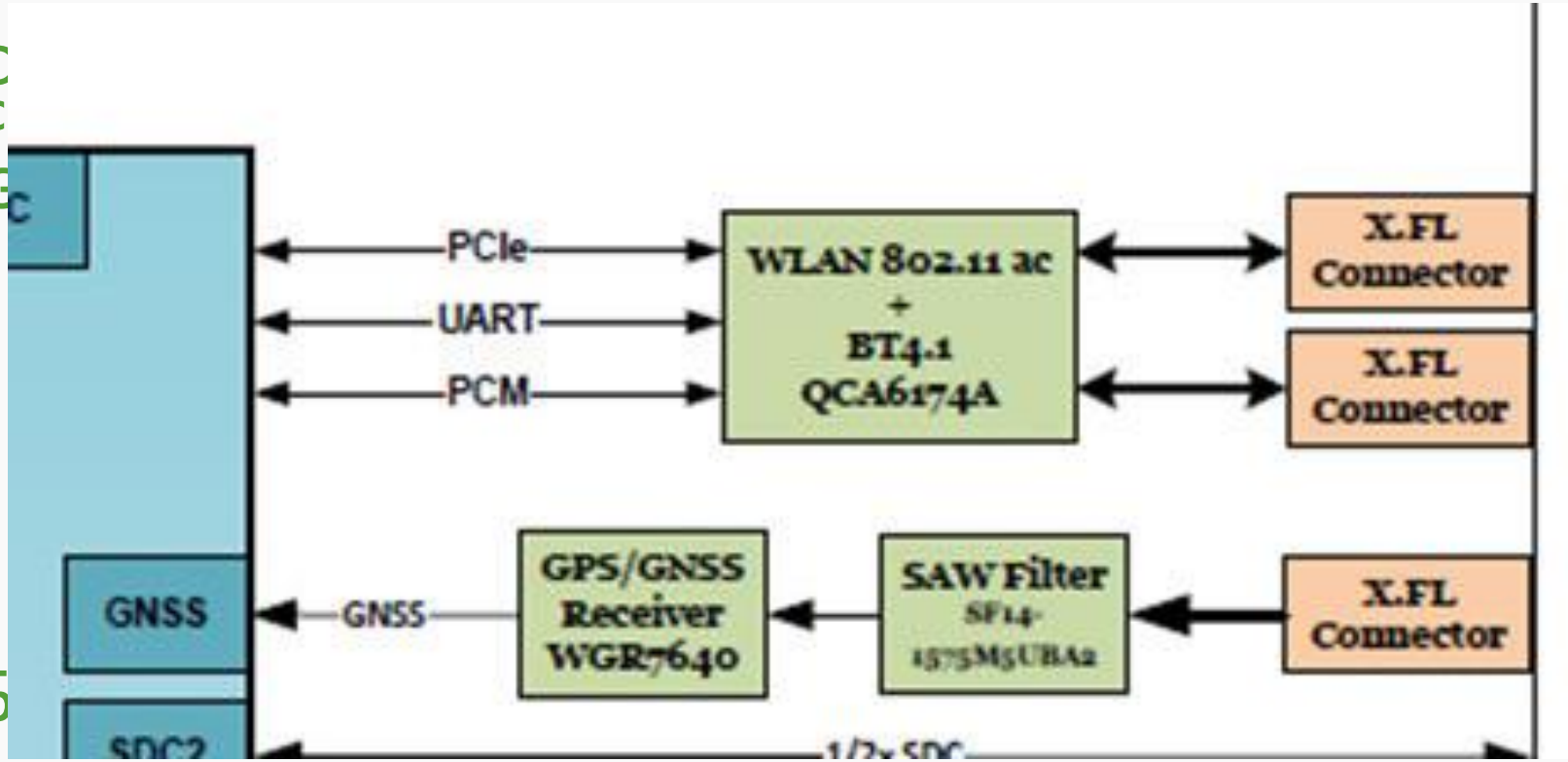
Depends on what the hardware has: SPI, I2C, I2S, etc are common sights.

Gonna see some weird shit

- SDIO wireless cards
- “sound cards” over I2S
- GSM modems are really just pretending to be Hayes AT modems.
- Power management, LED management, cameras, etc.
- “We need an Ethernet PHY” becomes “We hooked an Ethernet PHY up over USB”

Linux doesn’t care if they’re on-die or not, it’s all the same bus.

Peripherals



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Perip

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Bootloader

One Bootloader To Rule Them All: Das U-Boot

- Uses a simple scripting language
- Can pull from TFTP, HTTP, etc.
- Might be over Telnet, Serial, BT UART, etc.

Some don’t use U-Boot, use Fastboot or other loaders

- Android devices are a clusterfuck of options

Life and death of an SoC*

* Some restrictions apply

DFU Check
- First chance to load fresh code onto device, use for bootstrapping and recovery

IPL
- Does signature checking of early boot image
- Probably SoC vendor provided

Bootloader
- Early UART/network wakeup is likely here.

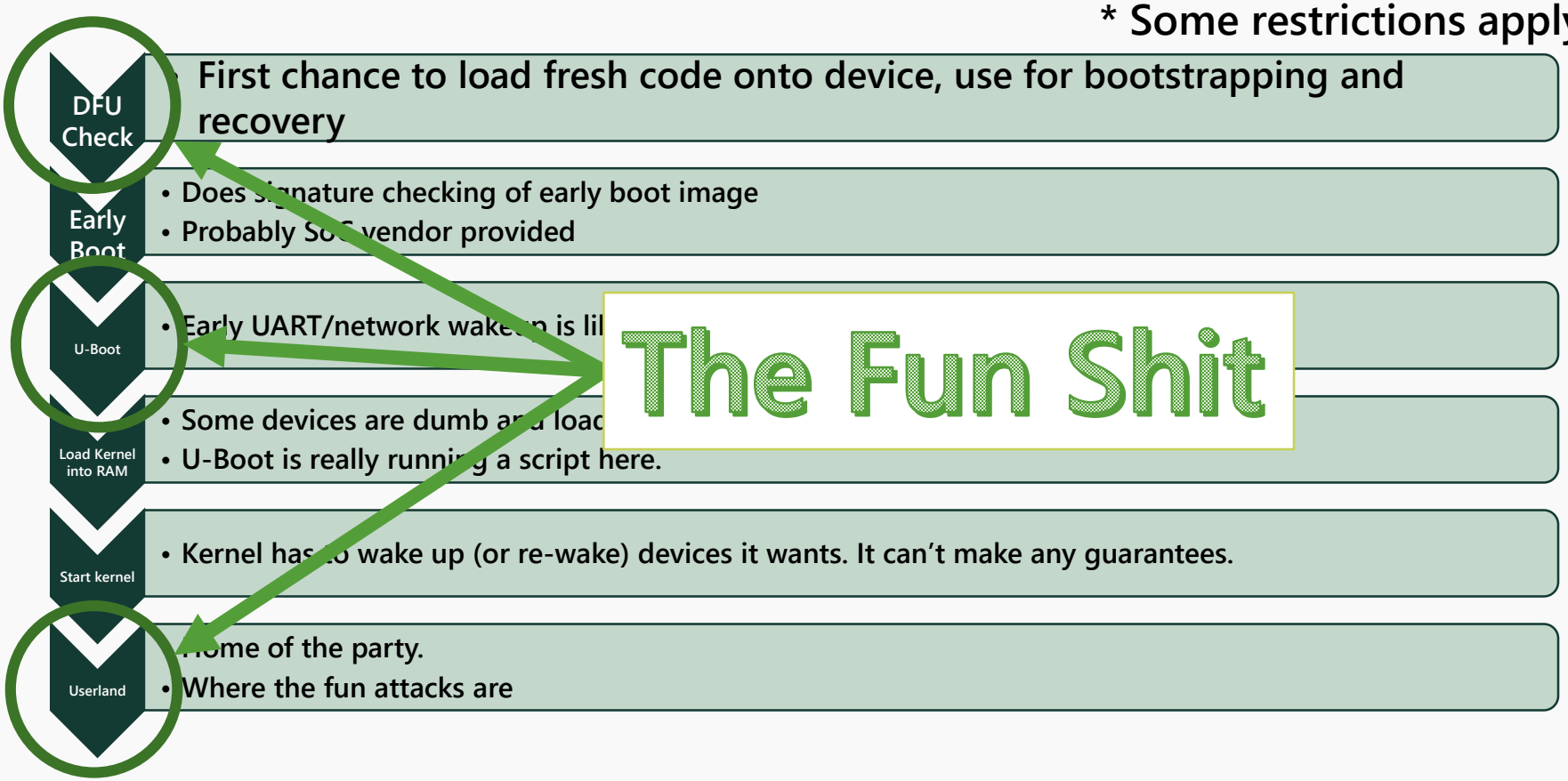
Load Kernel into RAM
- Some devices are dumb and load multiple kernels until one fails or they run out
- U-Boot is really running a script here.

Start kernel
- Kernel has to wake up (or re-wake) devices it wants. It can't make any guarantees.

Userland
- Home of the party.
- Where the fun attacks are

Life and death of an SoC*

* Some restrictions apply



Root Filesystem: Home to All

A root filesystem contains the bare minimum to boot Linux: Any shared object libraries, binaries, or other content that is necessary for what that device is going to do

Fluid content that needs to be changed or which is going to be fetched regularly is often stored on a Ramdisk; this might be loaded during init's early startup from a tarball.

- This is a super common thing to miss because it's a tmpfs outside of /tmp
- this is a super common way of keeping / “small”
- This often leads to rootfs extractions via tar that seem "too big“

There are sometimes multiple root filesystems overlaid upon each other

- Android uses this to some extent: /system is where many things really are

Might be from NFS, might try NFS first, etc.

Attacking these devices

Step 0: Scope out your device

Get to know what makes the device tick

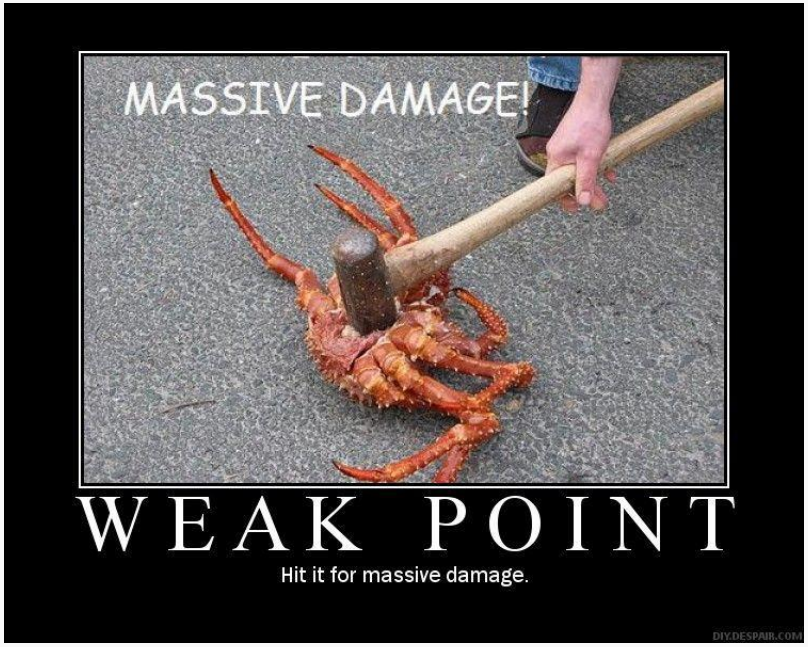
- Version of Linux
- Rough software stack
- Known vulnerabilities
- Debug shells, backdoors, admin shells, etc.

ARM executables are fairly generic

- Kobo updates are very, VERY generic and the Kobo userland is *very aware of this*.

Hardware vendors are lazy: many devices likely similar to kin-devices

- Possibly able to find update for similar device by same OEM



Don't Reinvent The Wheel

Since so many embedded linux devices are similar, or run similarly outdated software, you may well have some of your work cut out for you

OWASP has a whole task set devoted to IoT security:

https://www.owasp.org/index.php/OWASP_Internet_of_Things_Project

Tools like Firmwalker (https://github.com/craigz28/firmwalker) and Routersploit (https://github.com/threat9/routersploit) are already built and ready. Sometimes, thinking like a skid can save *time and energy* for other things, like beer!

Firmware Security blog is a great place to look, including a roundup of stuff (https://firmwaresecurity.com/2018/06/03/list-of-iot-embedded-os-firmware-tools/)

Option 1: It's a UNIX system, I know this

If you can get a shell, sometimes just beating against your target can be fun

Limited to only what is on the target (or what you can get to the target)

Can feel a bit like going into the wild with a bowie knife and a jar full of your own piss

Debugger? Fuzzer? *Compiler?* What are those?



Option 2: Black-Box it

Lots of fun once you're used to it or live service attacks.

Safe: Never directly exposes you to "secrets" (IP)

You don't have the bowie knife, just two jars of piss.



These options Can Really suck



Option 3: Reverse it

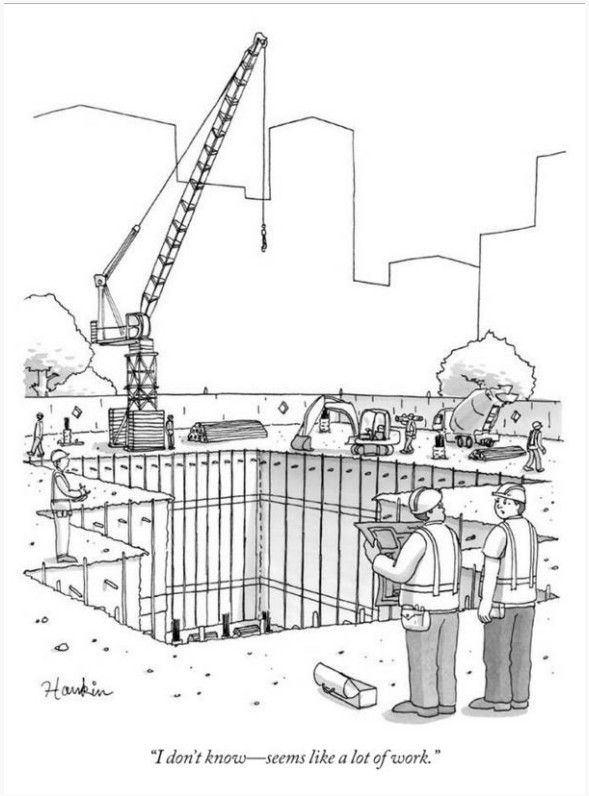
Pull out IDA/Radare

Grab a beer

Learn you a new ISA

The way of reversing IoT things that don't run Linux!

... but how the fuck do you get the binaries?



Yeah but I'm fucking lazy, asshole.

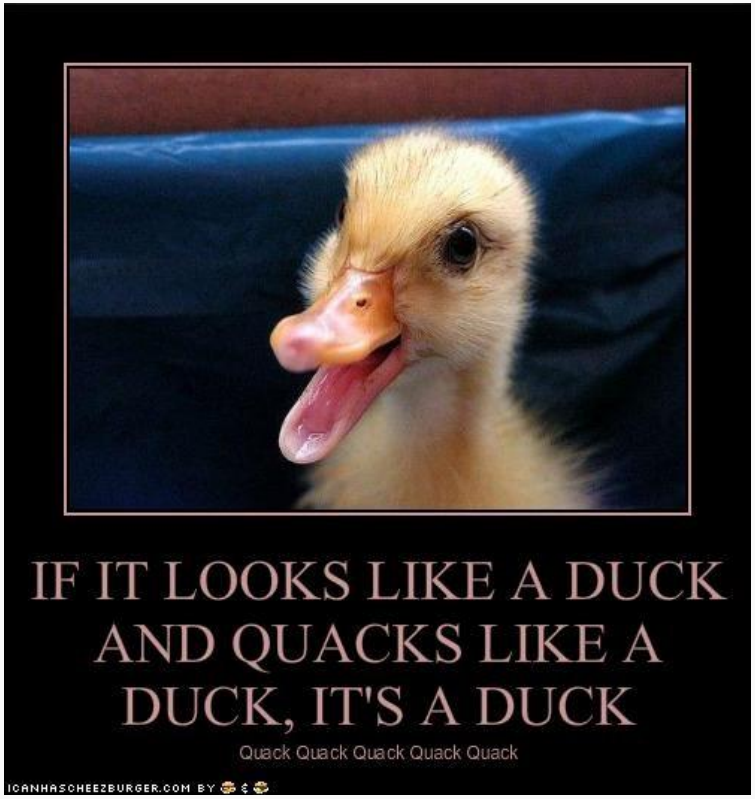
I don't want to learn IDA. I want to fuzz.

Option 4: Emulate It

You have every tool at your disposal

- Hot damn is that a debugger?
- Oh shit waddup it's fuzzy boiii

Once again, *how the fuck do you get your binary of choice?*



Getting root(fs)

Easy Mode: Update Packages

Updates for devices are the easiest way to extract a root filesystem

- Sometimes little more than a filesystem/partition layout that gets dd'd right to disk
- Android updates are ZIPs containing some executables, a script, and some filesystems
- Newer android updates (small ones) are very regularly "delta" updates: These touch a known filesystem directly, and are very small but don't contain a full filesystem.

Sometimes, rarely, they're an *actual executable* that gets run on the device

- Probably isn't signed
- Probably fetched over HTTP

Downside: They're occasionally *very* hard to find or are incremental, incomplete patches. Sometimes they're *encrypted*.

Medium: In-Vivo extraction

You need a shell
- Can you hijack an administrative interface?
- Some ping functions can be hijacked into shells
- Sometimes it's literally "telnet to the thing"
- Refer to step 0 for more

You need some kind of packer (cpio, tar, etc)
- Find is a builtin for most busybox implementations.

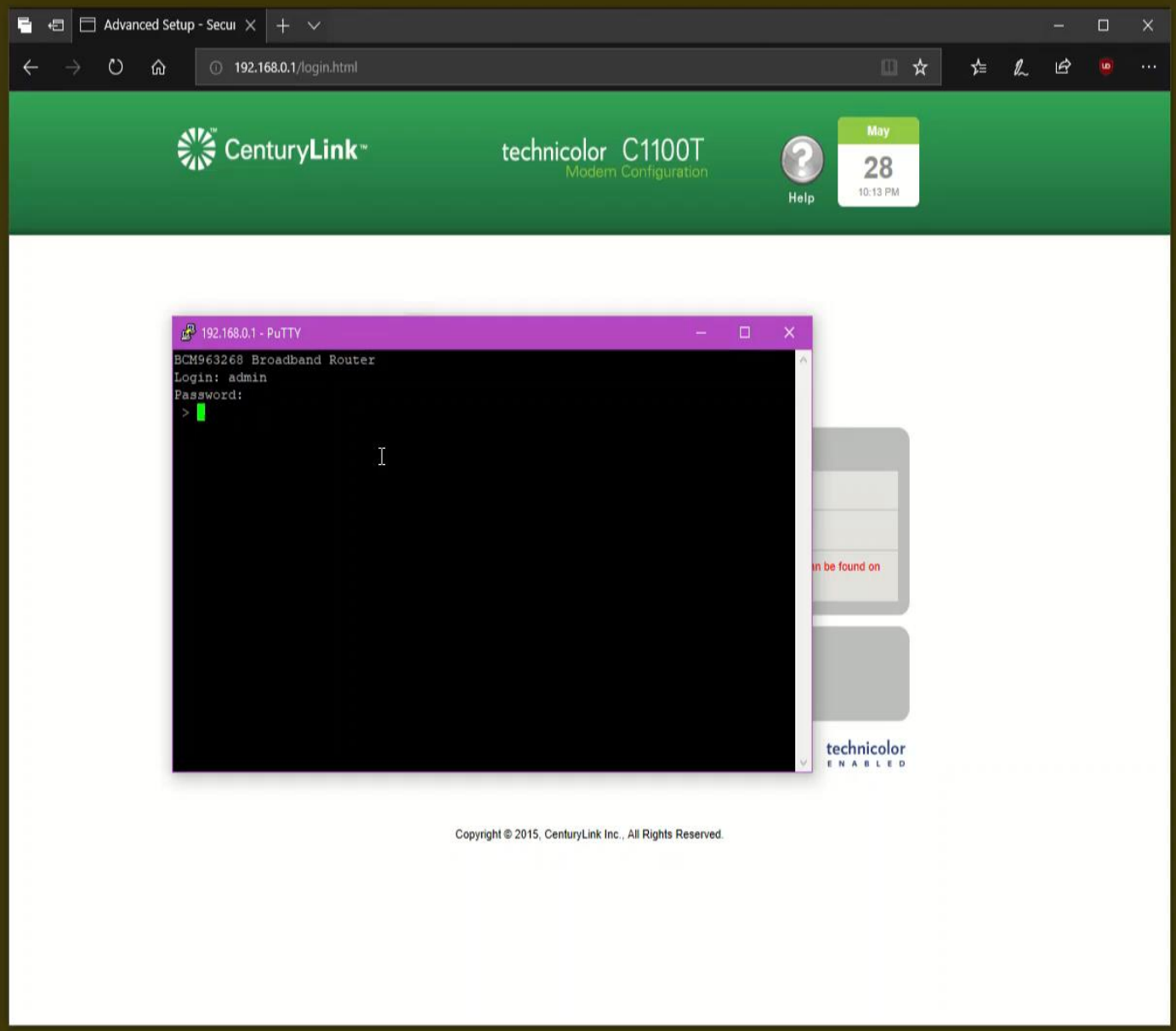
You need some way to put it somewhere (netcat, curl, etc)

You might have an HTTPD to fall back on

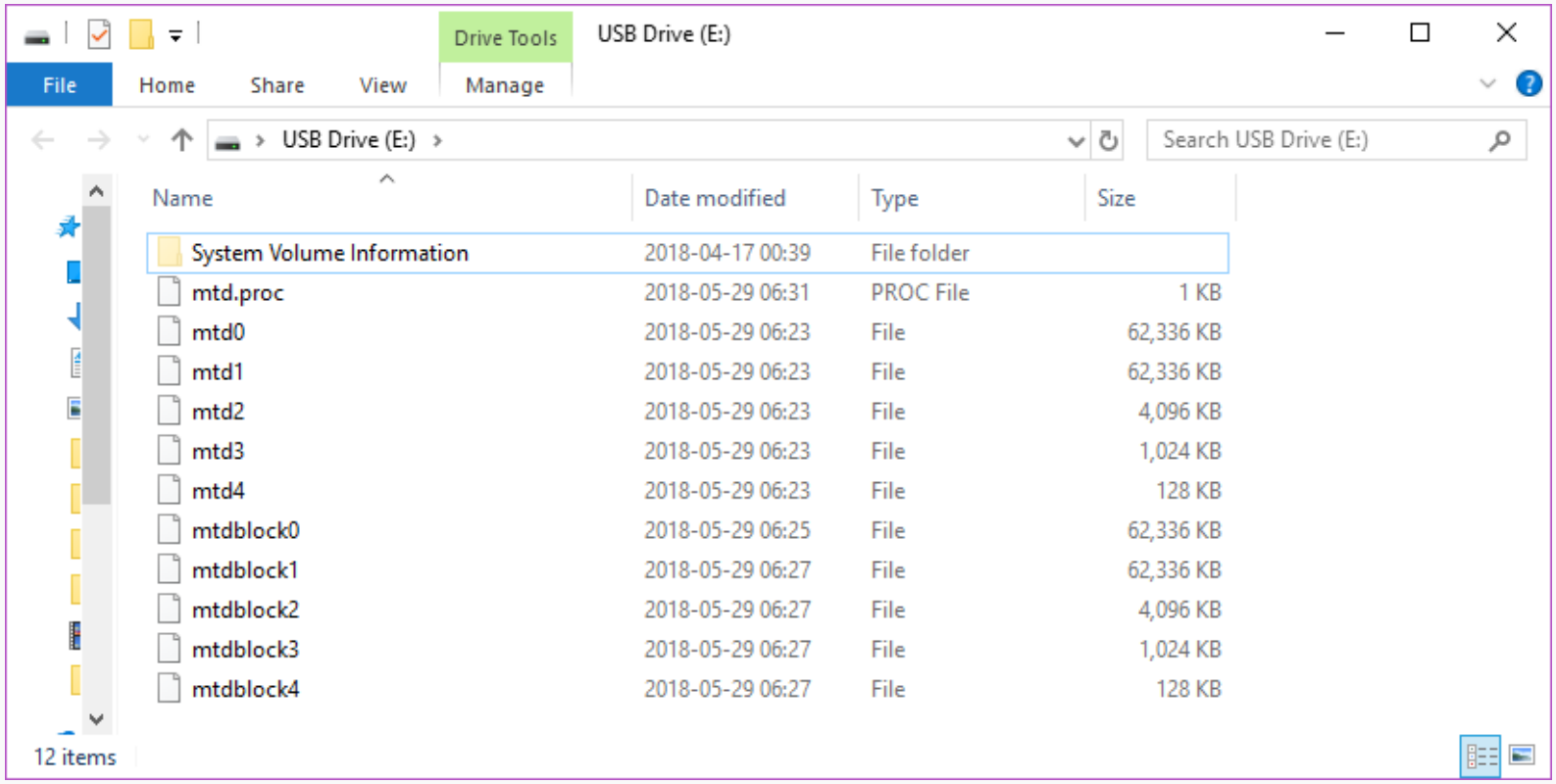
Need to do reconnaissance on your device

Might need some creativity
- Wireshark, Ettercap, Fiddler, etc

Demo: Router firmware extraction (Actiontec Router)


Advanced Setup - Secui
192.168.0.1/login.html
CenturyLink™
technicolor C1100T
Modem Configuration
Help
May
28
10:13 PM
192.168.0.1 - PuTTY
BCM963268 Broadband Router
Login: admin
Password:
>
technicolor
ENABLED
Copyright © 2015, CenturyLink Inc., All Rights Reserved.

What did we get?

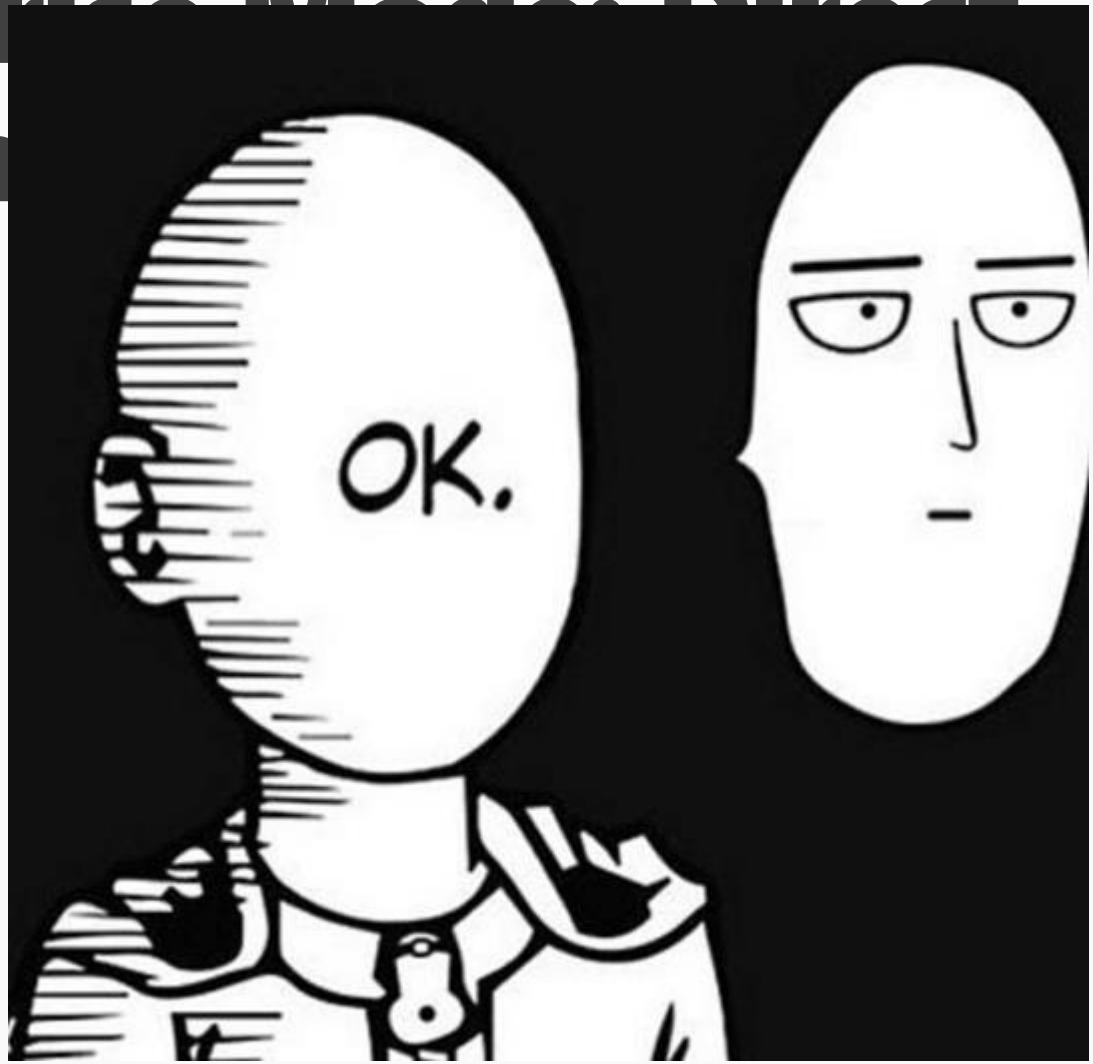


Surprise Mode: Direct Extraction

Could be as simple as “remove SD card, image it”

Surpr
Extra

Could be it”



Surprise Mode: Direct



CLOSED

RetroEngine Sigma - Mini Video Game Console

Retrogaming Simplified. The Greatest Retro-Station known to Man!

PROJECT OWNER

Doyodo Team
Santa Monica, United States
1 Campaign | More

l, image it”

By Rogue Foundry
First created

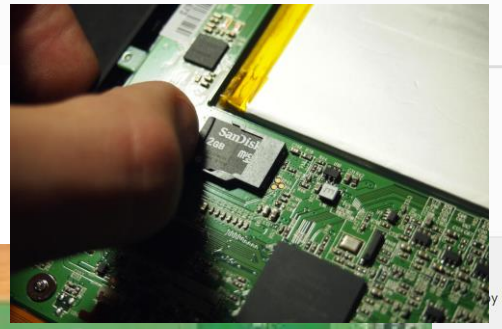
Sever: The Anti-Villain Box (Canceled)

Get ready to no longer exist online.

OVERVIEW

RetroEngine Sigma is as simple as plu







Anonymity

t, MA

Surprise Mode: Direct Extraction

- Could be as simple as “remove SD card, image it”
- eMMC is harder though, since you need to get to the data lines, but it can be done!
- You will need to understand how the disk is laid out
  - Binwalk can help later, as can “standard” DOS partition tables.
- Having some in-vivo information is helpful

Surprise Mode: Direct E

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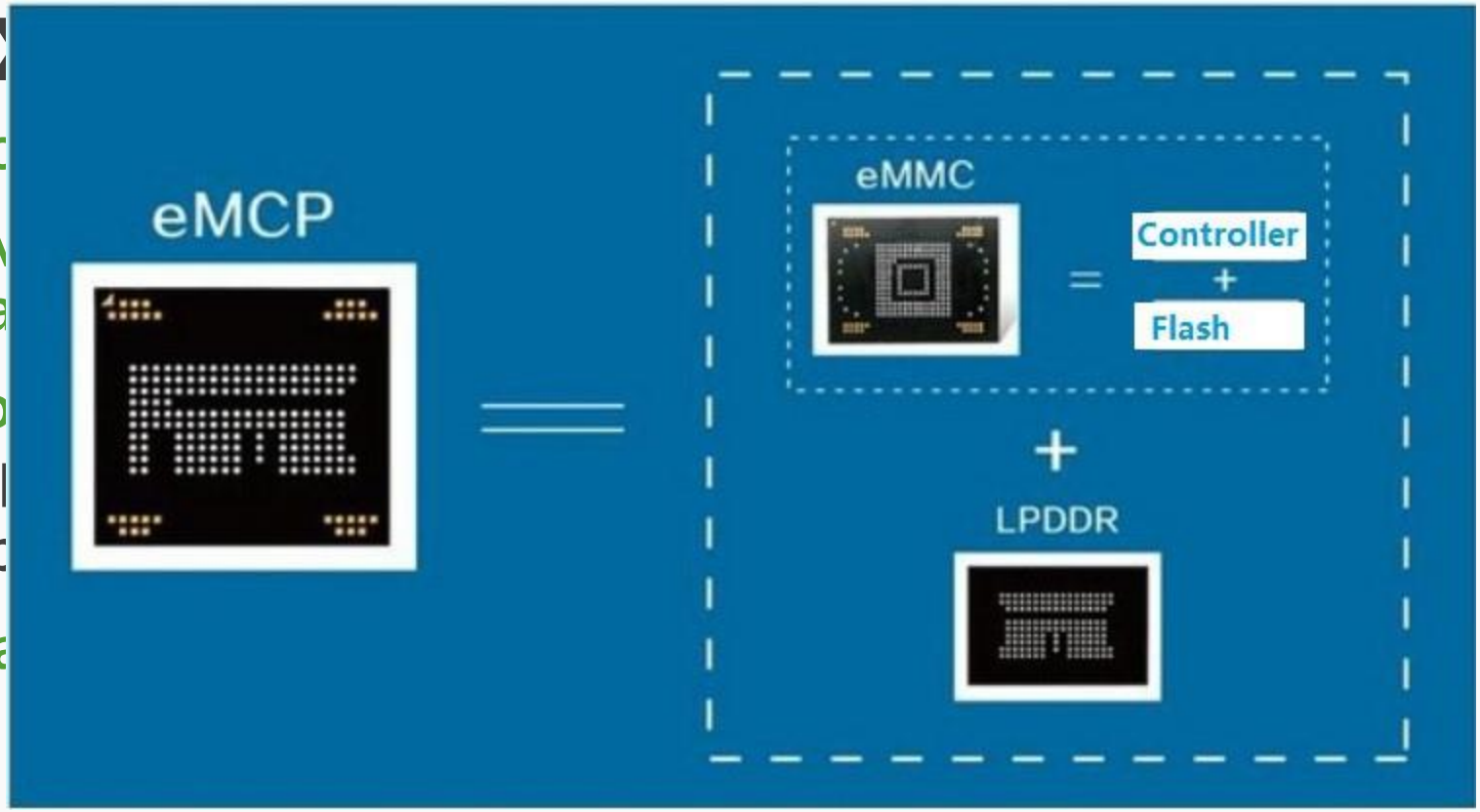
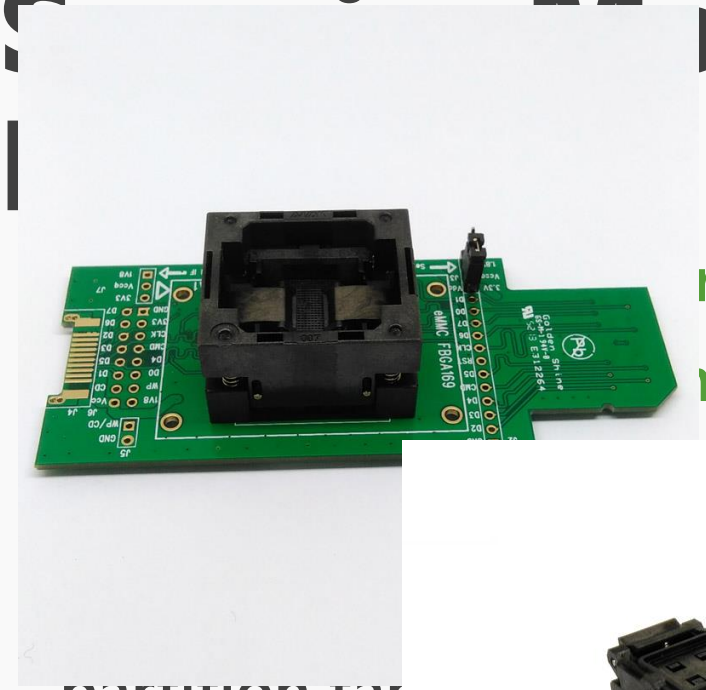


S ... Mode



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partition tab



Having some ... lpful

Surprise Mode: Direct E

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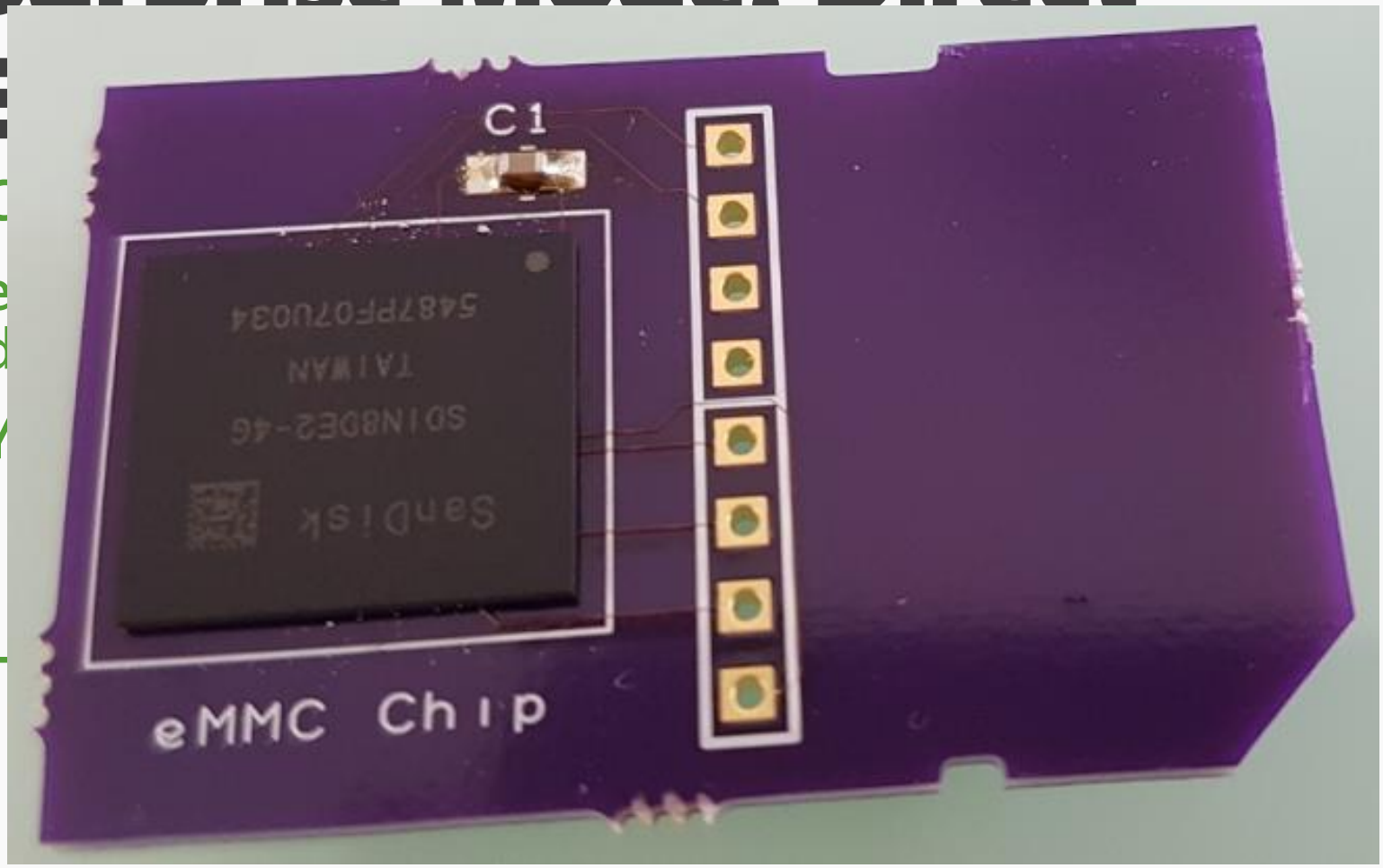
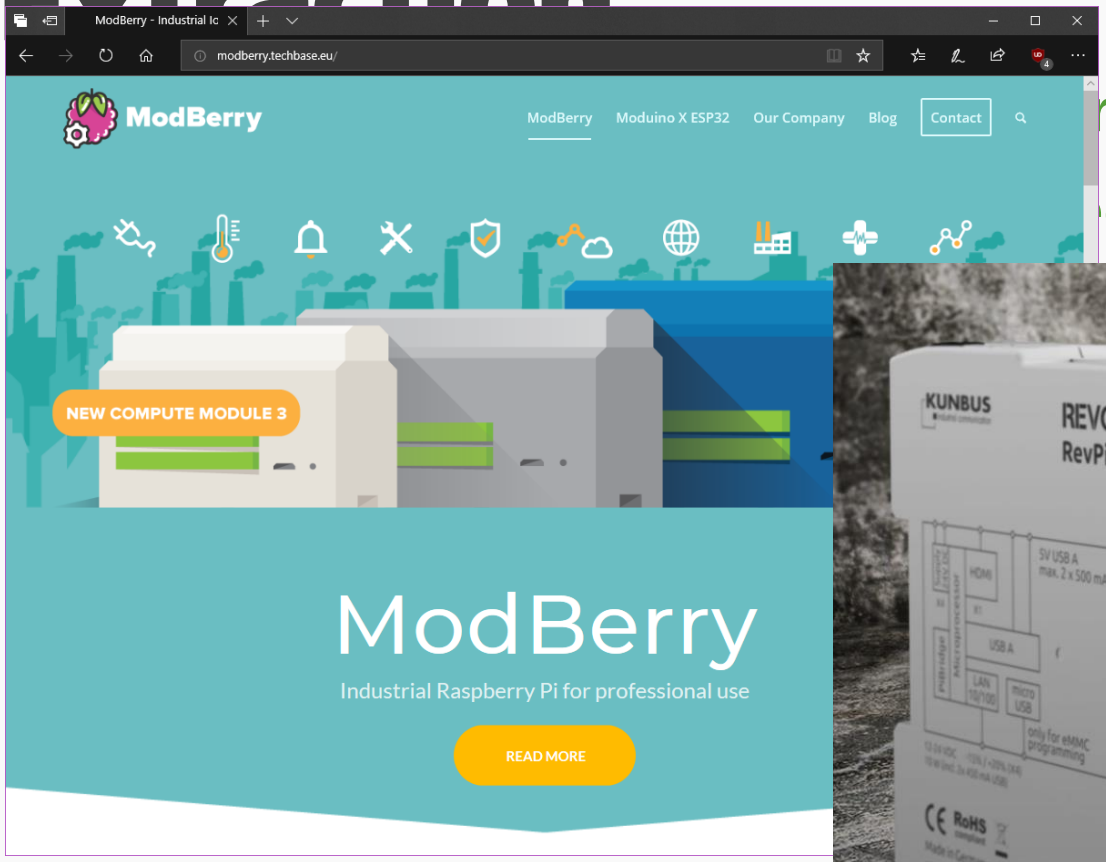


http://blog.oshpark.com/2017/02/23/retro-cpc-dongle/

Surprise Mode: Direct Extraction



rd, image it"

ed to get to the



Surprise Mode: Direct Extraction

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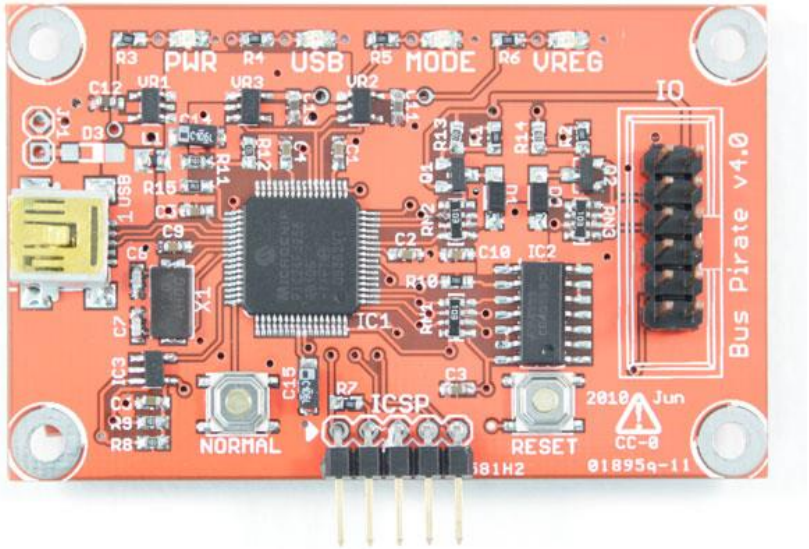
- You will need to understand how the disk is laid out
  - Binwalk can help later, as can “standard” DOS partition tables.
- Having some in-vivo information is helpful
- All Else Fails: Solder to the rescue
  - Might need to desolder some storage, or otherwise physically attack the hardware
  - MTD devices are weird. Prepare to get your hands dirty
  - Interested in more? HHV and friends are the place to start looking.
  - JTAG, etc. might be the hard way out.



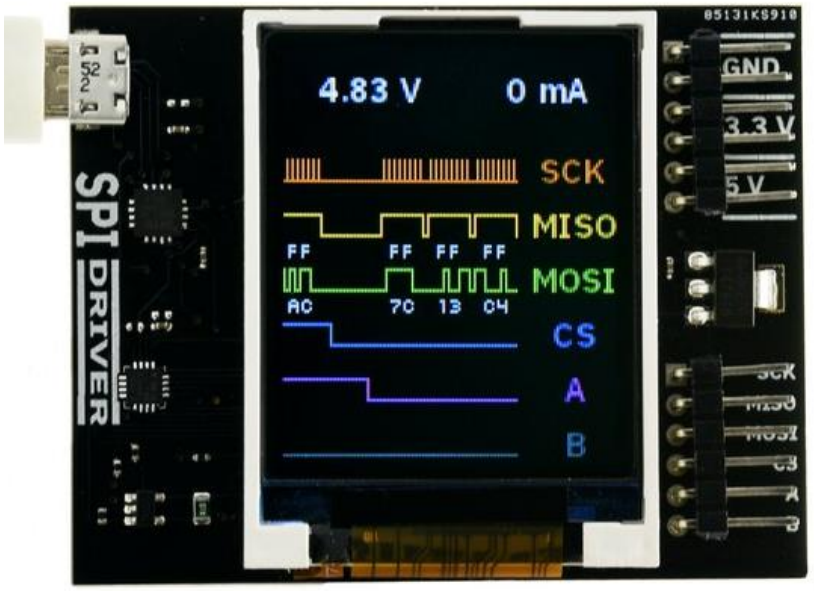
Logic Analyzers

Salae makes a good one

- Cheap
- Basic
- Runs over USB



http://dangerousprototypes.com/docs/Bus_Pirate



https://www.crowdsupply.com/excamera/spidriver

Hardware interfaces

Now that we have that, what do?

Try mounting it/extracting it/etc. `file` might give you a good idea of what it thinks it might be, as will `strings` and the like.

eMMCs sometimes have real partition tables

SD cards often do

Look at the reconnaissance you did

- Boot logs: lots of good information about partitions
- Fstab, /proc/mounts

Let automation do your work

Binwalk!

- Takes a rough guess at what might be in a place
- Makes educated guesses about filesystems
- High false positive rate

Photorec might be helpful

Get creative

- Losetup and friends are capable of more than you give them credit for.
- There are a lot of filesystems that are read-only or create-and-read, like cramfs and such. These are often spotted by binwalk but are even sometimes seen as lzma or other compressed or high-entropy data

If you're only looking to play in IDA/Radare/etc, the bulk extraction from binwalk might help.



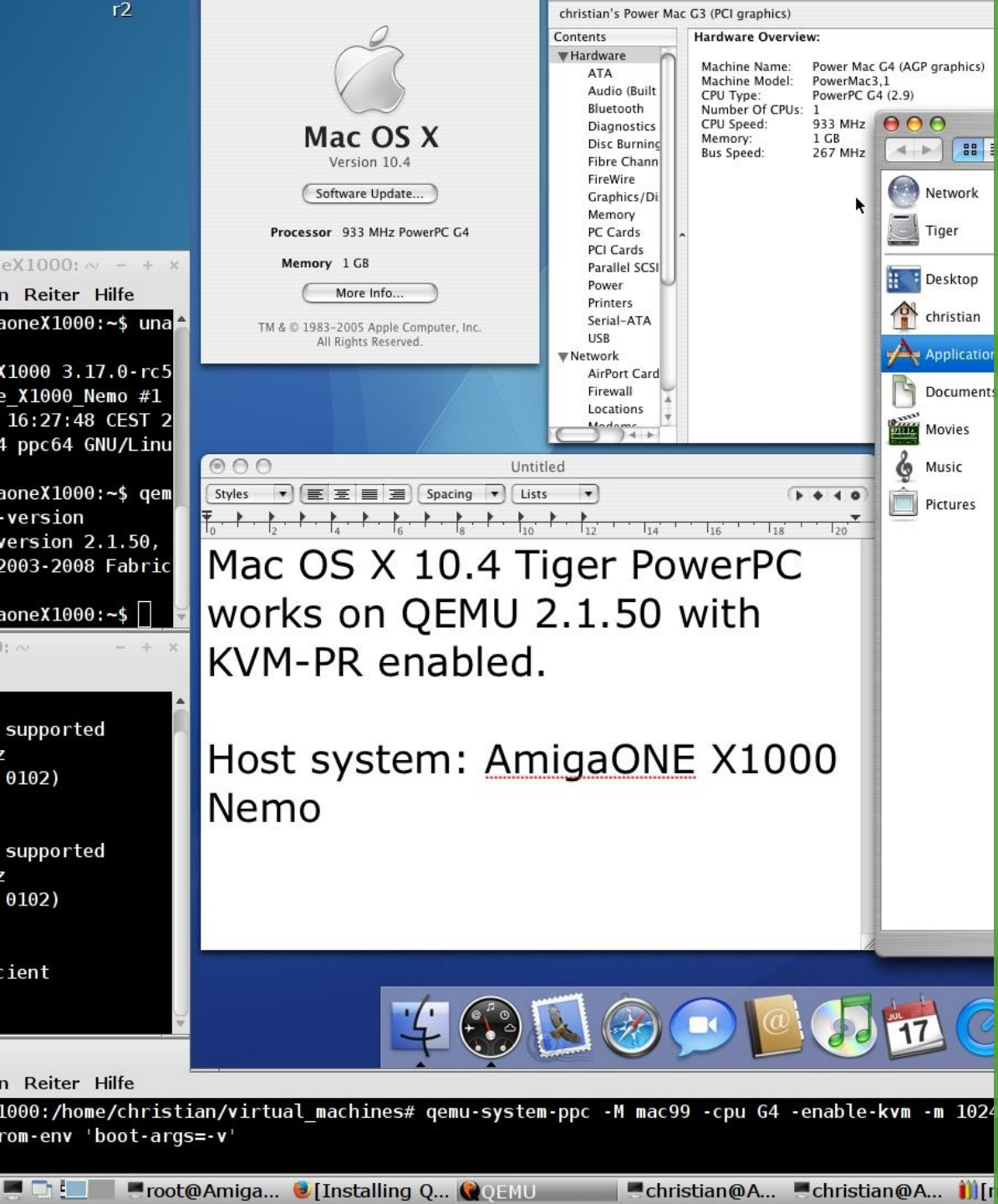
QEMU: the Quick EMUlator

QEMU is a fast processor emulator for a variety of targets.

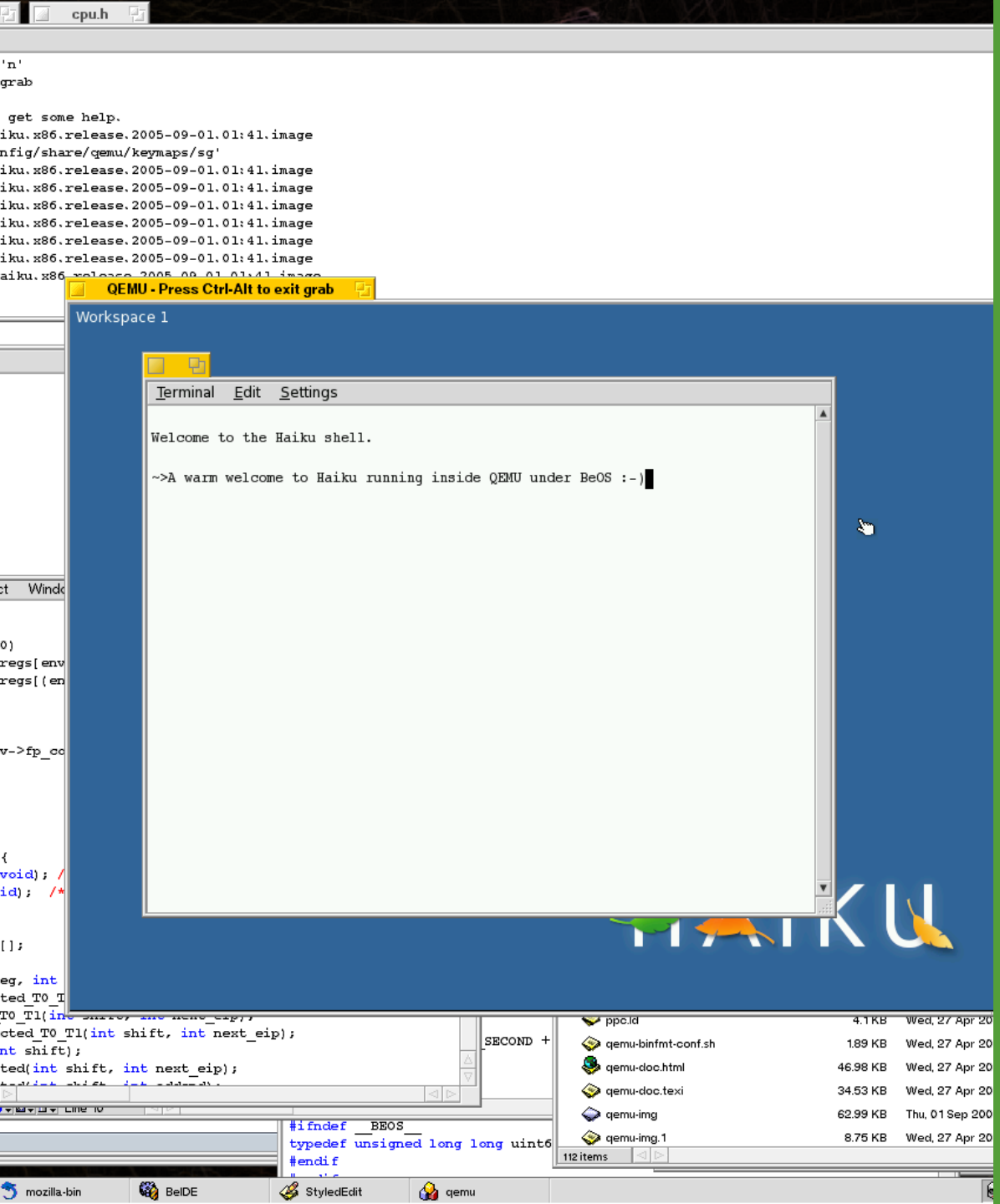
Targets you've never heard of?

- Mainframes
- ARM, MIPS
- PowerPC
- OpenRISC
- DEC Alpha

Lots of different ports and targets have been ported.



Did someone say "OSX on Amiga hardware"?



Or Haiku on BeOS?

Two ways to run QEMU

AS A FULL FAT VM

You preserve full control over the whole process

You've got access to things like gdb at a kernel level

Requires zero trust in the safety of the binary

But you probably want a special kernel and board setup, though there are generic setups to get you started

Any tools are going to need to be compiled for the target environment

I hate cross-compilers.

AS A TRANSLATING LOADER

You have access to all your existing x86-64 tools (or whatever your native tools are)

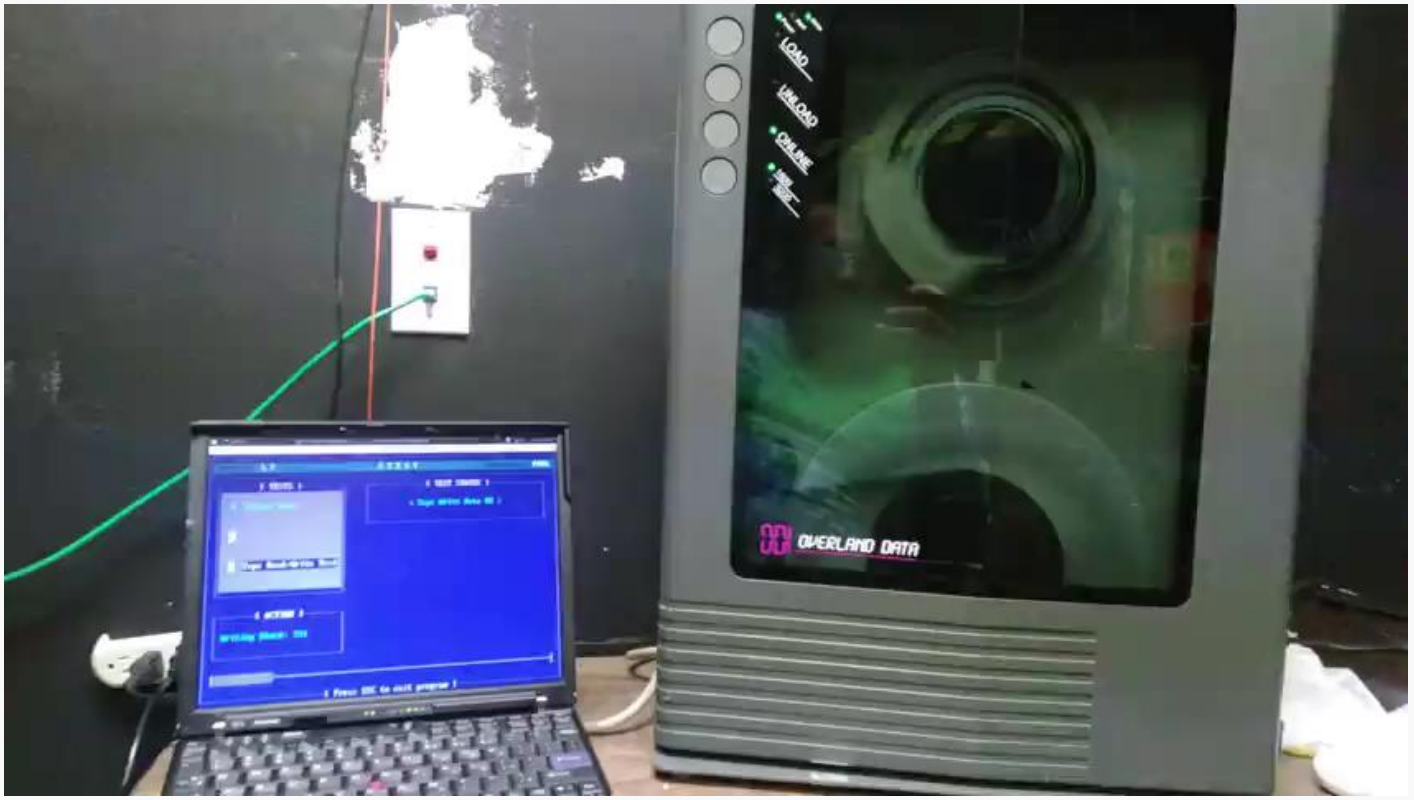
They're not only native, but they're running full-speed.

You can run AFL like it's meant to

Runs nicely in containers

You don't even need a container!

Full-Fat VM: 9 tracks of DOS



Binfmt: Linux' way of loading executables

Long ago, Linux added loadable loaders

Originally for the purposes of running JARs from the command line like God and Sun Microsystems intended.

Turns out this is a great place to put emulators.

Debian ships with support for this in its *binfmt-misc* package.

QEMU can be shipped as a "static userspace" environment (think WINE)

Uses "magic numbers" – signatures from a database – to determine which ones are supposed to load what.

Fairly simple to add new kinds of binaries. You could actually execute JPEGs if you really wanted to?

QEMU as loader

WITHOUT A CONTAINER

Dumb simple to set up:

qemu-whatever-static <binary>

With binfmt, just call your binary.

Must trust that the executable is not malicious

Might depend on your local environment looking like its target environment

This works best for static, monolithic executables

WITH A CONTAINER

Bring that whole root filesystem along!

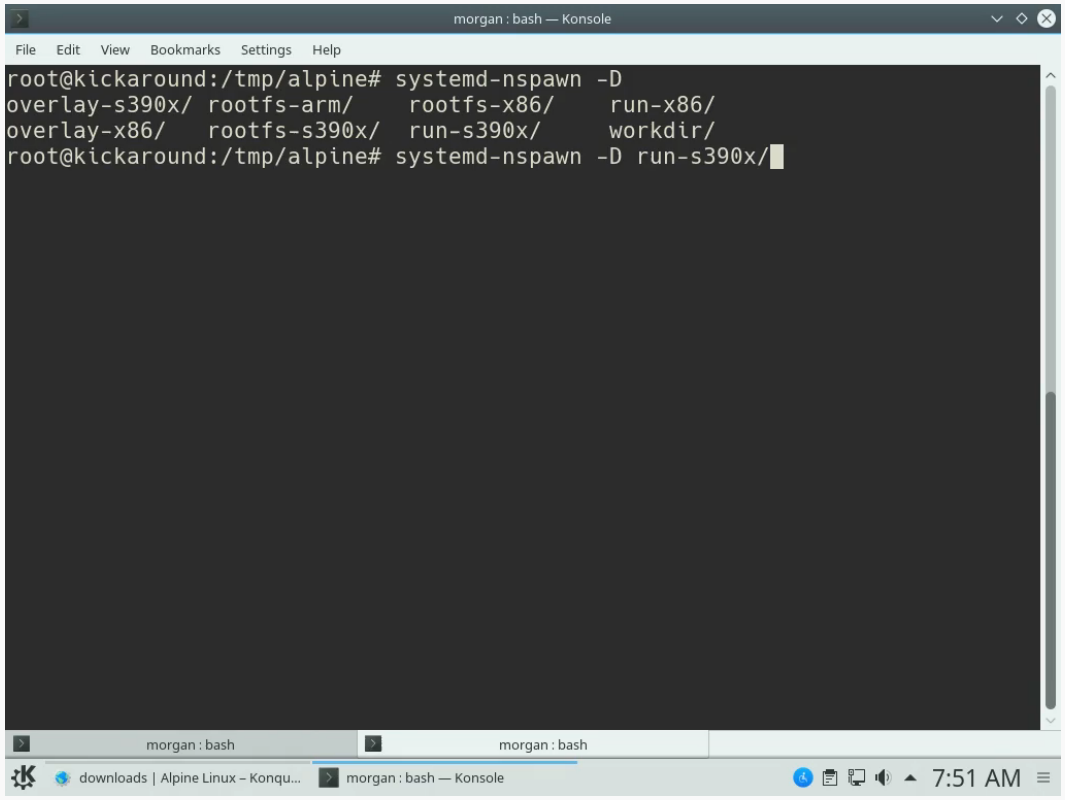
Run it in the confines of a jail, Docker instance, even something like Systemd containers

Might need root depending on your container (systemd)

Great for when your binary loads its own special versions of libraries that have weird things added to them


IBM z14

QEMU user Demo



AFL setup

Oh boy. Let's talk about AFL.

AFL needs to compiled with QEMU support

Magic sauce: CPU_TARGET=whatever ./build_qemu_support.sh

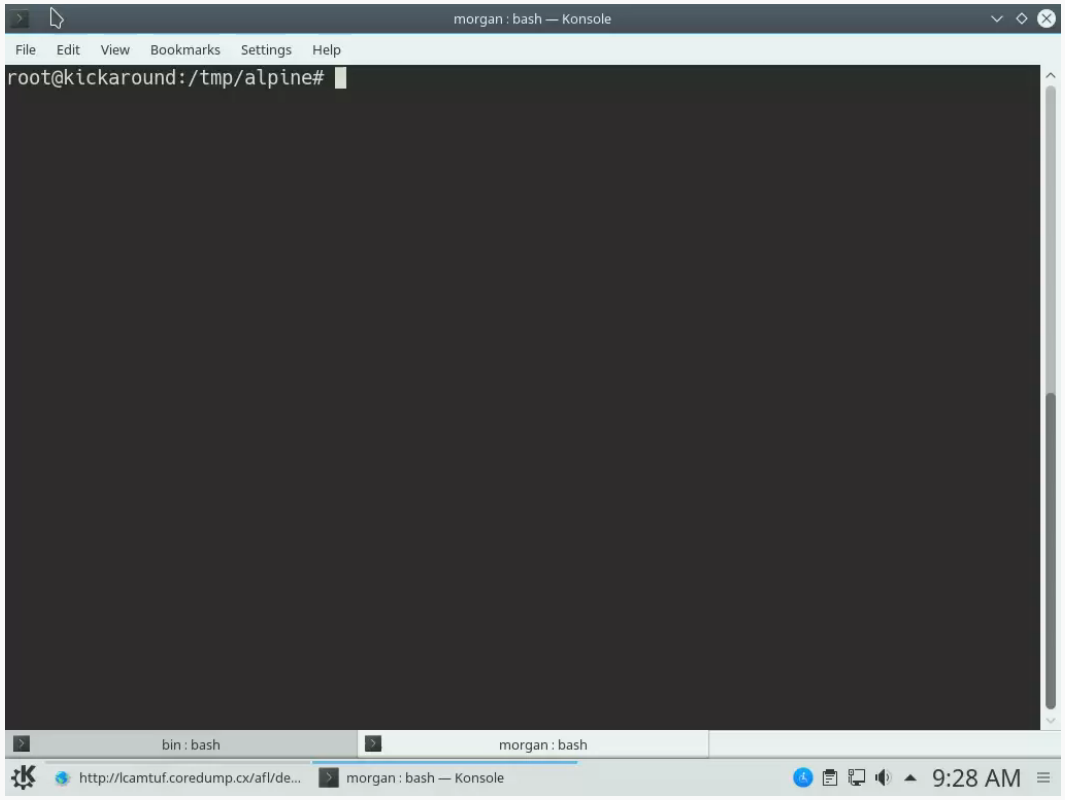
AFL needs to bring along the host's libraries

Easiest bound with systemd-nspawn

Don't do this in a VM

It hurts

AFL Demo


morgan : bash — Konsole
File Edit View Bookmarks Settings Help
root@kickaround:/tmp/alpine#
bin : bash
morgan : bash
http://lcamtuf.coredump.cx/afl/de...
morgan : bash — Konsole
9:28 AM

Wrapping up

What did we learn today?

- Hardware vendors are lazy
- Attacking hardware means getting creative
- QEMU is pretty neato
- AFL runs really slow when you're emulating an X86 emulating an IBM mainframe.

Going forward:

- I hope I've given you some idea of the landscape of tools
- Always remember rule 0

More Resources

Non-Linux targets:

RECON 2010 with Igor Skochinsky: Reverse Engineering for PC Reversers: http://hexblog.com/files/recon%202010%20Skochinsky.pdf

JTAG Explained: https://blog.senr.io/blog/jtag-explained

https://www.blackhat.com/presentations/bh-europe-04/bh-eu-04-dehaas/bh-eu-04-dehaas.pdf

https://beckus.github.io/qemu_stm32/ (among others)

Linux targets:

eLinux.org – *Fucking Gigantic* wiki about embedded Linux.

linux-mips.org – Linux on MIPS

Thank you

Keep on hacking.