Teaching Embedded Linux using File Abstractions

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  - Document sources: https://github.com/e-ale/Slides

bootlin e-ale

BeagleBoard.org's objectives

- Education
  - Design and use of open source SW/HW
  - Embedded computing
- Collaboration
  - Physical computing
  - Robotics
  - Industrial/machine controls

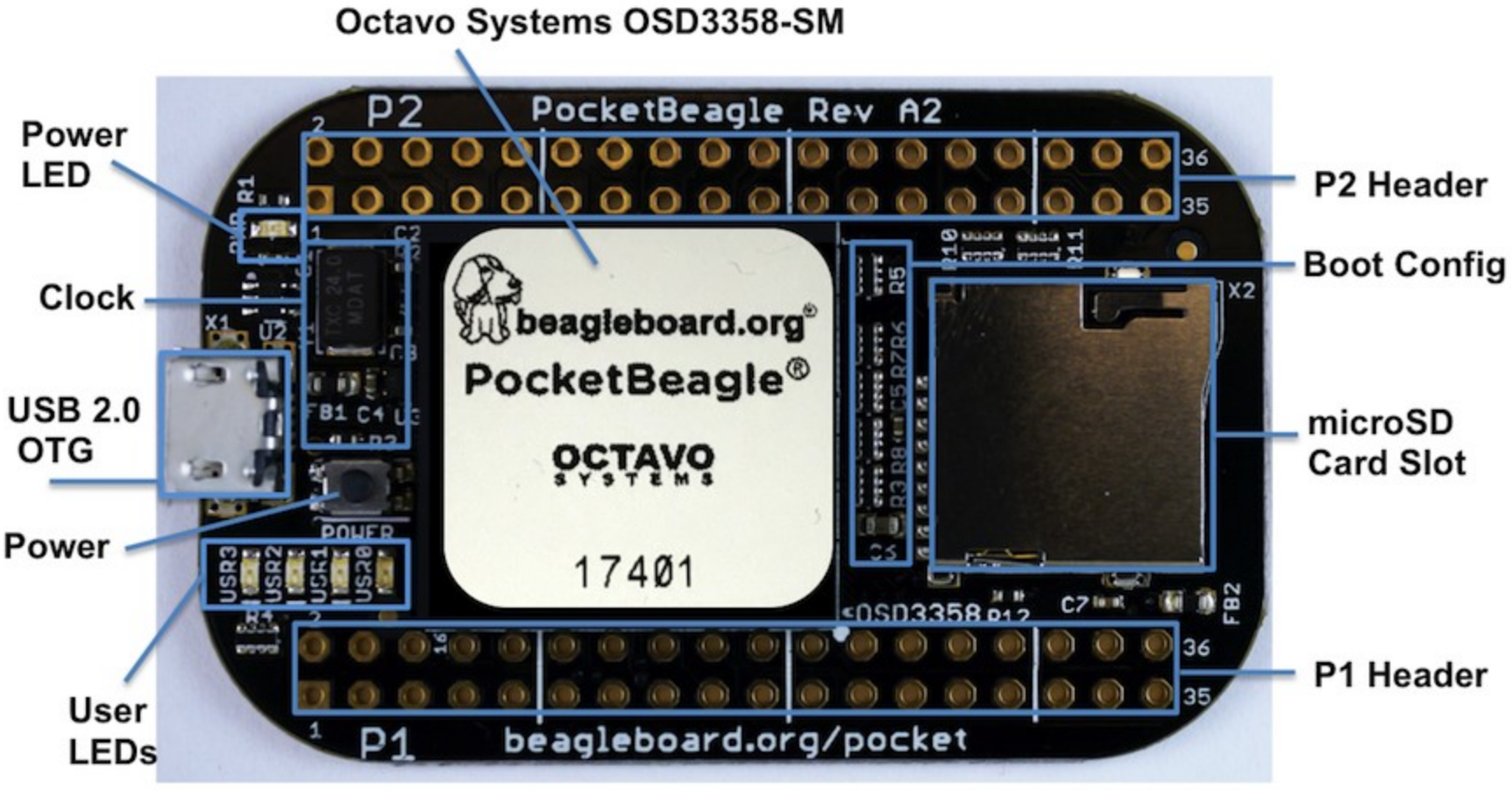
PocketBeagle objectives

- Get simple
  - 4-layer PCB done in both Kicad and EAGLE
  - Every expansion header pin has a useful predefined mode
- Get flexible
  - USB to holes, no on-board pin consumption, no header soldered
  - Support for 2 mikroBus Click boards (over 300 already exist)
- Get small
  - Stick with mint-tin survival-kit theme, but go to “smalls” (35mm x 55mm)
- Get low cost
  - System-in-package approach has can lower build costs
  - Launched/sustainable at $25

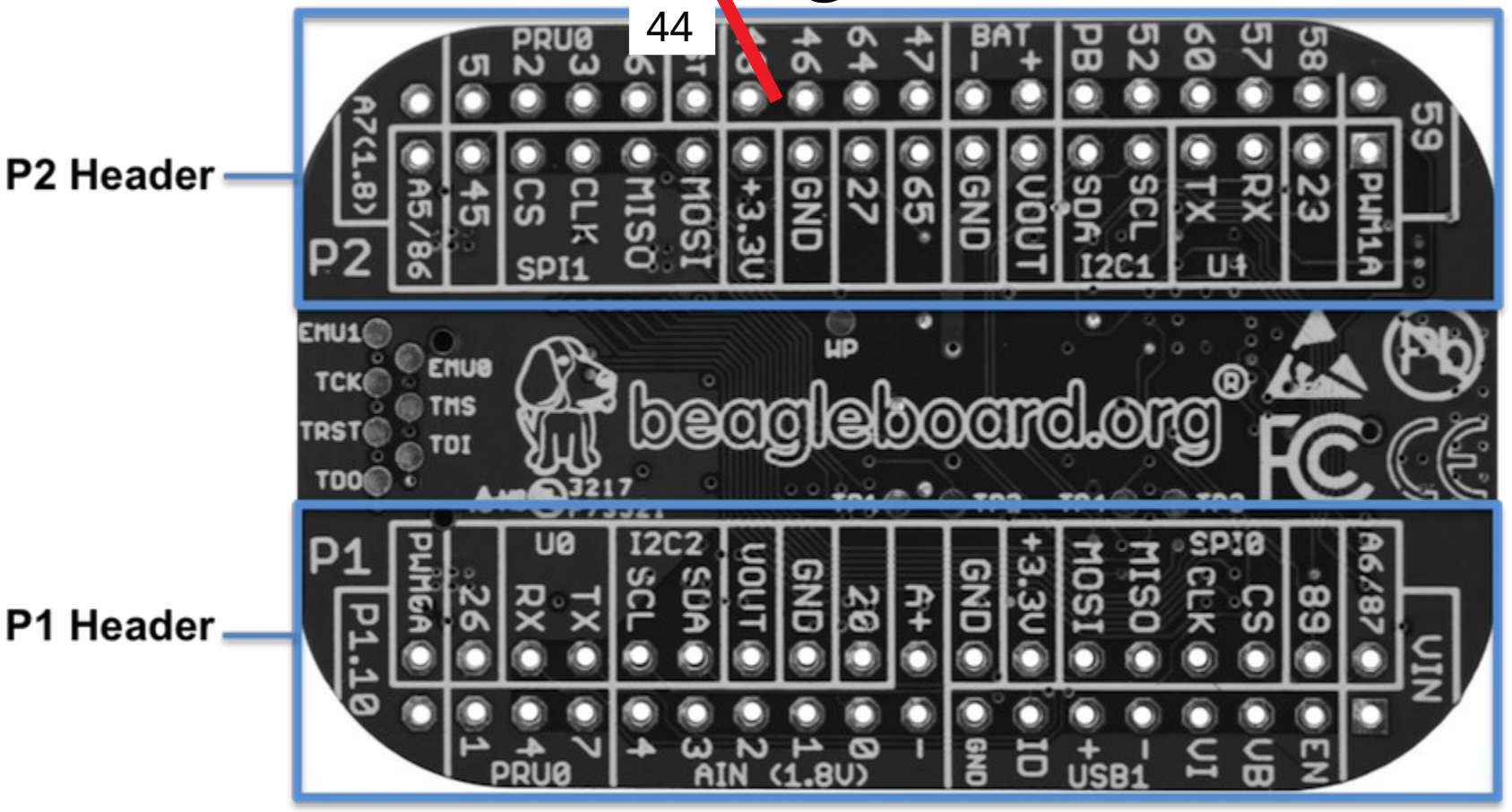
PocketBeagle key features

- Processing
  - 1-GHz ARM Cortex-A8 processor
  - 2x200-MHz programmable real-time units (PRUs)
  - ARM Cortex-M3 microcontroller for power and security
  - SGX530 graphics processor (OpenGLES)
- Memory
  - 512-MB DDR3
  - 4-KB I2C EEPROM
- Interfaces
  - USB 2.0 OTG
  - microSD
- 72 expansion header pins
  - 8 analog inputs (6@1.8V, 2@3.3V)
  - 44 digital I/Os (18 enabled)
  - 3 UARTs (2 enabled)
  - 2 I2C ports
  - 2 SPI ports
  - 2 quadrature encoders accessible
  - 2 CAN bus controllers accessible
  - USB, power/reset buttons, battery/DC

PocketBeagle top



PocketBeagle bottom



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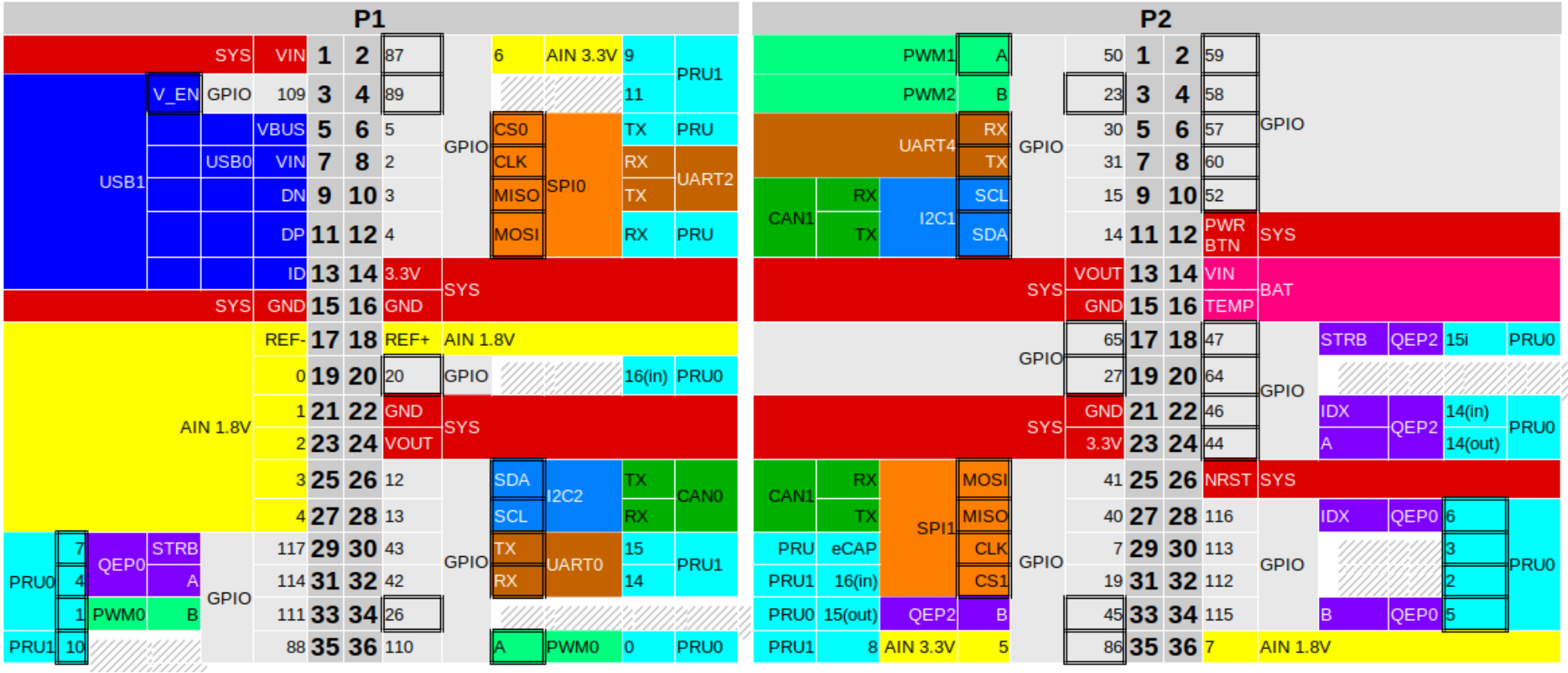
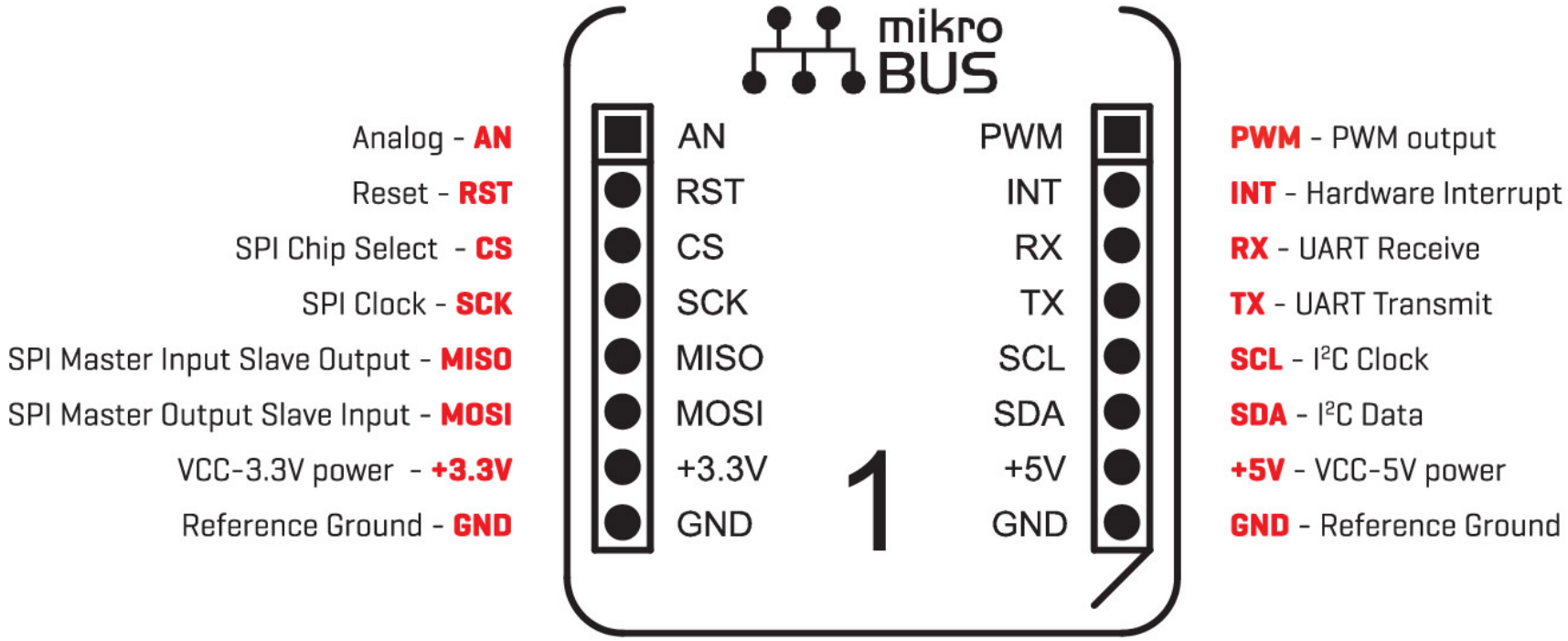
PocketBeagle expansion

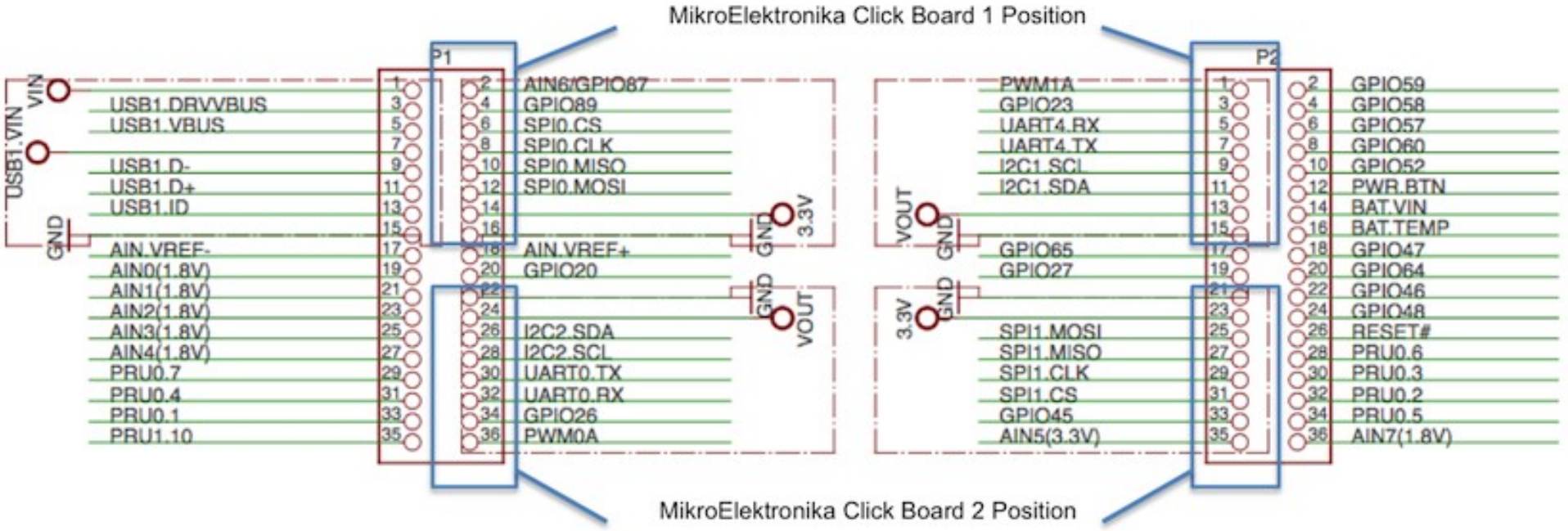
PocketBeagle Expansion Headers (Rev A2a)



mikroBus Click



Connecting mikroBus Clicks

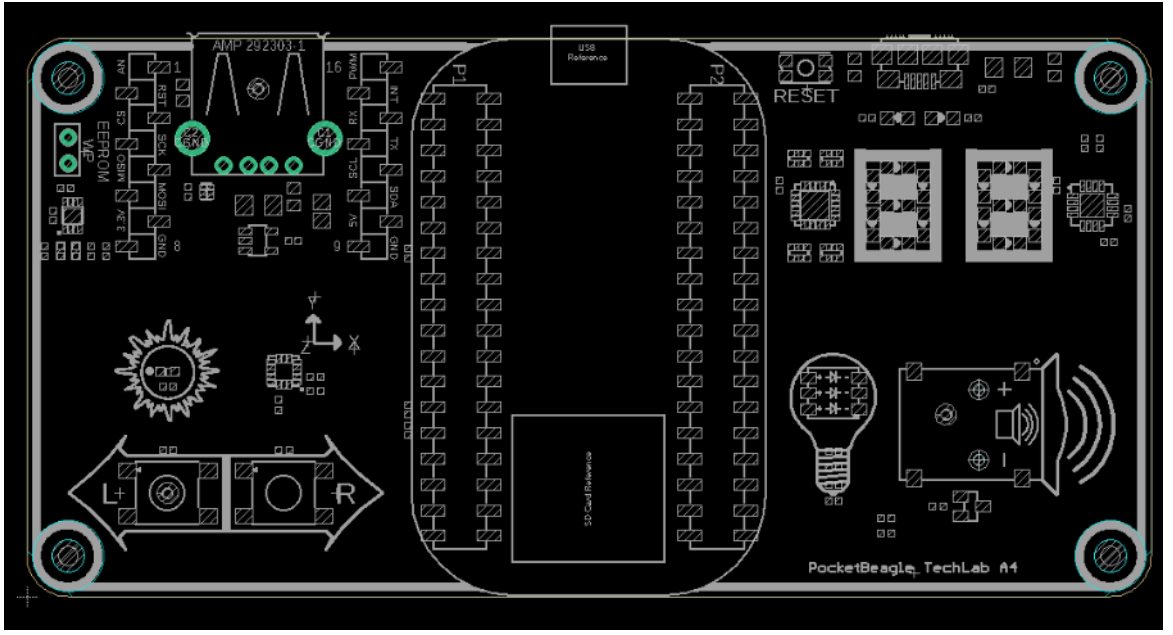


TechLab objectives

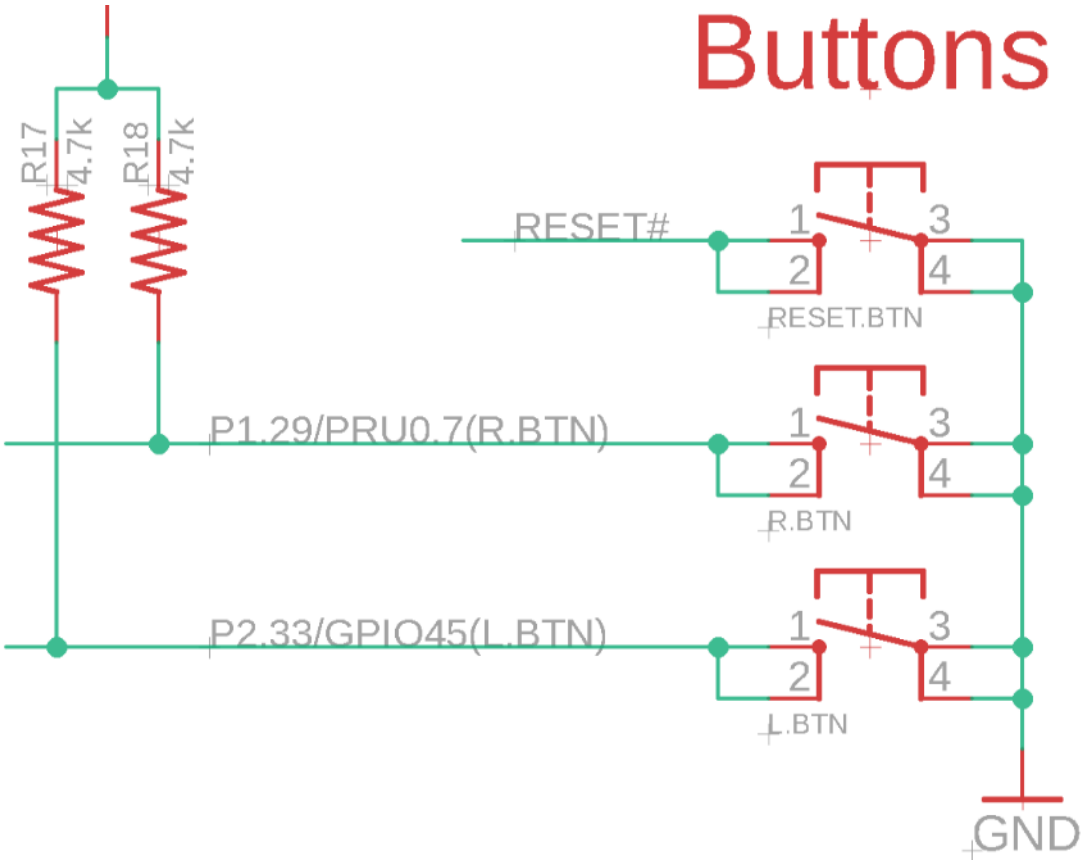
- Designed specifically for e-ale training
- Inspired by “Bacon Cape” by Dave Anders
  - Designed for similar purpose on BeagleBone
- Migrated to PocketBeagle as “BaconBits” by Michael Welling
- Updated to have mikroBus header and made “pretty”
  - Extra button (with PRU option), light sensor rather than potentiometer
- Provides target for common embedded interfaces
  - SPI, I2C, GPIO, PWM, ADC, USB, serial
- Avoid users needing to buy several modules

TechLab features

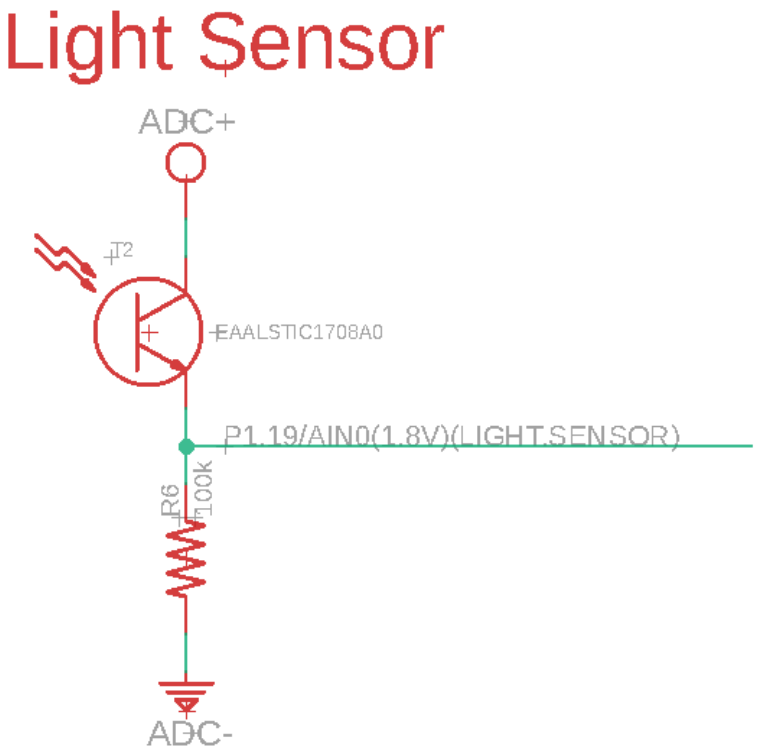
- USB-to-Serial micro B
- USB Host A with power
- Reset button
- 2 GPIO push buttons (L and R)
- ADC light sensor
- PWM tri-color LED
- SPI 2-digit 7-segment display
- I2C accelerometer
- mikroBus header



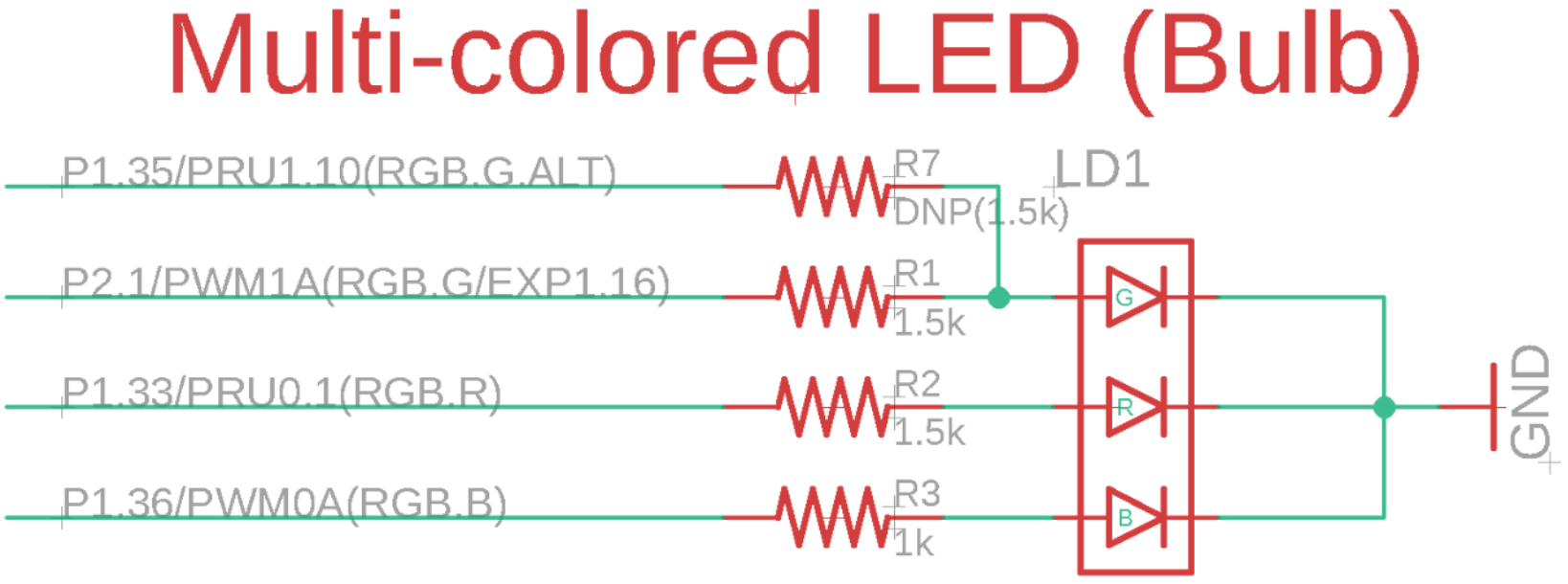
TechLab GPIO inputs



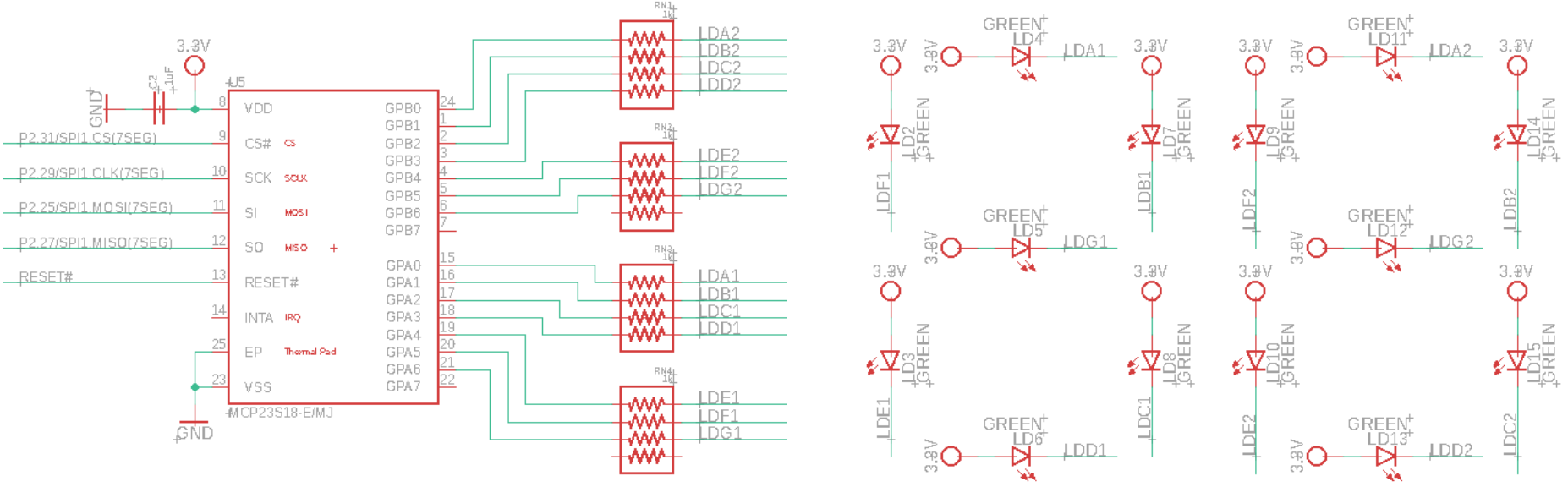
TechLab ADC input



TechLab PWM output

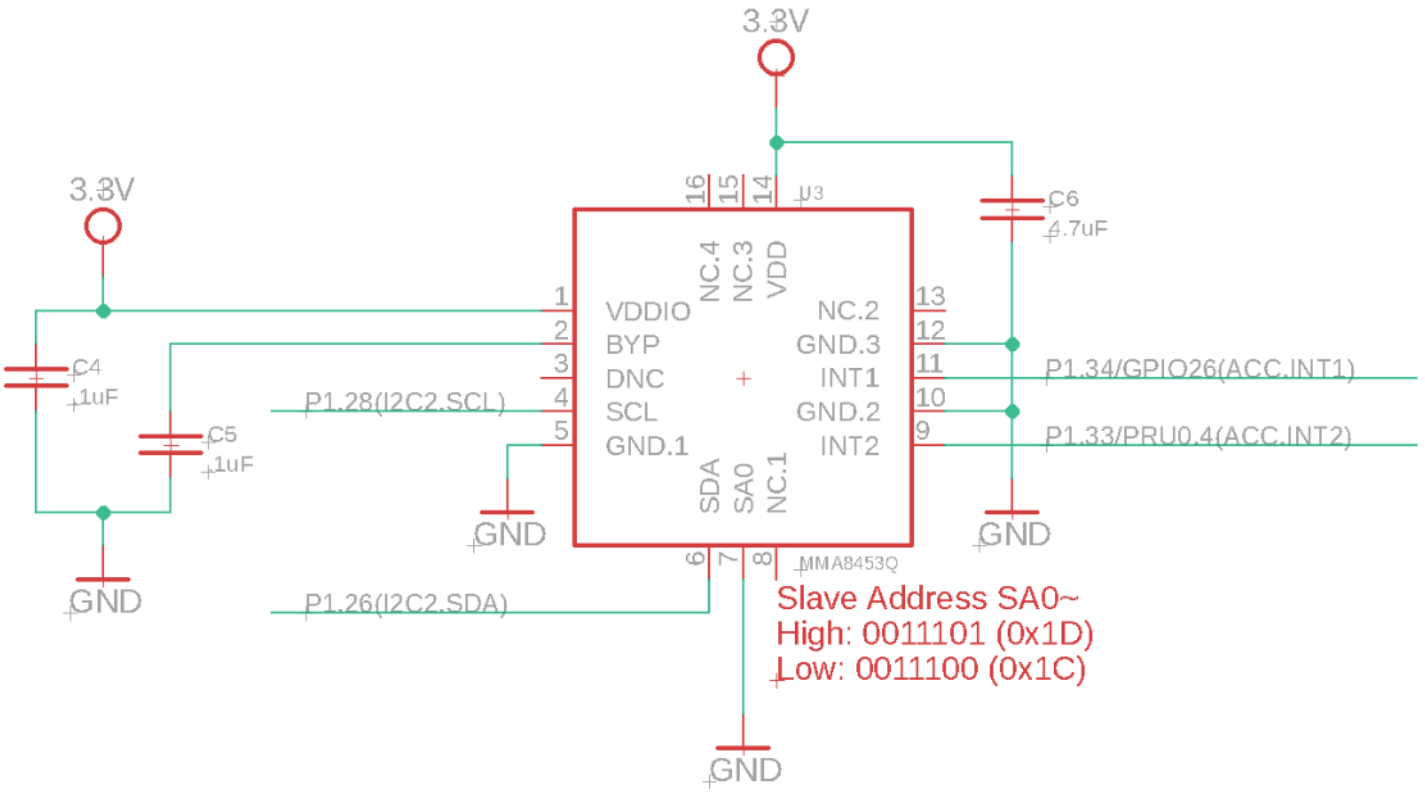


TechLab SPI 7-segment display

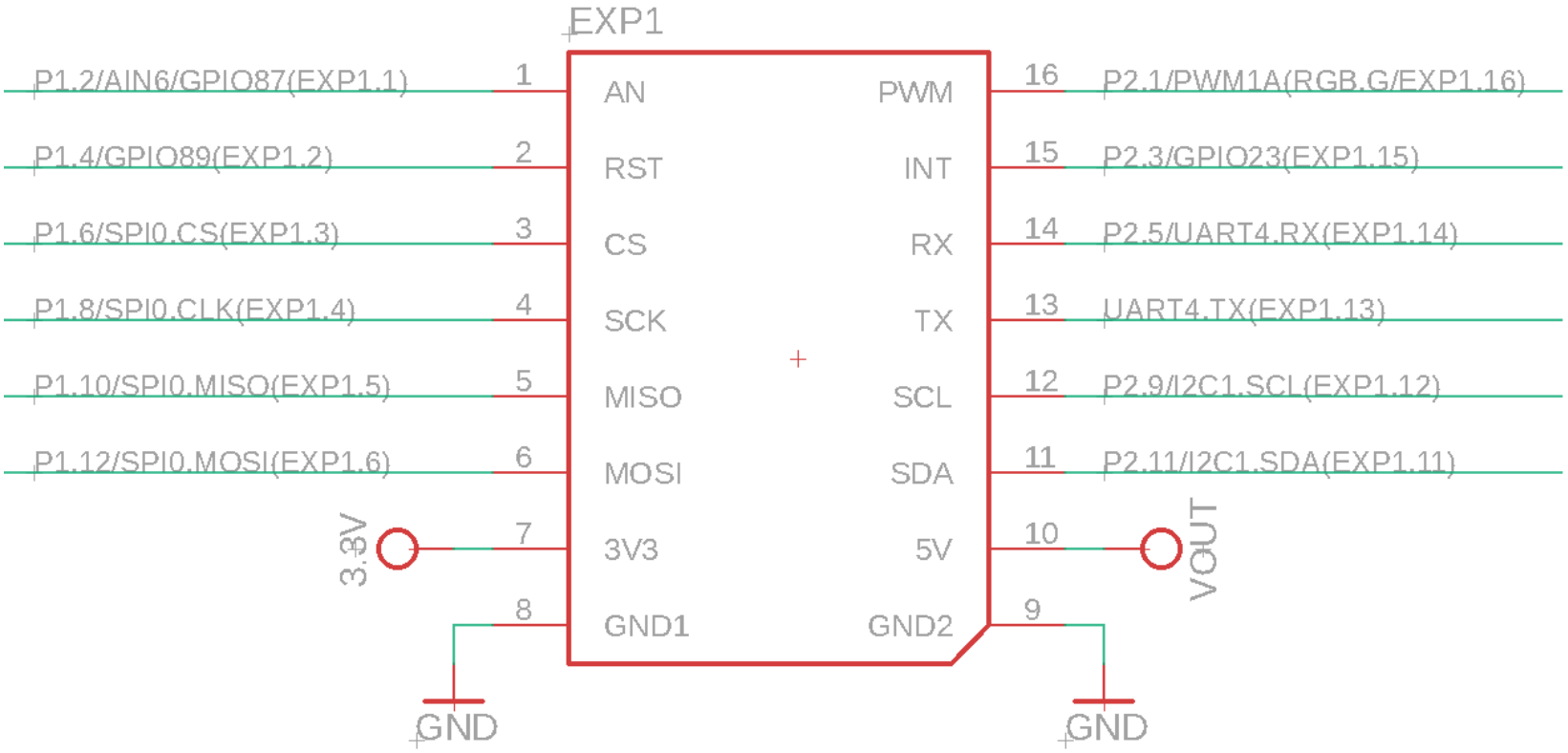


TechLab I2C sensor

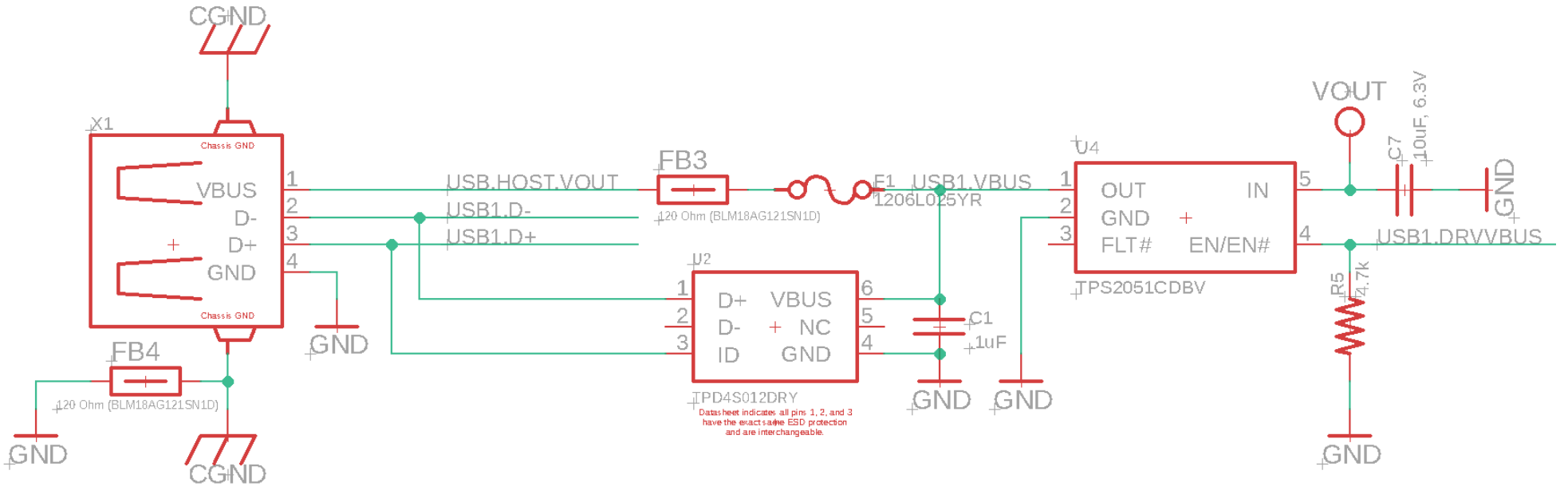
Accelerometer



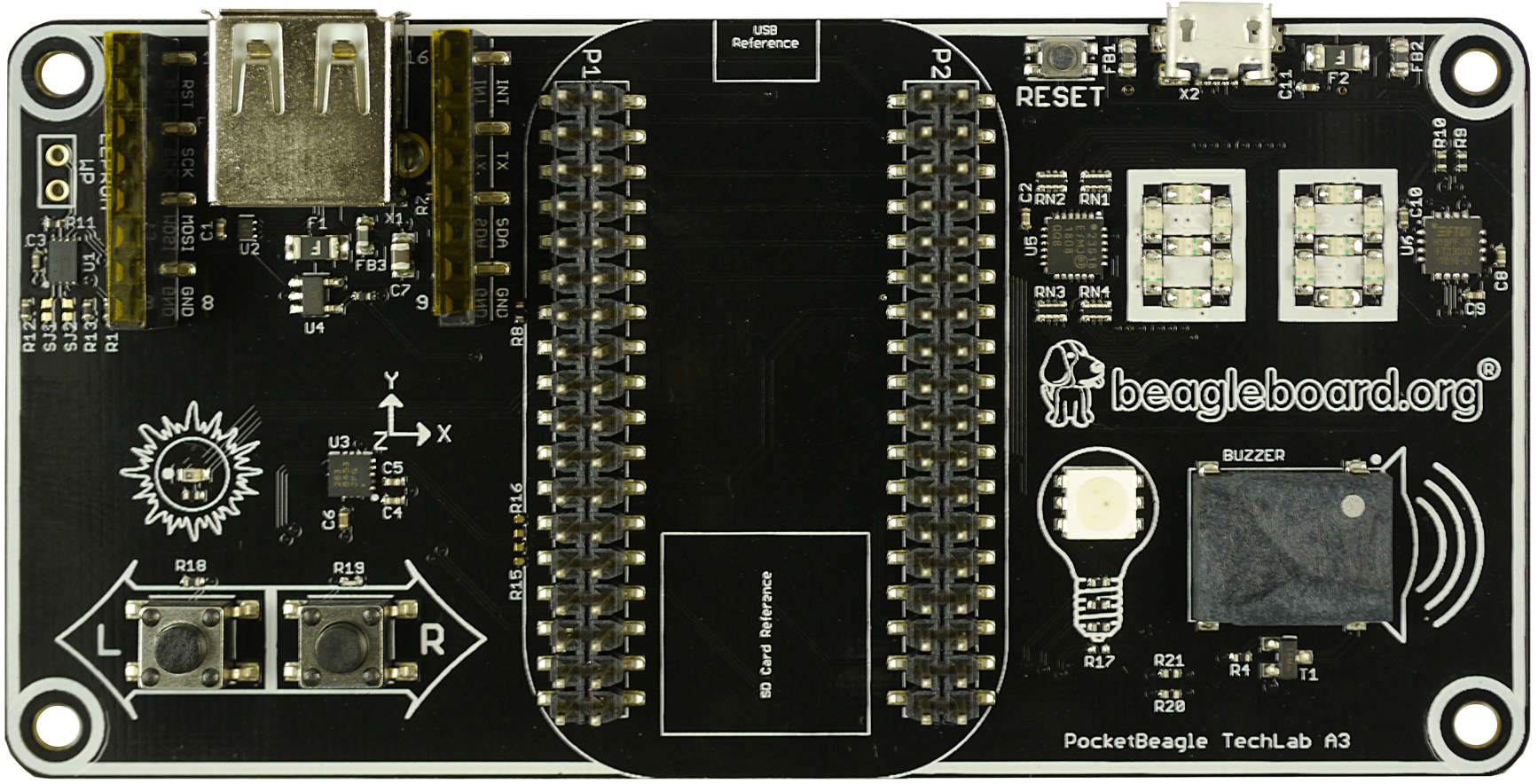
TechLab mikroBus header



TechLab USB host



TechLab board image



Developer experience

- Customized Debian images – bbb.io/latest
- Self-hosted tools for ARMs (A8/M3) and PRUs
- Libraries for various high-level languages
- Scripts for common tasks
- Sources for bootloader, device tree, etc.
- Servers for network-based development

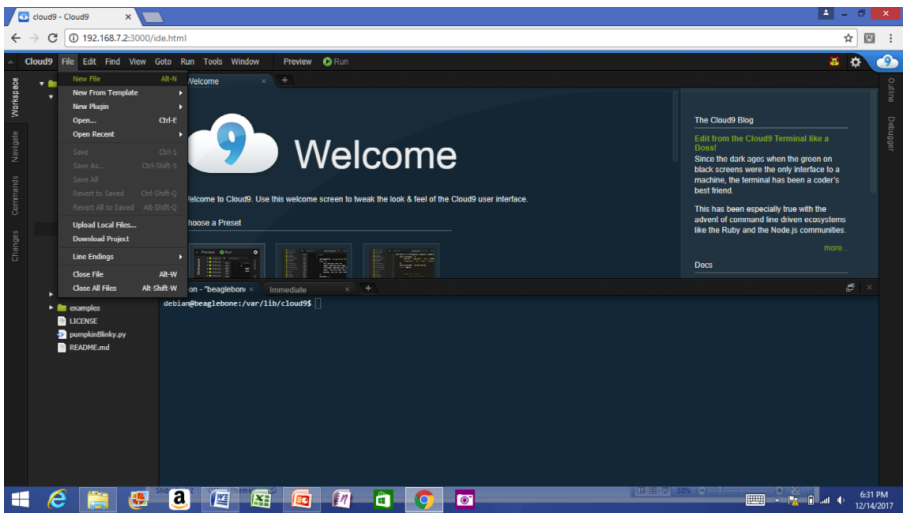
See labs in the Handouts

- No need to program the microSD card
  - The link is for your reference. This is already done for you.
- Do the first 4 labs
  - “Blink PocketBeagle on-board USRx LED”
  - “Read a button”
  - “Read an analog sensor”
  - “Fade an LED”
- I will interrupt with hints and discussion at intervals

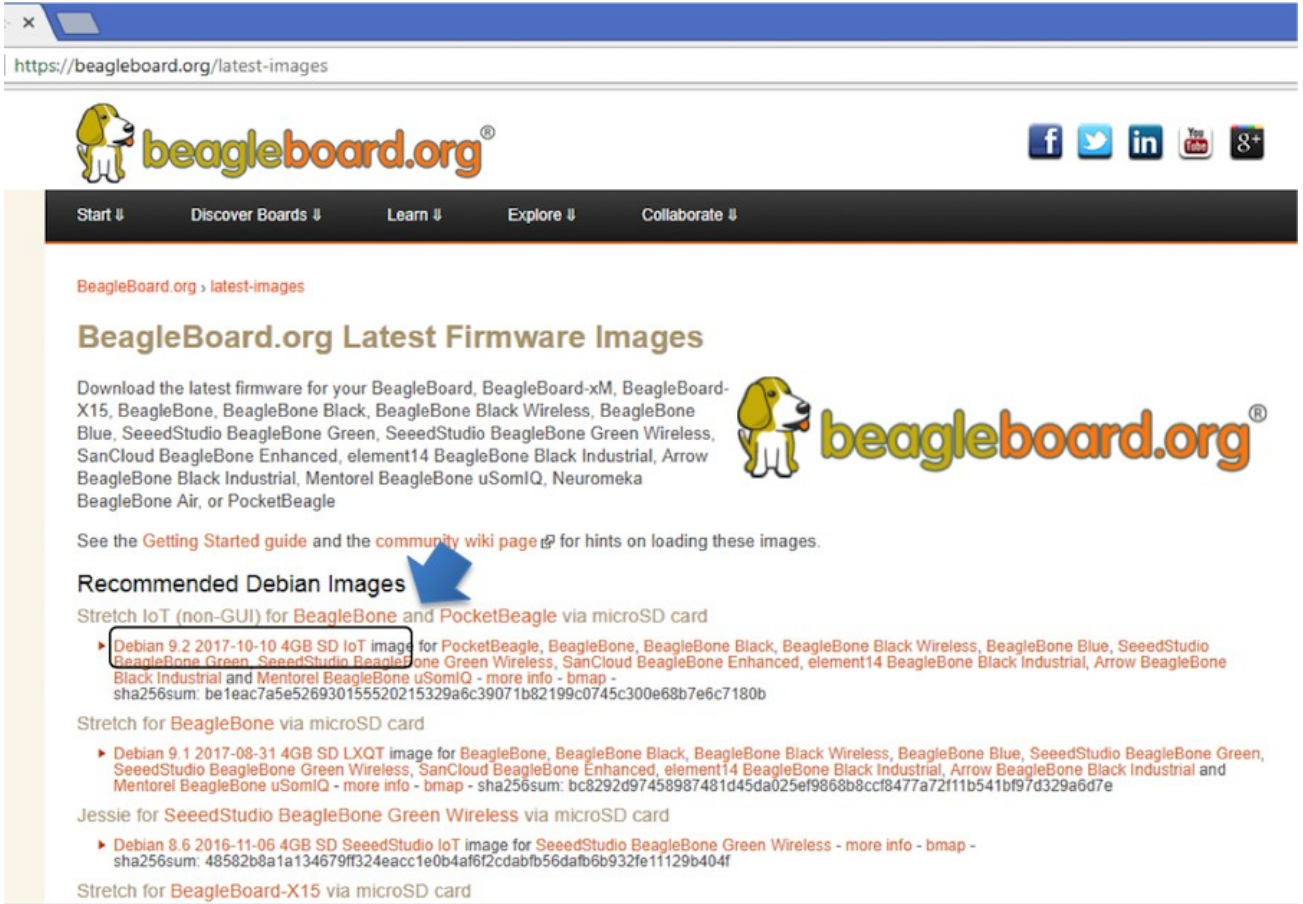
Walk me through the getting started process

Single cable development

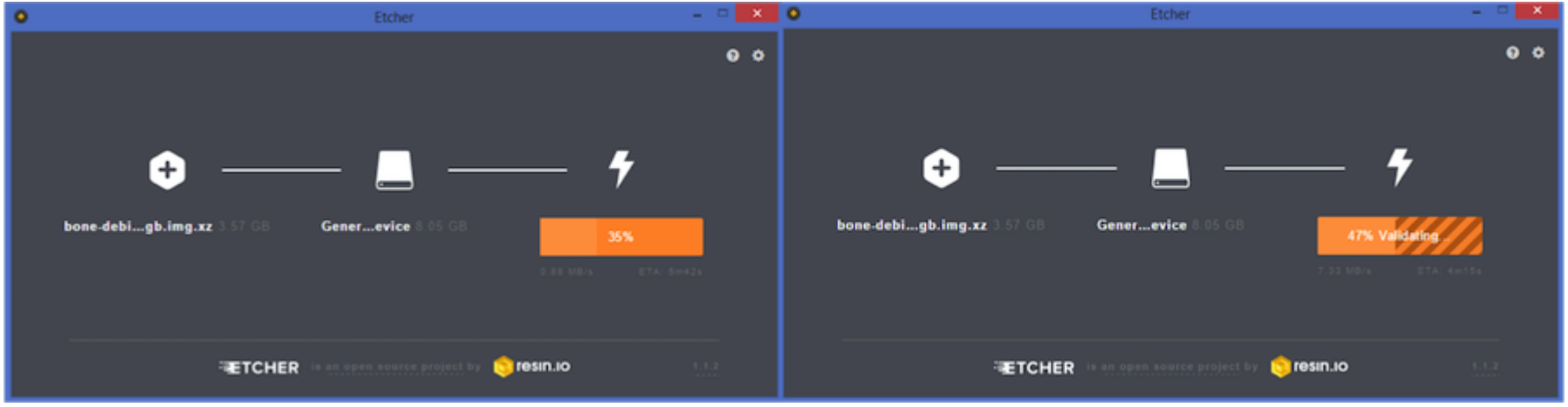
- Power, network, develop
- You can add a network and power many other ways



Download image

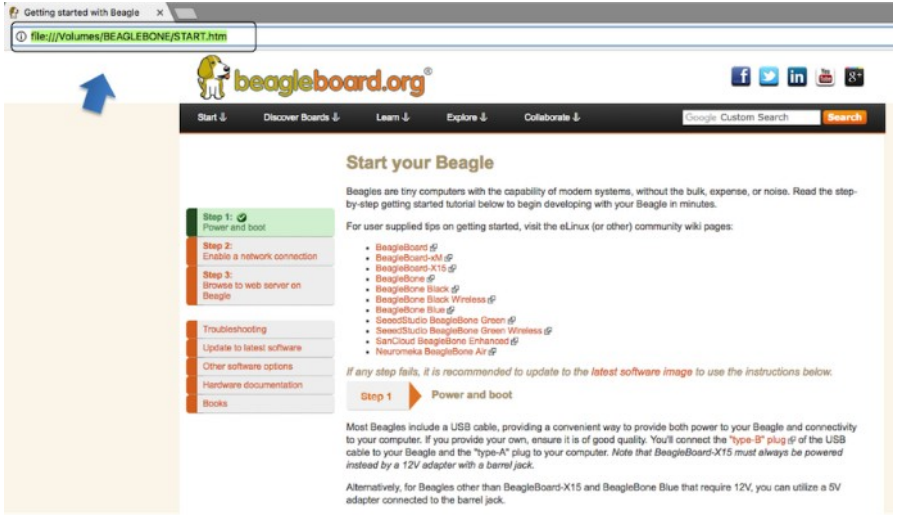


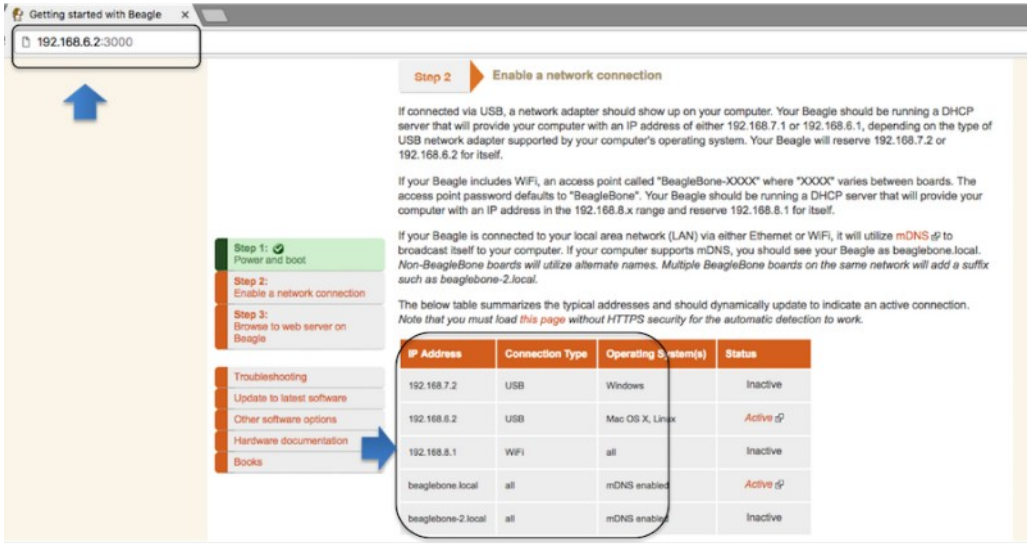
Write image to microSD with Etcher



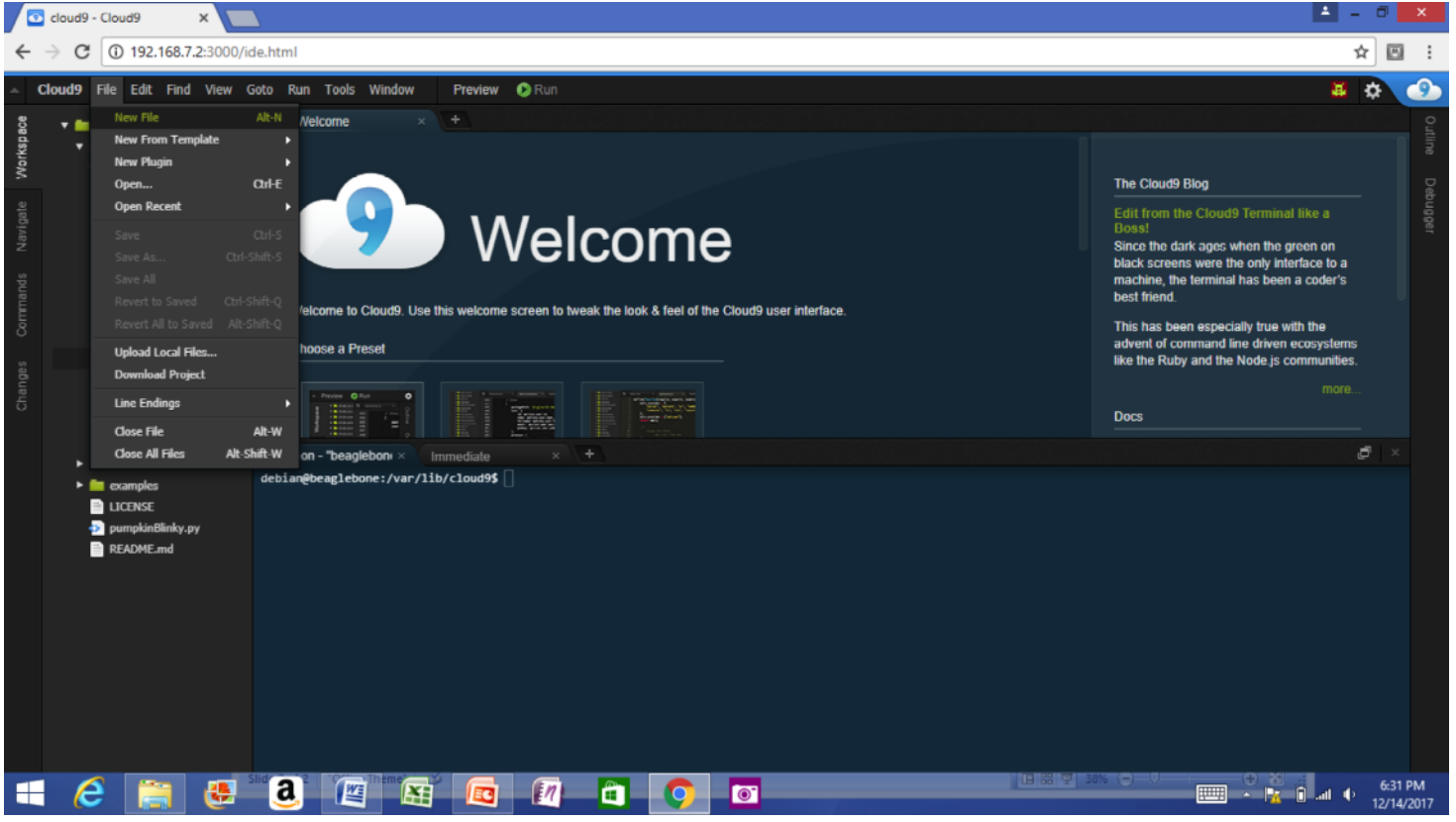
Insert microSD and boot

Connect to the USB network





Open the IDE


cloud9 - Cloud9
192.168.7.2:3000/ide.html
Cloud9
File
Edit
Find
View
Goto
Run
Tools
Window
Preview
Run
New File Alt-N
New From Template
New Plugin
Open... Ctrl-E
Open Recent
Save Ctrl-S
Save As... Ctrl-Shift-S
Save All
Revert to Saved Ctrl-Shift-Q
Revert All to Saved Alt-Shift-Q
Upload Local Files...
Download Project
Line Endings
Close File Alt-W
Close All Files Alt-Shift-W
Welcome
Welcome
elcome to Cloud9. Use this welcome screen to tweak the look & feel of the Cloud9 user interface.
hoose a Preset
The Cloud9 Blog
Edit from the Cloud9 Terminal like a Boss!
Since the dark ages when the green on black screens were the only interface to a machine, the terminal has been a coder's best friend.
This has been especially true with the advent of command line driven ecosystems like the Ruby and the Node.js communities.
more...
Docs
Immediate
debian@beaglebone:/var/lib/cloud9$
examples
LICENSE
pumpkinBlinky.py
README.md
Workspace
Navigate
Commands
Changes
Outline
Debugger
6:31 PM
12/14/2017

OK, how is this working?

USB gadgets

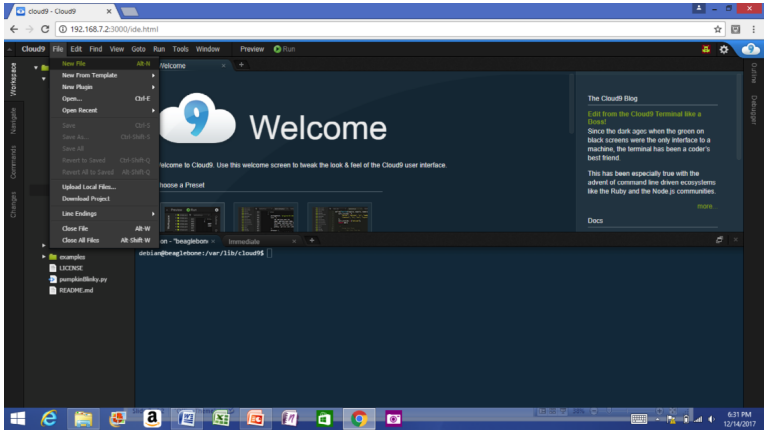
- Linux name for device/slave drivers
  - ie., when not host
- USB devices have “classes”
  - Mass storage
  - Camera
  - Audio
  - Printer
  - “HID” or human-interface device like mouse and keyboard
  - Communications

USB gadgets

- Default image USB gadgets
  - Virtual mass storage
    - Serves you up README.htm
  - Virtual serial
    - Provides access to console after kernel boot
  - Virtual network
    - Enables access to ssh and web servers

Cloud9 IDE

- Open source project
- Written in JavaScript
  - Node.js
- Hosted on PocketBeagle
  - No cloud server involved
  - No special tools on your computer, just your web browser

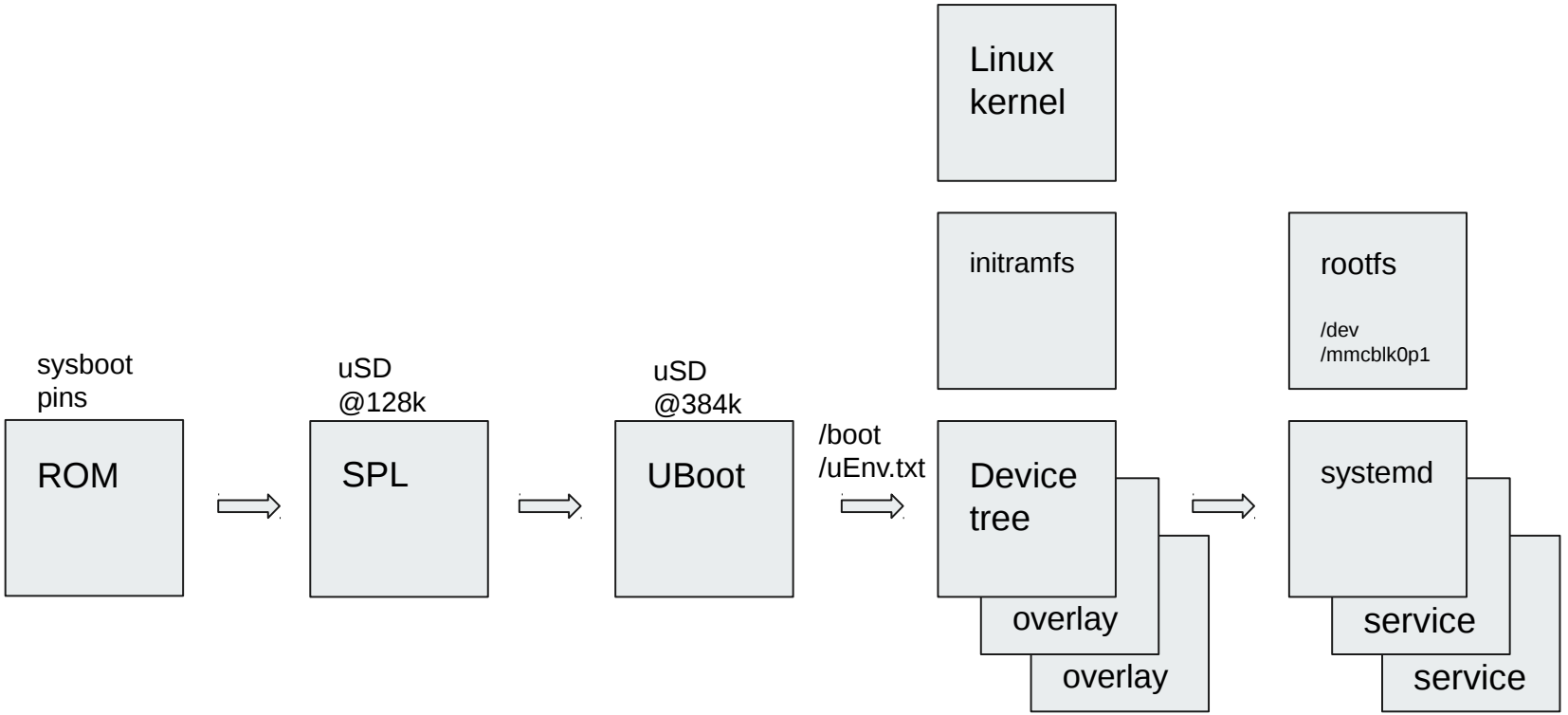


Cloud9 IDE

Your code anywhere, anytime

Yes, but what happens at startup?

Boot summary



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Device Tree

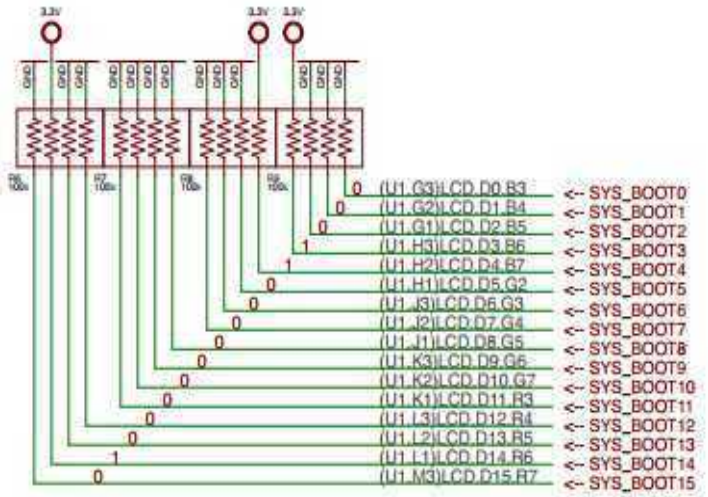
- See kernel documentation for bindings
  - devicetree/bindings/eeprom/eeprom.txt
- Local copies enable you to extend on the fly
  - /opt/source/dtb-4.14-ti
  - /opt/source/bb.org-overlays
- Overlays loaded in u-boot, but also possible via kernel configfs

Here are some more gory details
for your reference

TI AM335x: bootrom

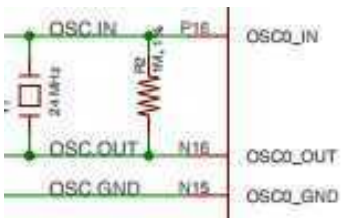
From: (AM335x and AMIC110 Sitara™ Processors Technical Reference Manual (Rev. P))

- http://www.ti.com/lit/ug/spruh73p/spruh73p.pdf (page 5032)



SYSBOOT[15:14] = 01 = 24Mhz
SYSBOOT[4:0] = 11000

1. SPI0
2. MMC0 - going to use today
3. USB0 - (node-beagle-boot)
4. UART0



TI AM335x: bootrom

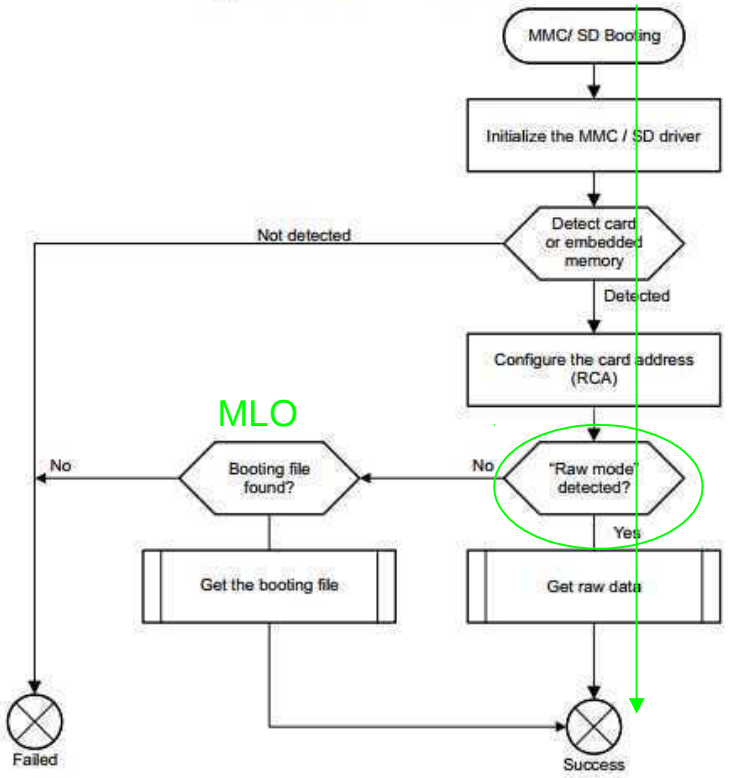
http://www.ti.com/lit/ug/spruh73p/spruh73p.pdf

Page: 5053

26.1.8.5.3 Booting Procedure

The high level flowchart of the eMMC / eSD and MMC/SD booting procedure is depicted in Figure 26-22.

Figure 26-22. MMC/SD Booting



TI AM335x: bootrom: raw mode:

http://www.ti.com/lit/ug/spruh73p/spruh73p.pdf (Page: 5054)

1. 0x0 <- (FAT Boot Sector, let's leave it blank...)
2. 0x20000 (128KB) <- We are going to use this location
3. 0x40000 (256KB) <- (2nd “backup” location)
4. 0x60000 (384KB) <- (3rd “backup” location)

Only 128KB in size... (hint, only 128KB of SRAM)

Das U-Boot (the Universal Boot Loader) U-Boot

Original Author: Wolfgang Denk, now maintained by Tom Rini

- https://www.denx.de/wiki/U-Boot
- http://git.denx.de/?p=u-boot.git;a=summary
- https://en.wikipedia.org/wiki/Das_U-Boot

U-Boot: AM335x

Outputs two files for TI am335x targets:

- MLO = SPL (or Secondary Program Loader)
- u-boot.img (or u-boot-dtb.img) (U-Boot)

U-Boot: SPL

1. Initializes main memory (DDRx for am335x)
2. Loads full (U-Boot) into DDR memory

Or:

3. Initializes main memory (DDRx for am335x)
4. Loads Linux Kernel into DDR memory (aka: Falcon mode, faster boot mode/etc)

U-Boot:

- Network
- USB
- MMC
- File System (fat/extX)
- Shell

Sometimes you don’t need a full OS, have U-Boot init and then have U-Boot load/run your application.

U-Boot:

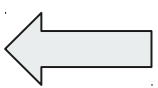
CPU : AM335X-GP rev 2.1
I2C: ready
DRAM: 512 MiB
Some drivers were not found
Reset Source: Power-on reset has occurred.
MMC: OMAP SD/MMC: 0, OMAP SD/MMC: 1
Using default environment

Board: BeagleBone Black
<ethaddr> not set. Validating first E-fuse MAC
BeagleBone Black:
Model: SeeedStudio BeagleBone Green:

U-Boot: microSD

Insert USB-microSD adapter, and type “lsblk”

```
voodoo@hestia:~/Supercon-2017-PocketBeagle$ lsblk
NAME        MAJ:MIN RM   SIZE RO TYPE MOUNTPOINT
sda           8:0    0 465.8G  0 disk
└─sda1        8:1    0 465.8G  0 part /
sde           8:64   1   7.4G  0 disk
└─sde1        8:65   1   7.4G  0 part
```



That’s our 8GB USB Flash Drive

Open: system.sh change: MMC=/dev/sde

U-Boot: Format microSD

```
sudo dd if=/dev/zero of=${MMC} bs=1M count=10

sudo sfdisk ${MMC} <<-__EOF__
4M,,L,*
__EOF__

sudo mkfs.ext4 -L rootfs ${MMC}1

voodoo@hestia:~/Supercon-2017-PocketBeagle$ ./scripts/format_drive.sh
```

U-Boot: (refresh for your memory)

http://www.ti.com/lit/ug/spruh73p/spruh73p.pdf (Page: 5054)

1. 0x0
2. 0x20000 (128KB) <- We are going to use this location
3. 0x40000 (256KB)
4. 0x60000 (384KB)

sudo dd if=./deploy/MLO of=${MMC} count=1 seek=1 bs=128k
sudo dd if=./deploy/u-boot.img of=${MMC} count=2 seek=1 bs=384k

Base Rootfs: Debian 9.x (Stretch)

Maintainer: Robert Nelson (with lots of help from all the Debian Developers and 1000's of other users)

- https://elinux.org/Beagleboard:BeagleBoneBlack_Debian#2017-11-05_-_Debian_9_.28Stretch.29_-_Weekly
- https://www.debian.org/
- https://github.com/beagleboard/image-builder

See more labs in the Handouts

- Do the last 3 labs
  - “Using Node-RED to read and write files”
  - “Explore the Linux command line”
  - “Toggle LED based on a button press using a PRU”
- I will interrupt with hints and discussion at intervals

In Linux, everything becomes a file

- Much to learn
  - I'm used to microcontrollers: just give me the datasheet with register definitions and set me free!
- Training on boot & device drivers useful
  - Often geared more at system bring-up
  - What about the everyday user?
  - Where is that abstraction benefit?
- Let's just walk a working system!

What is the baseline?

http://refspecs.linuxfoundation.org/lsb.shtml

- Every Linux system may be customized
  - This is the nature of open source
  - Stuff still needs to work together
- The Linux Standard Base
  - Umbrella for various Linux Foundation groups
  - A specification and a testkit
  - Documents typical libraries, functions and files expected to be found by the developer

lsb_release

```
debian@beaglebone:~$ sudo apt install -y lsb
debian@beaglebone:~$ lsb_release -a
No LSB modules are available.
Distributor ID: Debian
Description:    Debian GNU/Linux 9.5 (stretch)
Release:        9.5
Codename:       stretch
```

Filesystem Hierarchy Standard

http://www.pathname.com/fhs/

- /tmp: temporary files
- /var: data that is changes at run-time
- /proc: "information from processes" (virtual)
- /sys: "system filesystem" (virtual)
- /dev: device files
- /media: mount point for removable media
- /lost+found: data without directory entry
- /mnt: mount point for temporary mounted file systems
- /opt: add-on application software packages

/proc

```
debian@beaglebone:~$ ls /proc
1     1692  22    3354  878  990           fb           misc          sysvipc
10    17    23    3362  89   apm           filesystems  modules       thread-self
11    18    2370  34    9    asound        fs           mounts        timer_list
1110  1857  2375  4     90   buddyinfo     interrupts   mtd           tty
1112  19    2377  6     91   bus           iomem        net           uptime
1119  1951  2379  69    913  cgroups       ioports      pagetypeinfo  version
1150  1964  24    7     918  cmdline       irq          partitions    vmallocinfo
1151  2     25    70    92   config.gz     kallsyms     pvr           vmstat
1152  20    26    71    93   consoles      keys         sched_debug   zoneinfo
12    21    27    72    945  cpu           key-users    schedstat
1215  2107  28    73    951  cpuinfo       kmsg         self
1247  2120  29    74    959  crypto        kpagecgroup  slabinfo
13    2149  30    8     973  devices       kpagecount   softirqs
1440  2152  31    800   977  device-tree   kpageflags   stat
15    2153  32    820   980  diskstats     loadavg      swaps
159   2155  33    821   983  driver        locks        sys
16    2173  3353  858   984  execdomains   meminfo      sysrq-trigger
```

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/proc/cpuinfo

```
debian@beaglebone:~$ cat /proc/cpuinfo
processor       : 0
model name      : ARMv7 Processor rev 2 (v7l)
BogoMIPS        : 995.32
Features        : half thumb fastmult vfp edsp thumbee neon vfpv3
tls vfpd32
CPU implementer : 0x41
CPU architecture: 7
CPU variant     : 0x3
CPU part        : 0xc08
CPU revision    : 2

Hardware        : Generic AM33XX (Flattened Device Tree)
Revision        : 0000
Serial          : 1741GPB42934
```

The file interface abstraction

- What can I do with files?
  - open, read, write, close, delete
  - What is an "ioctl"?
  - What is "mmap"?
- What is a virtual file system?
  - Looks like a file, but executes code in the kernel
  - Not really storing anything to media
  - A bit like a "ram disk"

Kernel.org documentation

http://www.kernel.org/doc/

- Documentation extracted from the Linux kernel and mirrored on the web where Google can find it:
  - Documentation - Text files in the kernel source tarball's Documentation subdirectory
  - htmldocs - Kernel Documentation maintained in docbook format (output of "make htmldocs")
  - Menuconfig - help text for each kernel configuration option (from kconfig source)
  - README various README files scattered around Linux kernel source
  - RFC - List of IETF RFCs referred to by kernel source files. Links to both the text of the RFC and the source files that refer to it
  - Output of kernel's "make help"
- Standards documents applicable to the Linux kernel
- Other web pages containing kernel documentation
- Translations to other languages
- Documentation on memory management
- Miscellaneous

Kernel Application Binary Interface

http://www.kernel.org/doc/Documentation/ABI/

- Low-level kernel interface from "userland"
- Status of interface
  - Stable
    - Encouraged to use freely
    - Guaranteed for at least two years
  - Testing
    - Mostly complete, but might change
    - Let developers know how you are using
    - Where you'll find most of the good stuff
  - Obsolete
    - Scheduled for removal
  - Removed

Kernel Application Binary Interface

http://www.kernel.org/doc/Documentation/ABI/

- Types of interfaces
  - Syscalls
    - Trap interface with IDs
    - May be possible to have a direct entry
  - SYSFS
    - Virtual file system
    - See also DEBUGFS and CONFIGFS

Syscalls

http://www.kernel.org/doc/man-pages/online/pages/man2/syscalls.2.html

- open/read/write/lseek/close/unlink
- ioctl
- mknod
- fork/select/poll/...
- mkdir/...
- mount/umount
- mmap

What is SYSFS?

- Virtual file system that exposes drivers to userspace
- `mount | grep sysfs`
  - `sysfs on /sys type sysfs (rw,nosuid,nodev,noexec,relatime)`
- /sys/devices - driver hierarchy
- /sys/bus - symbolic links to bus owners
- /sys/class - common interfaces
- /sys/block - block interface
- How about some examples?

/sys/module

http://www.kernel.org/doc/Documentation/ABI/stable/sysfs-module

- /sys/module/MODULENAME
  - .../parameters: options you can provide
  - .../refcnt: number of times in use

```
debian@beaglebone:~$ ls /sys/module
8250              fb                  lockd                    pruss           sysrq            usb_f_ecm
apparmor          firmware_class      mma8452                  pruss_intc      tcp_cubic        usb_f_mass_storage
auth_rpcgss       fscrypto            mmcblk                   pruss_soc_bus   tda18271         usb_f_rndis
block             fuse                module                   pvrsrvkm        tda827x          usbhid
bone_capemgr      hid                 mt20xx                   r8188eu         tda8290          usb_storage
can               hid_logitech        netpoll                  random          tda9887          u_serial
cec               hid_logitech_hidpp  nf_conntrack             rc_core         tea5761          vt
cfg80211          i2c_algo_bit        nf_conntrack_ipv4        rcupdate        tea5767          watchdog
configfs          ima                 nf_defrag_ipv4           rcutree         ti_cpsw          wireguard
cpufreq           iptable_filter      nf_nat                   rfkill          tpm              workqueue
cpuidle           iptable_mangle      nf_nat_ipv4              rng_core        tuner_simple     xc4000
cryptomgr         iptable_nat         nfs                      scsi_mod        tuner_xc2028     xc5000
dns_resolver      ip_tables           nfs_layout_nfsv41_files  sdhci           ubi              xhci_hcd
drm               ipv6                nfsv4                    snd             ubifs            x_tables
drm_kms_helper    ir_kbd_i2c          omapdrm                  snd_pcm         udl              xz_dec
dvb_core          kernel              omap_mailbox             snd_timer       u_ether          zswap
dynamic_debug     keyboard            onenand                  spidev          uinput
eeprom_93cx6      leds_pwm            overlay                  spurious        uio
ehci_hcd          libahci             pinctrl_mcp23s08         srcutree        uio_pdrv_genirq
etnaviv           libata              printk                   sunrpc          usbcore
evdev             libcomposite        pru_rproc                suspend         usb_f_acm
```

/sys/class/leds

https://www.kernel.org/doc/Documentation/ABI/testing/sysfs-class-led

- /sys/class/leds/LED
  - .../brightness: 0-max_brightness, >0 = on
  - .../max_brightness: default is 255
  - .../trigger: triggers available from kernel
  - .../inverted: invert on/off state

```
debian@beaglebone:~$ ls /sys/class/leds
beaglebone:green:usr0  techlab::blue   techlab::seg1   techlab::seg13  techlab::seg3  techlab::seg7
beaglebone:green:usr1  techlab::green  techlab::seg10  techlab::seg14  techlab::seg4  techlab::seg8
beaglebone:green:usr2  techlab::red    techlab::seg11  techlab::seg15  techlab::seg5  techlab::seg9
beaglebone:green:usr3  techlab::seg0   techlab::seg12  techlab::seg2   techlab::seg6
```

/sys/class/gpio

http://www.kernel.org/doc/Documentation/ABI/testing/sysfs-gpio

- Must be explicitly exported to userspace and not claimed by kernel code
- /sys/class/gpio
  - .../export: asks the kernel to export a GPIO to userspace
  - .../unexport: to return a GPIO to the kernel
  - .../gpioN: for each exported GPIO #N
    - .../value: always readable, writes fail for input GPIOs
    - .../direction: r/w as: in, out (low); write: high, low
    - .../edge: r/w as: none, falling, rising, both
  - .../gpiochipN:for each gpiochip; #N is its first GPIO
    - .../base: (r/o) same as N
    - .../label: (r/o) descriptive, not necessarily unique
    - .../ngpio: (r/o) number of GPIOs; numbered N to N + (ngpio - 1)

```
debian@beaglebone:~$ ls /sys/class/gpio
export   gpio114  gpio13  gpio20  gpio30  gpio42  gpio47  gpio58  gpio7   gpiochip0    unexport
gpio110  gpio115  gpio14  gpio23  gpio31  gpio43  gpio5   gpio59  gpio86  gpiochip32
gpio111  gpio116  gpio15  gpio26  gpio4   gpio44  gpio50  gpio60  gpio87  gpiochip496
gpio112  gpio117  gpio19  gpio27  gpio40  gpio45  gpio52  gpio64  gpio88  gpiochip64
gpio113  gpio12   gpio2   gpio3   gpio41  gpio46  gpio57  gpio65  gpio89  gpiochip96
```

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On-chip peripherals (OCP)

```
debian@beaglebone:~$ ls /sys/devices/platform/ocp
40300000.ocmcram  480c8000.mailbox        53100000.sham          ocp:P1_32_pinmux  ocp:P2_20_pinmux
44e07000.gpio     480ca000.spinlock       53500000.aes           ocp:P1_33_pinmux  ocp:P2_22_pinmux
44e09000.serial   4819c000.i2c            56000000.sgx           ocp:P1_34_pinmux  ocp:P2_24_pinmux
44e0b000.i2c      481a0000.spi            driver_override        ocp:P1_35_pinmux  ocp:P2_25_pinmux
44e0d000.tscadc   481a8000.serial         modalias               ocp:P1_36_pinmux  ocp:P2_27_pinmux
44e35000.wdt      481ac000.gpio           ocp:cape-universal     ocp:P2_01_pinmux  ocp:P2_28_pinmux
44e3e000.rtc      481ae000.gpio           ocp:l4_wkup@44c00000   ocp:P2_02_pinmux  ocp:P2_29_pinmux
47400000.usb      481cc000.can            ocp:P1_02_pinmux       ocp:P2_03_pinmux  ocp:P2_30_pinmux
48022000.serial   481d0000.can            ocp:P1_04_pinmux       ocp:P2_04_pinmux  ocp:P2_31_pinmux
48024000.serial   48300000.epwmss         ocp:P1_06_pinmux       ocp:P2_05_pinmux  ocp:P2_32_pinmux
4802a000.i2c      48302000.epwmss         ocp:P1_08_pinmux       ocp:P2_06_pinmux  ocp:P2_33_pinmux
48030000.spi      48304000.epwmss         ocp:P1_10_pinmux       ocp:P2_07_pinmux  ocp:P2_34_pinmux
48042000.timer    48310000.rng            ocp:P1_12_pinmux       ocp:P2_08_pinmux  ocp:P2_35_pinmux
48044000.timer    49000000.edma           ocp:P1_20_pinmux       ocp:P2_09_pinmux  of_node
48046000.timer    49800000.tptc           ocp:P1_26_pinmux       ocp:P2_10_pinmux  power
48048000.timer    49900000.tptc           ocp:P1_28_pinmux       ocp:P2_11_pinmux  subsystem
4804a000.timer    49a00000.tptc           ocp:P1_29_pinmux       ocp:P2_17_pinmux  uevent
4804c000.gpio     4a326004.pruss-soc-bus  ocp:P1_30_pinmux       ocp:P2_18_pinmux
48060000.mmc      4c000000.emif           ocp:P1_31_pinmux       ocp:P2_19_pinmux
```

Instantiating a device: .dts example

```
&i2c0 {
        pinctrl-names = "default";
        pinctrl-0 = <&i2c0_pins>;

        status = "okay";
        clock-frequency = <400000>;

        tps: tps@24 {
                reg = <0x24>;
        };

        baseboard_eeprom: baseboard_eeprom@50 {
                compatible = "at,24c256";
                reg = <0x50>;

                #address-cells = <1>;
                #size-cells = <1>;
                baseboard_data: baseboard_data@0 {
                        reg = <0 0x100>;
                };
        };
};
```

Phandle (reference to label)

Pin muxing configuration (routing to external package pins)

Enabling this device, otherwise ignored

Node property: frequency

List of devices on i2c0

I2C bus identifier

From arch/arm/boot/dts/am335x-boneblue.dts

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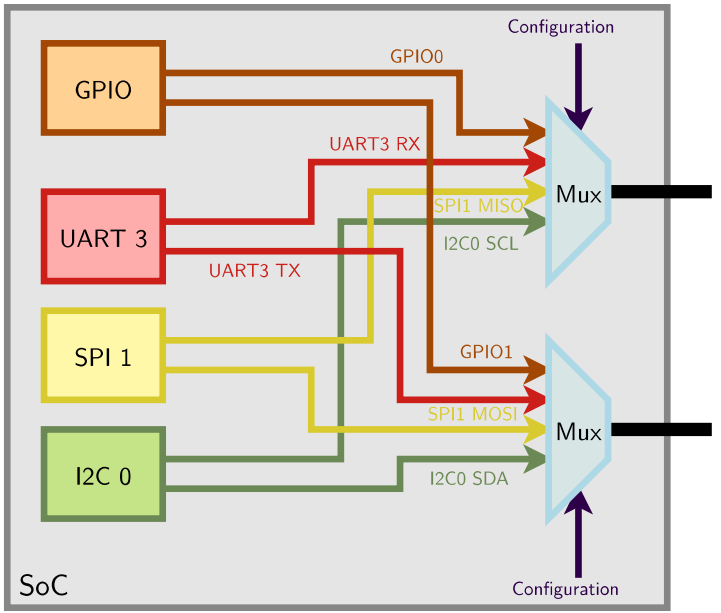
Pin multiplexing

- Modern SoCs have too many hardware blocks compared to physical pins exposed on the chip package.
- Therefore, pins have to be multiplexed
- Pin configurations are defined in the Device Tree
- Correct pin multiplexing is mandatory to make a device work from an electronic point of view.



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DT pin definitions

```
&am33xx_pinmux {
      ...
      i2c0_pins: pinmux_i2c0_pins {
            pinctrl-single,pins = <
                  AM33XX_IOPAD(0x988, PIN_INPUT_PULLUP | MUX_MODE0)       /* (C17) I2C0_SDA.I2C0_SDA */
                  AM33XX_IOPAD(0x98c, PIN_INPUT_PULLUP | MUX_MODE0)       /* (C16) I2C0_SCL.I2C0_SCL */
            >;
      };
      …
};

...

&i2c0 {
        pinctrl-names = "default";
        pinctrl-0 = <&i2c0_pins>;

        status = "okay";
        clock-frequency = <400000>;
        ...
};
```

Register offset corresponding to a given package pin

Configures the pin: input, output, drive strengh, pull up/down...

Allows to select a given SoC signal

Package pin name

SoC signal name

From arch/arm/boot/dts/am335x-boneblue.dts

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DT: matching devices and drivers

Platform drivers are matched with platform devices that have the same `compatible` property.

```
static const struct of_device_id omap_i2c_of_match[] = {
        {
                .compatible = "ti,omap4-i2c",
                .data = &omap4_pdata,
        },
        {
…
};
…
static struct platform_driver omap_i2c_driver = {
        .probe          = omap_i2c_probe,
        .remove         = omap_i2c_remove,
        .driver         = {
                .name   = "omap_i2c",
                .pm     = OMAP_I2C_PM_OPS,
                .of_match_table = of_match_ptr(omap_i2c_of_match),
        },
};
```

From drivers/i2c/busses/i2c-omap.c

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config-pin

https://github.com/beagleboard/bb.org-overlays - tools/beaglebone-universal-io

```
debian@beaglebone:~$ config-pin -i p1.36
Pin name: P1_36
Function if no cape loaded: pwm
Function if cape loaded: default gpio gpio_pu gpio_pd
gpio_input spi_sclk pwm pruout pruin
Function information: ehrpwm0a default gpio3_14 gpio3_14
gpio3_14 gpio3_14 spi1_sclk ehrpwm0a pru0_out0 pru0_in0
Kernel GPIO id: 110
PRU GPIO id: 142
debian@beaglebone:~$ config-pin -q p1.36
P1_36 Mode: default Direction: in Value: 0
debian@beaglebone:~$ config-pin p1.36 pruout
debian@beaglebone:~$ config-pin -q p1.36
P1_36 Mode: pruout
```

show-pins.pl

- perl /opt/scripts/device/bone/show-pins.pl -v

Enabling PRU

- 2 possible drivers: remoteproc or uio
- Enabled via device tree at boot
  - Different systems might have different defaults

mikroBus Click usage

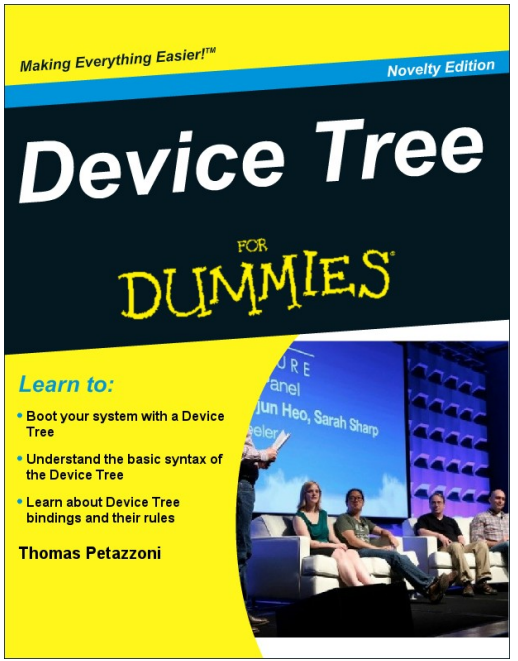
- See bbb.io/pbmb
- Supported with device-tree overlays loaded in u-boot

Some work in progress

- Add proxy for various services (in Buster IoT images today)
- Integrate common web-based WiFi provisioning
  - SeeedStudio BealgeBone Green Wireless ships with ‘wifidog’ → we will unify approach
- Cross-platform distro installer app
  - See USB NETCONSOLE presentation
- Support for Grove modules and mikroBus clicks
  - Focus on device-tree overlays and kernel patches
- Integration alignment with complete domain solutions
  - Intelligent Agent Replicape/Revolve, Bela Mini, BeagleLogic, PocketPilot, etc.
- Improved and integrated PRU examples
- Move to distro friendly approaches for customizations

Further reading

- Bootlin's kernel and driver development training materials for full details https://bootlin.com/training/kernel/
- Device Tree for Dummies presentation Thomas Petazzoni (Apr. 2014) http://j.mp/1jQU6NR



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Contributions and issues

- Cape/add-on support
  - https://github.com/beagleboard/bb.org-overlays
- Image deltas
  - https://github.com/beagleboard/image-builder
- In-system examples
  - https://github.com/beagleboard/bone101


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Questions?


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Thank you!