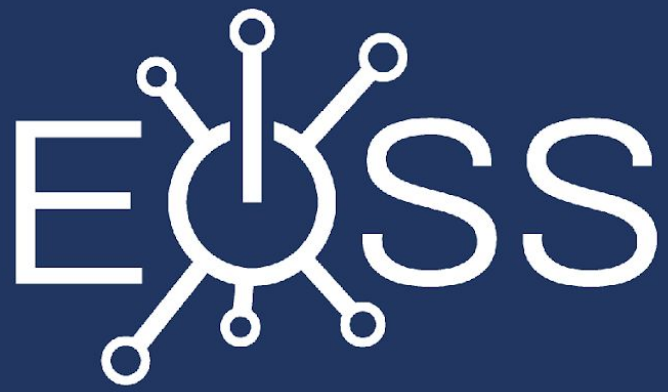

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Recent Advances in U-Boot

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Thursday 29 June 2023

Agenda

- What is U-Boot?
- Complexity in firmware
- How U-Boot helps with complexity
- New things in U-Boot in the last few years
- Demo

U-Boot

- Universal boot loader
  - Boot anything on anything
  - Project has been running for about 20 years
  - Typically 6k commits each year; under very active development
  - Four releases each year; release candidate every two weeks
- Large feature set
  - Around 3m lines of C code; some tools are in Python
  - Kernel style, shares APIs with Linux, configured with Kconfig
  - Main architectures are ARM, PowerPC, RISC-V, x86
  - CI covers a large subset of features
- On the forefront of embedded firmware technology

Why is U-Boot so popular?

- Supports most of the features that people want in a bootloader
  - Large array of board support
  - Linux compatibility / easy porting
- Easy to modify and extend
  - Relatively simple code base
  - Most feature development can be done on the host (sandbox builds)
  - Single-threaded (no locking infrastructure or concurrency problems)
  - Good documentation and test infrastructure
- Open to new ideas and features
- Consistent release schedule

The challenge of increasing complexity

- Complexity is growing in many areas
  - SoCs - more IP blocks, power domains, multiple CPU types
  - Firmware packaging - private tools and techniques
  - Security / signing - SoC-specific with many variations
  - Boot flow / firmware fragmentation - multiple firmware projects in one firmware image
  - Build and device configuration - different product models, features enabled/disabled
- What is U-Boot doing to cope with this complexity?

Dealing with SoC complexity

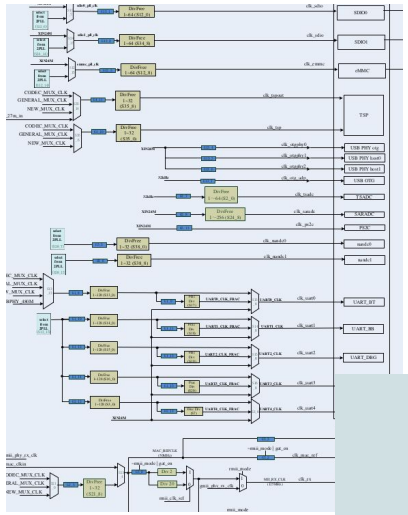
- U-Boot's driver model provides
  - Linux-compatible devicetree support
  - Over 100 driver classes, e.g. BLK, MMC, PCI, VIDEO
  - Parent / child relationships and automatic private data
  - Relatively easy porting from Linux (e.g. MTD layer)

```
&i2c0 {
      clock-frequency = <400000>;
      i2c-scl-rising-time-ns = <168>;
      i2c-scl-falling-time-ns = <4>;
      status = "okay";

      rk808: pmic@1b {
            compatible = "rockchip,rk808";
            reg = <0x1b>;
            interrupt-parent = <&gpio3>;
            interrupts = <10 IRQ_TYPE_LEVEL_LOW>;
            #clock-cells = <1>;
            clock-output-names = "xin32k", "rk808-clkout2";
            pinctrl-names = "default";
            pinctrl-0 = <&pmic_int_l>;
            rockchip,system-power-controller;
            wakeup-source;
```

```
mmc           1   [ + ]   rockchip_rk3288_dw_m  |-- mmc@ff0d0000
blk           1   [   ]   mmc_blk               |   |-- mmc@ff0d0000.blk
bootdev       1   [   ]   mmc_bootdev           |   `-- mmc@ff0d0000.bootdev
mmc           2   [ + ]   rockchip_rk3288_dw_m  |-- mmc@ff0f0000
blk           2   [   ]   mmc_blk               |   |-- mmc@ff0f0000.blk
bootdev       2   [   ]   mmc_bootdev           |   `-- mmc@ff0f0000.bootdev
spi           0   [ + ]   rockchip_rk3288_spi   |-- spi@ff110000
cros-ec       0   [ + ]   google_cros_ec_spi    |   `-- ec@0
i2c           0   [   ]   cros_ec_tunnel        |       |-- i2c-tunnel
keyboard      0   [ + ]   google_cros_ec_keyb   |       `-- keyboard-controller
spi           1   [   ]   rockchip_rk3288_spi   |-- spi@ff130000
spi_flash     0   [   ]   jedec_spi_nor         |   `-- spiflash@0
i2c           1   [   ]   rockchip_rk3066_i2c   |-- i2c@ff140000
i2c           2   [   ]   rockchip_rk3066_i2c   |-- i2c@ff150000
i2c           3   [   ]   rockchip_rk3066_i2c   |-- i2c@ff160000
i2c           4   [   ]   rockchip_rk3066_i2c   |-- i2c@ff170000
serial        0   [   ]   ns16550_serial        |-- serial@ff180000
serial        1   [   ]   ns16550_serial        |-- serial@ff190000
serial        2   [ + ]   ns16550_serial        |-- serial@ff690000
```

Complexity example: pinctrl, clocks, power

- Automatic pinmux, clock, power domains
- To get the first MMC device:
  - uclass_get_device(UCLASS_MMC, 0)
- U-Boot selects the pin muxing, enables required power domains and clocks



```
sdmmc: mmc@fe320000 {
        …
        clocks = <&cru HCLK_SDMMC>, <&cru SCLK_SDMMC>,
                 <&cru SCLK_SDMMC_DRV>, <&cru SCLK_SDMMC_SAMPLE>;
        clock-names = "biu", "ciu", "ciu-drive", "ciu-sample";
        resets = <&cru SRST_SDMMC>;
        reset-names = "reset";
        …
};
```

```
static int mmc_power_init(struct mmc *mmc) {
..
        ret = device_get_supply_regulator(mmc->dev, "vmmc-supply",
                                          &mmc->vmmc_supply);
```

```
sdio0_bus4: sdio0-bus4 {
        rockchip,pins =
                <2 RK_PC4 1 &pcfg_pull_up>,
                <2 RK_PC5 1 &pcfg_pull_up>,
                <2 RK_PC6 1 &pcfg_pull_up>,
                <2 RK_PC7 1 &pcfg_pull_up>;
};
```

```
&sdmmc {
        bus-width = <4>;
        cap-sd-highspeed;
        cd-gpios = <&gpio0 7 GPIO_ACTIVE_LOW>;
        disable-wp;
        max-frequency = <150000000>;
        pinctrl-names = "default";
        pinctrl-0 = <&sdmmc_clk &sdmmc_cmd &sdmmc_bus4>;
        vmmc-supply = <&vcc3v0_sd>;
        vqmmc-supply = <&vcc_sdio>;
        status = "okay";
};
```

Complexity example 2: Configuration

- Problem: many similar models based on a common design
- Traditional solution: one build for each model
- Better solution: run-time configuration
  - Single U-Boot build for all models
  - Devicetree describes the hardware
- U-Boot handles the differences at runtime
  - Devices instantiated based on devicetree
  - Device parameters come from devicetree
- Pass configuration between firmware components

```
fifo-depth = <256>;
```

```
priv->fifo_depth = dev_read_u32_default(dev, "fifo-depth", 0);
```

Complexity 3: Firmware Packaging


```
rom {
        filename = "u-boot.rom";
        size = <0x400000>;
        pad-byte = <0xff>;
                mkimage {
                args = "-n rk3399 -T rkspi";
                u-boot-spl {
                };
        };
        u-boot-img {
                offset = <0x40000>;
        };
        u-boot {
                offset = <0x300000>;
        };
        fdtmap {
        };
```

- 'Binman' tool collects binaries into an image
  - Binaries come from build systems
  - Image is the final firmware loaded into the device
- Data-driven operation, using an image description
  - Models an image as an ordered list of entries
  - Each has properties such as offset, size, contents, alignment, compression
  - Binman loads the input files, puts them together, writes the output image(s)
  - Works in parallel, typically in a single pass, so is extremely fast
  - Very easy to modify the image as needed; allows use of CONFIG options and entry arguments
  - Tool dependencies are including in the description
  - Supports FIT, FIP, CBFS, IWFI, etc.
- Provides a way to build and fetch vendor tools

Standard boot

- U-Boot has always had powerful booting features
  - Flat Image Tree (FIT) for multiple images (kernel, ramdisk, FPGA)
  - Signature verification, compression
  - Load a collection of images based on "vendor,model" compatible strings
- Standard boot adds a higher-level interface
  - Automatically locate boot devices
  - Automatically search for distros to boot
  - Provide a menu of available options
- Replaces 'run distro_bootcmd'
  - Easier configuration (generally none at all)

Standard boot - unifying all boot methods

- Three basic concepts
  - **bootdev** - storage devices to be scanned
  - **bootflow** - an OS to boot
  - **bootmeth** - methods for finding bootflows on bootdevs
- bootdev and bootmeth are uclasses
  - We have have bootdev drivers for MMC, USB
  - Bootmeth drivers for syslinux, EFI, ChromiumOS, custom
- bootflow is simply a data structure
  - E.g. points to a extlinux.conf file, a .efi executable
  - May not have a file at all
  - Indicates which bootmeth to use to boot
- U-Boot scans for available bootflows, provides a menu for the user

UEFI support

- EFI_LOADER provides a UEFI layer in U-Boot
  - Full GPL implementation supports booting distros like Ubuntu, Fedora
  - Supports UEFI secure boot; provides capsule updates, TPM measurement
  - Makes use of existing U-Boot drivers, so generally there is no need to adjust board support
  - Includes a boot-manager implementation along with menu support
- U-Boot can also run as an EFI application

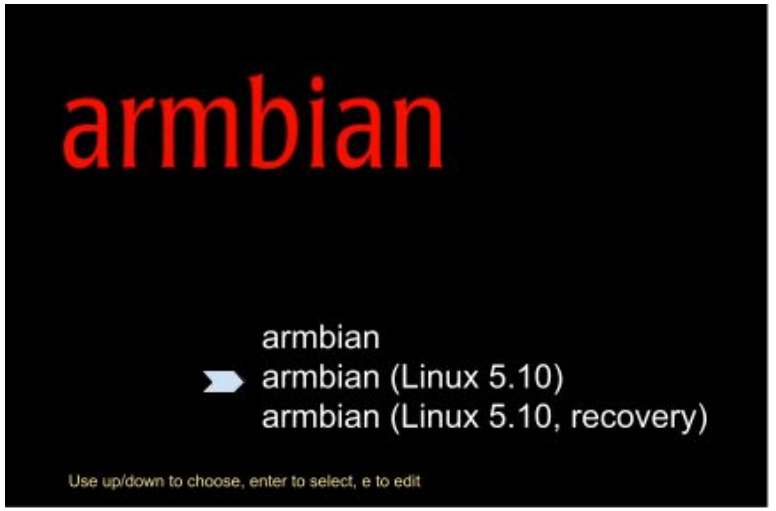
*** Future**
Complete full boot/update support including ARM FWU

```
=> bootflow scan -lb
Scanning for bootflows in all bootdevs
Seq  Method       State   Uclass    Part  Name                      Filename
---  -----------  ------  --------  ----  ------------------------  ----------------
Scanning global bootmeth 'efi_mgr':
Hunting with: nvme
Hunting with: qfw
Hunting with: scsi
scanning bus for devices...
Hunting with: virtio
Scanning bootdev 'qfw_pio.bootdev':
fatal: no kernel available
Scanning bootdev 'virtio-blk#0.bootdev':
  0  efi          ready   virtio       1  virtio-blk#0.bootdev.part efi/boot/bootx64.efi
** Booting bootflow 'virtio-blk#0.bootdev.part_1' with efi
EFI using ACPI tables at f0060
     efi_install_fdt() WARNING: Can't have ACPI table and device tree - ignoring DT.
       efi_run_image() Booting /efi\boot\bootx64.efi
```

VBE - Verified Boot for Embedded

- A true UEFI alternative
- Scope
  - boot flow
  - image selection
  - update

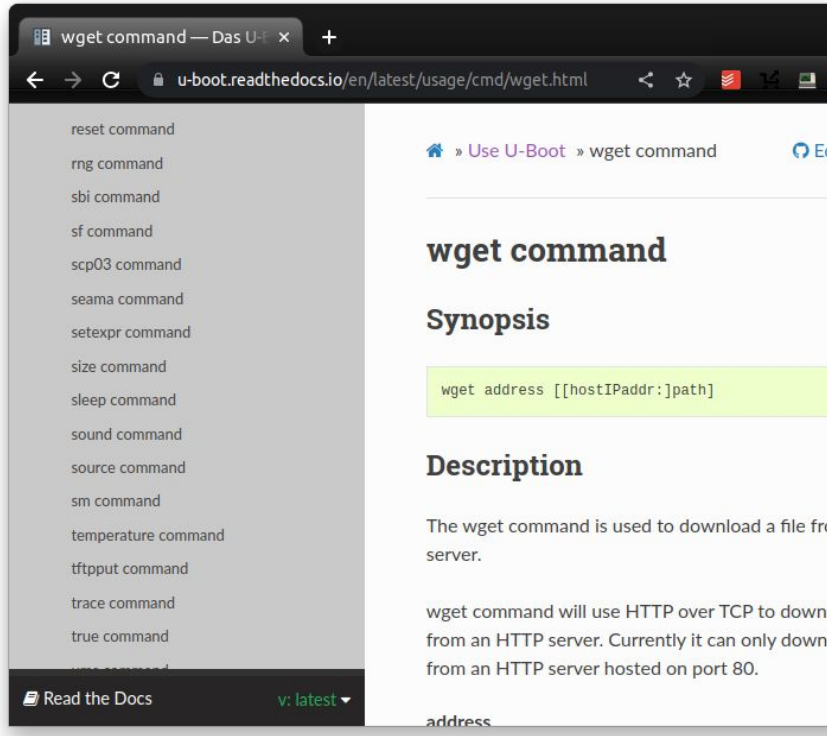
  } for both firmware and OS
- Uses FIT to package firmware / OS images
- Uses fwupd to perform firmware update
- You know in advance what you are booting and what it needs
  - No EFI callbacks
- See osfc'22 talk: 'Introduction to VBE Verified Boot for Embedded'



*** Future**
Future: A/B firmware update sample implementation on RockPRO64

Documentation

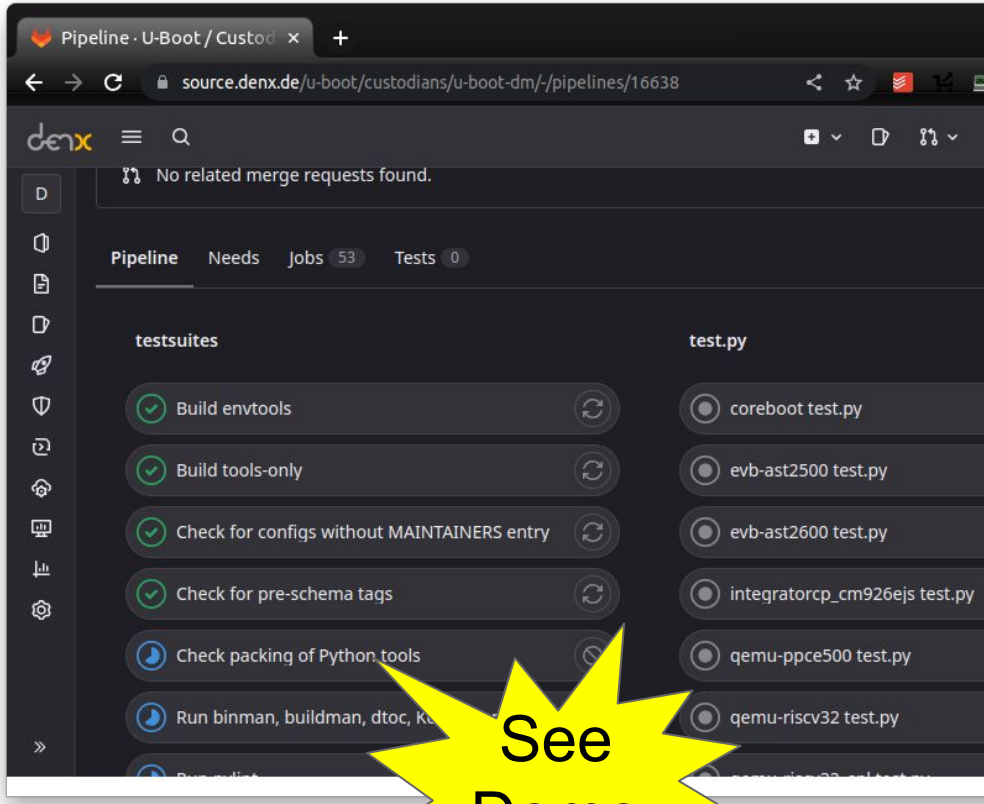
- U-Boot moved to rST a few years ago
  - Uses Sphinx, following Linux's lead
  - 'make htmldocs' builds the documentation
  - Allows patches to include documentation updates
  - Supports deep links, images, etc.
- Most existing documentation has been converted
  - Currently around 80K lines of rST
  - Some 80 commands (out of ~250) are documented
  - Some existing features are still undocumented, or not rST
- https://u-boot.readthedocs.io/en/latest/



*** Future**
Complete documentation for all commands and features

Testing and CI

- Expanded significantly over the past few years
  - Uses gitlab infrastructure with ~6 runners
  - Each run takes approx. 70 minutes to complete
  - Local tests can run in a few minutes (e.g. 'make pcheck')
  - Around 1120 tests in total
- Sandbox + emulators for fast, east tests



*** Future**
- Easier distributed labs with Labgrid
- Code-coverage tracking
- Booting common distros in CI

Devicetree and Schema

- U-Boot has used devicetree since 2011 (same year as Linux)
  - As a result there are quite a few differences in bindings
  - These are being resolved SoC by SoC
  - U-Boot has some schema 'upstream' (bootph-xxx and options/ node)
- Use of livetree (hierarchical data structure) is expanding
  - Provides an easy way to access nodes: ofnode
  - Provides an easy way for devices to read properties: dev_read...(dev, "prop")
  - Faster for updates; multiple trees are now supported
  - Some work on moving devicetree fix-ups to ofnode

*** Future**
Move schema upstream; run schema validation on U-Boot tree

Quality-of-life improvements

- Kconfig migration
  - Completed as of 2023.01
  - Very large effort by many people, over ~6 years
  - Provides a path to drop board-specific config.h files
- Text-based environment
  - Simple syntax in a text file
  - Avoids use of #defines in config.h files
- Link-time Optimisation (LTO)
- U-Boot shows a logo!
- Events
  - Allows 'spying' on events such as new-device creation
  - Alternative to weak functions, with better visibility and auditing (event-dumper tool)

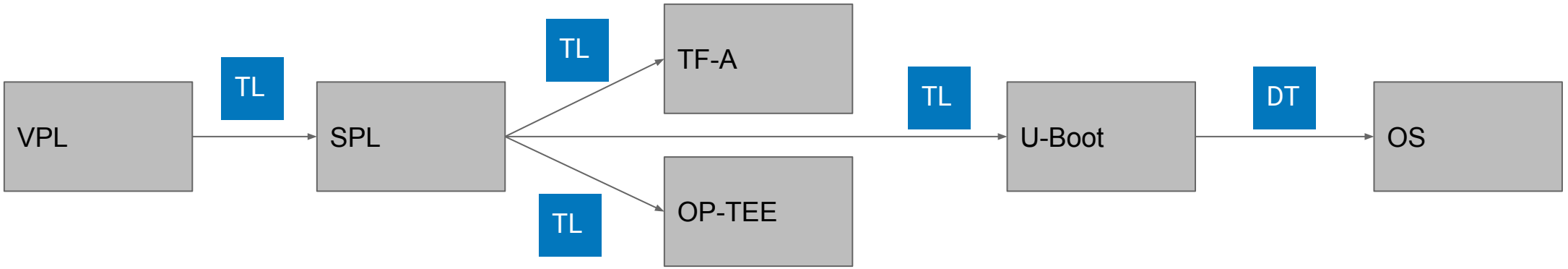
```
// SPDX-License-Identifier: GPL-2.0+
/*
 * Copyright (c) Siemens AG, 2023
 *
 * Authors:
 *   Jan Kiszka <jan.kiszka@siemens.com>
 */

usb_pgood_delay=900

watchdog_timeout_ms=CONFIG_WATCHDOG_TIMEOUT_MSECS
start_watchdog=
      if test ${watchdog_timeout_ms} -gt 0; then
            wdt dev watchdog@40610000;
            wdt start ${watchdog_timeout_ms};
            echo Watchdog started, timeout ${watchdog_timeout_ms
      fi
```

U-Boot

*** Future**
Updated HUSH shell

Cross-project communication

- Firmware Handoff (bloblist in U-Boot)
  - Provides a way to pass tagged data from one project to another
  - E.g. U-Boot can pass memory information to/from TF-A, OP-TEE
  - github.com/FirmwareHandoff



*** Future**
Industry-wide, universal format for firmware images

Networking

- TCP/IP support and wget
- IPv6
- New PHY API

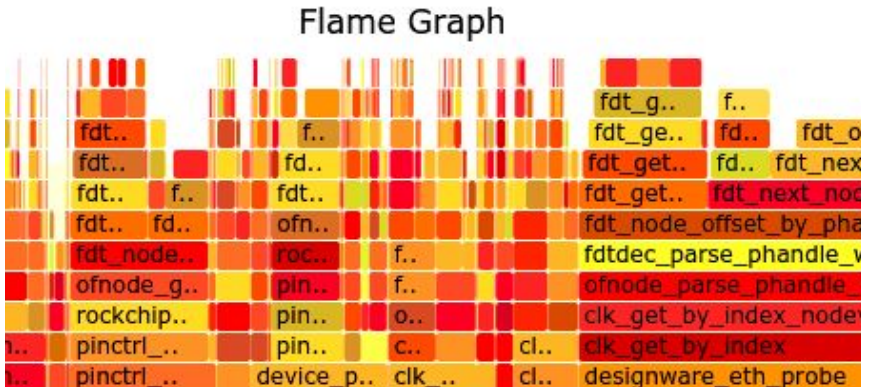
*** Future**
Discussions about moving to lwip

RISC-V and x86

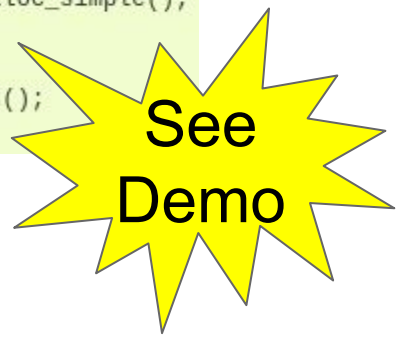
- RISC-V boards now up to 21
  - Boards from AndesTech, SiFive, Microchip, OpenPiton, Sipeed
  - Running in CI with QEMU
- Booting distros supported on x86 (pending patches)
- Coreboot support has been enhanced
  - Uses SPCR to find UART
  - 'cbsysinfo' command shows the sysinfo table
  - Now runs in CI with QEMU

Tracing

- Used (with bootstage) to find bottlenecks in boot
- Record function entry / exit
- Export data for use with trace-cmd and kernelshark
- .Also supports an interactive flamegraph




```
$ trace-cmd report trace.dat | less
cpus=1
          u-boot-1     [000]     3.116364: funcgraph_entry:        0.011 us   |    initf_malloc();
          u-boot-1     [000]     3.116386: funcgraph_entry:                   |    initf_bootstage() {
          u-boot-1     [000]     3.116396: funcgraph_entry:                   |      bootstage_init() {
          u-boot-1     [000]     3.116408: funcgraph_entry:                   |        malloc() {
          u-boot-1     [000]     3.116418: funcgraph_entry:                   |          malloc_simple() {
          u-boot-1     [000]     3.116429: funcgraph_entry:        0.012 us   |            alloc_simple();
          u-boot-1     [000]     3.116449: funcgraph_exit:         0.031 us   |            }
          u-boot-1     [000]     3.116457: funcgraph_exit:         0.049 us   |          }
          u-boot-1     [000]     3.116466: funcgraph_entry:        0.063 us   |        memset();
          u-boot-1     [000]     3.116539: funcgraph_exit:         0.143 us   |        }
```



- https://u-boot.readthedocs.io/en/latest/develop/trace.html

'Cyclic' subsystem

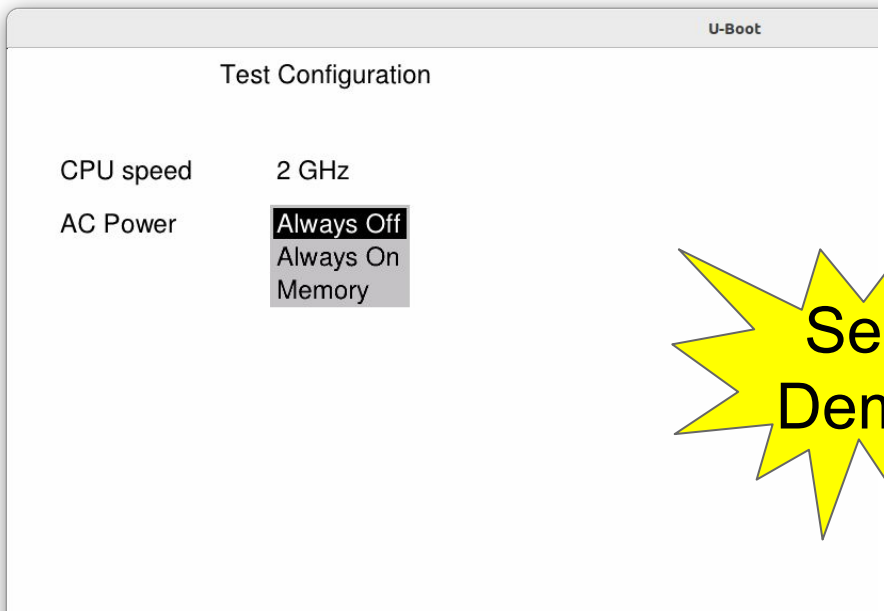
- Provides a way to run things in the background
  - Register a function to be called, setting a period in microseconds
  - The function will be called when U-Boot is idle
- Many possible (future) uses
  - Resetting the watchdog timer (implemented in 2022.10)
  - Scanning the USB bus in the background
  - Read files from the network in the background
  - Scanning for bootflows in the background

- https://u-boot.readthedocs.io/en/latest/develop/cyclic.html

GUI and menus

- New 'expo' subsystem supports graphical / text display
  - Arranged as a series of 'scenes', each with a list of items to display
  - The user can move through scenes using the keyboard
  - So far the only supported items are menus
- New 'cedit' command allows the user to edit configurations*
  - Like the BIOS configuration machine on x86 devices

```
scenes {
        main {
                id = <ID_SCENE1>;
                title-id = <ID_SCENE1_TITLE>;
                prompt = "UP and DOWN to choose, ENTER to

                cpu-speed {
                        type = "menu";
                        id = <ID_CPU_SPEED>;
                        title = "CPU speed";
                        title-id = <ID_CPU_SPEED_TITLE>;
                        item-label = "2 GHz", "2.5 GHz", "3
                        item-id = <ID_CPU_SPEED_1 ID_CPU_SP
                };

                power-loss {
                        type = "menu";
                        id = <ID_POWER_LOSS>;
                        title = "AC Power";
                        item-label = "Always Off", "Always
```



See Demo

* patches pending

*** Future**
Load / save configuration

Demo

- Standard boot
- Binman
- CI
- Tracing
- Configuration editor

Thank you for listening

- U-Boot is an open-source firmware project
- Patches and ideas are welcome

- My details
  - Simon Glass
  - to: u-boot@lists.denx.de
  - cc: sjg@chromium.org