Embedded Linux system development training

On-line seminar, 7 sessions of 4 hours

Latest update: May 08, 2024

Title	**Embedded Linux system development training**
Training objectives	• Be able to understand the overall architecture of Embedded Linux systems. • Be able to choose, build, setup and use a cross-compilation toolchain. • Be able to understand the booting sequence of an embedded Linux system, and to set up and use the U-Boot bootloader. • Be able to select a Linux kernel version, to configure, build and install the Linux kernel on an embedded system. • Be able to create from scratch a Linux root filesystem, including all its elements: directories, applications, configuration files, libraries. • Be able to choose and setup the main Linux filesystems for block and flash storage devices, and understand their main characteristics. • Be able to interact with hardware devices, configure the kernel with appropriate drivers and extend the *Device Tree* • Be able to select, cross-compile and integrate open-source software components (libraries, applications) in an Embedded Linux system, and to handle license compliance. • Be able to setup and use an embedded Linux build system, to build a complete system for an embedded platform. • Be able to develop and debug applications on an embedded Linux system.
Duration	**Seven** half days - 28 hours (4 hours per half day)
Pedagogics	• Lectures delivered by the trainer, over video-conference. Participants can ask questions at any time. • Practical demonstrations done by the trainer, based on practical labs, over video-conference. Participants can ask questions at any time. Optionally, participants who have access to the hardware accessories can reproduce the practical labs by themselves. • Instant messaging for questions between sessions (replies under 24h, outside of week-ends and bank holidays). • Electronic copies of presentations, lab instructions and data files. They are freely available at https://bootlin.com/doc/training/embedded-linux.
Trainer	One of the engineers listed on: `https://bootlin.com/training/trainers/`

Language	Oral lectures: English, French, Italian. Materials: English.
Audience	People developing devices using the Linux kernel People supporting embedded Linux system developers.
Prerequisites	• **Knowledge and practice of UNIX or GNU/Linux commands**: participants must be familiar with the Linux command line. Participants lacking experience on this topic should get trained by themselves, for example with our freely available on-line slides at bootlin.com/blog/command-line/. • **Minimal English language level: B1**, according to the *Common European Framework of References for Languages*, for our sessions in English. See bootlin.com/pub/training/cefr-grid.pdf for self-evaluation.
Required equipment	• Computer with the operating system of your choice, with the Google Chrome or Chromium browser for videoconferencing. • Webcam and microphone (preferably from an audio headset) • High speed access to the Internet
Certificate	Only the participants who have attended all training sessions, and who have scored over 50% of correct answers at the final evaluation will receive a training certificate from Bootlin.
Disabilities	Participants with disabilities who have special needs are invited to contact us at *training@bootlin.com* to discuss adaptations to the training course.

Hardware platform for practical demos, option #1

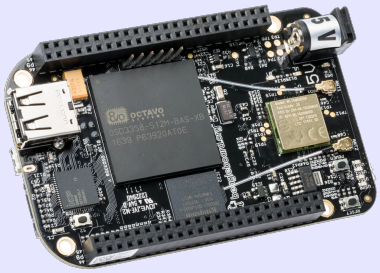
One of these Discovery Kits from STMicroelectronics: **STM32MP157A-DK1**, **STM32MP157D-DK1**, **STM32MP157C-DK2** or **STM32MP157F-DK2**

- STM32MP157, dual Cortex-A7 processor from STMicroelectronics
- USB powered
- 512 MB DDR3L RAM
- Gigabit Ethernet port
- 4 USB 2.0 host ports
- 1 USB-C OTG port
- 1 Micro SD slot
- On-board ST-LINK/V2-1 debugger
- Arduino compatible headers
- Audio codec, buttons, LEDs
- LCD touchscreen (DK2 kits only)

Hardware platform for practical demos, option #2

BeagleBone Black or **BeagleBone Black Wireless** board

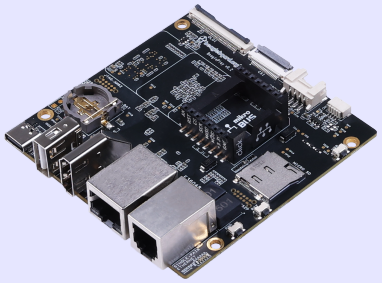
- An ARM AM335x (single Cortex-A8) processor from Texas Instruments
- USB powered
- 512 MB of RAM
- 2 or 4 GB of on-board eMMC storage
- USB host and device
- HDMI output
- 2 x 46 pins headers, to access UARTs, SPI buses, I2C buses and more.
- Ethernet or WiFi



Hardware platform for practical labs, option #3

BeaglePlay board

- Texas Instruments AM625x (4xARM Cortex-A53 CPU)
- SoC with 3D acceleration, integrated MCU and many other peripherals.
- 2 GB of RAM
- 16 GB of on-board eMMC storage
- USB host and USB device, microSD, HDMI
- 2.4 and 5 GHz WiFi, Bluetooth and also Ethernet
- 1 MicroBus Header (SPI, I2C, UART, ...), OLDI and CSI connector.



Half day 1

Lecture - Introduction to embedded Linux

- Advantages of Linux versus traditional embedded operating systems.
- Typical hardware platforms used to run embedded Linux systems.
- Overall architecture of embedded Linux systems: overview of the major software components.
- Development environment for Embedded Linux development.

Lecture - Cross-compiling toolchain and C library

- What's inside a cross-compiling toolchain
- Choosing the target C library
- What's inside the C library
- Ready to use cross-compiling toolchains
- Building a cross-compiling toolchain with automated tools.

Lab - Cross compiling toolchain

- Getting and configuring Crosstool-NG
- Executing it to build a custom cross-compilation toolchain
- Exploring the contents of the toolchain

Lecture - Boot process, firmware, bootloaders

- Booting process of embedded platforms, focus on the *x86* and *ARM* architectures
- Boot process and bootloaders on *x86* platforms (legacy and UEFI)
- Boot process on ARM platforms: ROM code, bootloaders, *ARM Trusted Firmware*
- Focus on U-Boot: configuration, installation, and usage.
- U-Boot commands, U-Boot environment, U-Boot scripts, U-Boot generic distro boot mechanism

Half day 2

Lab - Bootloader and U-boot

- Set up serial communication with the board.
- Configure, compile and install U-Boot for the target hardware.
- Only on STM32MP1: configure, compile and install Trusted Firmware-A
- Become familiar with U-Boot environment and commands.
- Set up TFTP communication with the board. Use TFTP U-Boot commands.

Using the embedded hardware platform.

Lecture - Linux kernel

- Role and general architecture of the Linux kernel
- Separation between kernel and user-space, and interfaces between user-space and the Linux kernel
- Understanding Linux kernel versions: choosing between vendor-provided kernel and upstream kernel, *Long Term Support* versions
- Getting the Linux kernel source code

Lab - Fetching Linux kernel sources

- Clone the mainline Linux tree
- Accessing stable releases

Lecture - Configuring, compiling and booting the Linux kernel

- Configuring the Linux kernel: ready-made configuration files, configuration interfaces
- Concept of *Device Tree*
- Cross-compiling the Linux kernel
- Study of the generated files and their role
- Installing and booting the Linux kernel
- The Linux kernel command line

Lab - Kernel cross-compiling and booting

- Configuring the Linux kernel and cross-compiling it for the embedded hardware platform.
- Downloading your kernel on the board through U-boot's TFTP client.
- Booting your kernel.
- Automating the kernel boot process with U-Boot scripts.

Using the embedded hardware platform

Half day 3

Lecture – Root filesystem in Linux

- Filesystems in Linux.
- Role and organization of the root filesystem.
- Location of the root filesystem: on storage, in memory, from the network.
- Device files, virtual filesystems.
- Contents of a typical root filesystem.

Lecture - BusyBox

- Detailed overview. Detailed features.
- Configuration, compiling and deploying.

Lab – Tiny root filesystem built from scratch with BusyBox

- Setting up a kernel to boot your system on a workstation directory exported by NFS
- Passing kernel command line parameters to boot on NFS
- Creating the full root filesystem from scratch. Populating it with BusyBox based utilities.
- System startup using BusyBox `init`
- Using the BusyBox HTTP server.
- Controlling the target from a web browser on the PC host.
- Setting up shared libraries on the target and compiling a sample executable.

Using the embedded hardware platform

Half day 4

Lecture - Accessing hardware devices

- How to access hardware on popular busses: USB, SPI, I2C, PCI
- Usage of kernel drivers and direct user-space access
- The *Device Tree* syntax, and how to use it to describe additional devices and pin-muxing
- Finding Linux kernel drivers for specific hardware devices
- Using kernel modules
- Hardware access using `/dev` and `/sys`
- User-space interfaces for the most common hardware devices: storage, network, GPIO, LEDs, audio, graphics, video

Lab - Accessing hardware devices

- Exploring the contents of `/dev` and `/sys` and the devices available on the embedded hardware platform.
- Using GPIOs and LEDs.
- Modifying the Device Tree to control pin multiplexing and to declare an I2C-connected joystick.
- Adding support for a USB audio card using Linux kernel modules
- Adding support for the I2C-connected joystick through an out-of-tree module.

Using the embedded hardware platform

Lecture - Block filesystems

- Accessing and partitioning block devices.
- Filesystems for block devices.
- Usefulness of journaled filesystems.
- Read-only block filesystems.
- RAM filesystems.
- How to create each of these filesystems.
- Suggestions for embedded systems.

Lab - Block filesystems

- Creating partitions on your SD card
- Booting a system with a mix of filesystems: *SquashFS* for the root filesystem, *ext4* for system data, and *tmpfs* for temporary system files.

Using the embedded hardware platform

Half day 5

Lecture - Flash filesystems

- The Memory Technology Devices (MTD) filesystem.
- Filesystems for MTD storage: JFFS2, Yaffs2, UBIFS.
- Kernel configuration options
- MTD storage partitions.
- Focus on today's best solution, UBI and UBIFS: preparing, flashing and using UBI images.

Note: as the embedded hardware platform used for the labs does not have any flash-based storage, this lecture will not be illustrated with a corresponding practical lab.

Lecture – Cross-compiling user-space libraries and applications

- Configuring, cross-compiling and installing applications and libraries.
- Concept of build system, and overview of a few common build systems used by open-source projects: Makefile, *autotools*, *CMake*, *meson*
- Overview of the common issues encountered when cross-compiling.

Lab – Cross-compiling applications and libraries

- Manual cross-compilation of several open-source libraries and applications for an embedded platform.
- Learning about common pitfalls and issues, and their solutions.
- This includes compiling *alsa-utils* package, and using its `speaker-test` program to test that audio works on the target.

Using the embedded hardware platform

Half day 6

Lecture - Embedded system building tools

- Approaches for building embedded Linux systems: build systems and binary distributions
- Principle of *build systems*, overview of Yocto Project/OpenEmbedded and Buildroot.
- Principle of *binary distributions* and useful tools, focus on Debian/Ubuntu
- Specialized software frameworks/distributions: Tizen, AGL, Android

Lab - System build with Buildroot

- Using Buildroot to rebuild the same basic system plus a sound playing server (*MPD*) and a client to control it (*mpc*).
- Driving music playback, directly from the target, and then remotely through an MPD client on the host machine.
- Analyzing dependencies between packages.

Using the embedded hardware platform

Lecture - Open source licenses and compliance

- Presentation of the most important open-source licenses: GPL, LGPL, MIT, BSD, Apache, etc.
- Concept of *copyleft* licenses
- Differences between (L)GPL version 2 and 3
- Compliance with open-source licenses: best practices

Lecture - Overview of major embedded Linux software stacks

- `systemd` as an *init* system
- Hardware management with *udev*
- Inter-process communication with *D-Bus*
- The graphics software stack: DRM/KMS, X.org, Wayland, Qt, Gtk, OpenGL
- The multimedia software stack: Video4Linux, GStreamer, Pulseaudio, Pipewire

Half day 7

Lab - Integration of additional software stacks

- Integration of *systemd* as an init system
- Use *udev* built in *systemd* for automatic module loading

Using the embedded hardware platform

Lecture - Application development and debugging

- Programming languages and libraries available.
- Build system for your application, an overview of *CMake* and *meson*
- The *gdb* debugger: remote debugging with *gdbserver*, post-mortem debugging with `core` files
- Performance analysis, tracing and profiling tools, memory checkers: `strace`, `ltrace`, `perf`, `valgrind`

Lab – Application development and debugging

- Creating an application that uses an I2C-connected joystick to control an audio player.
- Setting up an IDE to develop and remotely debug an application.
- Using *strace*, *ltrace*, *gdbserver* and *perf* to debug/investigate buggy applications on the embedded board.

Using the embedded hardware platform

Lecture - Useful resources

- Books about embedded Linux and system programming
- Useful online resources
- International conferences