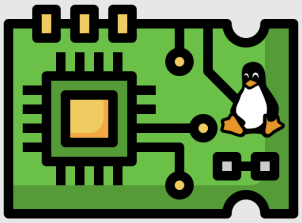

Embedded Linux system development training

Course duration

7 half days – 28 hours

Language

Materials	English
Oral Lecture	English
	French
	Portuguese
	Italian

Trainer

One of the following engineers

- Alexandre Belloni
- Alexis Lothoré
- Antonin Godard
- Grégory Clement
- Jérémie Dautheribes
- João Marcos Costa
- Luca Ceresoli
- Maxime Chevallier
- Miquèl Raynal
- Richard Genoud
- Thomas Petazzoni

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Online seminar

Audience

People developing devices using the Linux kernel
People supporting embedded Linux system developers.

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.

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.
- **Minimal English language level: B1**, according to the *Common European Framework of References for Languages*, for our sessions in English. See the CEFR grid for self-evaluation.

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 here.

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.

Required equipement

Mandatory 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.

Optionnally, if the participants want to be able to reproduce the practical labs by themselves, they must separately purchase the hardware platform and accessories, and must have a PC computer with a native installation of Ubuntu Linux 24.04.

Hardware platform for practical labs

STM32MP1 Discovery Kit

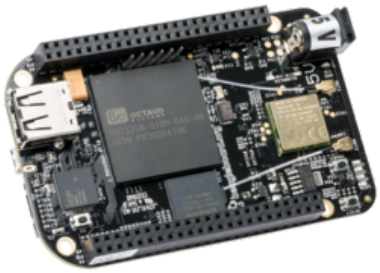
One of these Discovery Kits from STMicroelectronics: **STM32MP157A-DK1**, **STM32MP157D-DK1**, **STM32MP157C-DK2** or **STM32MP157F-DK2**

- 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)

BeagleBone Black

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



BeaglePlay

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.

Training Schedule

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.
Demo	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

Demo	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.
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
Demo	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

Demo	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.

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.
Demo	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.

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
Demo	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.
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.

Demo	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.

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.
Demo	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.

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
Demo	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.
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

Demo	Integration of additional software stacks	▪ Integration of *systemd* as an init system ▪ Use *udev* built in *systemd* for automatic module loading
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`
Demo	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.
Lecture	Useful resources	▪ Books about embedded Linux and system programming ▪ Useful online resources ▪ International conferences