



Real-Time Linux with *PREEMPT_RT* training

On-site training, 2 days

Latest update: April 26, 2024

Title	Real-Time Linux with <i>PREEMPT_RT</i> training
Training objectives	<ul style="list-style-type: none">• Be able to understand the characteristics of a real-time operating system• Be able to download, build and use the <i>PREEMPT_RT</i> patch• Be able to identify and benchmark the hardware platform in terms of real-time characteristics• Be able to configure the Linux kernel for deterministic behavior.• Be able to develop, trace and debug real-time user-space Linux applications.
Duration	Two days - 16 hours (8 hours per day)
Pedagogics	<ul style="list-style-type: none">• Lectures delivered by the trainer: 50% of the duration• Practical labs done by participants: 50% of the duration• Electronic copies of presentations, lab instructions and data files. They are freely available at https://bootlin.com/doc/training/preempt-rt.
Trainer	Maxime Chevallier https://bootlin.com/company/staff/maxime-chevallier/
Language	Oral lectures: English, French. Materials: English.
Audience	Companies and engineers interested in writing and benchmarking real-time applications and drivers on an embedded Linux system.



Prerequisites	<ul style="list-style-type: none">• 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 experience in embedded Linux development: participants should have a minimal understanding of the architecture of embedded Linux systems: role of the Linux kernel vs. user-space, development of Linux user-space applications in C. Following Bootlin's <i>Embedded Linux</i> course at bootlin.com/training/embedded-linux/ allows to fulfill this pre-requisite.• Minimal English language level: B1, according to the <i>Common European Framework of References for Languages</i>, for our sessions in English. See bootlin.com/pub/training/cefr-grid.pdf for self-evaluation.
Required equipment	<ul style="list-style-type: none">• Video projector• One PC computer on each desk (for one or two persons) with at least 8 GB of RAM, and Ubuntu Linux 22.04 installed in a free partition of at least 30 GB• Distributions other than Ubuntu Linux 22.04 are not supported, and using Linux in a virtual machine is not supported.• Unfiltered and fast connection to Internet: at least 50 Mbit/s of download bandwidth, and no filtering of web sites or protocols.• PC computers with valuable data must be backed up before being used in our sessions.
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 labs

STMicroelectronics STM32MP157D Discovery Kit 1 board

- STM32MP157D (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



Day 1 - Morning

Lecture - Introduction to Real-Time behaviour and determinism

- Definition of a Real-Time Operating System
- Specificities of multi-task systems
- Common locking and prioritizing patterns
- Overview of existing Real-Time Operating Systems
- Approaches to bring Real-Time capabilities to Linux



Lecture - The *PREEMPT_RT* patch

- History and future of the *PREEMPT_RT* patch
- Real-Time improvements from *PREEMPT_RT* in mainline Linux
- The internals of *PREEMPT_RT*
- Interrupt handling: threaded interrupts, softirqs
- Locking primitives: mutexes and spinlocks, sleeping spinlocks
- Preemption models

Lab - Building a mainline Linux Kernel with the *PREEMPT_RT* patch

- Downloading the Linux Kernel, and applying the patch
- Configuring the Kernel
- Booting the Kernel on the target hardware

Day 1 - Afternoon

Lecture - Hardware configuration and limitations for Real-Time

- Interrupts and deep firmware
- Interaction with power management features: CPU frequency scaling and sleep states
- DMA

Lecture - Tools: Benchmarking, Stressing and Analyzing

- Benchmarking with *cyclictst*
- System stressing with *stress-ng* and *hackbench*
- The Linux Kernel tracing infrastructure
- Latency and scheduling analysis with *ftrace*, *kernelshark* or *LTTng*

Lab - Tools: Benchmarking, Stressing and Analyzing

- Usage of benchmarking and stress tools
- Common benchmarking techniques
- Benchmarking and configuring the hardware platform



Day 2 - Morning

Lecture - Kernel infrastructures and configuration

- Good practices when writing Linux kernel drivers
- Scheduling policies and priorities: *SCHED_FIFO*, *SCHED_RR*, *SCHED_DEADLINE*
- CPU and IRQ Affinity
- Memory management
- CPU isolation with *isolcpus*

Lecture - Real-Time Applications programming patterns

- POSIX real-time API
- Thread management and configuration
- Memory management: memory allocation and memory locking, stack
- Locking patterns: mutexes, priority inheritance
- Inter-Process Communication
- Signaling

Day 2 - Afternoon

Lab - Debugging a demo application

- Make a demo userspace application deterministic
- Use the tracing infrastructure to identify the cause of a latency
- Learn how to use the POSIX API to manage threads, locking and memory
- Learn how to use the CPU affinities and configure the scheduling policy



Questions and Answers

- Questions and answers with the audience about the course topics
- Extra presentations if time is left, according what most participants are interested in.