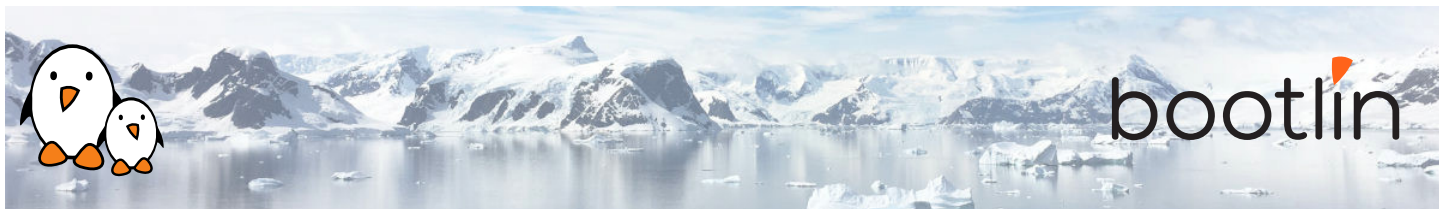


# Linux debugging, profiling, tracing and performance analysis training

On-site training, 3 days

Latest update: May 17, 2024

<b>Title</b>	<b>Linux debugging, profiling, tracing and performance analysis training</b>
<b>Training objectives</b>	<ul style="list-style-type: none"><li>• Be able to understand the main concepts of Linux that are relevant for performance analysis: process, threads, memory management, virtual memory, execution contexts, etc.</li><li>• Be able to analyze why a system is loaded and what are the elements that contributes to this load using common Linux observability tools.</li><li>• Be able to debug an userspace application using <i>gdb</i>, either live or after a crash, and analyze the contents of ELF binaries.</li><li>• Be able to trace and profile a complete userspace application and its interactions with the Linux kernel in order to fix bugs using <i>strace</i>, <i>ltrace</i>, <i>perf</i> or <i>Callgrind</i>.</li><li>• Be able to understand classical memory issues and analyze them using <i>valgrind</i>, <i>libefence</i> or <i>Massif</i>.</li><li>• Be able to trace and profile the entire Linux system, using <i>perf</i>, <i>ftrace</i>, <i>kprobes</i>, <i>eBPF</i> tools, <i>kernelshark</i> or <i>LTTng</i></li><li>• Be able to debug Linux kernel issues: debug kernel crashes live or post-mortem, analyze memory issues at the kernel level, analyze locking issues, use kernel-level debuggers.</li></ul>
<b>Duration</b>	<b>Three</b> days - 24 hours (8 hours per day)
<b>Pedagogics</b>	<ul style="list-style-type: none"><li>• Lectures delivered by the trainer: 40% of the duration</li><li>• Practical labs done by participants: 60% of the duration</li><li>• Electronic copies of presentations, lab instructions and data files. They are freely available at <a href="https://bootlin.com/doc/training/debugging">https://bootlin.com/doc/training/debugging</a>.</li></ul>
<b>Trainer</b>	One of the engineers listed on: <a href="https://bootlin.com/training/trainers/">https://bootlin.com/training/trainers/</a>
<b>Language</b>	Oral lectures: English, French. Materials: English.
<b>Audience</b>	Companies and engineers interested in debugging, profiling and tracing Linux systems and applications, to analyze and address performance or latency problems.



Prerequisites	<ul style="list-style-type: none"><li>• <b>Knowledge and practice of UNIX or GNU/Linux commands:</b> 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 <a href="https://bootlin.com/blog/command-line/">bootlin.com/blog/command-line/</a>.</li><li>• <b>Minimal experience in embedded Linux development:</b> 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 <a href="https://bootlin.com/training/embedded-linux/">bootlin.com/training/embedded-linux/</a> allows to fulfill this pre-requisite.</li><li>• <b>Minimal English language level: B1</b>, according to the <i>Common European Framework of References for Languages</i>, for our sessions in English. See <a href="https://bootlin.com/pub/training/cefr-grid.pdf">bootlin.com/pub/training/cefr-grid.pdf</a> for self-evaluation.</li></ul>
Required equipment	<ul style="list-style-type: none"><li>• Video projector</li><li>• 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 <b>free partition of at least 30 GB</b></li><li>• Distributions other than Ubuntu Linux 22.04 are not supported, and using Linux in a virtual machine is not supported.</li><li>• <b>Unfiltered and fast connection to Internet:</b> at least 50 Mbit/s of download bandwidth, and no filtering of web sites or protocols.</li><li>• <b>PC computers with valuable data must be backed up</b> before being used in our sessions.</li></ul>
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 <a href="mailto:training@bootlin.com">training@bootlin.com</a> to discuss adaptations to the training course.



## Hardware in practical labs

The hardware platform used for the practical labs of this training session is the **STMicroelectronics STM32MP157D-DK1 Discovery board** board, which features:

- STM32MP157D (dual Cortex-A7) CPU 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 Uno v3-compatible headers
- Audio codec
- Misc: buttons, LEDs



## Day 1 - Morning

### Lecture - Linux application stack

- Global picture: understanding the general architecture of a Linux system, overview of the major components.
- What is the difference between a process and a thread, how applications run concurrently.
- ELF files and associated analysis tools.
- Userspace application memory layout (heap, stack, shared libraries mappings, etc).
- MMU and memory management: physical/virtual address spaces.
- Kernel context switching and scheduling
- Kernel execution contexts: kernel threads, workqueues, interrupt, threaded interrupts, softirq



## Lecture - Common analysis & observability tools

- Analyzing an ELF file with GNU binary utilities (*objdump*, *addr2line*).
- Tools to monitor a Linux system: processes, memory usage and mapping, resources.
- Using *vmstat*, *iostat*, *ps*, *top*, *iotop*, *free* and understanding the metrics they provide.
- Pseudo filesystems: *procfs*, *sysfs* and *debugfs*.

## Day 1 - Afternoon

### Lab - Check what is running on a system and its load

- Observe running processes using *ps* and *top*.
- Check memory allocation and mapping with *procfs* and *pmap*.
- Monitor other resources usage using *iostat*, *vmstat* and *netstat*.

### Lecture - Debugging an application

- Using *gdb* on a live process.
- Understanding compiler optimizations impact on debuggability.
- Postmortem diagnostic using core files.
- Remote debugging with *gdbserver*.
- Extending *gdb* capabilities using python scripting

### Lab - Solving an application crash

- Analysis of compiled C code with compiler-explorer to understand optimizations.
- Managing *gdb* from the command line, then from an IDE.
- Using *gdb* Python scripting capabilities.
- Debugging a crashed application using a core dump with *gdb*.



## Day 2 - Morning

### Lecture - Tracing an application

- Tracing system calls with *strace*.
- Tracing library calls with *ltrace*.
- Overloading library functions using *LD\_PRELOAD*.

### Lab – Debugging application issues

- Analyze dynamic library calls from an application using *ltrace*.
- Overloading library functions using *LD\_PRELOAD*.
- Analyzing an application system calls using *strace*.

### Lecture - Memory issues

- Usual memory issues: buffer overflow, segmentation fault, memory leaks, heap-stack collision.
- Memory corruption tooling, *valgrind*, *libfence*, etc.
- Heap profiling using *Massif* and *heaptrack*

### Lab – Debugging memory issues

- Memory leak and misbehavior detection with *valgrind* and *vgdb*.
- Visualizing application heap using *Massif*.

## Day 2 - Afternoon

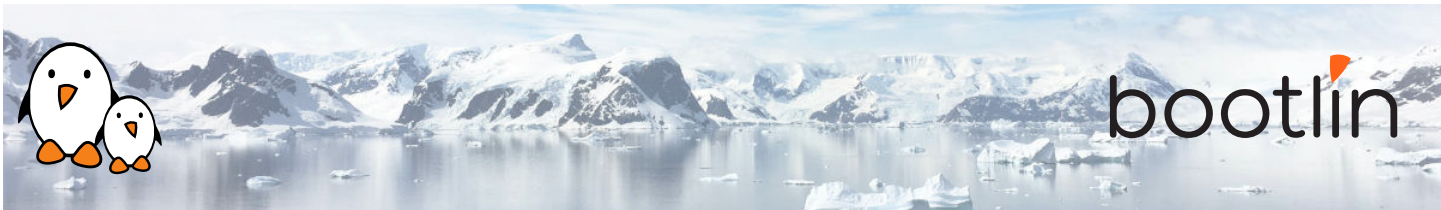
### Lecture – Application profiling

- Performances issues.
- Gathering profiling data with *perf*.
- Analyzing an application callgraph using *Callgrind* and *KCachegrind*.
- Interpreting the data recorded by *perf*.

### Lab - Application profiling

- Profiling an application with *Callgrind/KCachegrind*.
- Analyzing application performance with *perf*.
- Generating a flamegraph using *Flame-Graph*.





## Day 3 - Morning

### Lecture - System wide profiling and tracing

- System wide profiling using *perf*.
- Using *kprobes* to hook on kernel code without recompiling.
- *eBPF* tools (*bcctools*, *bpfftrace*, etc) for complex tracing scenarios.
- Application and kernel tracing and visualization using *ftrace*, *kernelshark* or *LTTng*

### Lab - System wide profiling and tracing

- System profiling with *perf*.
- IRQ latencies using *ftrace*.
- Tracing and visualizing system activity using *kernelshark* or *LTTng*

## Day 3 - Afternoon

### Lecture - Kernel debugging

- Kernel compilation results (*vmlinux*, *System.map*).
- Understanding and configuring kernel *oops* behavior.
- Post mortem analysis using kernel crash dump with *crash*.
- Memory issues (*KASAN*, *UBSAN*, *Kmem-leak*).
- Debugging the kernel using *KGDB* and *KDB*.
- Kernel locking debug configuration options (*lockdep*).
- Other kernel configuration options that are useful for debug.

### Lab - Kernel debugging

- Analyzing an *oops* after using a faulty module with *objdump* and *addr2line*.
- Debugging a deadlock problem using *PROVE\_LOCKING* options.
- Detecting undefined behavior with *UBSAN* in kernel code.
- Find a module memory leak using *kmem-leak*.
- Debugging a module with *KGDB*.