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How to boot Linux in one second

...why userland is a waste of time ;)

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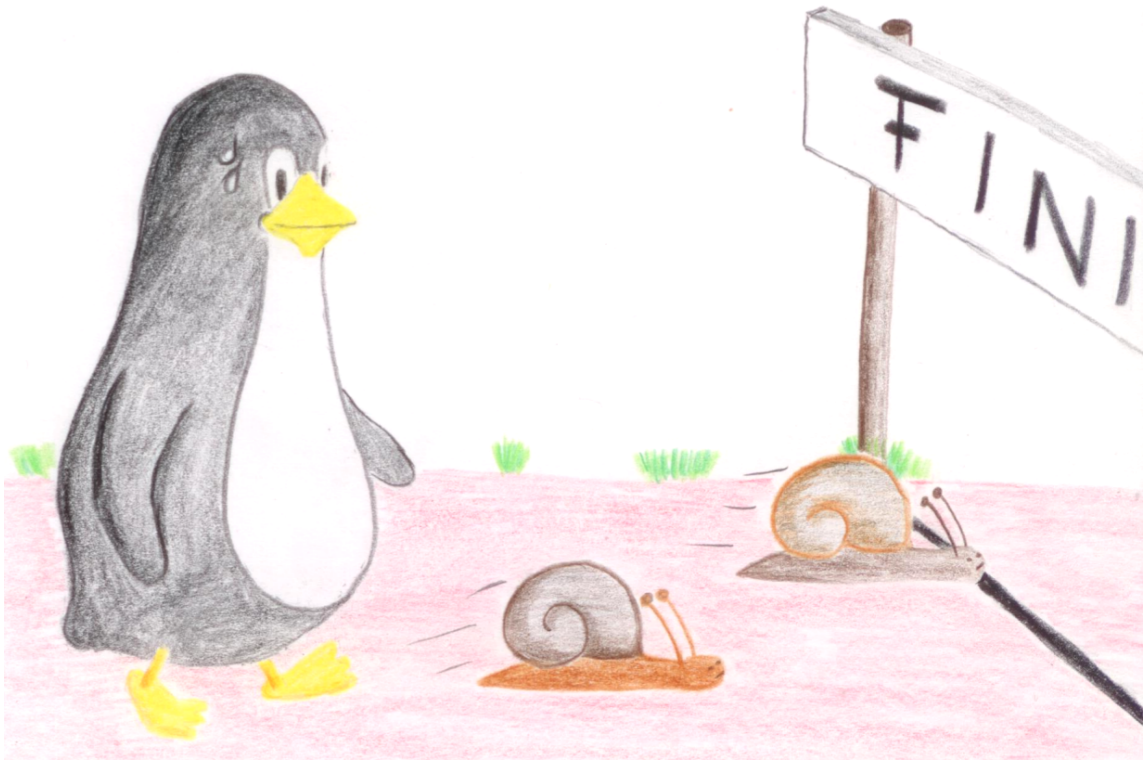
from zero...



to hero...

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Overview

1. **Basics**
   - Motivation
   - Some technical basics
2. **Optimizations**
   - Bootloader
   - Kernel
   - Filesystem
   - Application
3. **Example**
   - Optimizing an ARMv5 based device
   - Optimizing the test system

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Motivation

- "marketing"
- automotive applications
- energy saving

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  - **solution:** power-off instead of suspending

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Motivation

- "marketing"
- automotive applications
- energy saving
  - **solution:** power-off instead of suspending
  - **BUT:** Users are not used to wait

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First step: Define your requirements!!!!

- What's the limit for the boot time?
- Which functionality should be available?
- Speed vs. flexibility

NOTE: FastBOOT is not a product, it's a concept!!

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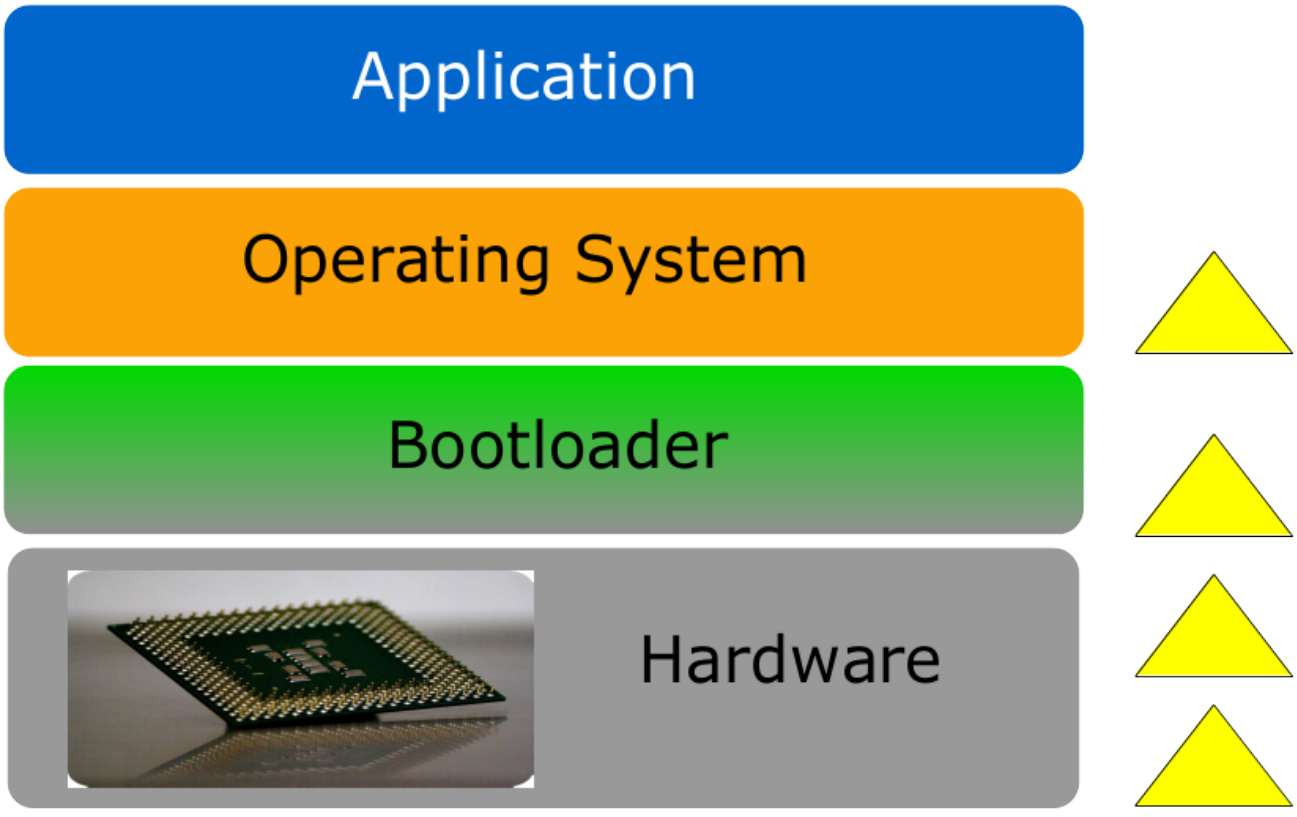
Boot process



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Components of the boot process

- Hardware reset
- Bootloader
- Operating System (drivers, filesystem, ...))
- INIT process, application (userland)

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Critical hardware components

- Power supply
- Reset logic
- Boot logic / boot order
- Boot media
- Peripherals which need to be accessed while booting

IMPORTANT: the hardware is a central part of a fastboot concept!!!

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Bootloader

- Basic setup of the CPU
- Preparing and handing over ATAGS / devicetree
- Flushing the caches
- Switch off the MMU

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The Linux Kernel

- A lot of functions for boot time optimization
- Very flexible
- Configurable compression type
- Can deffer or parallelize initializations
- 150ms - 250ms from starting the kernel to mounting the RFS

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The application

- Usually the biggest target for optimizations
- Start scripts / INIT process
- Linking

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Optimizing the bootloader (U-Boot) 1

Remove unused features:

```
/* include/configs/boardname.h */
[...]
#include <config_cmd_default.h>
#undef CONFIG_CMD_NET
[...]
```

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Optimizing the bootloader (U-Boot) 2

Verifying the kernel image:

```
setenv verify n
```

Switch off the bootloader console:

```
setenv silent 1
```

Switch off the boot delay:

```
setenv bootdelay 0
```

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Optimizing the bootloader: IPL / SPL

- Replacing the general purpose bootloader by an optimized IPL
- ...also useful for update concepts
- U-Boot offers a generic way: The U-Boot SPL (CONFIG_SPL_OS_BOOT)

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Optimizing the kernel

- Configuration and build
- Compression method
- Boot parameters (kernel commandline)
- Driver init calls
- Rootfilesystem (RFS)

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Optimizing the kernel: Configuration

```
General setup  --->
Kernel compression mode -->
```

- LZO usually a good choice for embedded system
- Copy vs. de-compress
- "Execute in Place (XIP)'

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Optimizing the kernel: Kernel commandline

- Delay Loop Calibration: "lpj="; can save > 100ms on ARMv5 based systems
- Parameters for boot time analysis: "initcall_debug", "printk_time=1"

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Optimizing the kernel: printk.time

```
...
[0.000000] VIC @f1140000: id 0x00041190,
           vendor 0x41
[0.000000] FPGA IRQ chip 0 "SIC" @ f1003000,
           21 irqs
[0.000000] Console: colour dummy device 80x30
[0.018847] Calibrating delay loop...
           626.68 BogoMIPS (lpj=3133440)
[0.316717] pid_max: default: 32768 minimum: 301
[0.317552] Mount-cache hash table entries: 512
...
```

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Optimizing the kernel: Delay Loop

```
...
[0.018847] Calibrating delay loop...
           626.68 BogoMIPS (lpj=3133440)
[0.316717] pid_max: default: 32768 minimum: 301
...
```

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Optimizing the kernel: initcall_debug

```
[0.452115] calling  exceptions_init+0x0/0x90 @ 1
[0.452172] initcall exceptions_init+0x0/0x90
               returned 0 after 0 usecs
[0.452203] calling  versatile_i2c_init+0x0/0x24 @ 1
[0.452321] initcall versatile_i2c_init+0x0/0x24
               returned 0 after 0 usecs
[0.452352] calling  pl011_init+0x0/0x54 @ 1
[0.452382] Serial: AMBA PL011 UART driver
[0.453647] dev:f1: ttyAMA0 at MMIO 0x101f1000
             (irq = 12) is a PL011 rev1
[0.481540] console [ttyAMA0] enabled
...
[0.484427] initcall pl011_init+0x0/0x54
               returned 0 after 29296 usecs
```

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bootgraph.pl

1. **Boot your system with "initcall_debug loglevel=8**
2. **On the target:**

```
$ dmesg > bootlog.txt
```

3. **On the host:**

```
$ cd linux-XXX
$ cat /path_to_rfs/bootlog.txt | \
   perl scripts/bootgraph.pl > bootlog.svg
```

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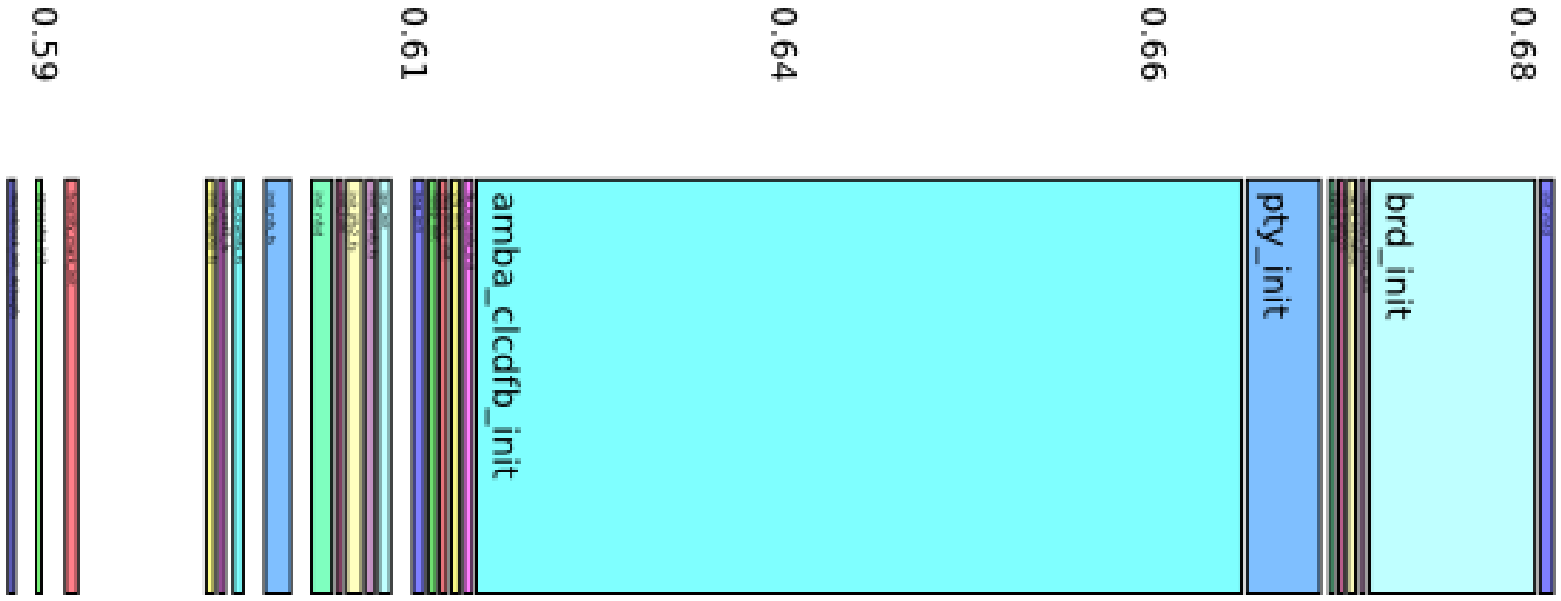
scripts/bootchart.pl



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UbiFS

- The best choice for flash devices
- Power-Fail safe
- The underlying UBI layer can be optimized with (FastMAP)
- ...

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InitRAMFS

```
dir /dev 755 0 0
nod /dev/console 644 0 0 c 5 1
nod /dev/loop0 644 0 0 b 7 0
dir /bin 755 1000 1000
slink /bin/sh busybox 777 0 0
file /bin/busybox initfs/busybox 755 0 0
[...]
dir /proc 755 0 0
dir /sys 755 0 0
dir /mnt 755 0 0
```

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InitRAMFS: Switch root

The INIT process for the InitRAMFS can be configured with rdinit=. For example: rdinit=/etc/init.d/start.sh

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InitRAMFS: Switch root

/etc/init.d/start.sh:

```
#!/bin/sh
mount -t proc proc /proc
mount -t sysfs sysfs /sys
mount -t devtmpfs devtmpfs /dev

# Mount RFS / do some critical stuff
mount /dev/mmcblk0p1 /media
fbsplash -s /media/splash.ppm -d /dev/fb0

mount -o move /proc /media/proc
mount -o move /sys /media/sys
mount -o move /dev /media/dev

# Switch to production system
exec switch_root /media /linuxrc
```

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The INIT process

- SystemV
- SystemD

One letter makes a BIG difference ;-)

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Optimizing the application

- Analyse the INIT process with bootchartd or systemd-analyze
- Replace the INIT process with your own application (init=)
- Linking
- Pre-Linking and function reordering

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Moving start script tasks into your application

```
ret = mount("sysfs", "/sys",
            "sysfs", 0, NULL);

if(ret < 0)
      perror("Can't mount sysfs\n");
```

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Dynamic linking

1. ELF DT_RPATH section
2. LD_LIBRARY_PATH
3. ELF DT_RUNPATH section
4. Binary file /etc/ld.so.cache
5. Default paths /lib und /usr/lib

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Dynamic linking: Debug and visualize

```
$ LD_DEBUG=libs ls
   3082: find library=librt.so.1 [0];
         searching
   3082: search cache=/etc/ld.so.cache
   3082: trying file=/lib/librt.so.1
```

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Test system

- ARM9 CPU (Atmel AT91 series)
- Starting point: Busybox based image (Angstrom Distribution)
- Boot media: NAND-Flash
- Test application: Toggling a GPIO via SysFS

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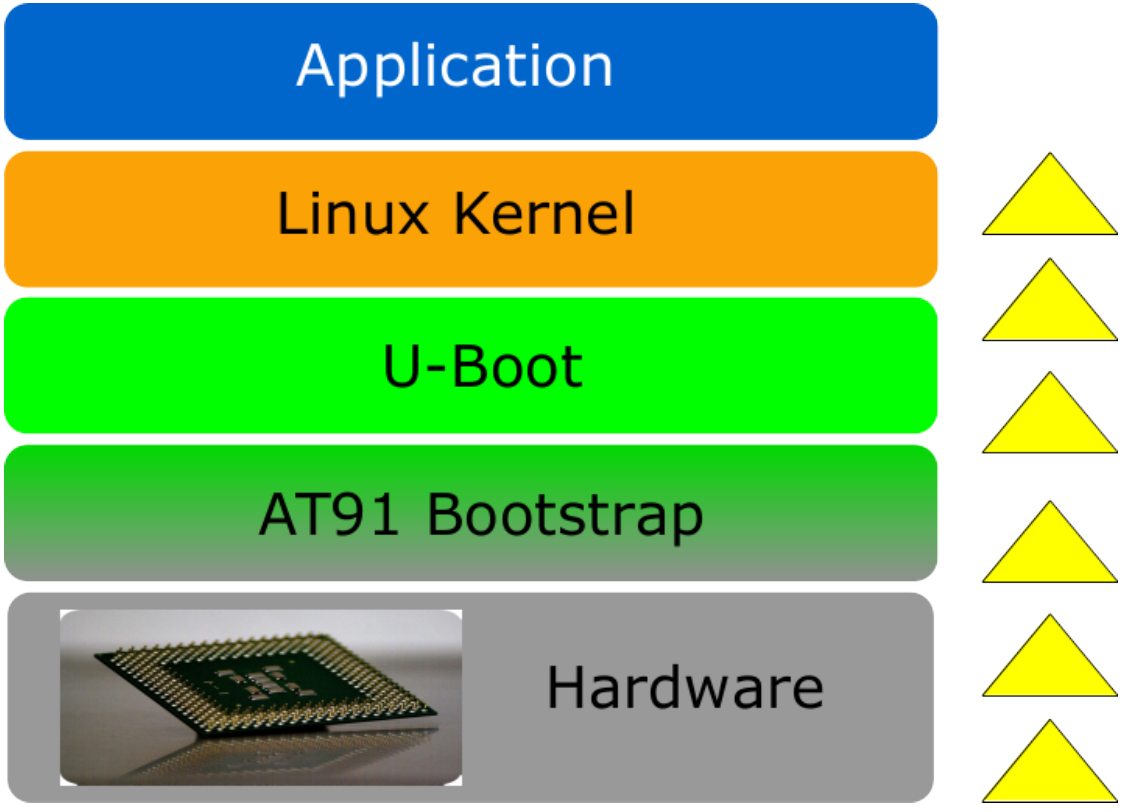
Boot strategy of the AT91 controller family



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Bootmodes of the AT91 controller family

- RomBOOT: internal boot logic
- External bus interface (CS0, e.g. NOR flash)

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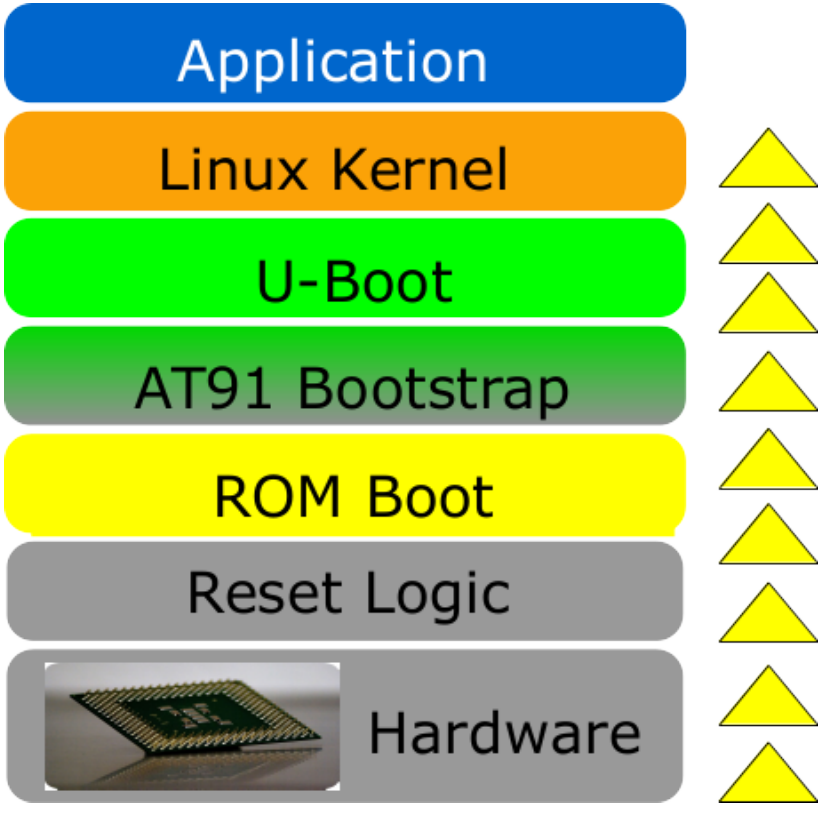
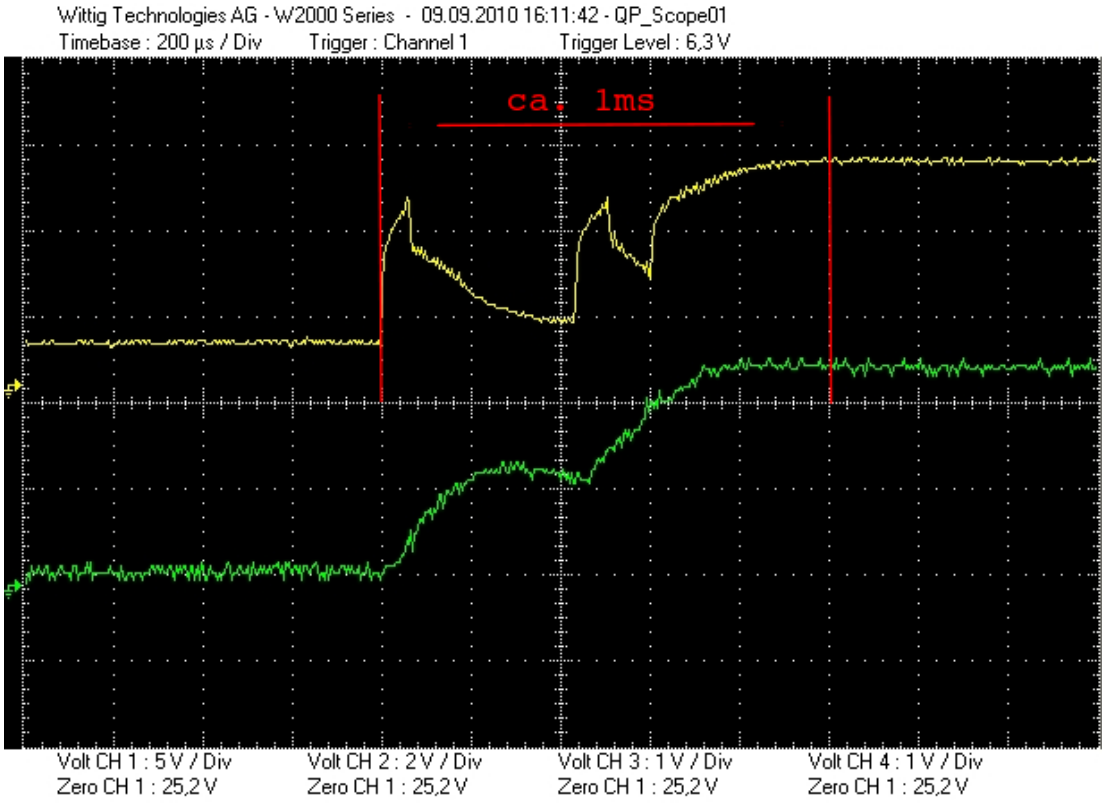
AT91 RomBOOT



Power supply



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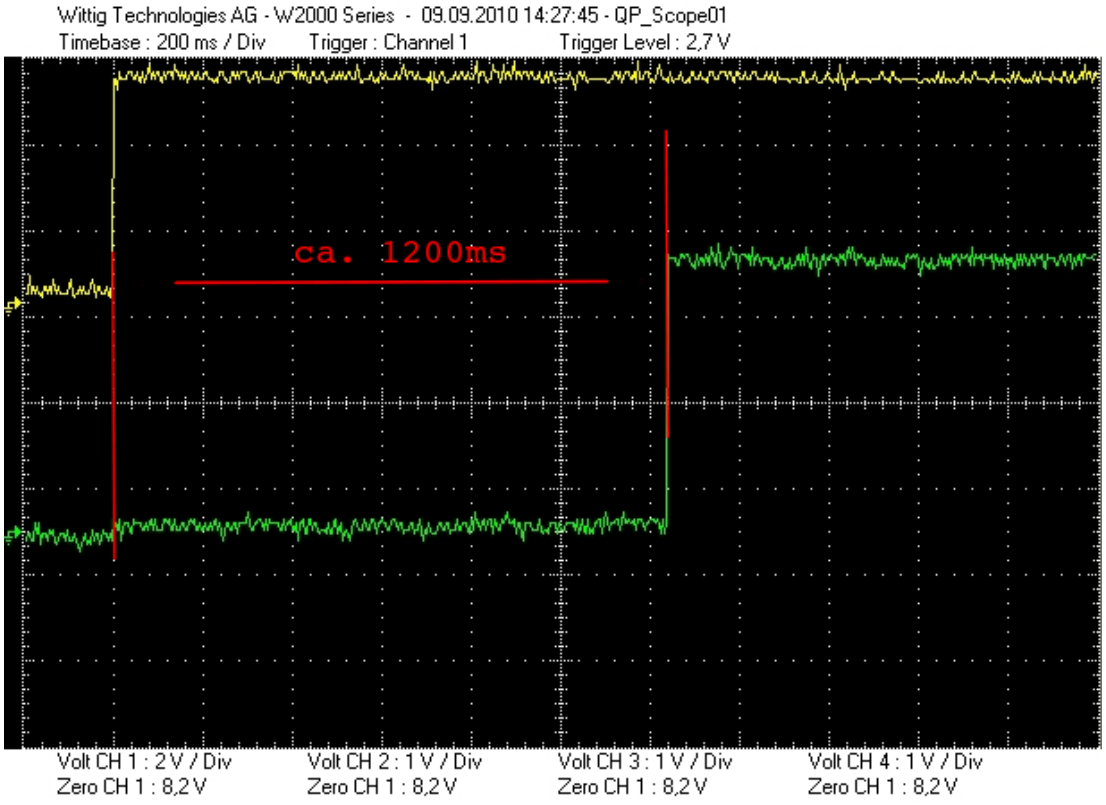
Reset logic



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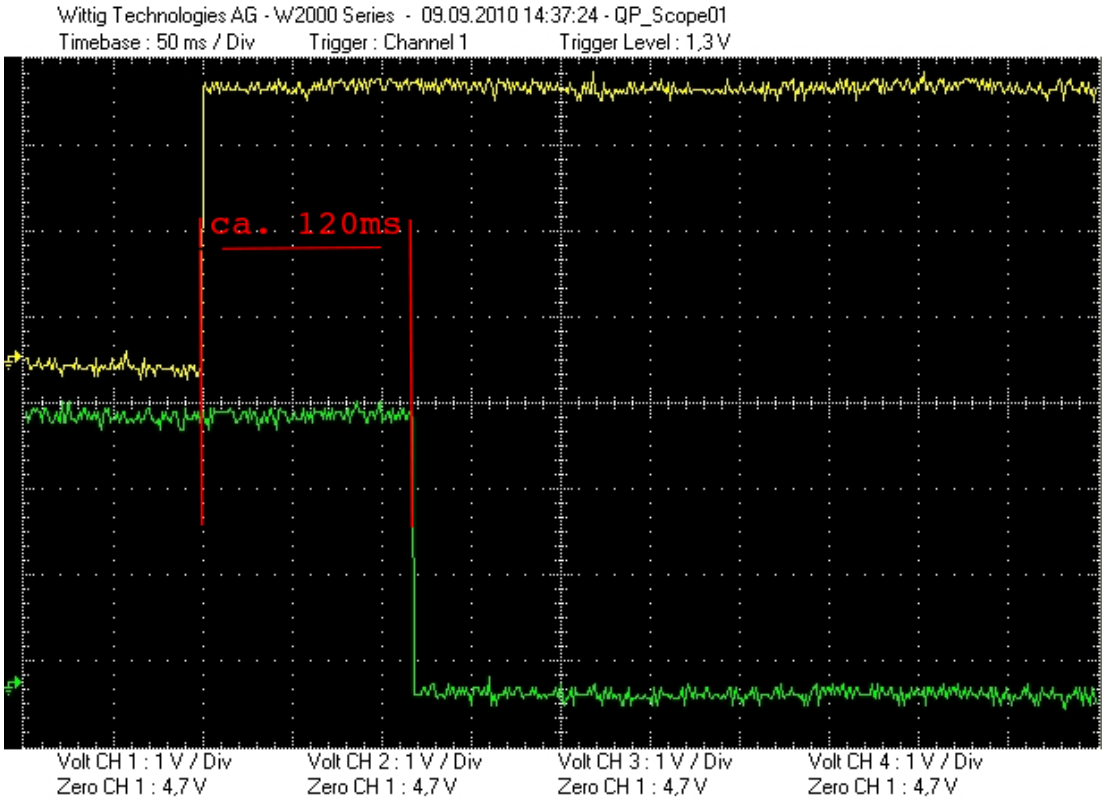
RomBOOT



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Possible hardware optimizations

- Using the internal oscillator for deriving the slowclock saves > 1s!!
- booting from CS0 will save 100 - 150ms

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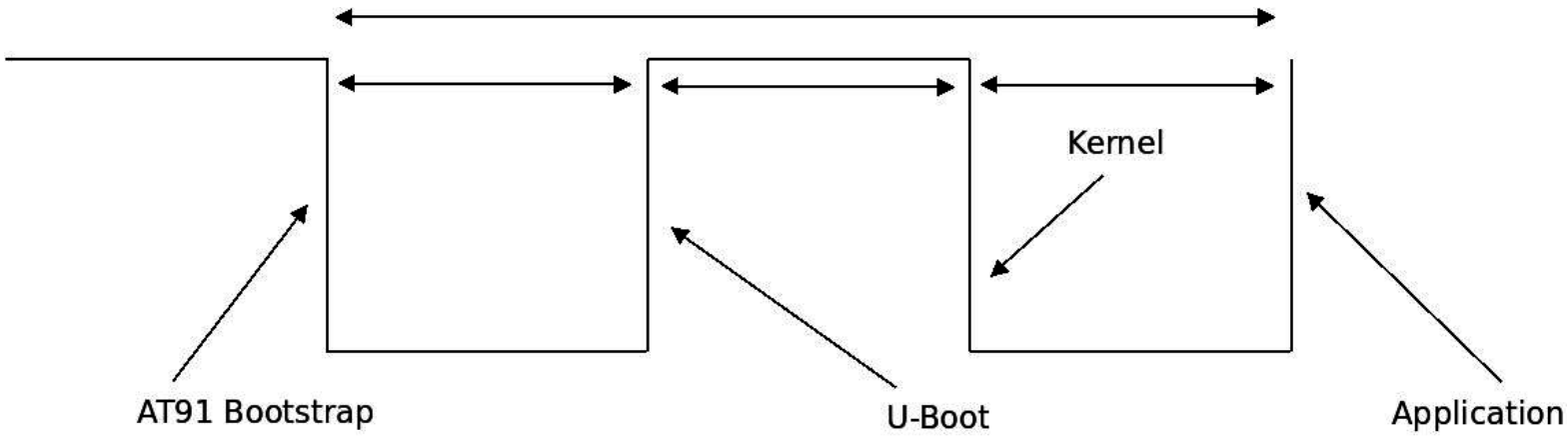
Boot time measurements with a GPIO



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Measuring points

- Bootstrap - U-Boot
- U-Boot - Early-Boot-Code of the kernel (incl. relocation and decompression)
- Kernel - application (incl. mounting the RFS)

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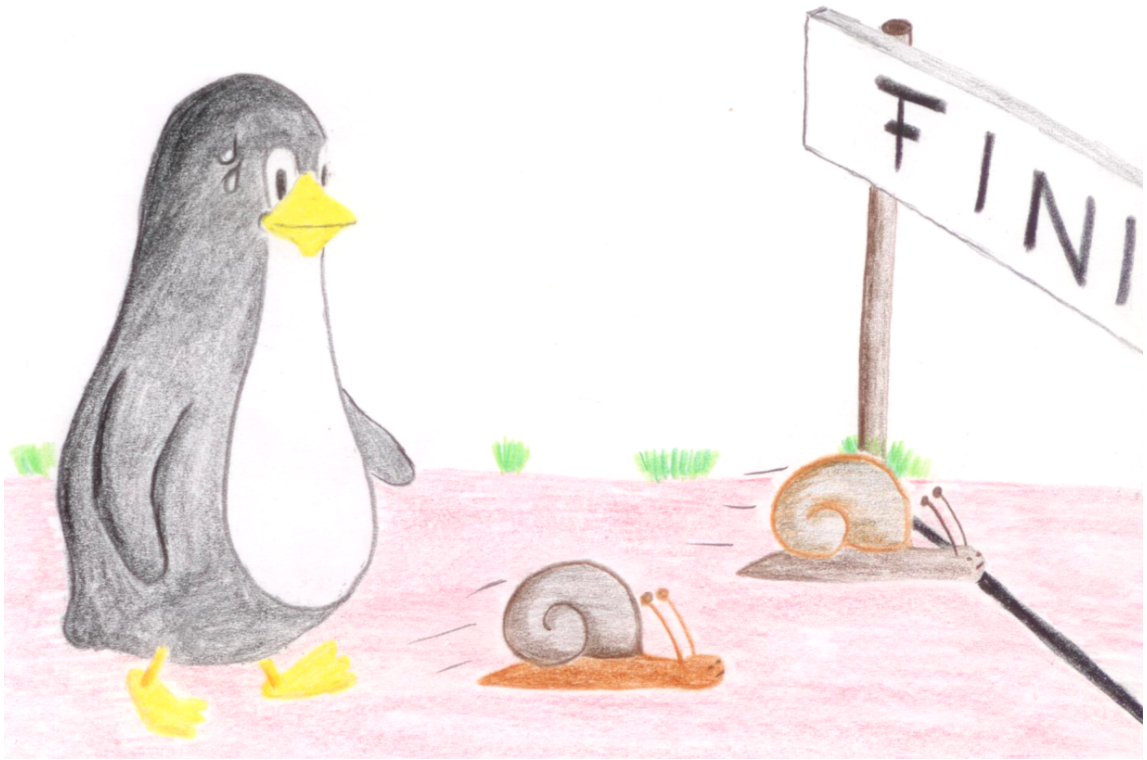
Initial boot time



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Initial boot time

measuring point	time
bootstrap - u-boot	---
u-boot - kernel	6,5s
kernel - application	4,5s
total	**11s**

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Simple optimizations

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U-Boot w/o networking support

measuring point	time
bootstrap - u-boot	---
u-boot - kernel	4,25s
kernel - application	4,5s
total	**8,75s**

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U-Boot verify=n

measuring point	time
bootstrap - u-boot	---
u-boot - kernel	3,89s
kernel - application	4,5s
total	**8,39s**

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Optimizing the kernel config

measuring point	time
bootstrap - u-boot	---
u-boot - kernel	3,77s
kernel - application	4,33s
total	**8,1s**

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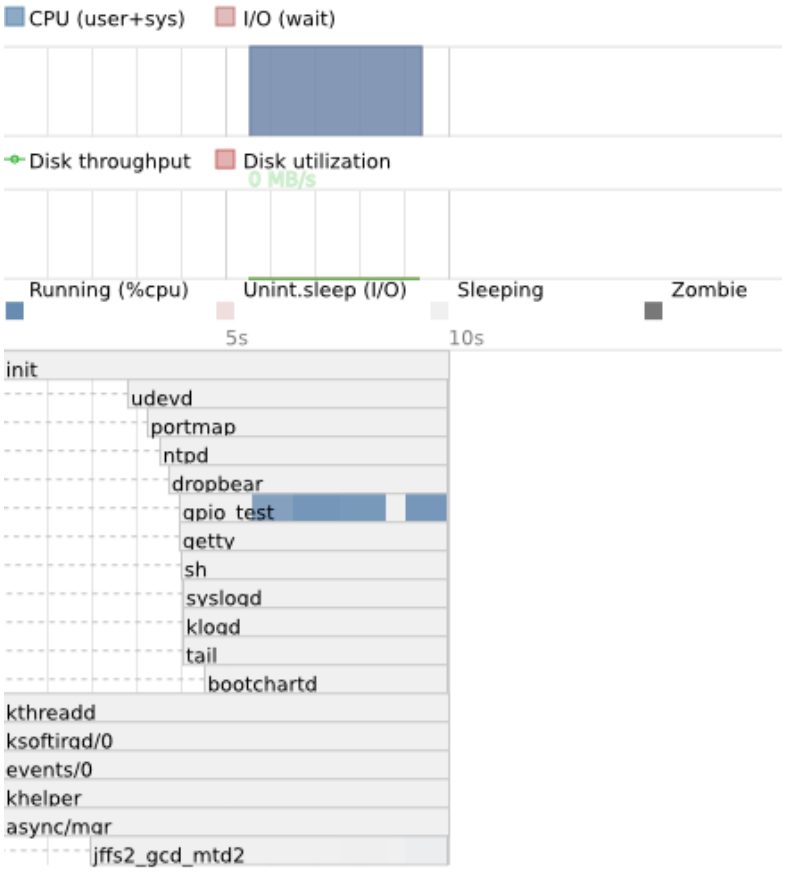
Analyzing the INIT process: Bootchartd



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Optimizing the start scripts

measuring point	time
bootstrap - u-boot	---
u-boot - kernel	3,77s
kernel - application	3,61
total	**7,38s**

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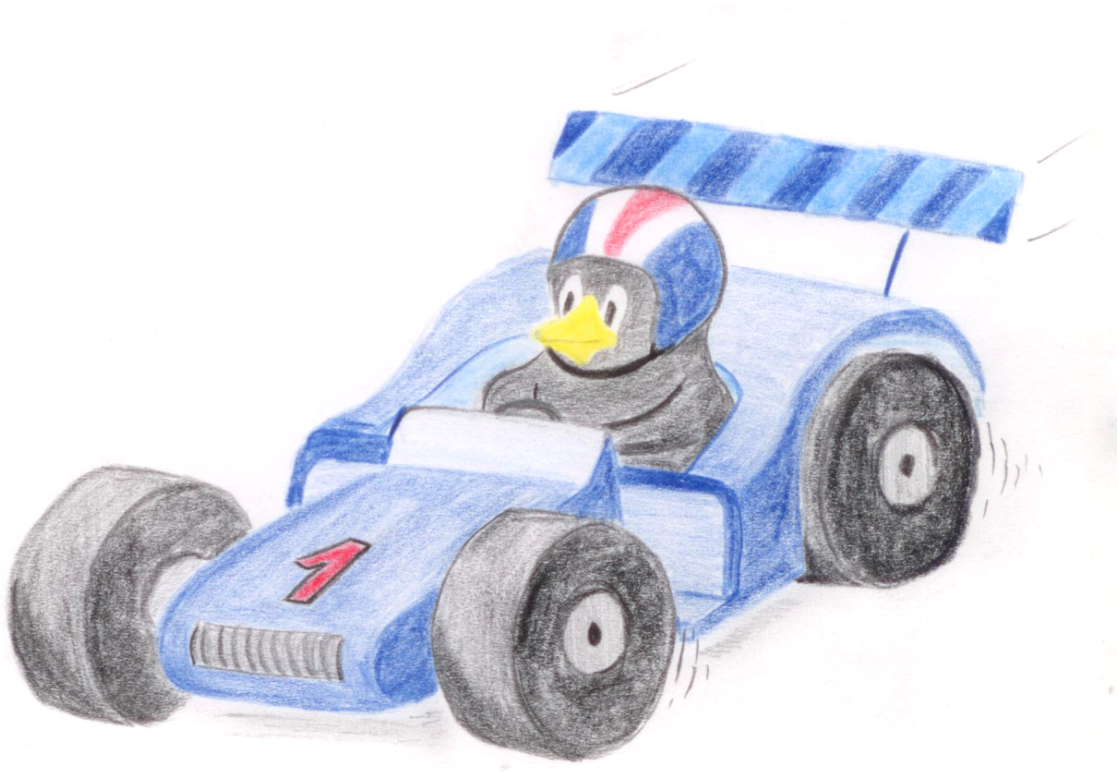
Booting an InitRAMFS



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LZO compressed InitRAMFS

The test application is used as an INIT process (rdinit=)

measuring point	time
bootstrap - u-boot	---
u-boot - kernel	3,79s
kernel - application	0,372s
total	**4,162s**

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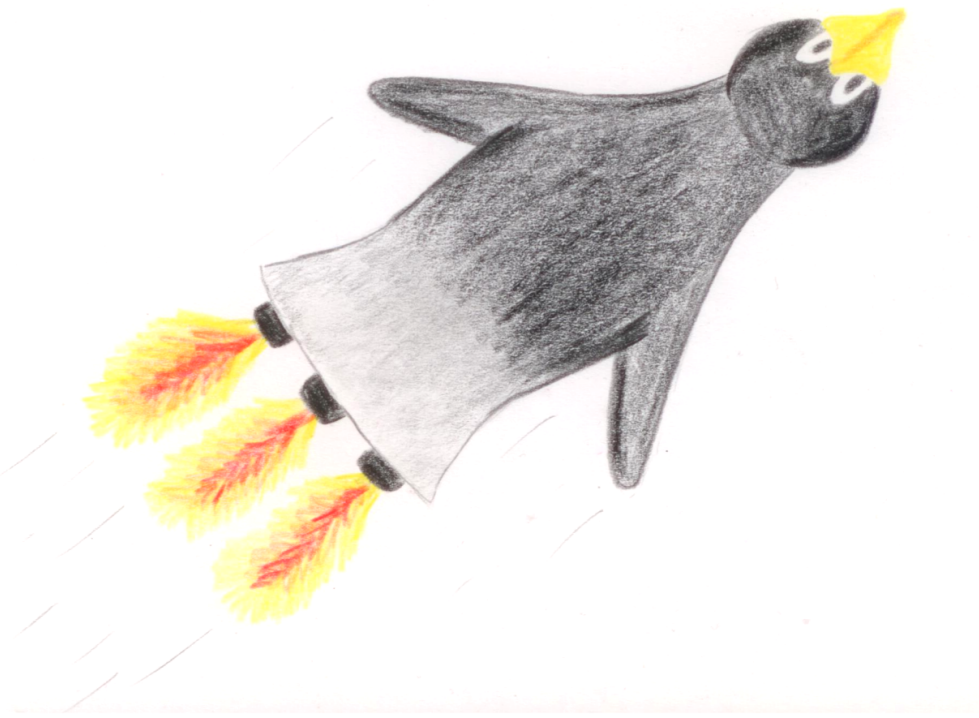
Modified AT91 Bootstrap



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Modified AT91 Bootstrap

AT91 Bootstrap starts Linux (without U-Boot)

measuring point	time
bootstrap - kernel	676ms
kernel - application	584ms
total	**1,260s**

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lpj=

measuring point	time
bootstrap - kernel	676ms
kernel - application	384ms
total	**1,060s**

Optimizing the test system

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< 1s !!

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No (serial) console output (quiet)

measuring point	time
bootstrap - kernel	524ms
kernel - application	212ms
total	**736ms**

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LZO compressed kernel image

measuring point	time
bootstrap - kernel	444ms
kernel - application	212ms
total	**656ms**

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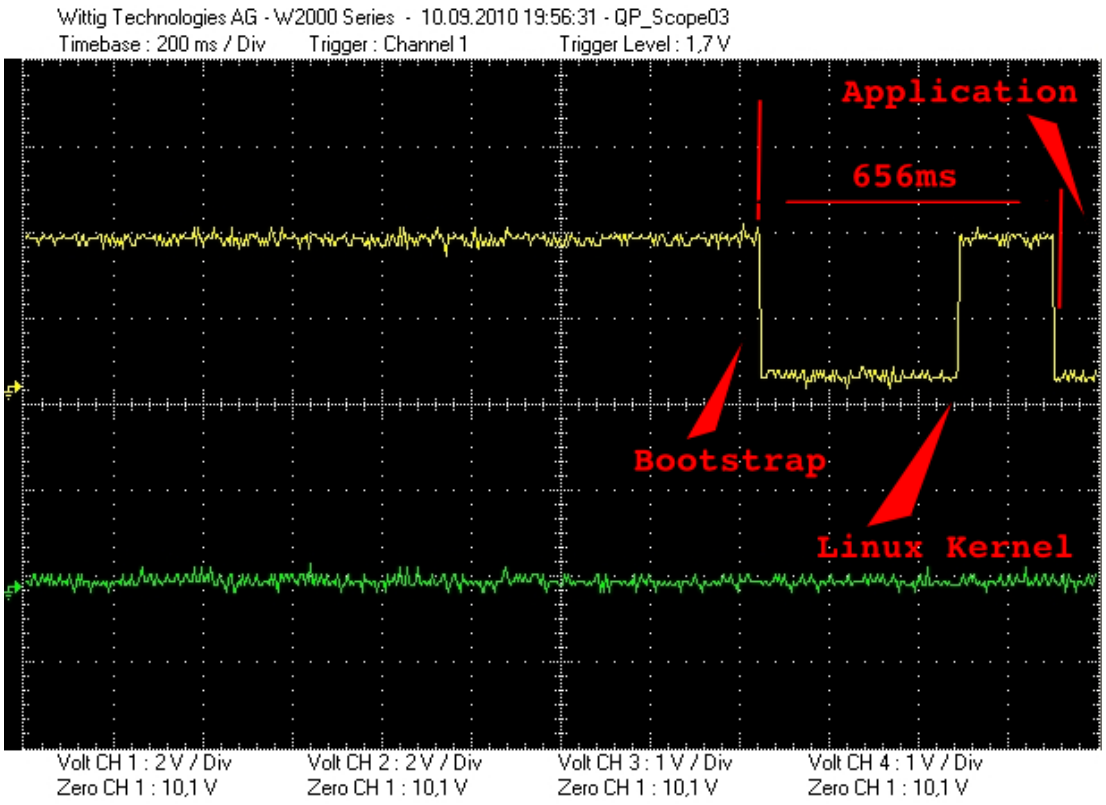
Final boot behaviour



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Conclusion

- Linux can combine the advantages of a modern OS with hard boot time requirements
- Saving boot time with simple optimizations
- The hardware is an IMPORTANT part of a FastBOOT concept
- The boot concept is architecture independent!

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Questions?

I'll also be around at the technical showcase! :)