Hacking on RISC-V and Operating Systems

Daniel Maslowski

Agenda

- What is RISC-V?
- Firmware and Boot Loaders
- Operating Systems

Introduction

Hello, I am Daniel :-)

Work and education

- IT security and computer science
- software engineer
- infrastructure and web
- applications and UI

Open Source contributions

- hardware and firmware
- operating systems
- software distributions
- reverse engineering

What is RISC-V?

Instruction Set Architecture (ISA)

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RISC-V is an open, royalty-free instruction set architecture (ISA).

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RISC-V is an open, royalty-free instruction set architecture (ISA).

The architecture is modular. A RISC-V chip may have extensions such as multiplication, floating point instructions, and some more, which are being ratified over time.

RISC-V Specifications

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Similar to x86 rings, there are privilege levels.

- M-mode (machine)
- S-mode (supervisor)
- U-mode (user)

Cores, Microcontrollers and SoCs (System on a Chip)

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Listing

https://riscv.org/exchange/cores-socs/

Development Boards

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BeagleV

https://liliputing.com/2021/07/beaglev-starlight-risc-v-single-board-computer-canceled-a-new-model-may-be-coming-in-2022.html

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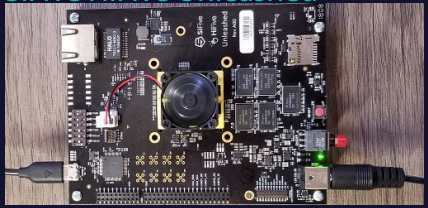
SiFive HiFive Unleashed



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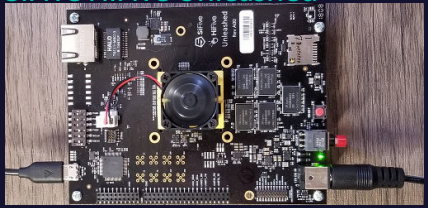

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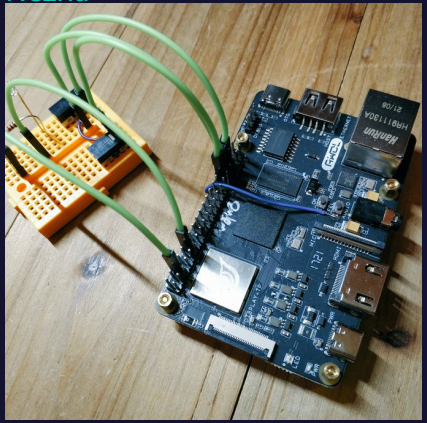
Allwinner D1 Boards

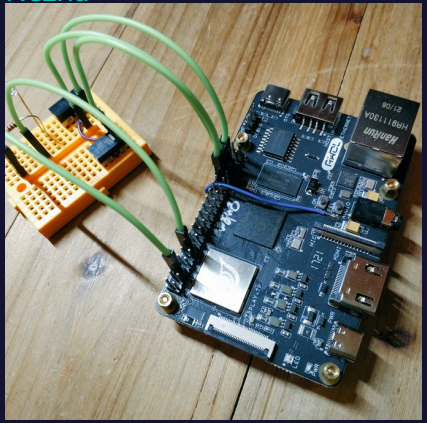
Nezha



Lichee RV

Allwinner D1 Boards

Nezha

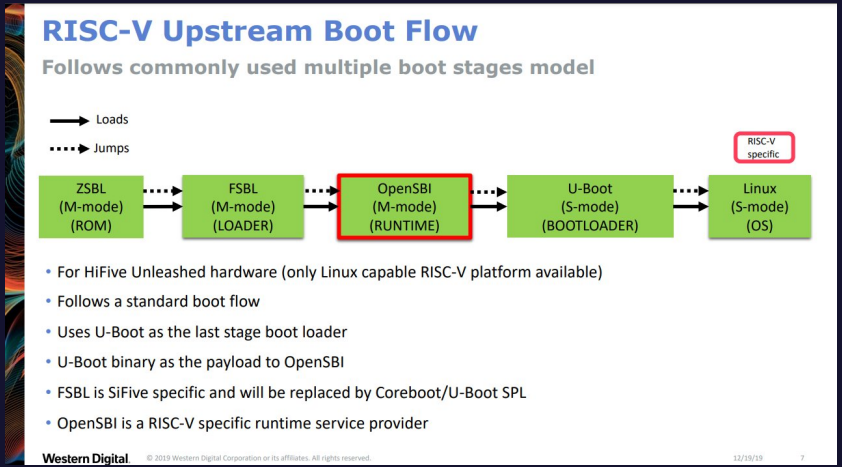


Lichee RV

D1s boards are coming as well, with 64MB RAM in package, e.g. from MangoPi.

Firmware and Boot Loaders

RISC-V Upstream Boot Flow[1]



[1] https://riscv.org/wp-content/uploads/2019/12/Summit_bootflow.pdf

SBI (Supervisor Binary Interface)

SBI is an interface described in the RISC-V privileged specification.

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Open source implementation in C, can be used as a library.

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RustSBI

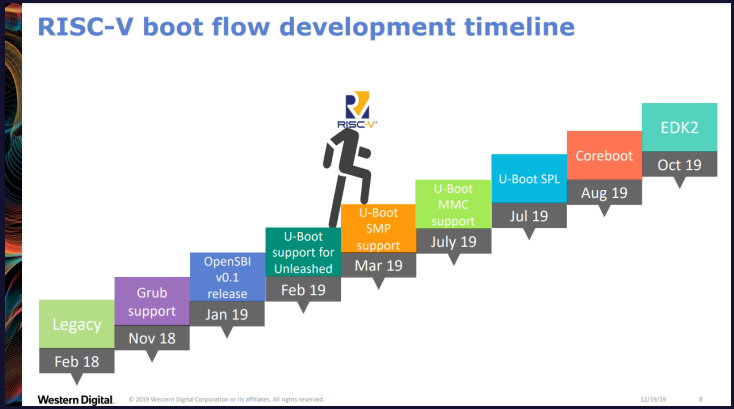
An open source implementation of SBI, written in Rust.
Both a crate and SoC-specific implementations are available.
https://github.com/rustsbi

Das U-Boot

Commonly known from Arm platforms, U-Boot is used by many SoC vendors in their SDKs.

Boot Flow Development

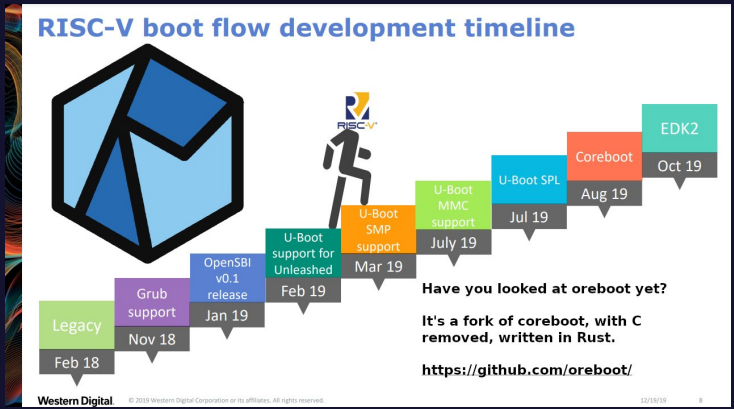
There is ongoing work towards UEFI and ACPI[2].



[2] https://www.youtube.com/watch?v=3WS6vCAC0Vs

oreboot

Downstream fork of coreboot, written in Rust.



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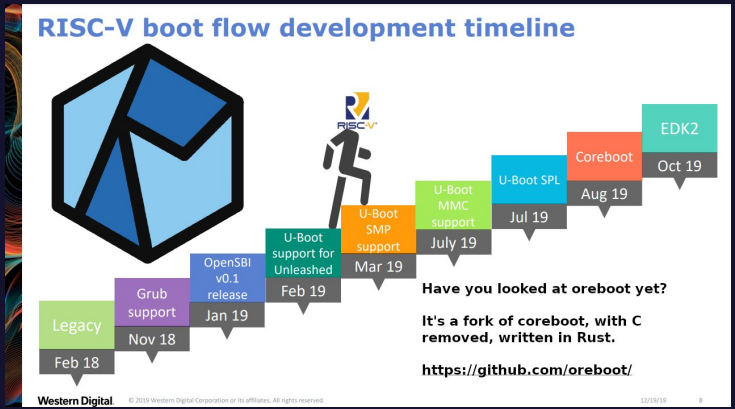
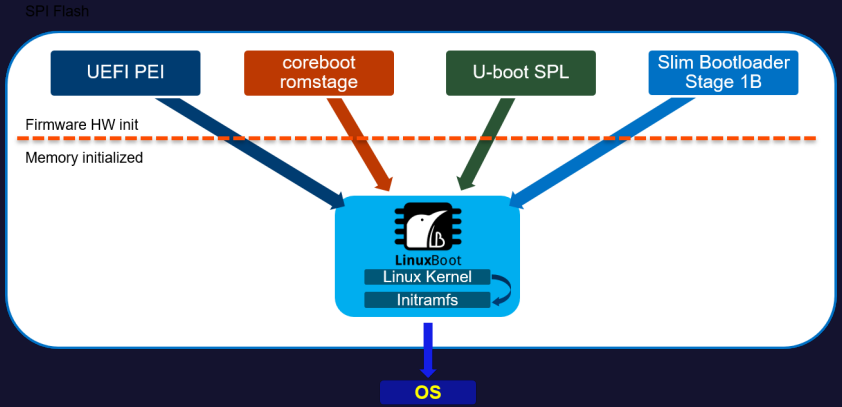


Initial RISC-V support was added in August 2019.

LinuxBoot


SPI Flash
UEFI PEI
coreboot romstage
U-boot SPL
Slim Bootloader Stage 1B
Firmware HW init
Memory initialized
LinuxBoot
Linux Kernel
Initramfs
OS


Remote Rhein Ruhr Stage

u-root

A small initramfs builder with a userland written in Go.

Operating Systems

welcome to oreboot

```
rank1 config same as rank0
DRAM BOOT DRIVE INFO: %s
DRAM CLK = 792 MHz
DRAM Type = 3 (2:DDR2,3:DDR3)
DRAMC ZQ value: 0x7b7bfb
DRAM ODT value: 0x42.
ddr_efuse_type: 0x0
DRAM SIZE =1024 M
DRAM simple test OK.
Welcome to oreboot

CTRL-A Z for help | 115200 8N1
```

Bare Metal Example

https://github.com/bigmagic123/d1-nezha-baremeta

```
[AUTO DEBUG] rank 1 row = 15
[AUTO DEBUG] rank 1 bank = 8
[AUTO DEBUG] rank 1 page size = 2 KB
rank1 config same as rank0
DRAM BOOT DRIVE INFO: %s
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DRAM SIZE =1024 M
DRAM simple test OK.
Welcome to oreboot
Welcome to oreboot
Loading payloadhello world

CTRL-A Z for help | 115200 8N1 | NOR | Minicom 2.8
```

xv6

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DRAM simple test OK.
Welcome to oreboot
Welcome to oreboot
Loading payload
Running payload

xv6 kernel is booting

init: starting sh
$ grep RISC README
but is implemented for a modern RISC-V multiprocessor using ANSI C.
You will need a RISC-V "newlib" tool chain from
$
CTRL-A Z for help | 115200 8N1 | NOR | Minicom 2.8 | VT102 | Offline
```

Linux

Linux

https://kernel.org/

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Remark: For the D1, we need to drop into S-mode as of now.

https://github.com/orangecms/oreboot/tree/nezha-next

From oreboot to RustSBI

```
Welcome to oreboot
## Loading payload
Running payload entry 0x40100000
[rustsbi] RustSBI version 0.2.0-alpha.4


.______        __    __       _______.___________.  _______..______   __
|   _  \      |  |  |  |     /       |           | /       ||   _  \ |  |
|  |_)  |     |  |  |  |    |   (----`---|  |----`|   (----`|  |_)  ||  |
|      /      |  |  |  |     \   \       |  |      \   \    |   _  < |  |
|  |\  \----. |  `--'  | .----)   |      |  |  .----)   |   |  |_)  ||  |
| _| `._____| \______/  |_______/       |__|  |_______/    |______/ |__|

[rustsbi] Platform Name: T-HEAD Xuantie Platform

[rustsbi] Implementation: RustSBI-NeZha Version 0.1.0

[rustsbi] misa: RV64ACDFIMSUVX
[rustsbi] mideleg: ssoft, stimer, sext (0x222)
[rustsbi] medeleg: ima, bkpt, uecall (0x109)
[rustsbi] enter supervisor 0x40200000

PMP0     0x0 - 0x40000000 (A,R,W,X)
PMP1     0x40000000 - 0x40200000 (A,R,W,X)
PMP2     0x40200000 - 0x80000000 (A,R,W,X)
PMP8     0x0 - 0x0 (A,R,W,X)
```

From oreboot to Linux

```
Welcome to oreboot
## Loading payload
Running payload entry 0x40100000
[rustsbi] RustSBI version 0.2.0-alpha.4

.______        ___      .______    _______.___________.  _______..______   __
|   _  \      /   \     |   _  \  /       |           | /       ||   _  \ |  |
|  |_)  |    /  ^  \    |  |  |  |   (----`---|  |----`|   (----`|  |_)  ||  |
|      /    /  /_\  \   |  |  |  |    \   \       |  |     \   \    |   _ < |  |
|  |\  \---/  _____  \  |  `--'  |.----)   |      |  |  .----)   |   |  |_)  ||  |
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PMP2     0x40200000 - 0x80000000 (A,R,W,X)
PMP8     0x0 - 0x0 (A,R,W,X)
```

Print Loop of Despair

```
_debug:
    li t0, 0x02500000
    li t2, 0x0
    sw t2, 4(t0)
_loop:
    li t1, 0x42424242
    sw t1, 0(t0)
    j _loop
```

Linux `head.S` Loop of Despair

```
Welcome to oreboot
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.______        __    __      _______.___________.  _______..______   __
|   _  \      |  |  |  |    /       |           | /       ||   _  \ |  |
|  |_)  |     |  |  |  |   |   (----`---|  |----`|   (----`|  |_)  ||  |
|      /      |  |  |  |    \   \       |  |      \   \    |   _  < |  |
|  |\  \----.|  `--'  |.----)   |      |  |  .----)   |   |  |_)  ||  |
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PMP8     0x0 - 0x0 (A,R,W,X)
BBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBB
```

Linux Instruction Fault

```
DRAM BOOT DRIVE INFO: %s
DRAM CLK = 792 MHz
DRAM Type = 3 (2:DDR2,3:DDR3)
DRAMC ZQ value: 0x7b7bfb
DRAM ODT value: 0x42.
ddr_efuse_type: 0x0
DRAM SIZE =1024 M
DRAM simple test OK.
Welcome to oreboot
Welcome to oreboot
## Loading payload
Running payload entry 0x40100000
[rustsbi] RustSBI version 0.2.0-alpha.4
.______       __    __      _______.___________.  _______..______   __
|   _  \     |  |  |  |    /       |           | /       ||   _  \ |  |
|  |_)  |    |  |  |  |   |   (----`---|  |----`|   (----`|  |_)  ||  |
|      /     |  |  |  |    \   \       |  |      \   \    |   _  < |  |
|  |\  \----.|  `--'  |.----)   |      |  |  .----)   |   |  |_)  ||  |
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[rustsbi] medeleg: ima, bkpt, uecall (0x109)
[rustsbi] enter supervisor 0x40200000
[rustsbi] dtb handed over from 0x40106d38
PMP0     0x0 - 0x40000000 (A,R,W,X)
PMP1     0x40000000 - 0x40200000 (A,R,W,X)
PMP2     0x40200000 - 0x80000000 (A,R,W,X)
PMP8     0x0 - 0x0 (A,R,W,X)
BCD8m@FGPQRSTUV[rustsbi] InstructionPageFault
[rustsbi] addr: [0x402000d0] mepc: [0x402000d0] 0x570031312000073
```

Linux Setup ecall Debugging

```
263 void __init setup_arch(char **cmdline_p)
264 {
265         __asm__("li a7,0x01");
266         __asm__("li a0,'L'");
267         __asm__("ecall");
268         parse_dtb();
269         __asm__("li a7,0x01");
270         __asm__("li a0,'I'");
271         __asm__("ecall");
272         setup_initial_init_mm(_stext, _etext, _edata, _end);
273         __asm__("li a7,0x01");
274         __asm__("li a0,'N'");
275         __asm__("ecall");
276
277         *cmdline_p = boot_command_line;
278
279         early_ioremap_setup();
280         jump_label_init();
281         __asm__("li a7,0x01");
282         __asm__("li a0,'U'");
283         __asm__("ecall");
284         parse_early_param();
285         __asm__("li a7,0x01");
286         __asm__("li a0,'X'");
287         __asm__("ecall");
288
289         efi_init();
kernel/setup.c                                                268,1-8
```

SBI console

```
Welcome to oreboot
## Loading payload
Running payload entry 0x40100000
[rustsbi] RustSBI version 0.2.0-alpha.4
.______       __    __      _______.___________.  _______..______   __
|   _  \     |  |  |  |    /       |           | /       ||   _  \ |  |
|  |_)  |    |  |  |  |   (---- `---|  |----`|   (----`|  |_)  ||  |
|      /     |  |  |  |    \   \     |  |      \   \    |   _  < |  |
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[rustsbi] medeleg: ima, ia, illinsn, bkpt, lma, la, sma, sa, uecall, ipage, lpage, spage (0xb1ff)
[rustsbi] enter supervisor 0x40200000
[rustsbi] dtb handed over from 0x401074f8
PMP0    0x0 - 0x40000000 (A,R,W,X)
PMP1    0x40000000 - 0x40200000 (A,R,W,X)
PMP2    0x40200000 - 0x80000000 (A,R,W,X)
PMP8    0x0 - 0x0 (A,R,W,X)
UVW12345
=DONE=
[    0.000000] Linux version 5.14.0-rc4-g4da1f2b067d4 (bob@thebuilder) (riscv64-linux-gnu-gcc (GCC) 11.1.0, GNU ld (GNU1
[    0.000000] OF: fdt: Ignoring memory range 0x40000000 - 0x40200000
[    0.000000] Machine model: sun20iw1p1
[    0.000000] earlycon: sbi0 at I/O port 0x0 (options '')
[    0.000000] printk: bootconsole [sbi0] enabled
[    0.000000] Unable to handle kernel paging request at virtual address ffffffdffff074f9
[    0.000000] Oops [#1]
[    0.000000] CPU: 0 PID: 0 Comm: swapper Not tainted 5.14.0-rc4-g4da1f2b067d4 #90
[    0.000000] Hardware name: sun20iw1p1 (DT)
[    0.000000] epc : fdt_check_header+0x0/0x1f6
[    0.000000]  ra : early_init_dt_verify+0x12/0x68
[    0.000000] epc : ffffffff8035611c ra : ffffffff80414904 sp : ffffffff80e03f20
[    0.000000]  gp : ffffffff80ecd0d0 tp : ffffffff80e08640 t0 : fffffcefefff000
[    0.000000]  t1 : ffffffff80606778 t2 : 0000000000000000 s0 : ffffffdffff074f8
[    0.000000]  s1 : ffffffff80e03fb8 a0 : ffffffdffff074f8 a1 : 0000000000000000
[    0.000000]  a2 : 0000000000000000 a3 : ffffffff80ecb000 a4 : 0000000000000000
[    0.000000]  a5 : 0000000401074f8 a6 : ffffffff80000000 a7 : fffffffd00000000
[    0.000000]  s2 : ffffffff80ec7058 s3 : 0000000000000000 s4 : 0000000000000000
[    0.000000]  s5 : 0000000000000000 s6 : 0000000000000000 s7 : 0000000000000000
[    0.000000]  s8 : 0000000000000000 s9 : 0000000000000000 s10: 0000000000000000
[    0.000000]  s11: 0000000000000000 t3 : 000000047fff000 t4 : ffffffffffffffff
[    0.000000]  t5 : 0000000048000000 t6 : ffffffff806066b0
[    0.000000] status: 0000002000000100 badaddr: ffffffdffff074f9 cause: 000000000000000d
[    0.000000] [<ffffffff8035611c>] fdt_check_header+0x0/0x1f6
[    0.000000] [<ffffffff80048286>] setup_arch+0xdc/0x560
[    0.000000] [<ffffffff80400626>] start_kernel+0x6e/0x682
[    0.000000] random: get_random_bytes called from oops_exit+0x2c/0x50 with crng_init=0
[    0.000000] ---[ end trace 0000000000000000 ]---
[    0.000000] Kernel panic - not syncing: Attempted to kill the idle task!
[    0.000000] ---[ end Kernel panic - not syncing: Attempted to kill the idle task! ]---
```

Oops on float instruction

```
[    0.000000] Inode-cache hash table entries: 65536 (order: 7, 524288 bytes, linear)
[    0.000000] mem auto-init: stack:off, heap alloc:off, heap free:off
[    0.000000] Memory: 997556K/1046528K available (3544K kernel code, 3058K rwdata, 20)
[    0.000000] SLUB: HWalign=64, Order=0-3, MinObjects=0, CPUs=1, Nodes=1
[    0.000000] rcu: Preemptible hierarchical RCU implementation.
[    0.000000]  Trampoline variant of Tasks RCU enabled.
[    0.000000] rcu: RCU calculated value of scheduler-enlistment delay is 25 jiffies.
[    0.000000] NR_IRQS: 64, nr_irqs: 64, preallocated irqs: 0
[    0.000000] riscv-intc: 64 local interrupts mapped
[    0.000000] plic: interrupt-controller@10000000: mapped 200 interrupts with 1 handl.
[    0.000000] Oops - illegal instruction [#1]
[    0.000000] CPU: 0 PID: 0 Comm: swapper Not tainted 5.15.5-00042-g312c3e9fdca4 #4
[    0.000000] Hardware name: sun20iw1p1 (DT)
[    0.000000] epc : rand_initialize+0x2e/0xf8
[    0.000000]  ra : rand_initialize+0x20/0xf8
[    0.000000] epc : ffffffff8041000a ra : ffffffff8040fffc sp : ffffffff80e03f90
[    0.000000]  gp : ffffffff80ebf130 tp : ffffffff80e08640 t0 : 0000000000000019
[    0.000000]  t1 : 0000000000000018 t2 : 0000000000000001 s0 : 0000000000000200
[    0.000000]  s1 : ffffffe03efc30c0 a0 : 0000000000000001 a1 : ffffffff80e03f98
[    0.000000]  a2 : 0000000000000000 a3 : 0000000000000018 a4 : 0000000000000001
[    0.000000]  a5 : ffffffff80a31900 a6 : 000000000000007f a7 : ffffffff80ef5e58
[    0.000000]  s2 : ffffffff80ec0038 s3 : 0000000000000000 s4 : ffffffff80ec0018
[    0.000000]  s5 : ffffffff80600018 s6 : 0000000000000000 s7 : 0000000000000000
[    0.000000]  s8 : 0000000000000000 s9 : 0000000000000000 s10: 0000000000000000
[    0.000000]  s11: 0000000000000000 t3 : ffffffff80e03f98 t4 : 0000000000000068
[    0.000000]  t5 : 000000000000004c t6 : 0000000000000033
[    0.000000] status: 0000000200000100 badaddr: 00000000c01027f3 cause: 00000000000002
[    0.000000] [<ffffffff8041000a>] rand_initialize+0x2e/0xf8
[    0.000000] [<ffffffff80400a14>] start_kernel+0x45a/0x63c
[    0.000000] random: get_random_bytes called from oops_exit+0x2c/0x50 with crng_init0
[    0.000000] ---[ end trace 0000000000000000 ]---
[    0.000000] Kernel panic - not syncing: Attempted to kill the idle task!
[    0.000000] ---[ end Kernel panic - not syncing: Attempted to kill the idle task! ]-
```

Welcome to u-root!

```
[   11.133354] dwmac-sun8i 4500000.ethernet: TX Checksum insertion supported
[   11.145348] dwmac-sun8i 4500000.ethernet: Normal descriptors
[   11.157355] dwmac-sun8i 4500000.ethernet: Chain mode enabled
[   11.169382] dwmac-sun8i 4500000.ethernet: device MAC address 7e:ad:75:01:38:db
[   11.201574] libphy: stmmac: probed
[   11.312957] usbvbus: supplied by vcc
[   11.322710] sunxi-mmc 4020000.mmc: Got CD GPIO
[   11.328881] sunxi-mmc 4021000.mmc: allocated mmc-pwrseq
[   11.364464] acked 85 in 0x00000274, was 0x00200000, now 0x00000000
[   11.381624] sunxi-mmc 4020000.mmc: initialized, max. request size: 2047 KB, uses new timings me
[   11.391270] sunxi-mmc 4021000.mmc: initialized, max. request size: 2047 KB, uses new timings me
[   11.401378] acked 84 in 0x00000274, was 0x00100000, now 0x00000000
[   11.454616] mmc1: new high speed SDIO card at address 0001
[   11.464185] clk: Not disabling unused clocks
[   33.136267] Freeing unused kernel image (initmem) memory: 4616K
[   33.142673] Run /init as init process
1970/01/01 00:00:33 Welcome to u-root!

                                _
   _   _      _ __ ___    ___ | |_
  | | | |____| '__/ _ \ / _ \| __|
  | |_| |____| | | (_) | (_) | |_
   \__,_|    |_|  \___/ \___/ \__|

init: 1970/01/01 00:00:33 no modules found matching '/lib/modules/*.ko'
~/# uname -a
Linux nezha 5.15.5-00125-g6a3e59063ef3-dirty #14 PREEMPT Thu Dec 16 01:09:25 CET 2021 riscv64 (non
e)
~/# cat /proc/cpuinfo
processor       : 0
hart            : 0
isa             : rv64imafdc
mmu             : sv39
uarch           : thead,c906

~/#                                                             root@nezha
CTRL-A Z for help | 115200 8N1 | NOR | Minicom 2.8 | VT102 | Offline | ttyUSB0
```

Networking and kexec

```
~/tmp# wget http://192.168.0.73:8000/vmlinux
~/tmp# kexec vmlinux
[    0.000000] Linux version 5.15.5-00131-g9fd1fcf0c67b (dan@orangepad) (riscv64-linux
-gnu-gcc (GCC) 11.1.0, GNU ld (GNU Binutils) 2.36.1) #17 PREEMPT Fri Dec 17 21:54:33 C
ET 2021
[    0.000000] OF: fdt: Ignoring memory range 0x40000000 - 0x40200000
[    0.000000] Machine model: Allwinner D1 NeZha
[    0.000000] earlycon: sbi0 at I/O port 0x0 (options '')
[    0.000000] printk: bootconsole [sbi0] enabled
[    0.000000] Zone ranges:
[    0.000000]   DMA32    [mem 0x0000000040200000-0x000000005fffffff]
[    0.000000]   Normal   empty
[    0.000000] Movable zone start for each node
[    0.000000] Early memory node ranges
[    0.000000]   node   0: [mem 0x0000000040200000-0x000000005fffffff]
[    0.000000] Initmem setup node 0 [mem 0x0000000040200000-0x000000005fffffff]
[    0.000000] SBI specification v0.3 detected
[    0.000000] SBI implementation ID=0x4 Version=0x200
[    0.000000] SBI TIME extension detected
[    0.000000] SBI IPI extension detected
[    0.000000] SBI SRST extension detected
[    0.000000] riscv: ISA extensions acdfim
[    0.000000] riscv: ELF capabilities acdfim
[    0.000000] Built 1 zonelists, mobility grouping on.  Total pages: 128775
[    0.000000] Kernel command line: clk_ignore_unused debug initcall_debug=1 console=t
tyS0,115200n8 loglevel=7 earlycon=sbi init=/init
[    0.000000] Dentry cache hash table entries: 65536 (order: 7, 524288 bytes, linear)
[    0.000000] Inode-cache hash table entries: 32768 (order: 6, 262144 bytes, linear)
[    0.000000] mem auto-init: stack:off, heap alloc:off, heap free:off
[    0.000000] Memory: 497716K/522240K available (3296K kernel code, 4175K rwdata, 204
8K rodata, 4796K init, 258K bss, 24524K reserved, 0K cma-reserved)
[    0.000000] SLUB: HWalign=64, Order=0-3, MinObjects=0, CPUs=1, Nodes=1
[    0.000000] rcu: Preemptible hierarchical RCU implementation.
```

SD Card and kexec

```
[   12.667733] mmc0: new high speed SDHC card at address e624
[   12.687251] mmcblk0: mmc0:e624 SC32G 29.7 GiB
[   12.730965]  mmcblk0: p1 p2 p3 < p5 p6 p7 p8 p9 p10 p11 p12 >
[   39.859938] Freeing unused kernel image (initmem) memory: 5192K
[   39.866313] Run /init as init process
1970/01/01 00:00:40 Welcome to u-root!

                              _
   _   _      _ __ ___   ___ | |_
  | | | |____| '__/ _ \ / _ \| __|
  | |_| |____| | | (_) | (_) | |_
   \__,_|    |_|  \___/ \___/ \__|

init: 1970/01/01 00:00:40 no modules found matching '/lib/modules/*.ko'
/# [   91.627774] acked 134 in 0x000002b4, was 0x00000040, now 0x00000000t@nezha
[   91.636220] acked 134 in 0x000002b4, was 0x00000040, now 0x00000000
[   91.642935] acked 134 in 0x000002b4, was 0x00000040, now 0x00000000
   mount /dev/mmcblk0p1 /tcz/
1970/01/01 00:04:26 open /dev/mmcblk0p1: no such file or directory
Exception: mount exited with 1
[tty 1], line 1: mount /dev/mmcblk0p1 /tcz/
/# [  299.952499] acked 134 in 0x000002b4, was 0x00000040, now 0x00000000t@nezha
   mount /dev/mmcblk0p1 /tcz/
[  305.006592] FAT-fs (mmcblk0p1): Volume was not properly unmounted. Some data may b
e corrupt. Please run fsck.
/# kexec --append "root=/dev/mmcblk0p5 rootwait" /tcz/vmlinux
[rustsbi] setTimer
[    0.000000] Linux version 5.15.11-00133-gbb8e198996a1 (dan@orangepad) (riscv64-lin
ux-gnu-gcc (GCC) 11.1.0, GNU ld (GNU Binutils) 2.36.1) #26 PREEMPT Wed Dec 22 22:48:0
9 CET 2021
[    0.000000] OF: fdt: Ignoring memory range 0x40000000 - 0x40200000
[    0.000000] Machine model: Allwinner D1 NeZha
[    0.000000] Zone ranges:
[    0.000000]   DMA32    [mem 0x0000000040200000-0x000000005fffffff]
[    0.000000]   Normal   empty
[    0.000000] Movable zone start for each node
[    0.000000] Early memory node ranges
[    0.000000]   node   0: [mem 0x0000000040200000-0x000000005fffffff]
```

Booting into OpenWrt

```
Please press Enter to activate this console.



BusyBox v1.34.1 (2021-12-21 14:11:53 UTC) built-in shell (ash)

  _______                     ________        __
 |       |.-----.-----.-----.|  |  |  |.----.|  |_
 |   -   ||  _  |  -__|     ||  |  |  ||   _||   _|
 |_______||   __|_____|__|__||________||__|  |____|
          |__| W I R E L E S S   F R E E D O M
 -----------------------------------------------------
 OpenWrt SNAPSHOT, r18404-0a9f91d0ed
 -----------------------------------------------------
=== WARNING! =====================================
There is no root password defined on this device!
Use the "passwd" command to set up a new password
in order to prevent unauthorized SSH logins.
--------------------------------------------------
root@nezha:/# [   24.421437] kmodloader: no module folders for kernel version 5.15.10
-00133-gc61da11077e1 found
[   24.421437] kmodloader: no module folders for kernel version 5.15.10-00133-gc61da1
1077e1 found
[   26.575832] urngd: v1.0.2 started.
[   26.575832] urngd: v1.0.2 started.

root@nezha:/# cat /proc/cmdline
root=/dev/mmcblk0p2 rw rootwait init=/sbin/init
root@OpenWrt:/# [   42.124370] ldob: disabling
[   42.124370] ldob: disabling
[   42.140420] usbvbus: disabling
[   42.140420] usbvbus: disabling

CTRL-A Z for help | 115200 8N1 | NOR | Minicom 2.8 | VT102 | Offline | ttyUSB0
```

openSUSE

openSUSE

oreboot + RustSBI -> LinuxBoot -> openSUSE

… and SSH from my phone :)

Thank you!

Kudos …

… to everyone working on RISC-V.

… to Drew Fustini for organizing and hosting RISC-V community meetups.

… to everyone involved in the oreboot project.

… to Luo Jia for creating and others contributing to RustSBI.

… to Sipeed, Allwinner, T-Head and others offering affordable SoCs and boards.

… to Samuel Holland for assistance with bringup and mainlining Linux and U-Boot patches.

… to Zoltan Herpai for the OpenWrt port[3].

[3] https://git.openwrt.org/?p=openwrt/staging/wigyori.git;h=refs/heads/d1-5.15

Questions?

Advanced

Svpbmt ISA extension

http://lists.infradead.org/pipermail/linux-riscv/2021-September/008578.html
https://github.com/riscv/virtual-memory/blob/main/README.md#svpbmt-page-based-memory-types

European Processor Initiative

https://www.european-processor-initiative.eu/epi-epac1-0-risc-v-test-chip-samples-delivered/
https://www.european-processor-initiative.eu/successful-conclusion-of-european-processor-initiative-phase-one/

rCore

https://github.com/rcore/