Western Digital

OpenSBI Deep Dive

Anup Patel <anup.patel@wdc.com>
Western Digital Research

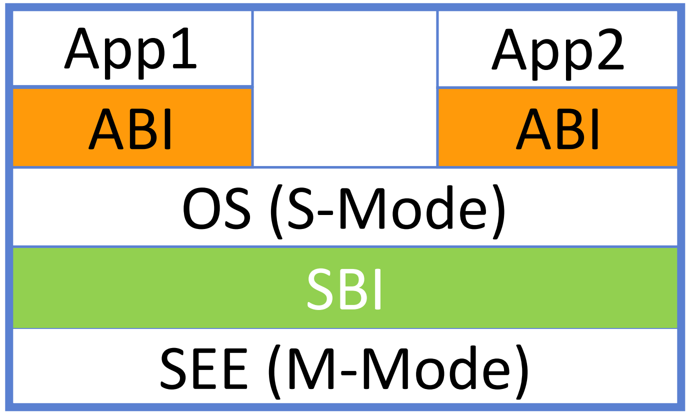
Outline

- OpenSBI Introduction
  - Overview and features
- OpenSBI Platform Specific Support
- OpenSBI Usage
  - As a firmware: Reference Firmwares
  - As a library: API
- Conclusion

OpenSBI Introduction

What is SBI ?

- SBI stands for RISC-V Supervisor Binary Interface
  - System call style calling convention between Supervisor (S-mode OS) and Supervisor Execution Environment (SEE)
- SEE can be:
  - A M-mode RUNTIME firmware for OS/Hypervisor running in HS-mode
  - A HS-mode Hypervisor for Guest OS running in VS-mode
- SBI calls help:
  - Reduce duplicate platform code across OSes (Linux, FreeBSD, etc)
  - Provide common drivers for an OS which can be shared by multiple platforms
  - Provide an interface for direct access to hardware resources (M-mode only resources)
- Specifications being drafted by the Unix Platform Specification Working group
  - Maintain and evolve the SBI specifications
  - Currently, SBI v0.1 in-use and SBI v0.2 in draft stage



App1 App2

ABI ABI

OS (S-Mode)

SBI

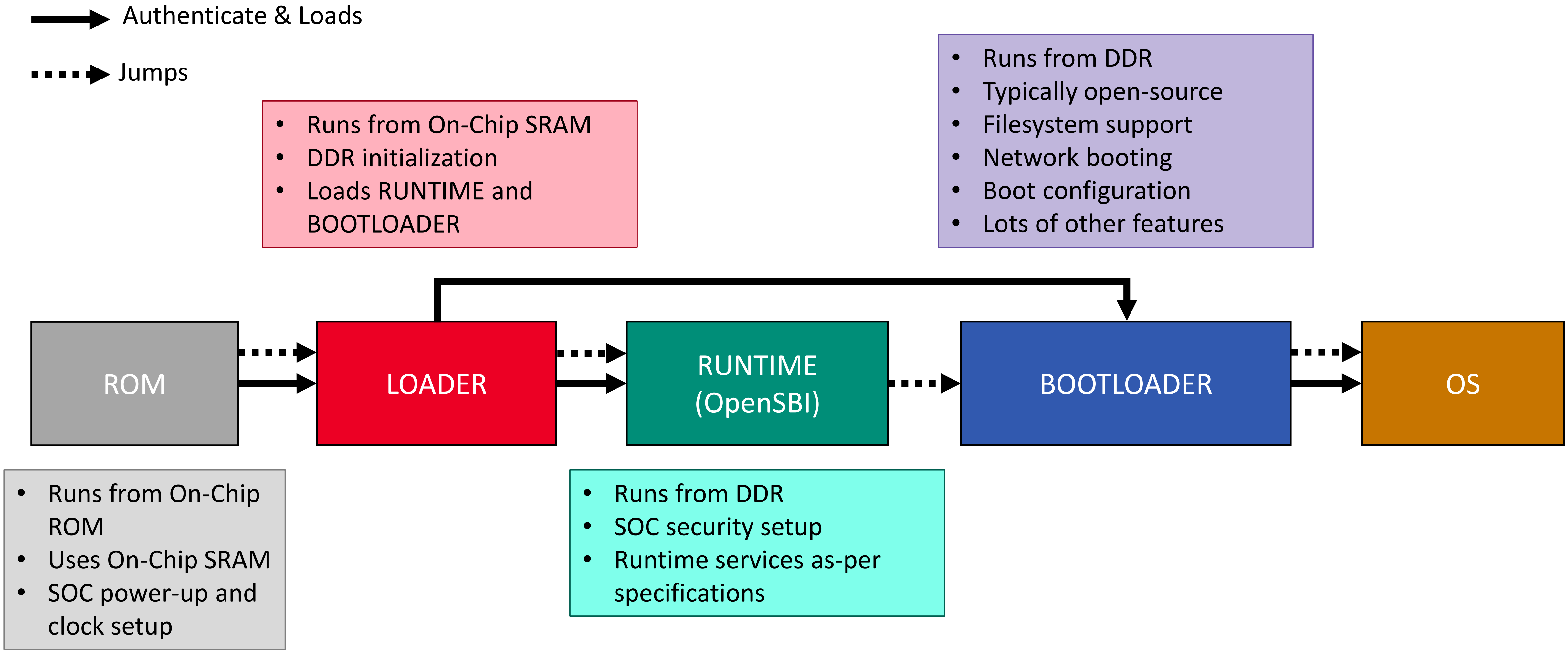
SEE (M-Mode)

Western Digital.

What is OpenSBI ?

- OpenSBI is an open-source implementation of the RISC-V Supervisor Binary Interface (SBI) specifications
  - Licensed under the terms of the BSD-2 clause license
  - Helps to avoid SBI implementation fragmentation
- Aimed at providing RUNTIME services in M-mode
  - Typically used in boot stage following ROM/LOADER
- Provides support for reference platforms
  - Generic simple drivers included for M-mode to operate
    - PLIC, CLINT, UART 8250
  - Other platforms can reuse the common code and add needed drivers

Typical Boot Flow



Authenticate & Loads

Jumps

ROM

- Runs from On-Chip ROM
- Uses On-Chip SRAM
- SOC power-up and clock setup

LOADER

- Runs from On-Chip SRAM
- DDR initialization
- Loads RUNTIME and BOOTLOADER

RUNTIME (OpenSBI)

- Runs from DDR
- SOC security setup
- Runtime services as-per specifications

BOOTLOADER

- Runs from DDR
- Typically open-source
- Filesystem support
- Network booting
- Boot configuration
- Lots of other features

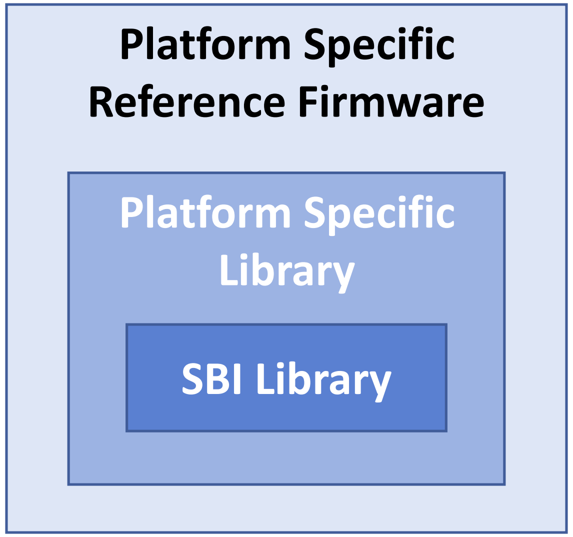
OS

Western Digital.

Important Features

- Layered structure to accommodate various use cases
  - Generic SBI library with platform abstraction
    - Typically used with external firmware and bootloader
      - EDK2 (UEFI implementation), Secure boot working group
  - Platform specific library
    - Similar to core library but including platform specific drivers
  - Platform specific reference firmware
    - Three different types of RUNTIME firmware
- Wide range of hardware features supported
  - RV32 and RV64
  - Misaligned load/store handling
  - Missing CSR emulation
  - Protects firmware using PMP support
- Well documented using Doxygen

OpenSBI Layers


Platform Specific Reference Firmware
Platform Specific Library
SBI Library

OpenSBI Platform Specific Support

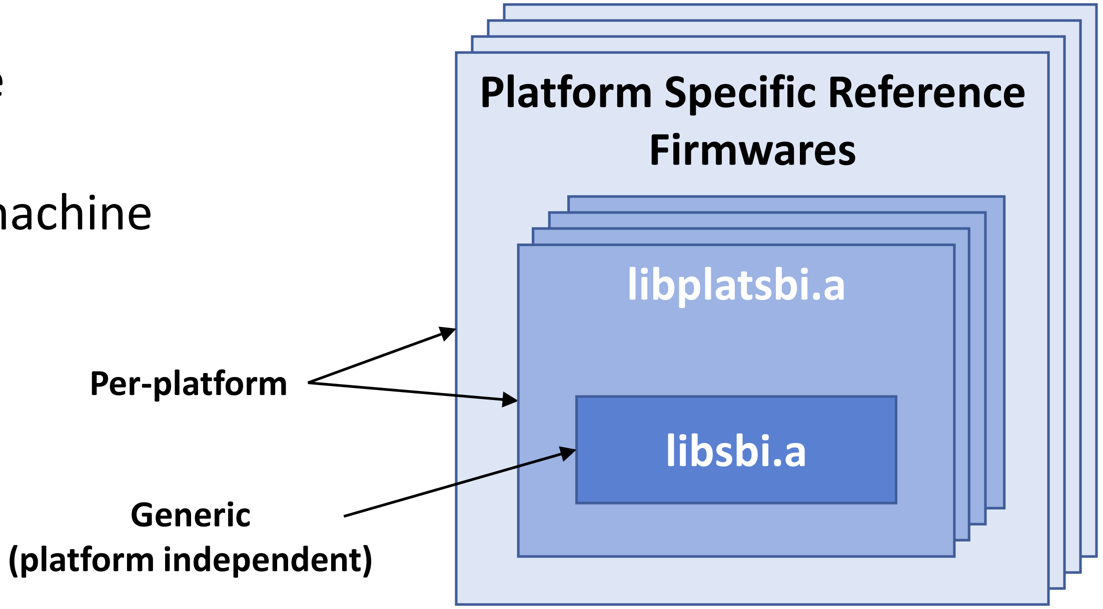
Why Platform Specific Support ?

- Any SBI implementation requires hardware dependent (platform-specific) methods
  - Print a character to console
  - Get an input character from console
  - Inject an IPI to any given HART subset
  - Get value of memory-mapped system timer
  - Start timer event for a given HART
  - … more to come …
- OpenSBI platform-specific support is implemented as a set of platform-specific hooks in the form of a *struct sbi_platform* data structure instance
  - Hooks are pointers to platform dependent functions
- Platform independent generic OpenSBI code is linked into a *libsbi.a static library*
- For every supported platform, we create a *libplatsbi.a static library*
  - *libplatsbi.a = libsbi.a + struct sbi_platform instance*

Supported Platforms

- Supported platforms are available under */platform* directory in OpenSBI source code tree
- Currently:
  - **qemu/virt**: QEMU RISC-V generic virtual machine *(Refer, docs/platform/qemu_virt.md)*
  - **qemu/sifive_u**: QEMU SiFive Unleashed virtual machine *(Refer, docs/platform/qemu_sifive_u.md)*
  - **sifive/fu540**: SiFive FU540 SOC *(Refer, docs/platform/sifive_fu540.md)*
  - **kendryte/k210**: Kendryte K210 SOC
- More to come

OpenSBI Layers



Adding Support for New Platforms

- To add support for a new *<xyz>* platform
  1. Create directory named *<xyz>* under */platform* directory
  2. Create platform configuration file *<xyz>/config.mk*
     - *config.mk* will provide compiler flags, select common drivers, and select firmware options
     - *platform/template/config.mk* can be used as reference for creating *config.mk*
  3. Create platform objects file *<xyz>/objects.mk* for listing platform-specific objects to be compiled
     - *platform/template/objects.mk* can be used as reference for creating *objects.mk*
  4. Create platform source file *<xyz>/platform.c* providing "*struct sbi_platform*" instance
     - *platform/template/platform.c* can be used as reference for creating *platform.c*
- The *<xyz>* platform support directory can also placed outside OpenSBI sources

Compilation Options for Platform Support

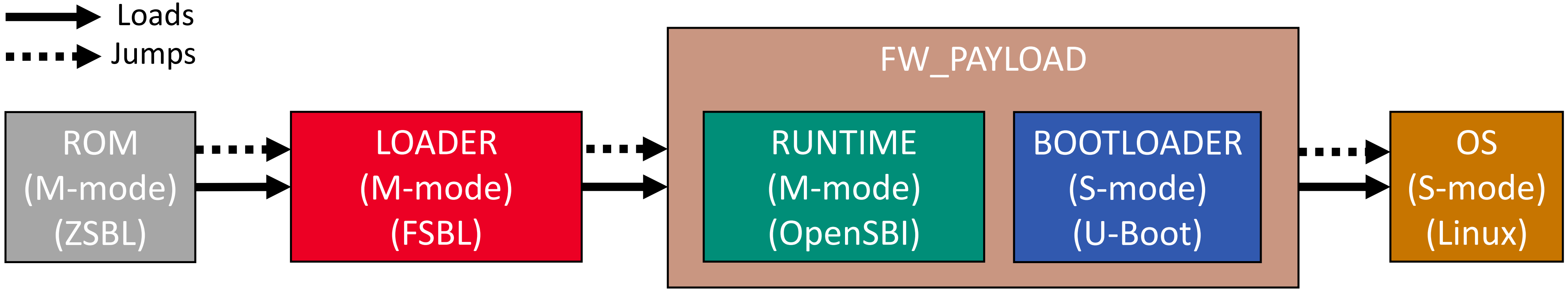
- *CROSS_COMPILE* environment variable need to be set for cross-compilation
- Build only generic OpenSBI (*libsbi.a*)
  - *make*
- Build platform-specific OpenSBI (*libplatsbi.a*) for *platform/<xyz>* in OpenSBI sources
  - *make PLATFORM=<xyz>*
- Build platform-specific OpenSBI (*libplatsbi.a*) for *<xyz>* not part of OpenSBI sources
  - *make PLAFORM_DIR=<path_to_<xyz>_directory>*

Using OpenSBI As a Firmware

Reference Firmwares

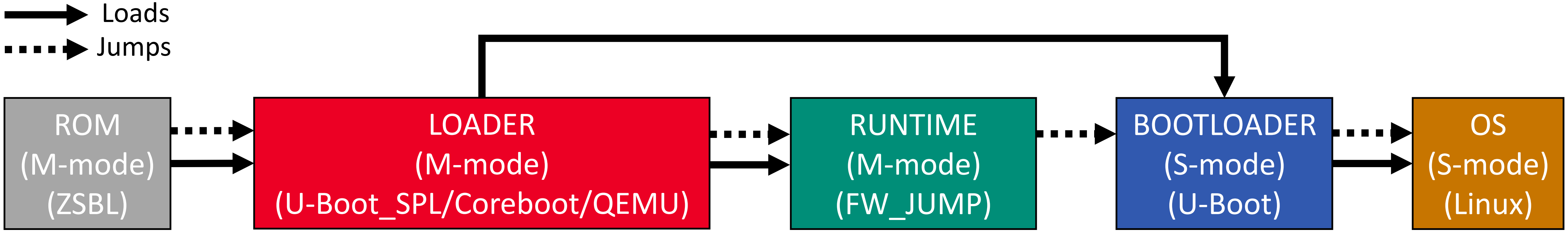
- OpenSBI provides several types of reference firmware, all platform-specific
  - **FW_PAYLOAD**: Firmware with the next booting stage as a payload
  - **FW_JUMP**: Firmware with static jump address to the next booting stage
  - **FW_DYNAMIC:** Firmware with dynamic information on the next booting stage
- SOC Vendors may choose:
  - Use one of OpenSBI reference firmwares as their M-mode RUNTIME firmware
  - Build M-mode RUNTIME firmware from scratch with OpenSBI as library
  - Extend existing M-mode firmwares (U-Boot_M_mode/EDK2) with OpenSBI as library

FW_PAYLOAD



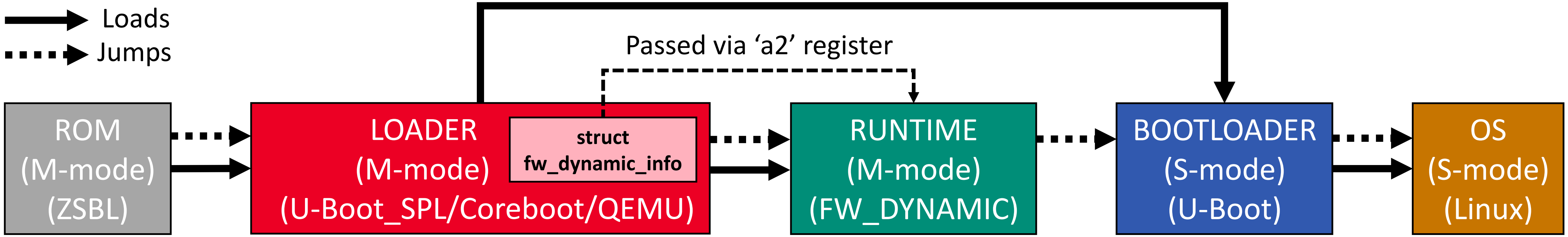
- OpenSBI firmware with the next booting stage as a payload
  - Any S-mode BOOTLOADER/OS image as the payload to OpenSBI FW_PAYLOAD
  - Allows overriding device tree blob (i.e. DTB)
  - Very similar to BBL hence fits nicely in existing boot-flow of SiFive Unleashed board
- Down-side:
  - We have to re-create FW_PAYLOAD image whenever OpenSBI or the BOOTLOADER (U-Boot) changes
  - No mechanism to pass parameters from previous booting stage (i.e. LOADER) to FW_PAYLOAD

FW_JUMP



- OpenSBI firmware with a fixed jump address to the next booting stage
  - Next stage booting stage (i.e. BOOTLADER) and FW_JUMP are loaded by the previous booting stage (i.e. LOADER)
  - Very useful for QEMU because we can use pre-compiled FW_JUMP
- Down-side:
  - Previous booting stage (i.e. LOADER) has to load next booting stage (i.e. BOOTLADER) at a fixed location
  - No mechanism to pass parameters from pervious booting stage (i.e. LOADER) to FW_JUMP

FW_DYNAMIC


Loads
Jumps
Passed via ‘a2’ register
ROM (M-mode) (ZSBL)
LOADER (M-mode) (U-Boot_SPL/Coreboot/QEMU)
struct fw_dynamic_info
RUNTIME (M-mode) (FW_DYNAMIC)
BOOTLOADER (S-mode) (U-Boot)
OS (S-mode) (Linux)

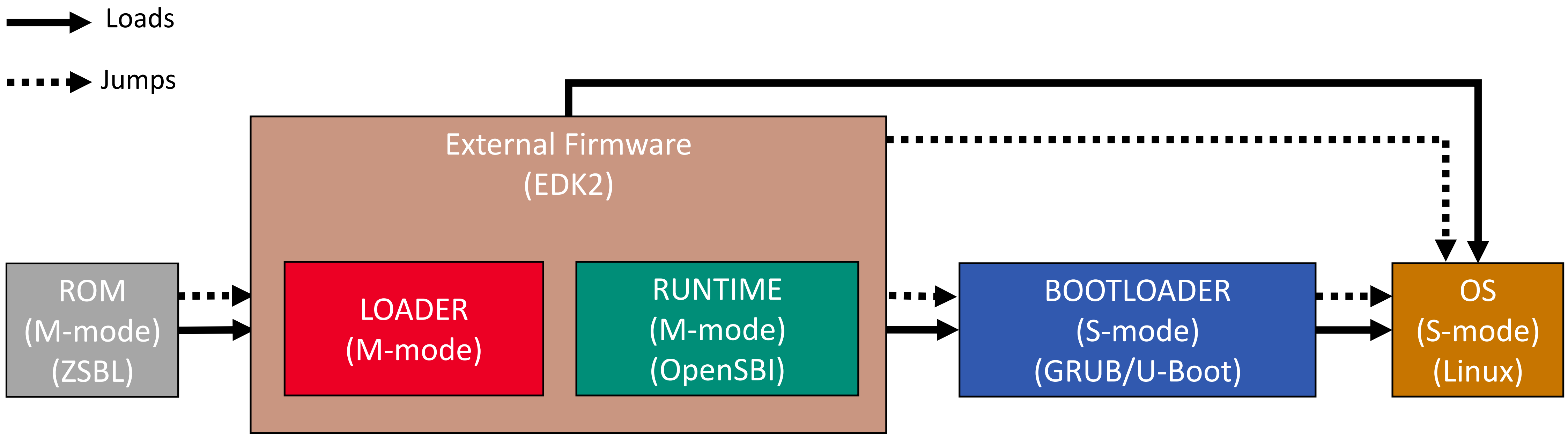
- OpenSBI firmware with dynamic information about the next booting stage
  - The next stage booting stage (i.e. BOOTLADER) and FW_DYNAMIC are loaded by the previous booting stage (i.e. LOADER)
  - The previous booting stage (i.e. LOADER) passes the location of *struct fw_dynamic_info* to FW_DYNAMIC via ‘a2’ register
- Down-side:
  - Previous booting stage (i.e. LOADER) needs to be aware of *struct fw_dynamic_info*

struct fw_dynamic_info
unsigned long magic
unsigned long version
unsigned long next_addr
unsigned long next_mode
unsigned long options

Western Digital.

Using OpenSBI As a Library

Typical use as Library



- External M-mode firmware linked to OpenSBI library
- Example: open-source EDK2 (UEFI implementation) OpenSBI integration
  - HPE leading this effort (Ongoing)
  - OpenSBI built with EDK2 build environment

Constraints on using OpenSBI Library

- Same GCC target options (i.e. *-march*, *-mabi*, and *-mcmodel*) need to be used for the external firmware and OpenSBI sources
- External firmware must create per-HART non-overlapping:
  1. Program Stack
  2. OpenSBI scratch space (i.e. *struct sbi_scratch* instance with extra space above)
- Two constraints in calling any OpenSBI functions from external firmware:
  1. *MSCRATCH* CSR of calling HART must be set to its own OpenSBI scratch space
  2. *SP* register (i.e. the stack pointer) of calling HART must be set to its own stack
- External firmware must also ensure that:
  - Interrupts are disabled in the *MSTATUS* and *MIE* CSRs when calling *sbi_init()*
  - *sbi_init()* is called for each HART that is powered-up at boot-time or in response to a CPU hotplug event
  - *sbi_trap_handler()* is called for M-mode interrupts and M-mode traps

Conclusion

Important Facts

- OpenSBI provides only RUNTIME firmware/library
- OpenSBI platform specific support makes OpenSBI easily extensible for new SOCs
- OpenSBI reference firmwares:
  - **Are optional** and SOC vendors can choose to implement their own
  - **Don’t enforce any particular boot-flow**

On-Going and Future Work

- SBI specifications
  - SBI v0.2 specification
  - SBI v0.2 HART power management extension
  - SBI v0.2 remote fences extension (fence.i, sfence.vma, hfence.gvma, and hfence.bvma)
- OpenSBI
  - RISC-V hypervisor extension support (We have a demo here !!!)
  - SBI v0.2 support
  - SBI v0.2 HART power management support
  - SBI v0.2 remote fences support
  - Support other M-mode bootloaders such as U-Boot_SPL/Coreboot
  - Support RISC-V EDK2 integration
  - More platforms support
    - Need hardware !

Western Digital®