XEN ON THE I.MX8 PROCESSOR

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Agenda

- Hypervisor Overview
- Xen Overview
- Xen System Configuration
- Controlling System Performance
- Xen Performance
- Example Systems
- Xen on i.MX 8

Hypervisor Overview

A general overview of what a hypervisor is, its purpose, and its function

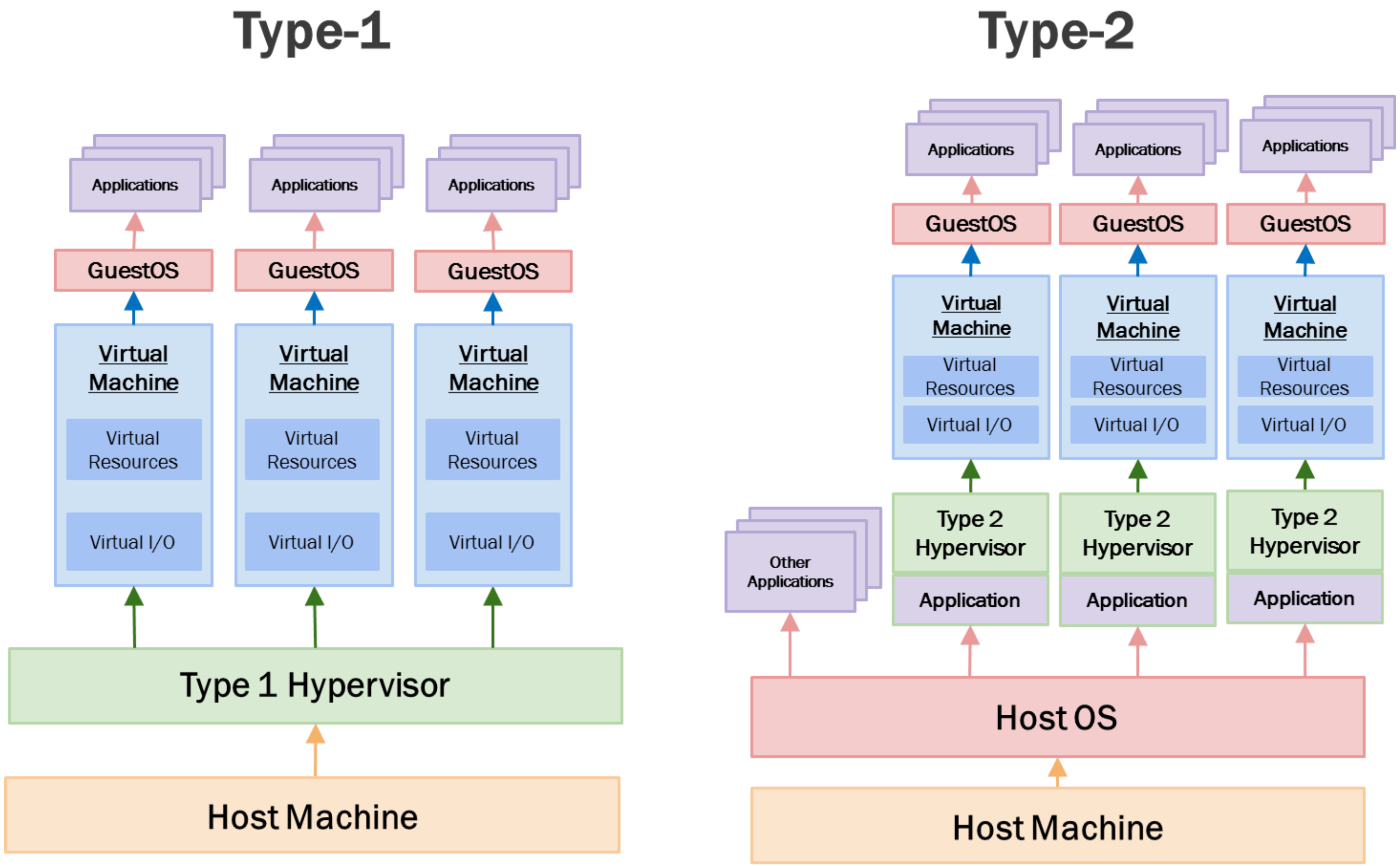
Hypervisor

- **Allocates and partitions** system resources such as RAM, CPU time across all cores, and I/O
- **Enforces isolation** of domains and their resources, such as CPU, memory, and I/O
- **Starts, stops, and configures** all of the guest domains (virtual machines) in the system
- **Configures inter-domain communication** via shared devices and memory while maintaining isolation

Hypervisor Benefits

- Increase **resource utilization**
- **Isolate** applications and operating systems
  - Isolation can provide both **security** and **safety**
- Reduce the **SWaP-c** of a system
- Improve **code portability**
  - Between both existing systems and future hardware
- Ease **legacy system migration**
- Increase **reliability** by providing **redundancy**

Type-1 vs Type-2 Hypervisor Diagram

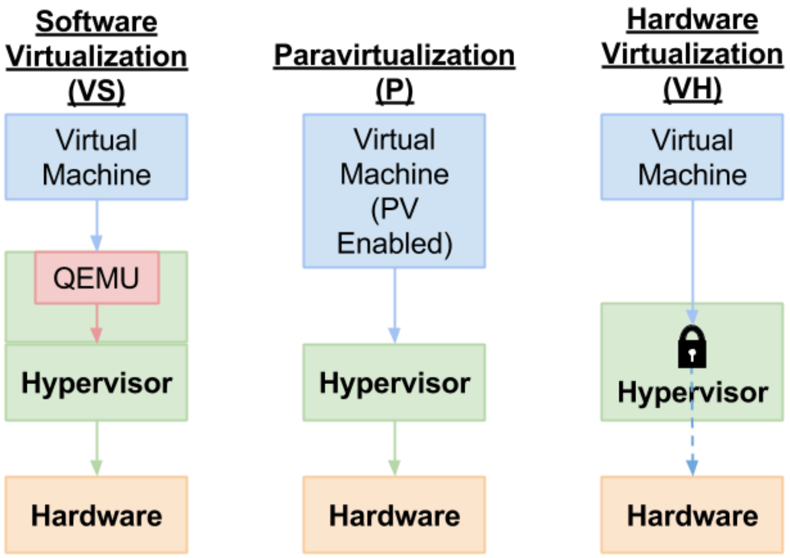


Type-1 vs Type-2 Hypervisor

- An embedded system should always use a Type-1 HV
  - Much lower system resource overhead
  - Highly efficient, can achieve near native performance
  - True isolation of domains at hardware level
  - Very fine grain control of **all** system resources
- A Type-2 HV is typically only used by desktops and servers
  - Useful for running a 2nd OS different from the base OS
    - Legacy OS for old software
    - Different OS for proprietary software (Windows + Linux, Mac + Windows, etc)
  - Generally simpler to use than Type-1 with the cost of high resource overhead, limited customizability, and limited controls

Virtualization Techniques

- **Software Virtualization** is the most portable, but is complicated
- **Paravirtualization** is less complex, but is less portable



- **Hardware Virtualization** is the least complex and most efficient, but has limited portability as it requires support from the hardware itself

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Xen Overview

How Xen implements these hypervisor concepts and how they apply to ARM

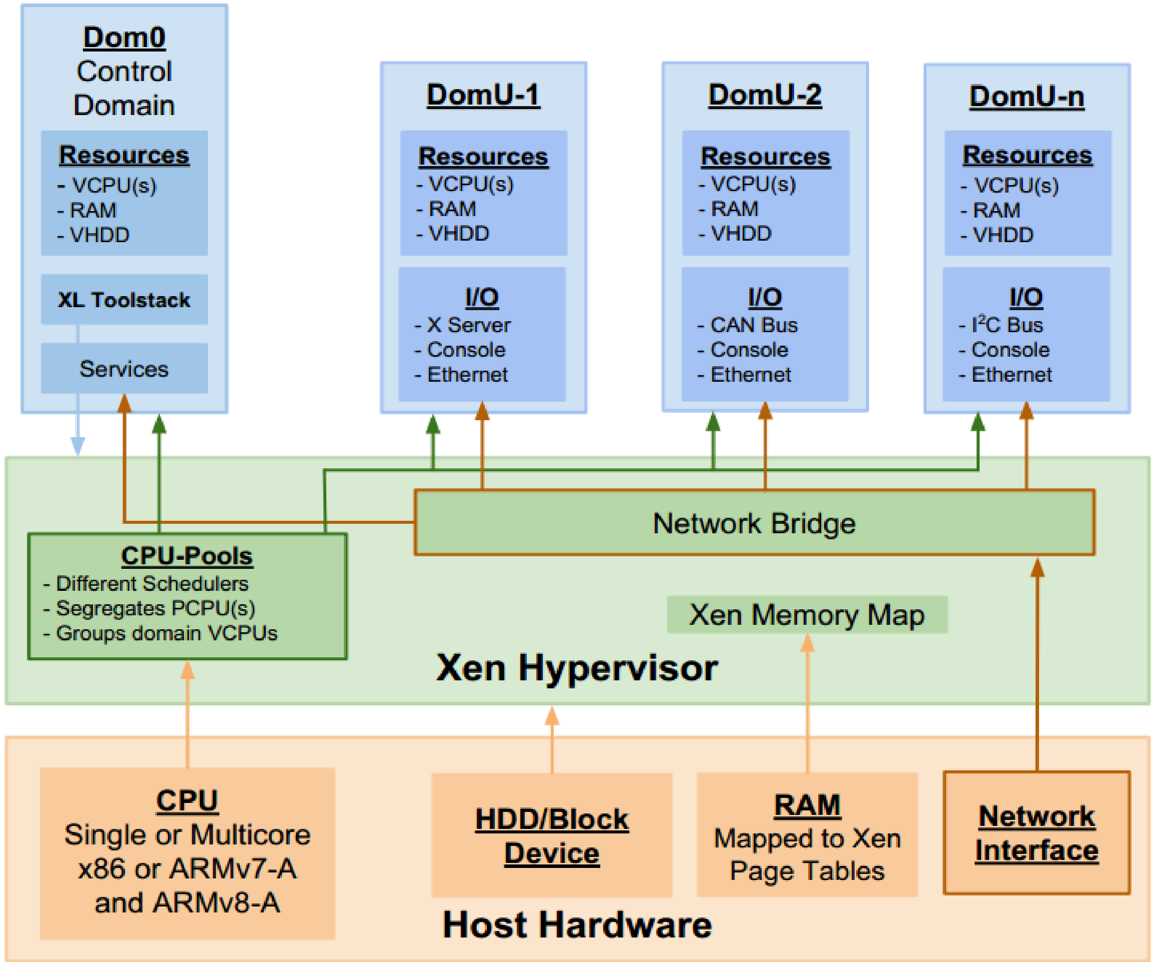
Xen Hypervisor Overview

- Xen is a Type-1 Hypervisor
- Open Source project started over 12 years ago
  - GPLv2 License, same as Linux Kernel
- Initially developed for desktop and servers
- Port to ARM embedded processors began in 2008
  - DW Involved in early stage of embedded development (Navy SBIR)
  - Fully functional prototypes for ARMv7a with VE released in 2011
  - Xen for ARM was incorporated into mainline Xen in 2013
- Long track record with major companies including Amazon Web Services, AMD, Bromium, Calxeda, CA Technologies, Cisco, Citrix, Google, Intel, Oracle, Samsung, and Verizon

Xen Terminology

- Some basic Xen/Hypervisor terminology:
  - **Resources** - All of the available hardware
  - **pCPU** - Physical CPU residing on the motherboard or SoC
  - **vCPU** - Virtual CPU, a schedulable processor unit used by a domain
  - **Scheduler** - The algorithm used by the hypervisor to give guests time on the pCPU's
  - **Dom0** - The special "privileged" domain used to configure Xen
  - **DomU** - An "unprivileged" guest domain in Xen
- For a large glossary of terms and concepts: http://wiki.xenproject.org/wiki/XenTerminology
  - Note that some terms and features referenced in the wiki may be applicable to x86-only Xen

Example Xen System



Virtualization as Implemented by Xen

Poor Performance
Scope for Improvement
Optimal Performance

P = Paravirtualized
VS = Software Virtualized (QEMU)
VH = Hardware Virtualized

Shortcut	Mode	With	Disk and Network	Interrupts & Timers	Emulated Motherboard, Legacy Boot	Privileged Instructions, Page Tables
HVM / Fully Virtualized	HVM		VS	VS	VS	VH
PV	PV		P	P	P	P
PVH	PV	pvh=1	P	P	P	VH

Xen on ARM

- Xen on ARM uses a blend of these techniques known as **PVH**
- This blend provides an optimized balance between complexity, efficiency, and portability

Poor Performance
Scope for Improvement
Optimal Performance

P = Paravirtualized
VS = Software Virtualized (QEMU)
VH = Hardware Virtualized

Shortcut	Mode	With	Disk and Network	Interrupts & Timers	Emulated Motherboard, Legacy Boot	Privileged Instructions, Page Tables
PVH	PV	pvh=1	P*	VH	NA	VH

* Devices can be passed through to avoid any paravirtualization

ARM Hardware Virtualization

- Exception Level (EL)
  - **EL3**: Secure Monitor
  - **EL2**: Hypervisor
  - **EL1**: Operating System
  - **EL0**: Application
  - Each EL has its own copy of certain registers (e.g. MMU, SP)
- Virtualized Registers
  - e.g. Virtual Timer
- Configurable privilege for specific register access and specific instructions
  - e.g. TLBI VAE1 (TLB invalidate by VA, EL1)

Components of a Xen based System

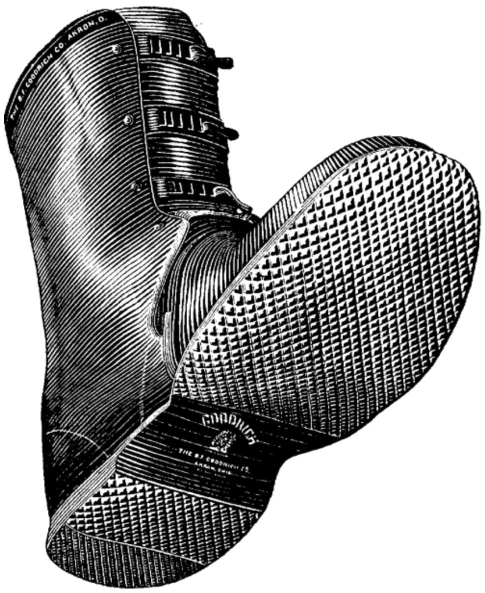
- A full solution is much more than the hypervisor itself!
  - Xen Kernel
  - Device Tree Blob (DTB)
    - This DTB is used by Xen and Dom0 Linux
    - Contains Xen bootargs and SMMU `mmu-masters` entries (discussed later)
  - Dom0 Kernel
    - Drivers for Xen hypercalls (used by toolstack)
    - Backend Drivers (if needed)
  - Dom0 FileSystem
    - Xen ToolStack (xl)
  - Guest
    - Kernel (or bare metal application)
      - Frontend drivers (if needed)
      - Xen specific drivers (for shared mem, etc)
    - Guest File System (if needed)
    - Guest Configuration File
    - Partial DTB (if needed; for pass-through devices)

Xen System Configuration

Configuring the Xen system components to start Xen and dom0 to launch your guest OSes and bare metal applications

Boot Sequence

1. FSBL
   - Initiates System Controller(SC), executes U-Boot
2. U-Boot
   - Loads the Xen kernel, Dom0 Linux kernel, and DTB into RAM and starts execution of Xen
3. Xen
   - Reads in the system DTB (which also contains the Xen bootargs) and configures the systems resources
   - Executes the Dom0
4. Dom0 Kernel
   - Privileged domain, executes toolstack commands and uses guest configuration file to boot up DomU's
5. DomU
   - Executes system guest operating systems, applications, and functions as configured



System Device Tree

- System dtb is generated by a dts (device tree source) file and loaded on startup by U-boot
  - Formatted and used in the same way as a standard Linux device tree
- The same DTB is used by Xen and Dom0 Linux (slight changes for Dom0)
- Relevant entries include:
  - Xen bootargs
    - Example: `xen,xen-bootargs = "console=dtuart dtuart=serial0 dom0_mem=512M bootscrub=0 maxcpus=4 dom0_max_vcpus=1 dom0_vcpus_pin timer_slop=0";`
    - Full documentation of all Xen bootargs: http://xenbits.xen.org/docs/unstable/misc/xen-command-line.html
  - SMMU mmu-masters entries
- Full documentation of device trees is available here: http://elinux.org/Device_Tree_Usage

Dom0 Kernel and xl Toolstack

- The dom0 Linux kernel must be configured for Xen when it is compiled, this includes adding:
  - Drivers for Xen hypercalls (used by toolstack)
  - Backend Drivers for PV devices (if needed)
- The toolstack used by dom0 to configure Xen is known as `xl`
  - The `xl` toolstack is a user-space program that is run in dom0 Linux
  - Commands are available to control many aspects of the system, we call many of these aspects in the following slides
  - Full documentation is available in the Xen Man pages: http://xenbits.xen.org/docs/4.6-testing/man/xl.1.html

Dom0 File System

- Dom0 File System can be located on: SD Card, RAM Disk, NFS, SATA
- Uses any Linux compatible format
  - Prefer ext4, ext3, ext2, etc
- In addition to Linux system files, the FS must also contain:
  - Xen xl toolstack
  - Any backend drivers needed for PV (hvc is minimum for console)
  - Standard Linux drivers for all the board devices
  - May optionally contain guest kernels and/or FSes
- Where/How it is configured:
  - The file system is set by the Dom0 bootargs (located in system DTB); must point to the correct partition

Domain Memory Assignment

- Domains are given permission to access a particular range of memory addresses
  - Xen does this by configuring the EL2 MMU
  - Each guest has its own physical memory location
    - But the guest is only aware of the Intermediate address that Xen sets up via the EL2 MMU
  - The guest then sets up the EL1 MMU
- Minimum memory segment size

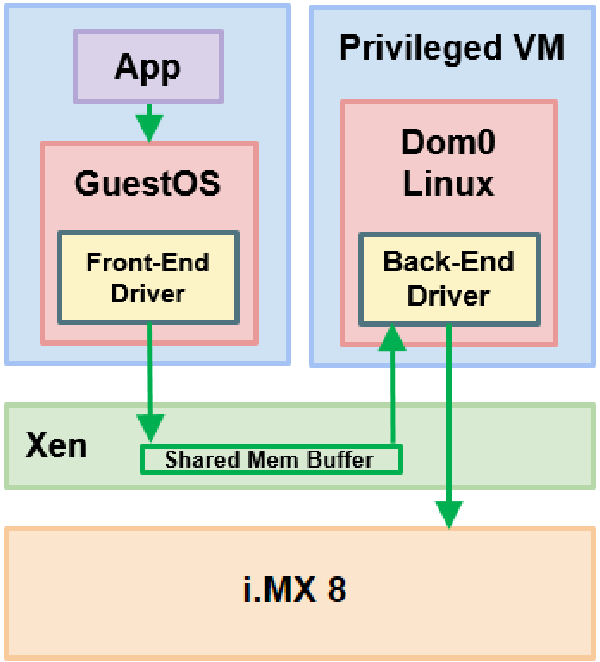
- Where/How it is configured:
  - Dom0 memory size is set via xen bootargs
  - Guest memory size is set in the guest config file
  - Configuration file entries
    - memory
    - maxmem

Controlling System Performance

Xen tools and features for achieving desired performance

Input/Output (Paravirtualization)

- Split Driver
  - Use if **multiple guests** need to access a particular device
- A single privileged guest has sole, direct access to device
  - Privileged guest provides backend device driver
- Each guest using the device talks to backend driver in the privileged guest through its own frontend driver



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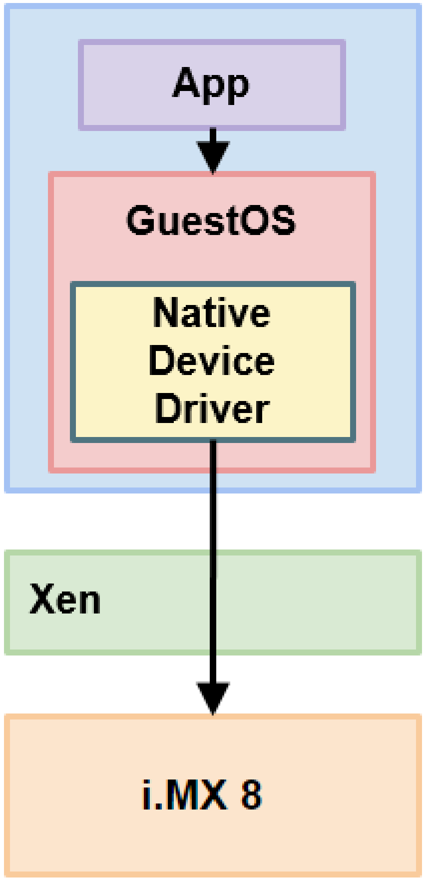
Input/Output (Pass-Through)

- Pass-Through Driver
  - Generally, use if **only one** guest needs access to a particular device (In most cases)
- Utilizes the SMMU
  - System DTB sets up devices as SMMU `mmu-masters`
    - These can be passed-through
  - The guest config file tells Xen to allow the device to be passed through to that guest
- The guest controls the device directly
  - This means guest can use the original unaltered device driver as if running directly on HW



Multicore and Scheduling

- Schedulers
  - **Credit**: Default Xen scheduler; a "fair time" algorithm similar to default Linux scheduler
  - **RTDS**: Soft Real-time scheduler that uses deferrable server algorithm to assign vCPUs
  - **ARINC653**: Soft Real-time scheduler, assigns vCPUs according to ARINC653 specification
- CPU Pinning
  - Assign a vCPU to run on specific pCPUs **only**
- CPU Pools
  - Group pCPUs to be managed by an scheduler instance
  - Allows for multiple schedulers to be run at the same time
    - This flexibility allows the system to be configured to run SMP or Heterogeneous or Homogeneous AMP as needed

i.MX 8 SC Partitioning

- Pros
  - No need for Emulation/Virtualization SW
  - Partitioning cannot be compromised due to SW
  - Avoids some ASIL complications
- Cons
  - Fixed limit of HW resources
  - Vendor Dependent feature
  - Just delays the inevitable need to address ASIL cert
- Combined Use Cases
  - HW partitioning as additional assurance
  - HW partitioning first, SW Partitioning as needed

Xen Performance

Xen performance/overhead on an ARM platform

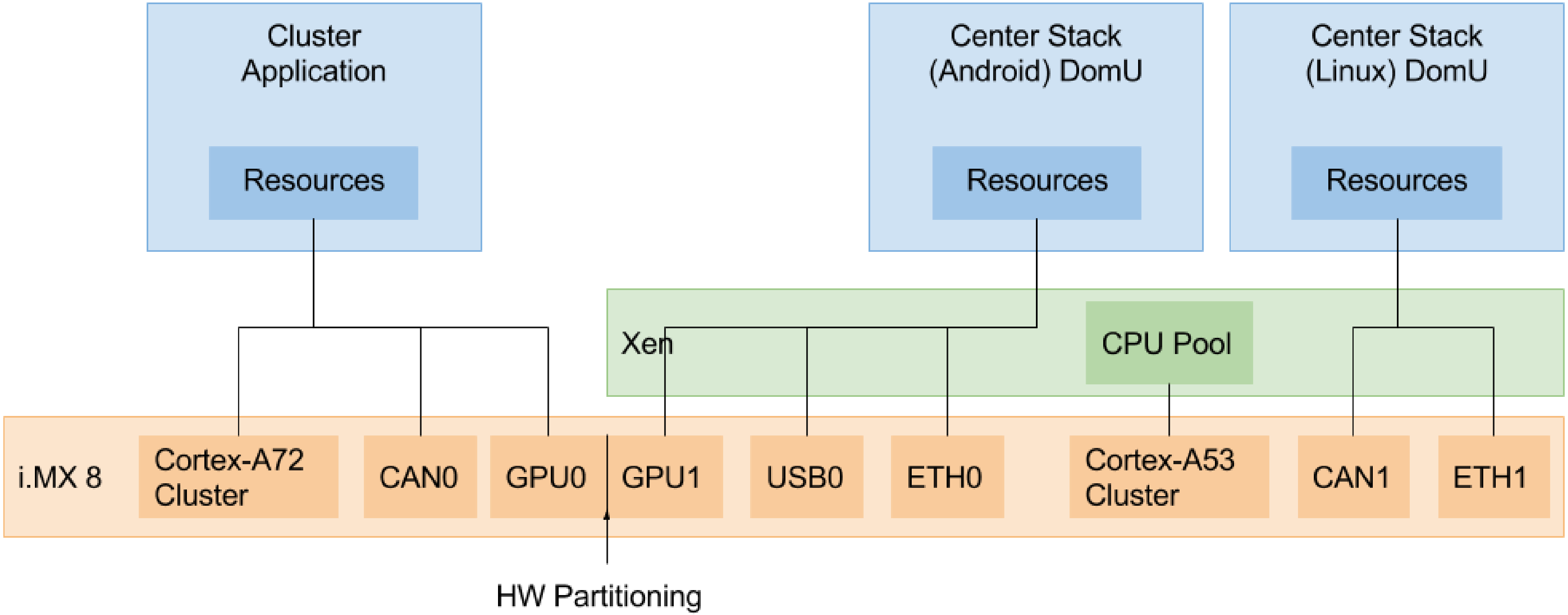
Xen Performance

- Quad Core Cortex-A53
- Boot times
  - Xen 0.8 sec, *dom0* 5.1 sec
- Interrupt Latency
  - 2.3 µsec
- Context Switch Overhead
  - ~0% to 0.6%
- For more information see: http://schd.ws/hosted_files/xensummit2016/39/Embedded%20Xen%20Perf.pdf

Example Systems

Examples on how Xen can be used in automotive applications

Cluster/Center Stack Example



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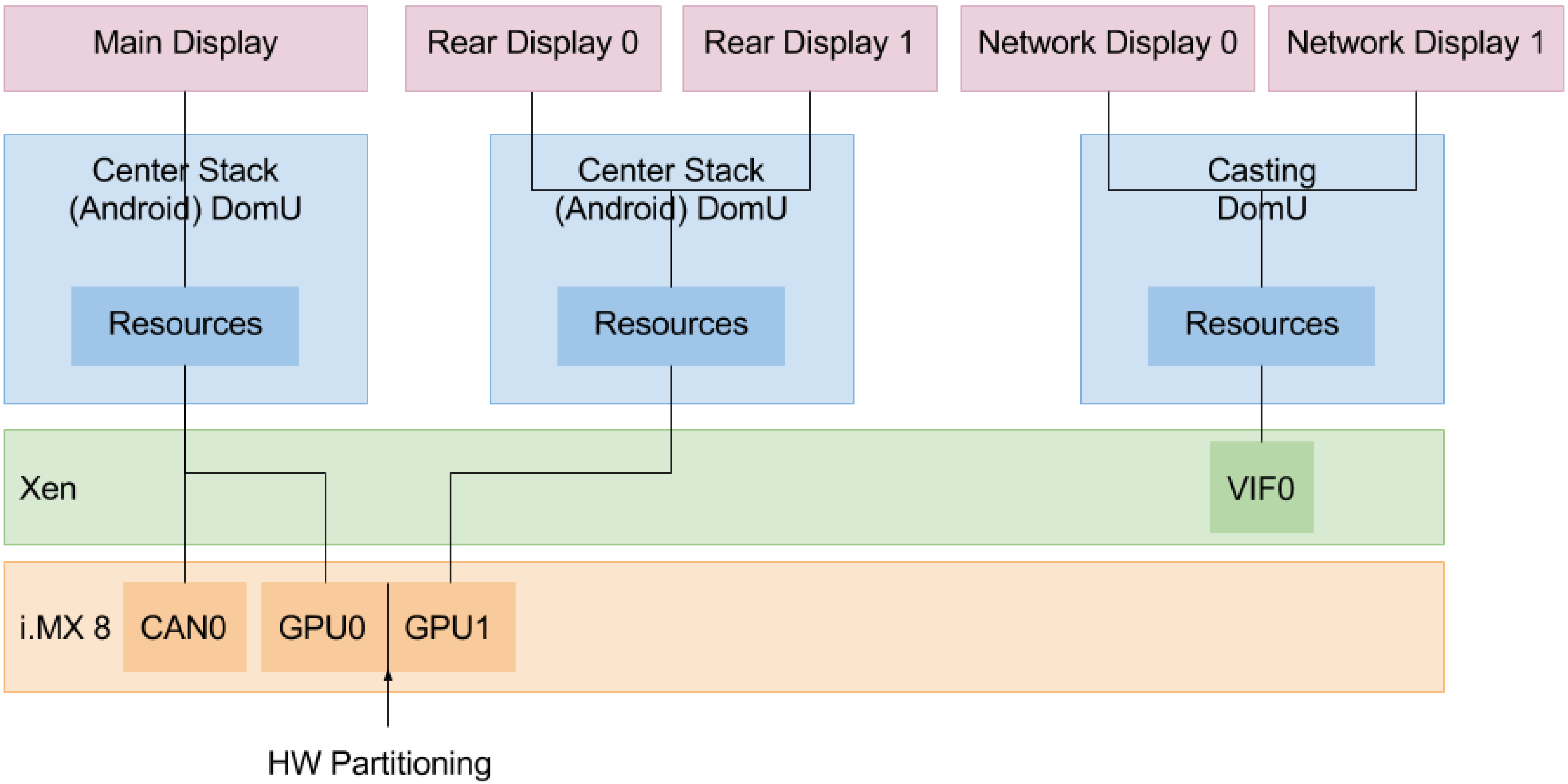
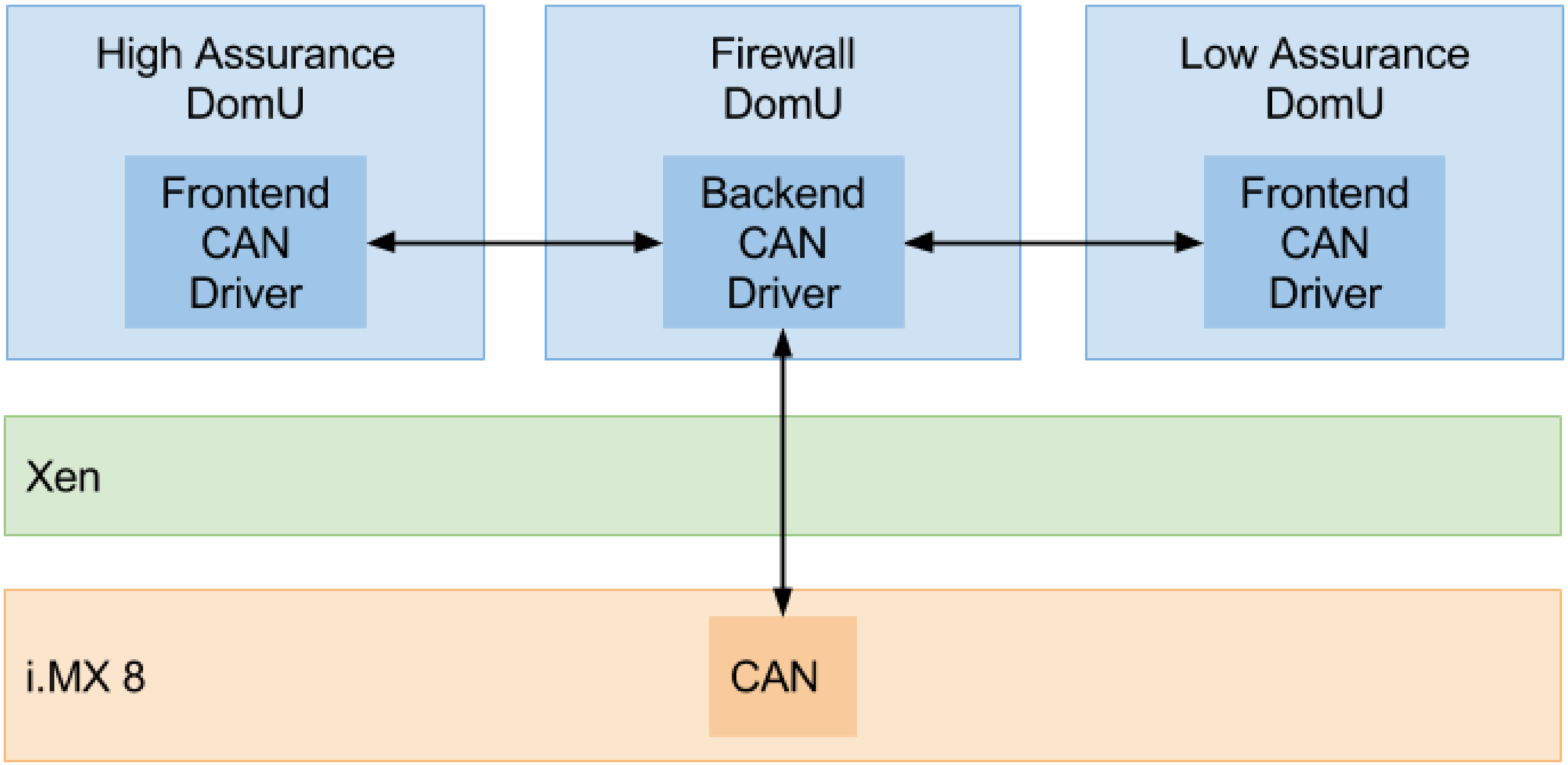
Entertainment Example



CAN Firewall Example



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Xen on i.MX 8

Current status and future plans of Xen on the i.MX 8

Xen i.MX 8 Current Status

- Xen 4.7 is running on A53 cluster
- Linux 4.1.30 Control Domain (Dom0)
  - Graphics (GPU, DPU, FBs)
  - Networking
  - SD Card
- Linux 4.1.30 guest with PV IO
  - VIF, VBD, hvc
- Demonstration

Xen i.MX 8 Challenges

- Make sure Dom0 ends up in 32-bit Space
  - Needed so DMA works
  - Difficult due to Xen allocator
- User Space Application DMA
  - Implement new function for Dom0 in Linux Kernel
- Integrating xl toolstack build into Yocto
- Disable SC interaction for Guests

Xen i.MX 8 Planned Features

- Pass-through of half of graphics to a single guest
- Xen and Guests running heterogeneously on Cortex-A72 cluster (big.LITTLE)
- Provide a Xen Distribution for i.MX 8
- More guests in Demo & Distro

Xen i.MX 8 Distribution

- Continued Updates & Support
  - Free and Paid Support options
- Components
  - Xen Kernel
  - Dom0 Linux Kernel & File System
  - System Device Tree
  - Example guests & configuration files
    - Linux, FreeRTOS, BareMetal Guest

Questions

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