Multi-Function PCI Pass-Through

Simon Horman <simon@valinux.co.jp>
VA Linux Systems Japan K.K.
Jun Kamada <kama@jp.fujitsu.com>
Fujitsu Limited

Japan Linux Symposium
21st – 23rd October 2009

Motivation

- Aim of my work:
  To enhance Xen PCI pass-through to allow multi-function devices appear in unprivileged-domains (guests) as multi-function devices.

Motivation

- Aim of my work:
  To enhance Xen PCI pass-through to allow multi-function devices appear in unprivileged-domains (guests) as multi-function devices.
- Aim of this presentation:
  To explain what that means and some of the challenges encountered while making it possible.

Part I

Overview of PCI Pass-Through

PCI Pass-Through

- Method of making a PCI function available to a guest.
- KVM calls this feature PCI Device Assignment
- Typically uses an IOMMU to provide isolation
  - Otherwise guests can use DMA to access memory they shouldn't.
- This discussion focuses on fully-virtualised guests,
  although it should also be applicable to para-virtualised guests.

PCI Devices and Functions

- A PCI device may include between 1 and 8 functions
- Function numbers range from 0 to 7
- Function 0 must always be present
- Classified as single-function and multi-function devices

Single-Function PCI Device

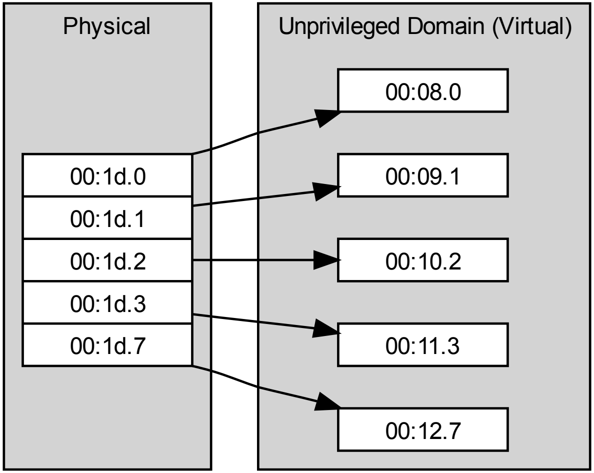
```
$ lspci -s 02:02.*
02:02.0 Ethernet controller: Realtek Semiconductor Co., Ltd.
        RTL-8169 Gigabit Ethernet (rev 10)
```

Multi-Function PCI Device

```
$ lspci -s 00:1d.*
00:1d.0 USB Controller: Intel Corporation
        82801G (ICH7 Family) USB UHCI Controller #1 (rev 01)
00:1d.1 USB Controller: Intel Corporation
        82801G (ICH7 Family) USB UHCI Controller #2 (rev 01)
00:1d.2 USB Controller: Intel Corporation
        82801G (ICH7 Family) USB UHCI Controller #3 (rev 01)
00:1d.3 USB Controller: Intel Corporation
        82801G (ICH7 Family) USB UHCI Controller #4 (rev 01)
00:1d.7 USB Controller: Intel Corporation
        82801G (ICH7 Family) USB2 EHCI Controller (rev 01)
```

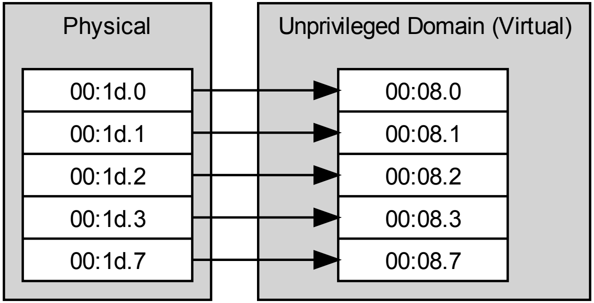
No Multi-Function in Unprivileged Domains

Prior to this work Xen allowed functions to be passed through as single-function devices.



Multi-Function in Unprivileged Domains

This work allows functions of a multi-function device to be passed-through as a multi-function device.



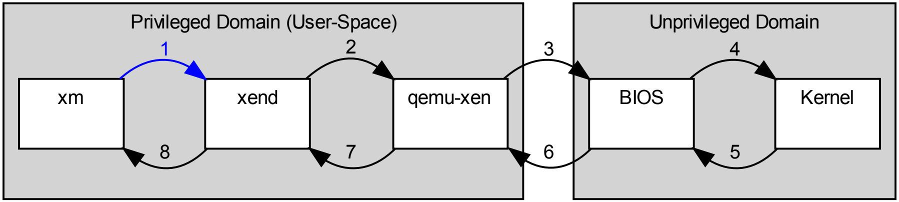
Xen Pass-Through Architecture

Four operations

- Attachment
  - At unprivileged domain boot-time (static assignment)[1]
  - While unprivileged domain is running (hot-plug)
- Detachment
  - While unprivileged domain is running (hot-unplug)
- Listing of attached devices
- Listing of attachable devices

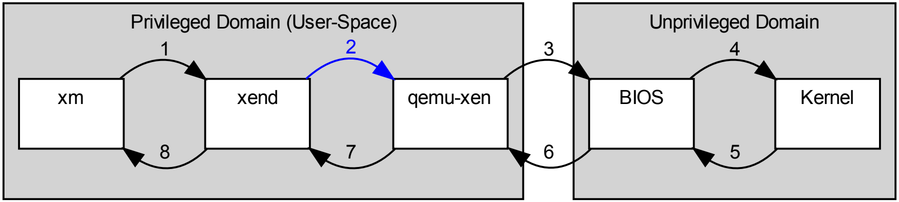
[1]Satic assignment isn't actually static as such devices may be hot-unplugged

Attachment and Detachment Events: xm



1 xm is a command-line tool
- Accepts commands from the end-user
- Makes corresponding requests to xend

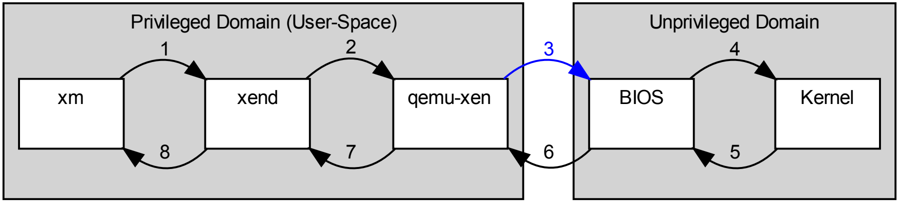
Attachment and Detachment Events: xend



2 xend marshals information between sub-systems

- Checks the pass-through commands sent by xm
- Reconciles them with the current state of the system
- Passes them on to qemu-xend

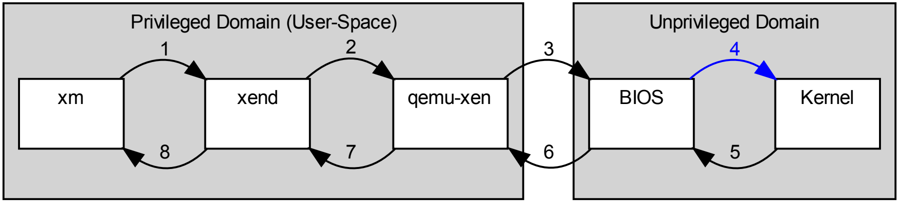
Attachment and Detachment Events: qemu-xen



3 qemu-xen is used to emulate devices and control pass-through devices

- Reconfigures the xen hypervisor accordingly
- Triggers a corresponding ACPI event in the virtual BIOS of the target unprivileged domain

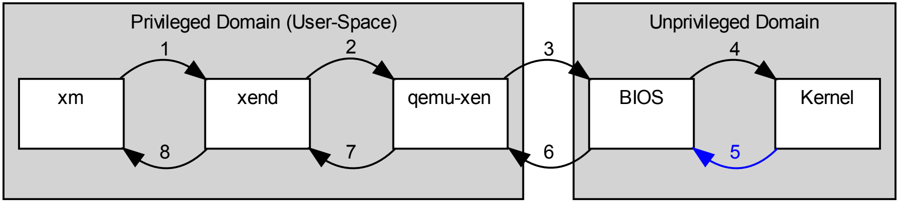
Attachment and Detachment Events: BIOS



4 Unprivileged domain's virtual BIOS

- Triggers a corresponding ACPI event in the kernel

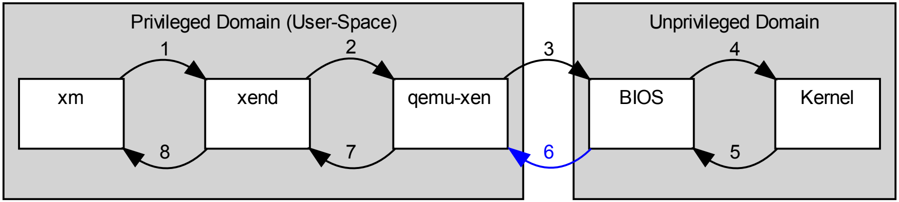
Attachment and Detachment Events: Kernel



5 Unprivileged domain's kernel

- Hot-plugs or unplugs the device
- Sends an acknowledgement back to the BIOS

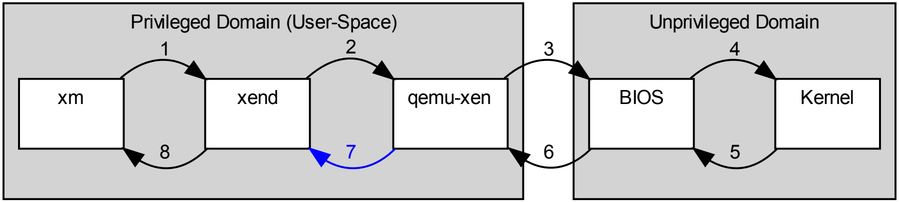
Attachment and Detachment Events: BIOS Ack



6 Unprivileged domain's virtual BIOS

- Sends an acknowledgement to qemu-xen

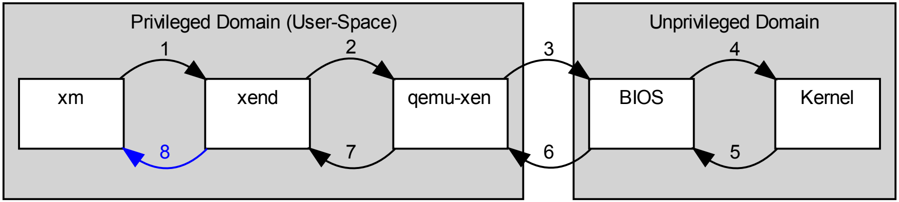
Attachment and Detachment Events: qemu-xen ACK



7 qemu-xen

- Updates its internal state
- Sends an acknowledgement to xend

Attachment and Detachment Events: xend Ack



8 xend

- Updates its internal state and that of xenstore
- Sends an acknowledgement to xm

Part II

Implementation Challenges

User Interaction

- Problem: Need a succinct way to describe multi-function devices
- Solution: Extend BDF notation
    - BDF stands for Bus Device Function
    - Used to describe PCI and PCIe devices

Simple BDF Notation

```
00:02.0
```

- PCI Bus number in hexadecimal
- A colon (:)
- PCI Device number in hexadecimal
  Sometimes referred to as the slot number
- A decimal point (.)
- PCI Function number

Extended BDF Notation

Optionally prefixes simple BDF with the PCI domain[2]

```
0000:00:02.0
```

- PCI domain number
- A colon (:)
- Simple BDF Notation

[2] PCI domains do not correspond to Xen domains

Extended BDF Notation with Virtual-Slots

Optionally suffixes extended BDF with the virtual-slot or pass-through options to be used.

```
0000:00:02.0@7,msitranslate=1
```

- Extended BDF Notation
- An at-sign (@)
- A virtual slot

Or any number of:

- A comma (,)
- An option name
- An equal sign (=)
- A value for the option and yes or no.

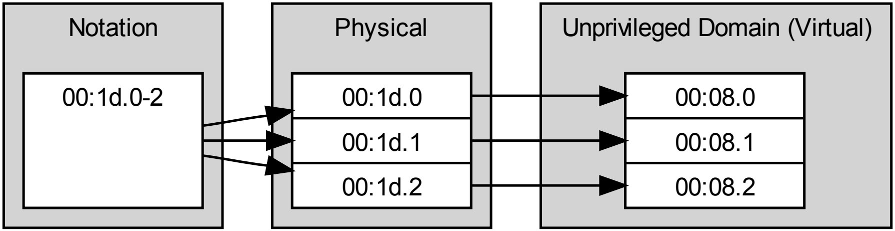
In the case where both a virtual-slot and options are specified, the virtual-slot must come first

BDF Notation for Multi-Function

The function field is expanded to accept a comma-delimited list of:

- Function numbers
- A range of function numbers, denoted by:
  - The first function number
  - A hyphen (-)
  - The last function number
- An asterisk (*)

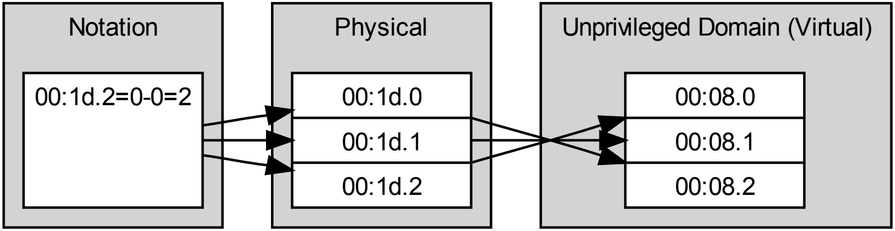
This notation is internally expanded into groups of functions



BDF Notation for Multi-Function with Explicit Vfunctions

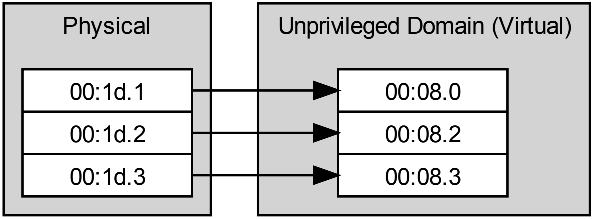
Allows control over the mapping of physical to virtual functions
Physical function numbers are replaced by function units which comprise of:

- Physical function number and optionally;
- An equal sign and;
- A virtual function number to use



Mapping Physical-Functions to Virtual-Functions

- Use any virtual functions in BDF
- Then, map the lowest remaining physical function to virtual function 0 as needed
- Finally, identity map the rest of the functions



- A virtual device must always include virtual function zero

Allocating Virtual-Functions

- Virtual-Functions are assigned by xm (hot-plug) or xend (boot-time assignment) at the time BDFs are parsed
  - It knows which functions belong to the same device
  - Allows for BDF to specify virtual-functions

Allocating Virtual-Slots

- Virtual-Slots are assigned by qemu-xen
  - It knows which slots are free
- An extended devfn scheme is used
  - Between xm and xend
  - Between xend and qemu-xen
  - Flag is set:
    - qemu-xen should allocate a free slot
    - device/slot bits are filled in by qemu-xen
  - Flag is not set:
    - BDF specifies slots
    - device/slot bits read by qemu-xen

flag (bit 9)	device/slot (bits 3–7)	function (bits 0–2)

Device Keys

- xend, qemu-xen and ACPI deal with per-function requests
- Need a way to identify functions that are members of the same function device
- A key is added to the functions internal representation in xend
    - At this stage it is the BDF string used to specify the device
    - Due to insertion-time checks it is guaranteed to be unique

Attachment

1. Find all the functions with the same key
2. Order the functions so that virtual-function zero is last
3. Attach the first function
4. If there are no more functions, finish — it is a single-function device
5. Else, if the virtual-slot is to be automatically assigned
   - 5.1 Request the virtual function of the function that was just inserted
   - 5.2 Set the virtual-slot of all remaining functions to this value
6. Attach each of the remaining functions

qemu-xen only sends an ACPI event to the BIOS for function zero, which is always last

Detachment

1. Find all the functions with the same key
2. Order the functions so that virtual-function zero is last
3. Detach each function

xend only sends a notification to qemu-xen for function zero, which is always last

Conclusion

- Incremental improvement to pass-through for Xen
  - user/xm/xend/qemu-xen interaction was by far the most time-consuming portion
- Functions from multiple virtual devices in a single multi-function virtual-device would be interesting — possibly very broken

ACPI BIOS

- Extended from 2 slots to 32
  - Removed arbitrary limitation in original Xen pass-through code
- Extended from 1 function per slot to 8
- Auto-generated the BIOS ASL code
  - Very repetitive
  - $\sim 32 \text{ lines} \times 32 \text{ slots} \times 8 \text{ functions} \approx 8000 \text{ lines}$
- Matching changes in qemu-xen
  - Not matching verbosity

This work was partly funded by Ministry of Economy, Trade and Industry (METI) of Japan as the Secure Platform project of Association of Super-Advanced Electronics Technologies (ASET).

Questions?