

# **XenGT: A High Performance Graphics Virtualization Solution on Intel® Processor Graphics**

Kevin Tian, Software Architect, Intel Corporation

David Cowperthwaite, Software Architect, Intel  
Corporation

**SFTS008**

# Agenda

- Why GPU Virtualization?
- The Way to Full GPU Virtualization
- Architecture Overview
- Key Techniques
- Summary

# Agenda

- Why GPU Virtualization?
- The Way to Full GPU Virtualization
- Architecture Overview
- Key Techniques
- Summary

# GPU Use Cases



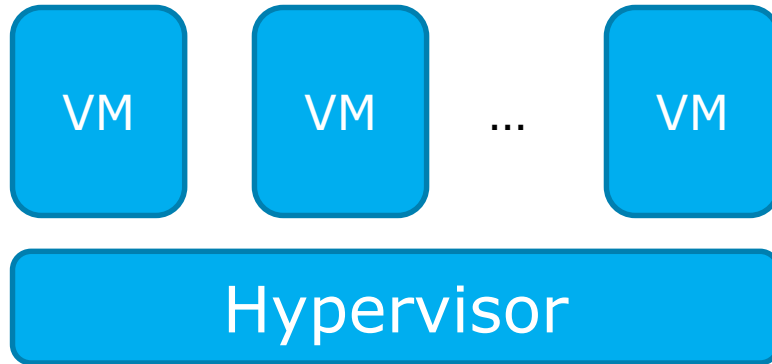
3D Graphics

Media

Compute



# Virtualization Use Cases



## Use Cases

Virtual Data Center  
Cloud

Remote Virtual Desktop

Rich Virtual Client

Bring Your Own Device

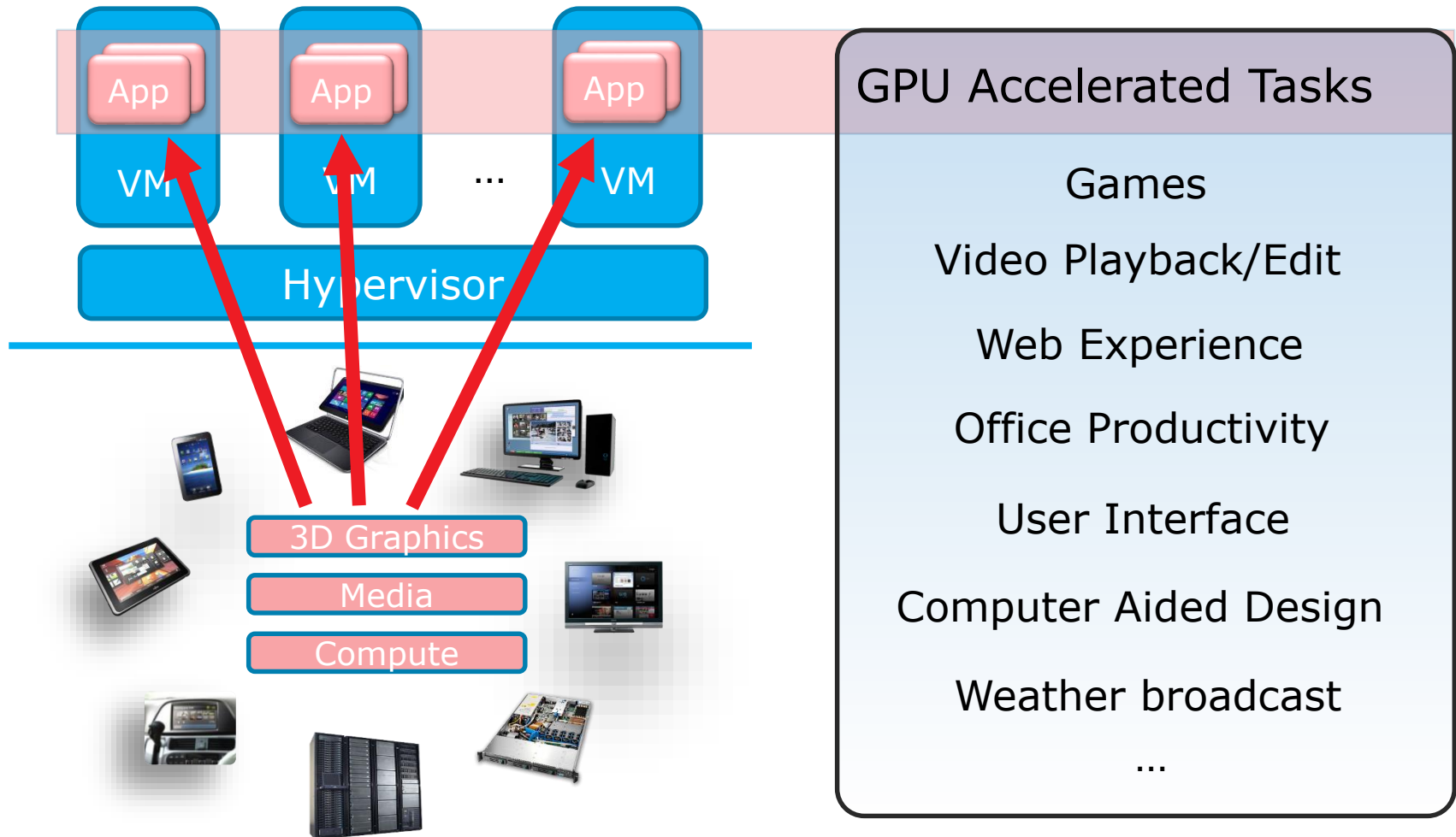
Smart TV

Multi-Screen Infotainment

Secure e-Payment

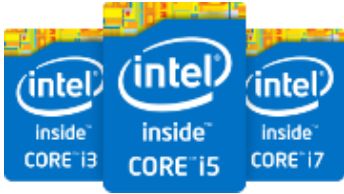
...

# So...GPU Virtualization



***GPU virtualization becomes a fundamental requirement***

# Intel® Processor Graphics



22nm

Built into 4<sup>th</sup> generation  
Intel® Core™ processors



GT3

**2x** computational shader  
power with new GT3 -  
**Intel® Iris™ Graphics**



EDRAM

128MB fast cache for  
bandwidth saving with GT3e -  
**Intel® Iris™ Pro Graphics**



Intel® Quick  
Sync Video

High Speed Video Decode &  
Encode H.264/MPEG-4 AVC,  
VC-1

# Agenda

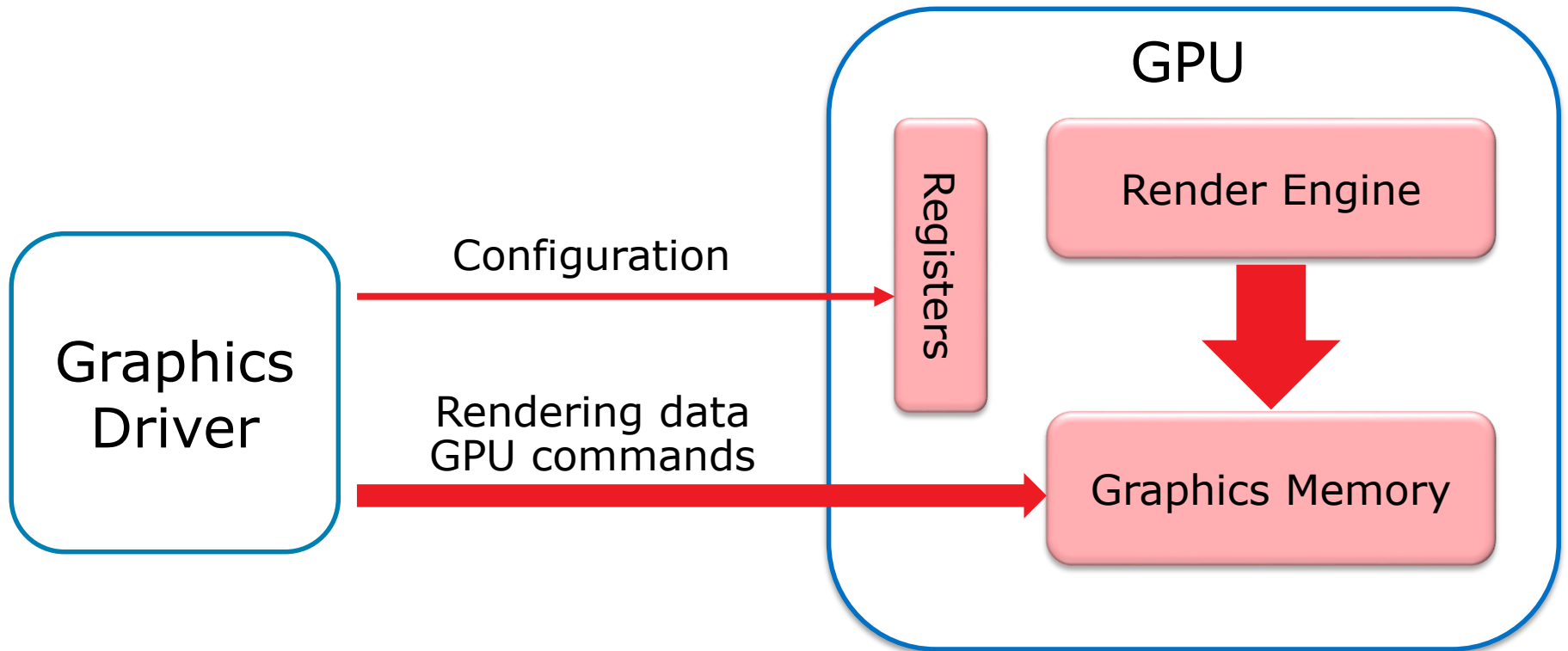
- Why GPU Virtualization?
- The Way to Full GPU Virtualization
- Architecture Overview
- Key Techniques
- Summary



# Legacy Display Cards

- Only for display purpose
- Simple functionalities
  - A few registers
  - Small video RAM
- Emulation of legacy display cards is easy
  - Basic feature in most device models

# Modern GPUs



***Emulation of Render Engine is impractical!***

# Requirements of GPU Virtualization



Performance



Direct GPU acceleration



Feature



Consistent visual experience

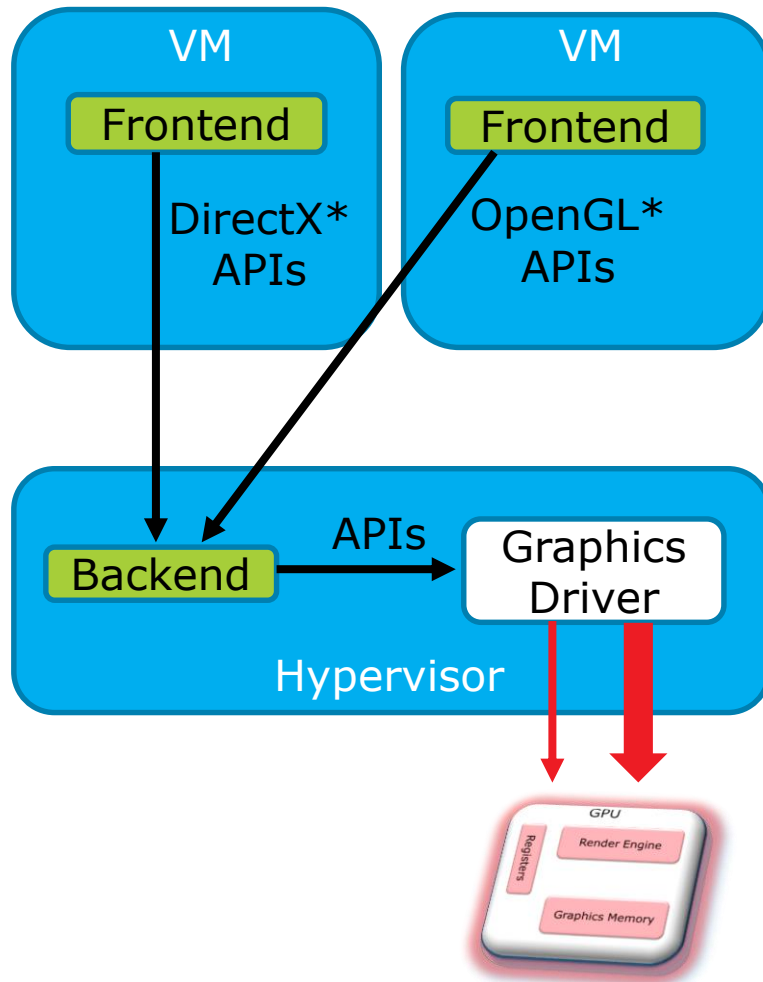


Sharing



Multiple Virtual Machines

# API Forwarding



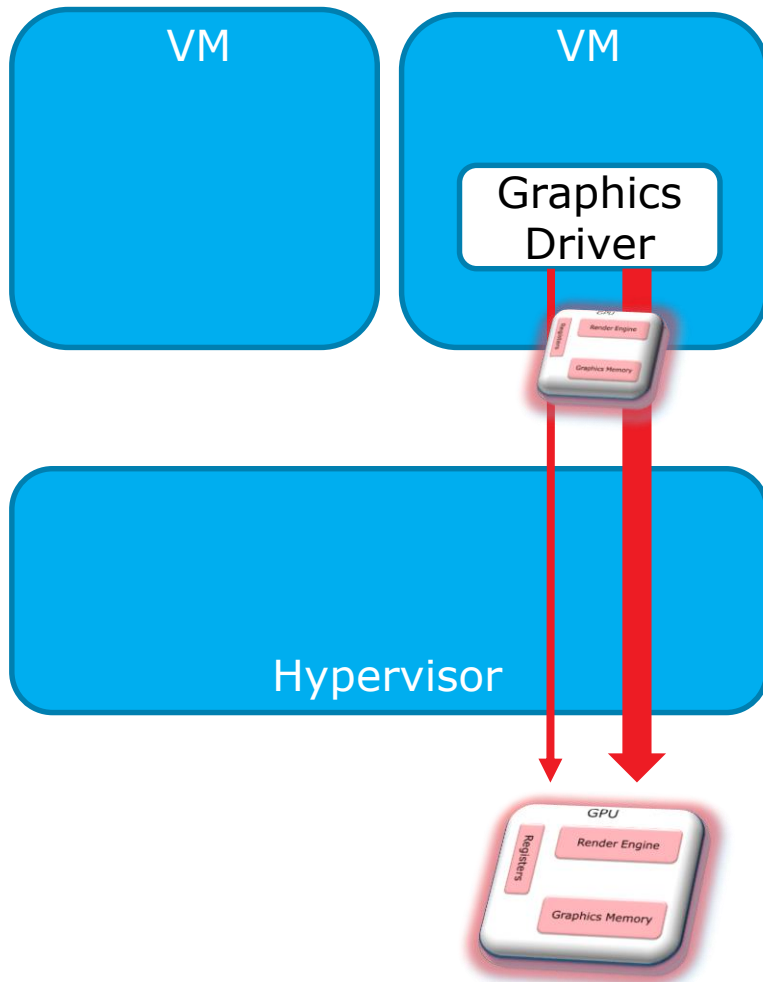
## Pros

- Performance
- Sharing capability

## Cons

- Lagging features

# Direct Pass-Through



## Pros

---

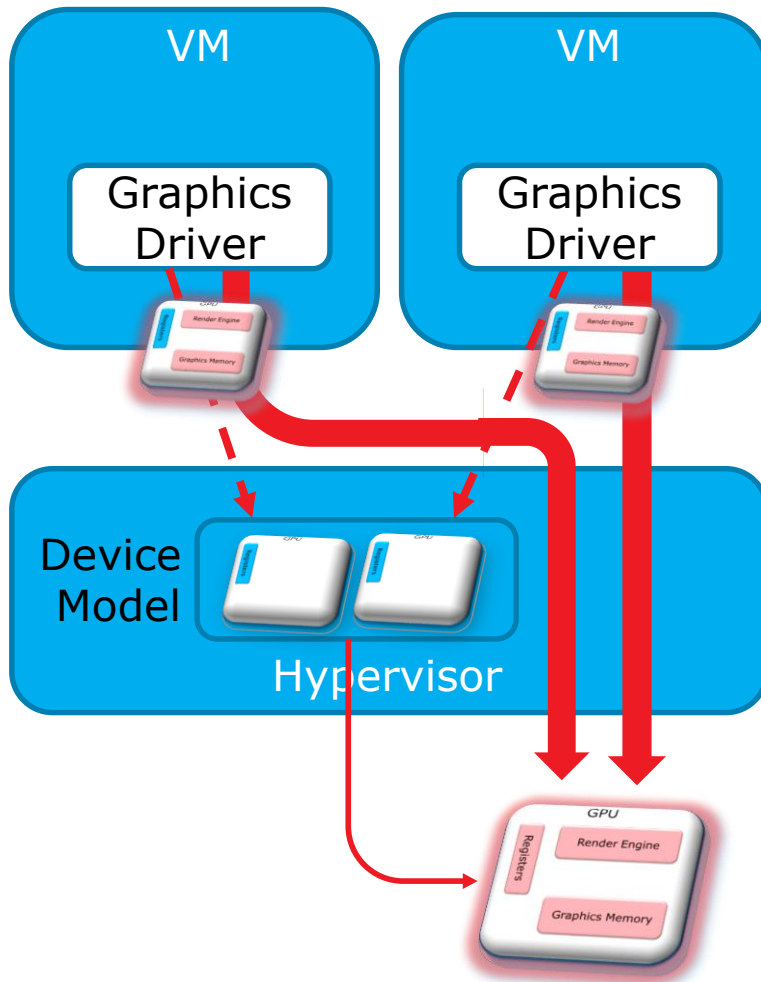
- Performance
- Feature

## Cons

---

- No sharing capability

# Full GPU Virtualization



## Pros

- Performance
- Feature
- Sharing capability

***Run native graphics stack inside VMs!***

# Agenda

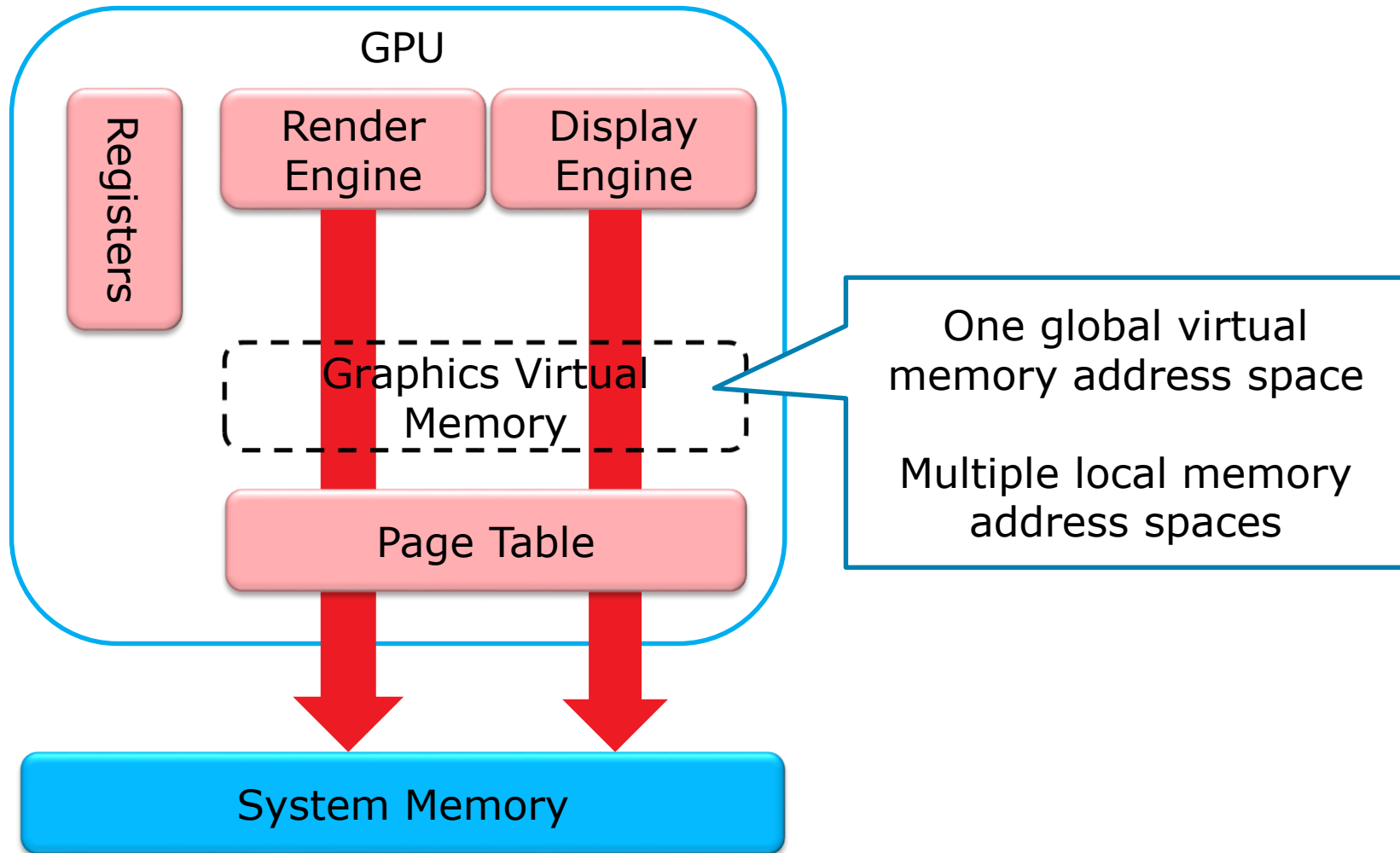
- Why GPU Virtualization
- The Way to Full GPU Virtualization
- Architecture Overview
- Key Techniques
- Summary

# XenGT: A Full GPU Virtualization Solution

- Built on a mediated pass-through framework
  - Privileged I/O operations are trap-and-emulated
  - Performance critical operations are passed through
- Virtual GPU (vGPU) device model
  - Equivalent features as physical Intel® Processor Graphics
- Running native graphics driver inside VMs
  - Leverage existing driver optimizations and stability fixes
- First implementation on Xen hypervisor
  - Core device model reusable in other hypervisors

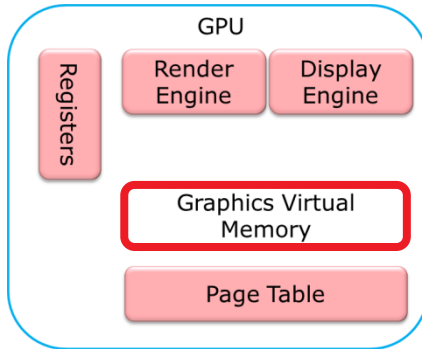


# Processor Graphics: Components



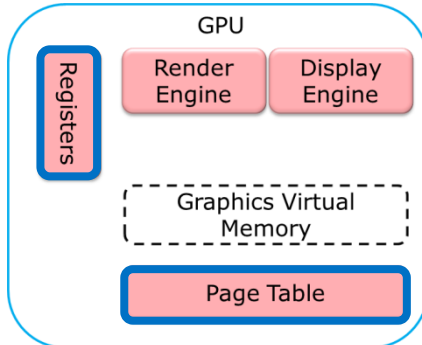
# Virtualization Policies

## Pass-Through



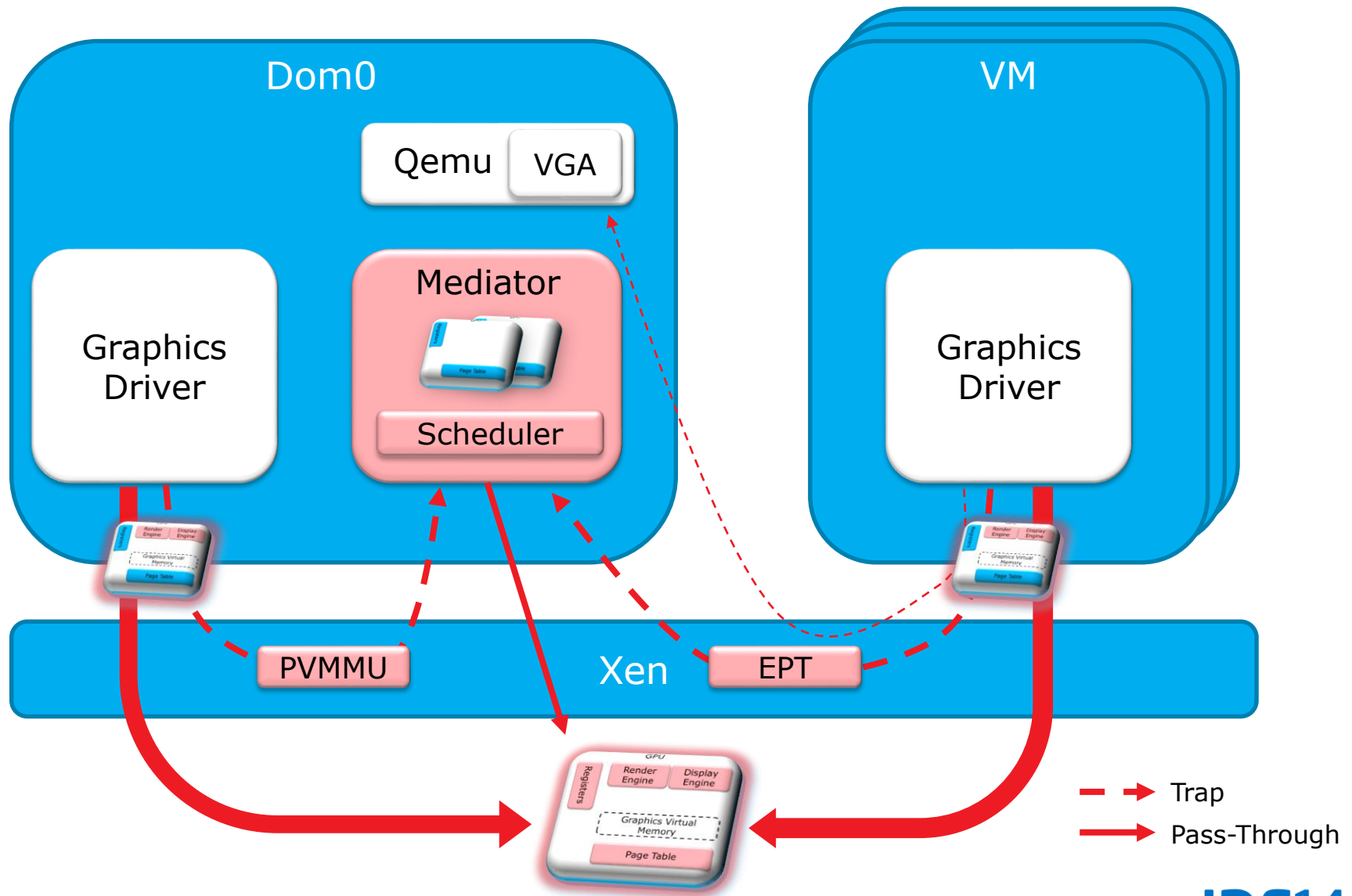
- Frame buffer
  - Command buffer
- (Both in Graphics Memory)

## Trap-and-Emulation



- Memory-mapped I/O registers
- Port I/O registers
- PCI configuration registers
- GPU page table entries

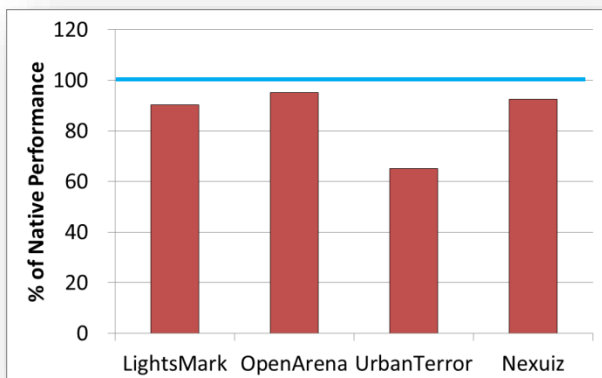
# Architecture Overview



# Capabilities

## Performance

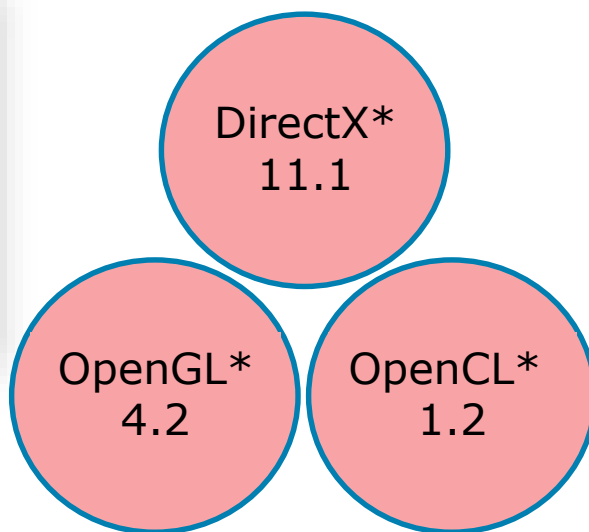
Near native performance with direct GPU execution



Software and workloads used in performance tests may have been optimized for performance only on Intel microprocessors. Performance tests, such as SYSmark\* and MobileMark\*, are measured using specific computer systems, components, software, operations and functions. Any change to any of those factors may cause the results to vary. You should consult other information and performance tests to assist you in fully evaluating your contemplated purchases, including the performance of that product when combined with other products. For more information go to <http://www.intel.com/performance>.

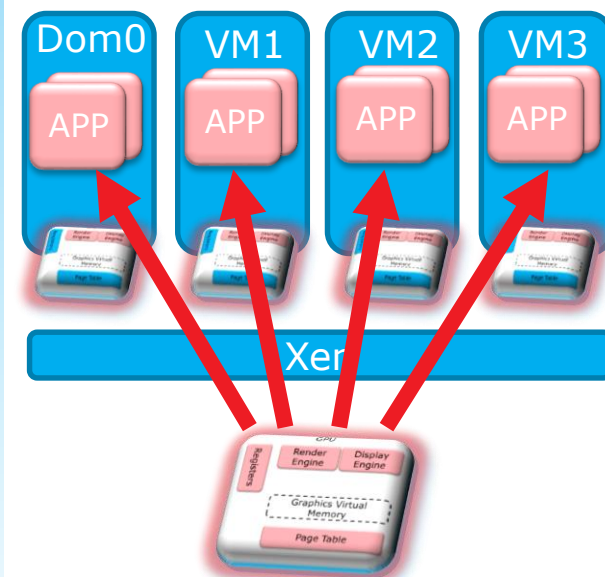
## Feature

Run native graphics stack to sustain visual experience



## Sharing

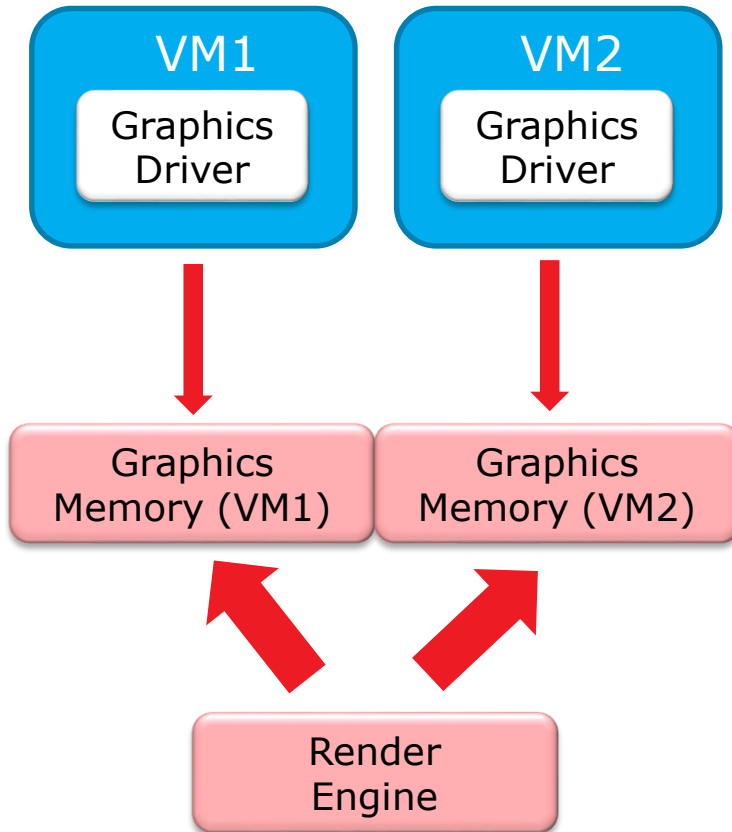
Accelerate 3 VMs plus Dom0 simultaneously



# Agenda

- Why GPU Virtualization
- The Way to Full GPU Virtualization
- Architecture Overview
- Key Techniques
- Summary

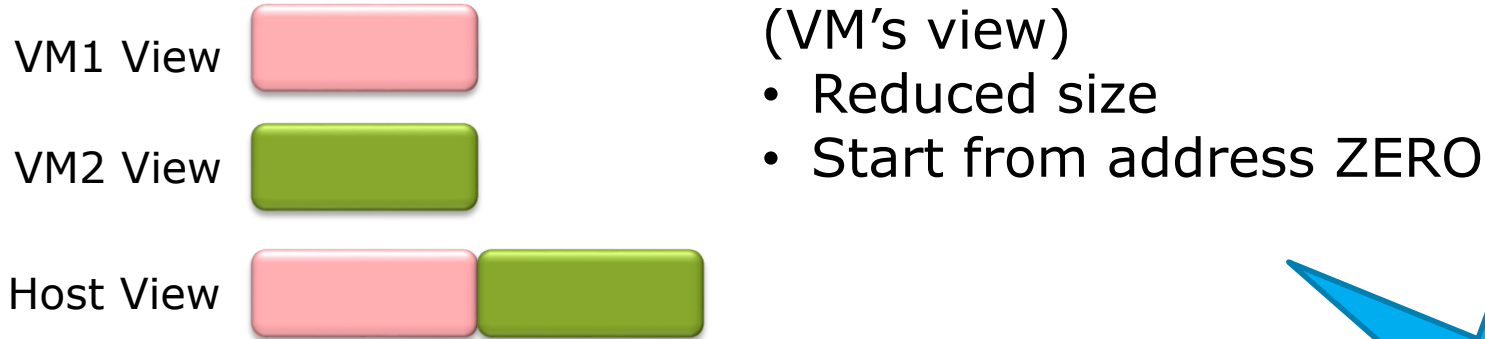
# Pass-Through: Graphics Memory



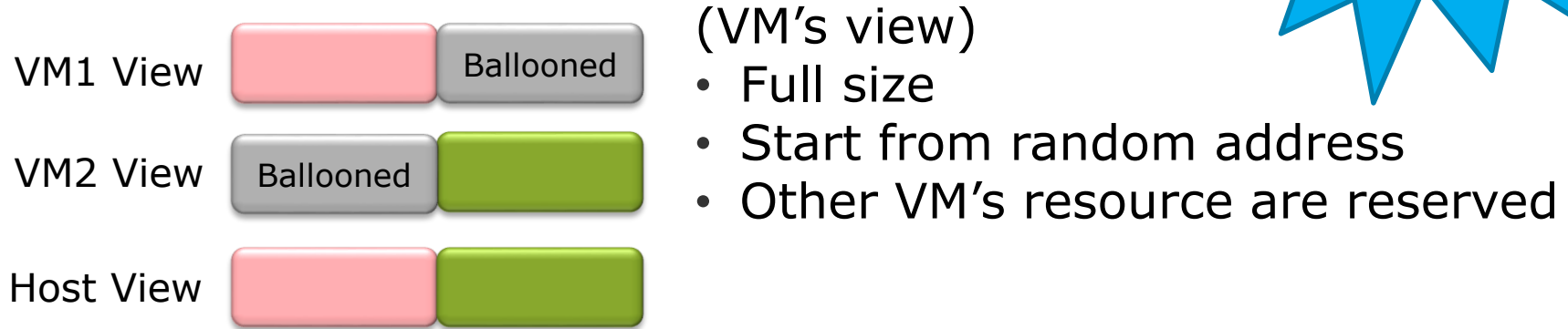
- Parallel accesses from both CPU and GPU
  - Split CPU/GPU scheduling
- Graphics memory partition
  - Dedicated resource for each VM
- Local graphics memory is fully passed through

# Pass-Through: Graphics Address Space

Inconsistent view due to graphics memory partition

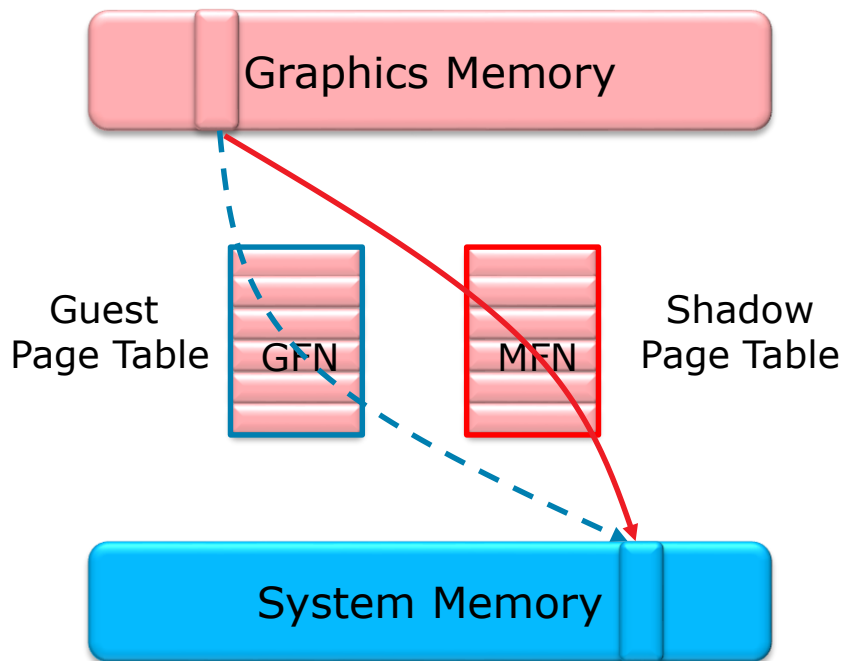


Consistent view with address space ballooning



Avoid  
address  
translation!

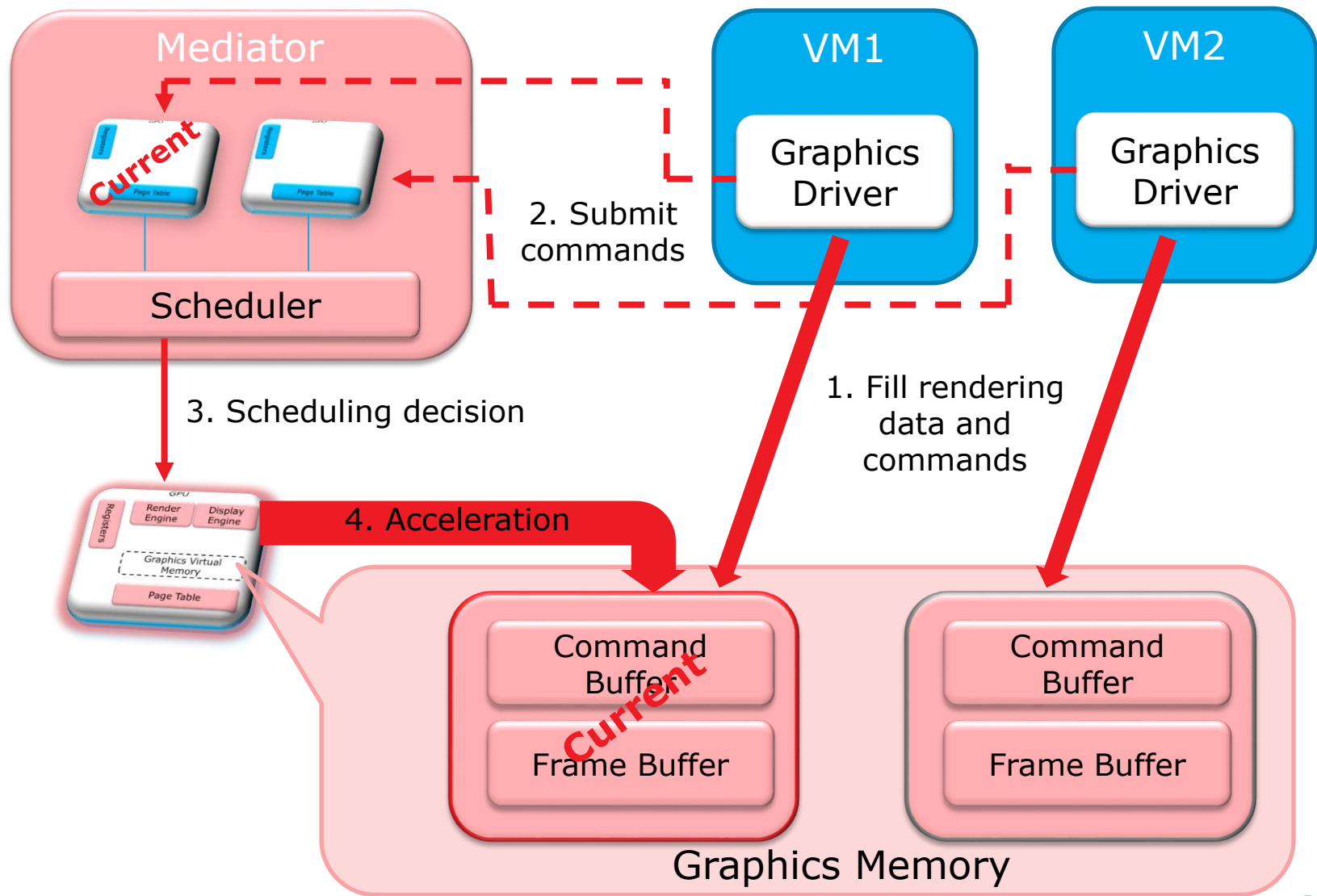
# GPU Page Table Virtualization



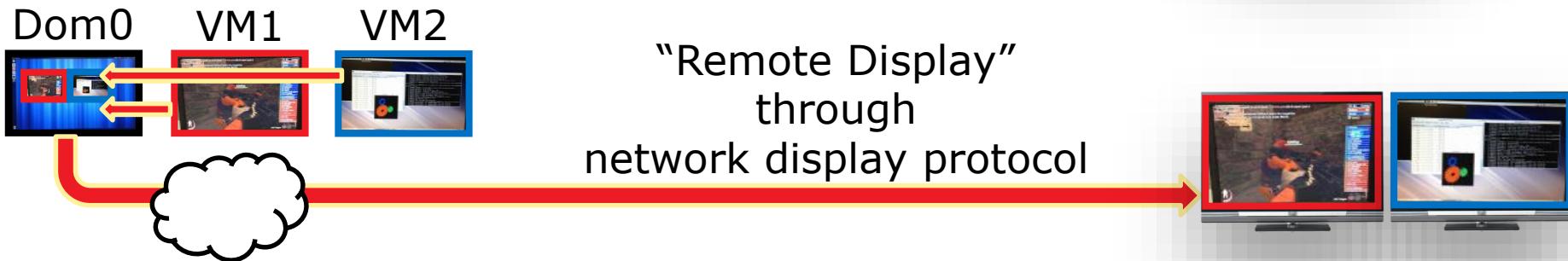
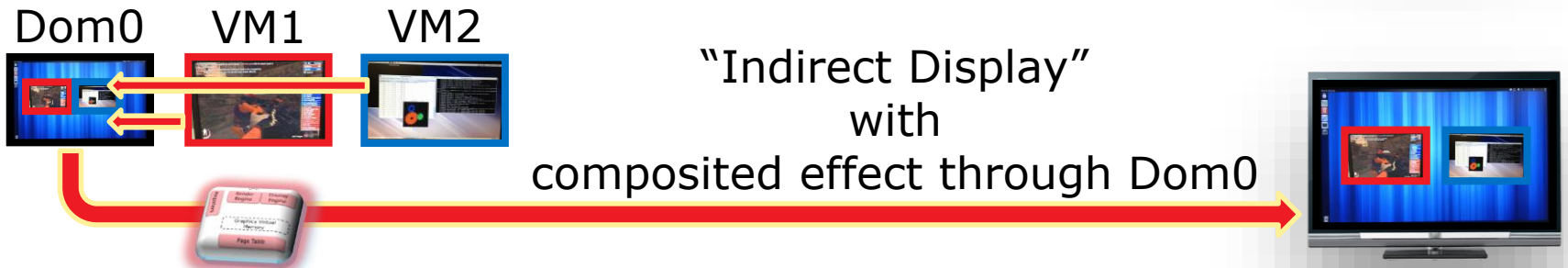
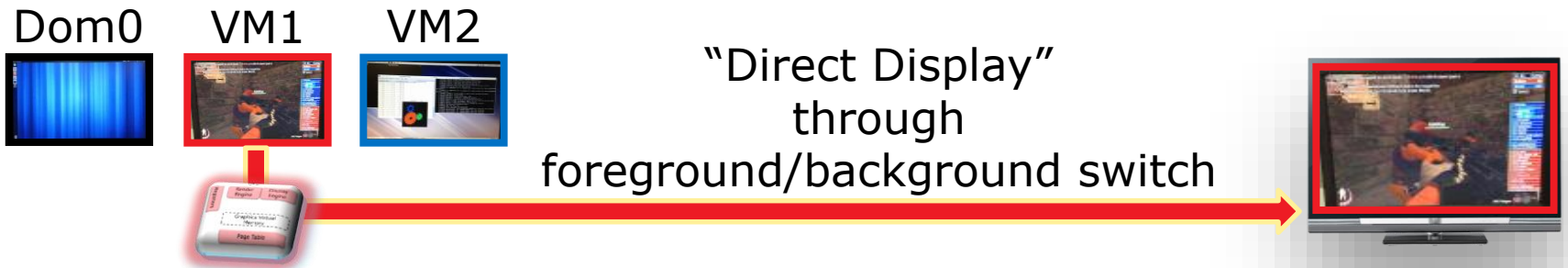
- GPU page tables
  - Back system memory into virtual address spaces
- Shadow page table
  - Guest PFN  $\leftrightarrow$  Machine PFN



# GPU Scheduler



# Display Sharing



# Agenda

- Why GPU Virtualization
- The Way to Full GPU Virtualization
- Architecture Overview
- Key Techniques
- Summary

# Summary

- GPU virtualization is becoming a fundamental requirement in many virtualization usages
- Full GPU virtualization achieves good balance among performance, feature, and sharing capability
- XenGT is a full GPU virtualization solution, on Intel® Processor Graphics, running native graphics driver inside VMs

# Call to Action

- Open source project: Try it and provide feedback
  - <https://github.com/01org/XenGT-Preview-kernel>
  - <https://github.com/01org/XenGT-Preview-xen>
  - <https://github.com/01org/XenGT-Preview-qemu>

PDF of this presentation is available is available from our Technical Session Catalog: [www.intel.com/idfsessionsSZ](http://www.intel.com/idfsessionsSZ). The URL is on top of Session Agenda Pages in Pocket Guide.

# Please Fill Out The Online Session Evaluation Form

**Enter to win fabulous prizes!**

**You will receive an email with a link to the online session evaluation prior to the end of this session. Please submit the evaluation by 10am tomorrow to be entered to win.**

***Winners will be announced by email***

**Sweepstakes rules are available at the Help Desk on Floor 4  
All sessions evaluations must be submitted by Friday, April 4 at 5pm**

# Q&A

# Legal Disclaimer

INFORMATION IN THIS DOCUMENT IS PROVIDED IN CONNECTION WITH INTEL PRODUCTS. NO LICENSE, EXPRESS OR IMPLIED, BY ESTOPPEL OR OTHERWISE, TO ANY INTELLECTUAL PROPERTY RIGHTS IS GRANTED BY THIS DOCUMENT. EXCEPT AS PROVIDED IN INTEL'S TERMS AND CONDITIONS OF SALE FOR SUCH PRODUCTS, INTEL ASSUMES NO LIABILITY WHATSOEVER AND INTEL DISCLAIMS ANY EXPRESS OR IMPLIED WARRANTY, RELATING TO SALE AND/OR USE OF INTEL PRODUCTS INCLUDING LIABILITY OR WARRANTIES RELATING TO FITNESS FOR A PARTICULAR PURPOSE, MERCHANTABILITY, OR INFRINGEMENT OF ANY PATENT, COPYRIGHT OR OTHER INTELLECTUAL PROPERTY RIGHT.

A "Mission Critical Application" is any application in which failure of the Intel Product could result, directly or indirectly, in personal injury or death. SHOULD YOU PURCHASE OR USE INTEL'S PRODUCTS FOR ANY SUCH MISSION CRITICAL APPLICATION, YOU SHALL INDEMNIFY AND HOLD INTEL AND ITS SUBSIDIARIES, SUBCONTRACTORS AND AFFILIATES, AND THE DIRECTORS, OFFICERS, AND EMPLOYEES OF EACH, HARMLESS AGAINST ALL CLAIMS COSTS, DAMAGES, AND EXPENSES AND REASONABLE ATTORNEYS' FEES ARISING OUT OF, DIRECTLY OR INDIRECTLY, ANY CLAIM OF PRODUCT LIABILITY, PERSONAL INJURY, OR DEATH ARISING IN ANY WAY OUT OF SUCH MISSION CRITICAL APPLICATION, WHETHER OR NOT INTEL OR ITS SUBCONTRACTOR WAS NEGLIGENT IN THE DESIGN, MANUFACTURE, OR WARNING OF THE INTEL PRODUCT OR ANY OF ITS PARTS.

Intel may make changes to specifications and product descriptions at any time, without notice. Designers must not rely on the absence or characteristics of any features or instructions marked "reserved" or "undefined". Intel reserves these for future definition and shall have no responsibility whatsoever for conflicts or incompatibilities arising from future changes to them. The information here is subject to change without notice. Do not finalize a design with this information.

The products described in this document may contain design defects or errors known as errata which may cause the product to deviate from published specifications. Current characterized errata are available on request.

Contact your local Intel sales office or your distributor to obtain the latest specifications and before placing your product order. Copies of documents which have an order number and are referenced in this document, or other Intel literature, may be obtained by calling 1-800-548-4725, or go to: <http://www.intel.com/design/literature.htm>

Intel, Core, Look Inside, and the Intel logo are trademarks of Intel Corporation in the United States and other countries.

\*Other names and brands may be claimed as the property of others.

Copyright ©2014 Intel Corporation.



# Risk Factors

The above statements and any others in this document that refer to plans and expectations for the first quarter, the year and the future are forward-looking statements that involve a number of risks and uncertainties. Words such as “anticipates,” “expects,” “intends,” “plans,” “believes,” “seeks,” “estimates,” “may,” “will,” “should” and their variations identify forward-looking statements. Statements that refer to or are based on projections, uncertain events or assumptions also identify forward-looking statements. Many factors could affect Intel’s actual results, and variances from Intel’s current expectations regarding such factors could cause actual results to differ materially from those expressed in these forward-looking statements. Intel presently considers the following to be the important factors that could cause actual results to differ materially from the company’s expectations. Demand could be different from Intel’s expectations due to factors including changes in business and economic conditions; customer acceptance of Intel’s and competitors’ products; supply constraints and other disruptions affecting customers; changes in customer order patterns including order cancellations; and changes in the level of inventory at customers. Uncertainty in global economic and financial conditions poses a risk that consumers and businesses may defer purchases in response to negative financial events, which could negatively affect product demand and other related matters. Intel operates in intensely competitive industries that are characterized by a high percentage of costs that are fixed or difficult to reduce in the short term and product demand that is highly variable and difficult to forecast. Revenue and the gross margin percentage are affected by the timing of Intel product introductions and the demand for and market acceptance of Intel’s products; actions taken by Intel’s competitors, including product offerings and introductions, marketing programs and pricing pressures and Intel’s response to such actions; and Intel’s ability to respond quickly to technological developments and to incorporate new features into its products. The gross margin percentage could vary significantly from expectations based on capacity utilization; variations in inventory valuation, including variations related to the timing of qualifying products for sale; changes in revenue levels; segment product mix; the timing and execution of the manufacturing ramp and associated costs; start-up costs; excess or obsolete inventory; changes in unit costs; defects or disruptions in the supply of materials or resources; product manufacturing quality/yields; and impairments of long-lived assets, including manufacturing, assembly/test and intangible assets. Intel’s results could be affected by adverse economic, social, political and physical/infrastructure conditions in countries where Intel, its customers or its suppliers operate, including military conflict and other security risks, natural disasters, infrastructure disruptions, health concerns and fluctuations in currency exchange rates. Expenses, particularly certain marketing and compensation expenses, as well as restructuring and asset impairment charges, vary depending on the level of demand for Intel’s products and the level of revenue and profits. Intel’s results could be affected by the timing of closing of acquisitions and divestitures. Intel’s results could be affected by adverse effects associated with product defects and errata (deviations from published specifications), and by litigation or regulatory matters involving intellectual property, stockholder, consumer, antitrust, disclosure and other issues, such as the litigation and regulatory matters described in Intel’s SEC reports. An unfavorable ruling could include monetary damages or an injunction prohibiting Intel from manufacturing or selling one or more products, precluding particular business practices, impacting Intel’s ability to design its products, or requiring other remedies such as compulsory licensing of intellectual property. A detailed discussion of these and other factors that could affect Intel’s results is included in Intel’s SEC filings, including the company’s most recent reports on Form 10-Q, Form 10-K and earnings release.

Rev. 1/16/14