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SFTS008
Agenda

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

GPU Accelerated Tasks
- Games
- Video Playback/Edit
- Office Productivity
- User Interface
- Computer Aided Design
- Weather broadcast

3D Graphics
Media
Compute

App
VM

Hypervisor
## Intel® Processor Graphics

<table>
<thead>
<tr>
<th>Technology</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>22nm</strong></td>
<td>Built into 4&lt;sup&gt;th&lt;/sup&gt; generation Intel® Core™ processors</td>
</tr>
<tr>
<td><strong>GT3</strong></td>
<td>2x computational shader power with new GT3 - Intel® Iris™ Graphics</td>
</tr>
<tr>
<td><strong>EDRAM</strong></td>
<td>128MB fast cache for bandwidth saving with GT3e - Intel® Iris™ Pro Graphics</td>
</tr>
<tr>
<td><strong>Intel® Quick Sync Video</strong></td>
<td>High Speed Video Decode &amp; Encode H.264/MPEG-4 AVC, VC-1</td>
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</tbody>
</table>
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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!

IDF14
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!
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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

- Registers
- Render Engine
- Display Engine
- Page Table

One global virtual memory address space
Multiple local memory address spaces
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

Dom0

Qemu  VGA

Mediator

Scheduler

Graphics Driver

PVMMU

Xen

EPT

VM

Graphics Driver

Trap

Pass-Through
Capabilities

Performance

Near native performance with direct GPU execution

Feature

Run native graphics stack to sustain visual experience

Sharing

Accelerate 3 VMs plus Dom0 simultaneously

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.
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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

- VM1 View: Reduced size; Start from address ZERO
- VM2 View: Full size; Start from random address
- Host View: Other VM’s resource are reserved

Consistent view with address space ballooning

- VM1 View: Full size; Start from random address
- VM2 View: Full size; Start from random address
- Host View: Other VM’s resource are reserved

Avoid address translation!
GPU Page Table Virtualization

- GPU page tables
  - Back system memory into virtual address spaces

- Shadow page table
  - Guest PFN <-> Machine PFN
1. Fill rendering data and commands
2. Submit commands
3. Scheduling decision
4. Acceleration
Display Sharing

“Direct Display” through foreground/background switch

“Indirect Display” with composited effect through Dom0

“Remote Display” through network display protocol
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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-kernel)
  – [https://github.com/01org/XenGT-Preview-xen](https://github.com/01org/XenGT-Preview-xen)
  – [https://github.com/01org/XenGT-Preview-qemu](https://github.com/01org/XenGT-Preview-qemu)

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Q&A
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