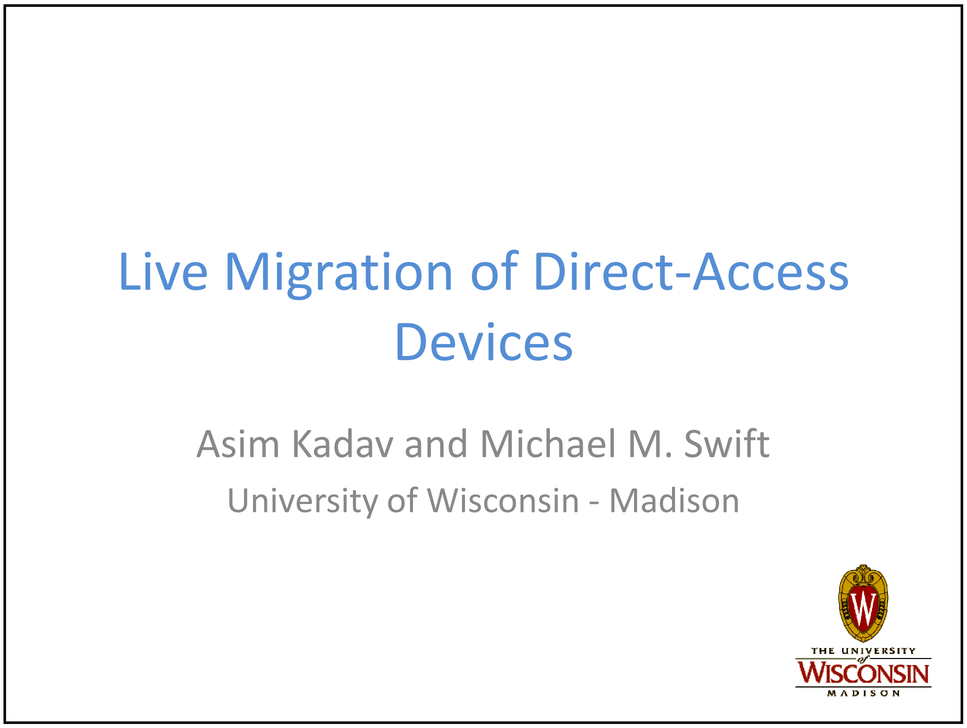
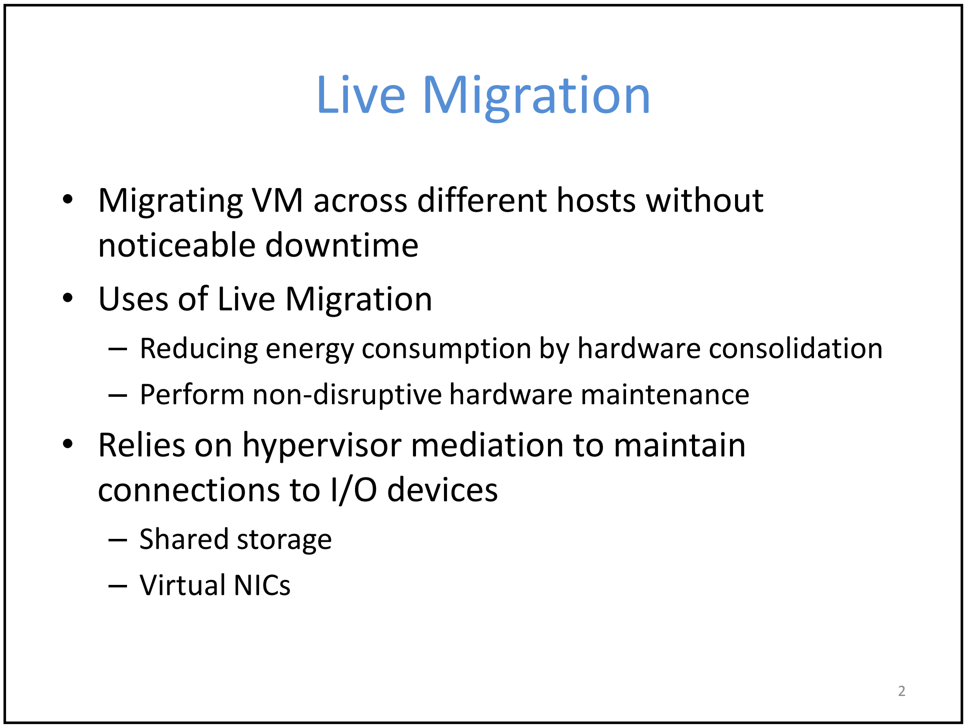


Live Migration of Direct-Access Devices

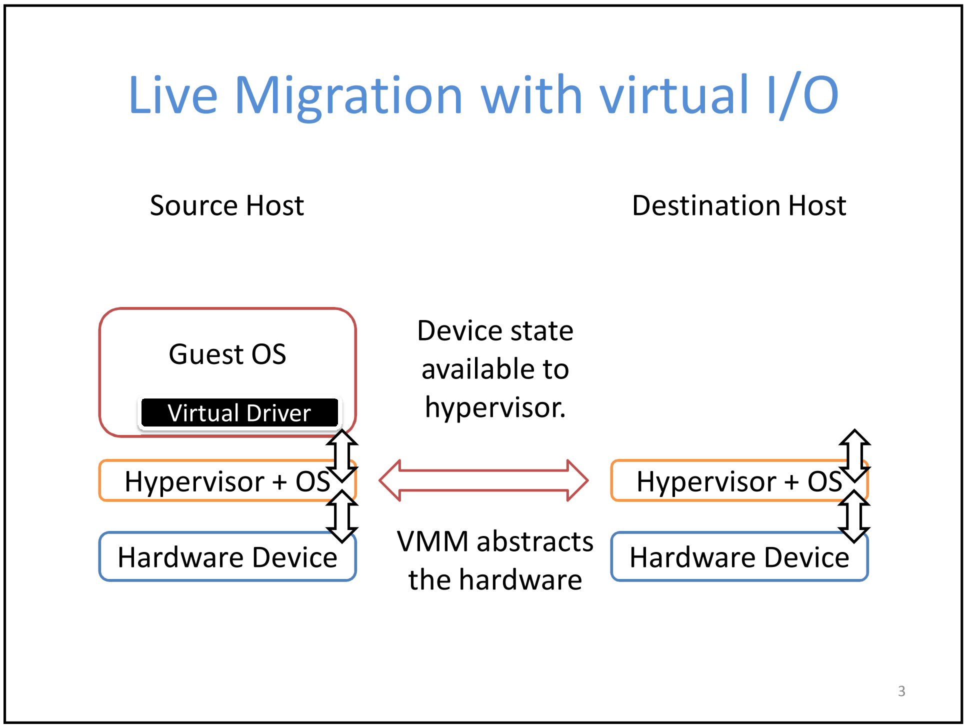
Asim Kadav and Michael M. Swift

University of Wisconsin - Madison



Live Migration

- Migrating VM across different hosts without noticeable downtime
- Uses of Live Migration
  - Reducing energy consumption by hardware consolidation
  - Perform non-disruptive hardware maintenance
- Relies on hypervisor mediation to maintain connections to I/O devices
  - Shared storage
  - Virtual NICs



Live Migration with virtual I/O

Source Host

Destination Host

Guest OS

Virtual Driver

Hypervisor + OS

Hardware Device

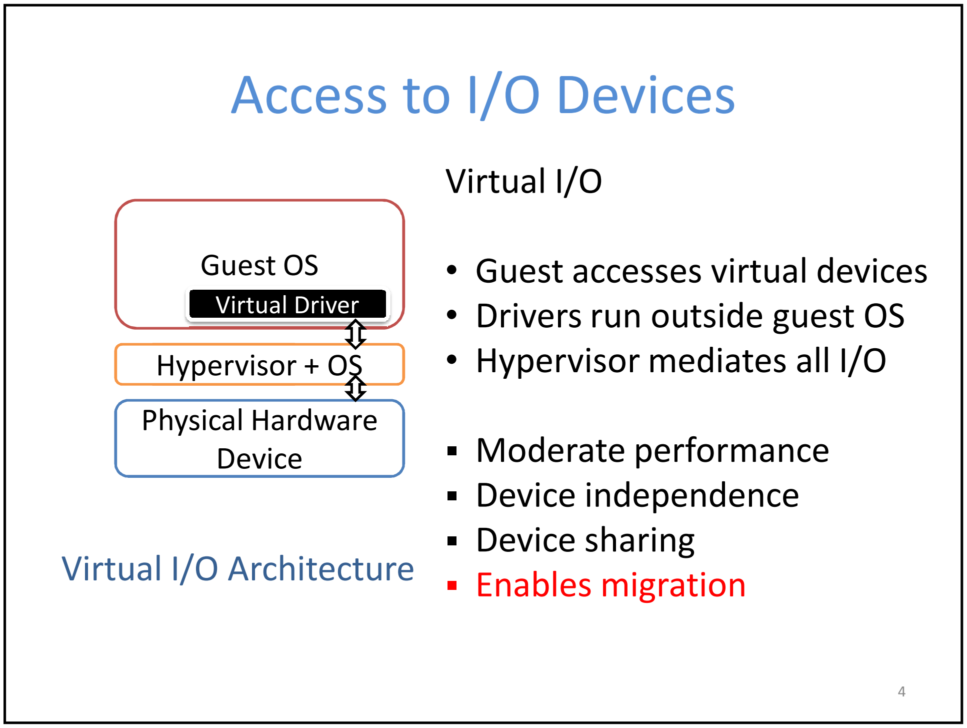
Device state available to hypervisor.

VMM abstracts the hardware

Hypervisor + OS

Hardware Device

3



Access to I/O Devices

Guest OS

Virtual Driver

Hypervisor + OS

Physical Hardware Device

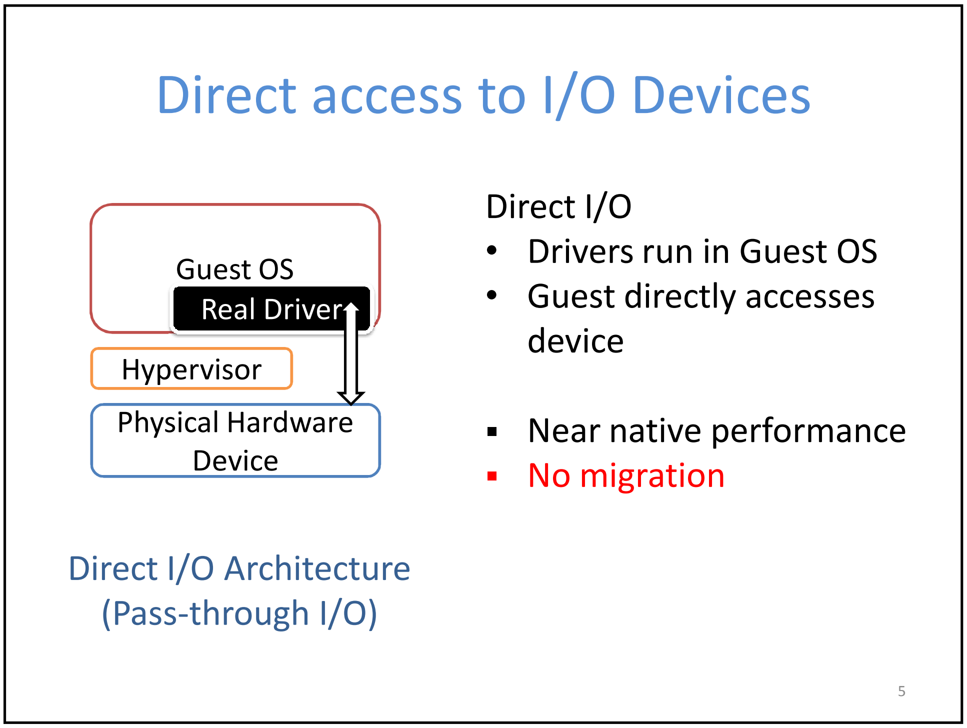
Virtual I/O Architecture

Virtual I/O

- Guest accesses virtual devices
- Drivers run outside guest OS
- Hypervisor mediates all I/O

- Moderate performance
- Device independence
- Device sharing
- Enables migration

4



Direct access to I/O Devices

Guest OS

Real Driver

Hypervisor

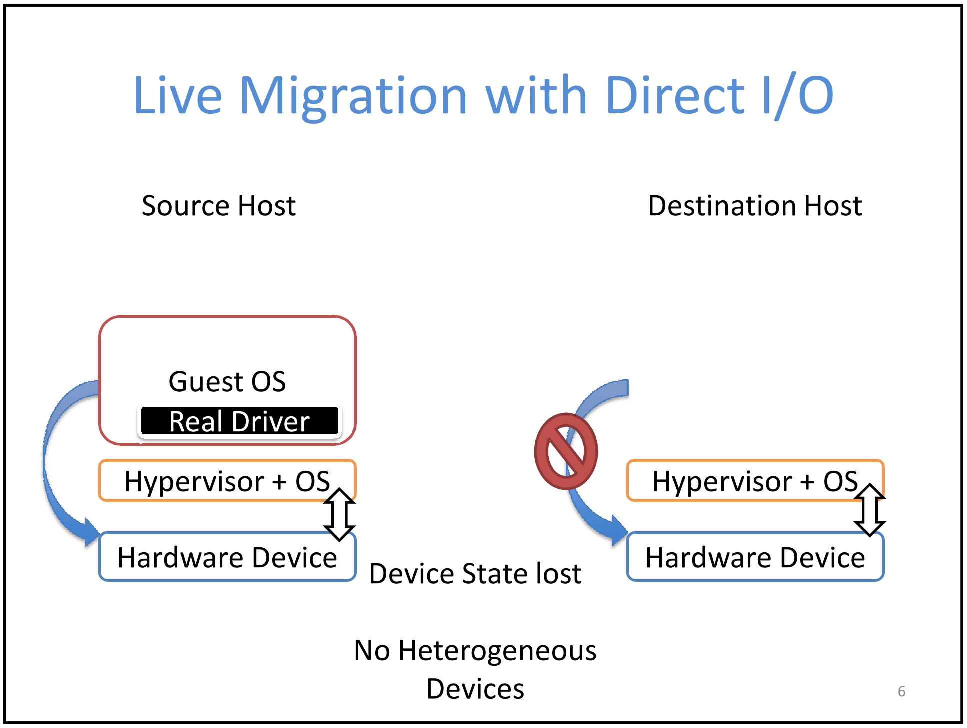
Physical Hardware Device

Direct I/O Architecture (Pass-through I/O)

Direct I/O

- Drivers run in Guest OS
- Guest directly accesses device

- Near native performance
- No migration



Live Migration with Direct I/O

Source Host

Destination Host

Guest OS

Real Driver

Hypervisor + OS

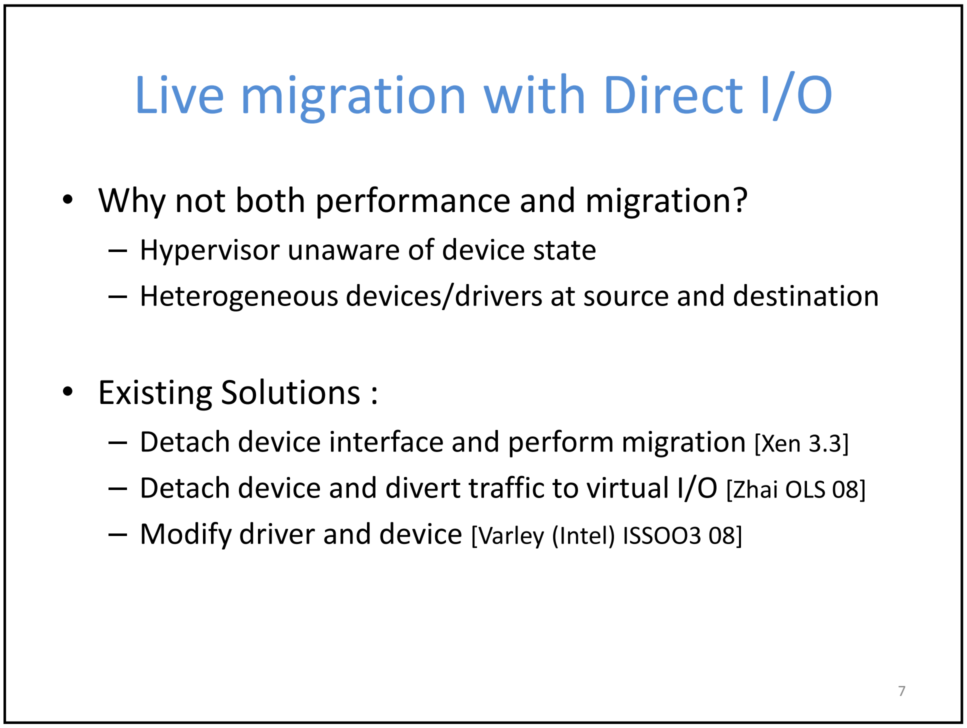
Hardware Device

Hypervisor + OS

Hardware Device

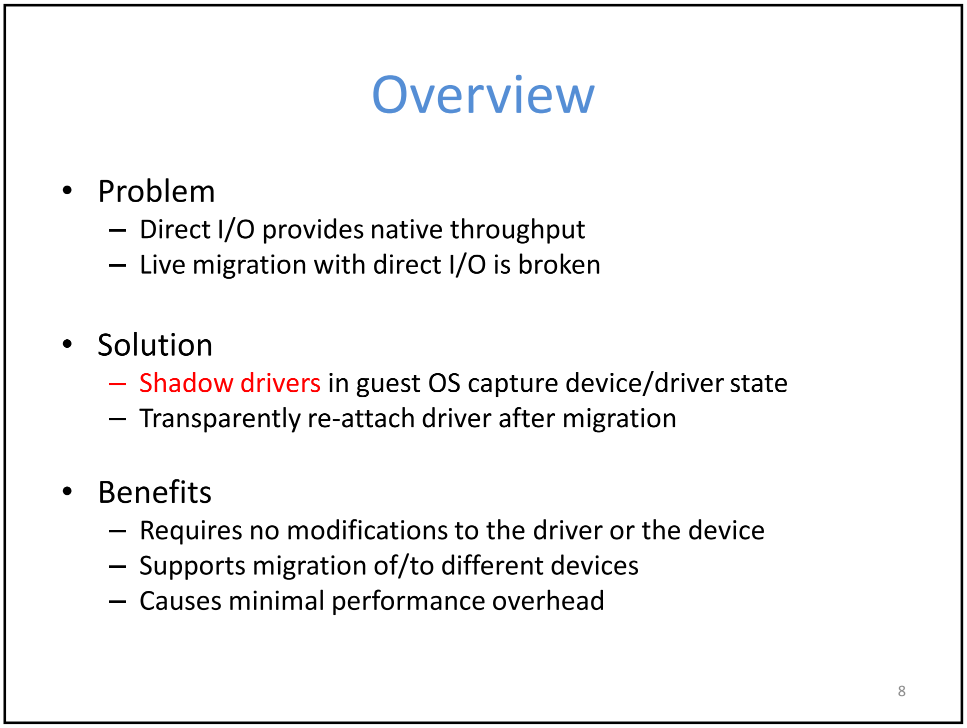
Device State lost

No Heterogeneous Devices



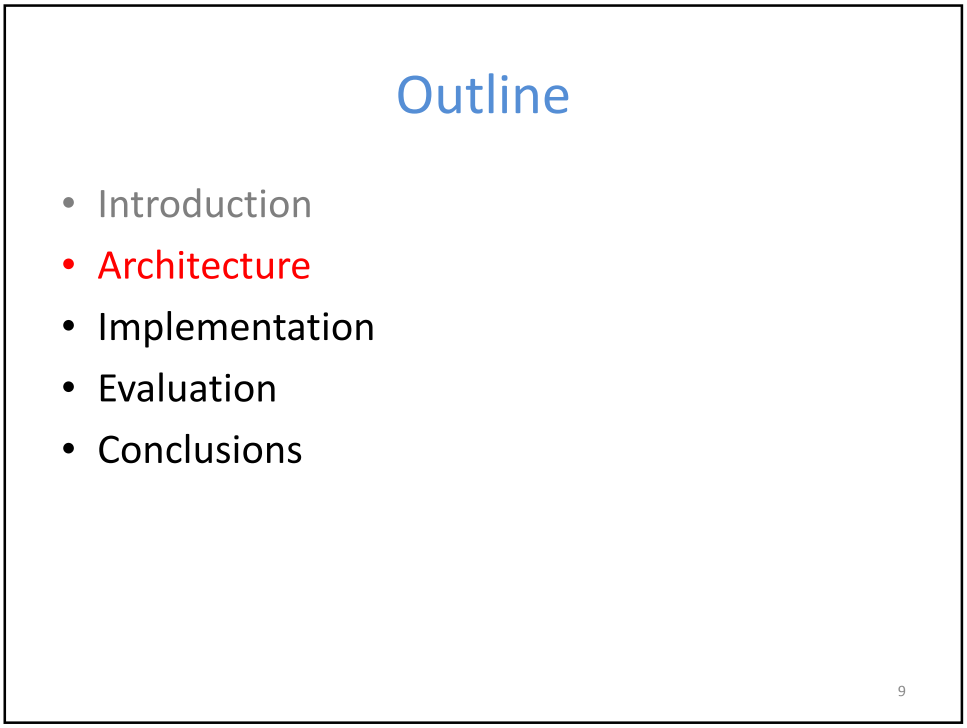
Live migration with Direct I/O

- Why not both performance and migration?
  - Hypervisor unaware of device state
  - Heterogeneous devices/drivers at source and destination
- Existing Solutions :
  - Detach device interface and perform migration [Xen 3.3]
  - Detach device and divert traffic to virtual I/O [Zhai OLS 08]
  - Modify driver and device [Varley (Intel) ISSOO3 08]



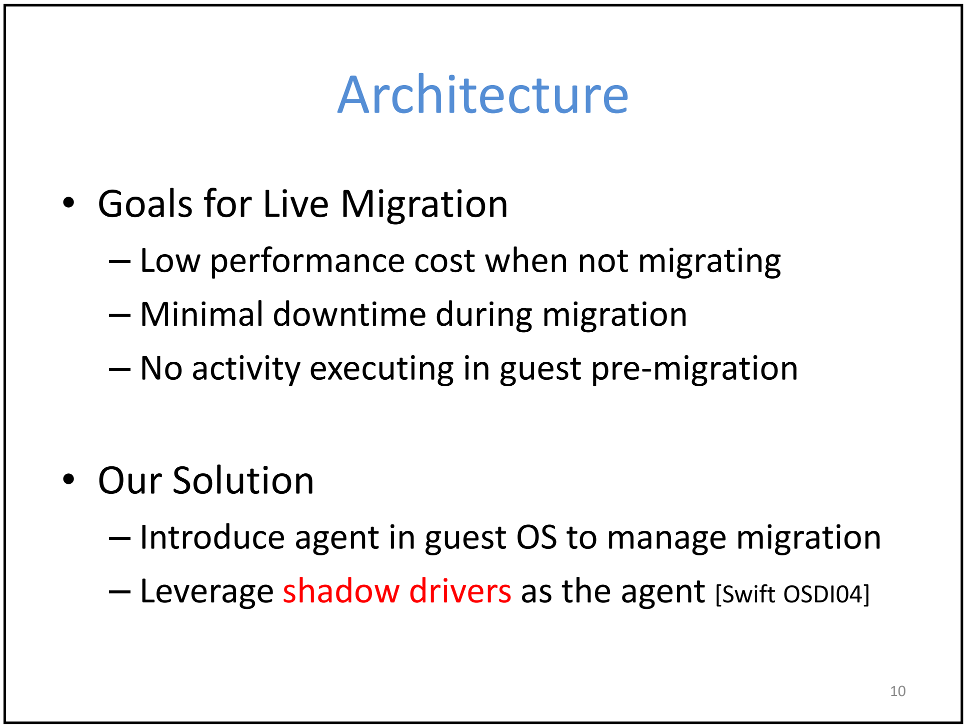
Overview

- Problem
  - Direct I/O provides native throughput
  - Live migration with direct I/O is broken
- Solution
  - Shadow drivers in guest OS capture device/driver state
  - Transparently re-attach driver after migration
- Benefits
  - Requires no modifications to the driver or the device
  - Supports migration of/to different devices
  - Causes minimal performance overhead



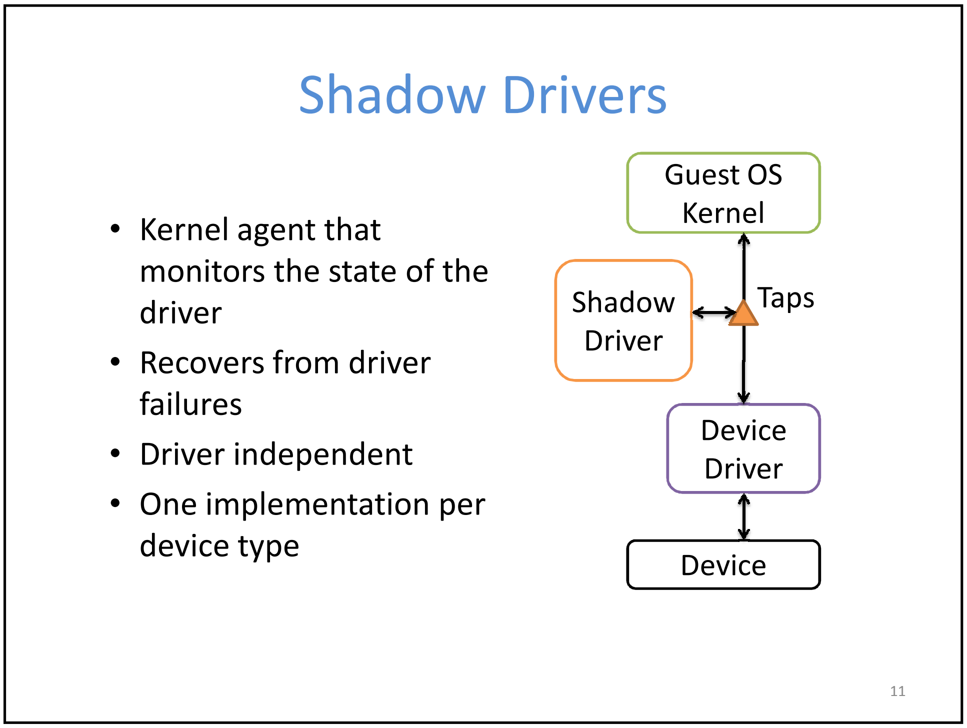
Outline

- Introduction
- Architecture
- Implementation
- Evaluation
- Conclusions



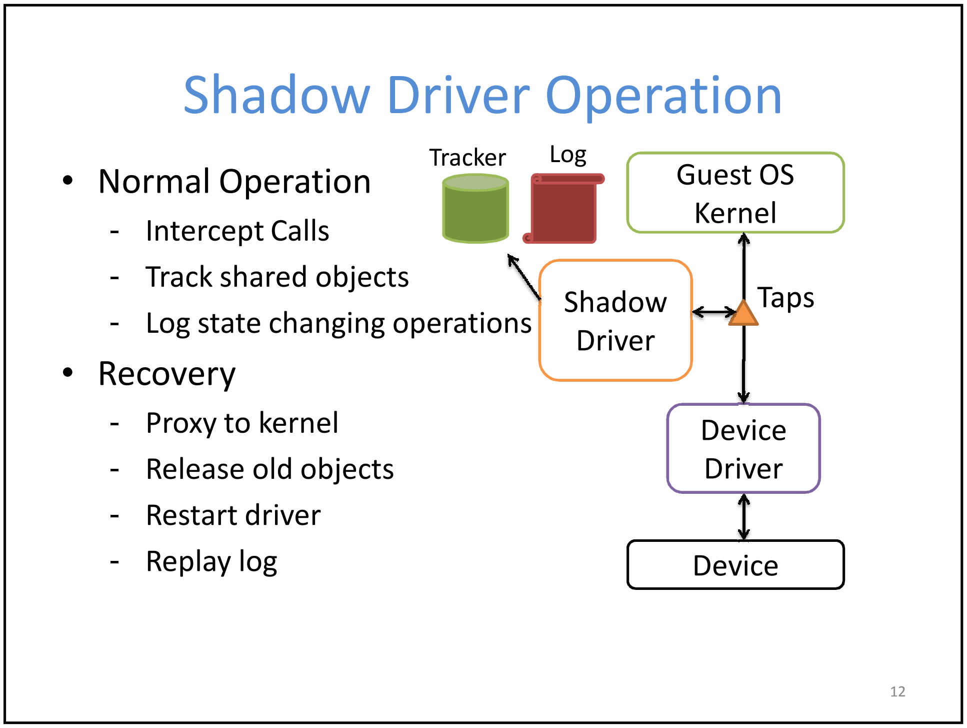
Architecture

- Goals for Live Migration
  - Low performance cost when not migrating
  - Minimal downtime during migration
  - No activity executing in guest pre-migration
- Our Solution
  - Introduce agent in guest OS to manage migration
  - Leverage shadow drivers as the agent [Swift OSDI04]



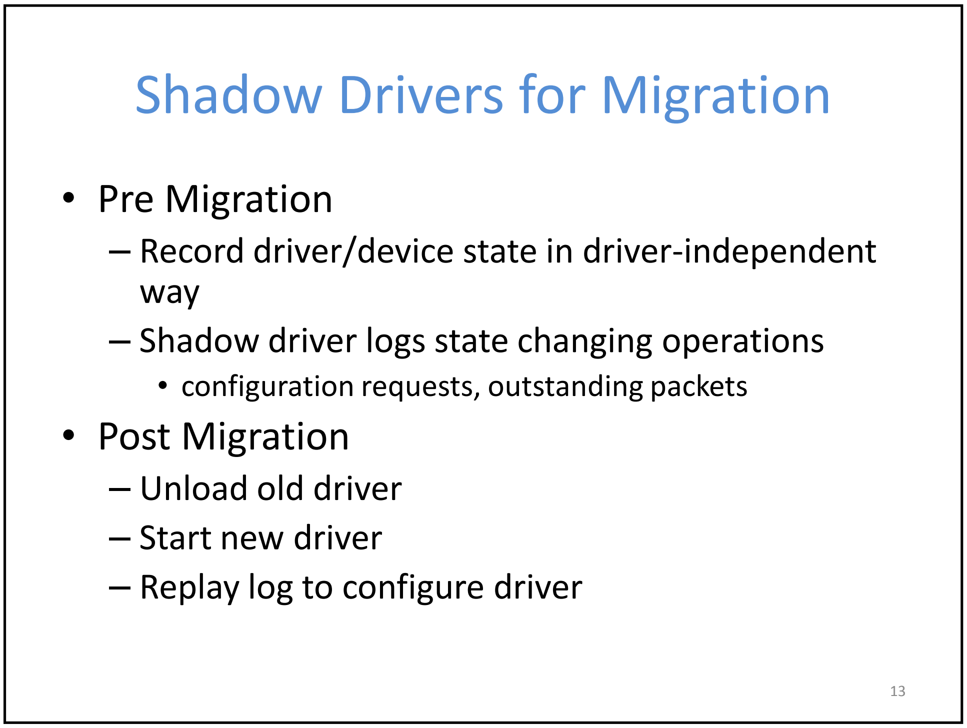
Shadow Drivers

- Kernel agent that monitors the state of the driver
- Recovers from driver failures
- Driver independent
- One implementation per device type



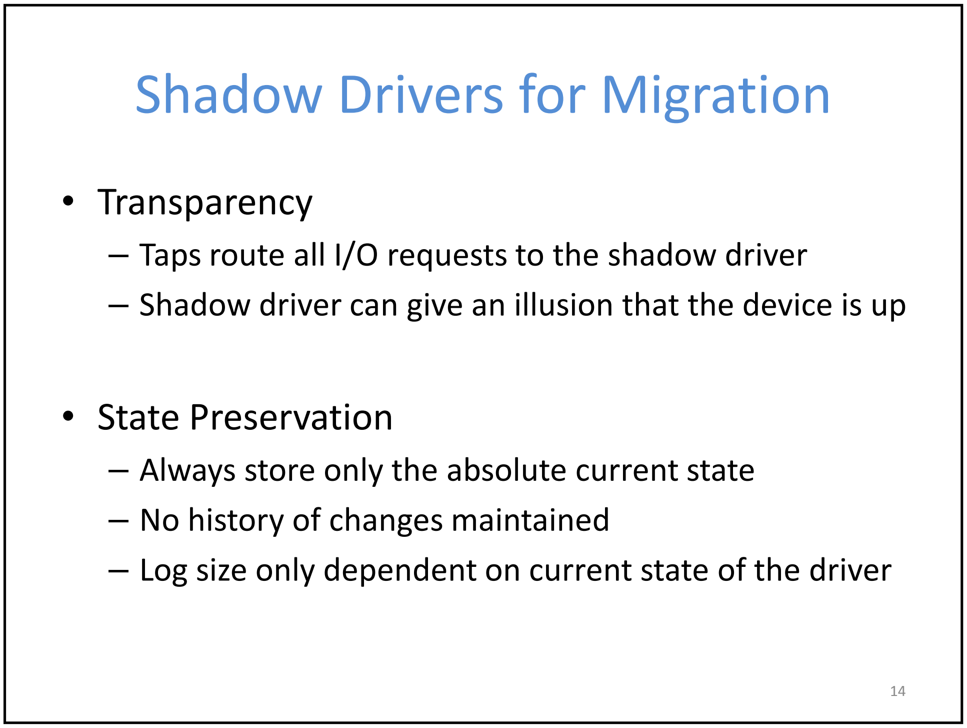
Shadow Driver Operation

- Normal Operation
  - Intercept Calls
  - Track shared objects
  - Log state changing operations
- Recovery
  - Proxy to kernel
  - Release old objects
  - Restart driver
  - Replay log



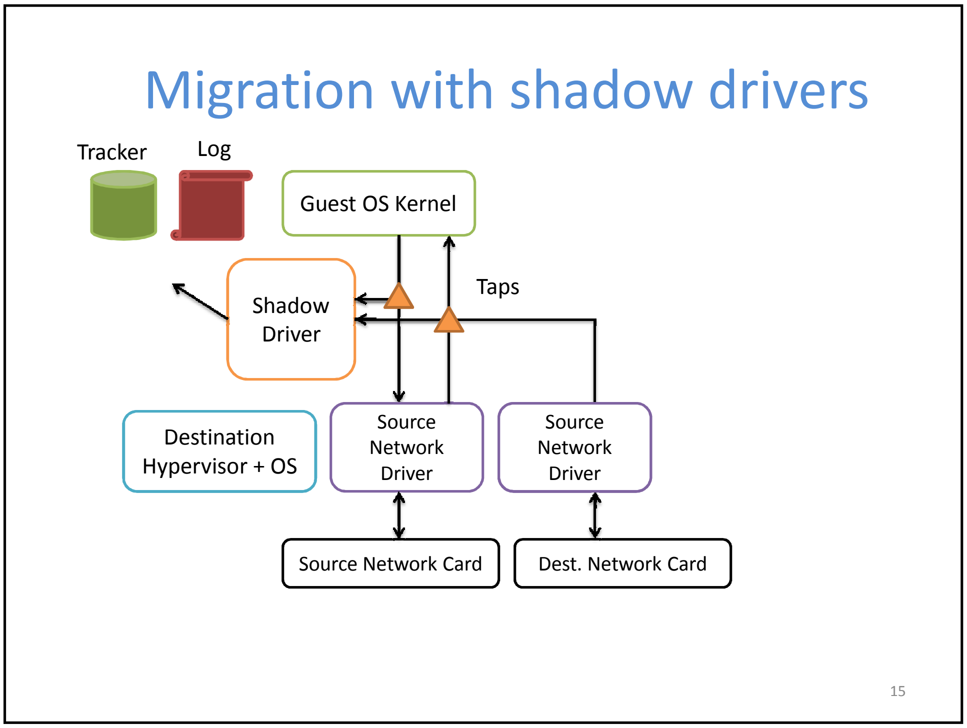
Shadow Drivers for Migration

- Pre Migration
  - Record driver/device state in driver-independent way
  - Shadow driver logs state changing operations
    - configuration requests, outstanding packets
- Post Migration
  - Unload old driver
  - Start new driver
  - Replay log to configure driver

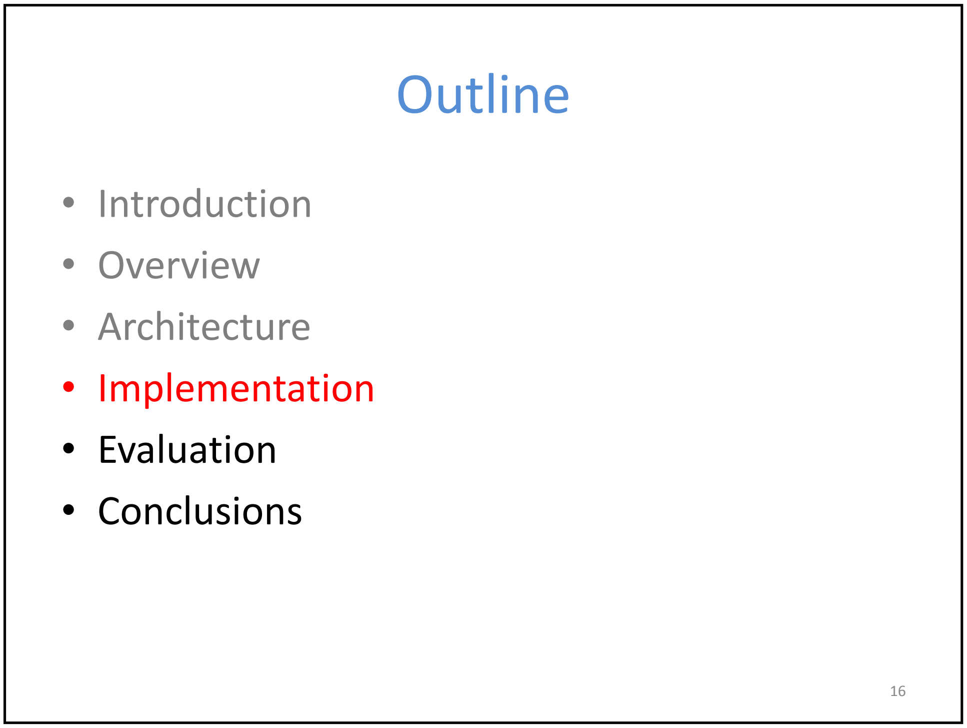


Shadow Drivers for Migration

- Transparency
  - Taps route all I/O requests to the shadow driver
  - Shadow driver can give an illusion that the device is up
- State Preservation
  - Always store only the absolute current state
  - No history of changes maintained
  - Log size only dependent on current state of the driver



Migration with shadow drivers



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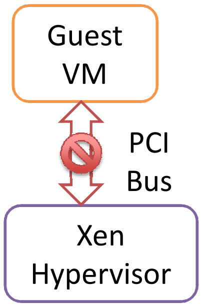
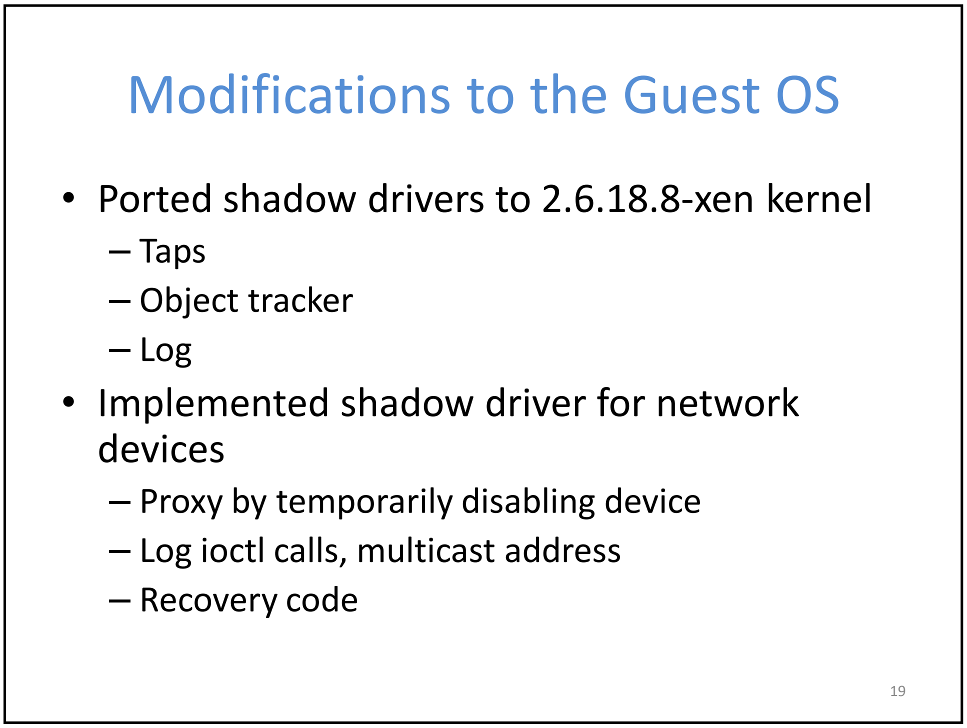
Implementation

- Prototype Implementation
  - VMM: Xen 3.2 hypervisor
  - Guest VM based on linux-2.6.18.8-xen kernel
- New code: Shadow Driver implementation inside guest OS
- Changed code: Xen hypervisor to enable migration
- Unchanged code: Device drivers

Changes to Xen Hypervisor

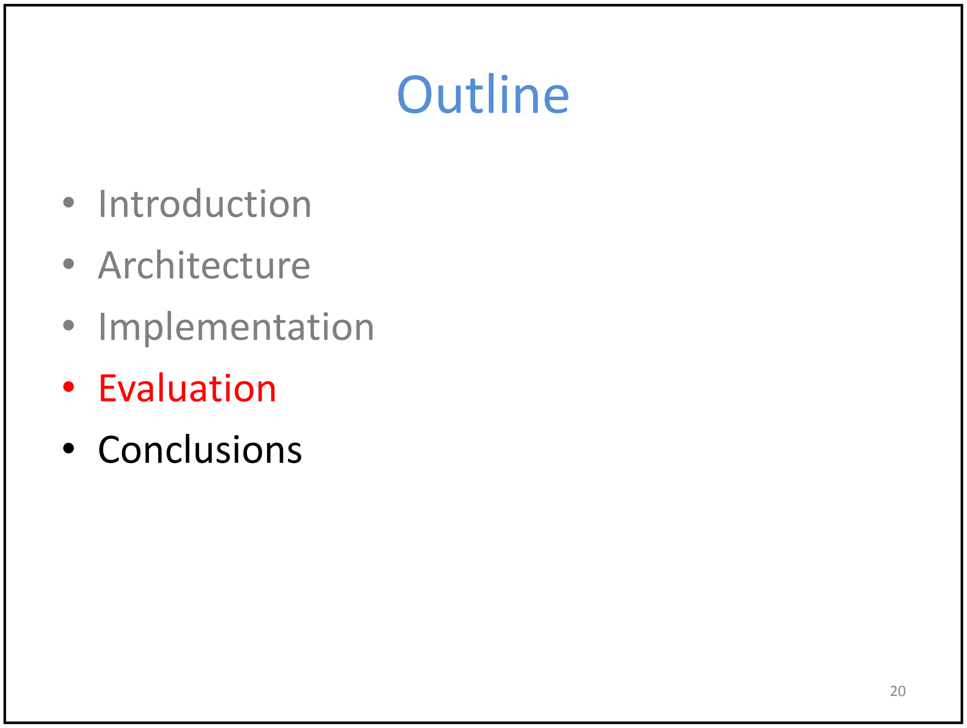
- Migration code modified to allow
  - Allow migration of PCI devices
  - Unmap I/O memory mapped at the source
  - Detach virtual PCI bus just before VM suspension at source and reconnect virtual PCI bus at the destination
  - Added ability to migrate between different devices





Modifications to the Guest OS

- Ported shadow drivers to 2.6.18.8-xen kernel
  - Taps
  - Object tracker
  - Log
- Implemented shadow driver for network devices
  - Proxy by temporarily disabling device
  - Log ioctl calls, multicast address
  - Recovery code



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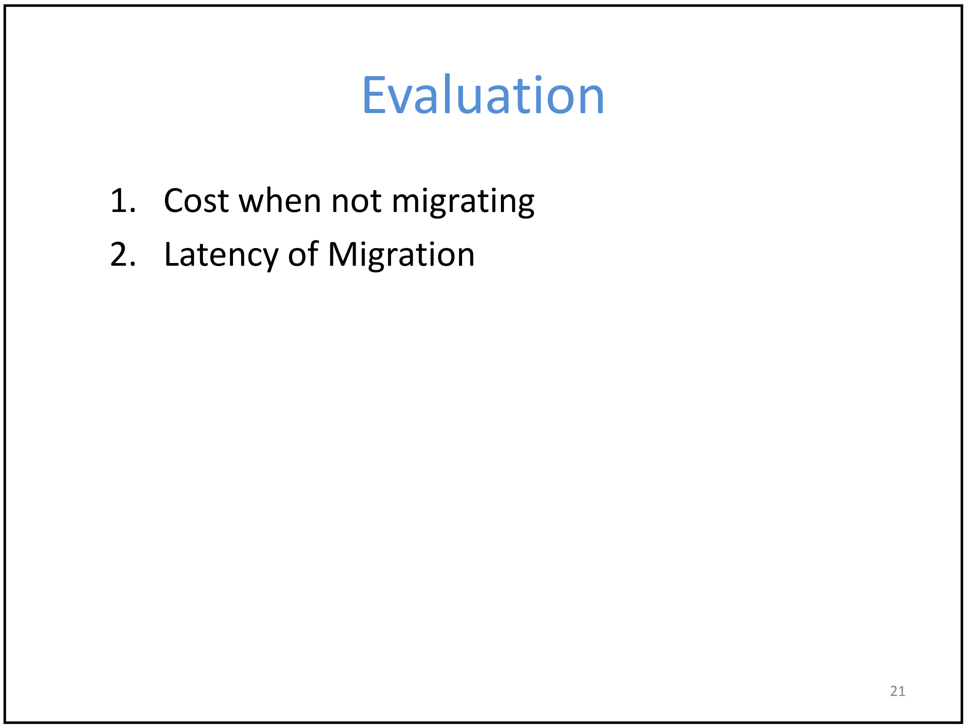
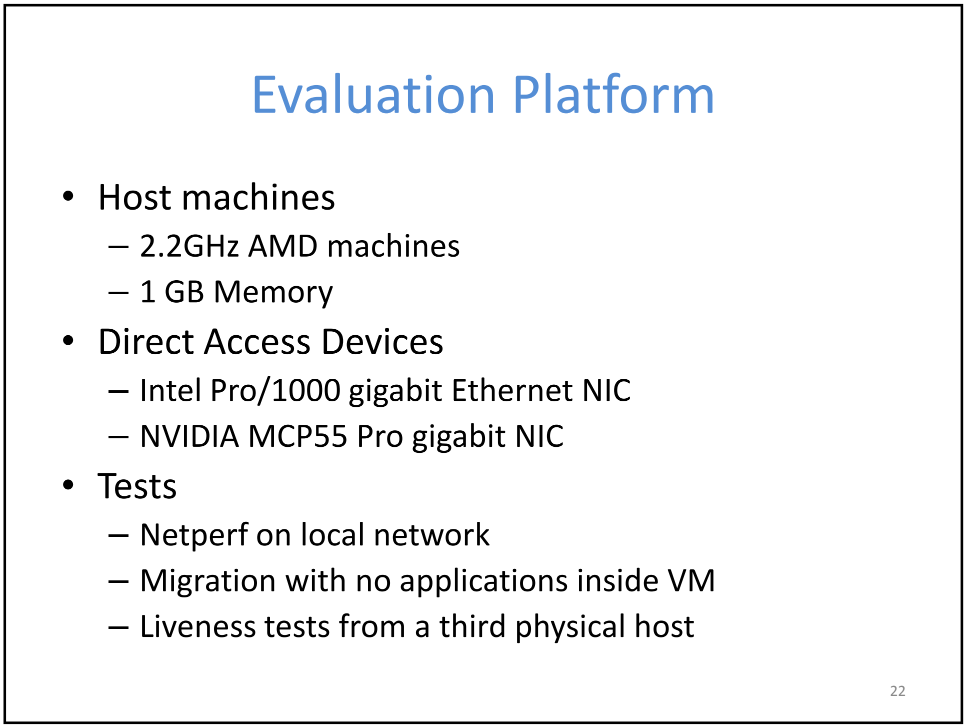


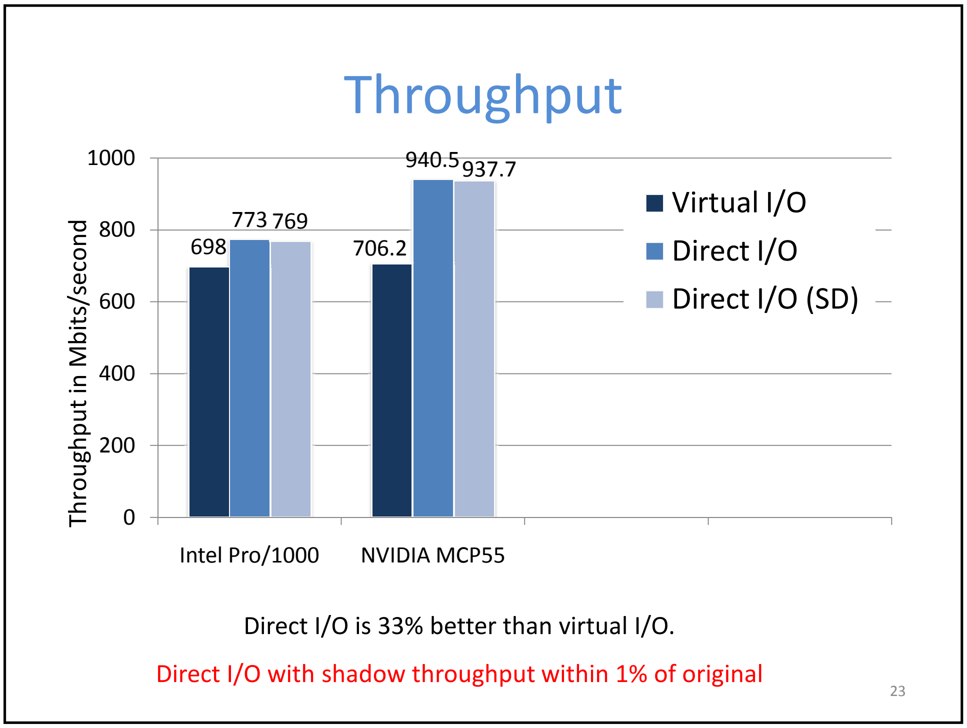
Evaluation

1. Cost when not migrating
2. Latency of Migration



Evaluation Platform

- Host machines
  - 2.2GHz AMD machines
  - 1 GB Memory
- Direct Access Devices
  - Intel Pro/1000 gigabit Ethernet NIC
  - NVIDIA MCP55 Pro gigabit NIC
- Tests
  - Netperf on local network
  - Migration with no applications inside VM
  - Liveness tests from a third physical host



Throughput

Direct I/O is 33% better than virtual I/O.

Direct I/O with shadow throughput within 1% of original

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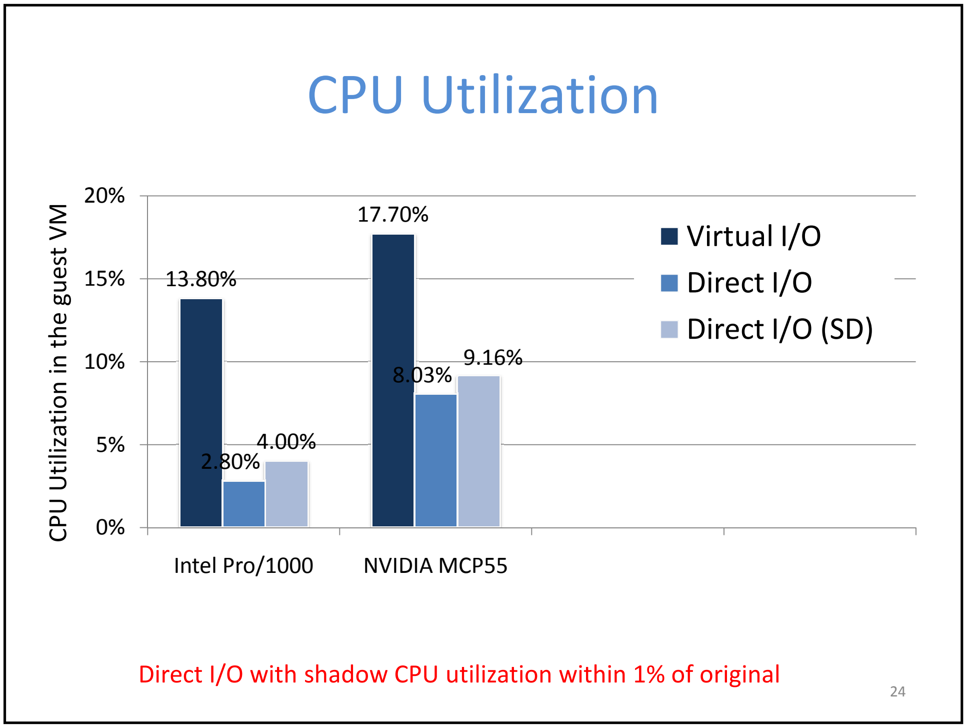
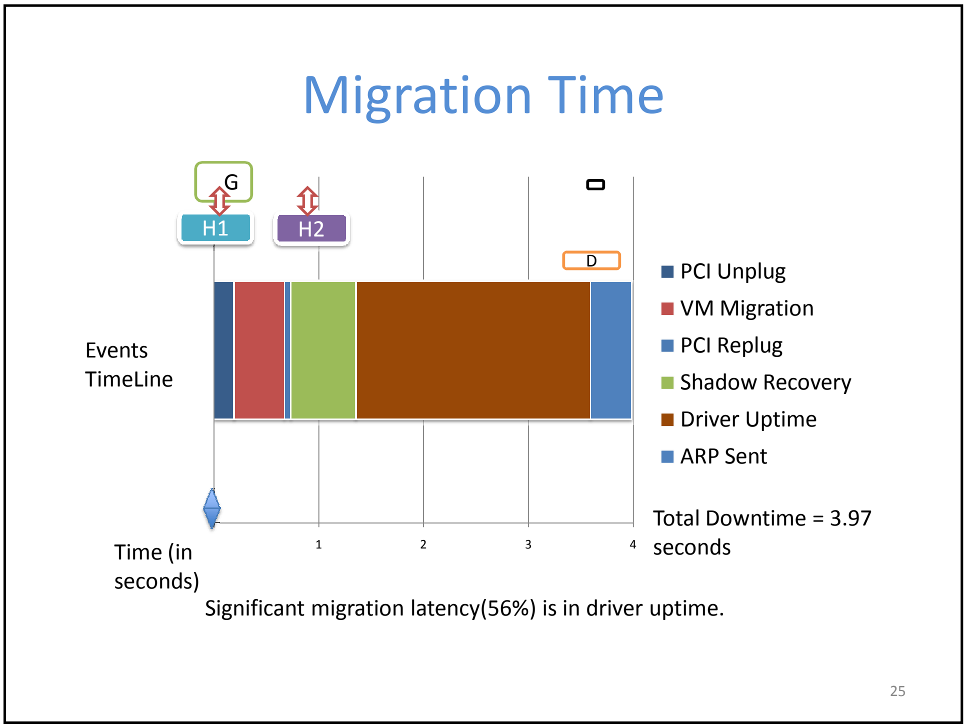


CPU Utilization

Direct I/O with shadow CPU utilization within 1% of original

24

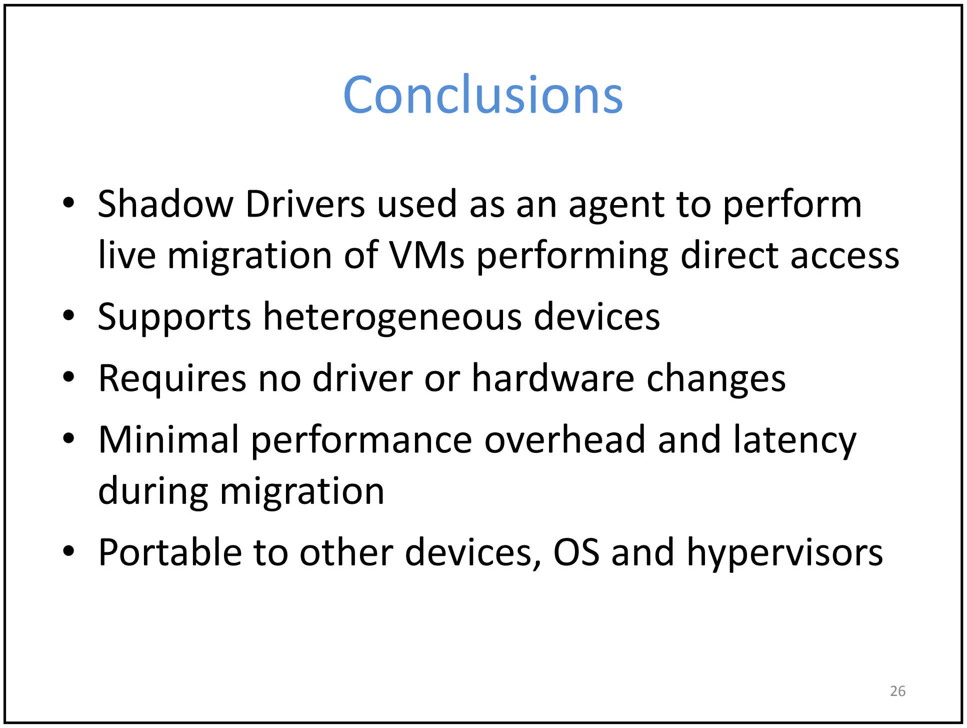


Migration Time

- 🟦 PCI Unplug
- 🟥 VM Migration
- 🟦 PCI Replug
- 🟩 Shadow Recovery
- 🟫 Driver Uptime
- 🟦 ARP Sent

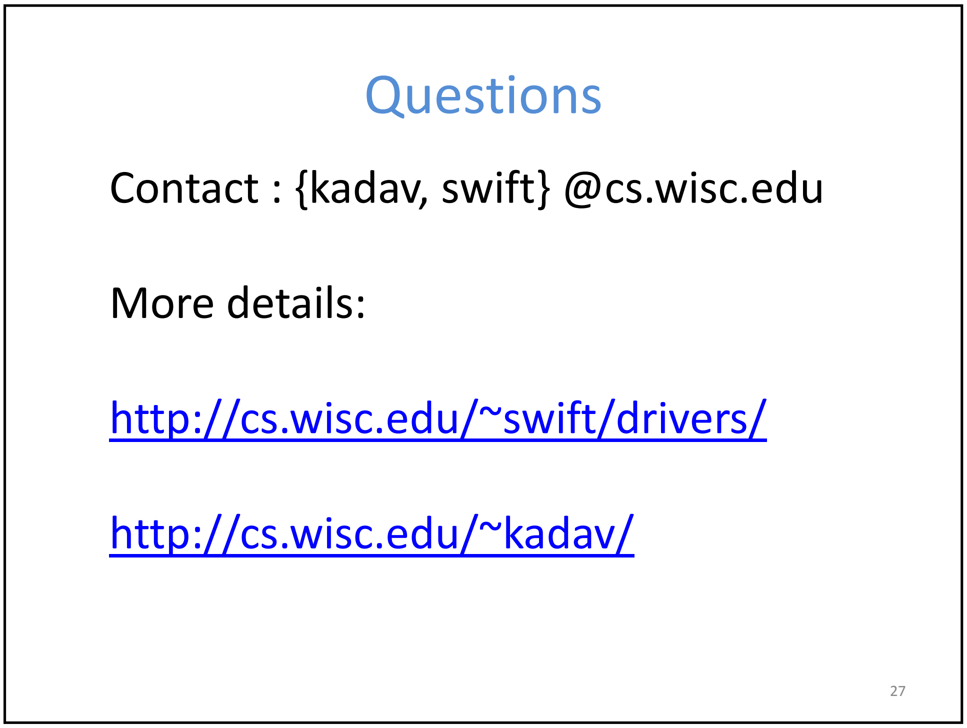
Total Downtime = 3.97 seconds

Significant migration latency(56%) is in driver uptime.



Conclusions

- Shadow Drivers used as an agent to perform live migration of VMs performing direct access
- Supports heterogeneous devices
- Requires no driver or hardware changes
- Minimal performance overhead and latency during migration
- Portable to other devices, OS and hypervisors



Questions

Contact : {kadav, swift} @cs.wisc.edu

More details:

http://cs.wisc.edu/~swift/drivers/

http://cs.wisc.edu/~kadav/

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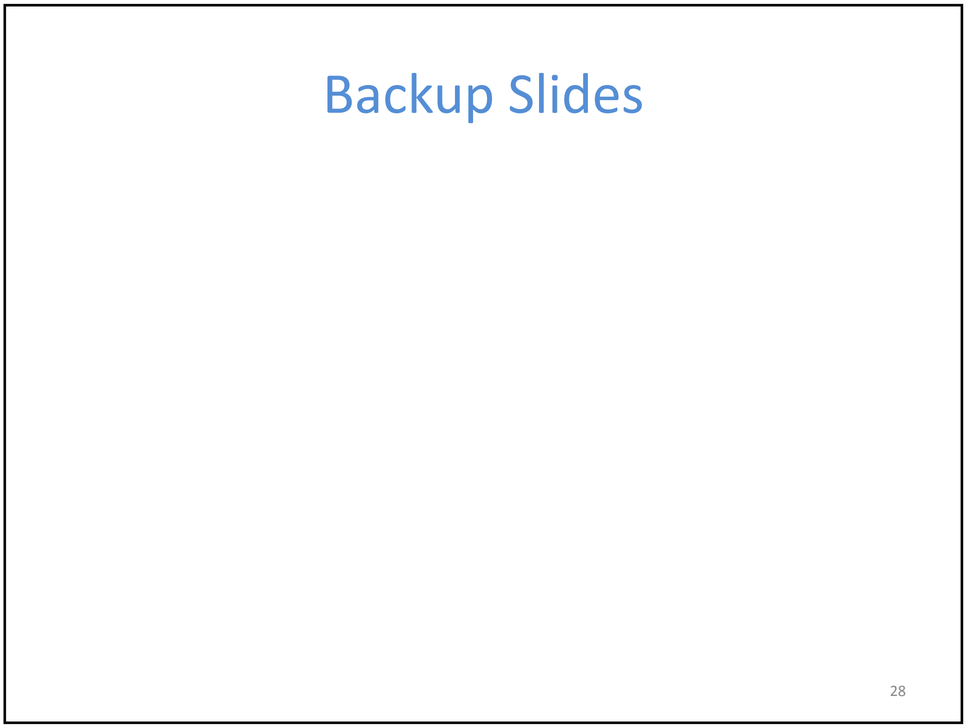

Backup Slides

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Complexity of Implementation

- ~19000 LOCs
- Bulk of this (~70%) are wrappers around functions.
  - Can be automatically generated by scripts

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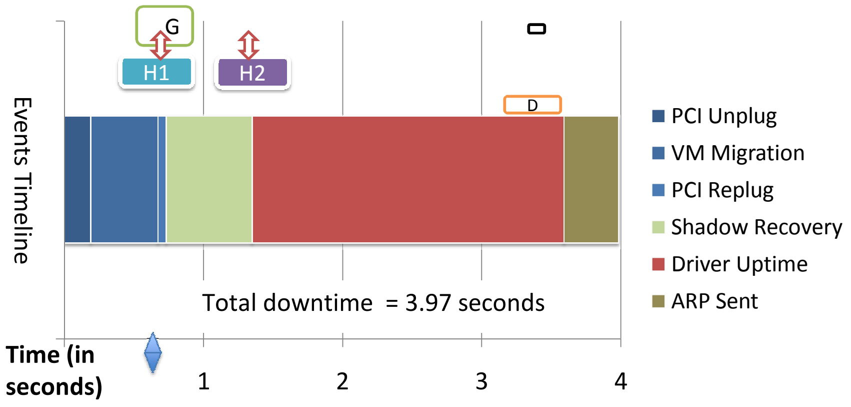
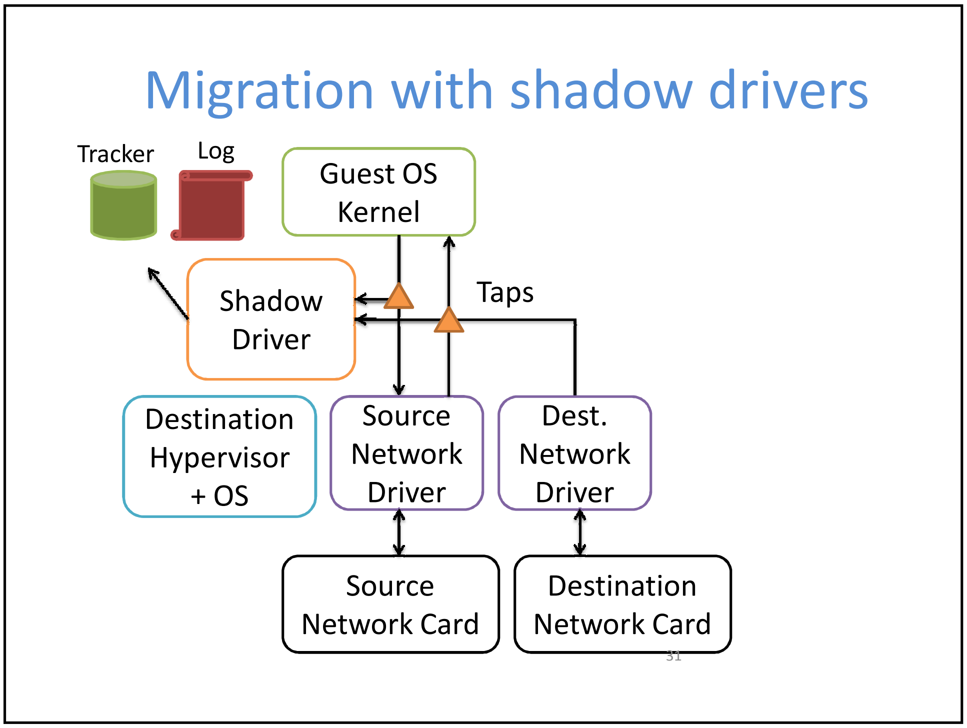
Migration Time



Significant migration latency(56%) is in driver uptime.

30



Migration with shadow drivers

Tracker

Log

Guest OS Kernel

Shadow Driver

Taps

Destination Hypervisor + OS

Source Network Driver

Dest. Network Driver

Source Network Card

Destination Network Card