Legacy Reuse and Improved System Dependability via Virtual Machines

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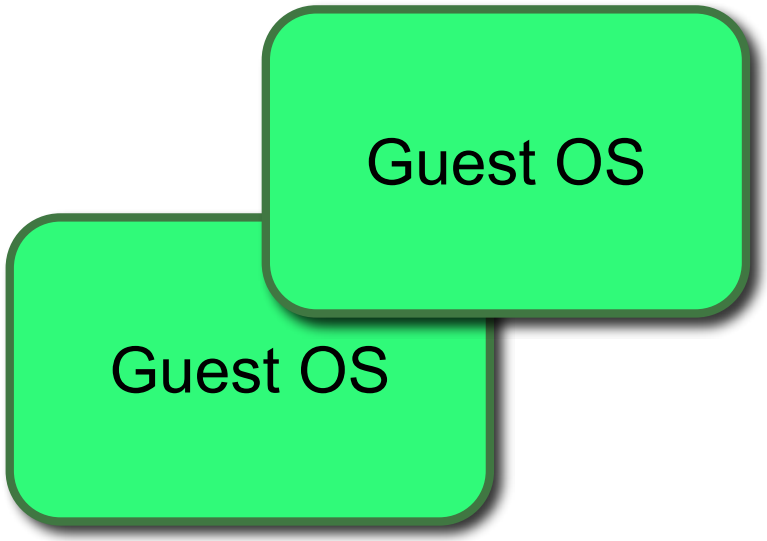
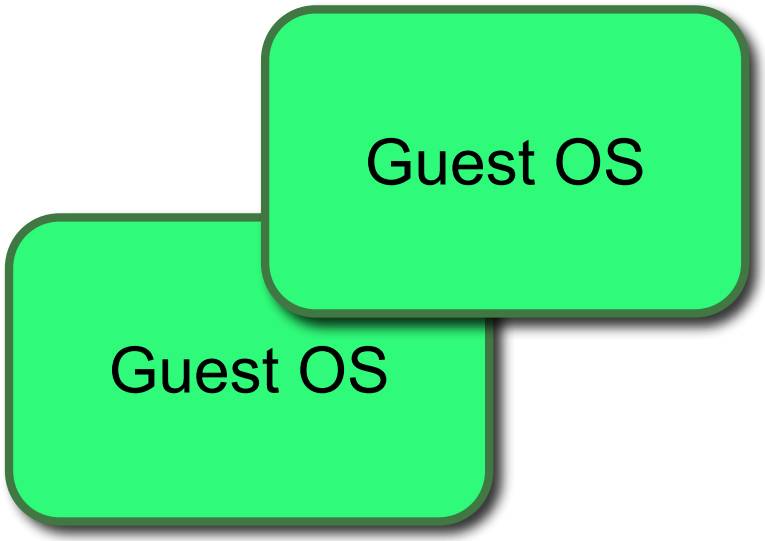
Virtual Machine (VM)

- A software duplicate of the hardware
  - Indistinguishable from real hardware
    - Except for timing
- Statistically, most instructions execute directly on real CPU
  - Faster than full emulation

Basic VM Structure



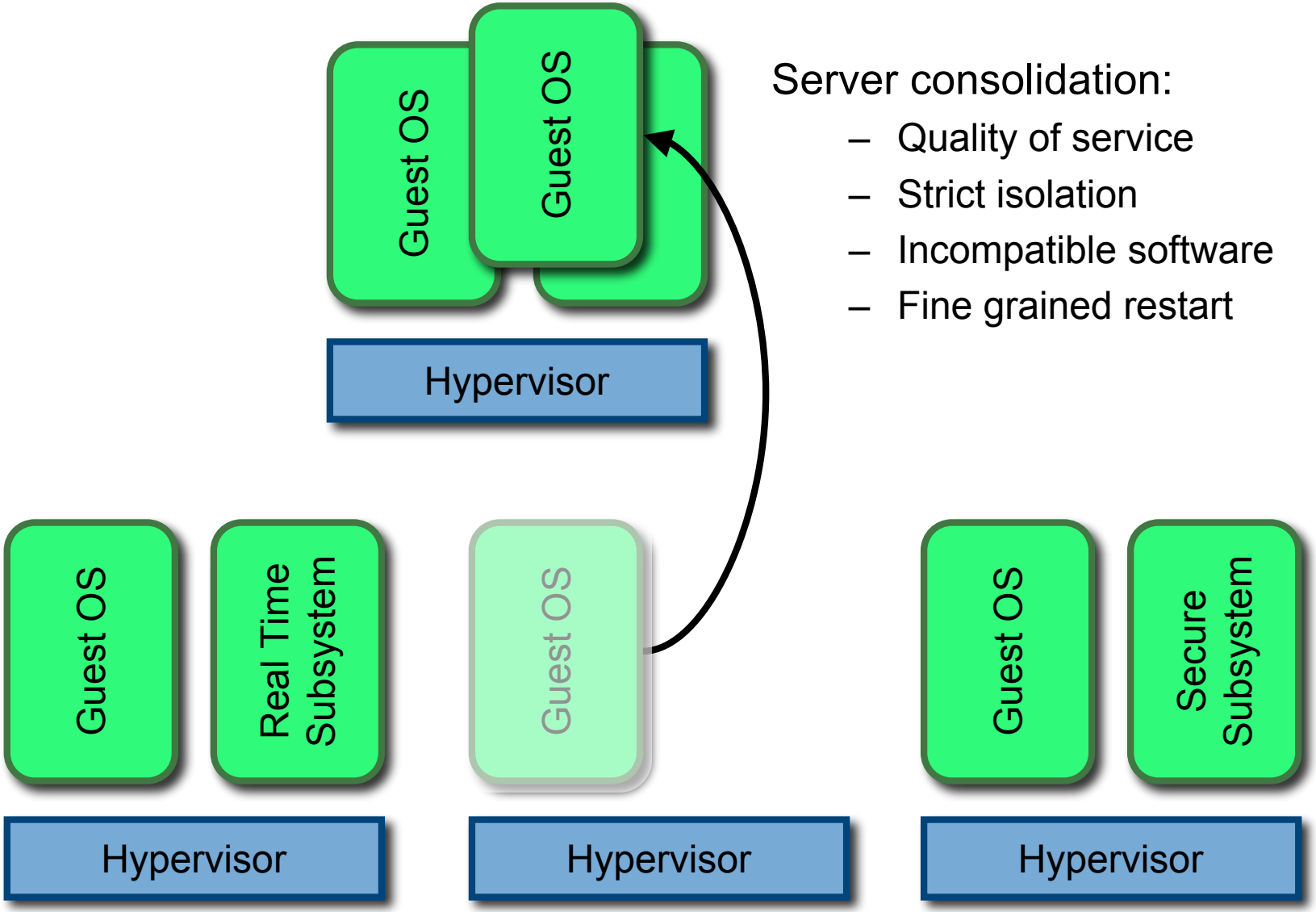


Hypervisor + Virtual Machine Monitor

User-level VMM

L4 Microkernel

Uses of VMs



Server consolidation:

- Quality of service
- Strict isolation
- Incompatible software
- Fine grained restart

Legacy Reuse

- VMs enhance legacy code
- Modular encapsulation
  - Guest OS is nearly a black box
  - Well defined interface (but sometimes buggy)
  - Communication with the black box via platform interfaces (network, disk, …)
- Traditionally, enhancement is via loadable kernel modules

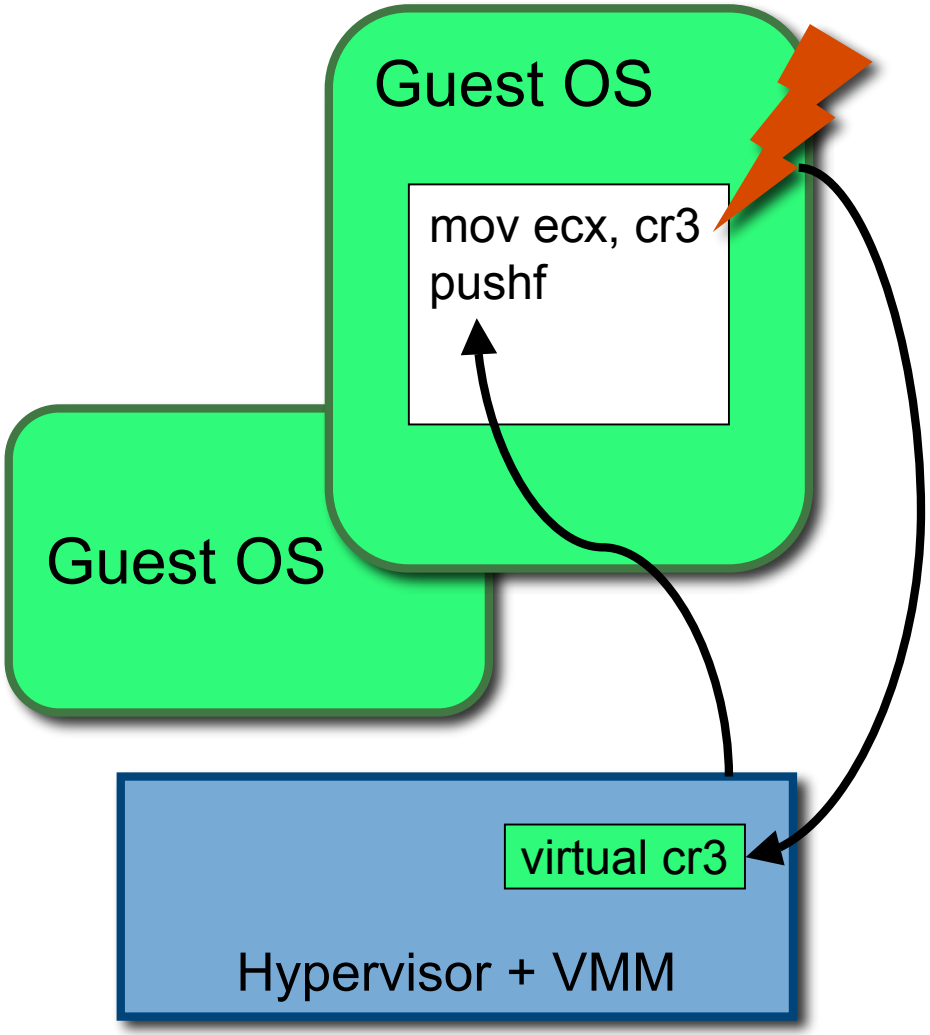
Current OS design is flawed.

The VM is a hack to fix the problems.

Virtualization Definitions

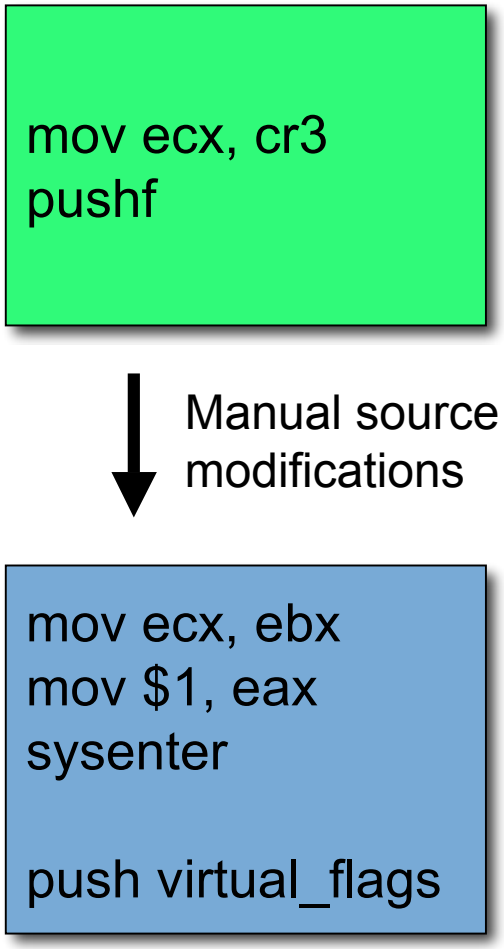
- Sensitive instruction:
  - Destroys the illusion of virtualization
- Innocuous instruction:
  - Safe to execute within a VM
- Privileged instruction:
  - No side effects when executed at user level; raises a fault
- Virtualizable ISA: all sensitive instructions are privileged

Pure Virtualization



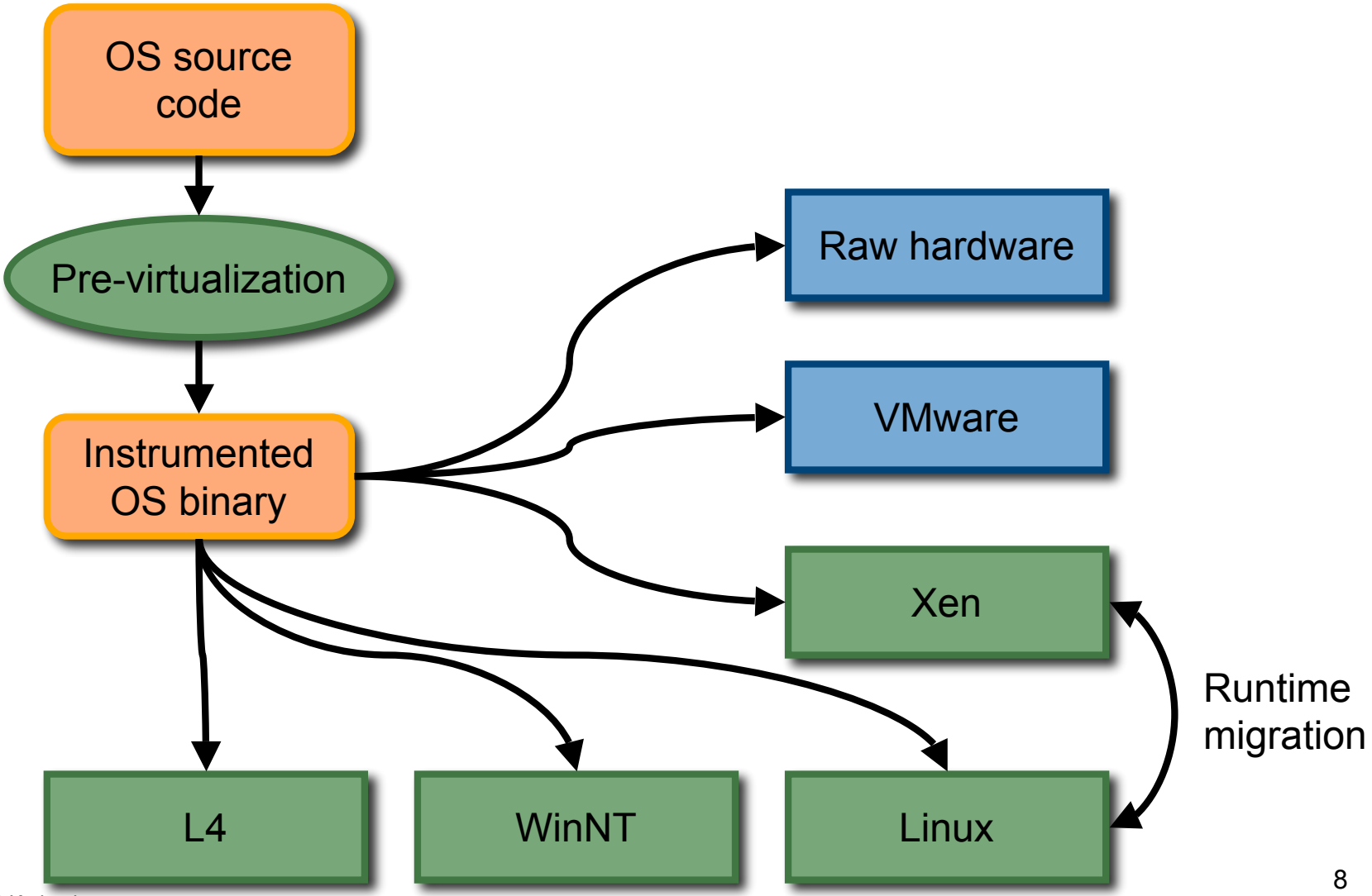
- Problems:
  - Trapping is costly (cycles, pipe flush)
  - x86 isn't fully virtualizable
- VMware's solution:
  - Dynamic code rewriting
  - Difficult

Para-virtualization

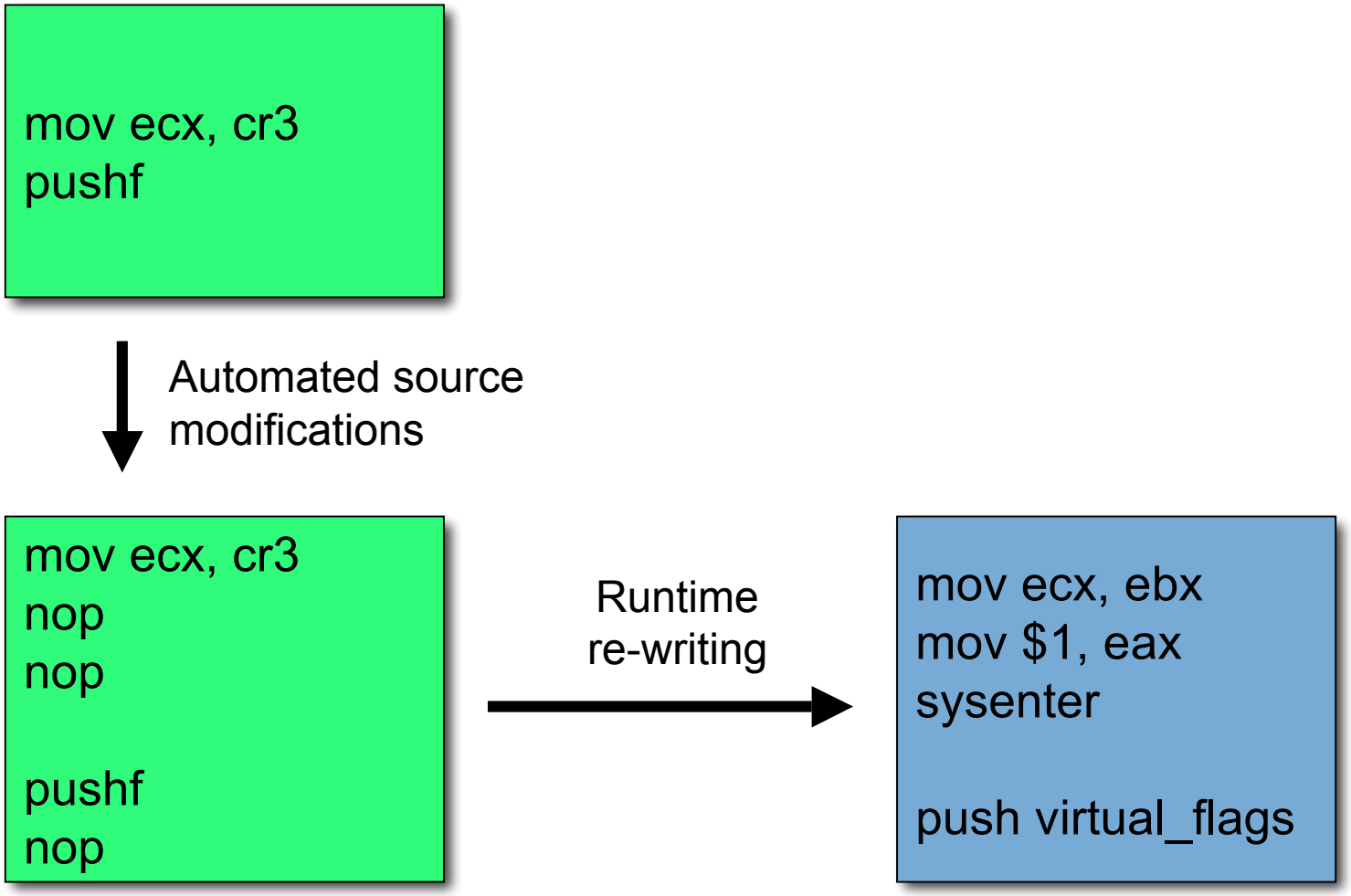


- L4Linux, Denali, Xen
- Replace sensitive instructions with hypercalls
  - Avoids costs of trapping
  - Batch state changes into single hypercall
  - Use apps unmodified
- Problems:
  - Engineering effort
  - Reduces trustworthiness of guest OS
  - Ties guest OS directly to a single hypervisor

Pre-virtualization



Pre-virtualization Basics

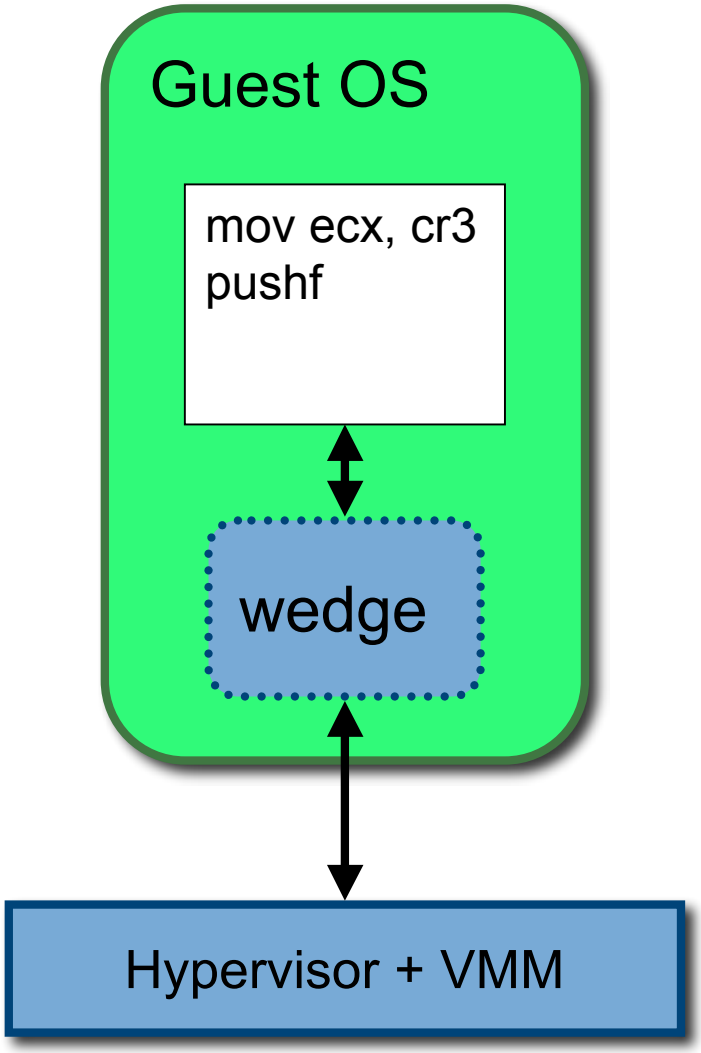


Sensitive Memory and Pre-virtualization

- Virtualization-sensitive state in memory:
  - page tables, tss, idt, gdt, etc.
  - memory mapped devices

- Use a profile-feedback loop to detect
  - Instrument and annotate the instructions that access sensitive memory
  - Or compiler data-flow analysis?

In-Place Virtualization



- The wedge creates a virtual CPU
- Invokes hypercalls only when necessary
- Frequent operations, such as cli/sti, emulated in the wedge

Driver Reuse

Support New OS Endeavors

- Unmodified device driver reuse:
  - Binary or recompiled source
  - Combine drivers from different OS's
- Reuse without legacy constraints
- Isolate drivers
  - Protect new OS from drivers
- Ex: 64+ CPU scalability

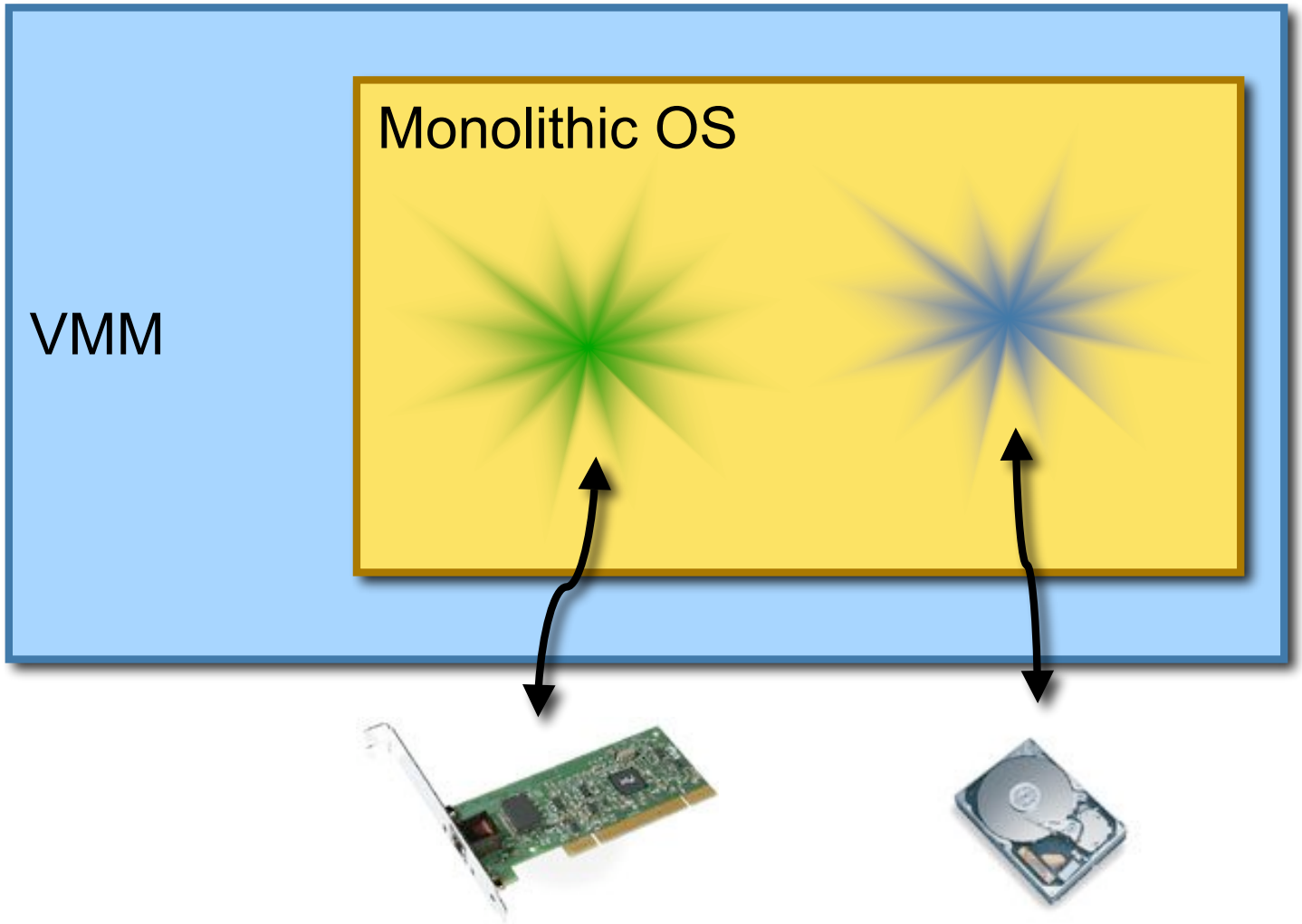
Overview

1. Motivation
2. Our solution
3. Virtualization issues
4. Evaluation

Motivation

- Building a new OS
  - It needs device drivers
- Drivers are major component of OS
  - Linux 2.4.21: 70% of code for ia32
- Implement new drivers
  - Linux, BSD: device documentation
  - Windows: many 3rd party drivers, no code
  - Exotic or out-of-production hardware

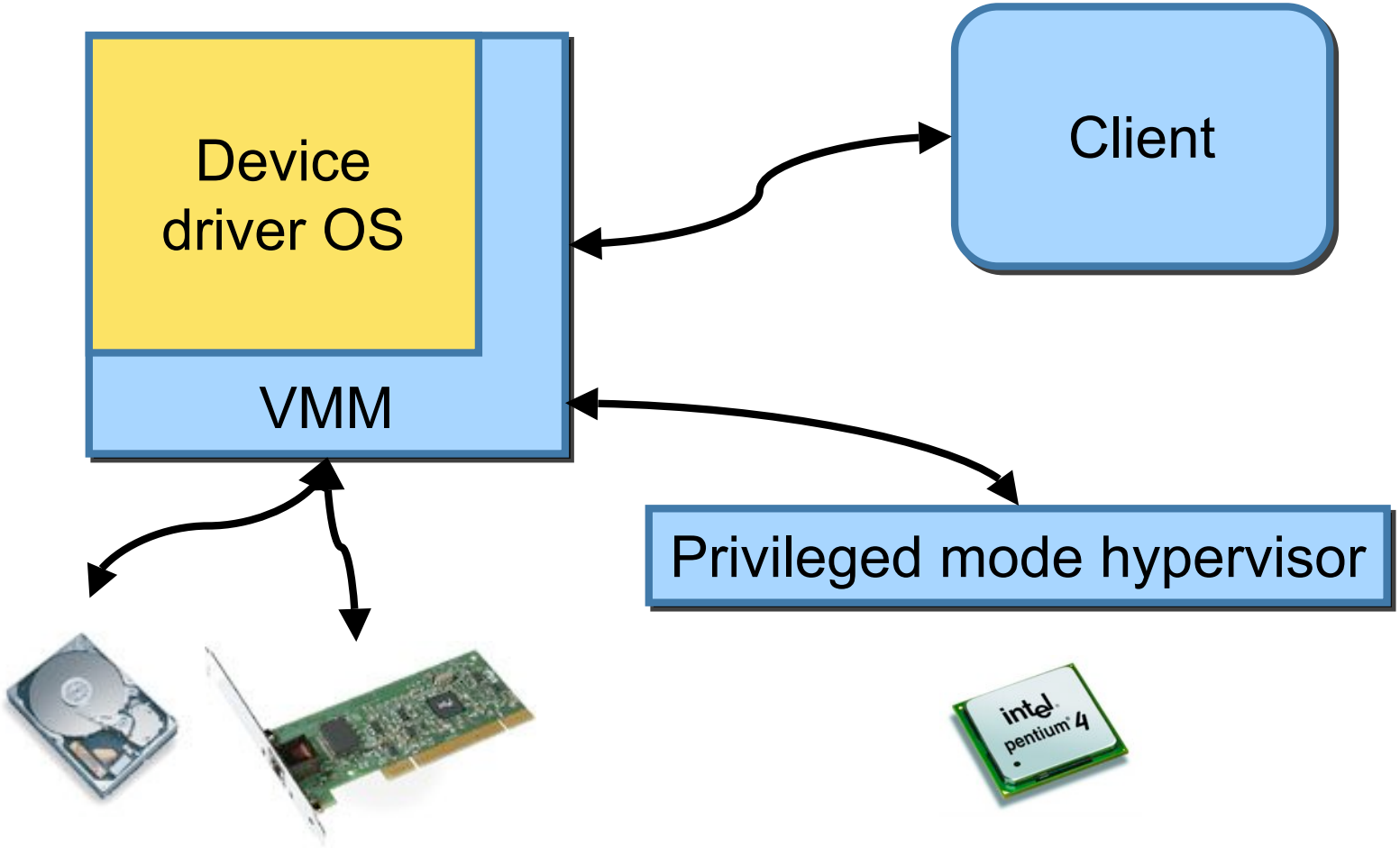
Driver State Machine



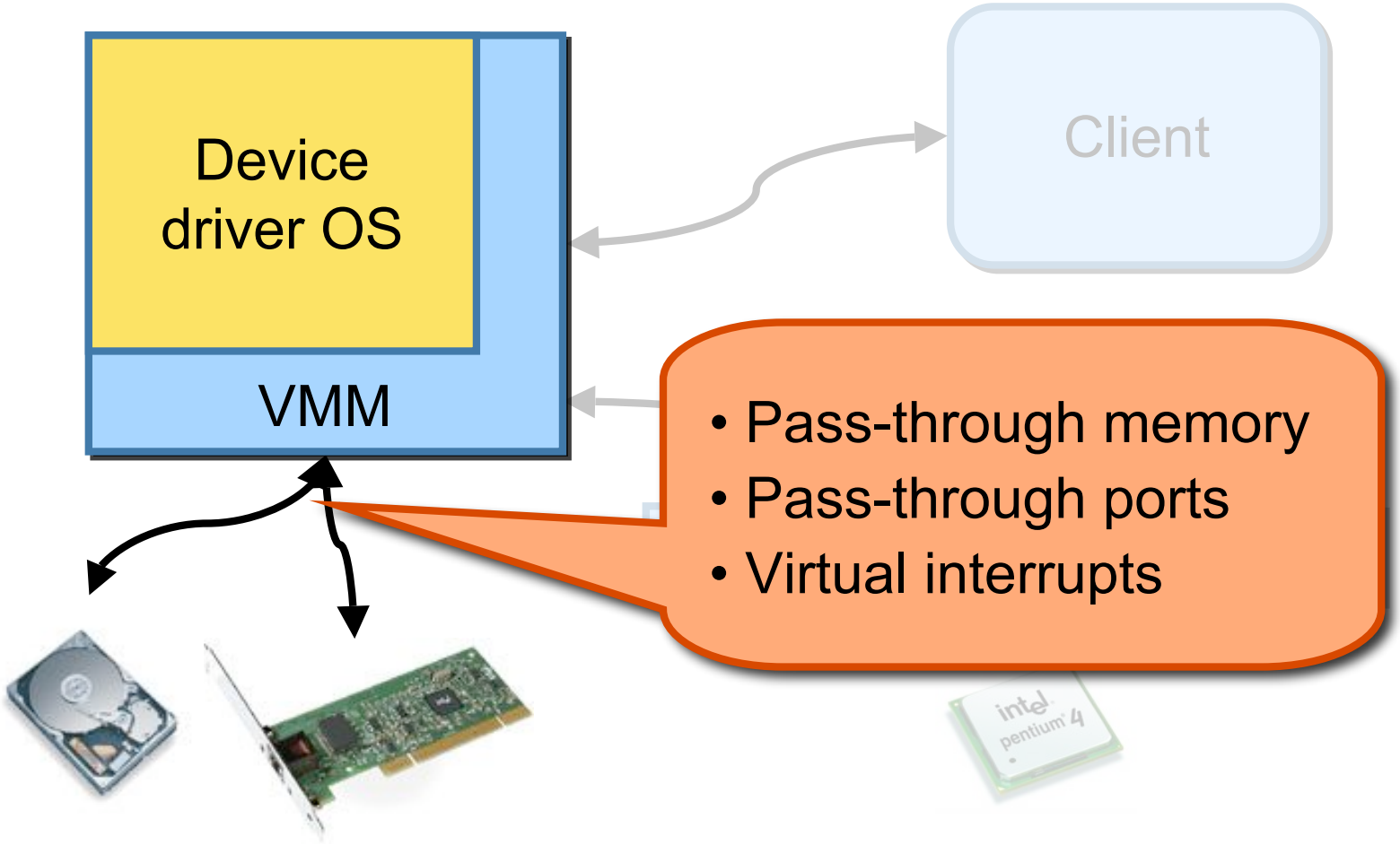
Interface Categories

- Providing resources to drivers
  - Pure virtualization API (e.g. VMware)
  - Para-virtualization API (e.g. Xen)
- Passing requests to drivers
  - Translation modules

Resource Interfacing



Resource Interfacing



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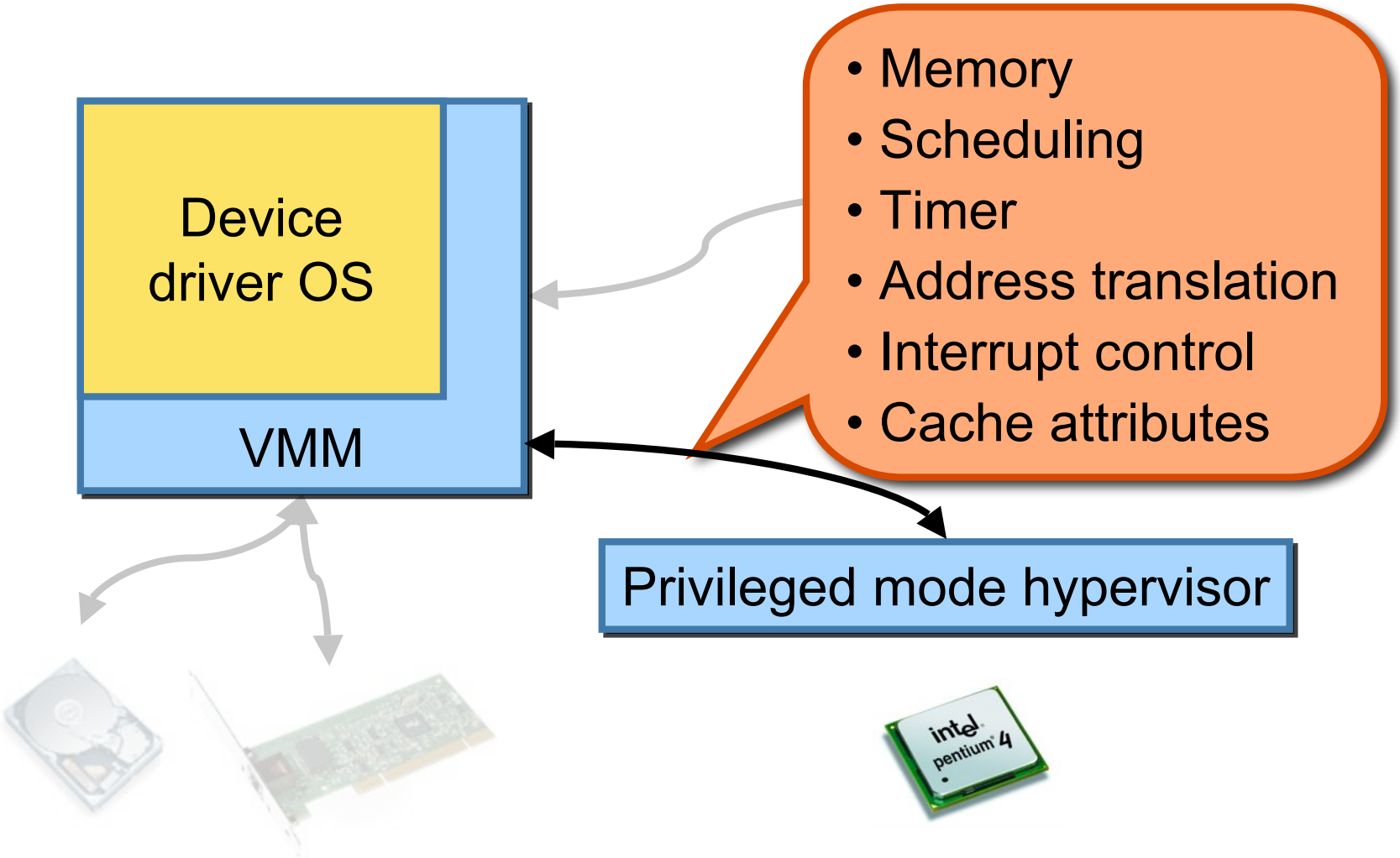
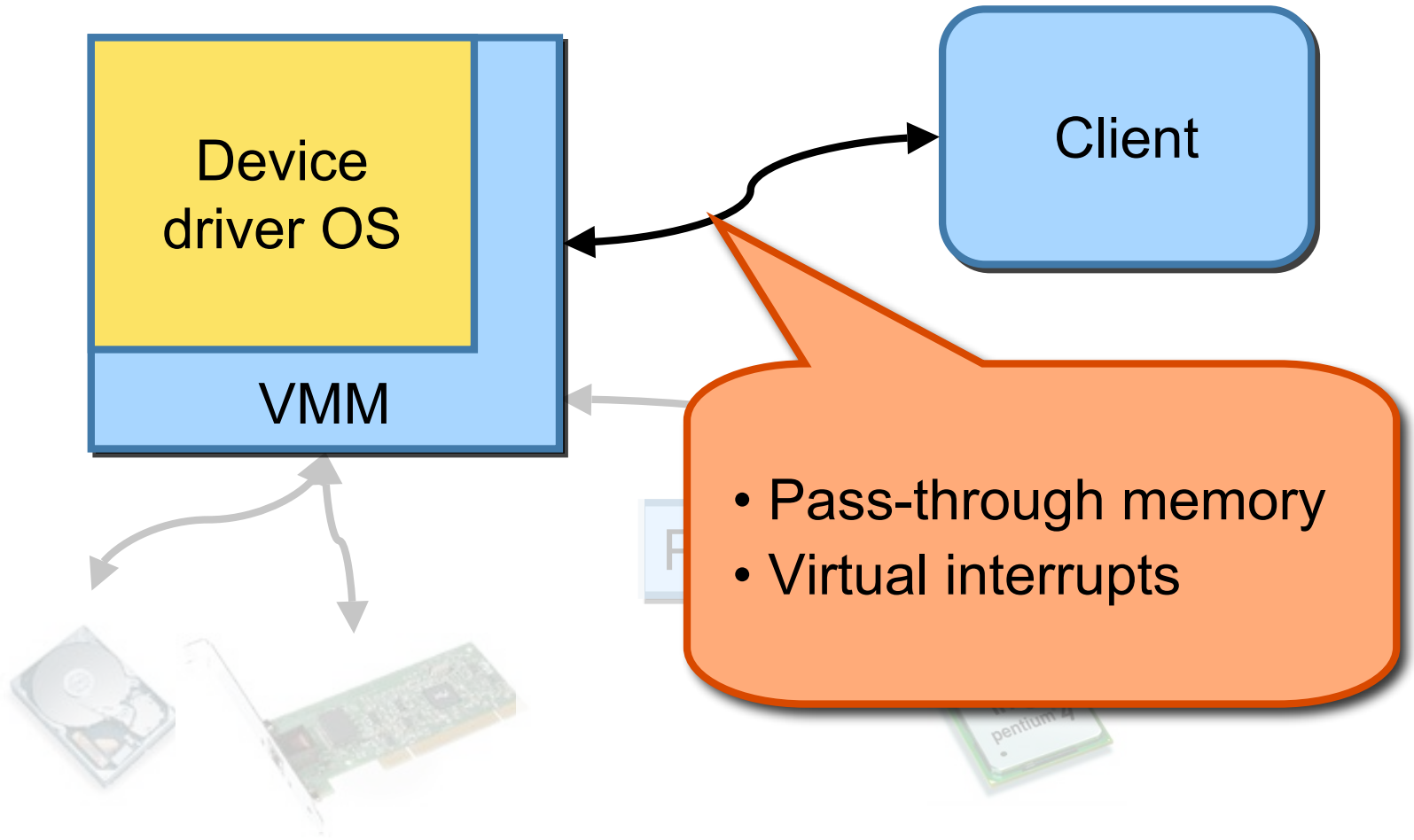
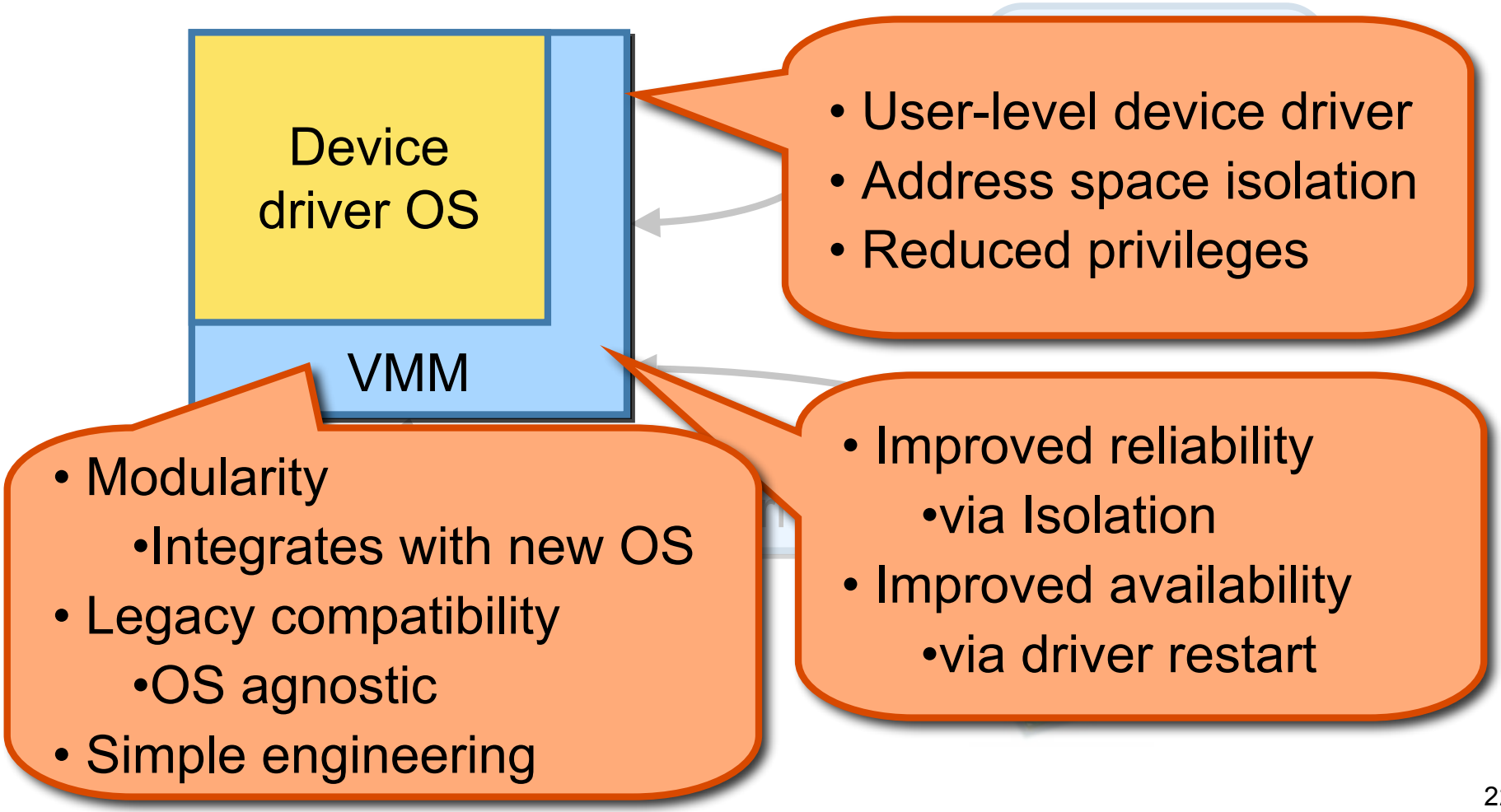


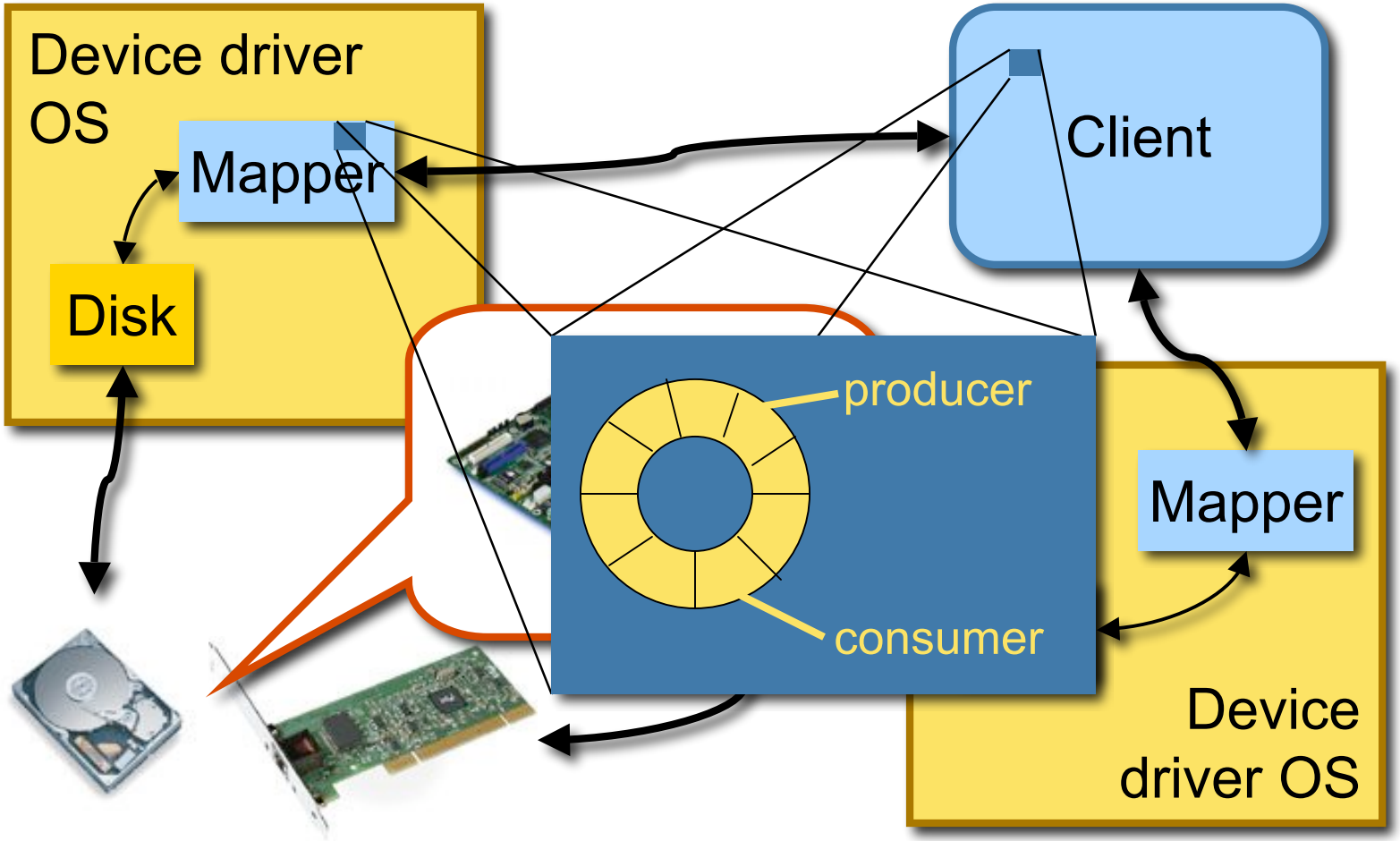
Resource Interfacing



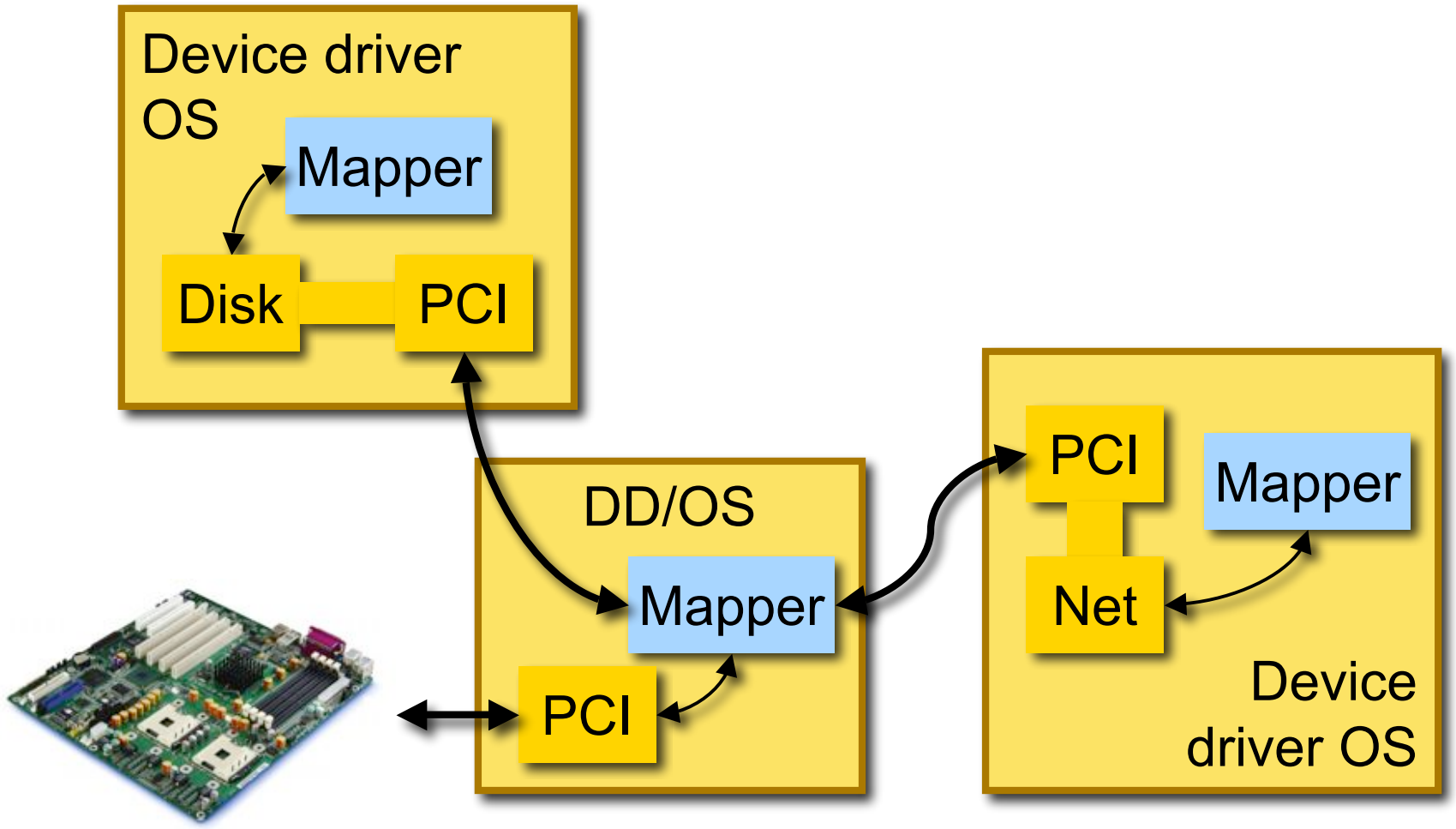
Resource Interfacing



Driver Interfacing



Recursive Driver Interfacing



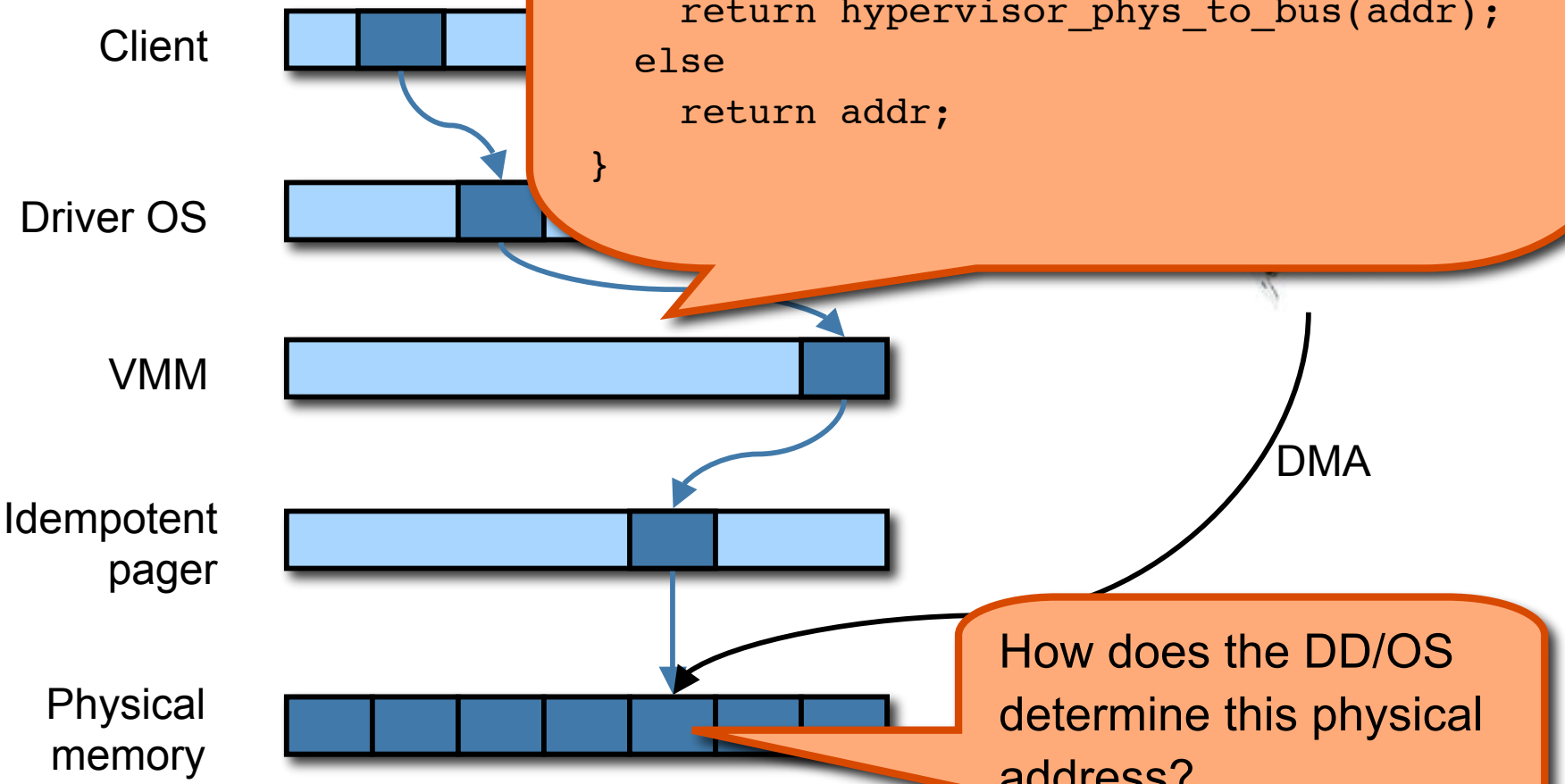
Virtualization Issues

1. DMA address translation
2. DMA and trust
3. Resource consumption
4. Timing
5. Shared hardware & recursion

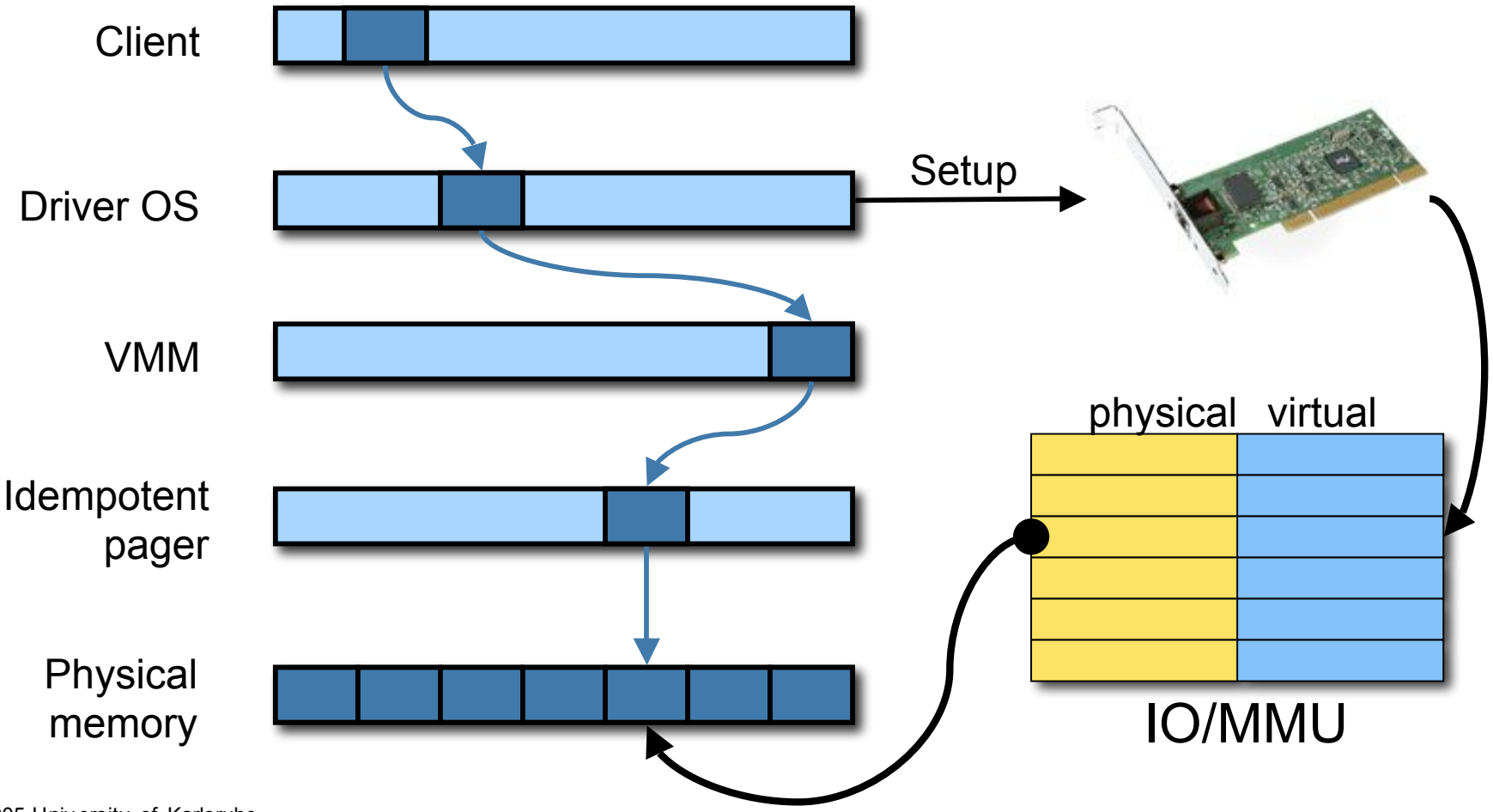
DMA A

Simple with *para-virtualization*: queries VMM for translation.

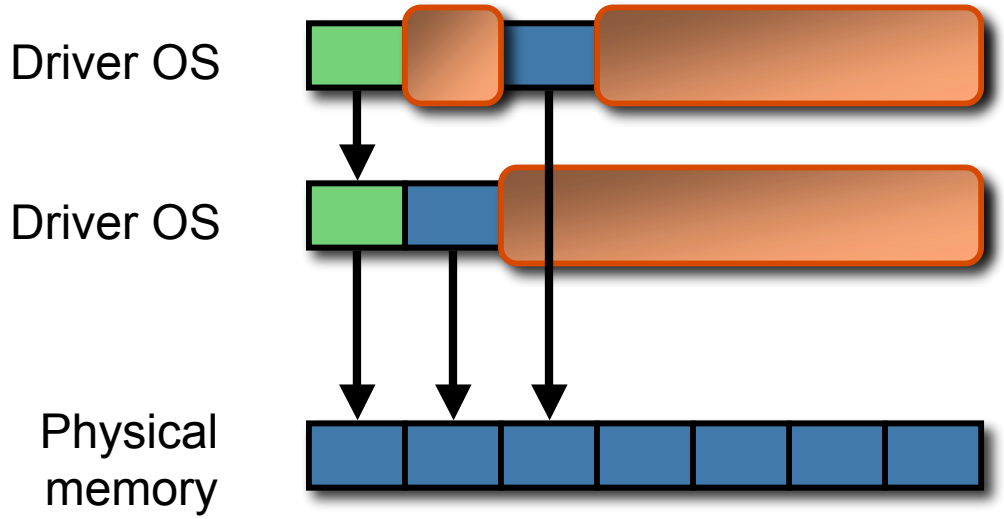
```
phys_to_bus(addr) {
  if( paravirtualization )
    return hypervisor_phys_to_bus(addr);
  else
    return addr;
}
```



IO/MMU Address Translation



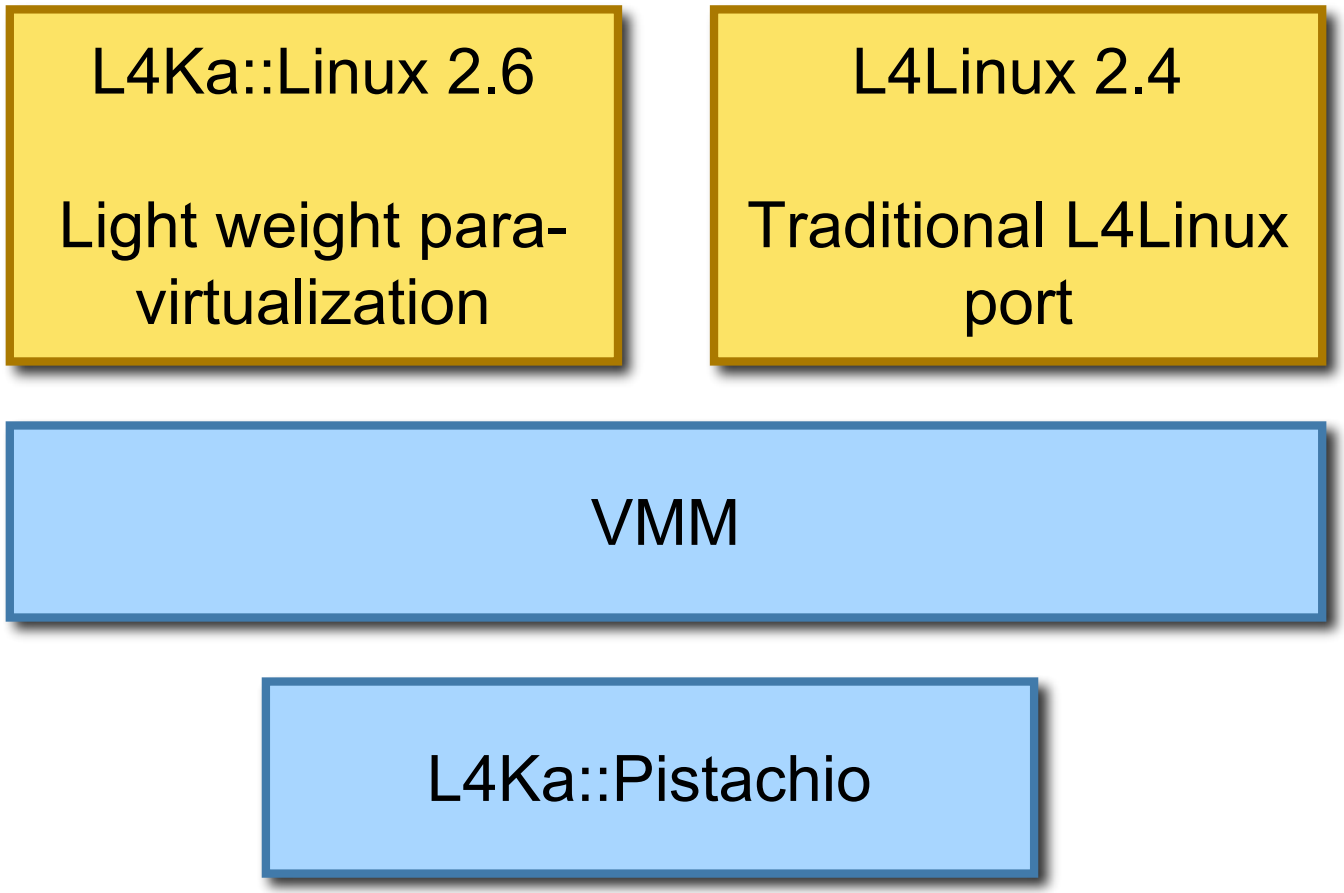
Careful DMA Address Translation



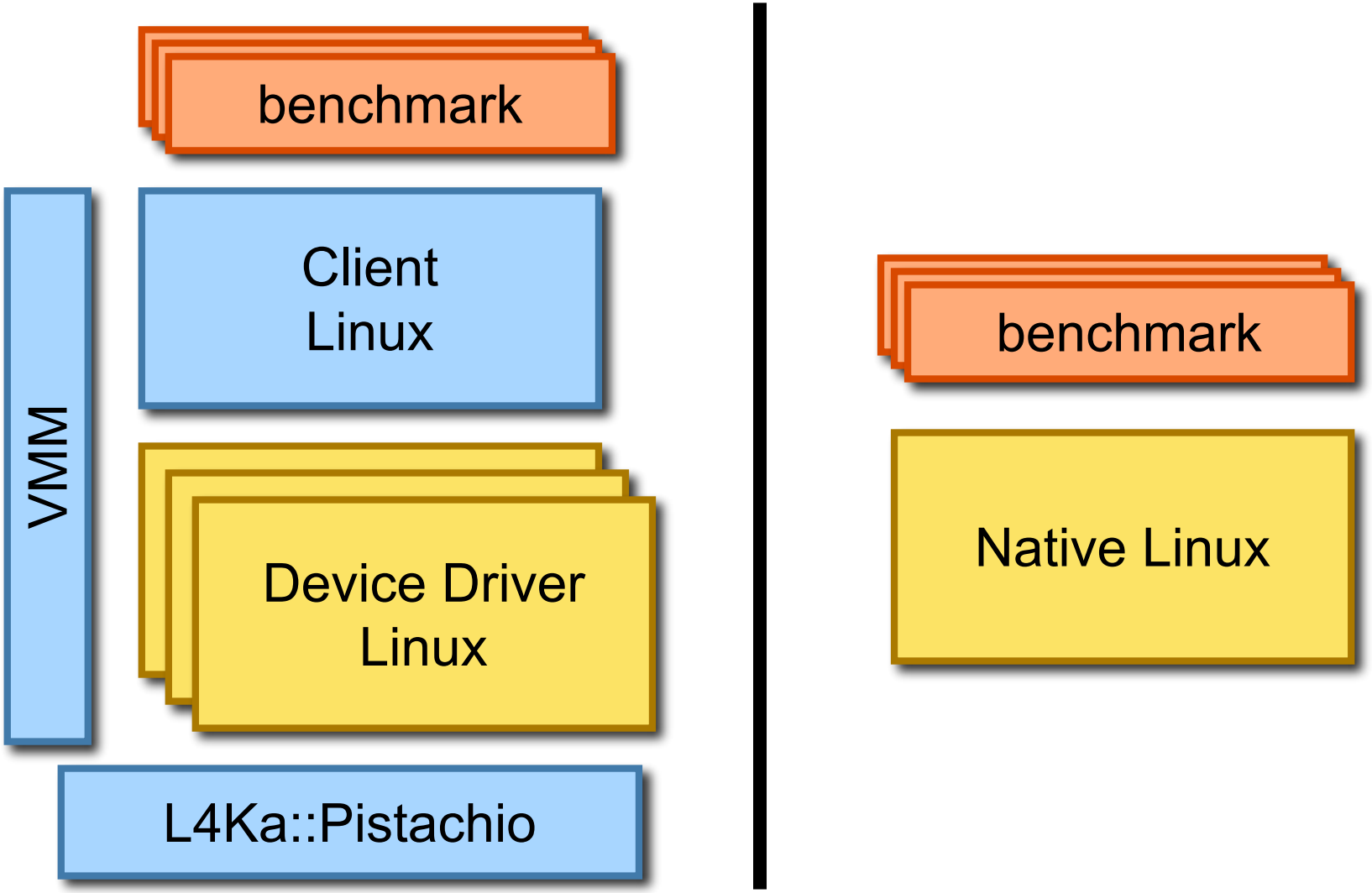
Timing

- DD/OS's have virtualized time
- Devices unaware of virtual time
- Preemption could violate driver timing
- Heuristic: "obey" disabled interrupts
  - Delay DD/OS preemption
  - Hard preemption to avoid denial of service

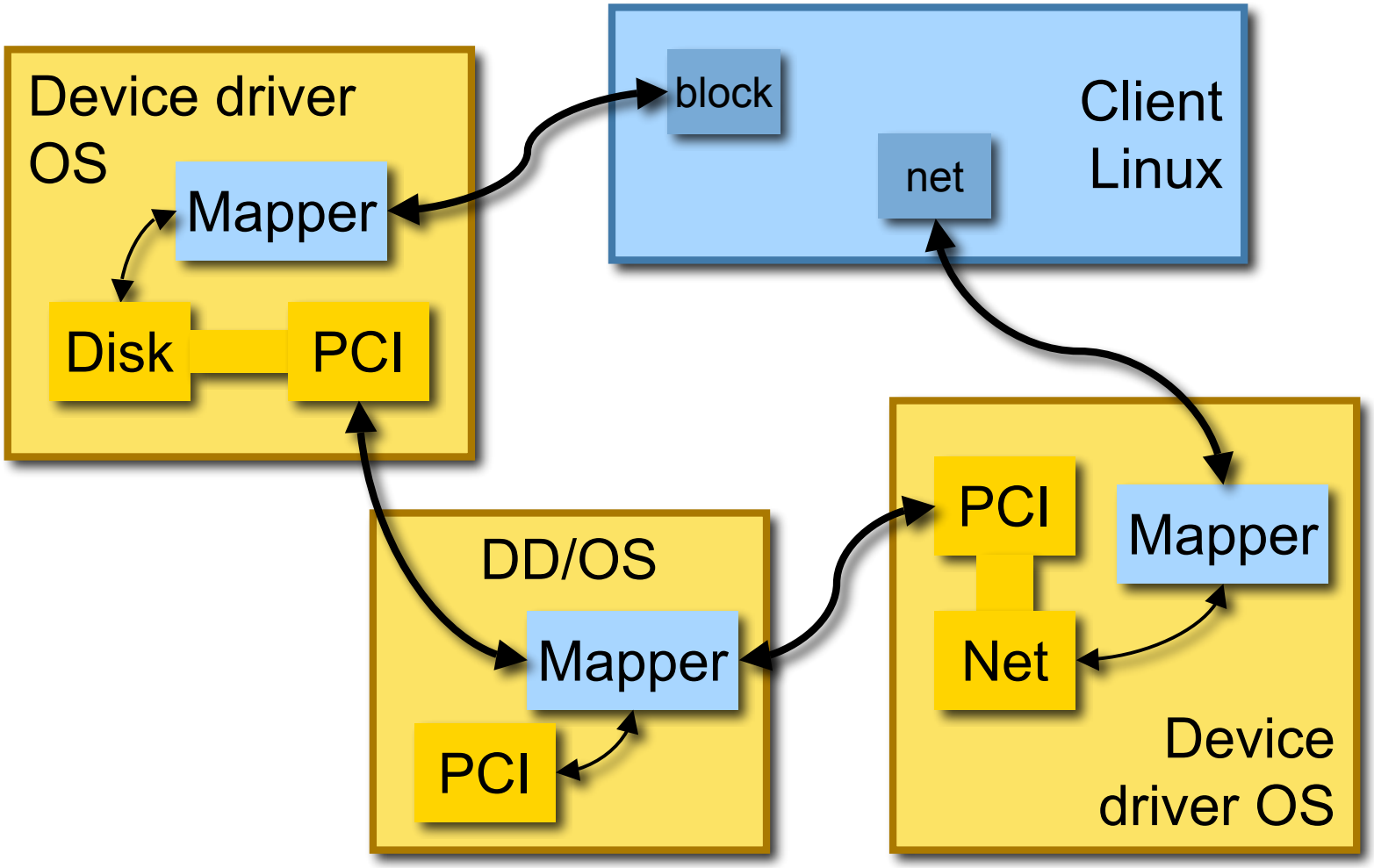
Evaluation (w/ Para-virtualization)



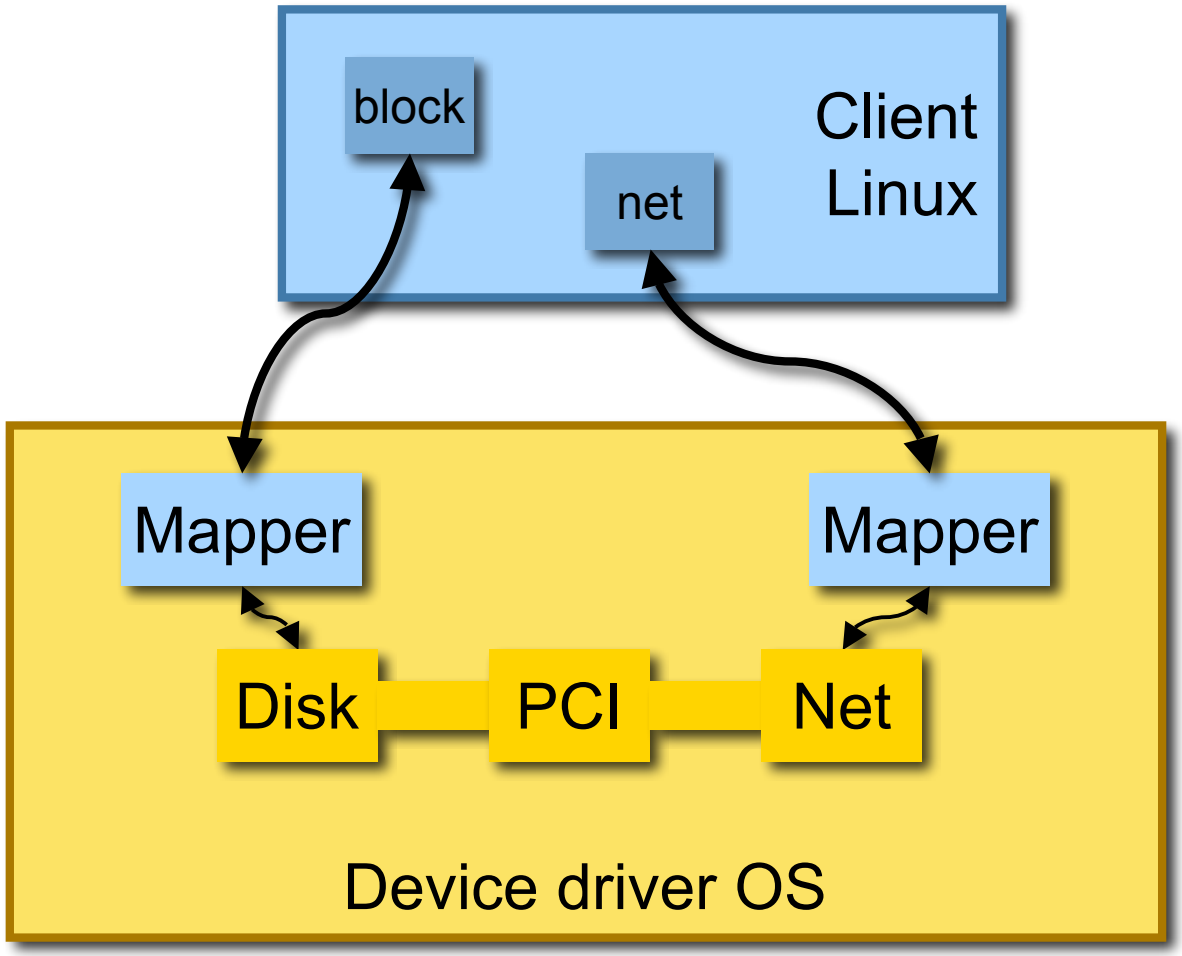
Comparative Benchmarking



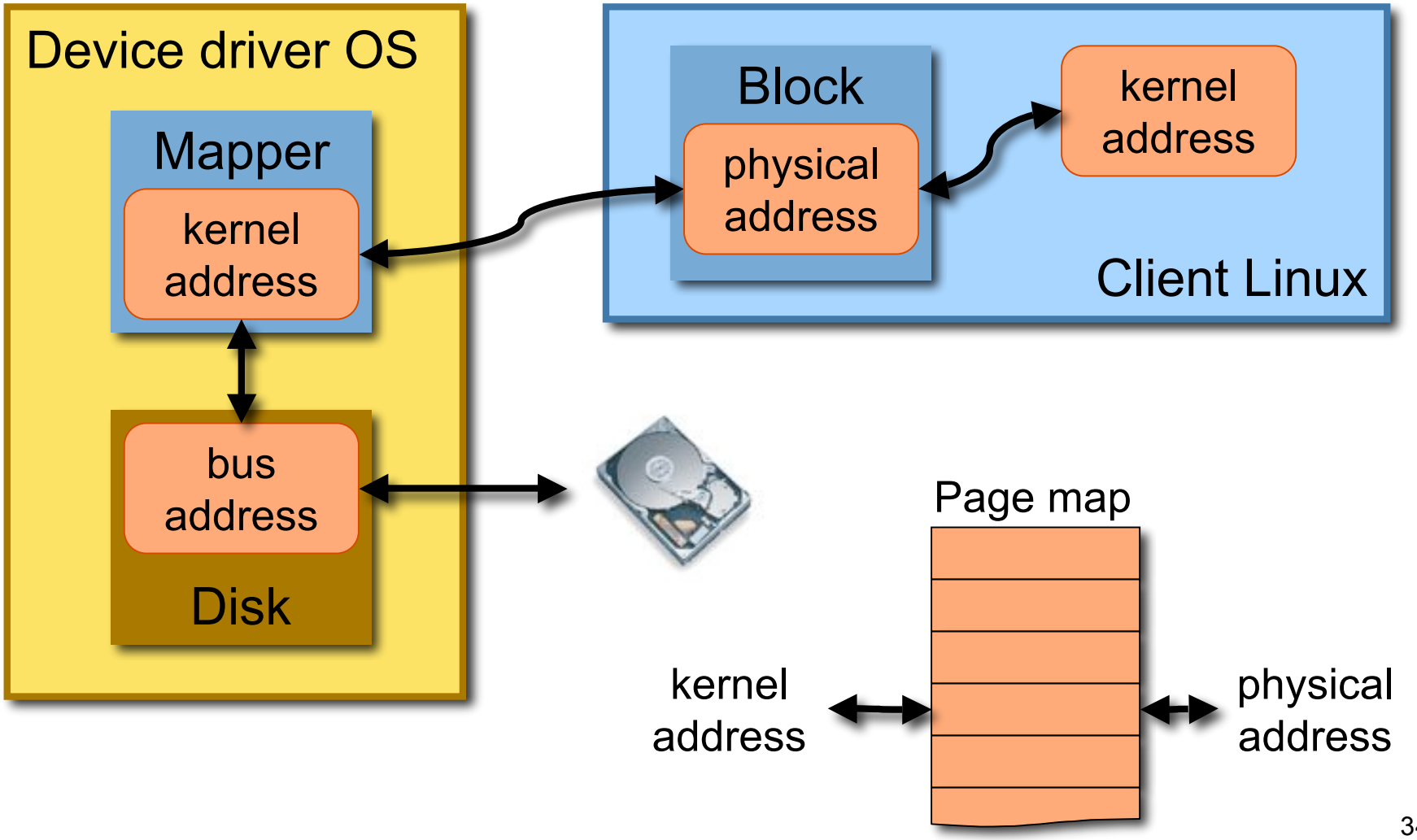
Isolated Architecture



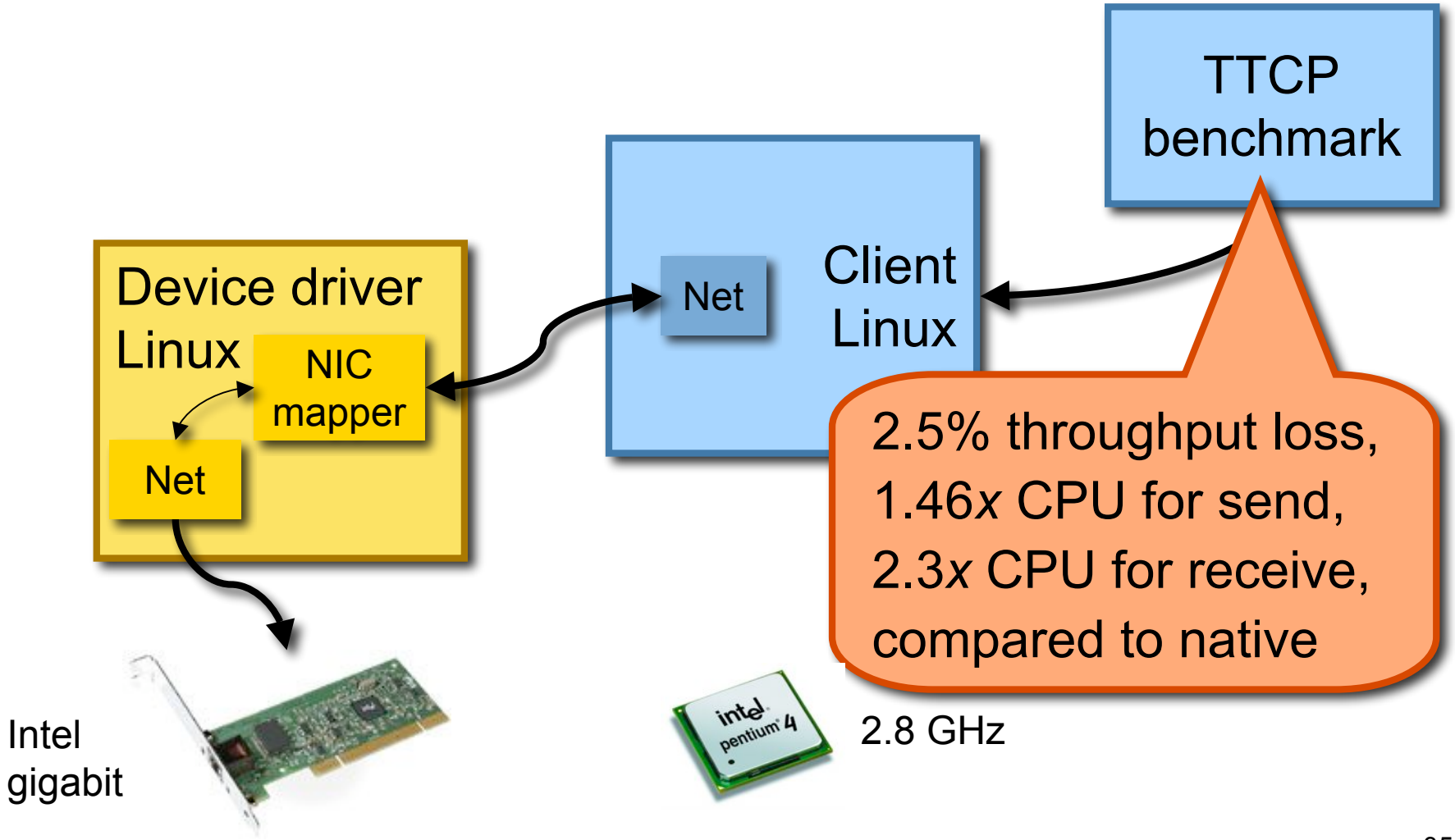
Consolidated Architecture



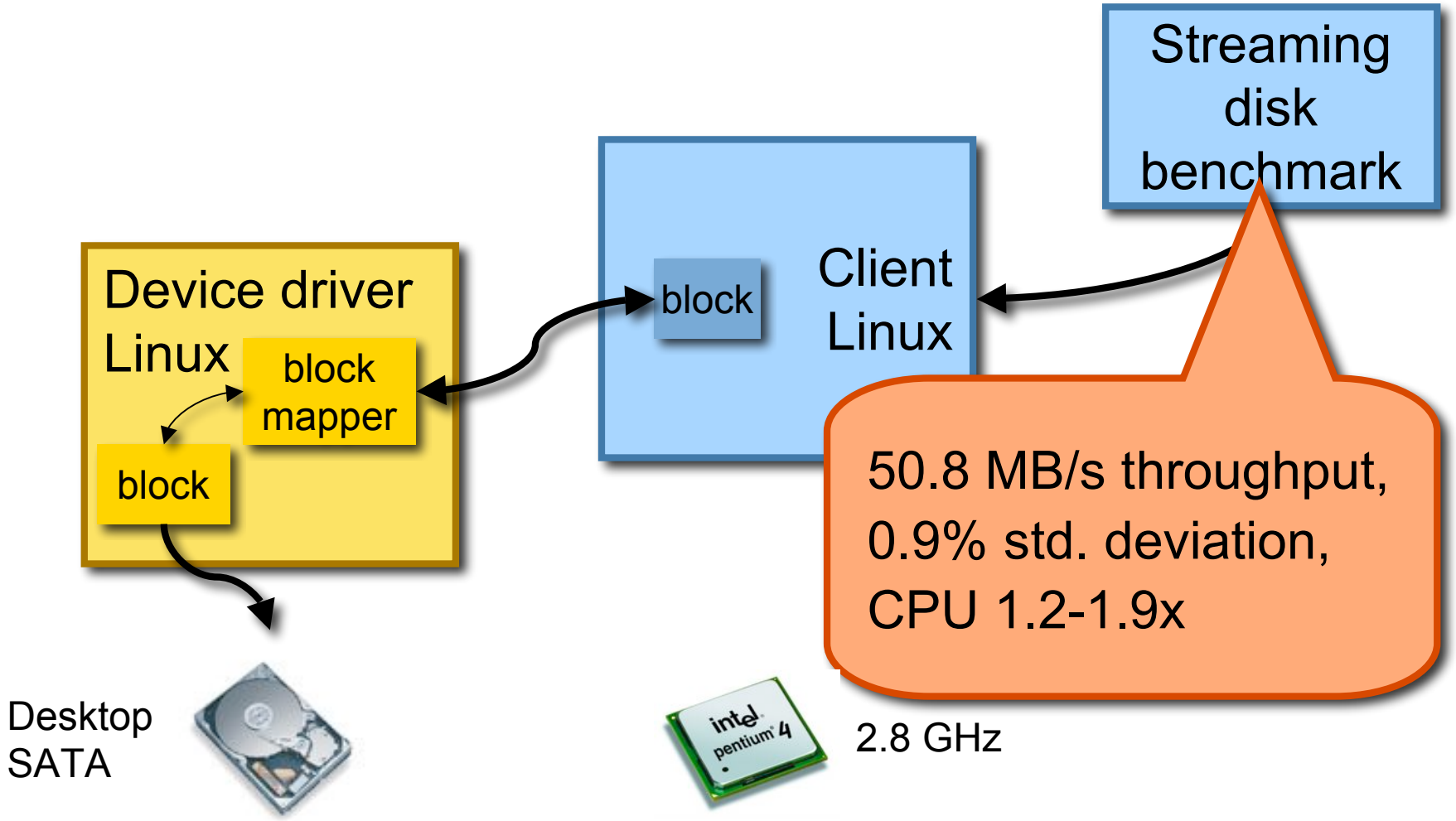
Address Mapping



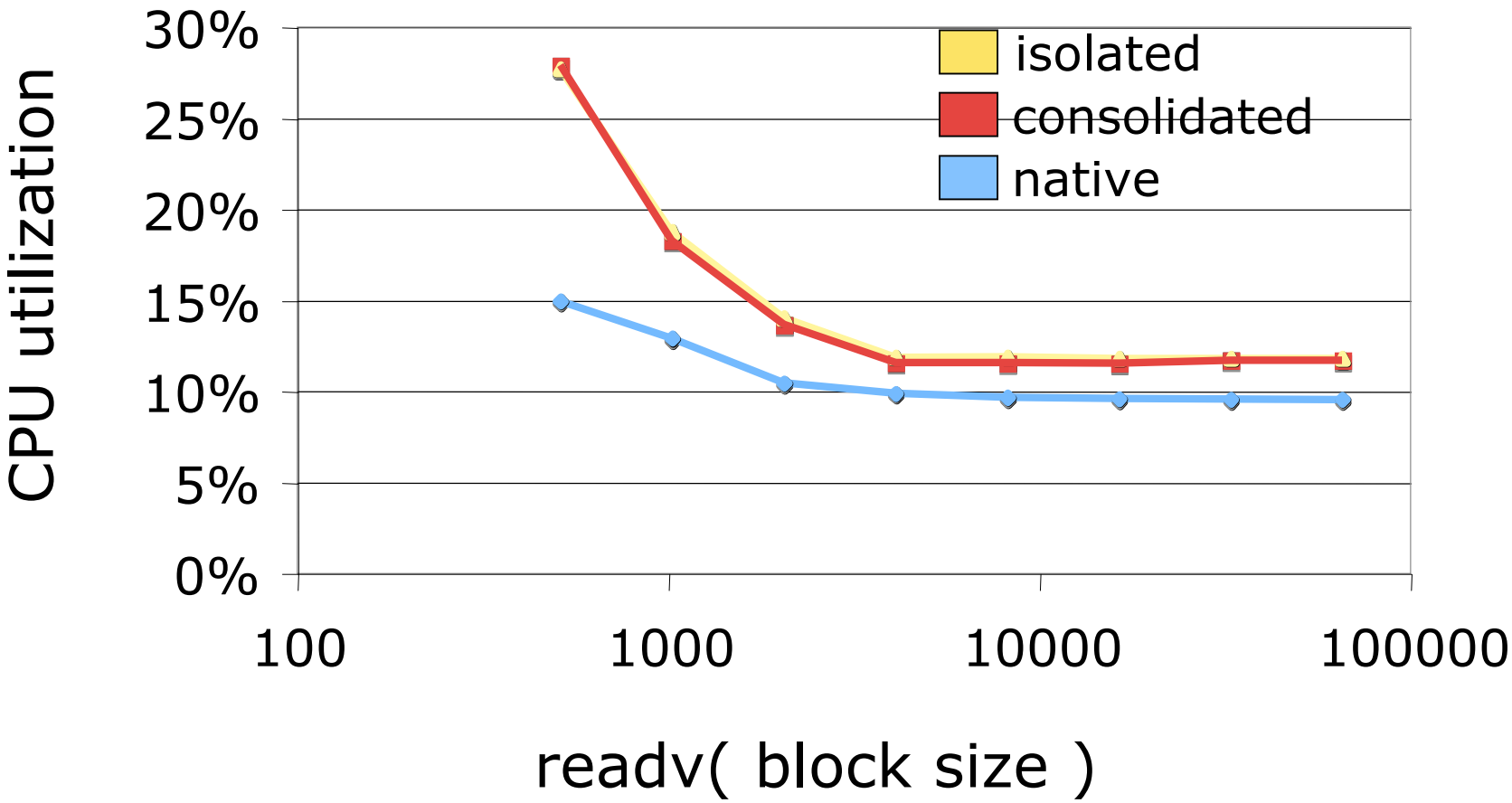
Network Performance



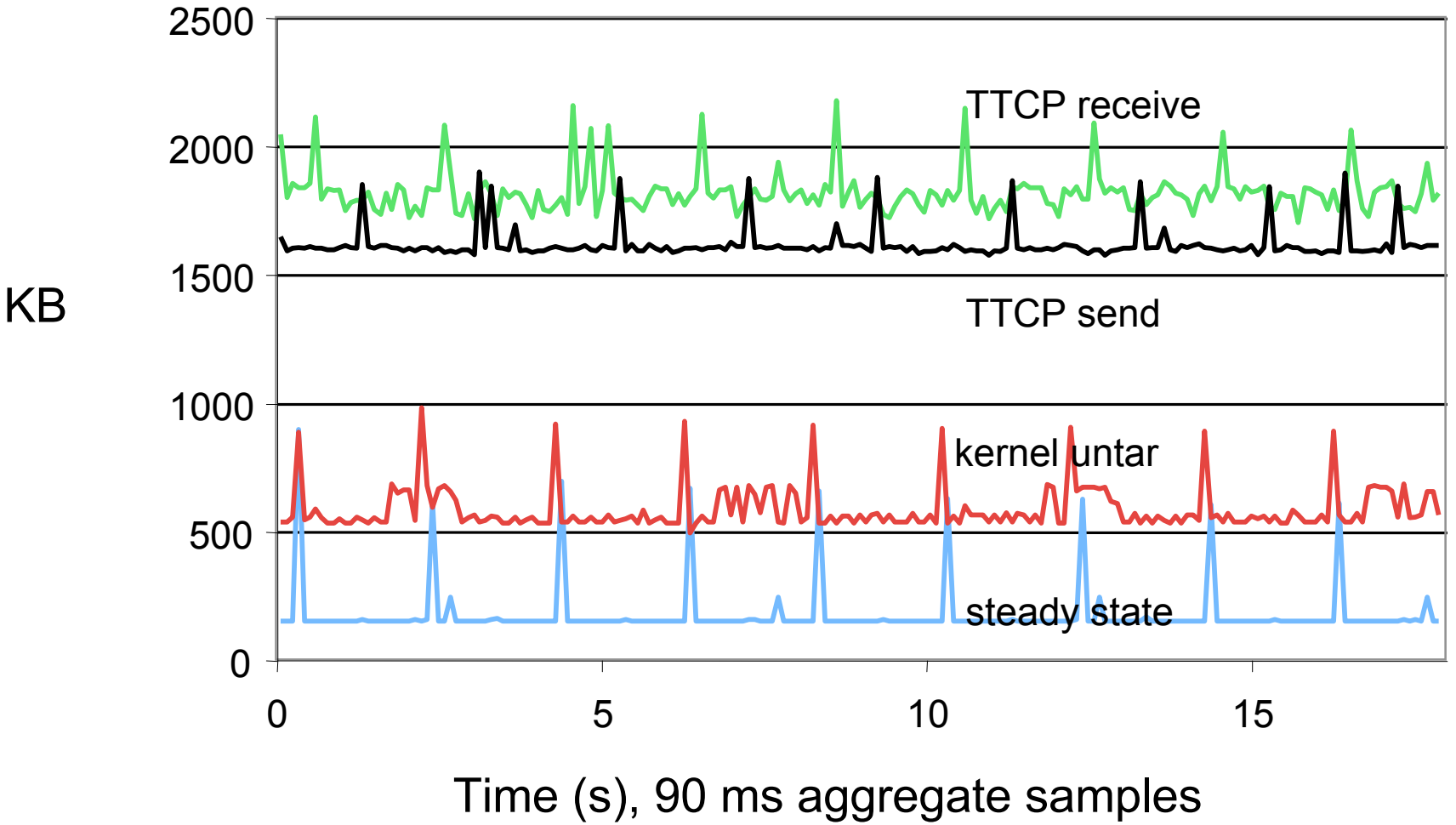
Disk Performance



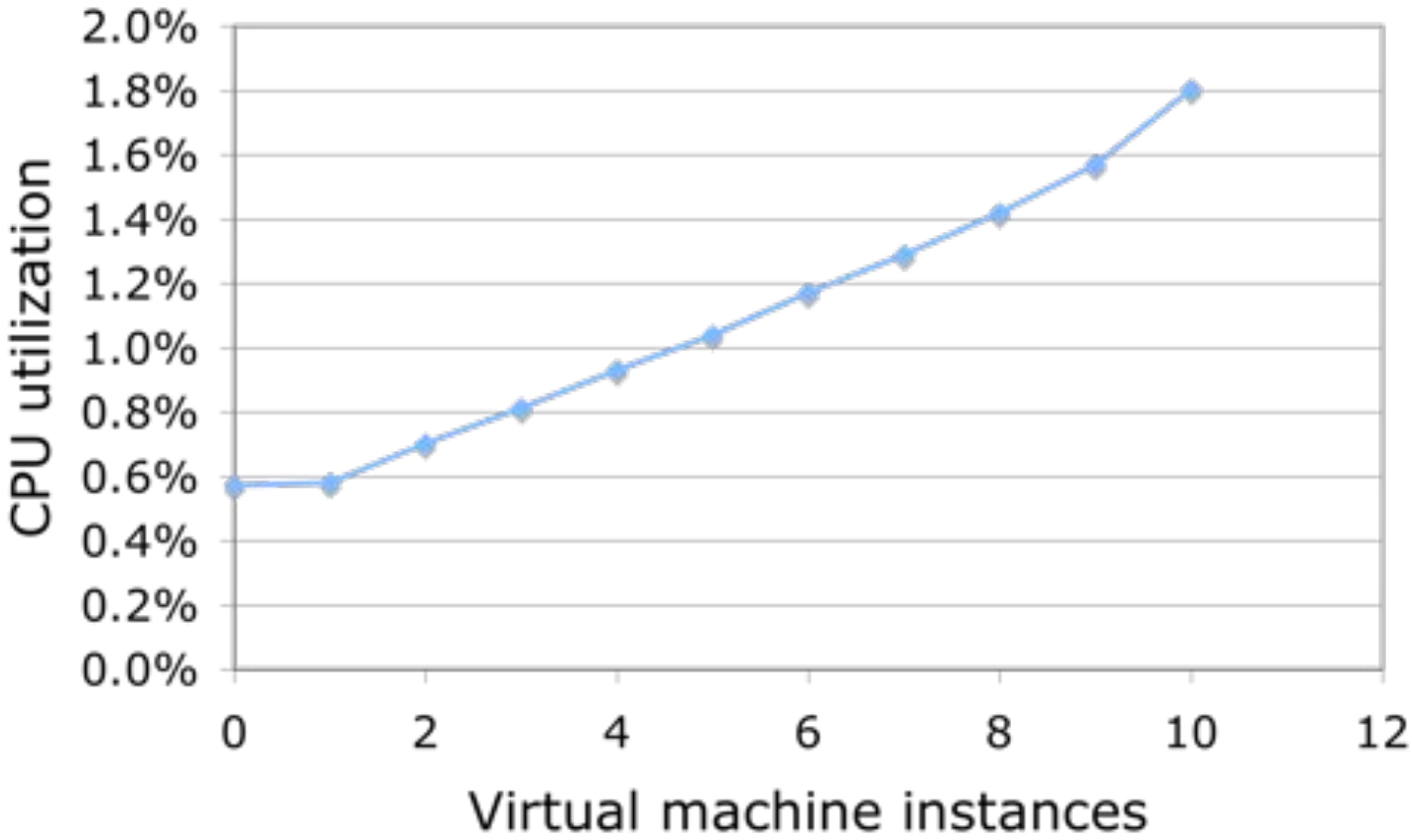
Disk CPU Utilization



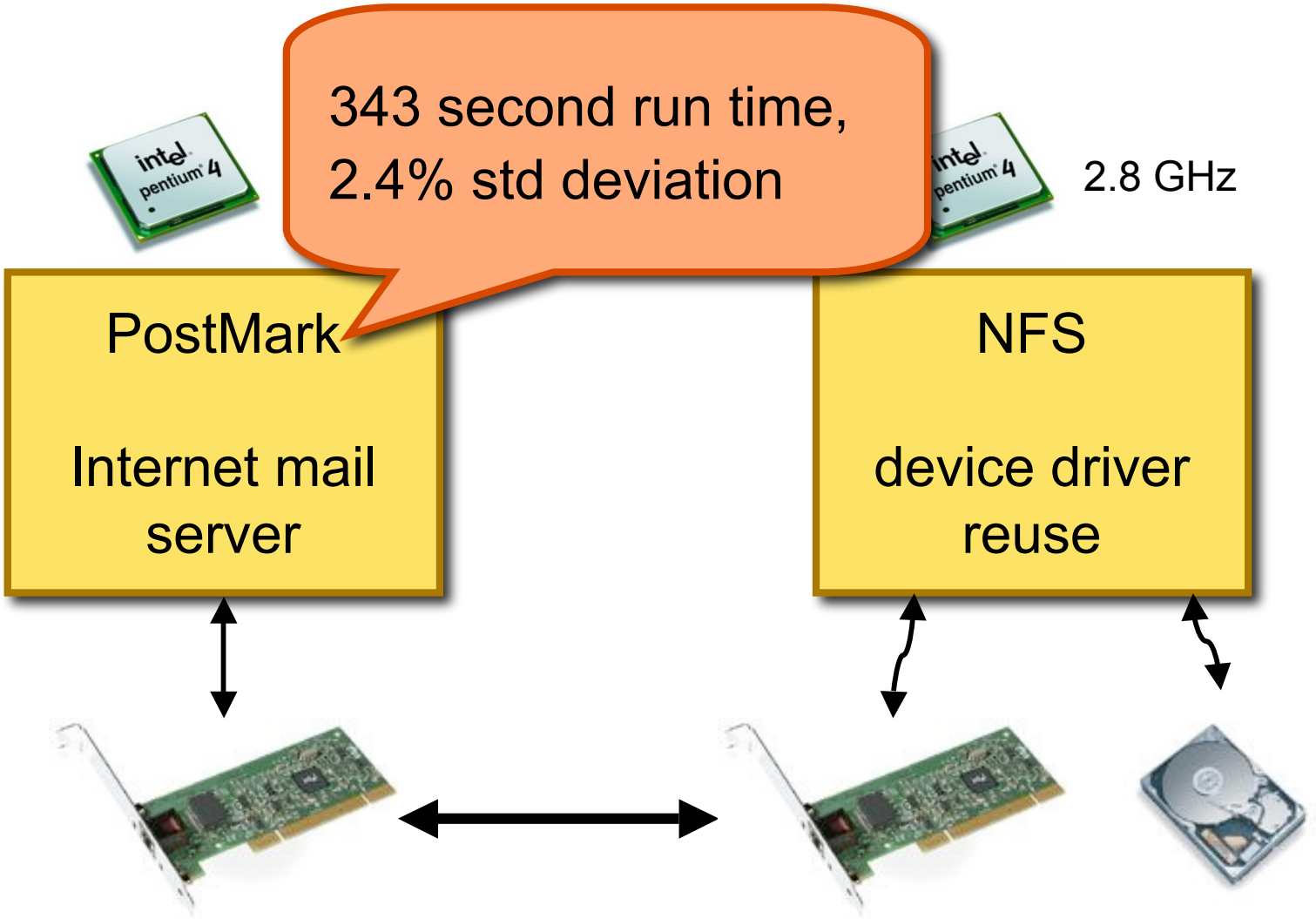
Memory Working Set



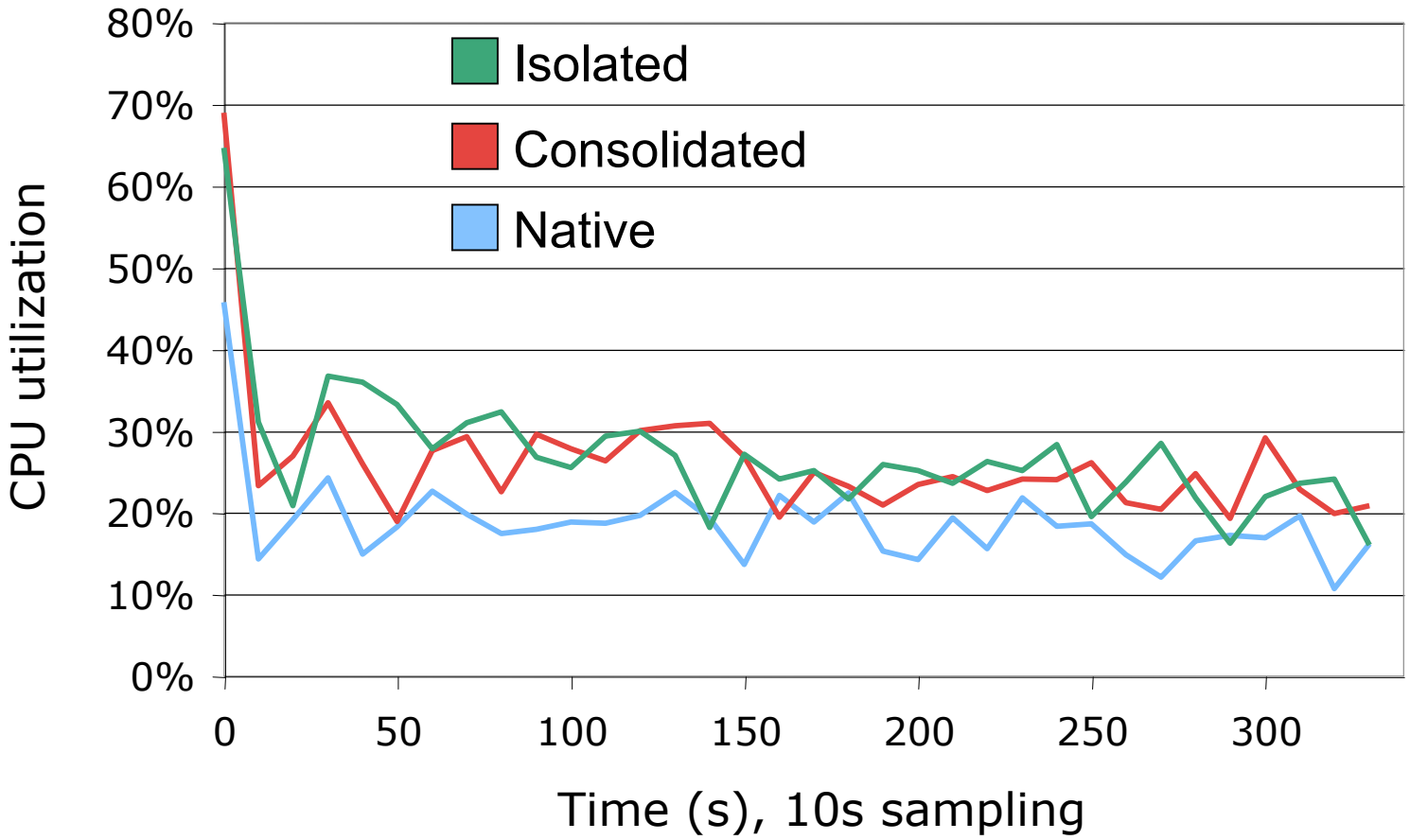
Inherent CPU Utilization



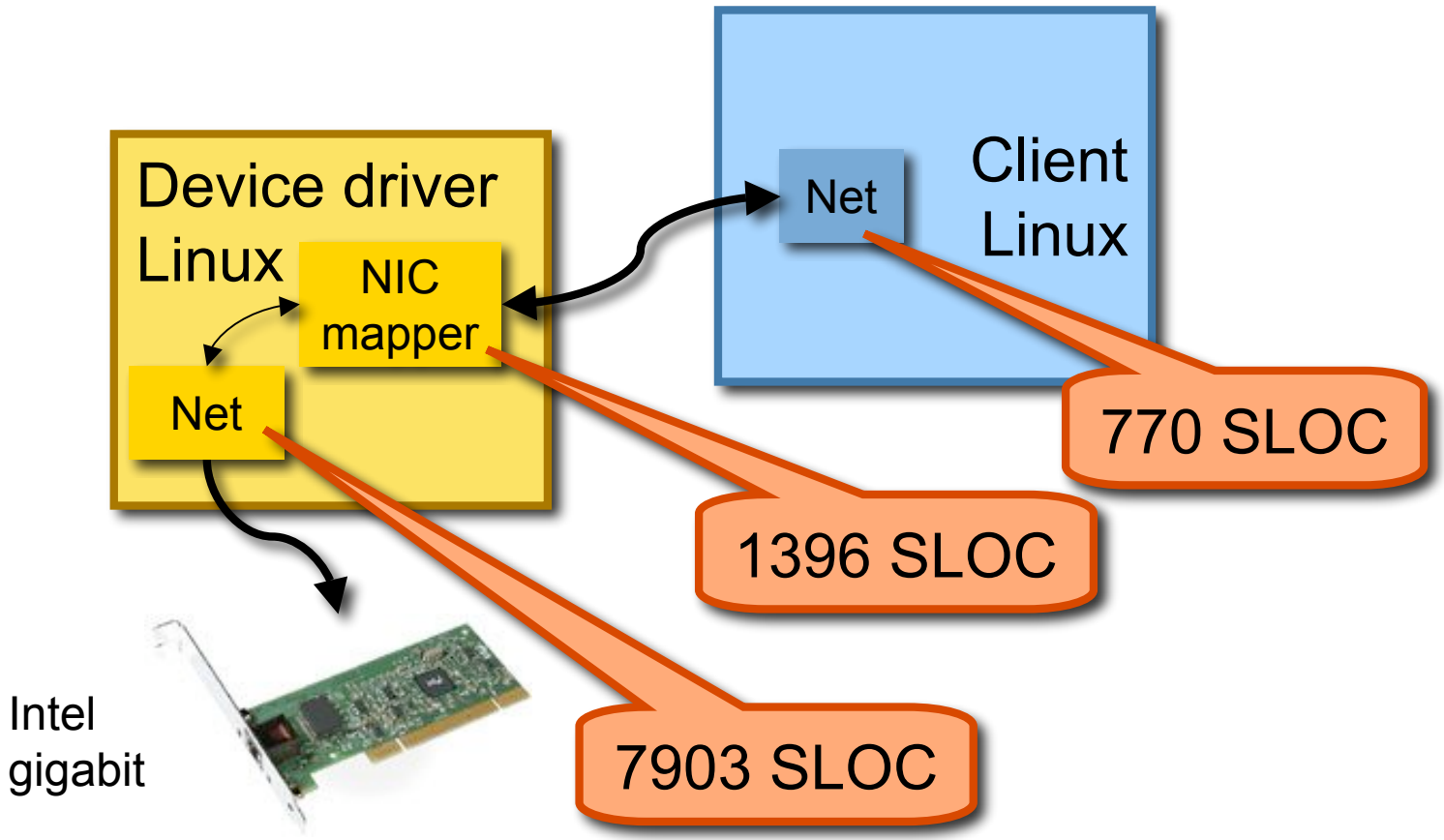
PostMark Benchmark



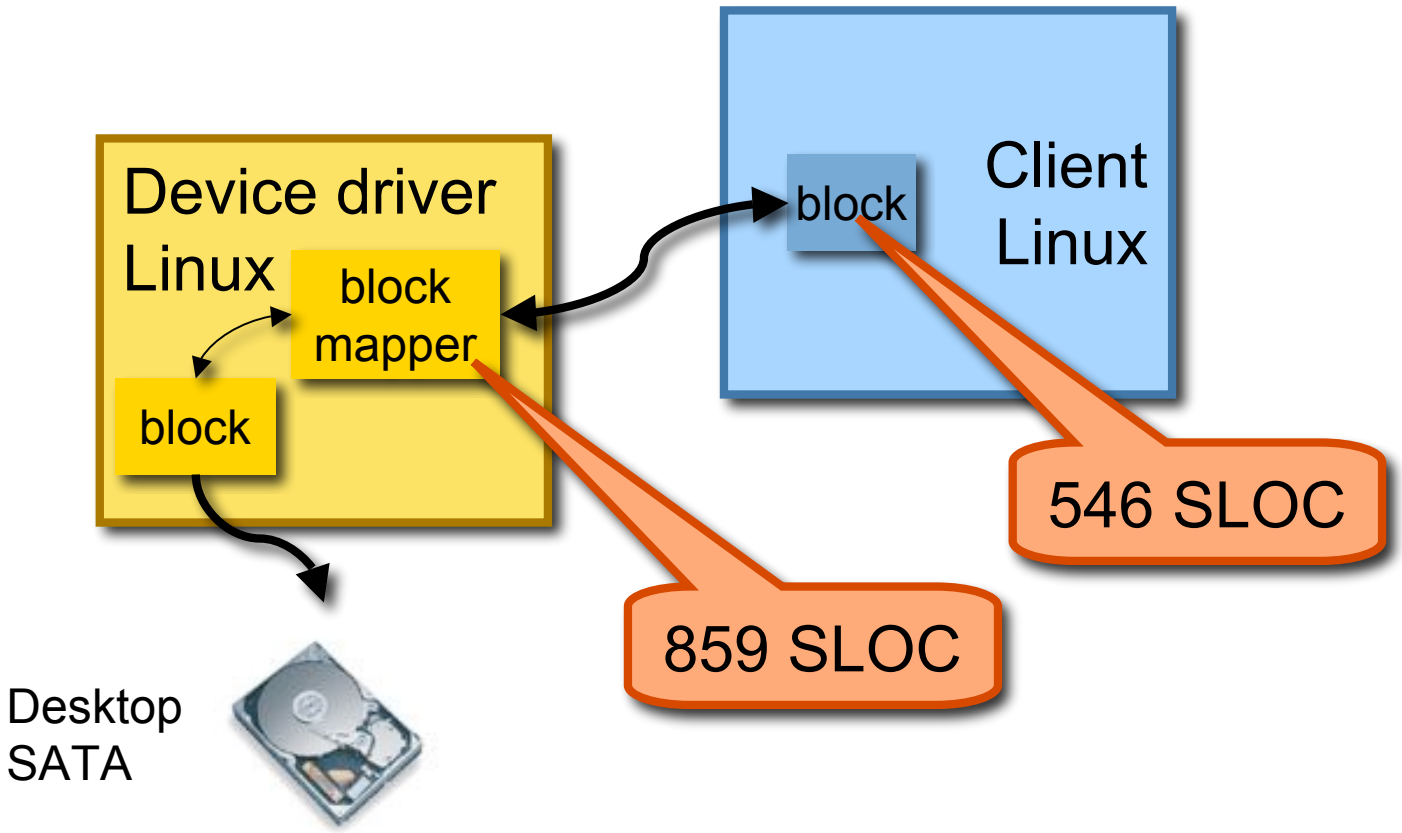
PostMark NFS CPU Utilization



Engineering Effort: Network



Engineering Effort: Disk



Conclusion

- Device driver reuse
  - Binary drivers
  - Source code drivers
- Run the original driver OS in a VM
  - Isolated drivers
  - Orthogonal design
- Little engineering effort for massive reuse
- Enhanced dependability