

VM Memory Management

CS592: Datacenter Memory Systems, Fall 2026

Administrivia

- Reminder to sign up for presentations!

Goals for today

- Virtual machines brief background
- Paper discussion
- Today's picture: Hardware and software

Memory Resource Management in VMware ESX Server

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OSDI 2002

Paper author

- Carl Waldspurger
 - PhD at MIT
 - DEC Systems Research Center
 - **VMware**
 - Nowadays: Independent consultant

**Stride Scheduling:
Deterministic Proportional-Share Resource Management**

Carl A. Waldspurger *

William E. Weihl *

Lottery Scheduling: Flexible Proportional-Share Resource Management

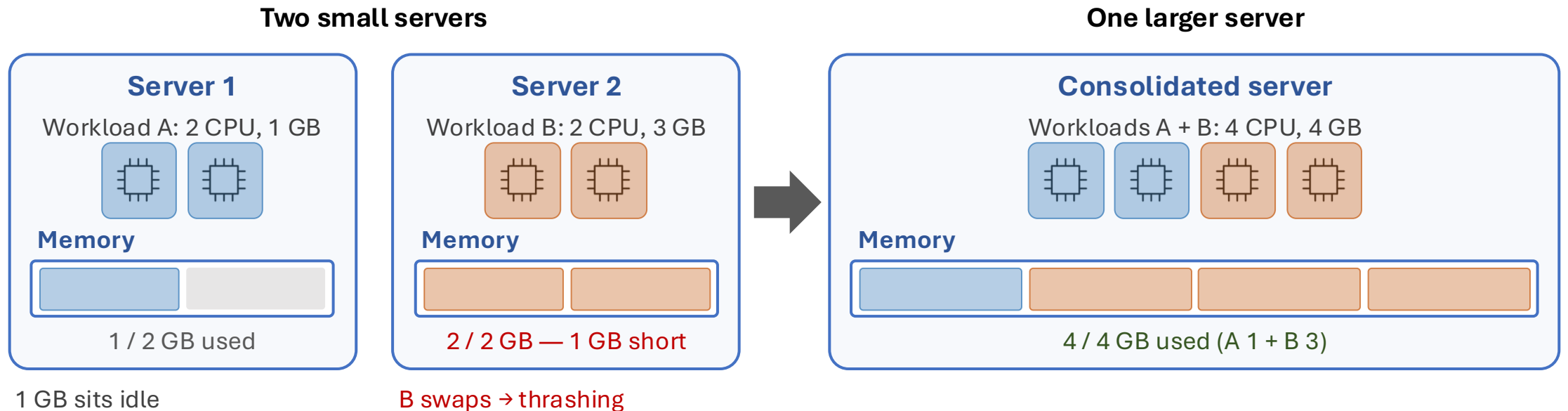
Carl A. Waldspurger *

William E. Weihl *



Motivation: Server consolidation

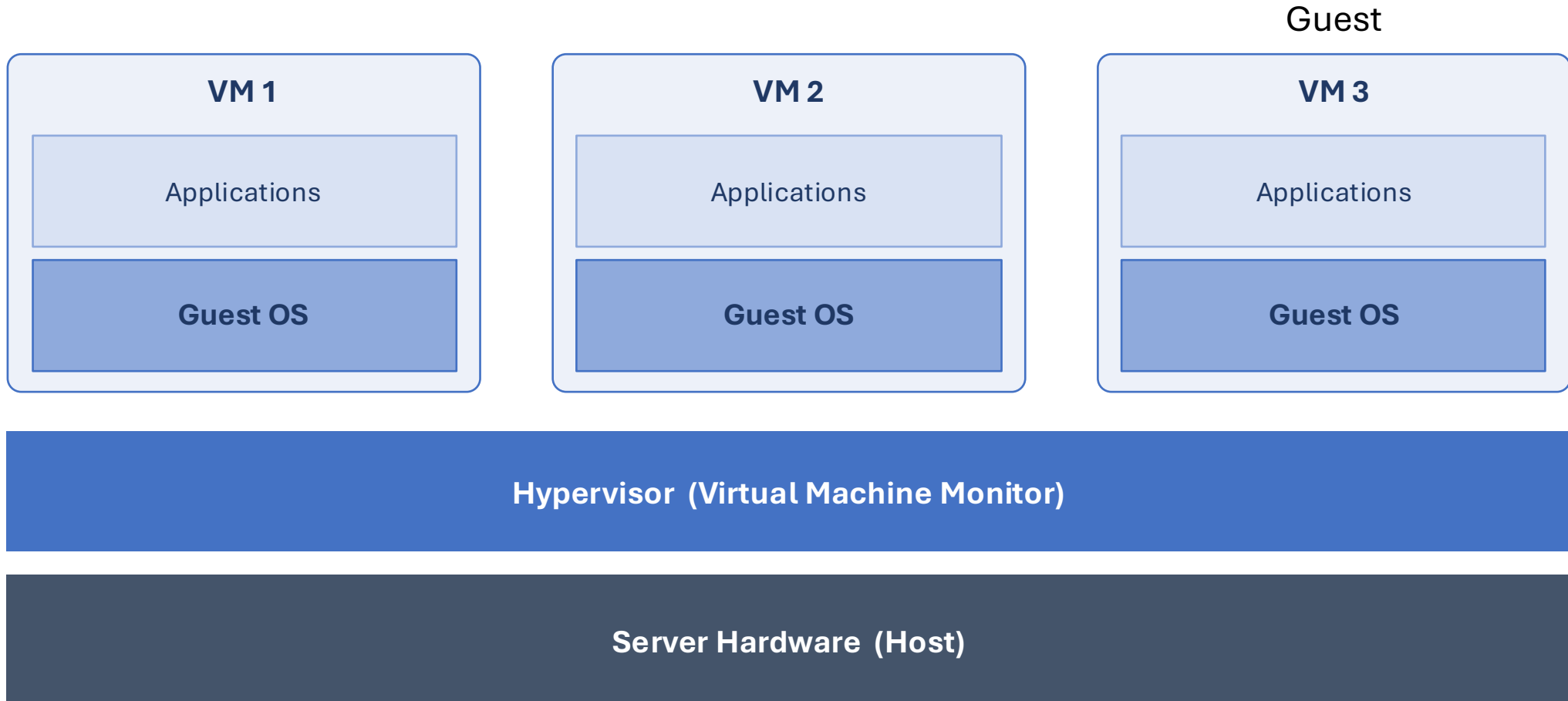
- Many small servers consolidated into fewer larger machines
- Benefits?
- Drawbacks?



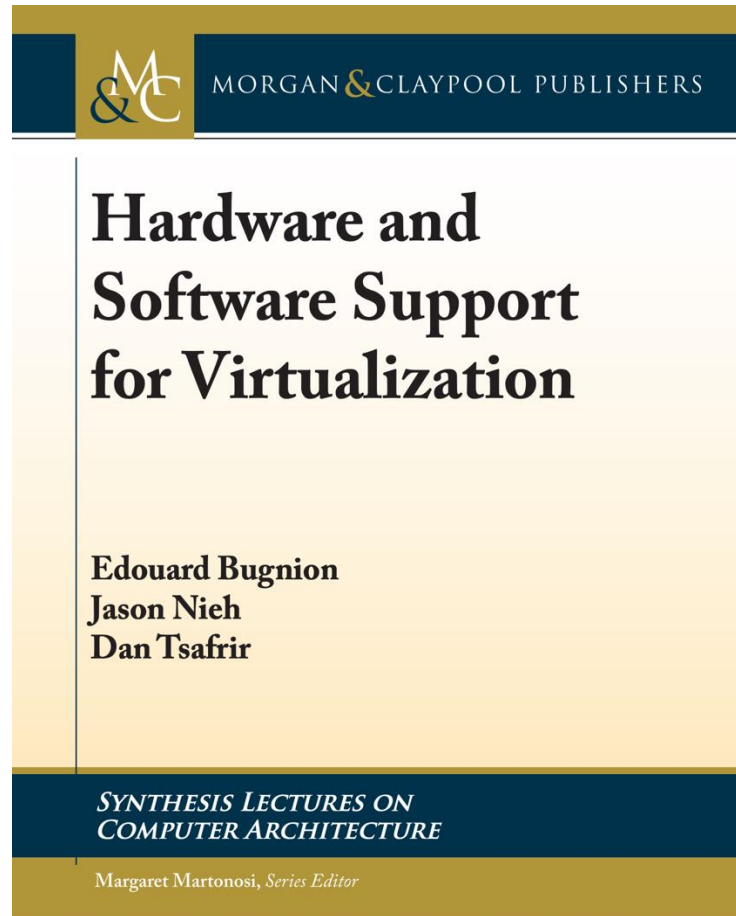
Software support for server consolidation

- Why not just use OS-level multiprogramming?
 - Each customer/workload: one or more process(es)
 - OS multiplexes hardware while providing isolation

Virtual machines

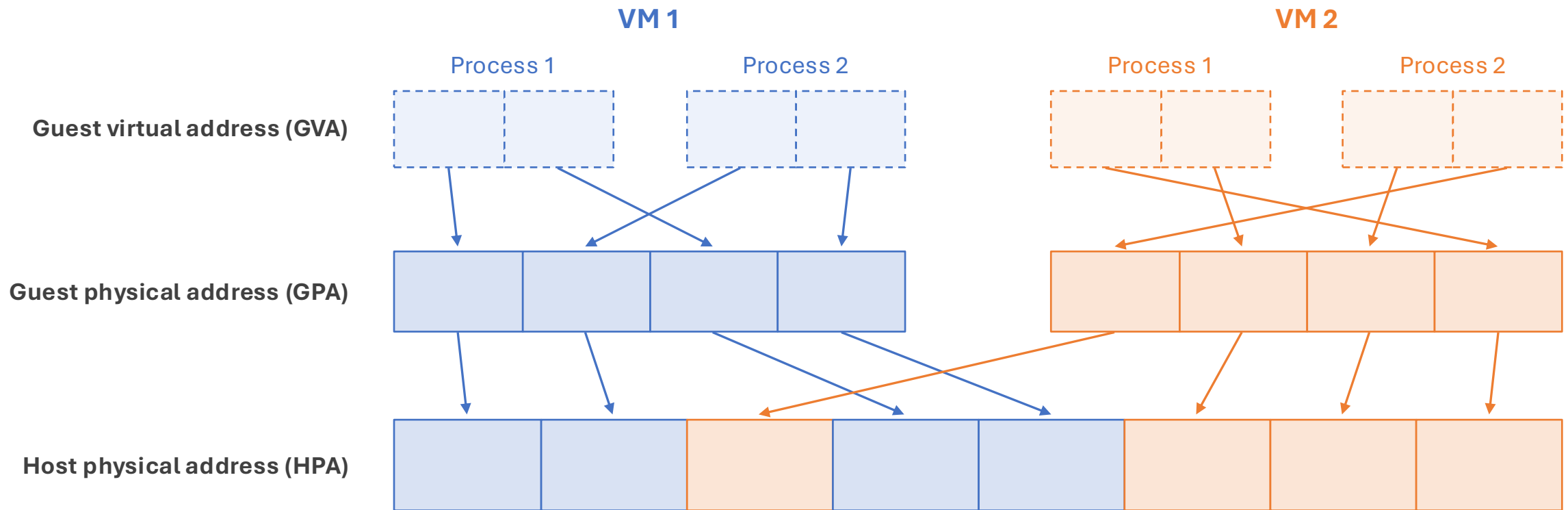


Aside: Highly recommended book



Virtualizing memory for VMs

- Goal: Virtualize the physical address space

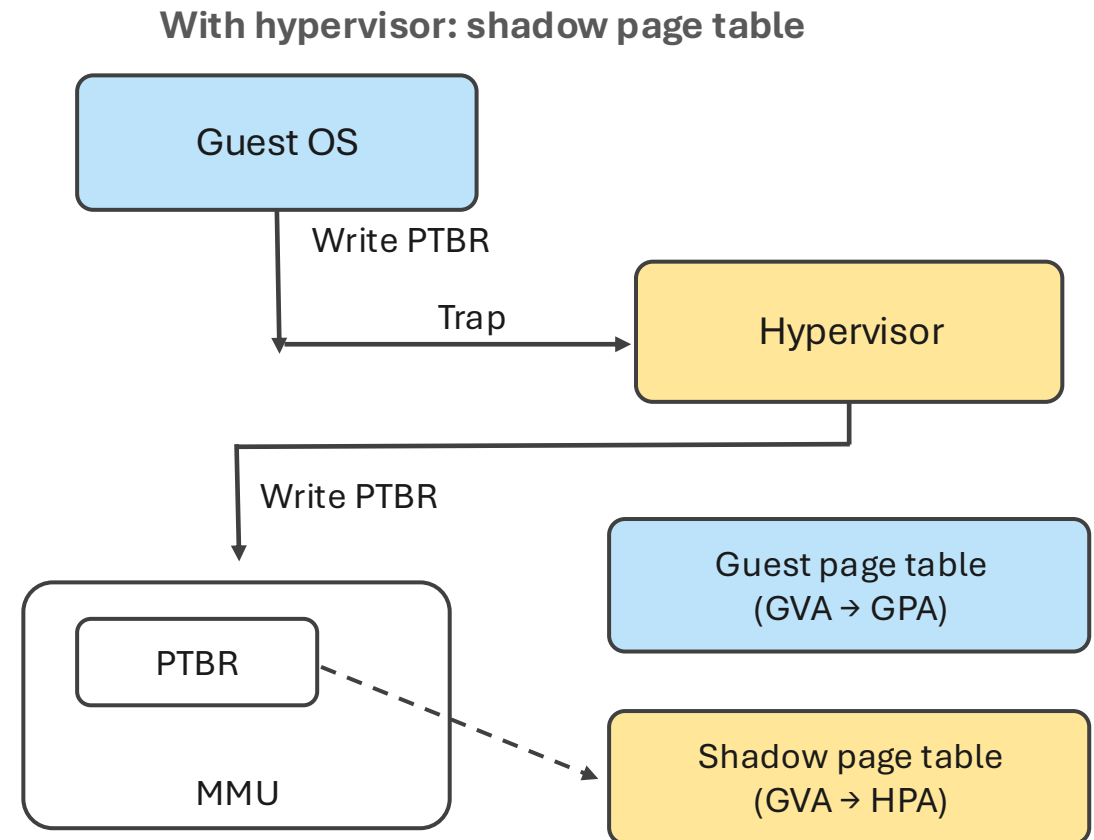
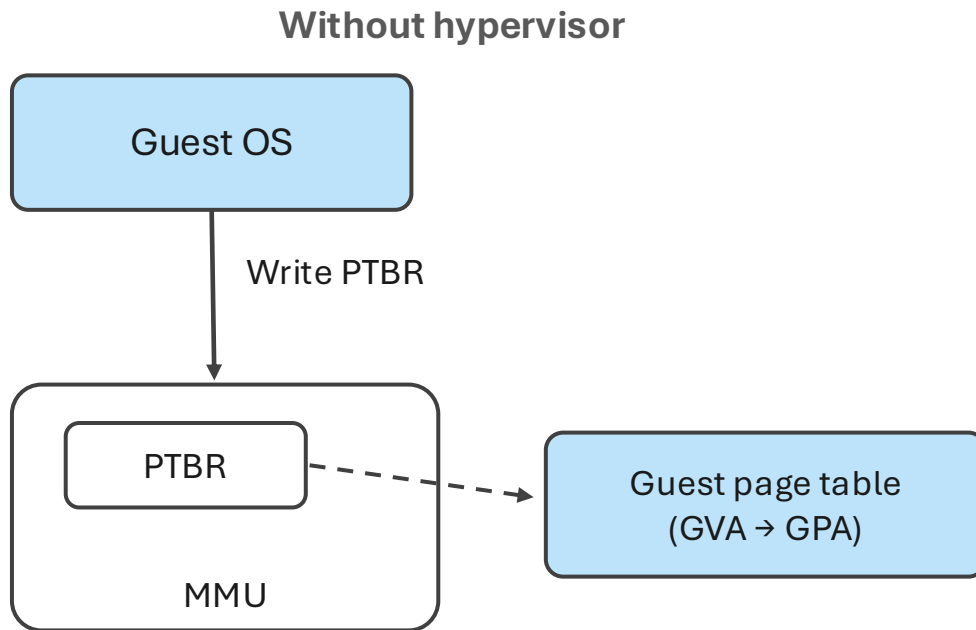


How to virtualize memory for VMs?

- Naive approach: “Trap and emulate” every memory access
- Problems?

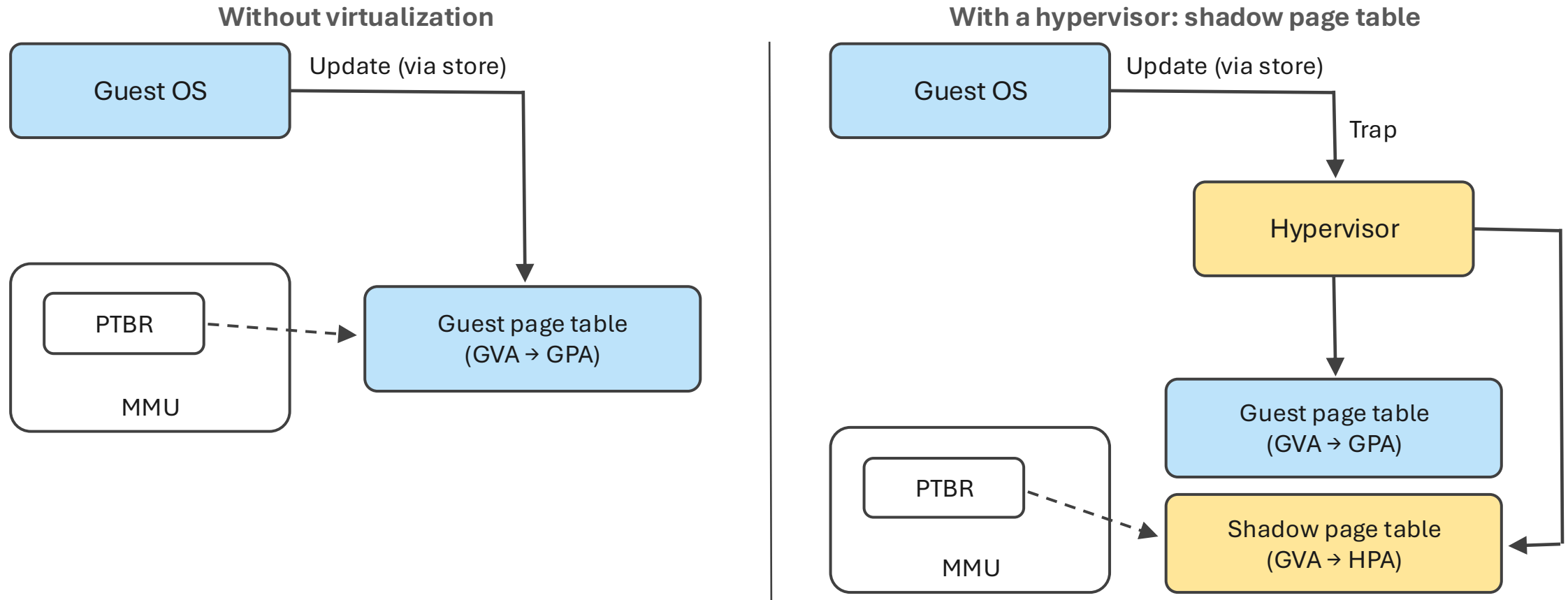
How to virtualize memory for VMs?

- Observation: Processors access memory via **virtual addresses**



How to virtualize memory for VMs?

- Synchronizing guest and shadow page tables



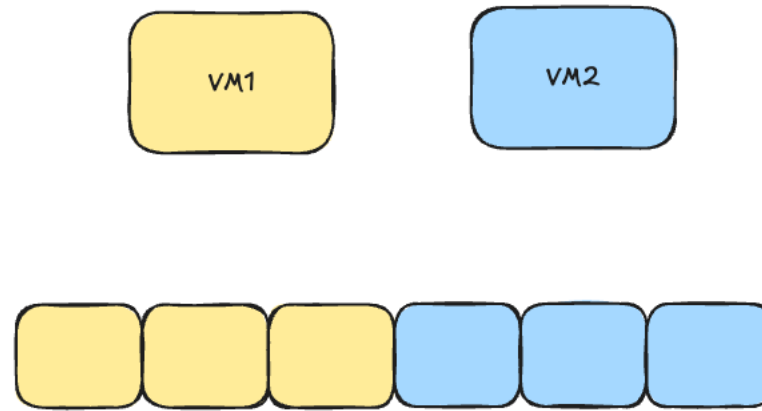
Questions?

Problem statement of the paper

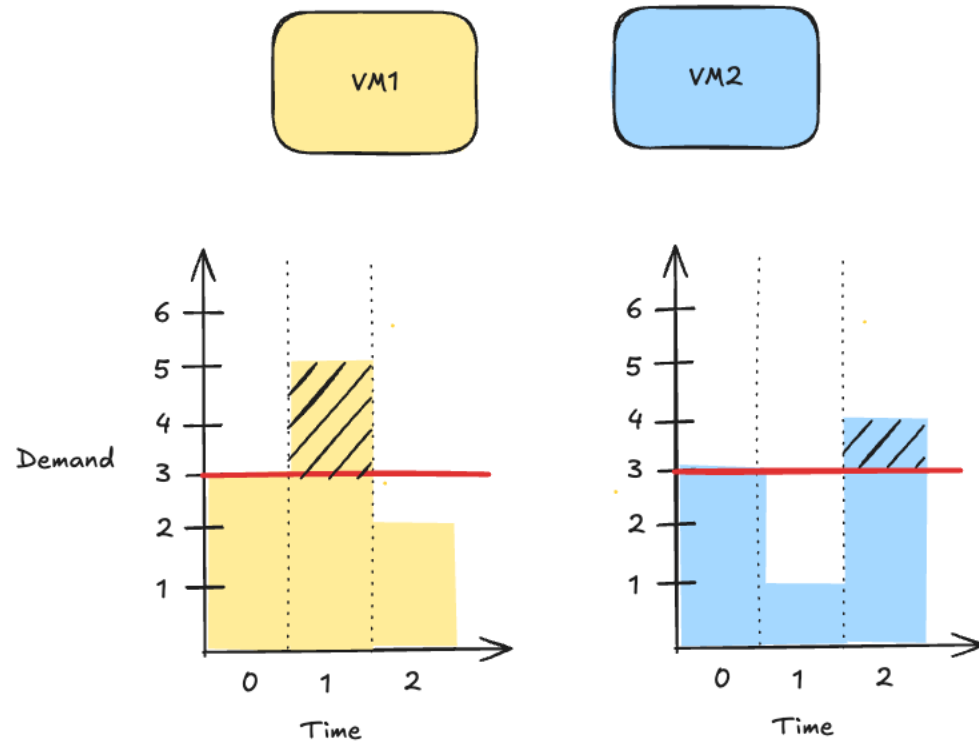
- How to allocate physical memory across VMs?
- Goals
 - Maximize aggregate utilization
 - Preserve performance isolation and resource guarantees
- Constraints
 - VMs run unmodified guest OSes

Naive solution: Static memory allocation

- Each VM receives fixed partition of physical memory



Problem: Dynamic demands



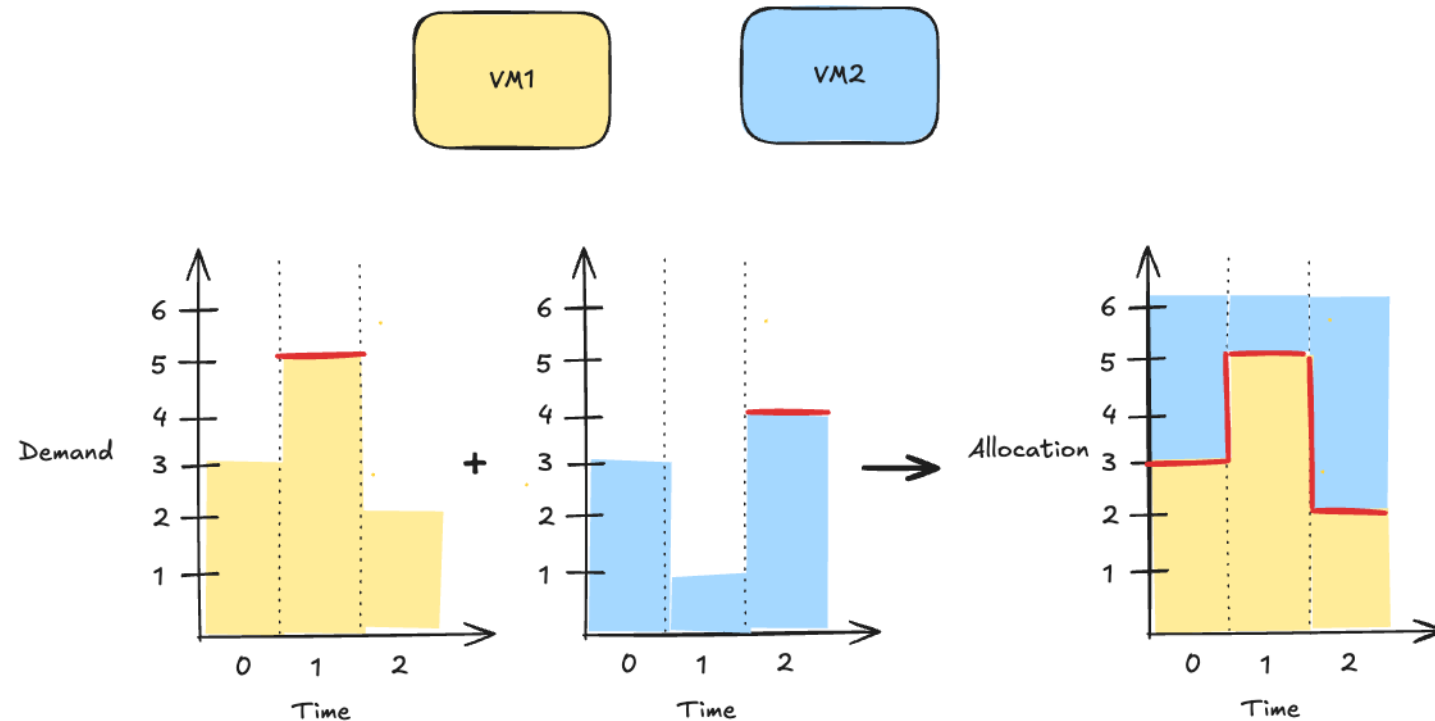
Static allocation under dynamic demands

Resource guarantees ✓

Optimal utilization ✗

Dynamic memory allocation

- Overcommit
- Statistical multiplexing: Sum of peaks > peak of sums



Key contributions of the paper

- Mechanisms
 - Ballooning (reclaiming memory from VMs)
 - Idle memory tracking
 - Content-based page sharing
 - I/O page remapping
- Policies
 - Admission control
 - Dynamic reallocation algorithm (with idle memory tax)
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