UMassAmherst

An Empirical Study of Memory Sharing in Virtual Machines

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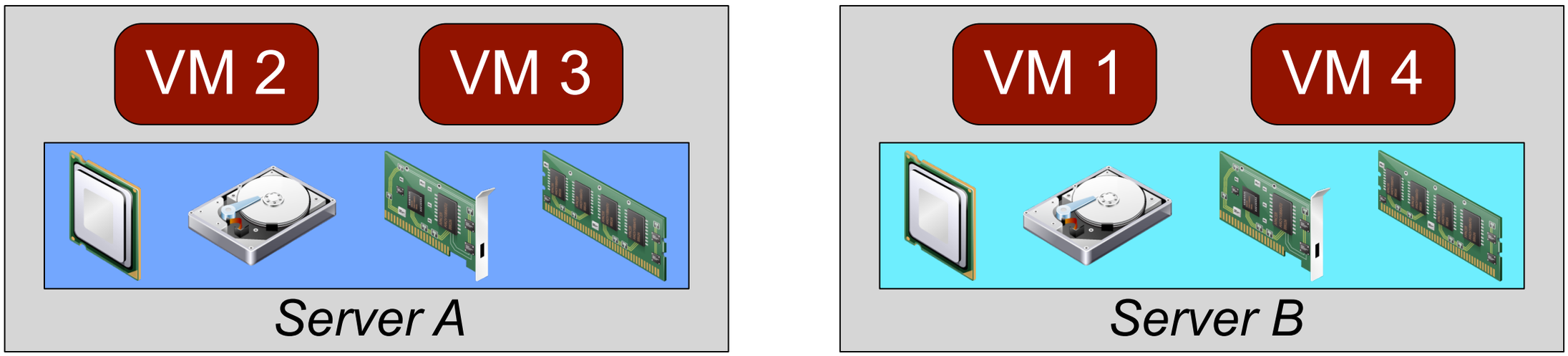
Virtualization in Data Centers

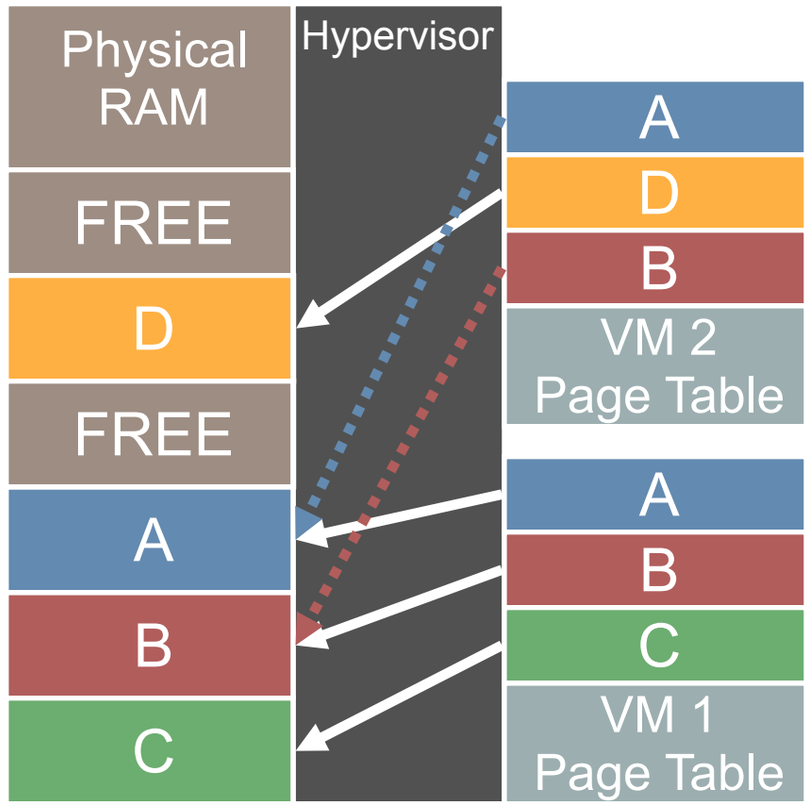
- Data centers use **virtualization** to improve resource utilization
  - Flexible mapping of resources to users
  - More servers and applications
  - Smaller hardware footprint

- Maximizing benefits
  - Efficient resource sharing
  - Virtual machine placement



Content Based Page Sharing

- Eliminate **identical pages** of memory across multiple VMs
- Virtual VM pages mapped to physical pages
- Hypervisor detects duplicates
- Replaced with copy-on-write references



Page Sharing Systems

- Extensive prior work in exploiting page sharing

- VMware ESX Server [SIGOPS 02]
  - Periodic memory **scanning** to detect duplicates
  - **>30%** memory savings

- Difference Engine [OSDI 08]
  - **Sub-page** sharing and patching
  - **>60%** memory savings

- Satori [USENIX 09]
  - Sharing of **short-lived** pages
  - **>90%** of possible sharing captured

Open Questions on Sharing

- What levels of sharing are possible in typical **real-world machines**?

- What are the **factors** that impact sharing potential?
  - OS family? Versions? Applications?

- How will **emerging technologies** impact sharing?
  - New OS technologies?
  - VDI farms? LAMP clusters?

- **Our goal:** Provide practical insights into these questions through a careful study of memory data

Outline

- Background and motivation
- Data collection and types of sharing
- Study of real-world sharing potential
- Study of the factors impacting sharing
- Conclusions

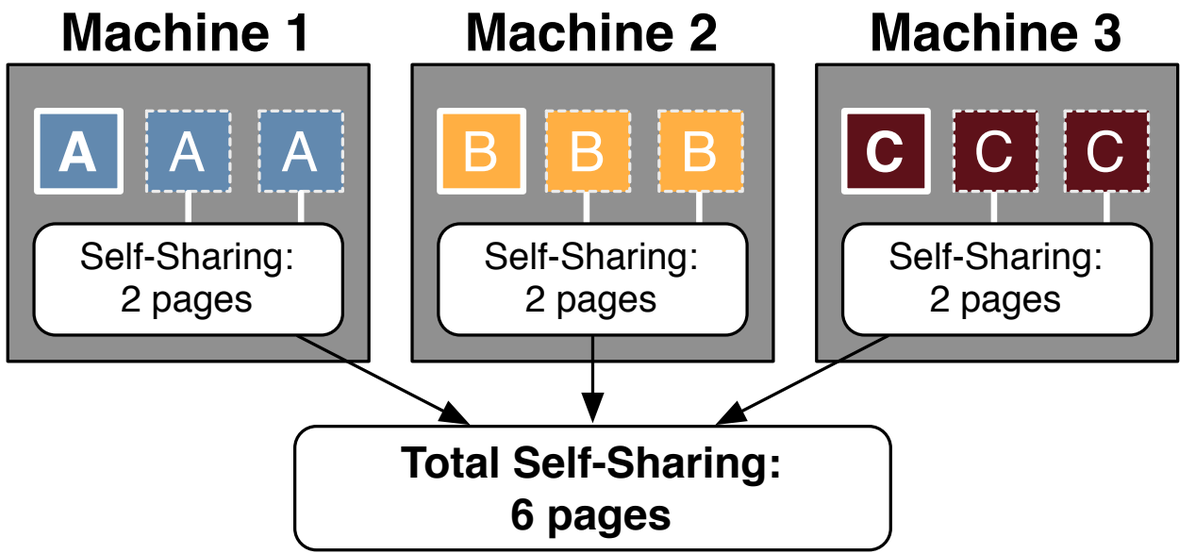
Data Collection

- Real-world memory traces
  - ~50 real machines (server/desktop mix)
  - Uncontrolled user workloads
  - Memory snapshots every 30 minutes

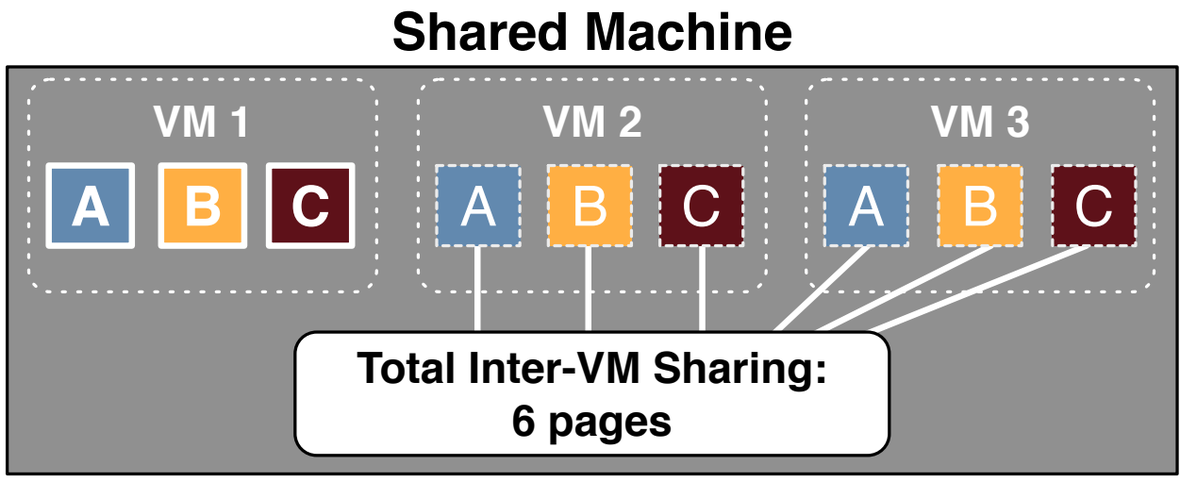
- Supplementary traces from controlled VMs
  - Mac/Win/Linux, mixed versions, 32/64 bit
  - 3 application setups per VM:
    - No workload (freshly booted)
    - Server apps (LAMP stack)
    - Desktop apps (office, browser, media player)

Types of Sharing

- **Self-sharing**: sharing within individual VMs
  - E.g., multiple zero pages



- **Inter-VM sharing**: sharing across multiple VMs
  - E.g., shared OS state



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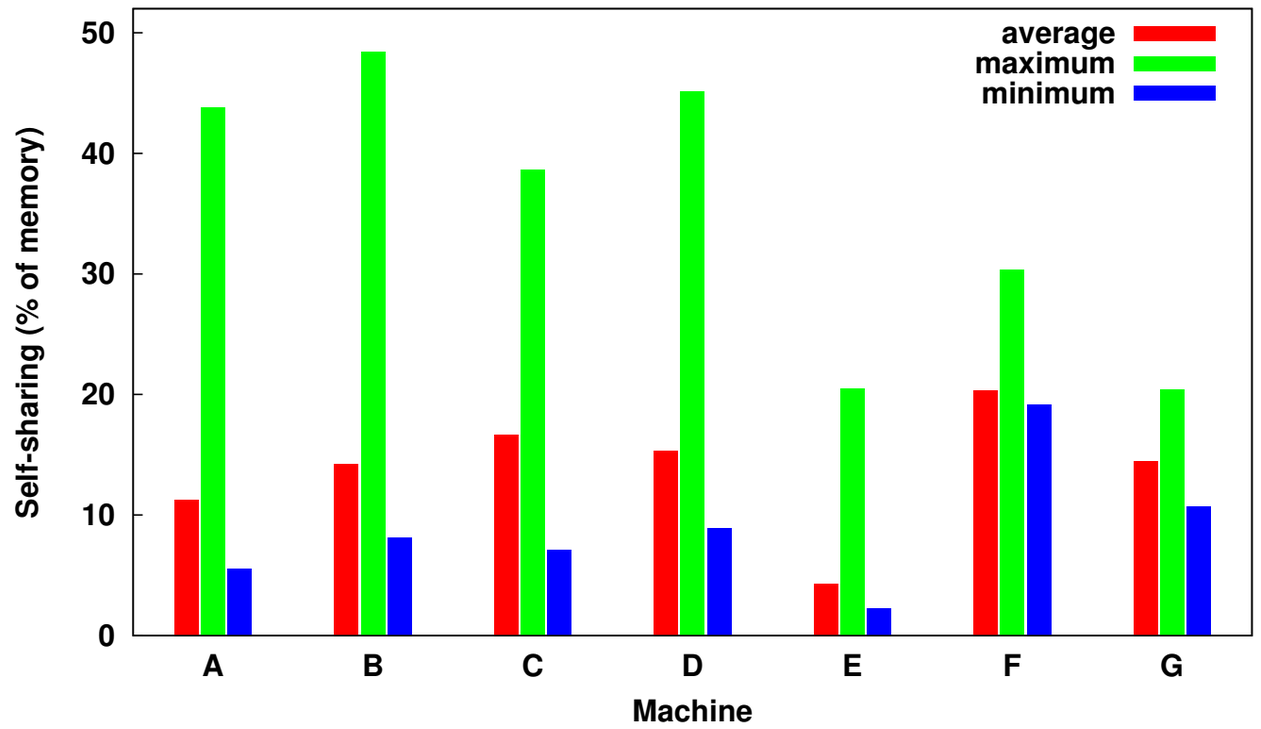
Self-Sharing in Real-World Traces

- Average sharing of **14%**
  - Excluding zero pages
- Peak sharing up to **50%**

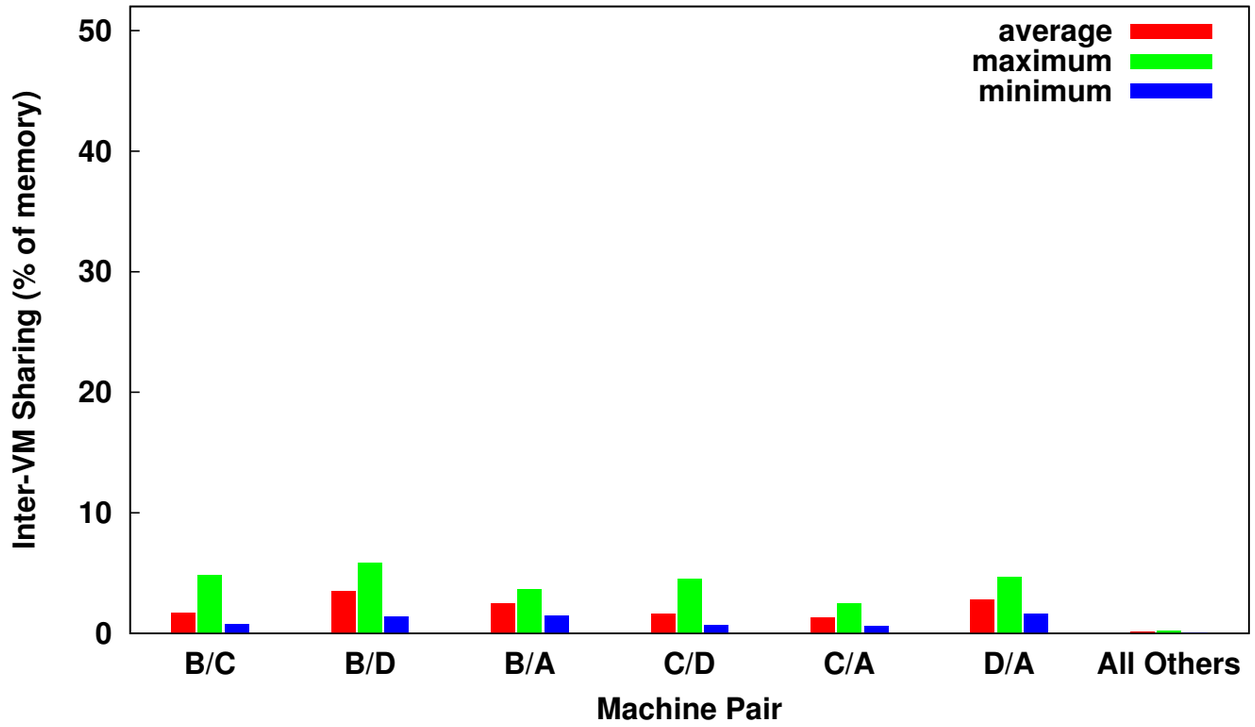


- Stable ‘baseline’ sharing of **8%**

- Significant (**~15%**) self-sharing potential observed

Inter-VM Sharing in Real-World Traces

- 'High' average sharing of just **2%**
- **<0.1%** sharing in 15 of 21 pairings



- In our traces, inter-VM sharing never above **6%**

- Observed minimal (**<2%**) inter-VM sharing potential

Real-World Trace Observations

- Typical **15%** possible sharing observed
  - Significant, but less than expected from synthetic workloads
- Most (**85+%**) sharing derived from self-sharing
  - What about collocating many VMs?
  - All 7 machines…still **80+%** from self-sharing
- Self-sharing doesn't require virtualization!
  - Could capture it within a VM or nonvirtualized host

- Self-sharing is significant, but what causes it?

Self-Sharing Case Study

- What causes self-sharing in a Linux desktop?
  - Looking at nonzero sharing

- Expanded version of Linux memory tracer
  - Track page contents and processes

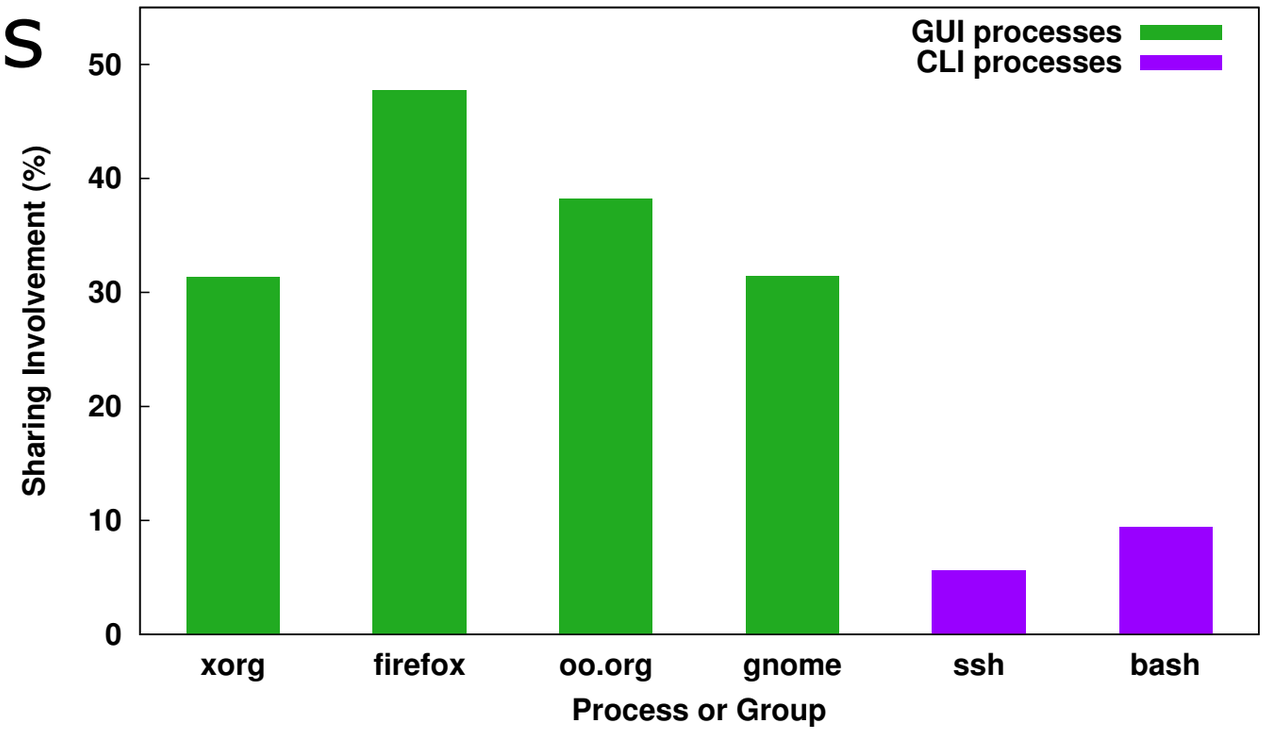
```
[libc-2.12.so 000b6000 r-xp]: sshd apache2
```

- Group sharing involvement (% of self-sharing) by content and process

Self-Sharing by Process

- **>30%** sharing processes GUI apps/libraries

- **<20%** sharing from other system processes

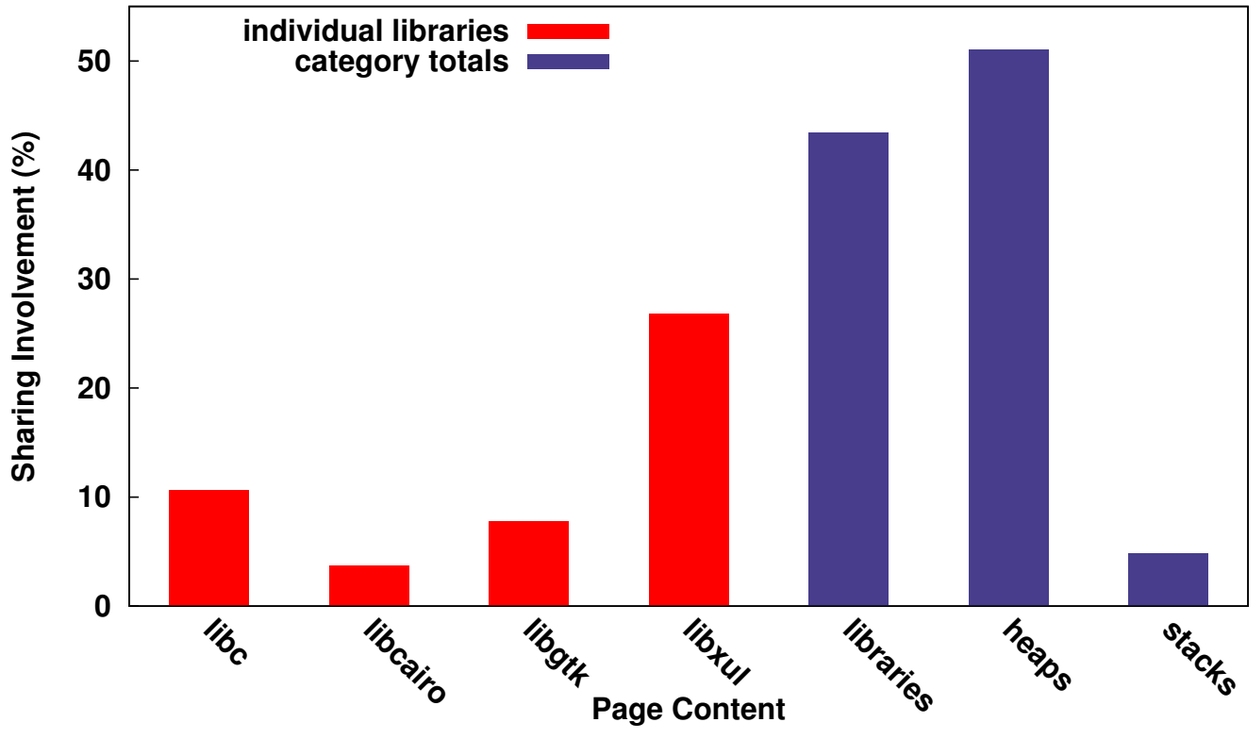


- Memory footprint likely dominated by GUI

- Process self-sharing resulting from user workload

Self-Sharing by Content

- **94%** sharing from libraries and heaps
- Possibly from recreated data structures



- **2.3 MB** sharing from single Xorg heap page (~600 copies)

- Duplicate data allocations evident in processes

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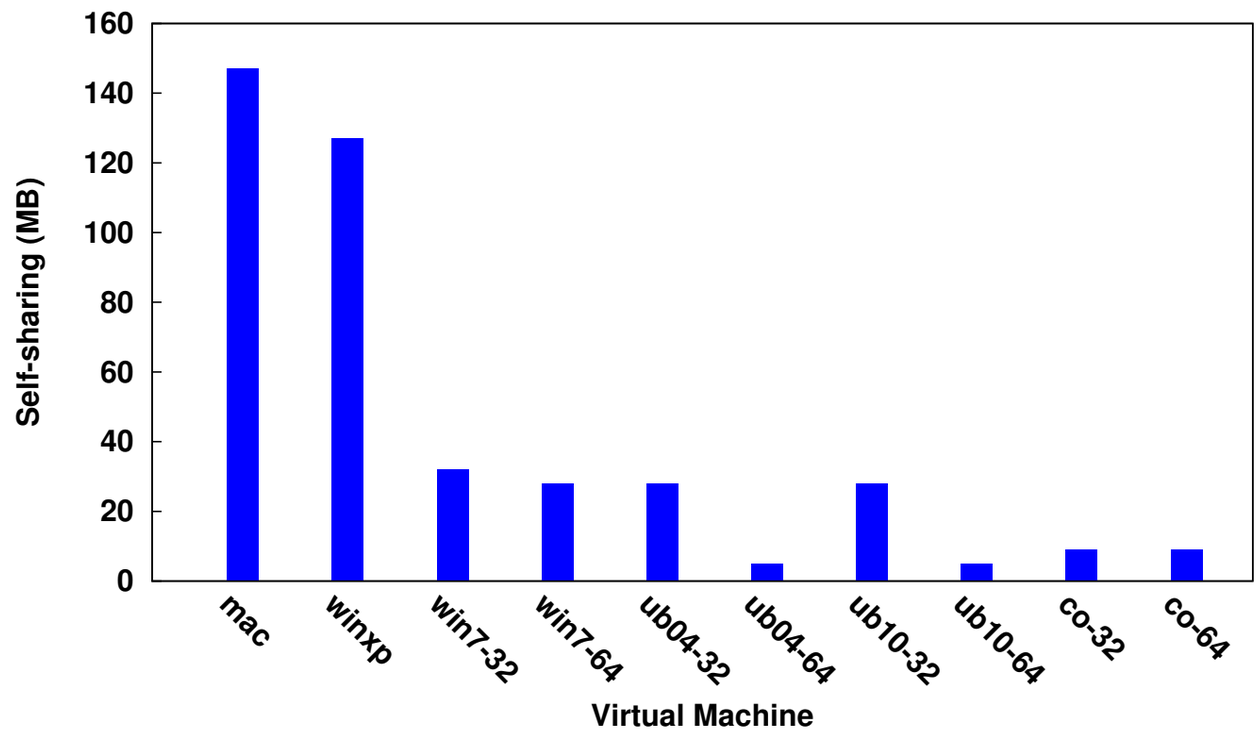
Factors Impacting Sharing

- How do various properties influence sharing?
- Operating system characteristics
  - Family (e.g., Linux or Windows)
  - Version (e.g., Windows XP/7, Ubuntu 10.04/10.10)
  - Architecture (x86 or x64)
- Application setup (LAMP and VDI setups)
- Sharing granularity (number of pages per chunk)
- New OS technologies (e.g., ASLR)

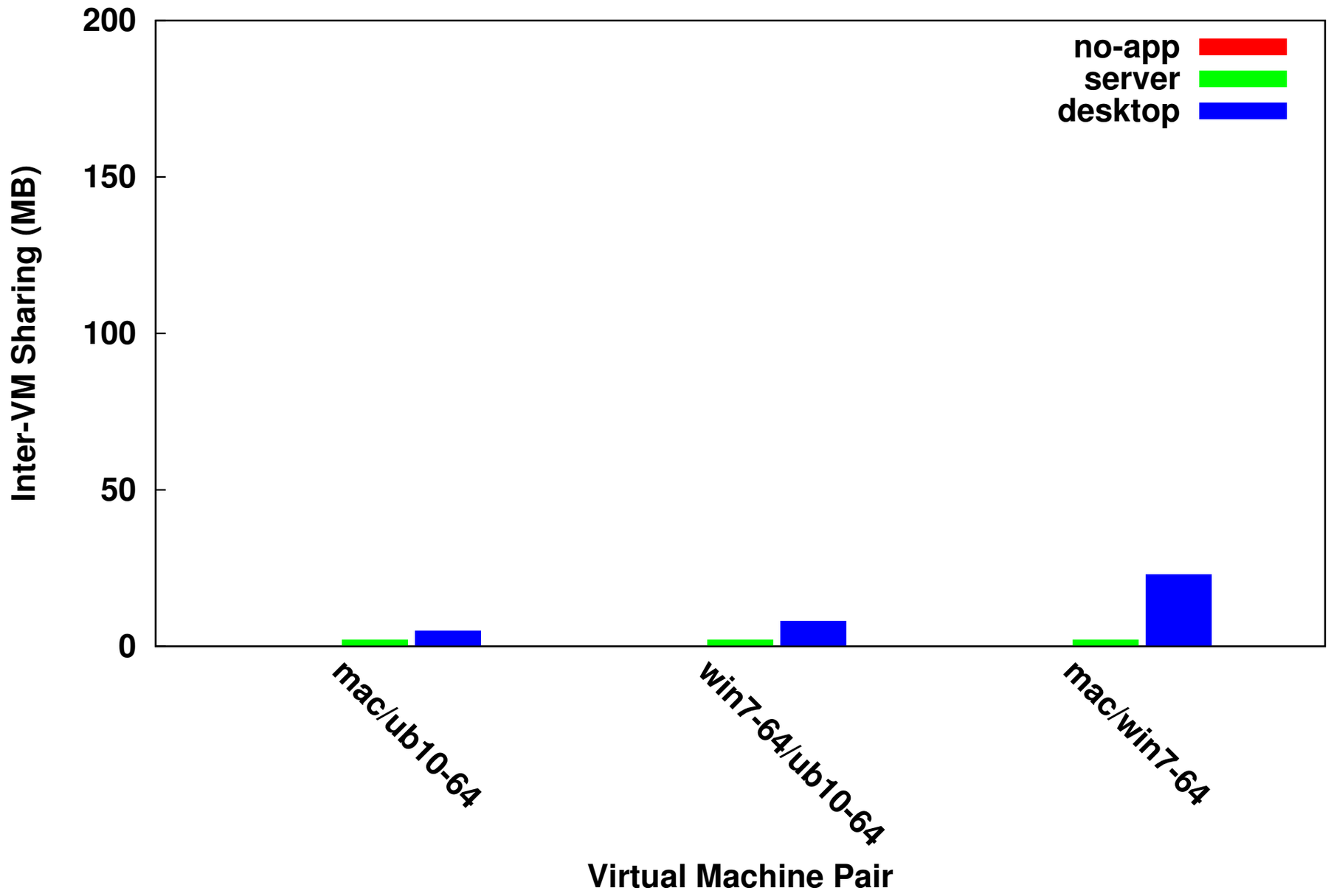
Self-Sharing Across VMs

- **~100 MB** differences between OS families, major versions (XP/7)
- **<20 MB** differences between minor versions, architectures



- Large self-sharing variations between 'base' OSes

Sharing Across VMs



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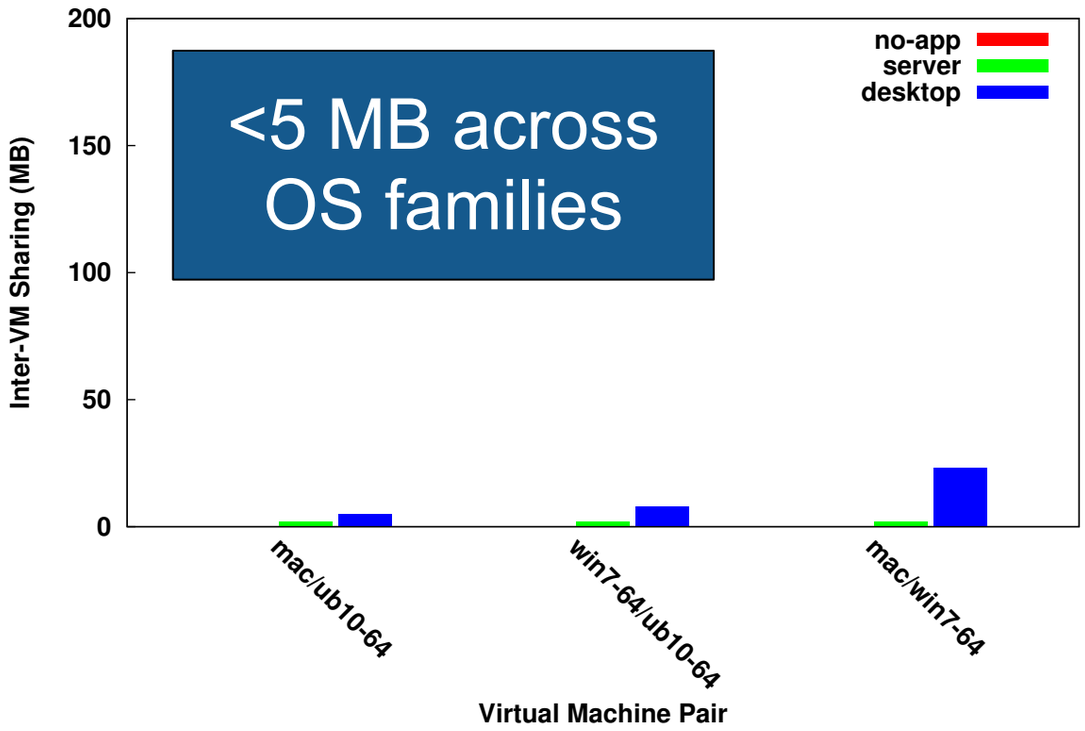

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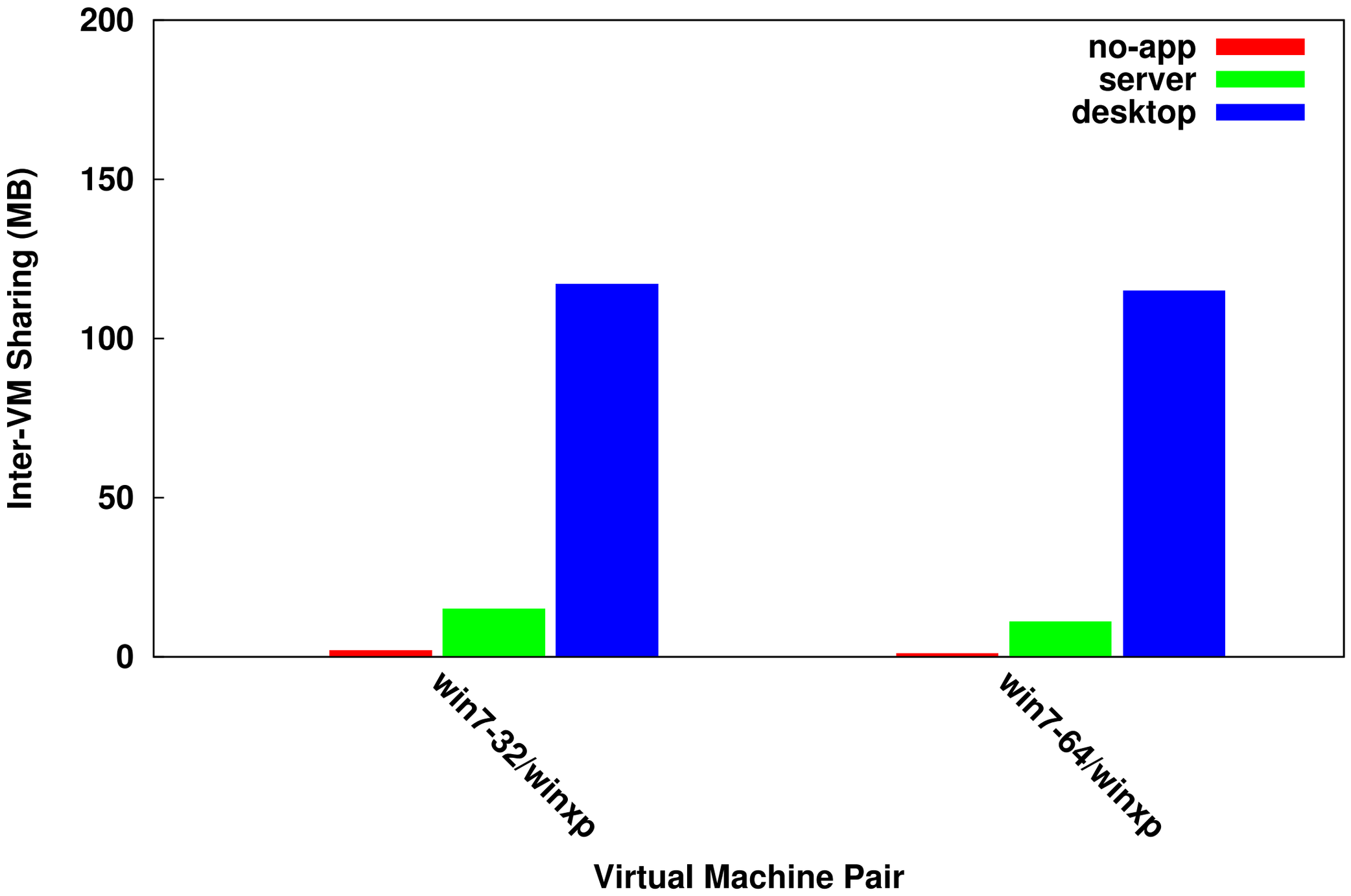

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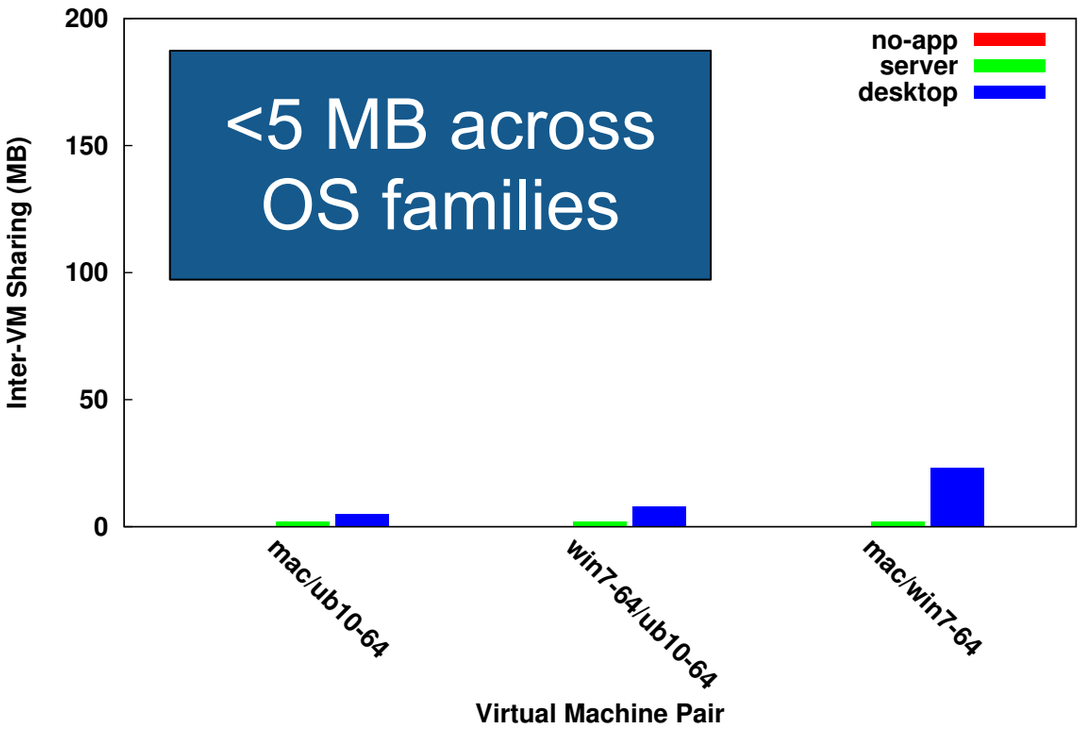

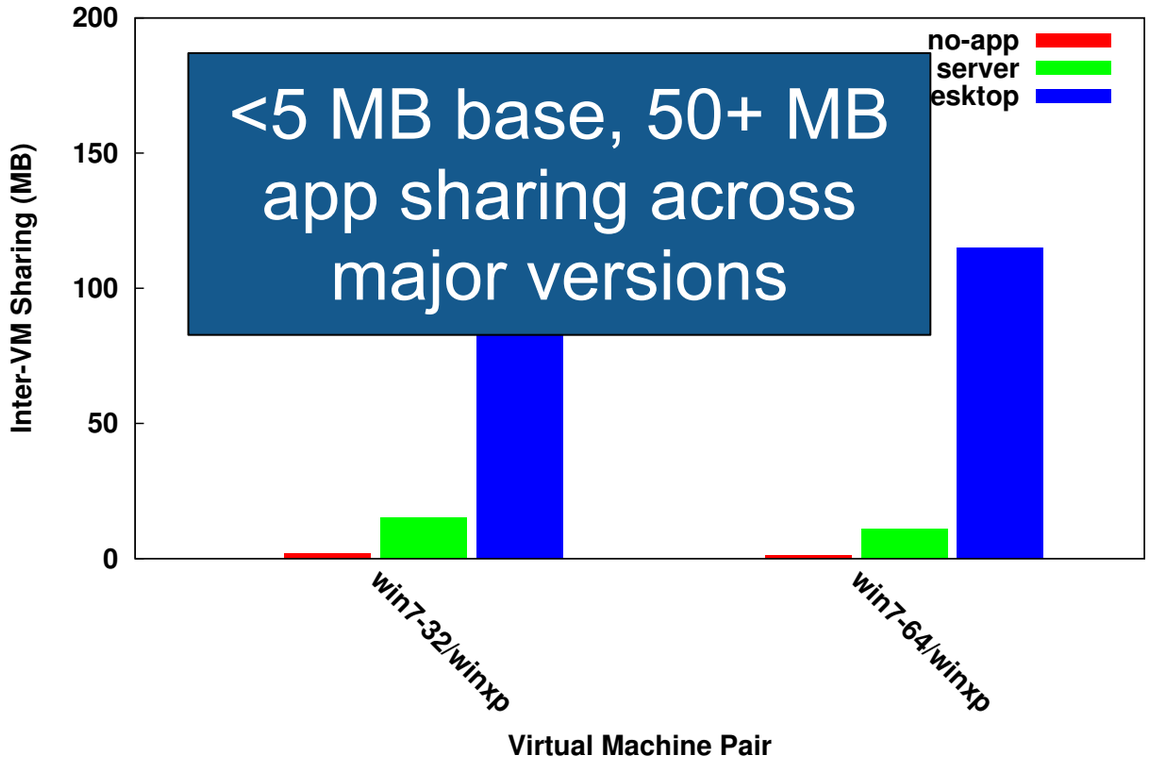

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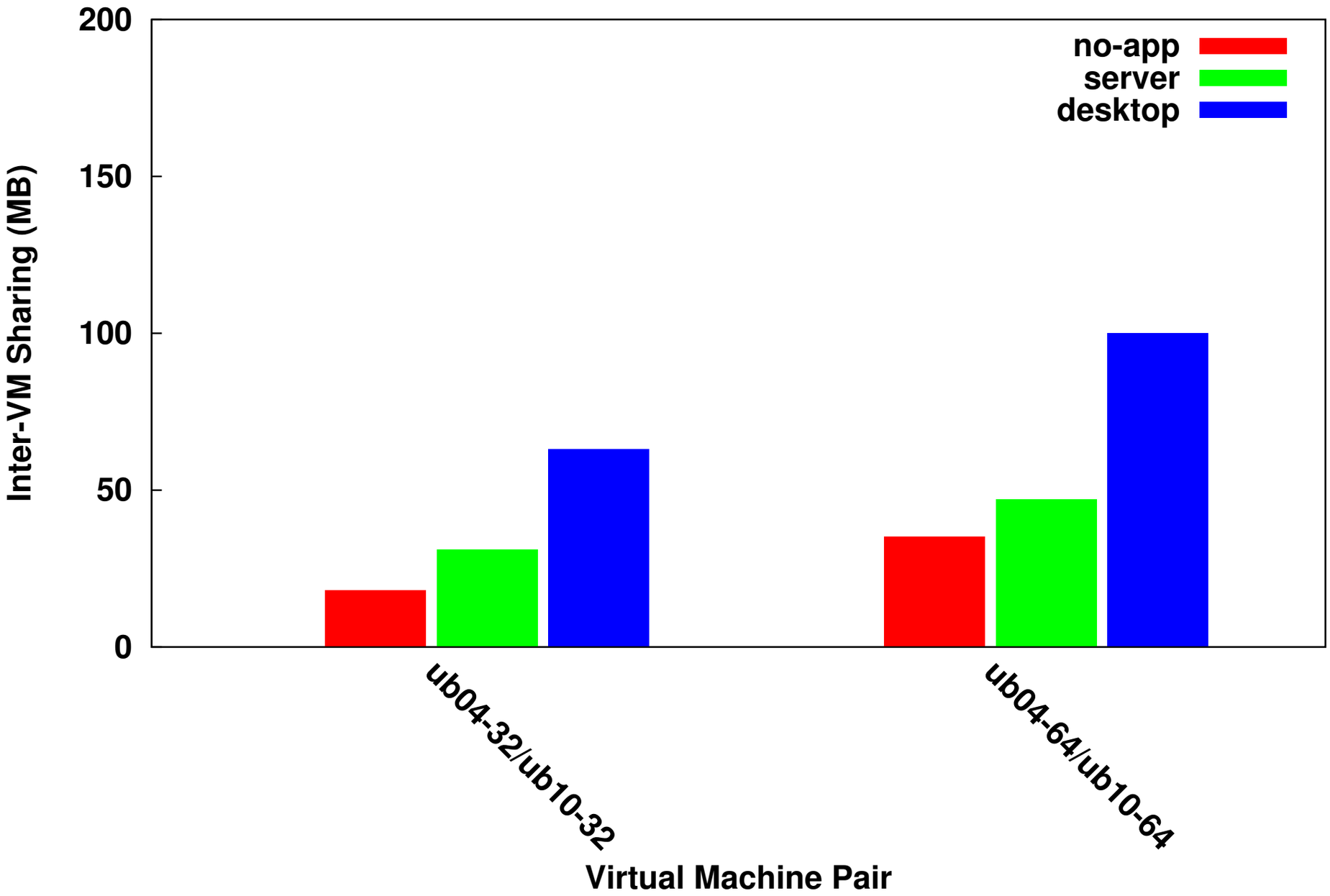

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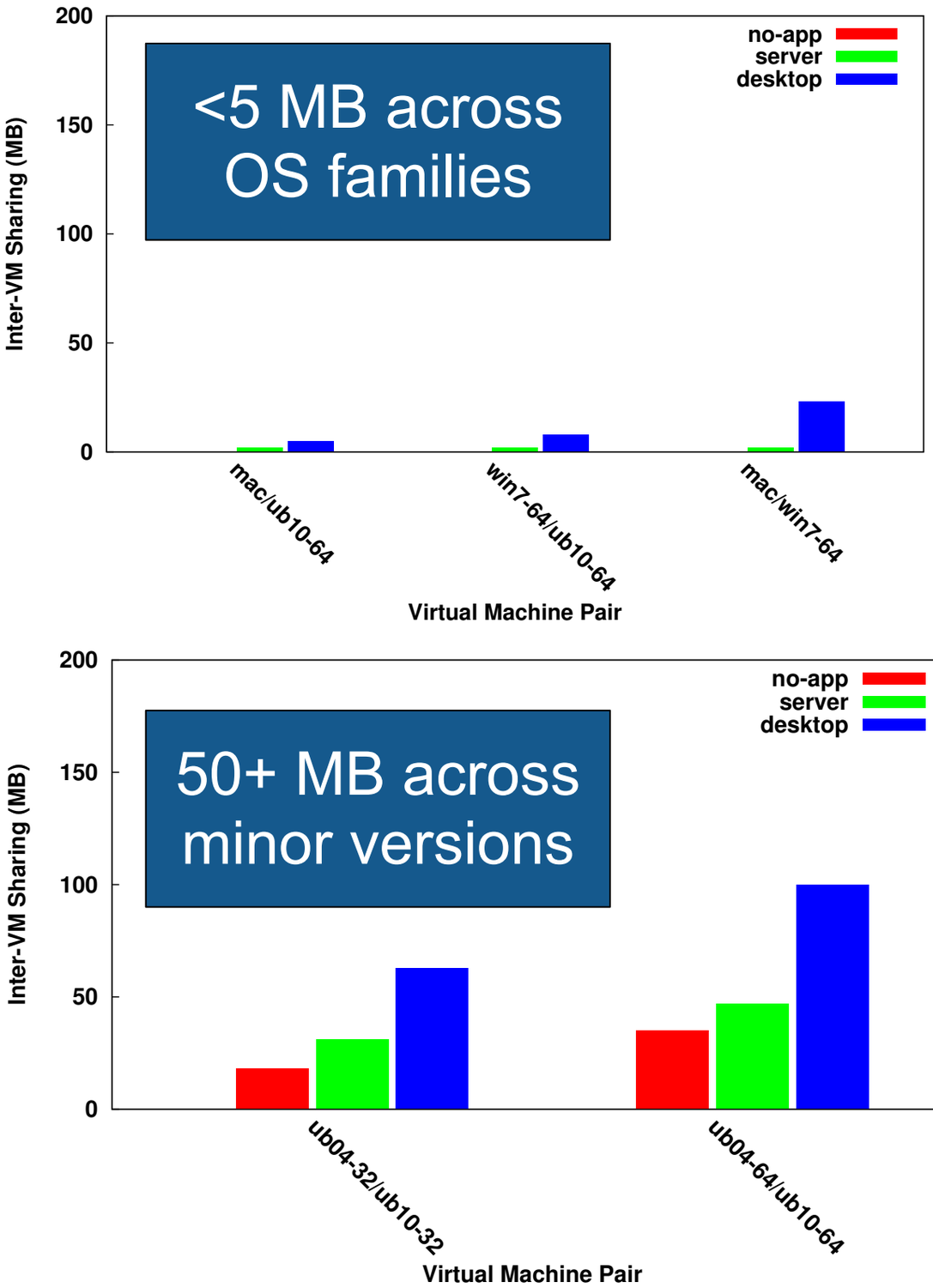

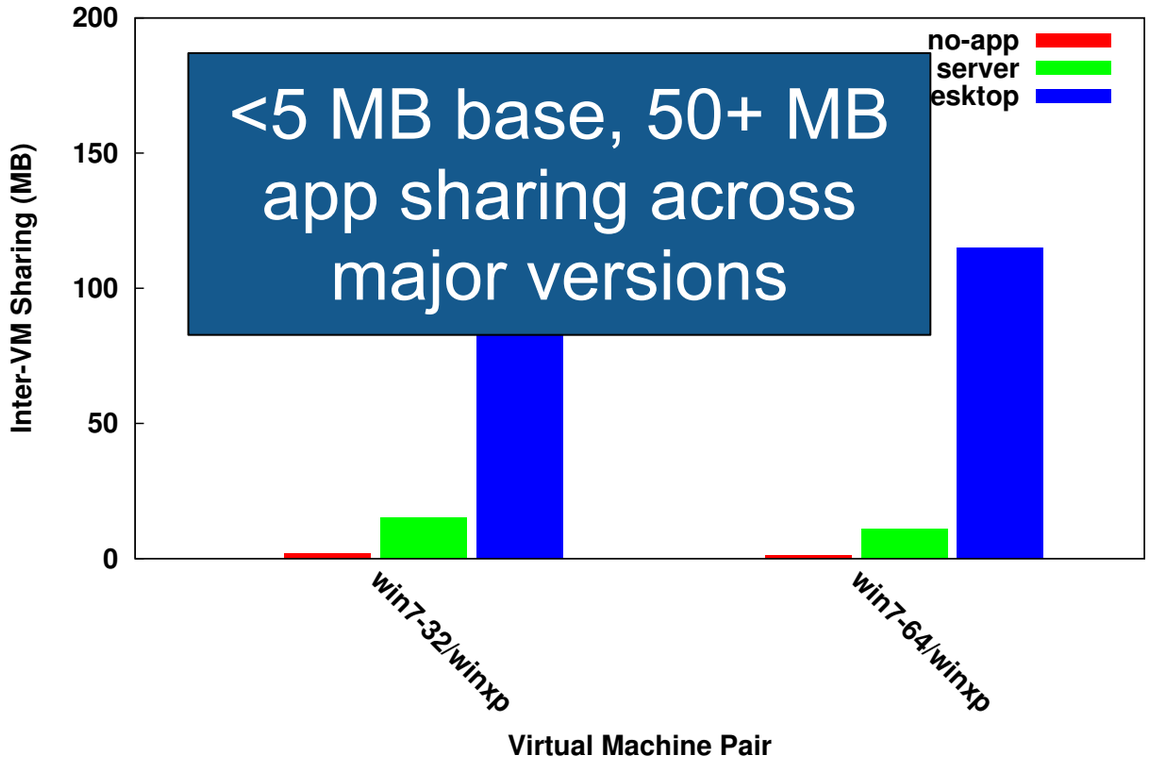

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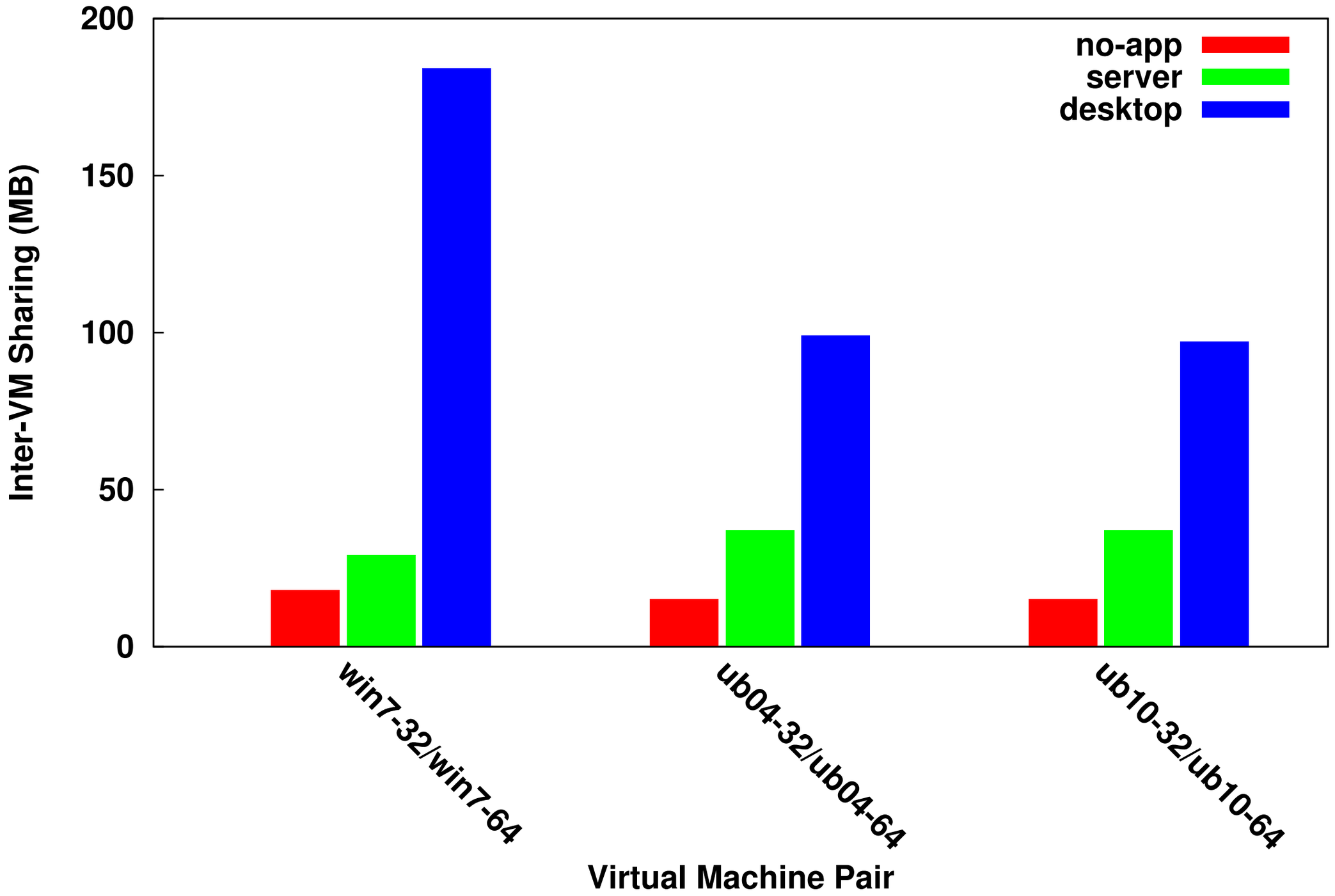

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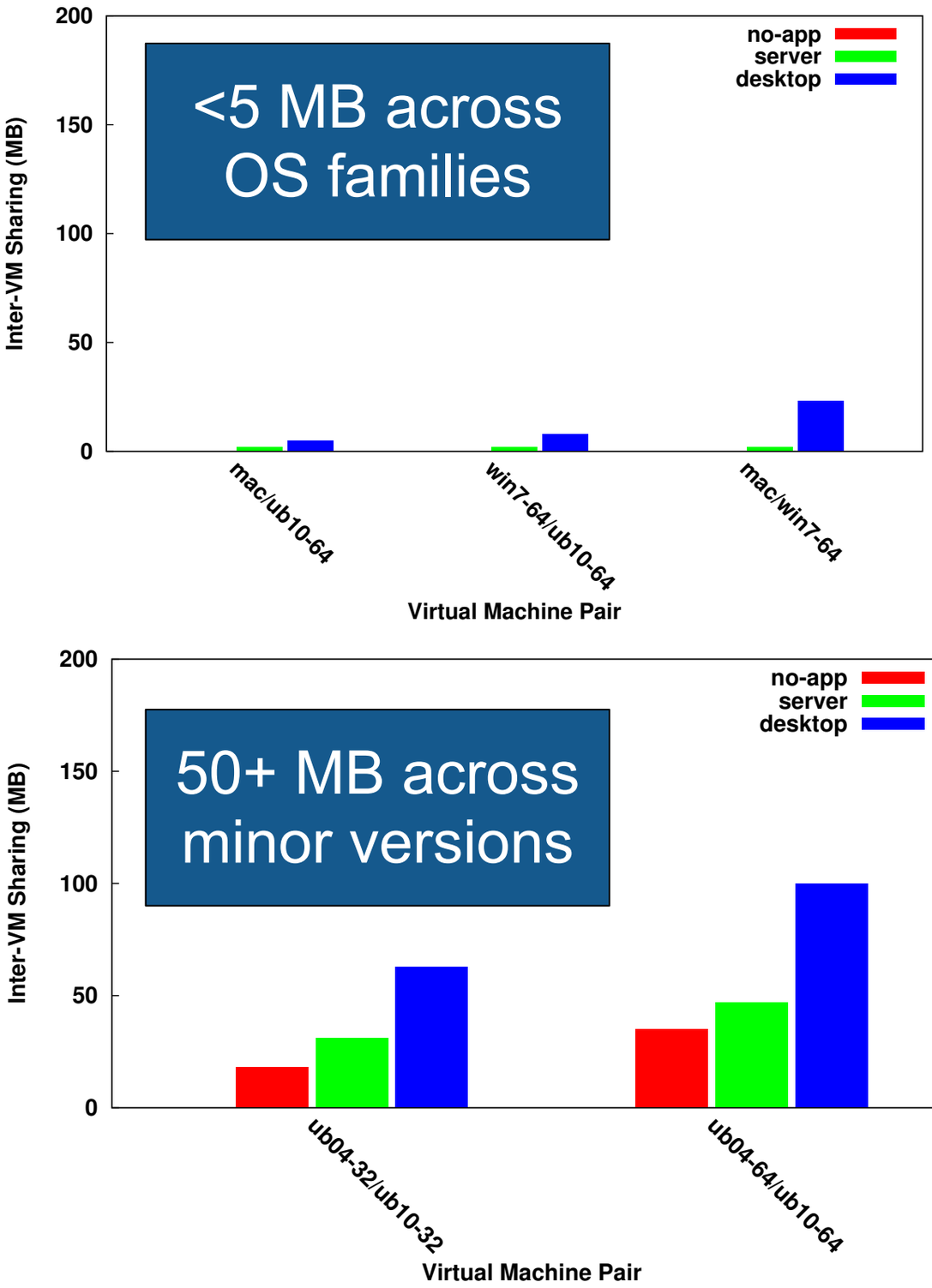

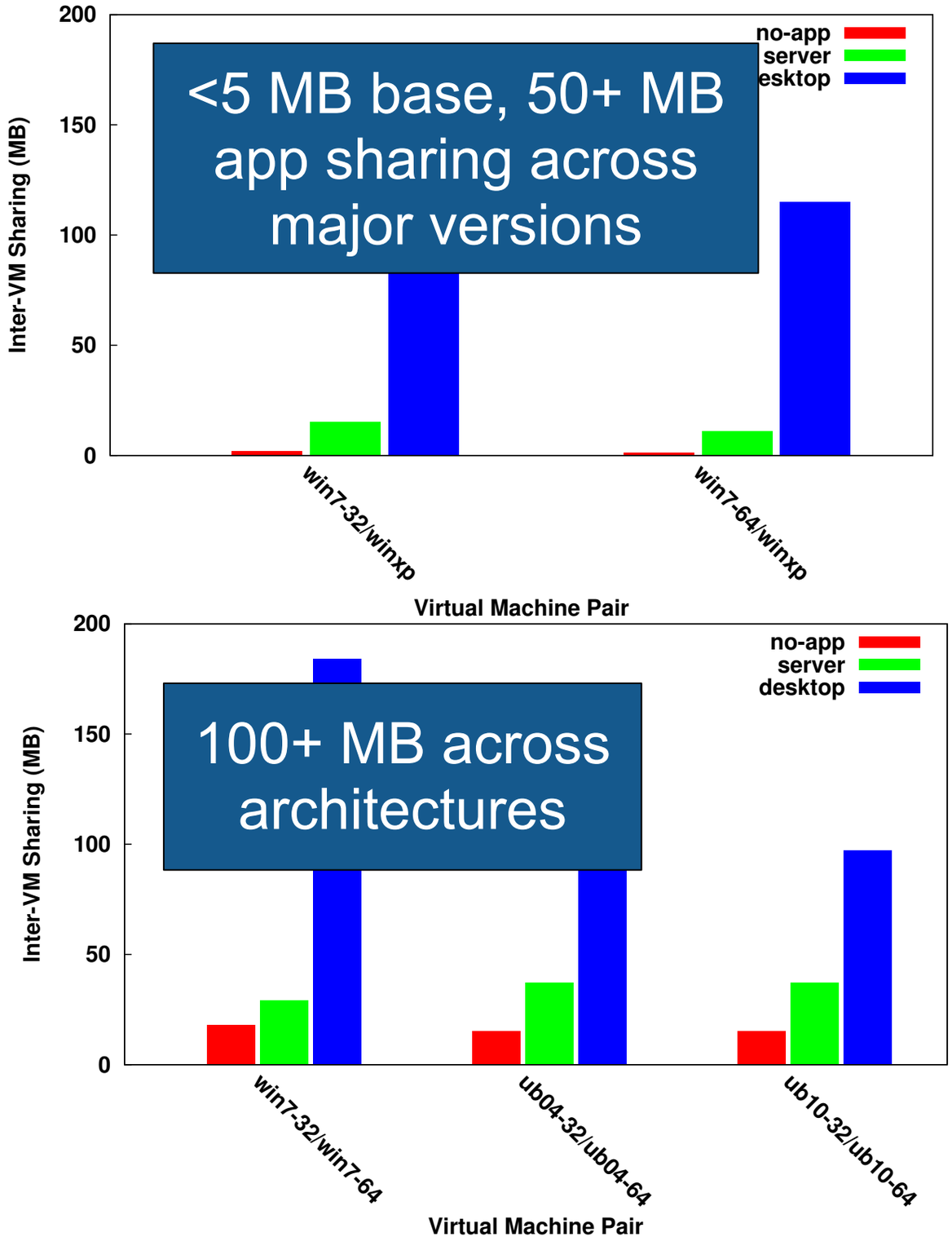

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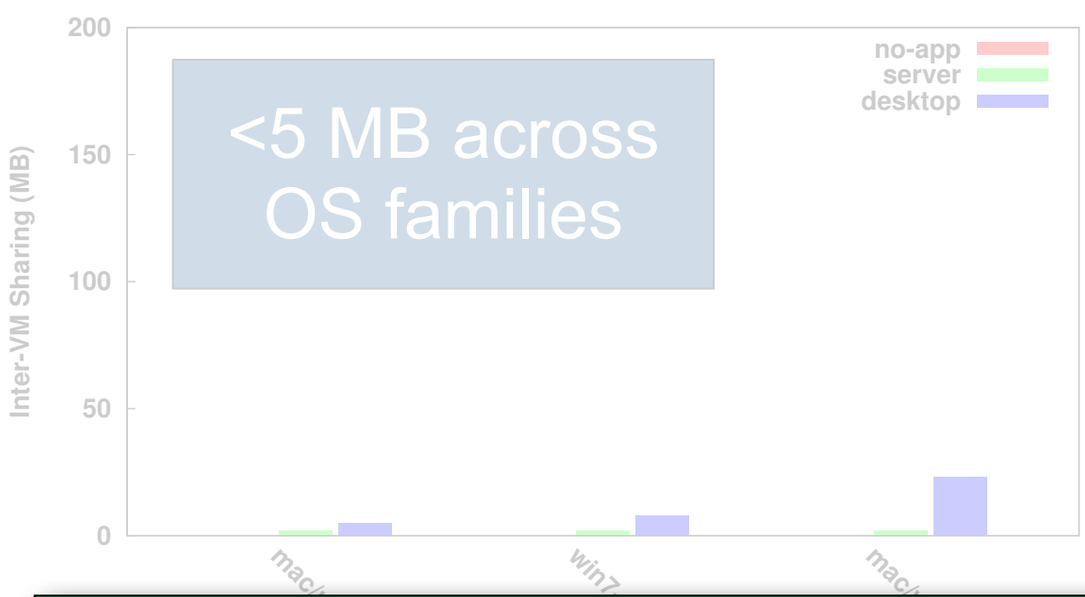
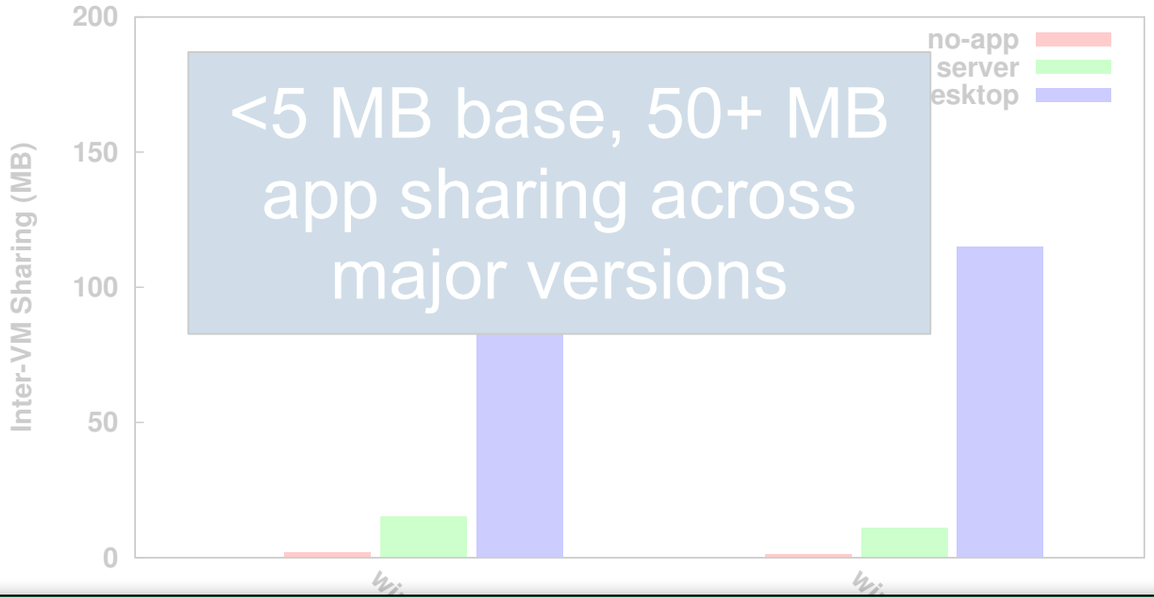
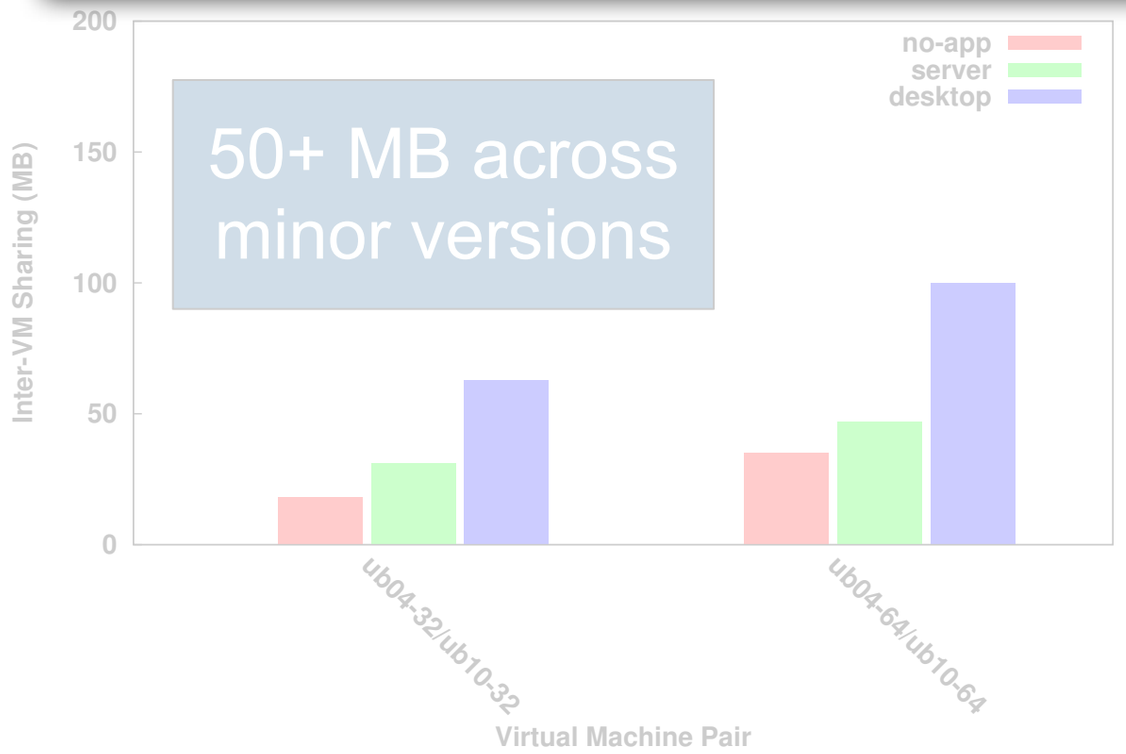
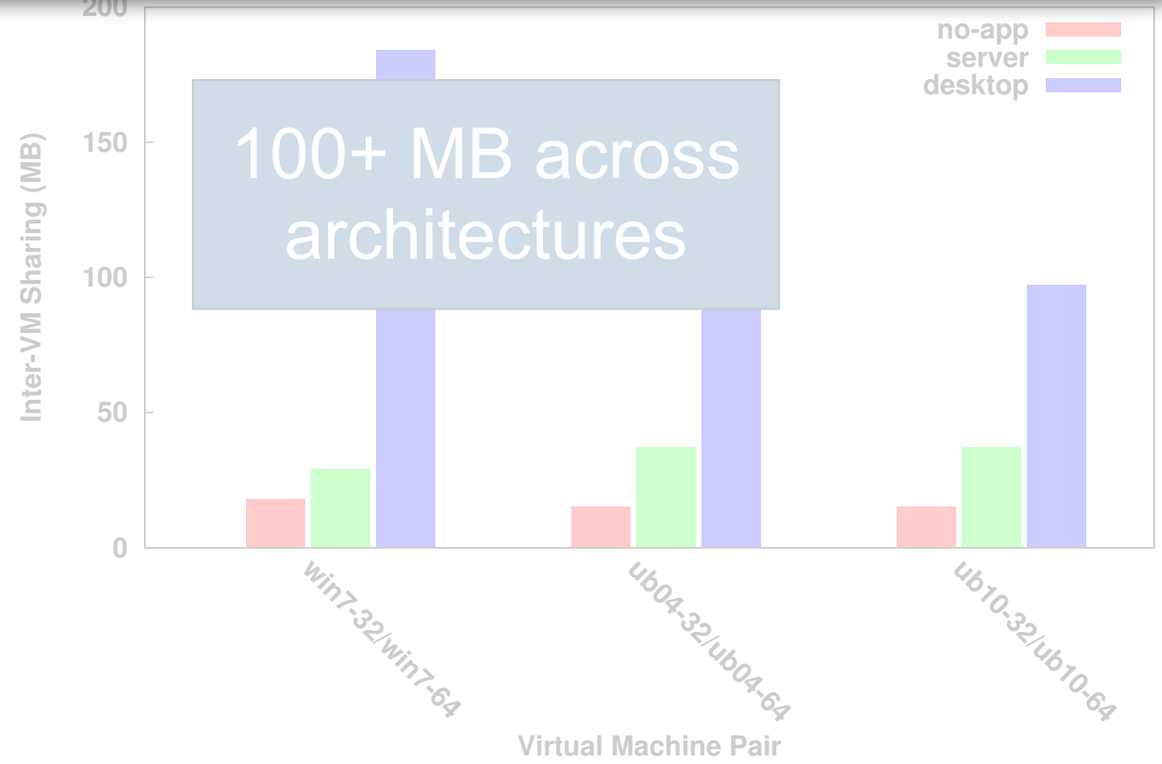




- Hierarchy: family, applications, version, architecture





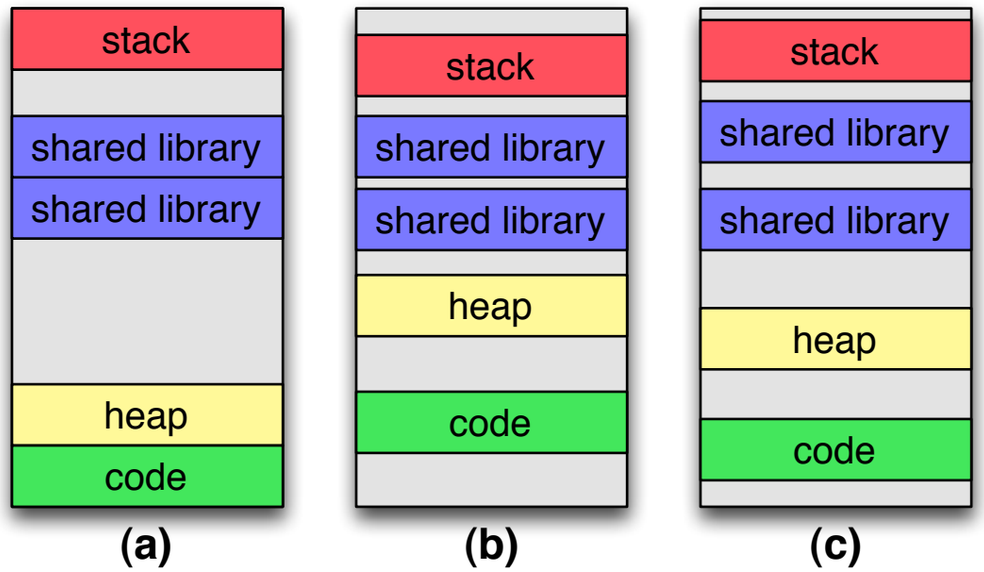
Sharing Granularity

- Share memory chunks of size k (≠1) pages
- Only even page divisions provide decent returns
- Diminishing benefits from smaller chunk sizes

- Tradeoff between overhead and sharing potential

Address Space Layout Randomization

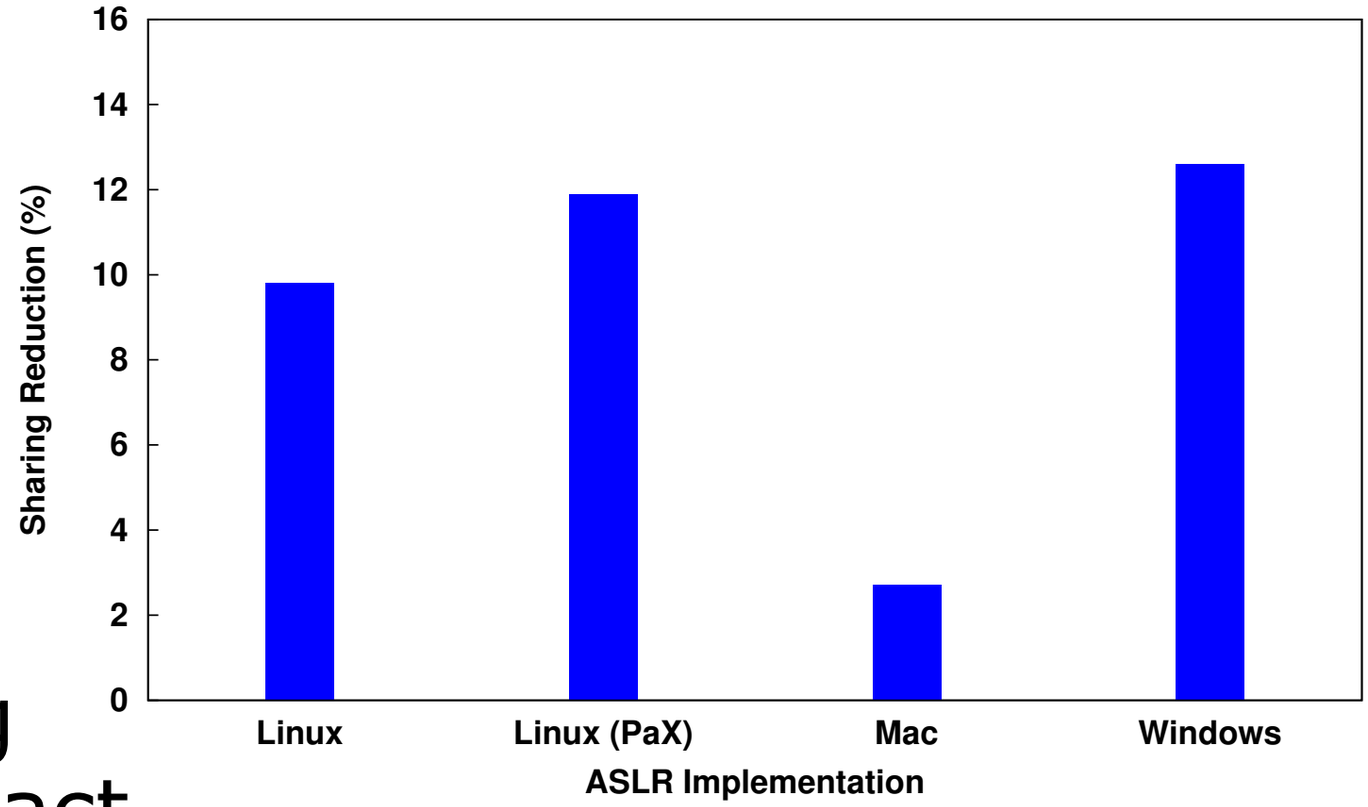
- ASLR scrambles memory to improve system security
  - libraries, code, stack, heap, ...
- Does ASLR have a negative impact on memory sharing?



- Impact of 4 ASLR implementations:
  - Linux: mainline (2.6.32) and PaX
  - Windows 7 (SP1)
  - Mac OS X (Lion)
- Desktop applications with and without ASLR

Sharing Impact of ASLR

- **>10%** reduction in three of four cases



- ‘Better’ (PaX) sharing in Linux worsens impact

- ASLR doesn’t prevent sharing but does reduce it

Sharing Factor Observations

- Hierarchy with respect to sharing potential
  - OS family, application setup, OS version, OS architecture
- Platform homogeneity
  - Minimal sharing across heterogeneous systems
  - Significant gains in homogeneous deployments (but still modest absolute levels)
- Finer-grained sharing may be leveraged to improve sharing potential
- OS improvements like ASLR may reduce sharing

Conclusions

- Study into practical issues of page sharing
  - Examined real-world machines and specific sharing scenarios

- Observed real-world sharing around **15%**
  - Significant, but less than expected
  - Largely self-sharing, for which **no virtualization needed**

- Studied a variety of factors impacting sharing
  - Key role of platform homogeneity
  - Varying impact of modifying OS characteristics and applications
  - New technologies may change the impact of sharing

Questions?
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