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Outline

- Motivation for page sharing
- Existing systems (a.k.a. state of the art)
- Satori overview
- Implementation
- Performance results

Motivation

- Virtualisation becomes ubiquitous

  "The number of virtualized PCs is expected to grow from less than 5 million in 2007 to 660 million by 2011"

  Source: Gartner, 2008

- Provisioning computer systems with memory
  - is expensive (hardware cost)
  - consumes power (running cost)
  - is inflexible (limited # of slots, limited chip size)

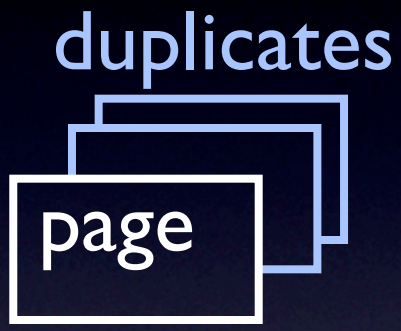
Motivation

- Homogeneous VMs common
- Identical OSes use identical data:
  - binaries (kernel + programs)
  - libraries
  - configuration files
  - some data files
- Amount of sharable memory
  - up to 70-80% for synthetic workloads
  - ~21% for Linux kernel compilation

Motivation

- Memory sharing reduces VM footprint
- Memory overhead of subsequent homogenous VMs is smaller
- Extra memory can be used to
  - increase page cache size, and thus reduce paging I/O rate
  - increase # of VMs on the host

Sharing cycle



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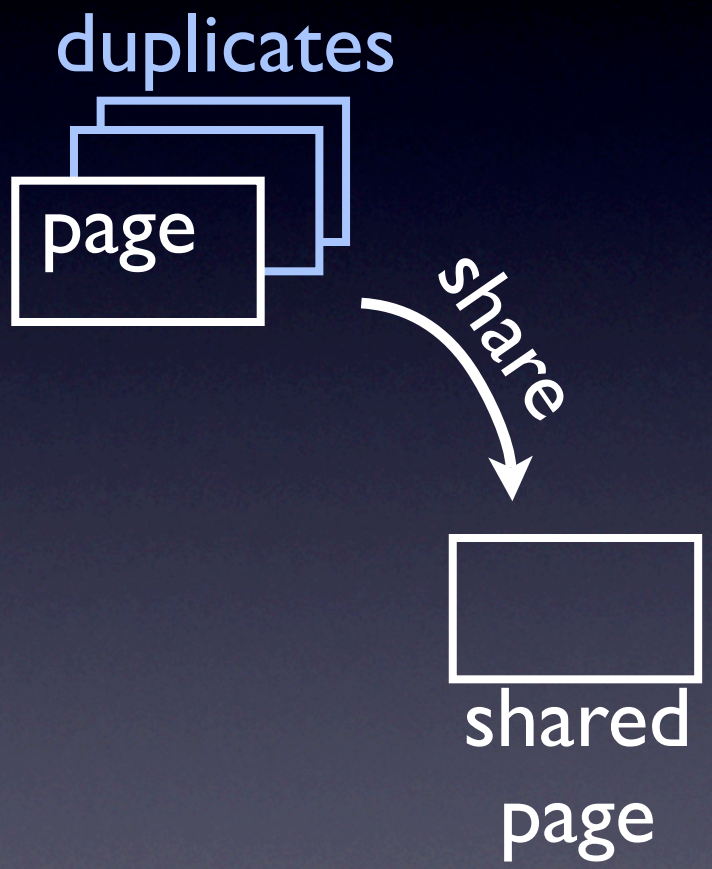

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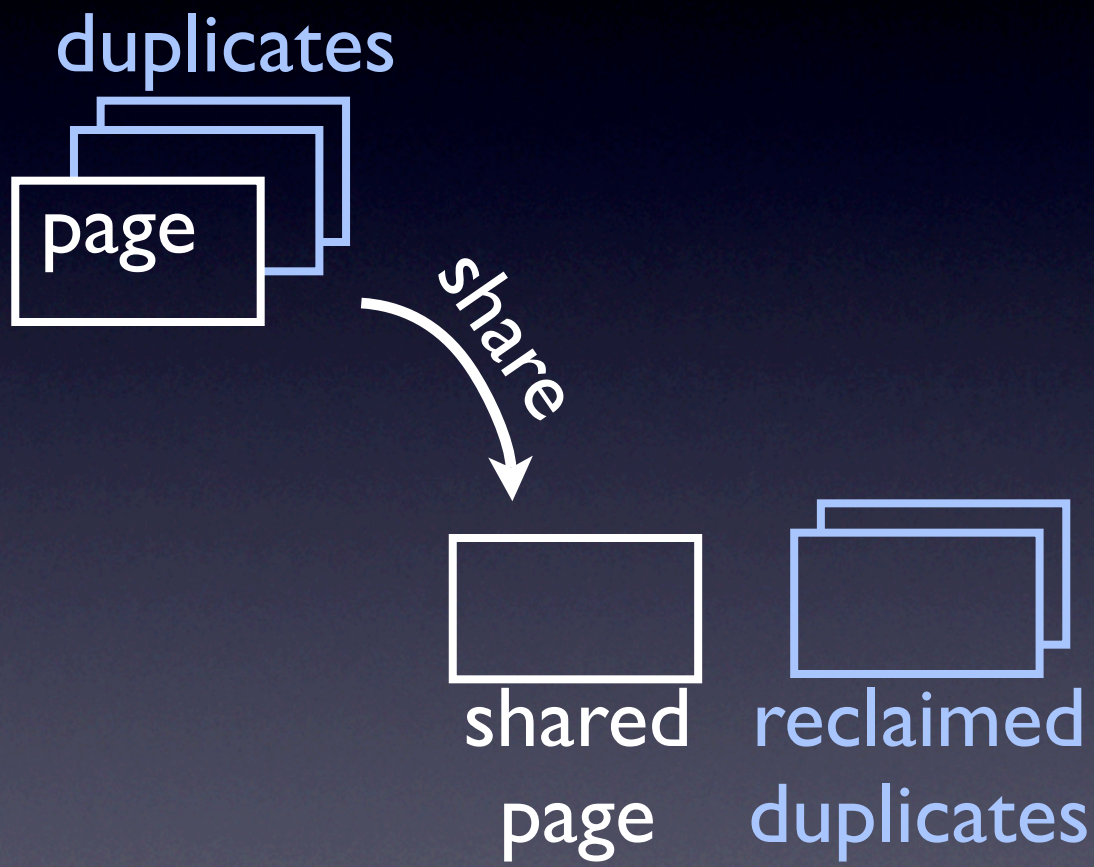

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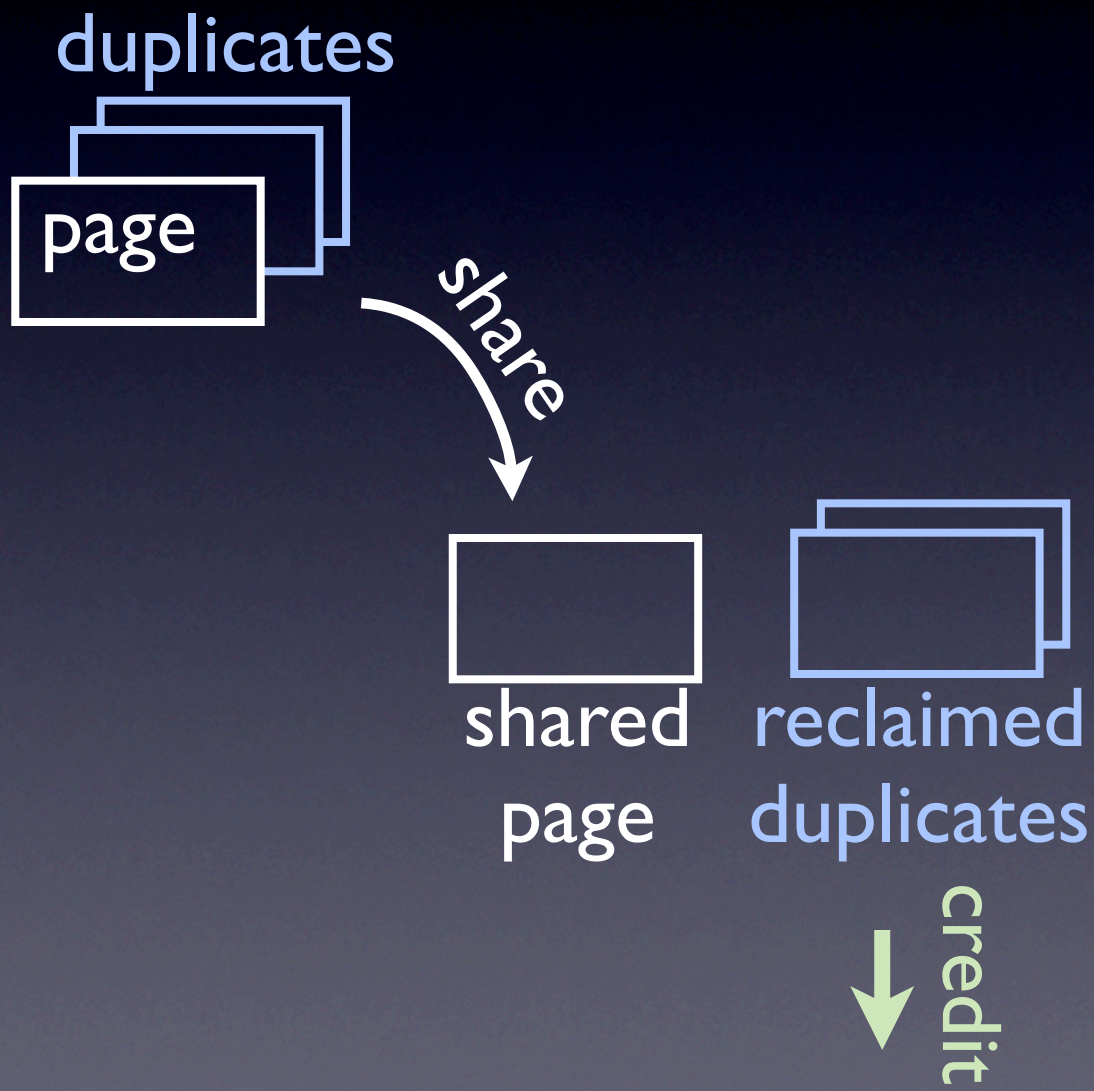

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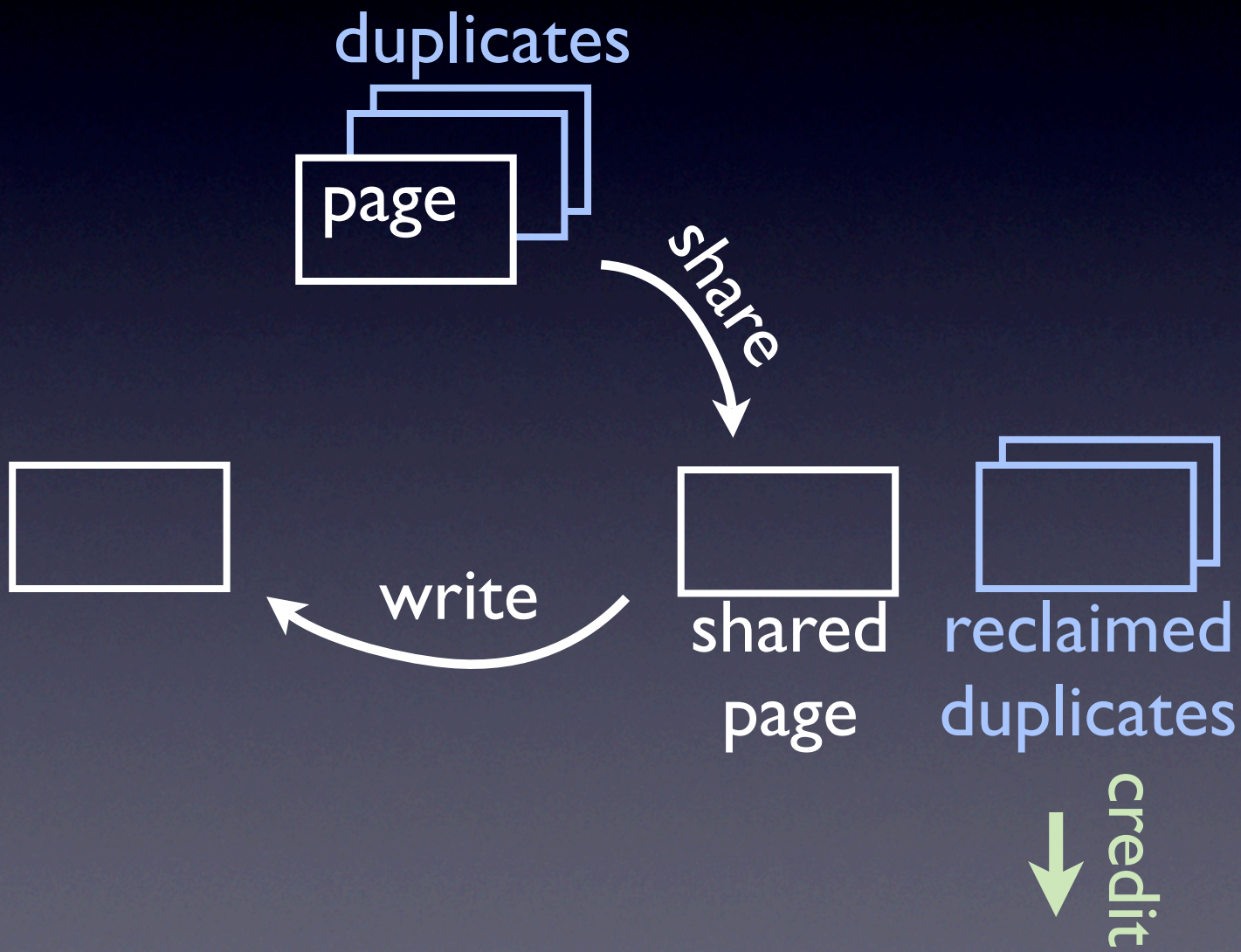

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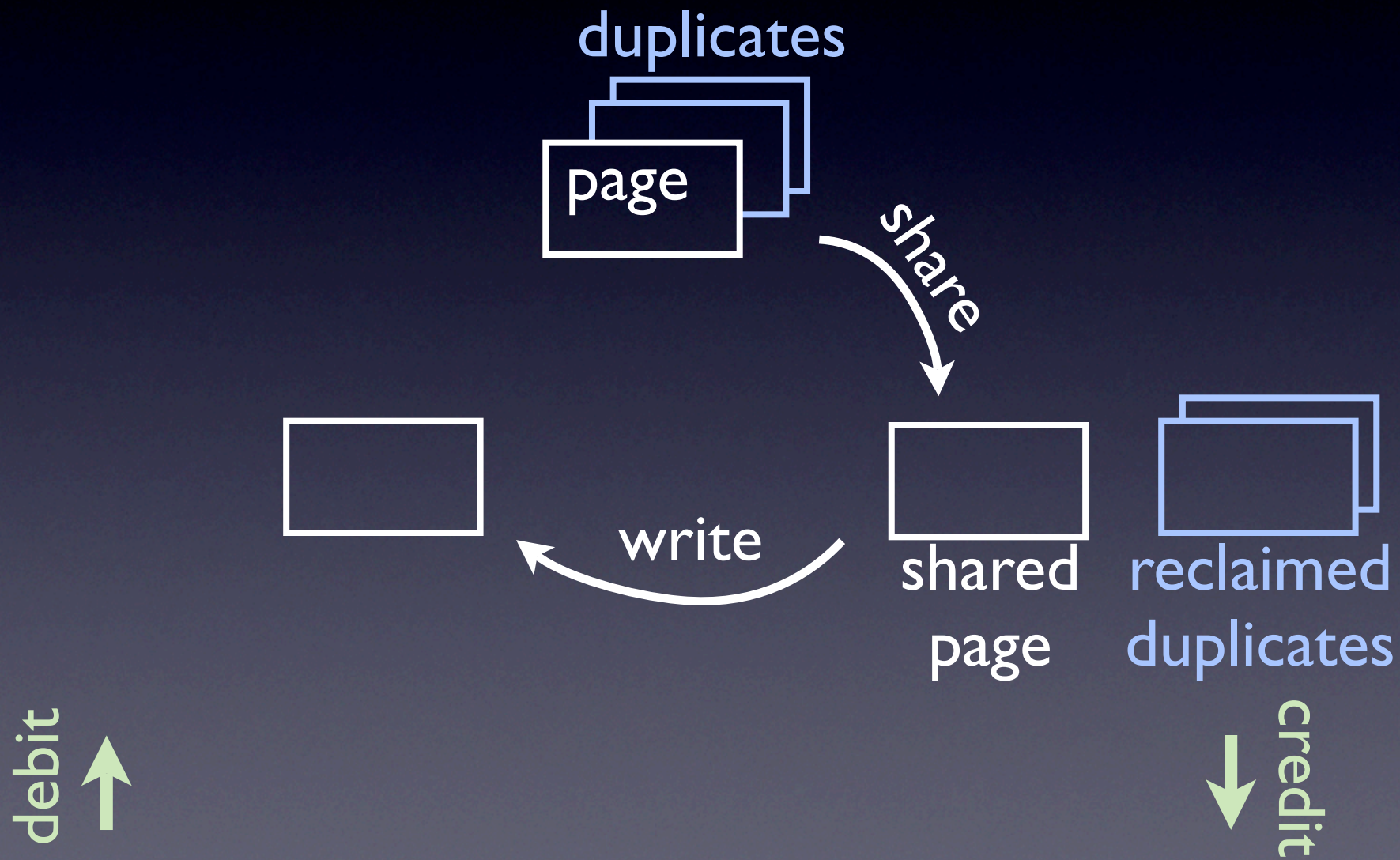

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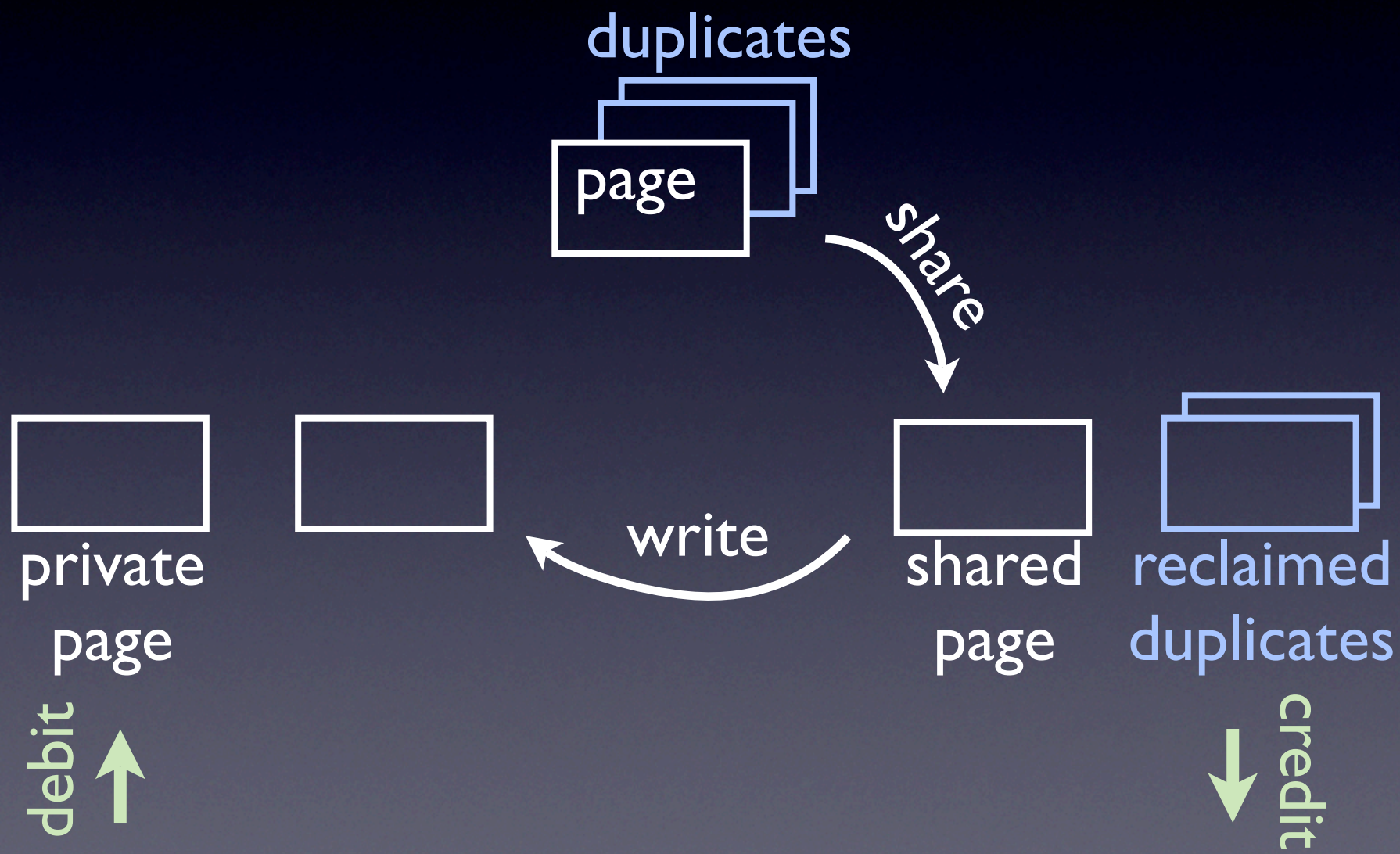

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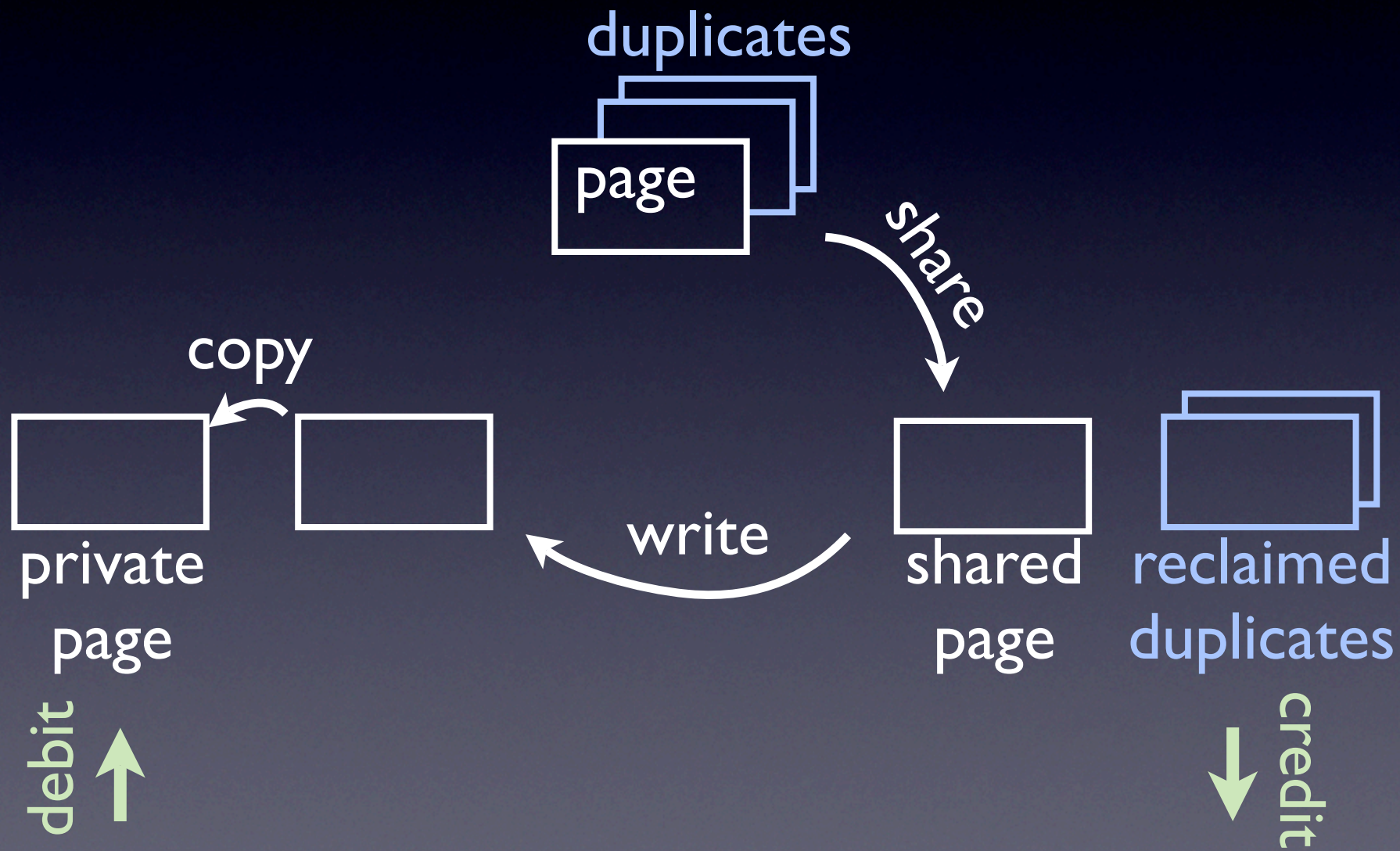

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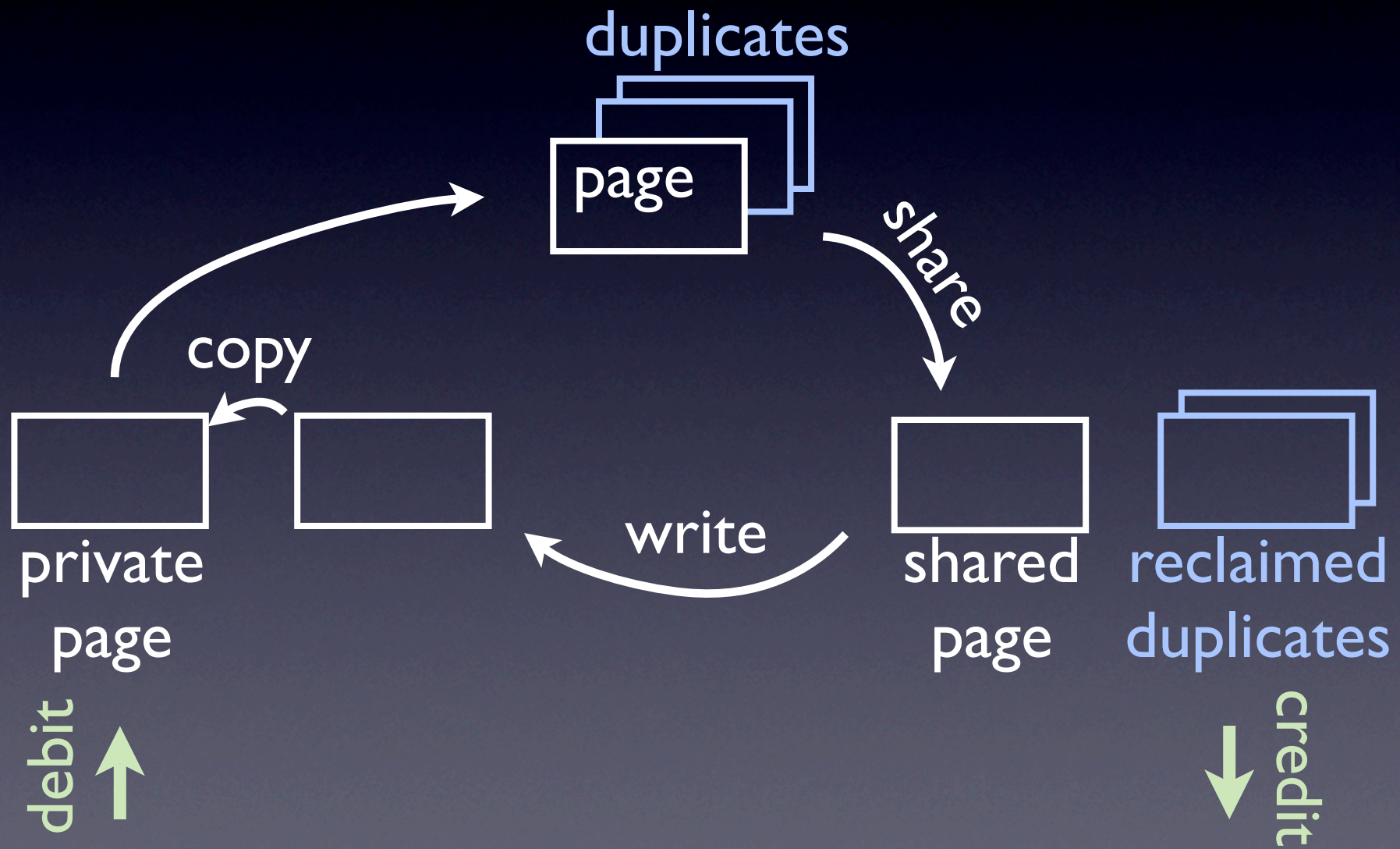

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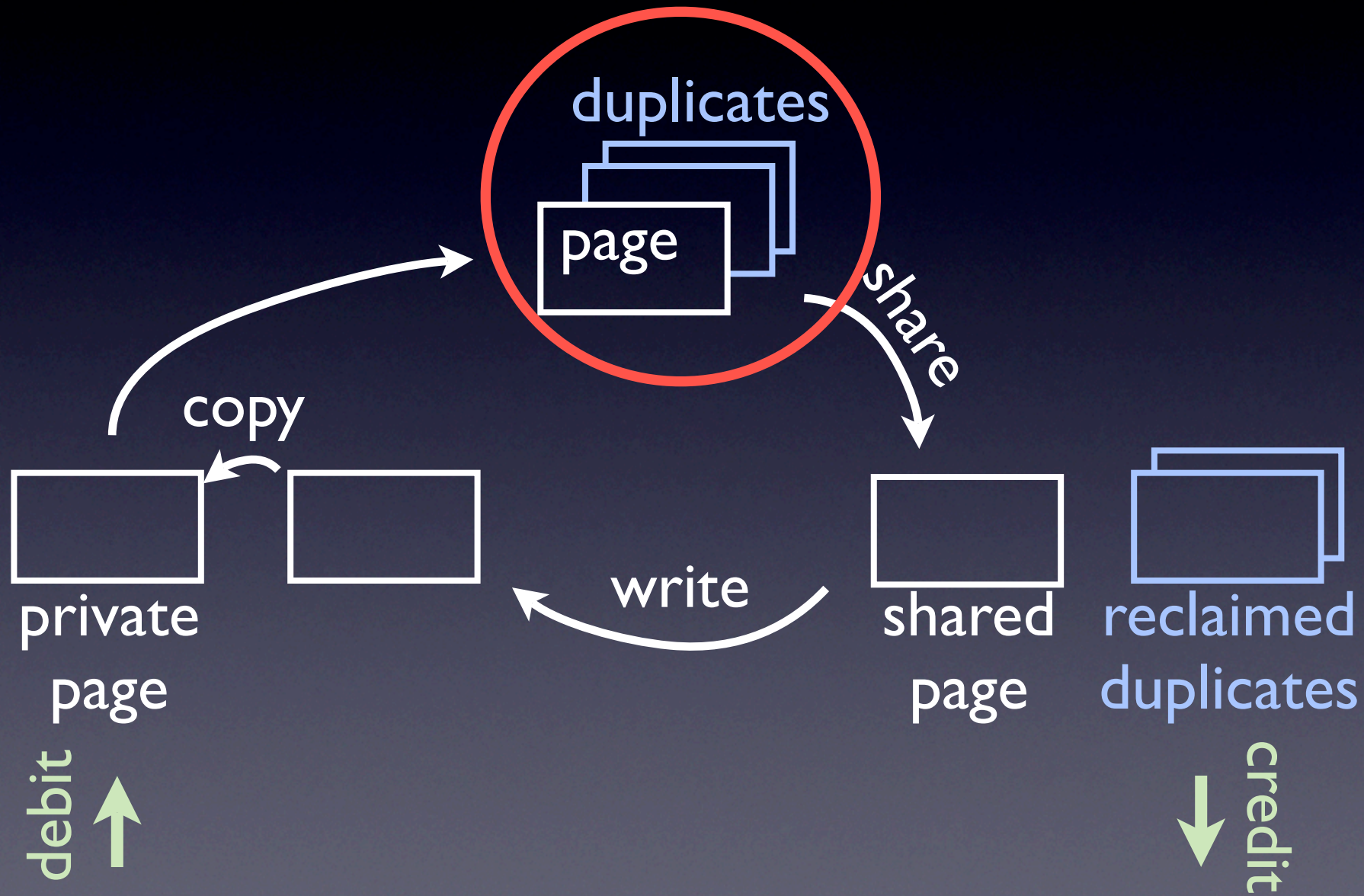

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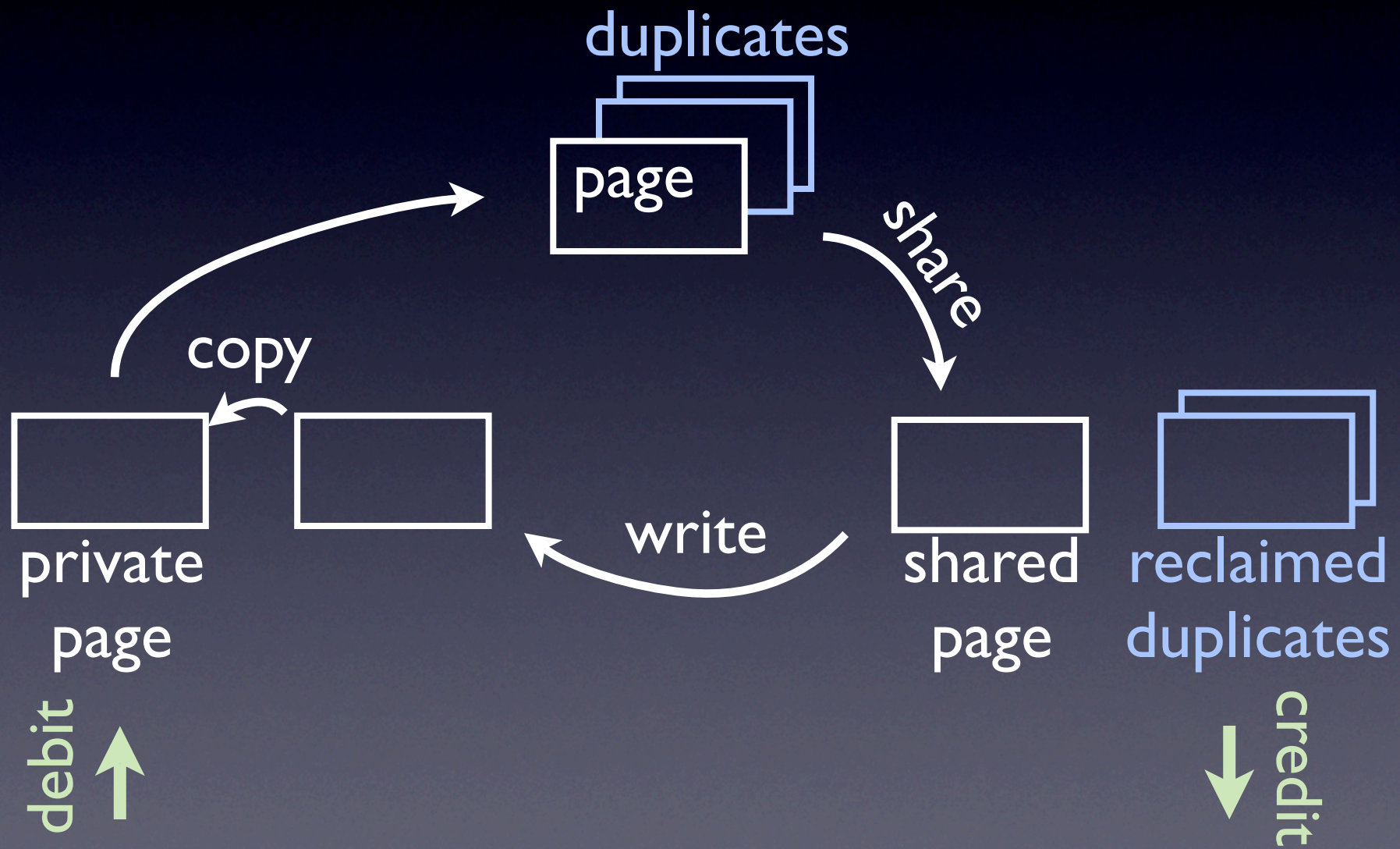

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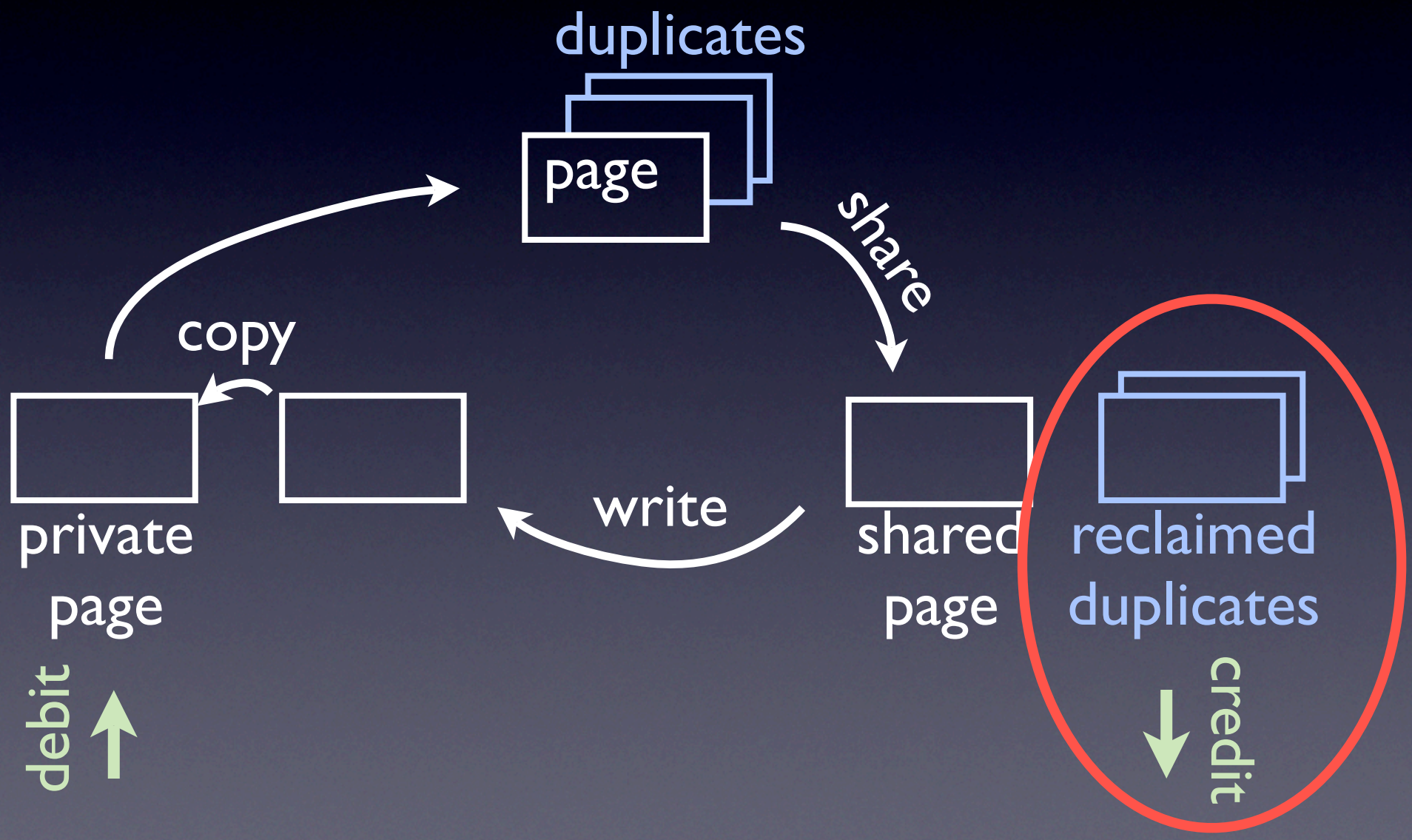

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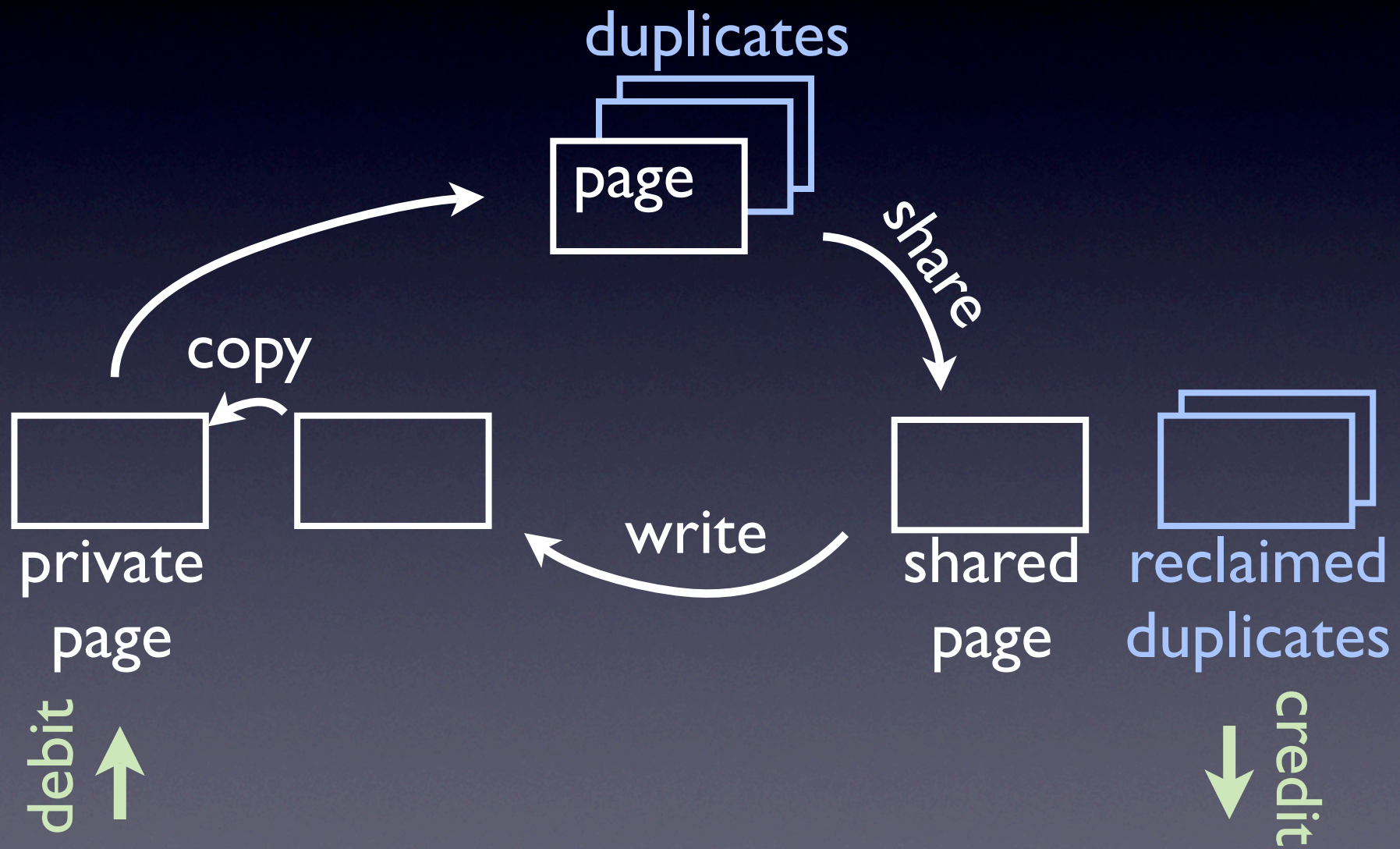

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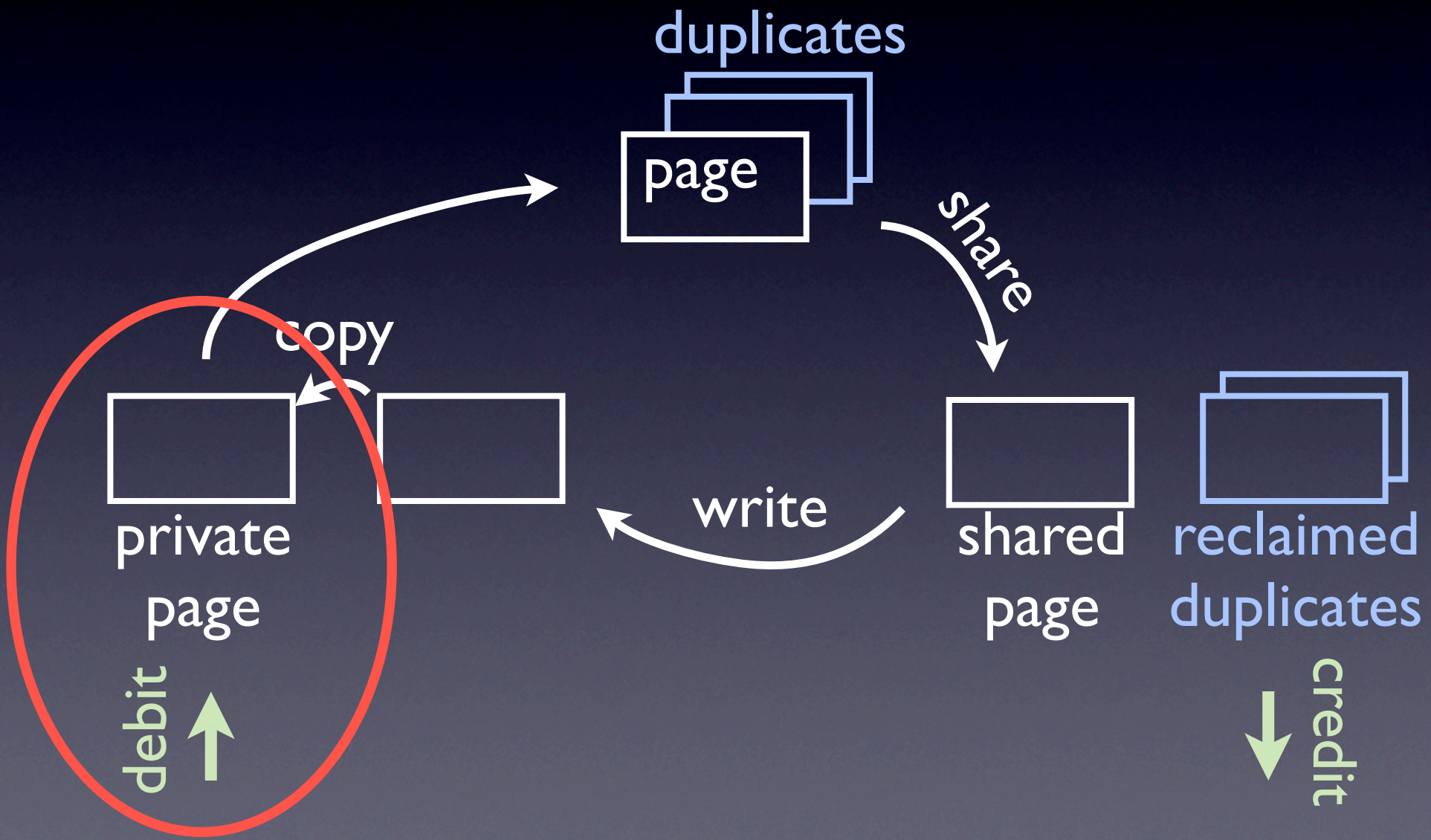

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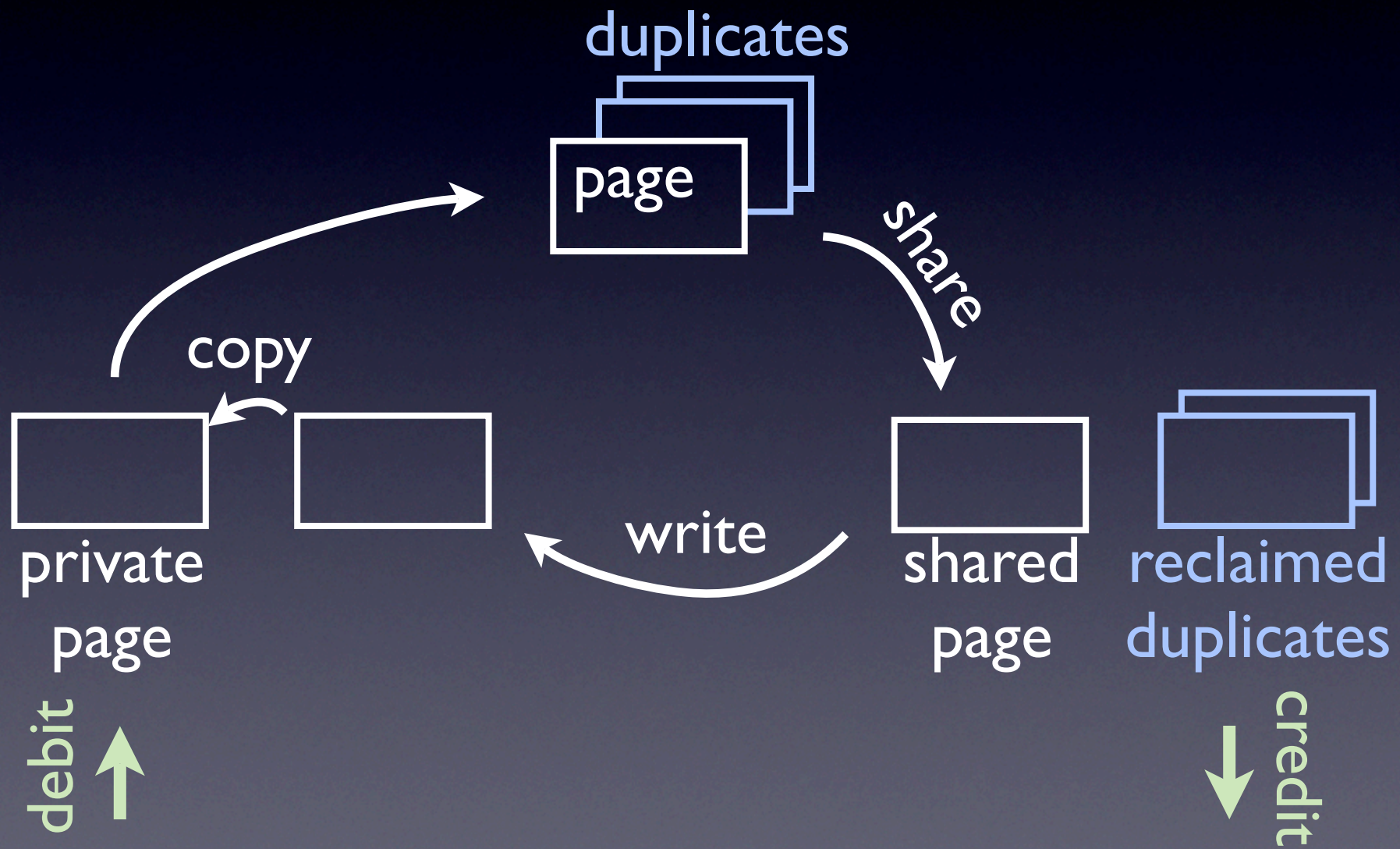

Satori key objectives

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1. Detect sharing quickly and cheaply

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   Hypervisor scans guest memory
   and compares fingerprints

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Satori monitors virtual I/O devices

→ *no periodic scanning*

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Hypervisor manages common pool of surplus memory

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Hypervisor implements secondary
memory paging algorithm

Satori key objectives

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Satori monitors virtual I/O devices

→ *no periodic scanning*

2. Distribute memory savings fairly

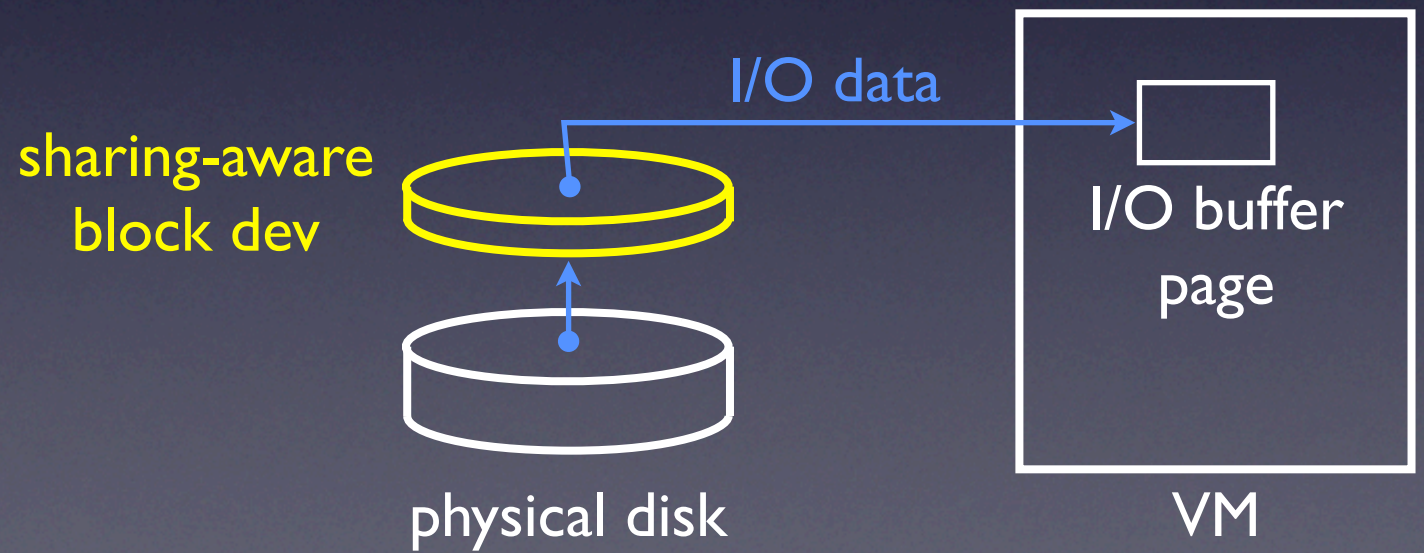
VMs receive *sharing entitlements*
in proportion to # pages shared

3. Reclaim memory efficiently

Memory managed *exclusively* by the VMs
sharing exposed to the VMs

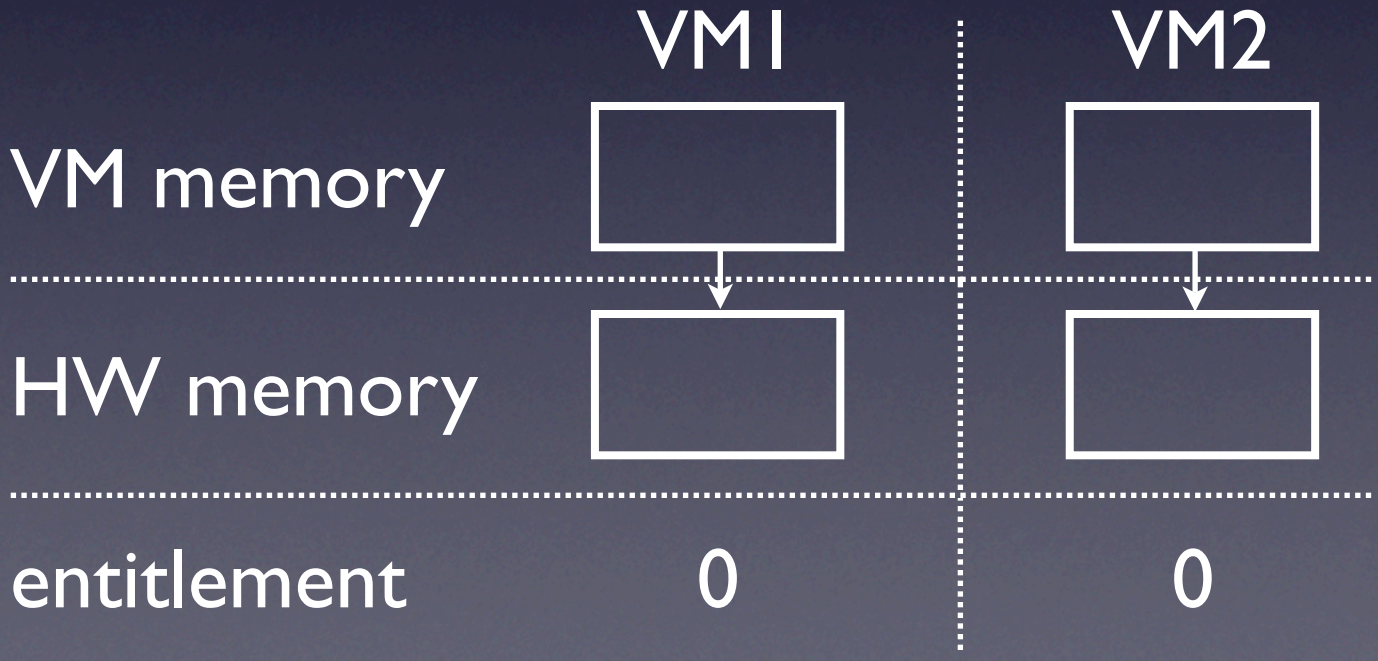
Sharing-aware block devs

- Intuition: most (non-zero) duplicates originate from VM page caches
- Sharing-aware block devices observe I/O reads to build up knowledge of page caches



Sharing entitlements

- Satori tracks the owners of shared pseudo-physical pages
- Entitlement proportional to the # of pages shared & # of pages reclaimed



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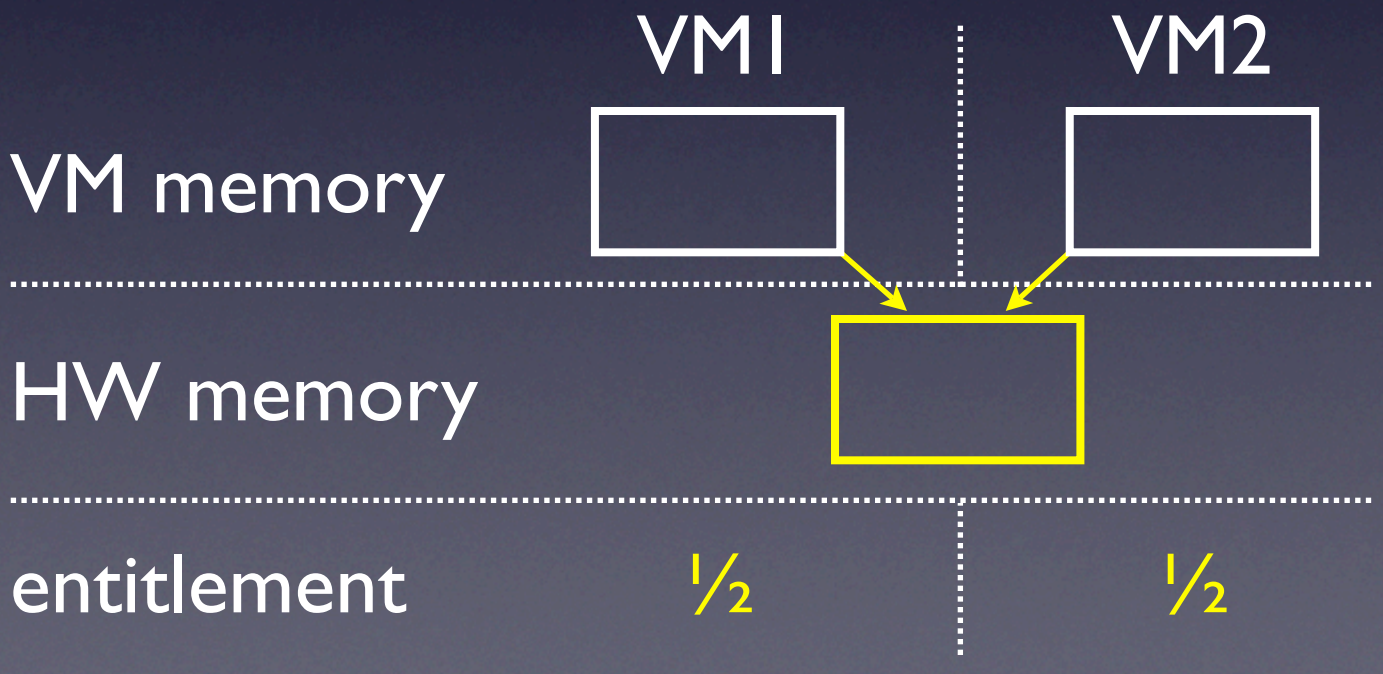

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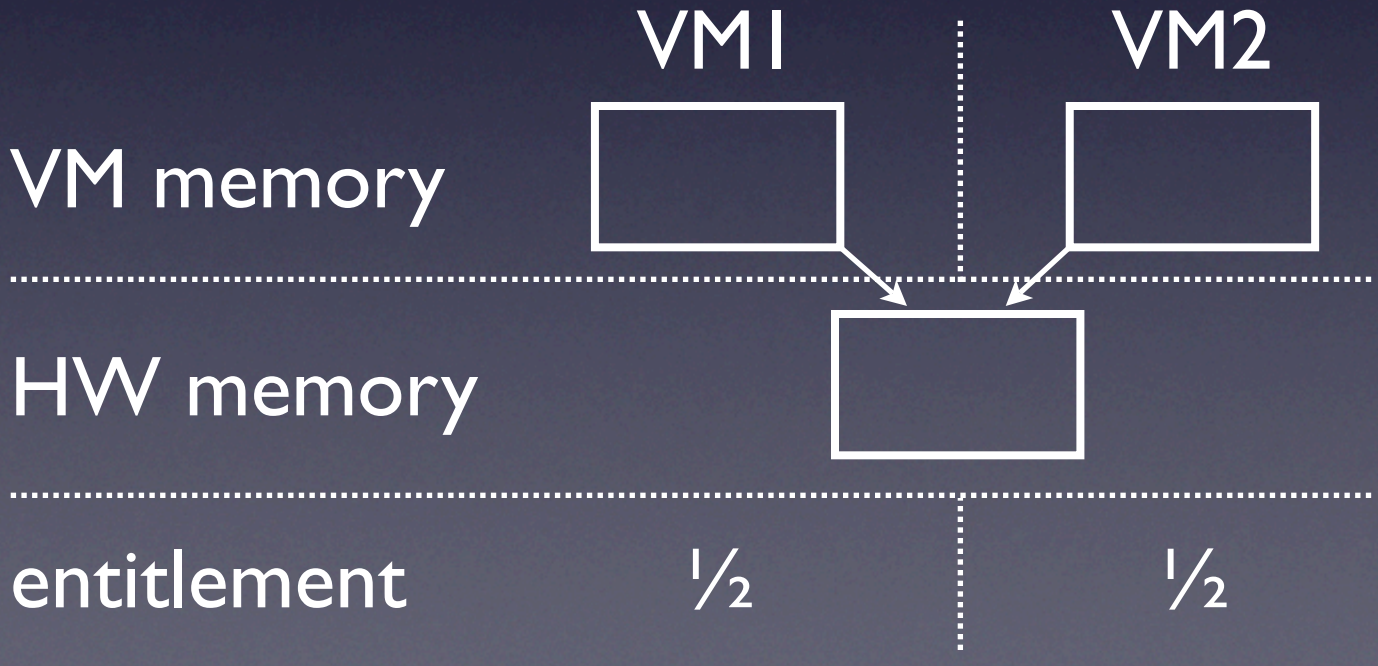

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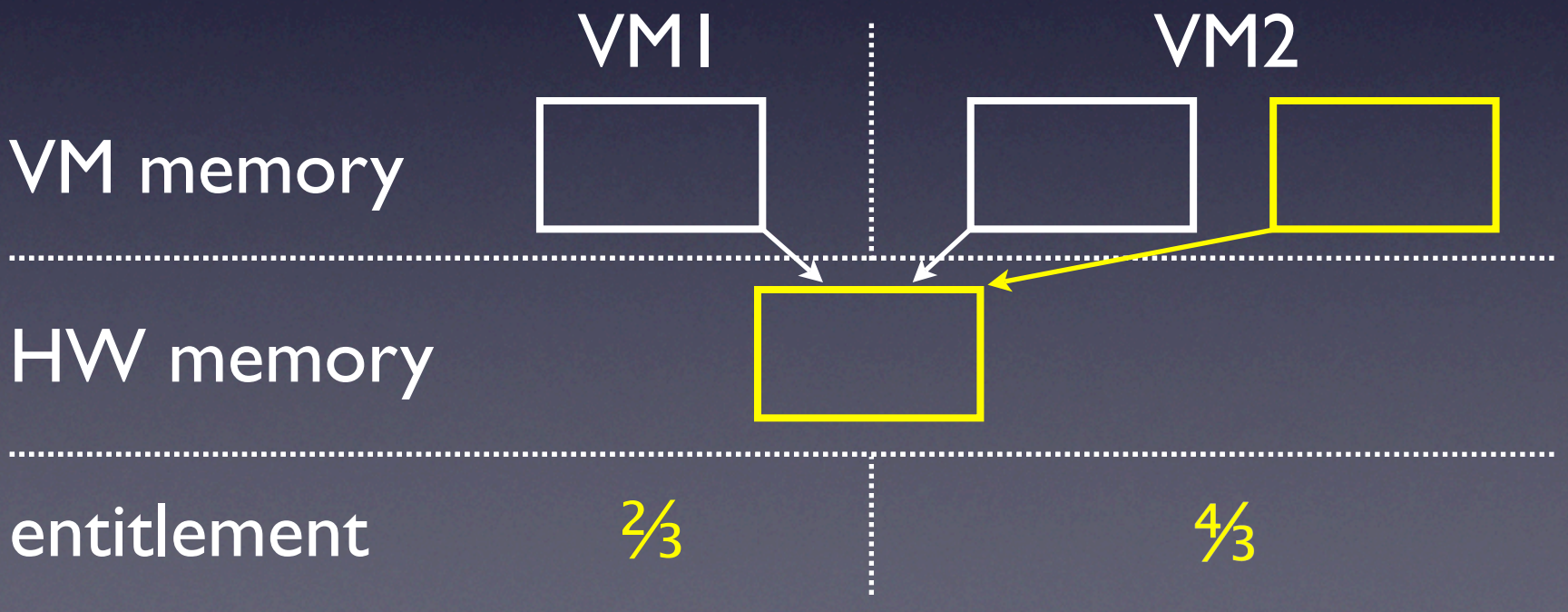

Memory transfer

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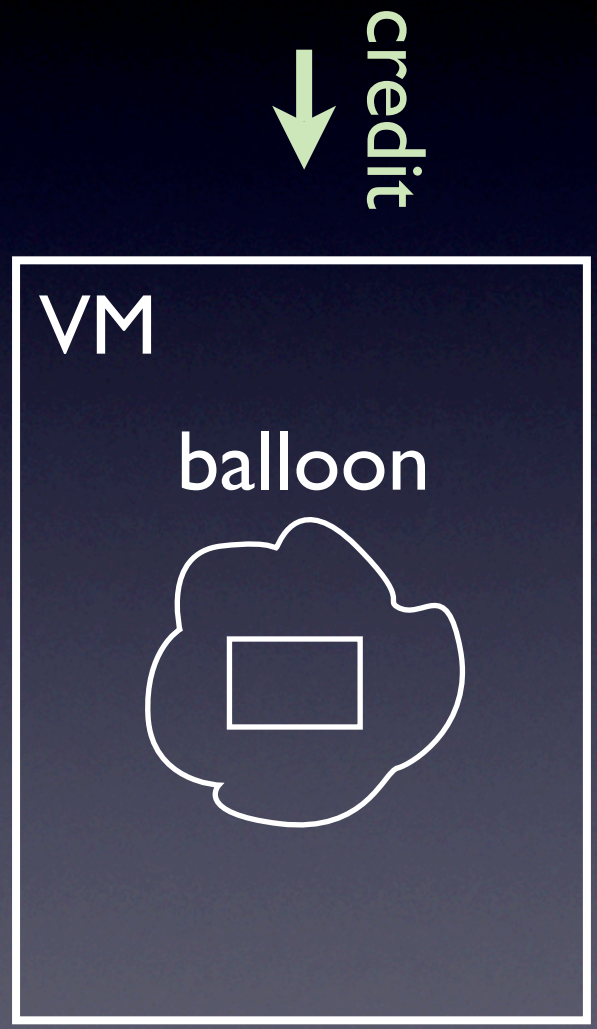

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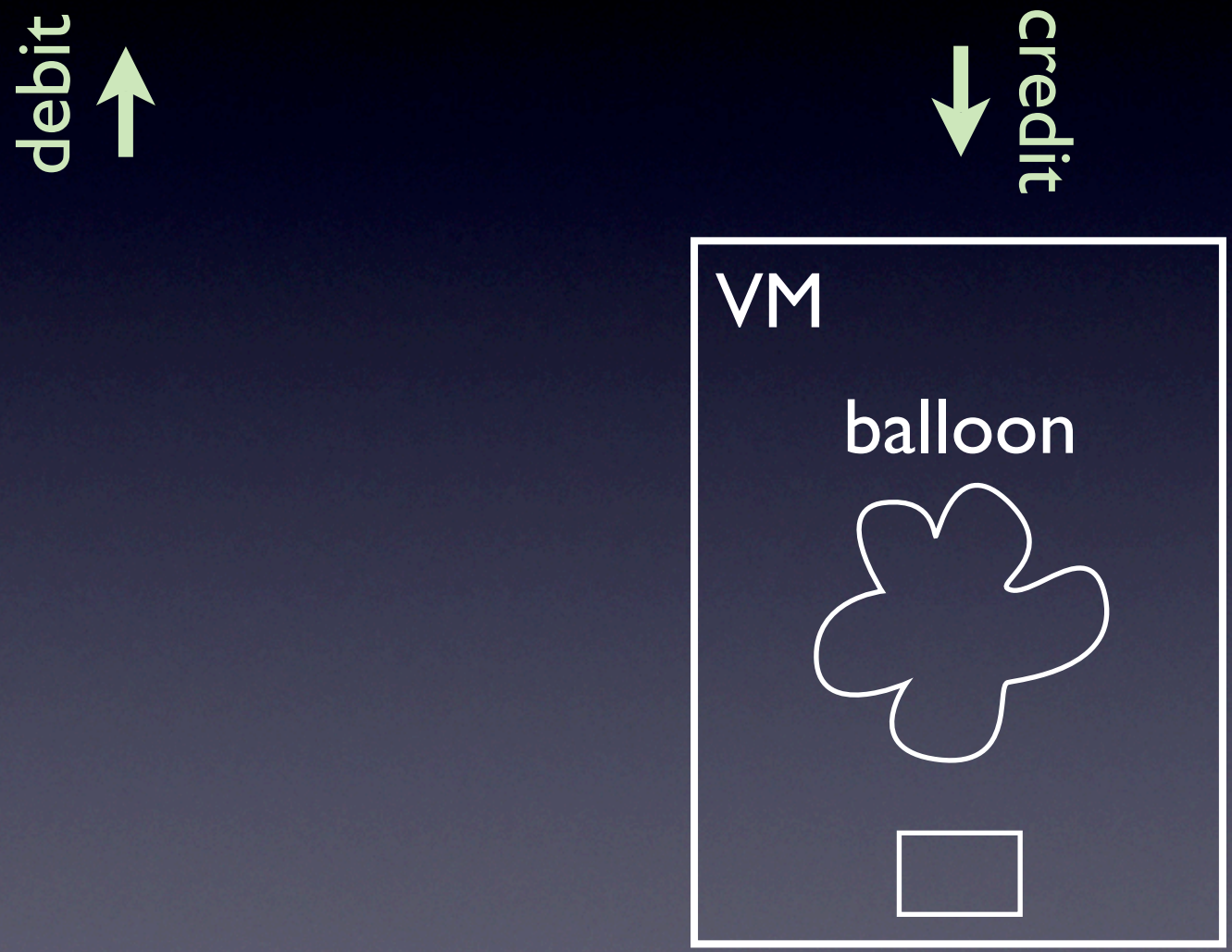

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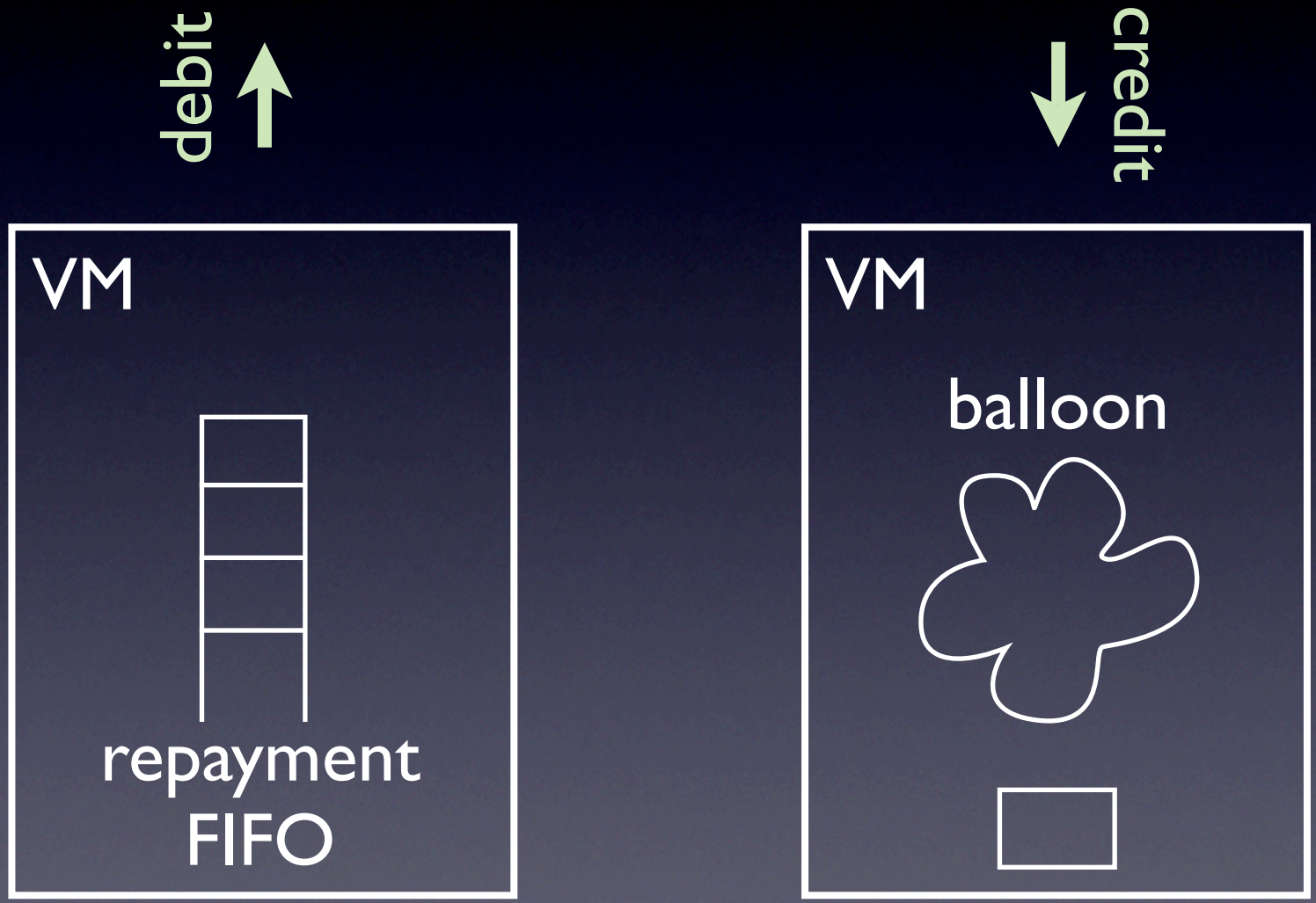

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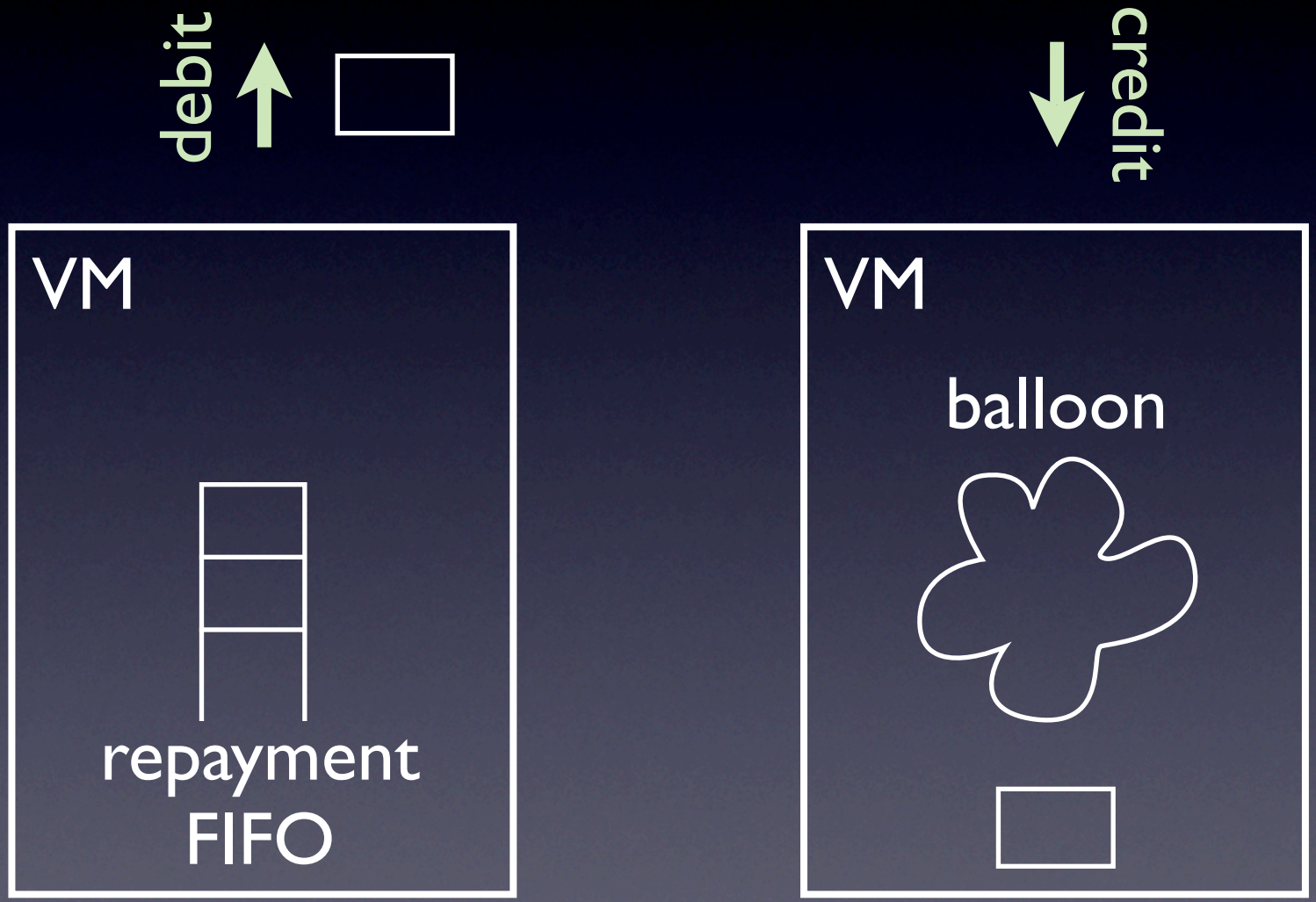


Implementation in Xen

- Changes in the Xen hypervisor (5351 LoC)
  - low-level sharing support
  - sharing entitlement computation
  - fault handling
- Changes in Domain 0 (3894 LoC)
  - sharing-aware block devices
  - management tools
- Changes in Domain U (2306 LoC)
  - repayment FIFO (volatile pgs from IBM CMM)

Performance results

Overheads

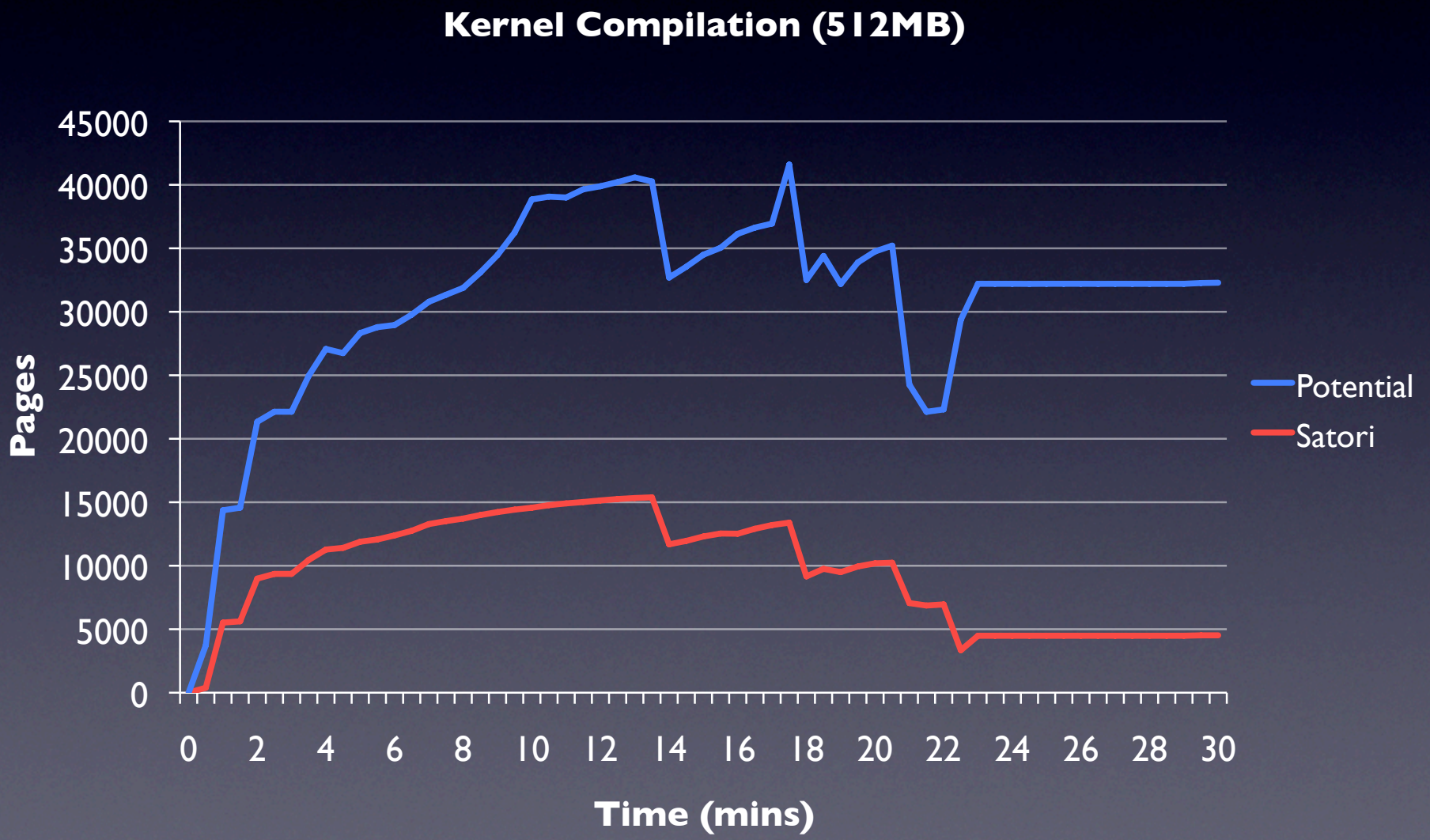
- Sharing-aware block devices interpose on data read path
- Worst-case overhead for sequential reads

hashing	0.2%
hashing + IPC	34.8%

- Negligible for non-sequential reads
- Kernel compilation macro-benchmark: without Satori: 780s, with Satori 779s

Performance results

Detection effectiveness



Performance results

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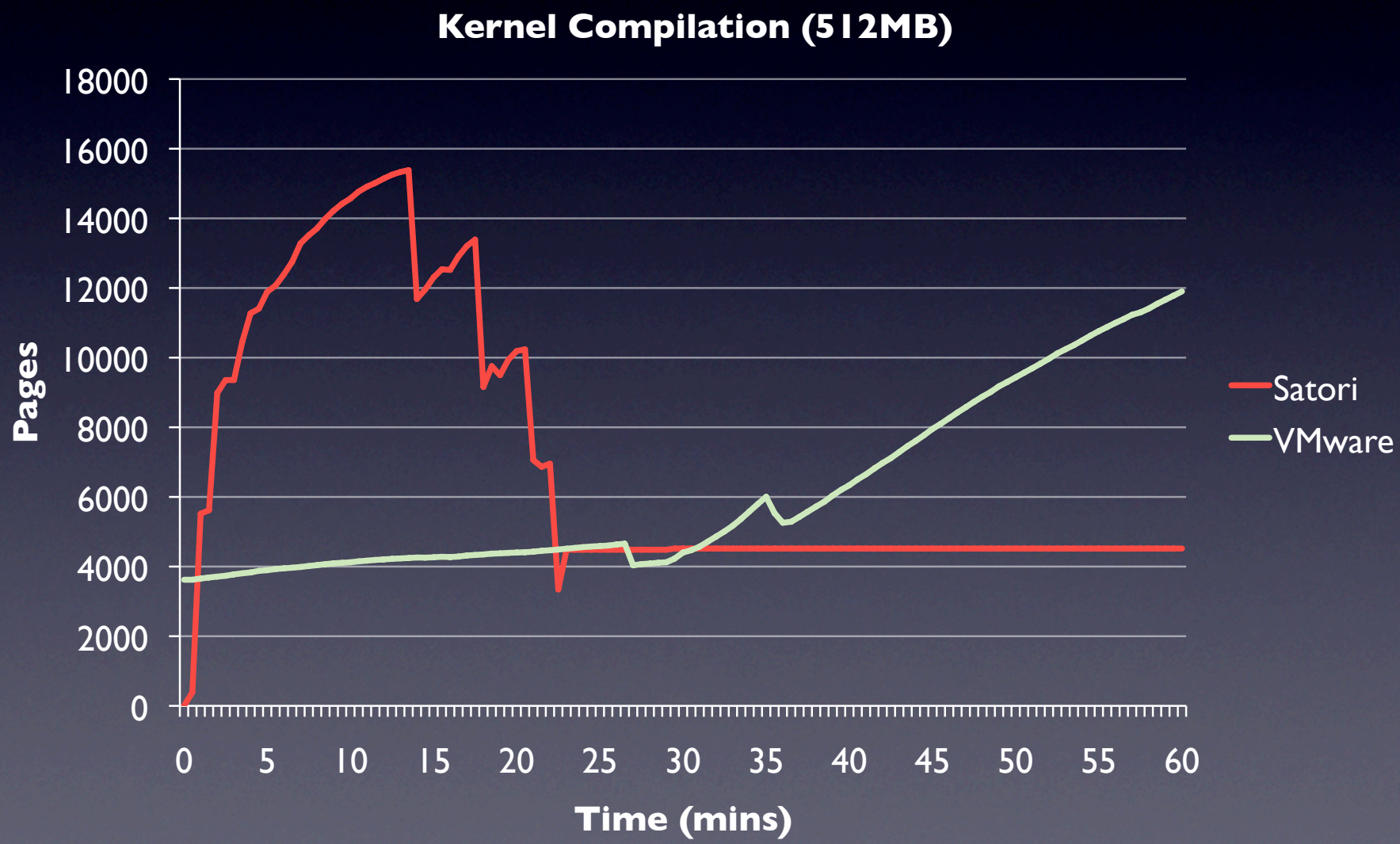
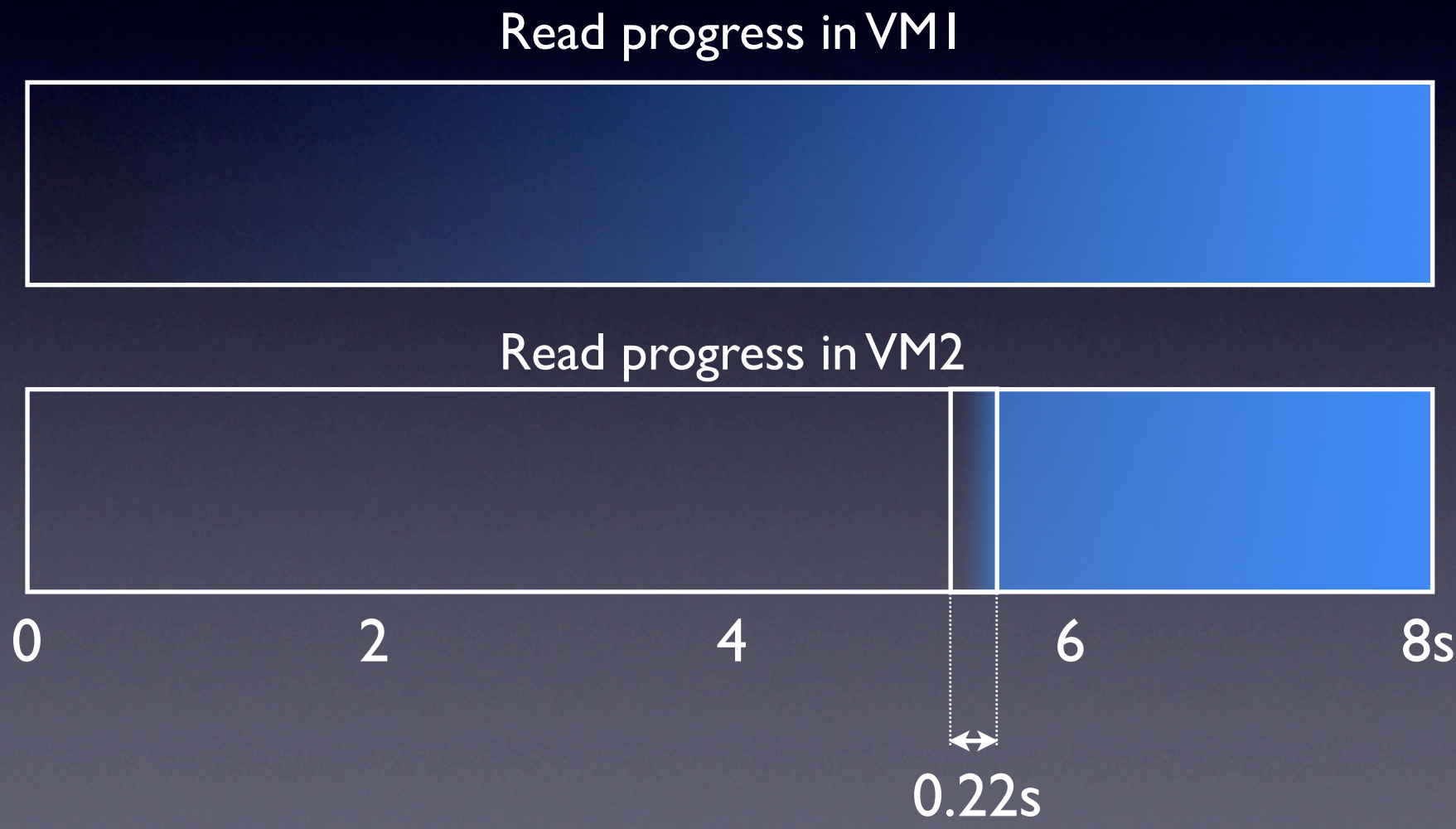


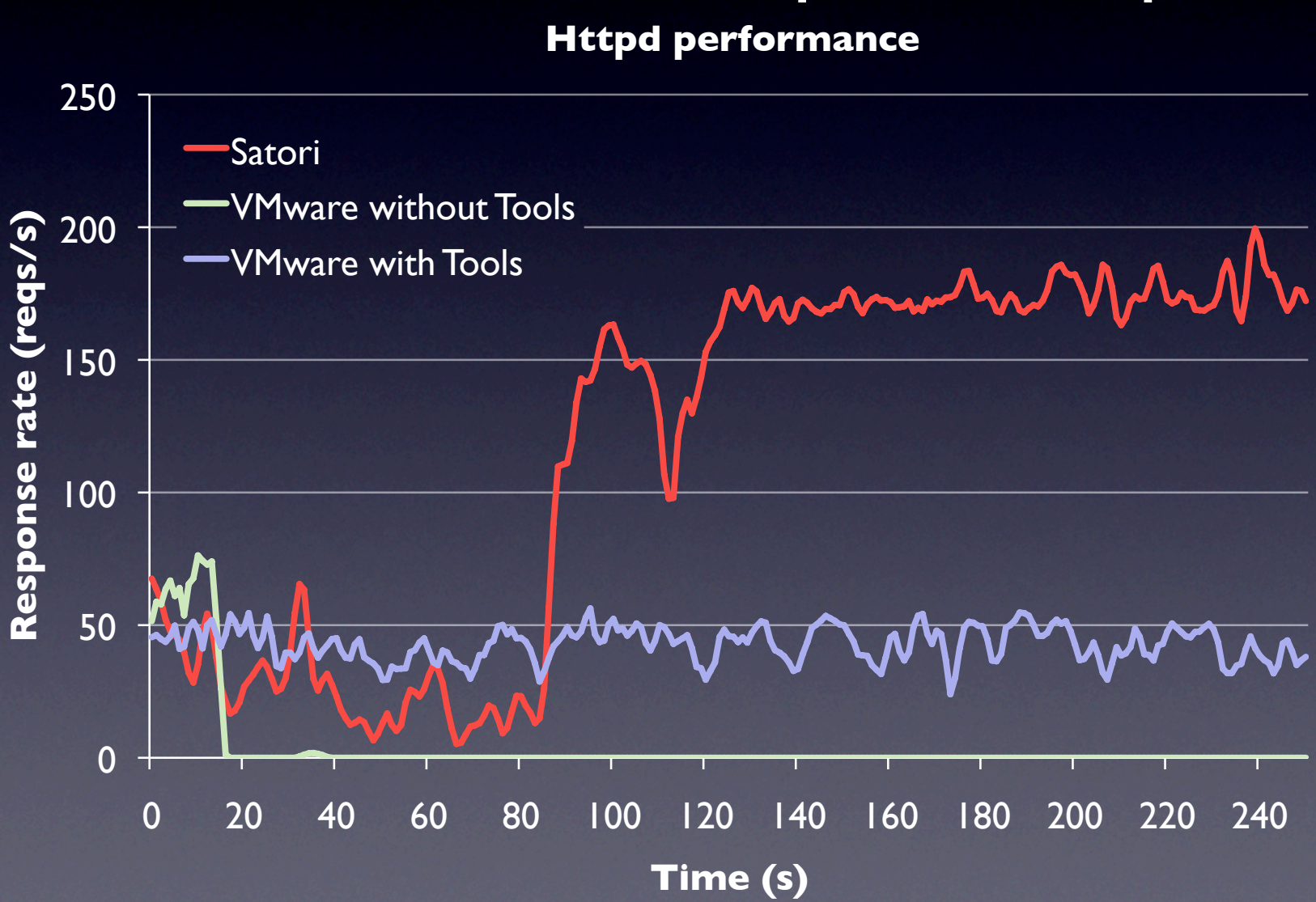
Performance results

Performance impact – reads



Performance results

Performance impact – httpd



Performance results

One slide summary

- Detection cheap and effective
  - less than 1% overhead (except IPC)
  - duplicates detected immediately
  - more effective than scanning
- No physical I/O if data already present in any virtual machine memory
- Surplus memory improves overall system performance

Conclusions

- Satori implements enlightened page sharing
- Satori is efficient (low overheads)
- Satori is effective (high coverage)
- Satori is fair (proportional entitlements)
- Satori maintains isolation (security and perf)

Thanks!

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