PHX: Memory Speed HPC I/O with NVM

Pradeep Fernando

Sudarsun Kannan, Ada Gavrilovska, Karsten Schwan

Node Local Persistent I/O ?

- Node local checkpoint/ restart
  - Recover from transient failures (node restart)
  - Transient/ soft failures – not permanent failures
  - More soft failures in future machines

- Locally stored analytics output
  - Co-running analytics

NVRAM is Ideal for Persistent I/O

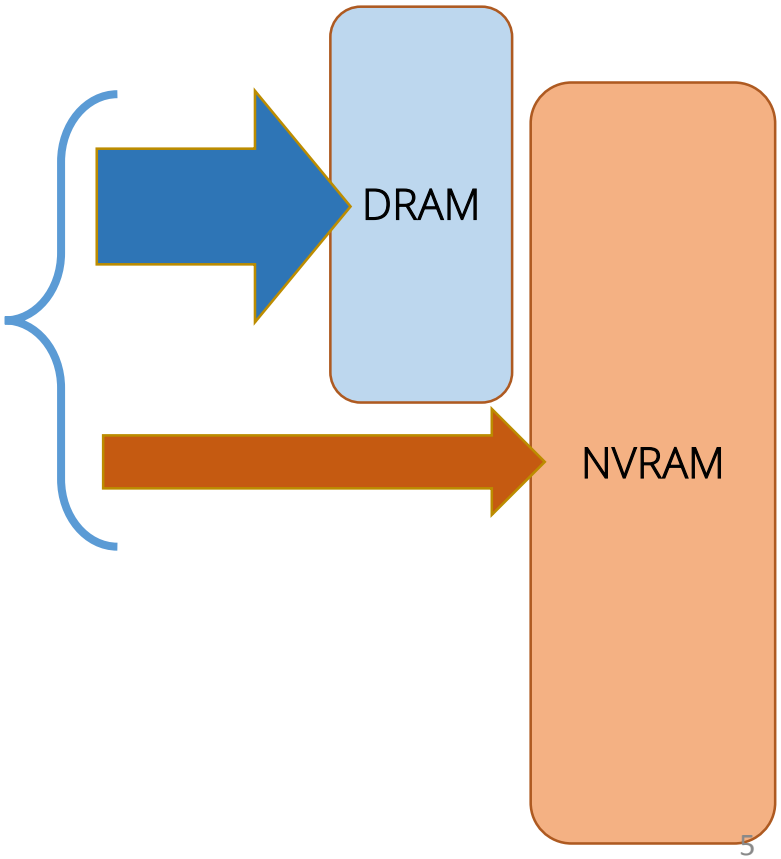
- Read/ write latencies comparable to DRAM
  - 100x faster than SSD
- Persistent data writes
  - Data retention time is >10 years for Memristor
- Denser memory
  - Low chip area per bit -> more capacity
- Memory device -> load/ store operations

NVRAM Bandwidth?

- HPC applications move data in bulk
  - I/O after implicit/explicit synchronization
- More I/O in future Exascale simulations
  - More cores per node -> more data
- Poor bandwidth scaling of NVRAM
  - Device physics
  - RAID like structures -> more energy

Key Idea: Aggregate Bandwidth Checkpoints

- NVRAM provides denser persistent memory, but has limited bandwidth
- DRAM has superior bandwidth compared to NVRAMs (4x-8x)
- Accelerate critical path data movement with bandwidth aggregation



Phoenix (PHX) Design

Problem : Software Stack Overheads

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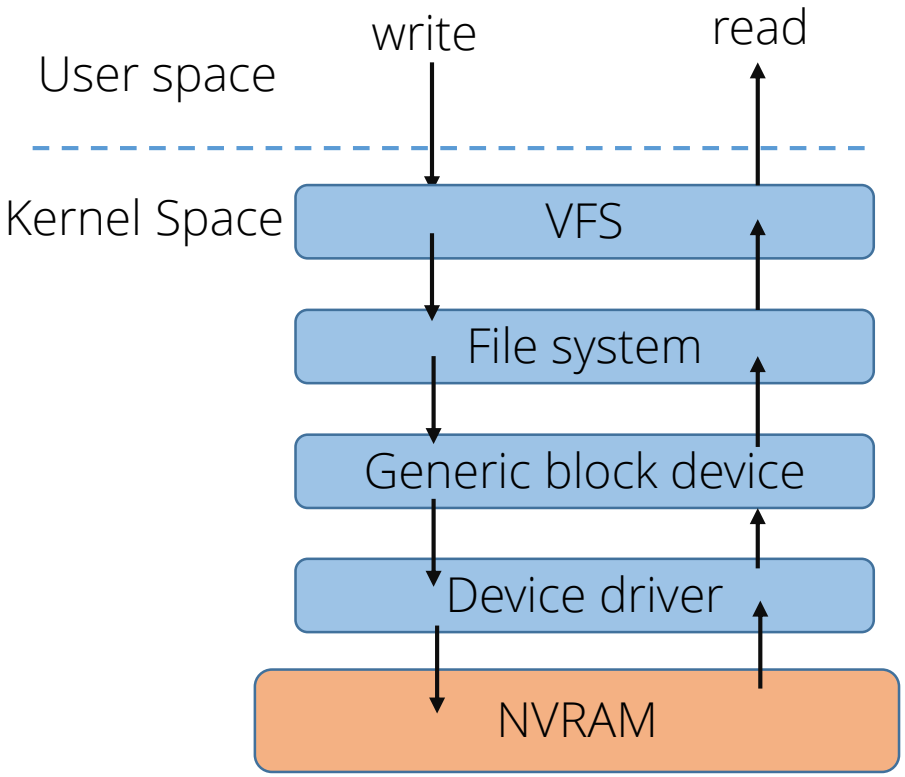

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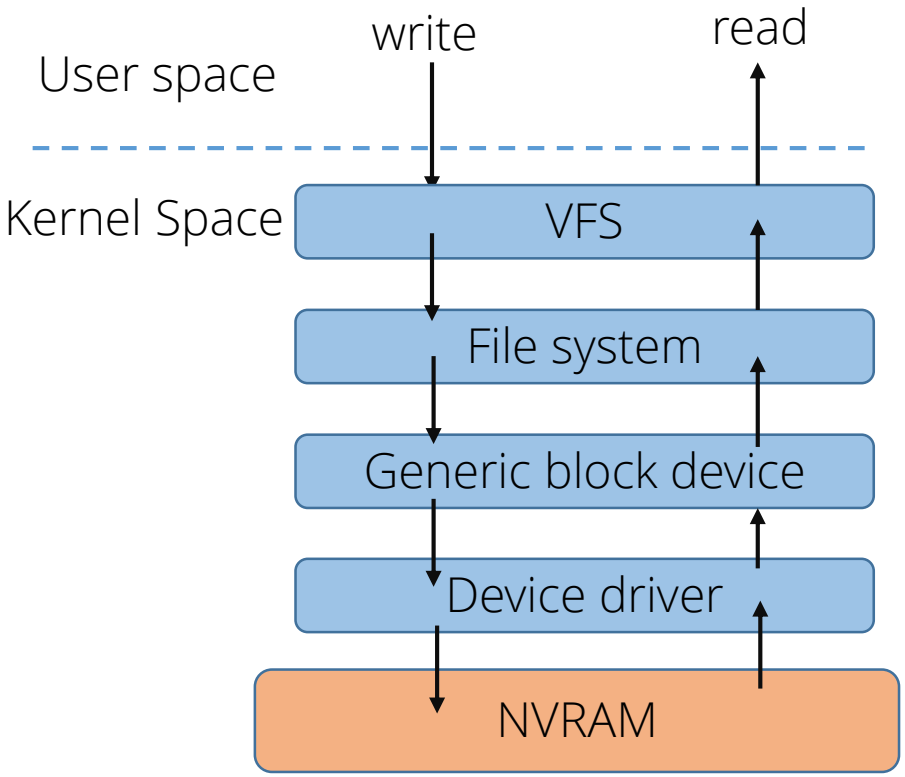

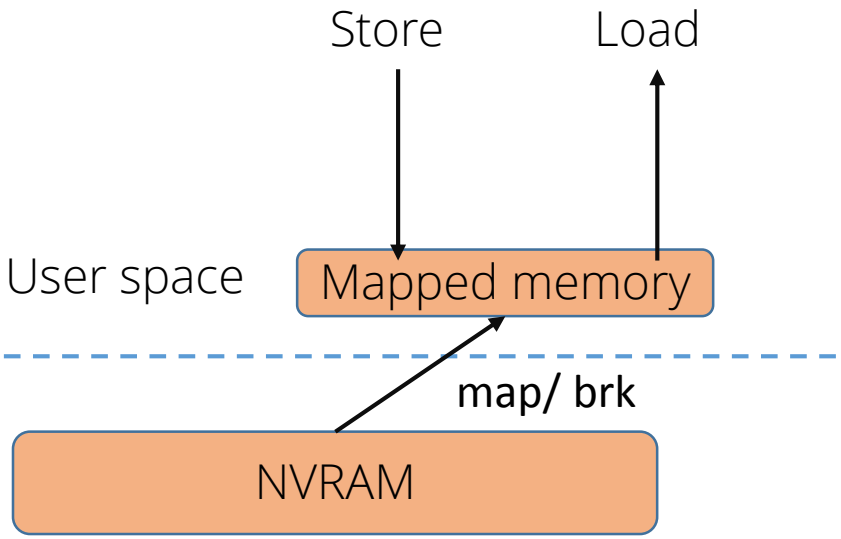

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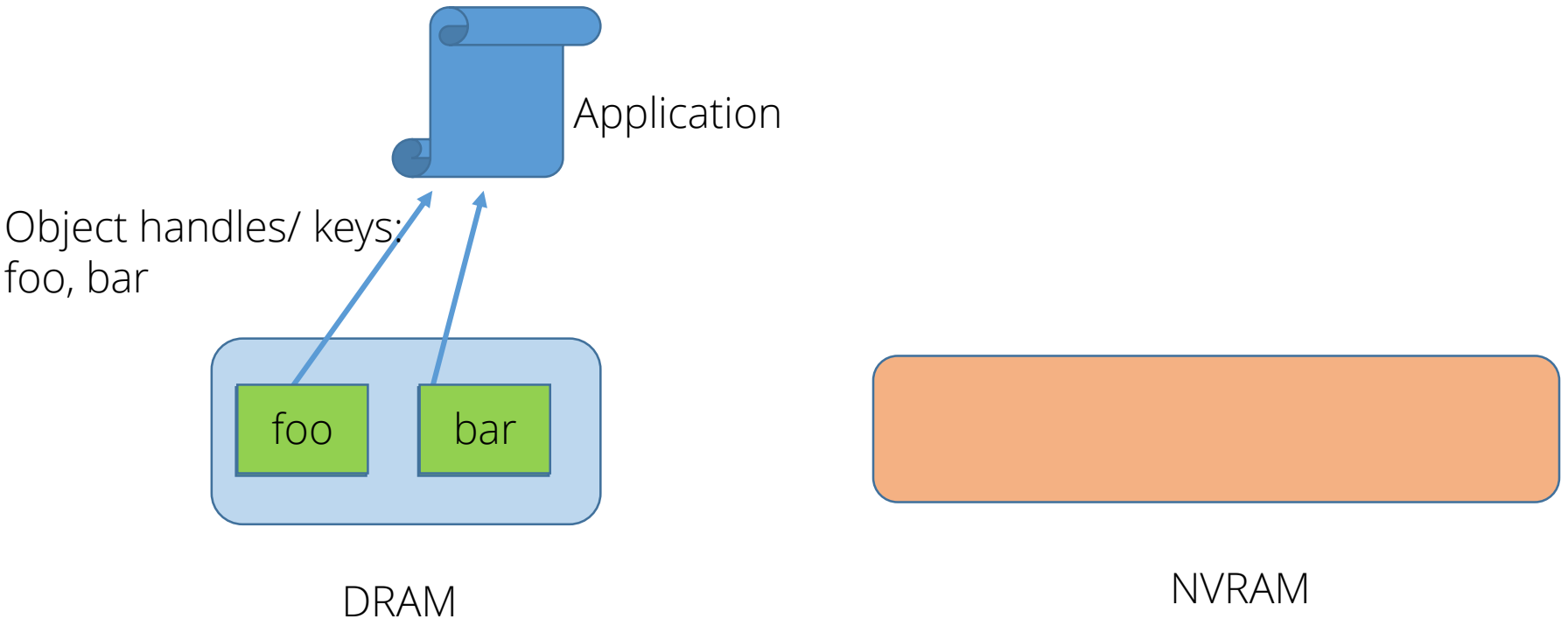

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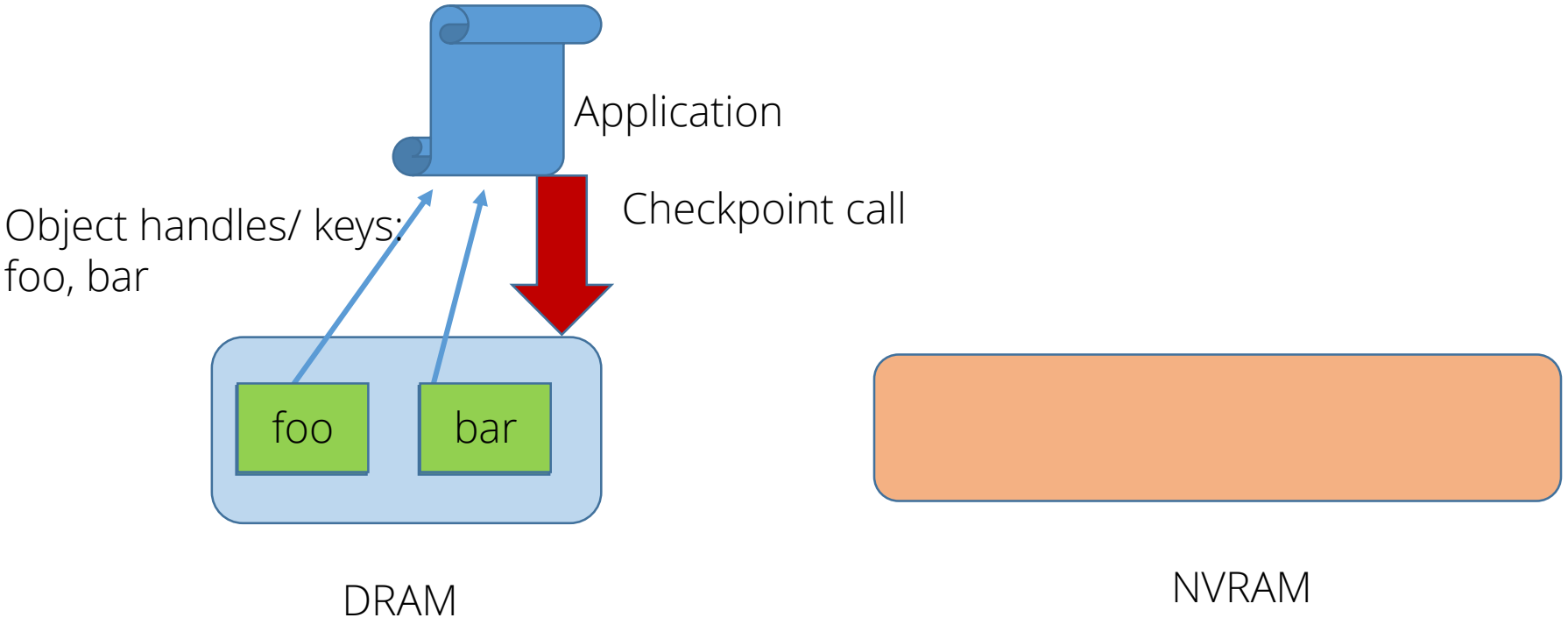

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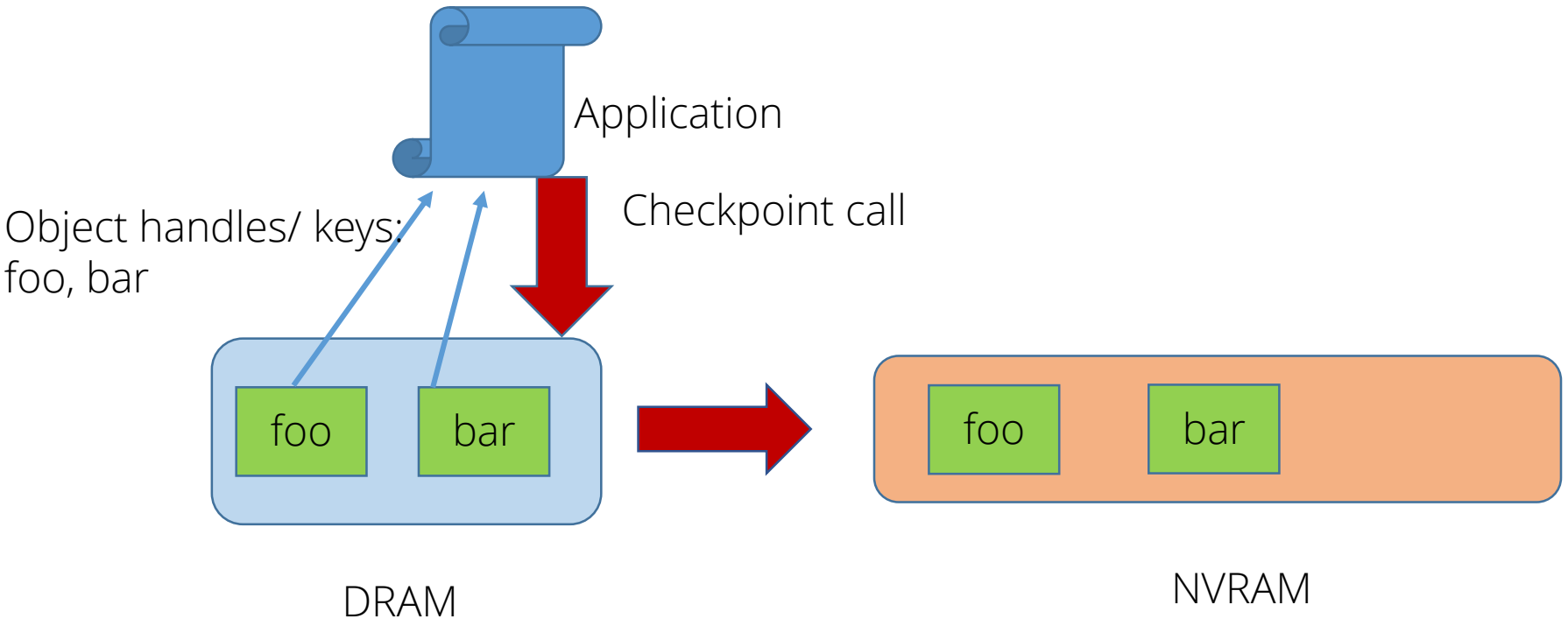

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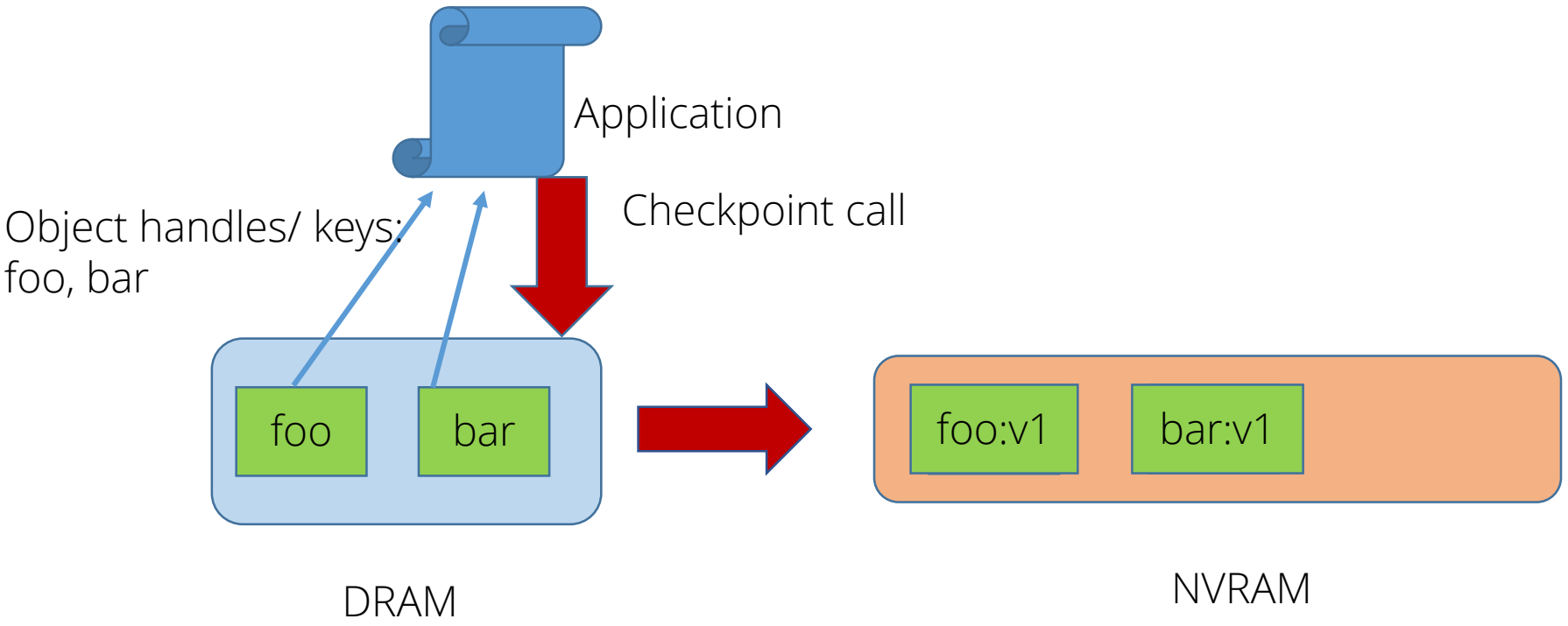

Resulting PHX C/R API

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1 char key[]="foo";
2 /*create checkpointable object instance*/
3 struct properties prop = {.checkpoint = true, ...};
4 void *ptr=create_obj(key,SIZE,prop);
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Allocate checkpoint object

Create a versioned copy and move it to NVRAM

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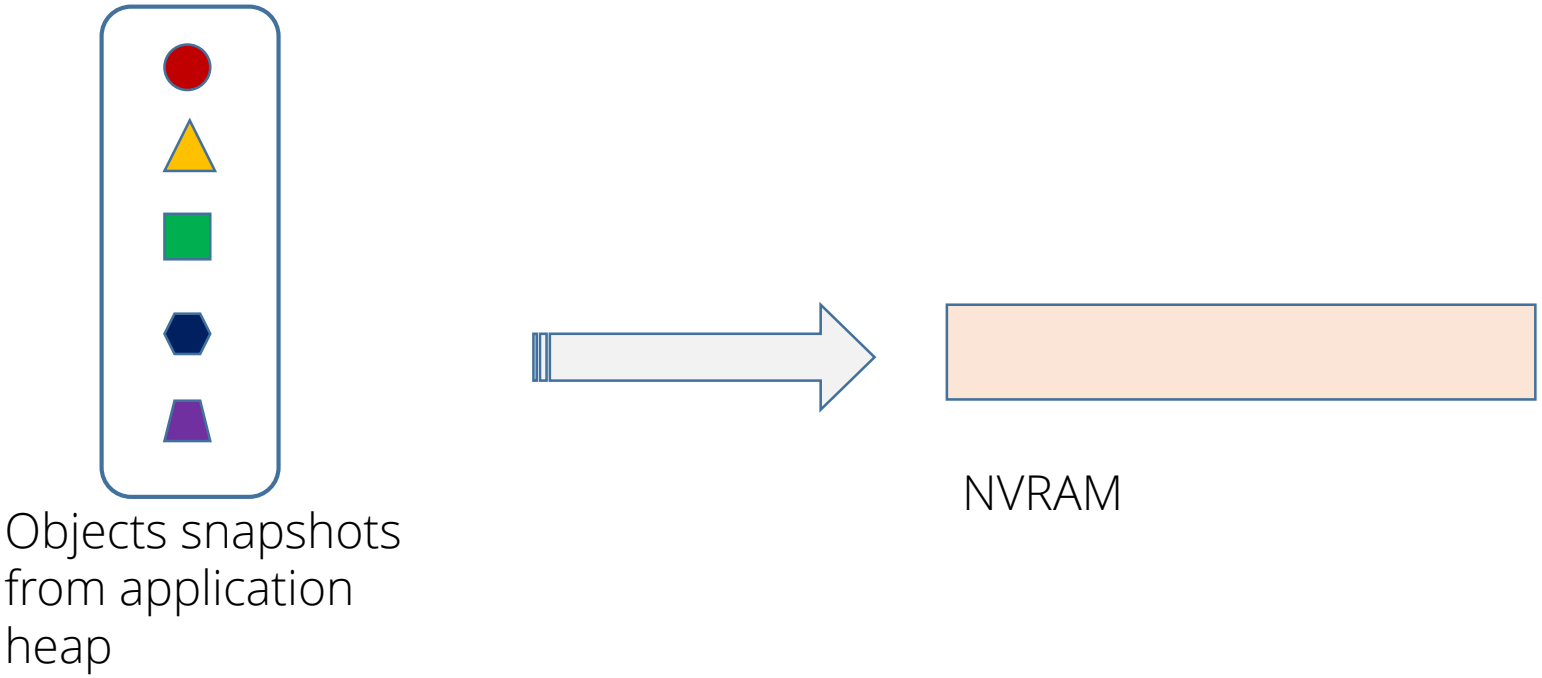

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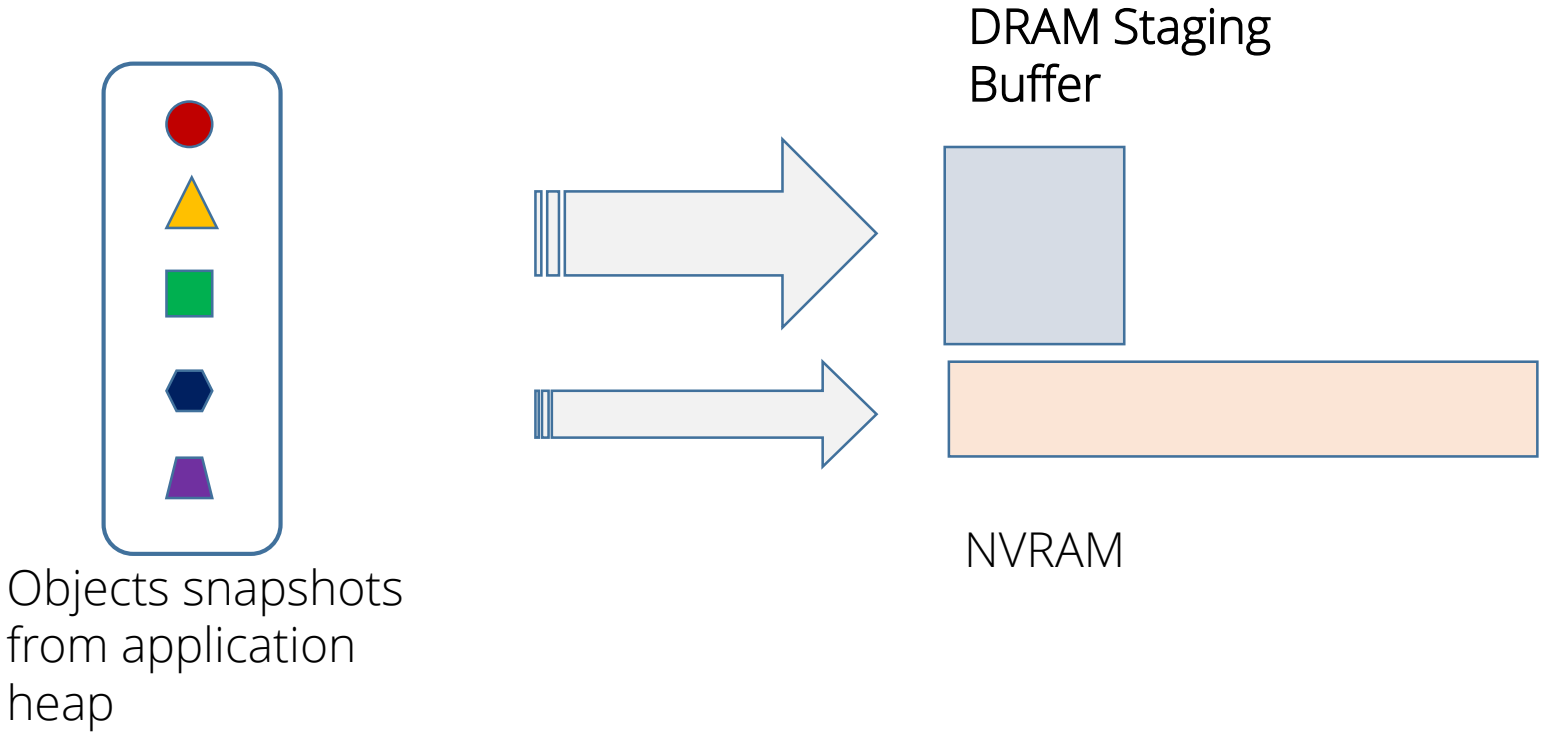

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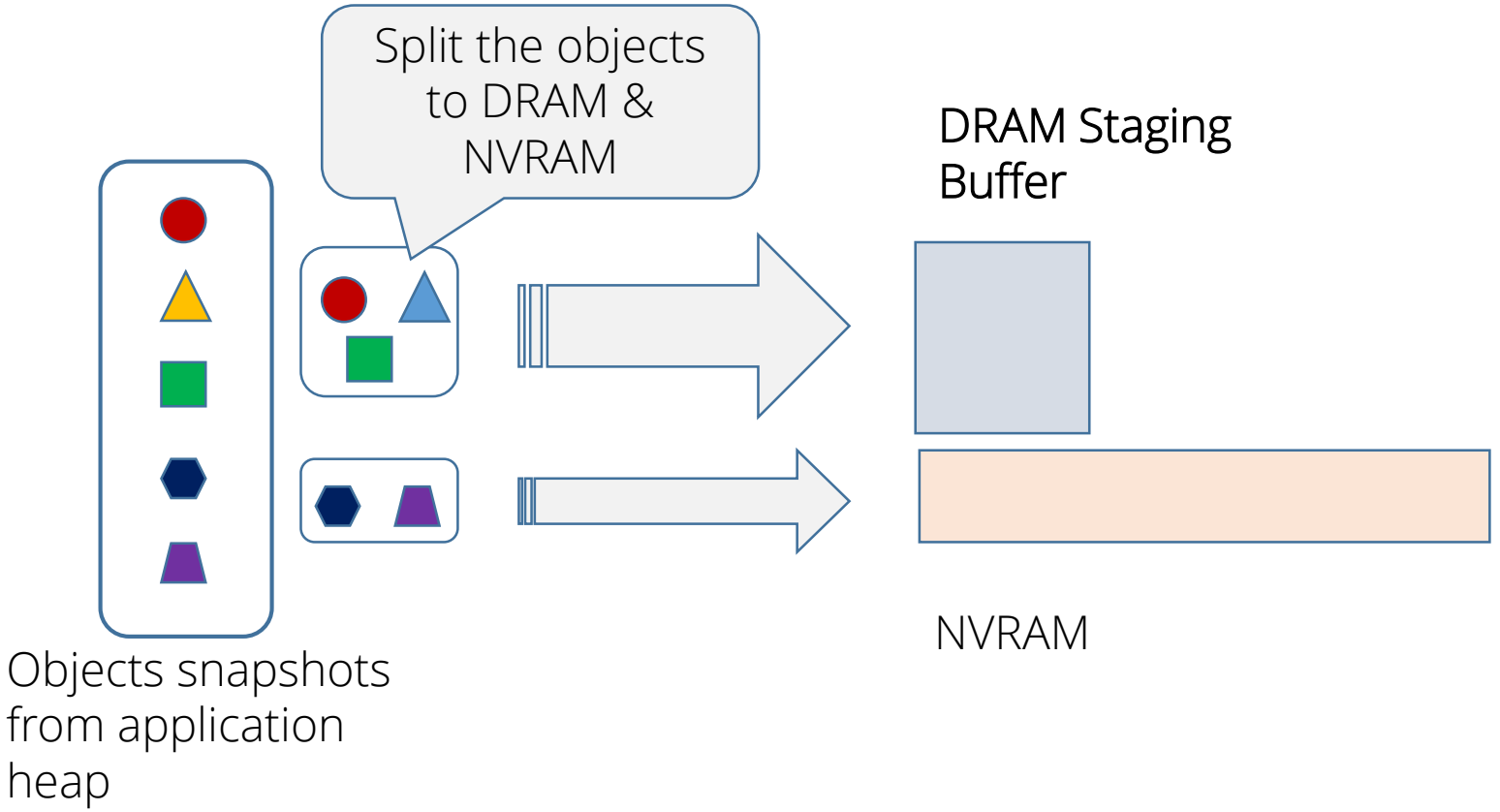

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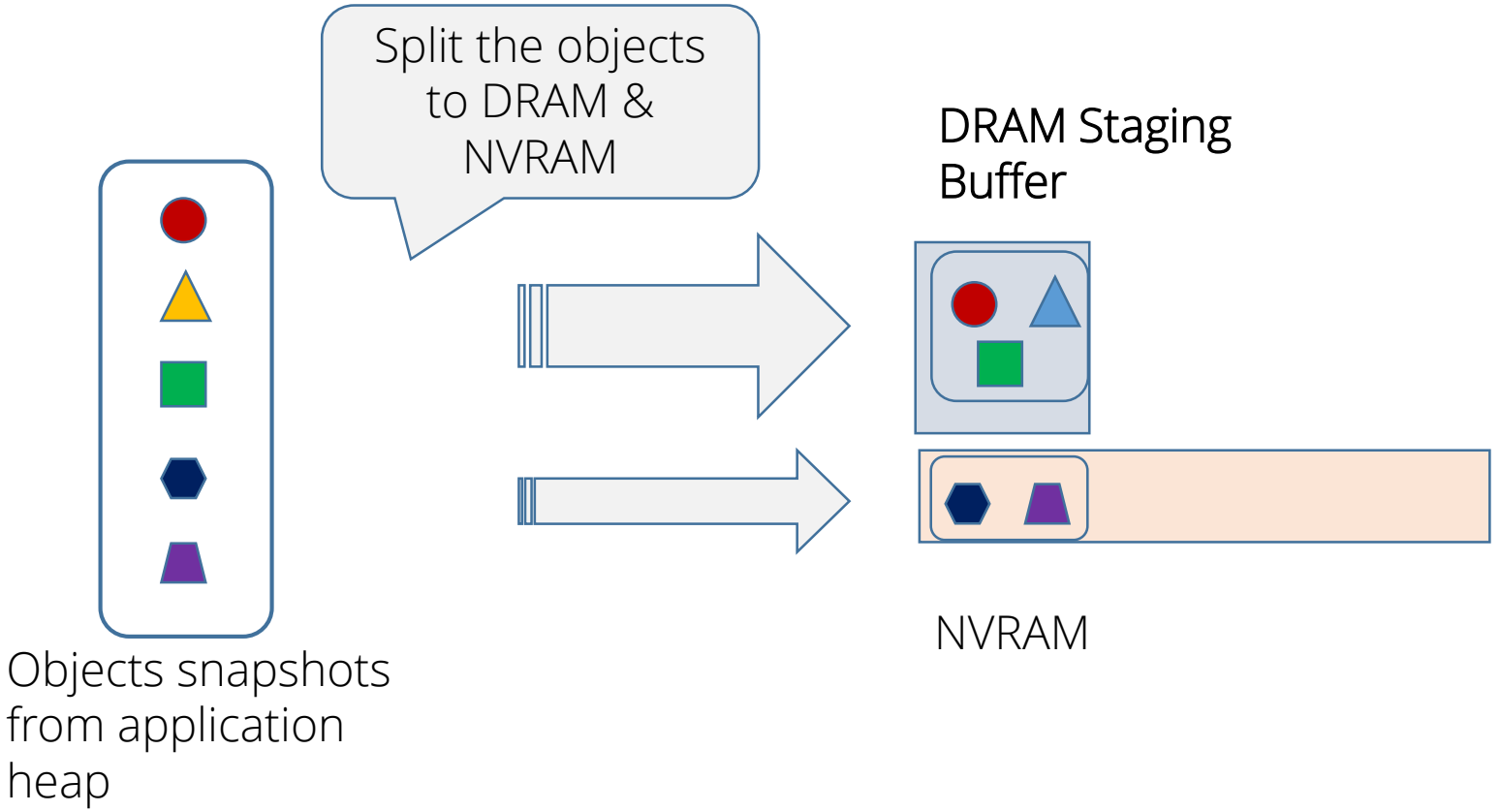

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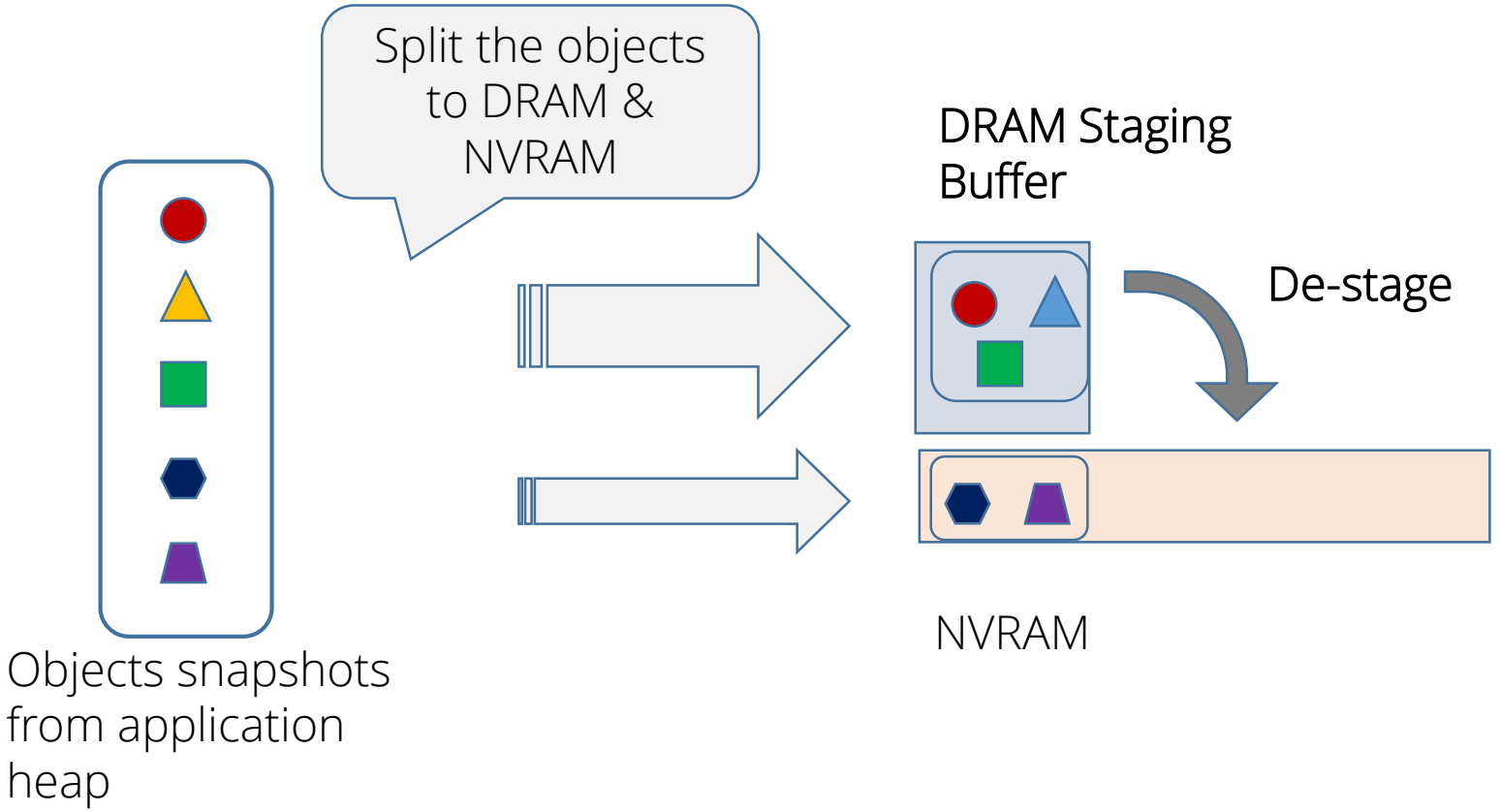

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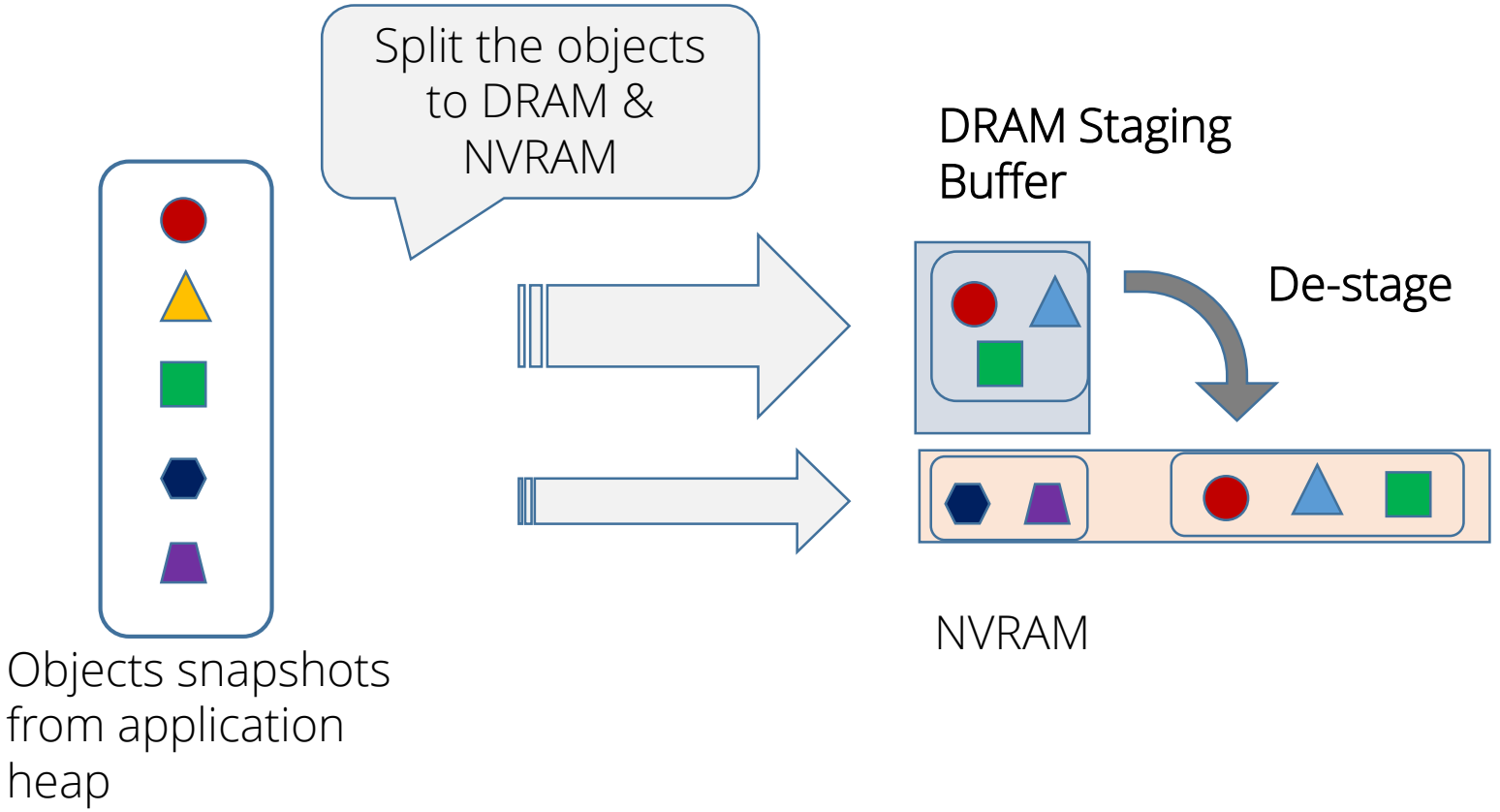

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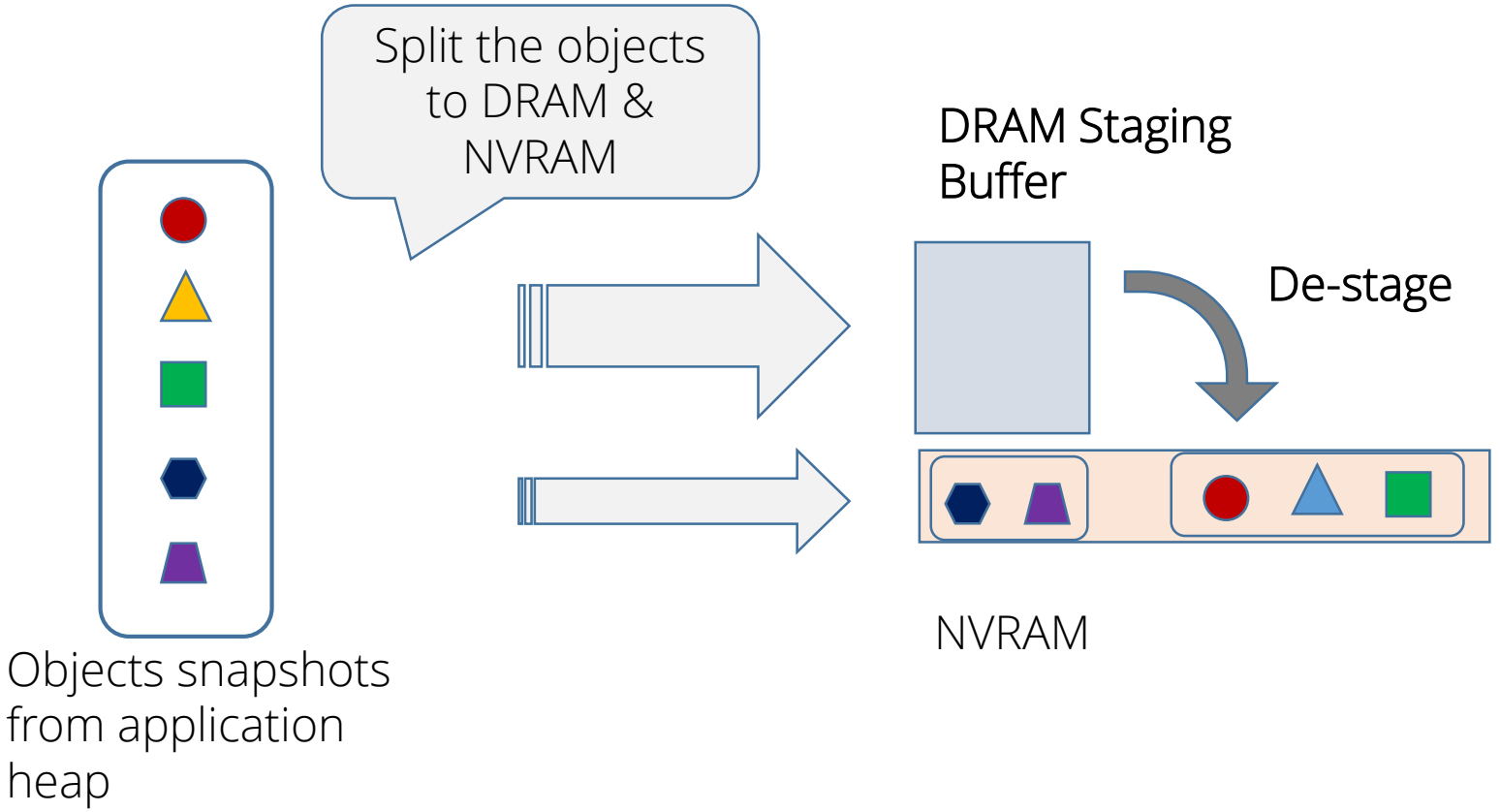
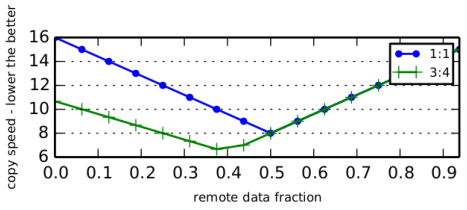
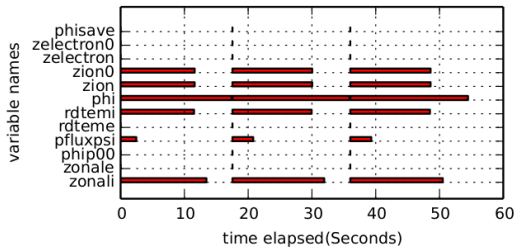


Checkpoint Data Split





1. Optimal data split ratio is same as the device bandwidth ration
2. Prioritize staging for late access variables – immune to optimizations (e.g. Pre-copy)
3. Memory budget allocated for staging.

Fault Tolerance of Staged Data

Staging Buffer Data Loss

- Staged data is vulnerable to transient node failures.

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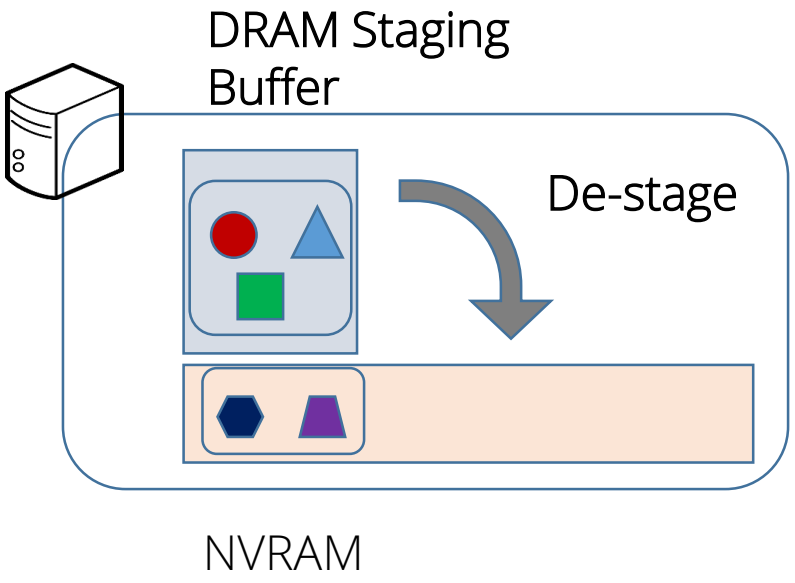

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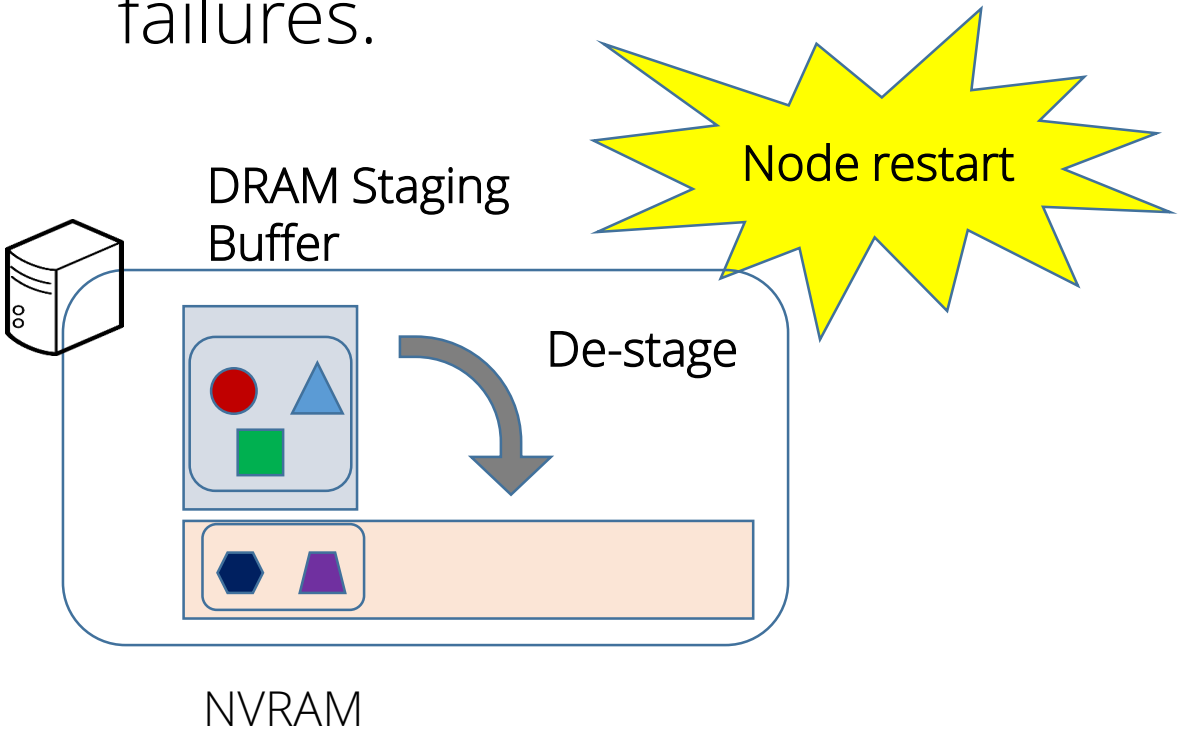

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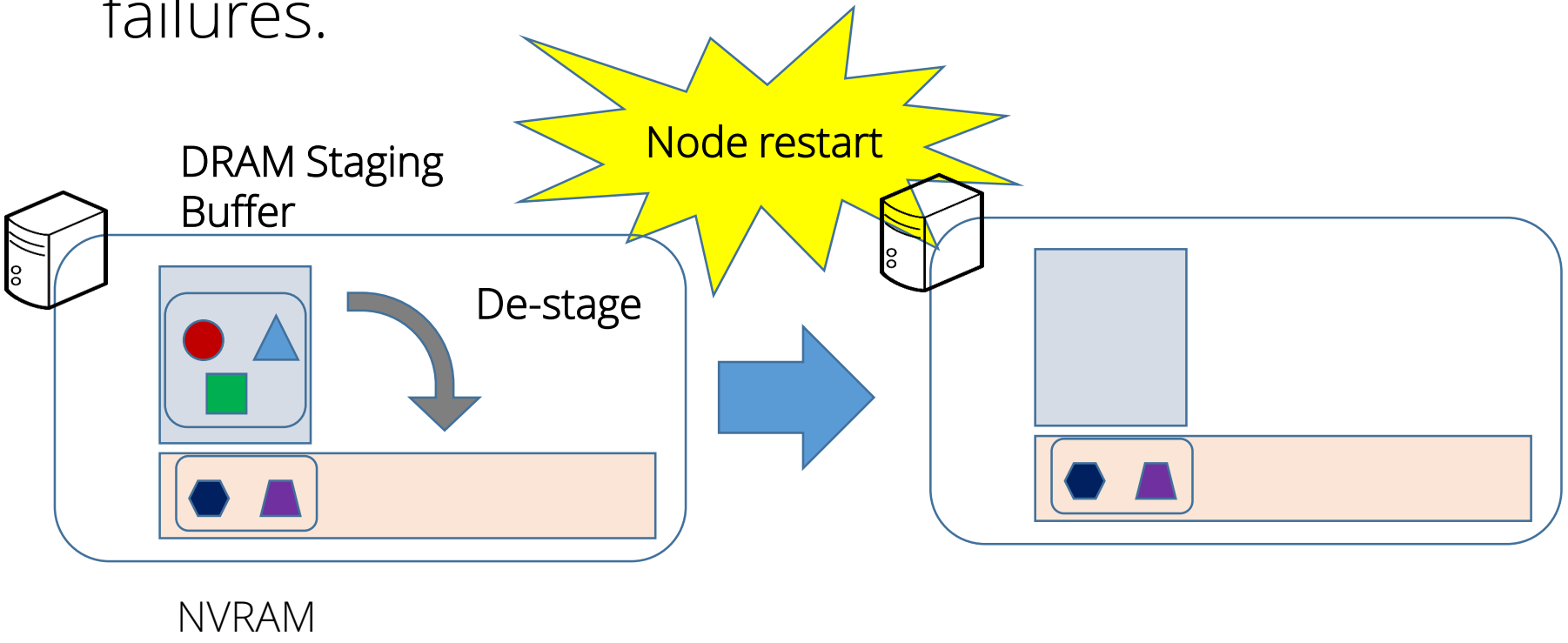

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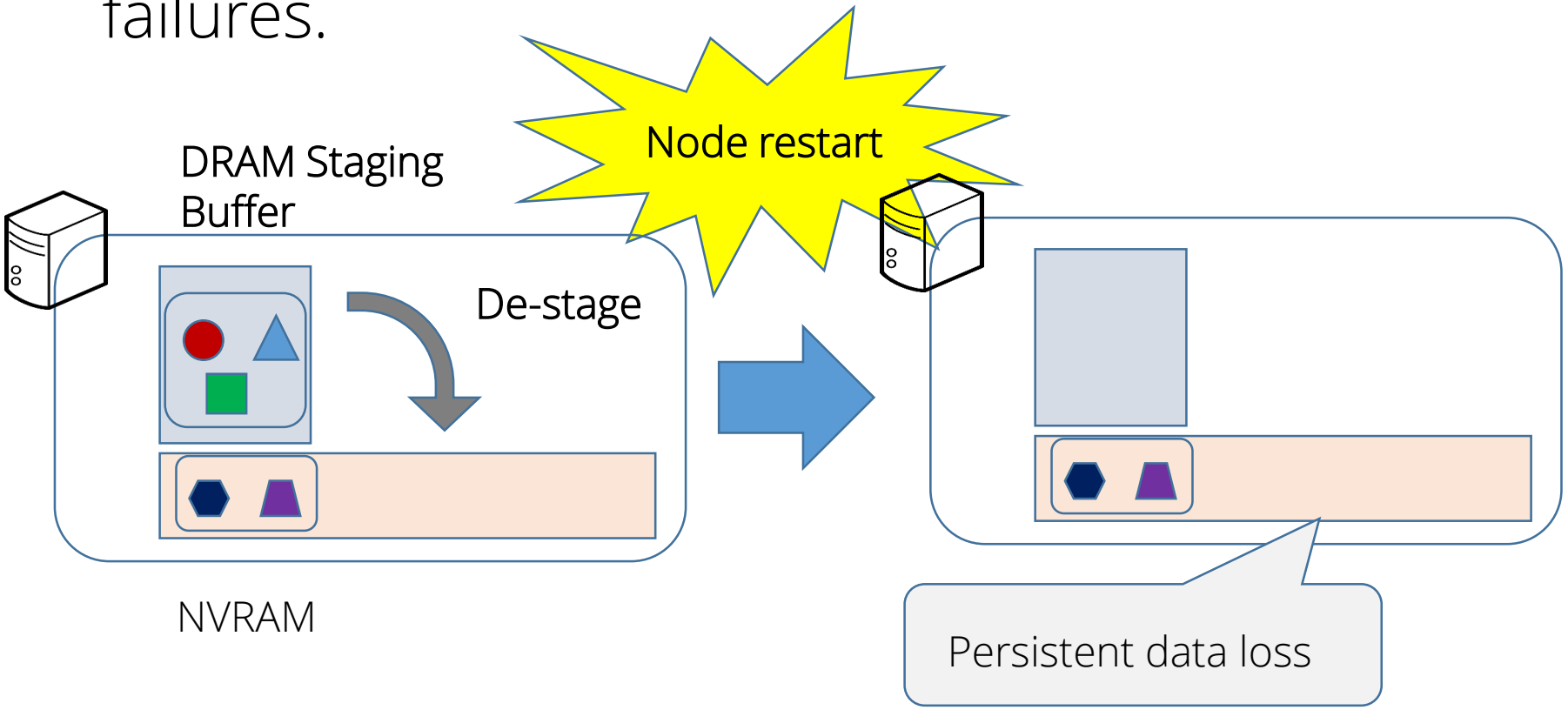
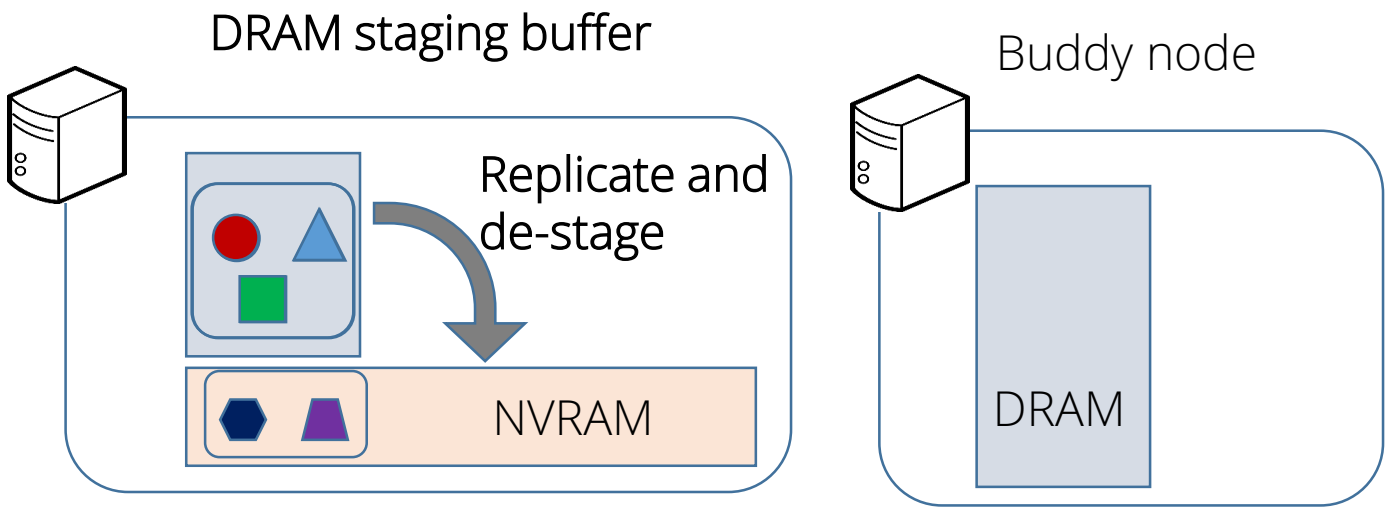


Buddy Node Replication (N=2)



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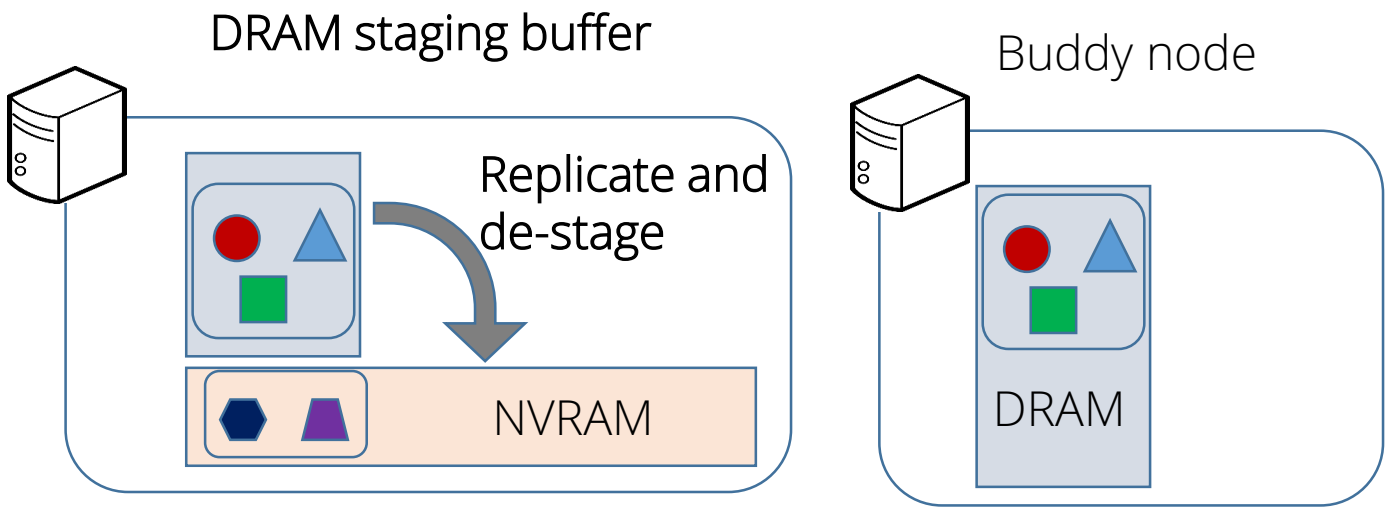

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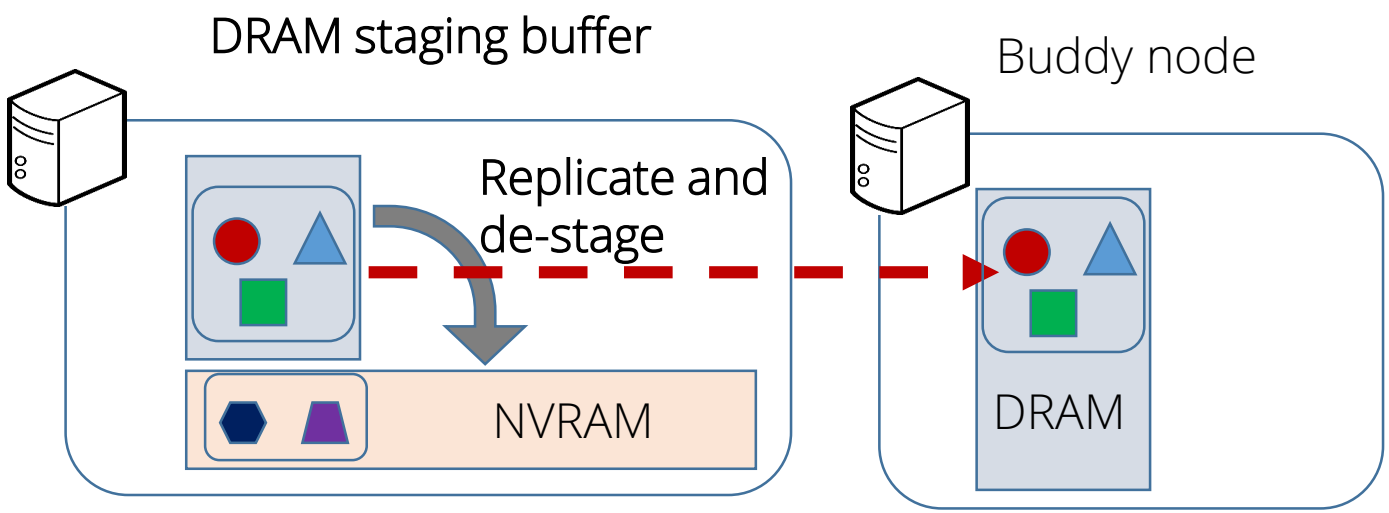

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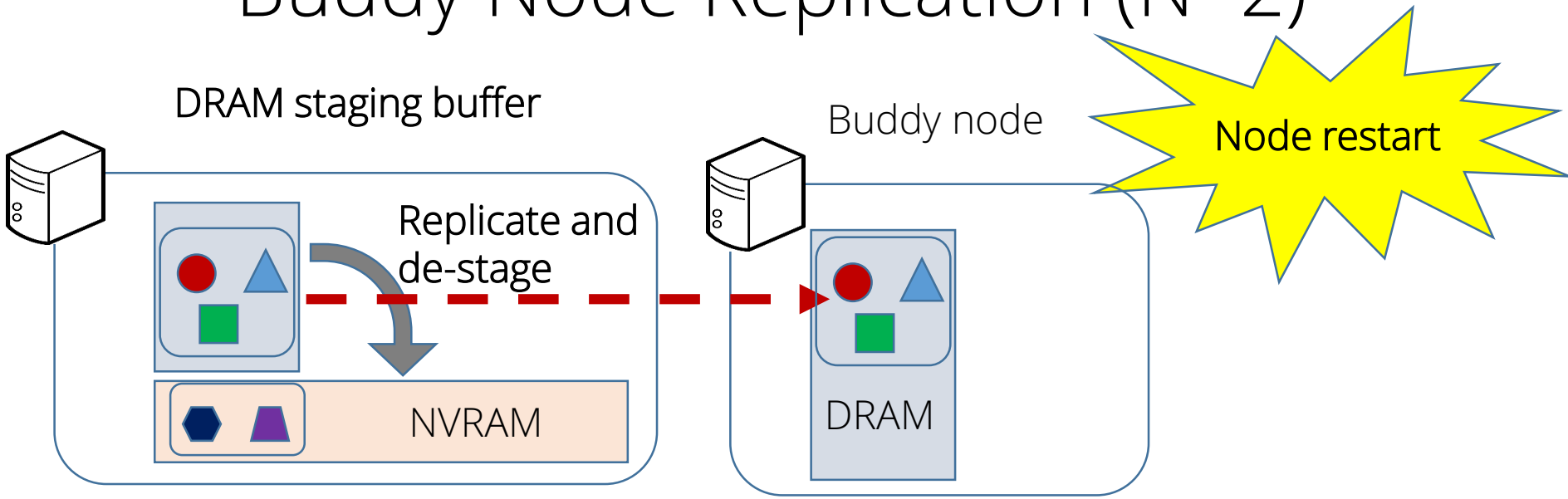

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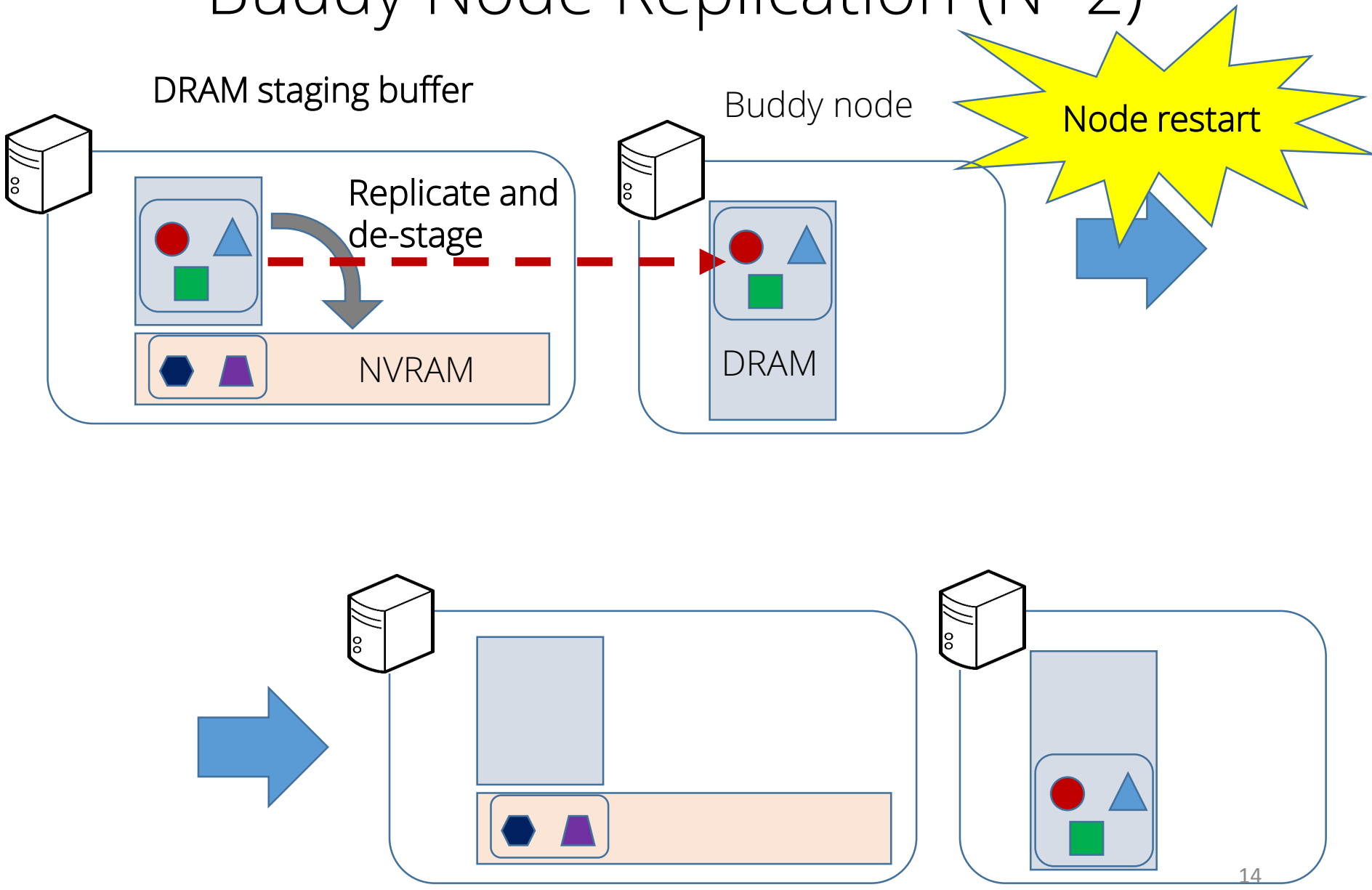

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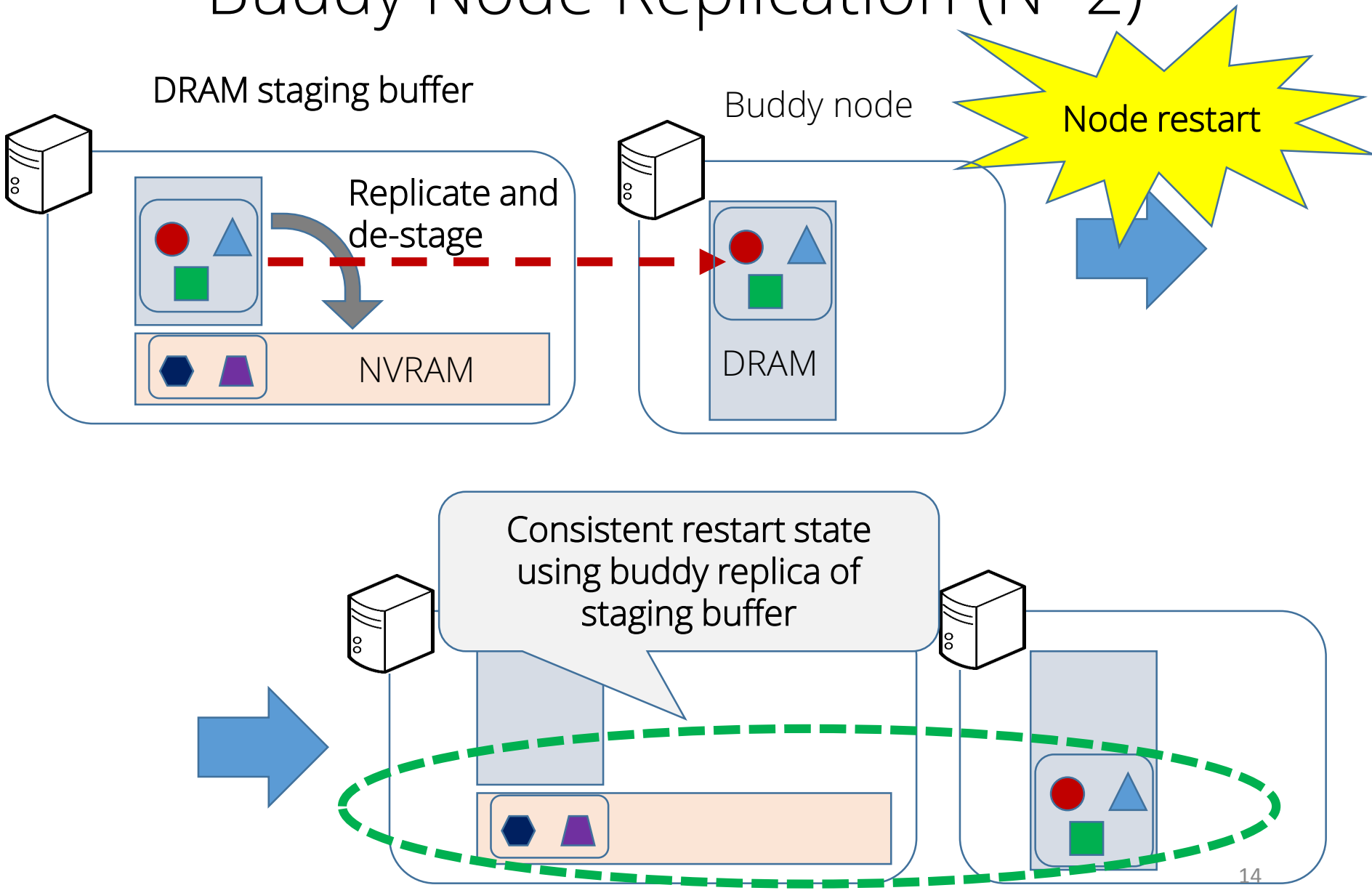

Failure Probability of Staged Data

Scheme	Execution time	Checkpoint interval	Max de-stage interval	Failure probability
Free run	24 hrs	-	-	0.99999887
PHX, N=1	48 hrs	60 s	10 s	0.98960270
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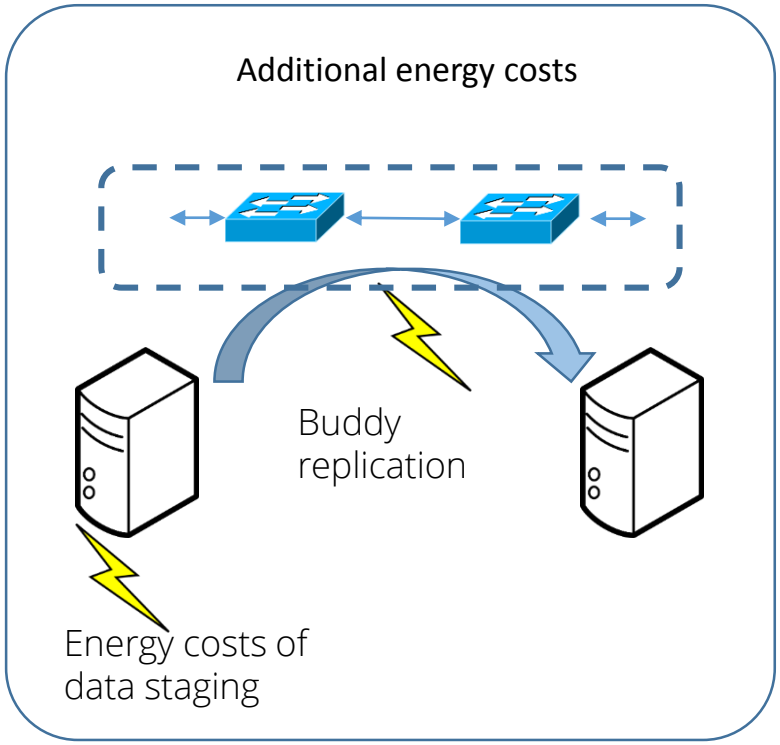
- N=2, buddy replication scheme brings down the staged data loss probability to negligible level.

Energy Cost Analysis

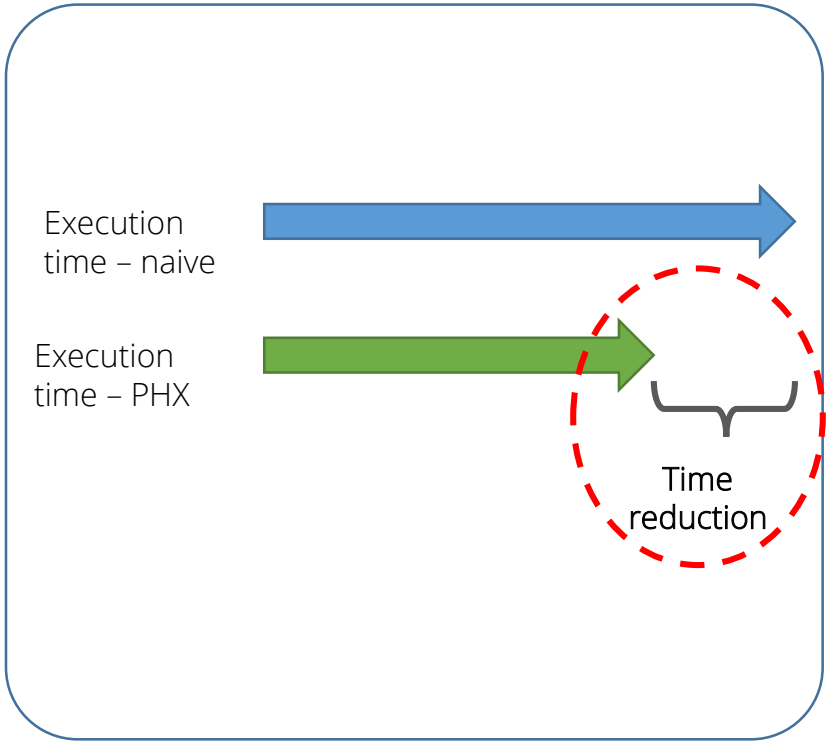
Energy Overheads of PHX

- PHX energy overheads
  - Checkpoint staging
  - Stage buffer replication
- Depends on
  - Interconnect technology
  - Distance to buddy
  - DRAM write costs



Energy Savings of PHX

- Fast PHX checkpoints cut down the total simulation time.
- Energy savings!



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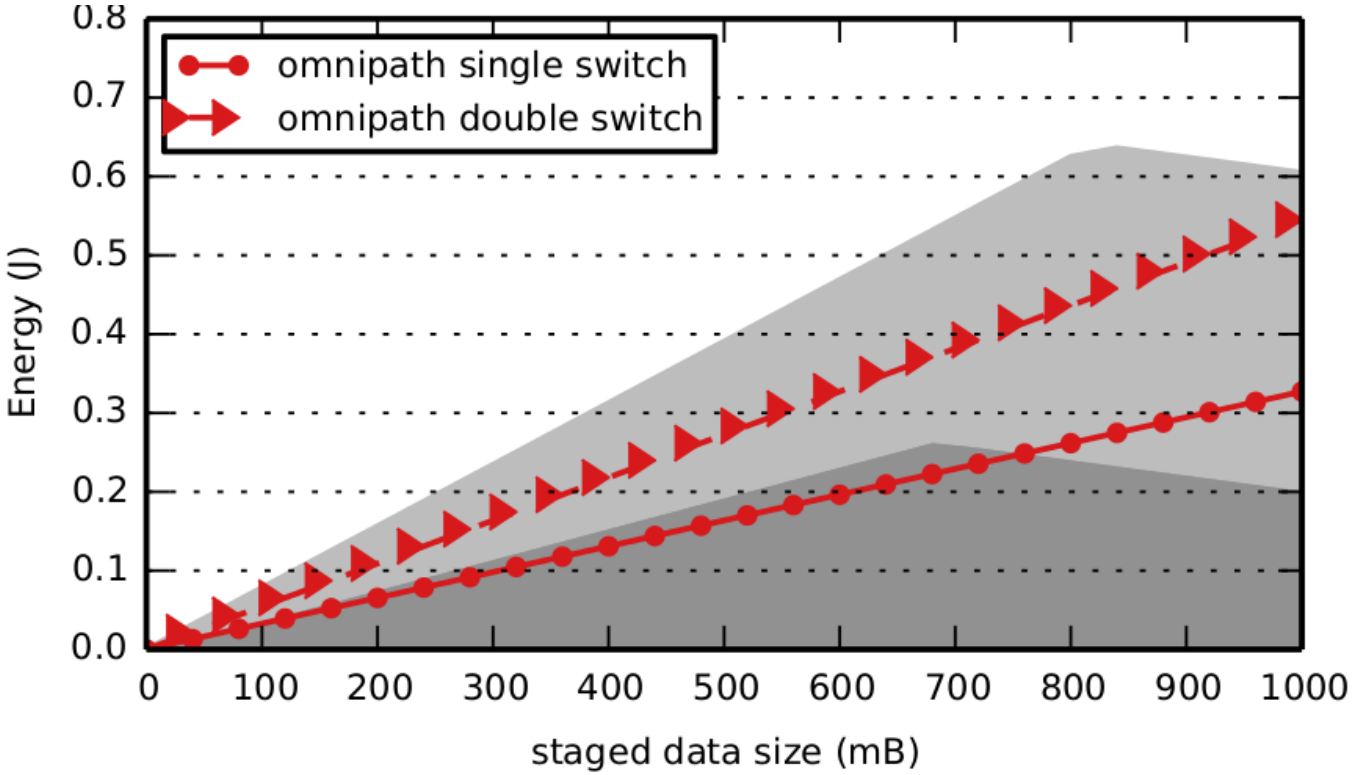

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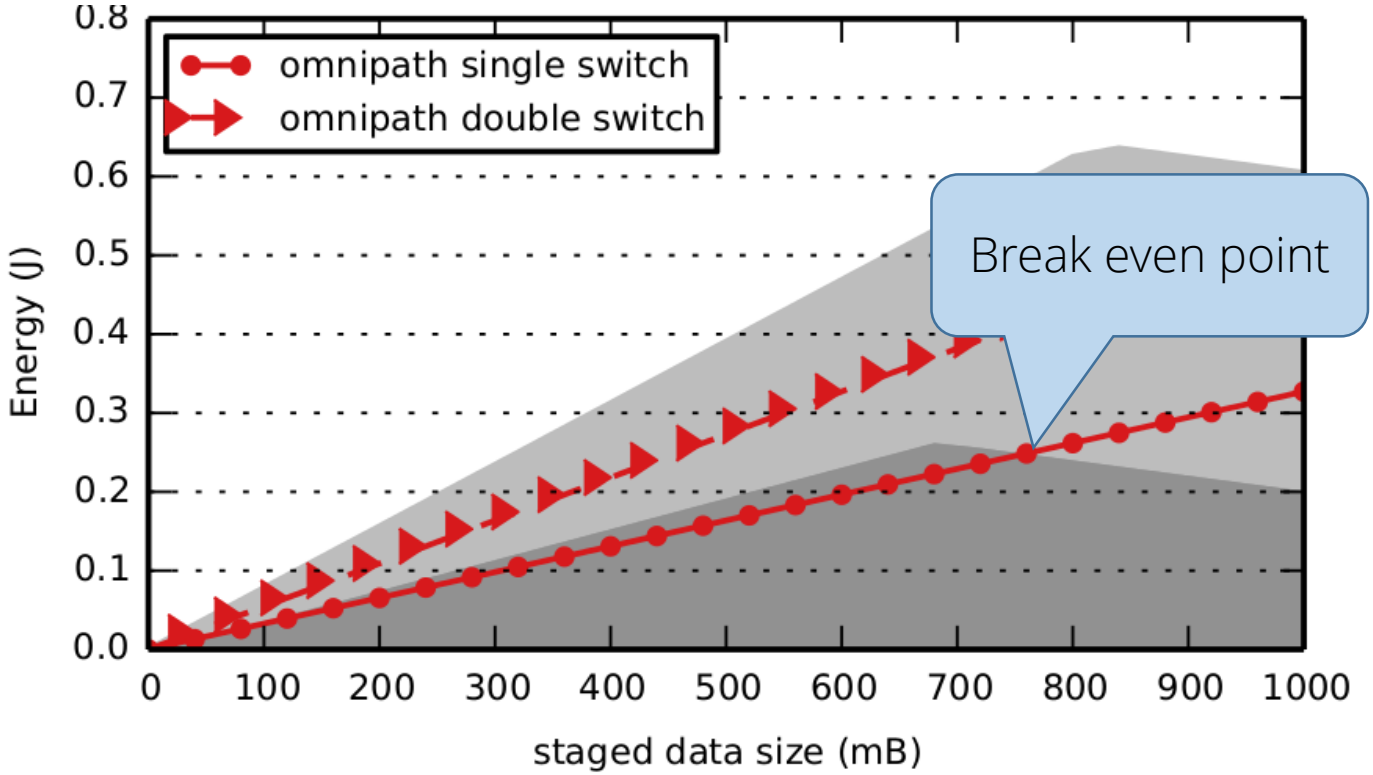

- For DRAM:NVRAM bandwidth ratio of 2:1 PHX can stage up to ~750 MB (total checkpoint size is 1GB) when the buddy node is one switch away

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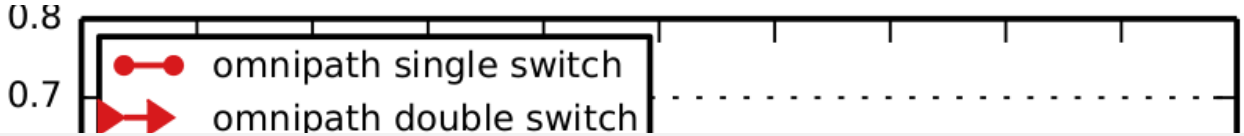

Careful selection of PHX configuration parameters will lead to both fast checkpoints and energy savings.

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Evaluation

- Four node cluster run in the stampede supercomputer
- Emulated NVRAM using software delays
- Three application benchmarks
  - GTC
  - CM1
  - S3D

GTC Benchmark

- Checkpoint data-intensive application
- Staging buffer size -- 50% of checkpoint data per interval
- Lot of early access variables

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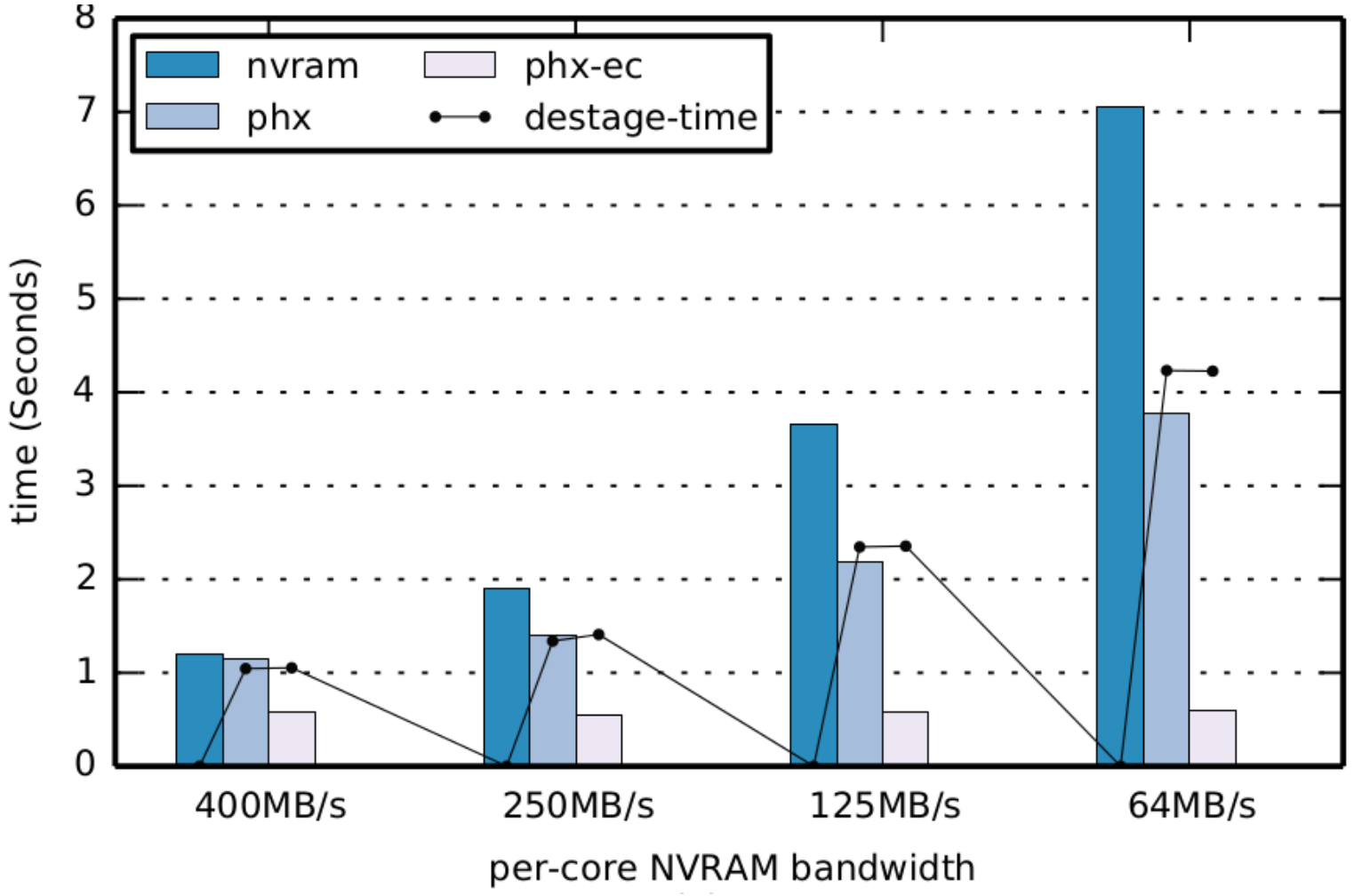

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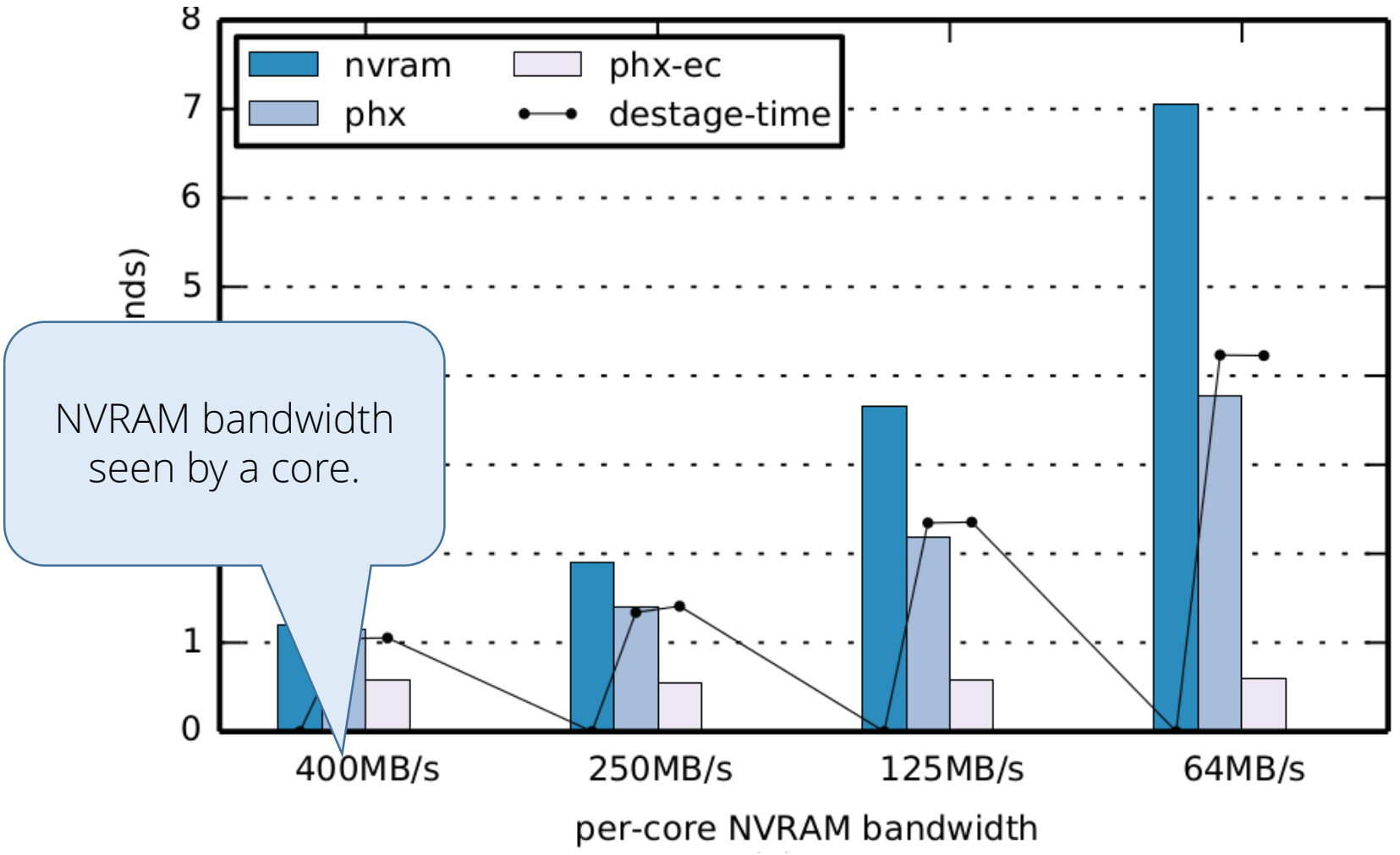

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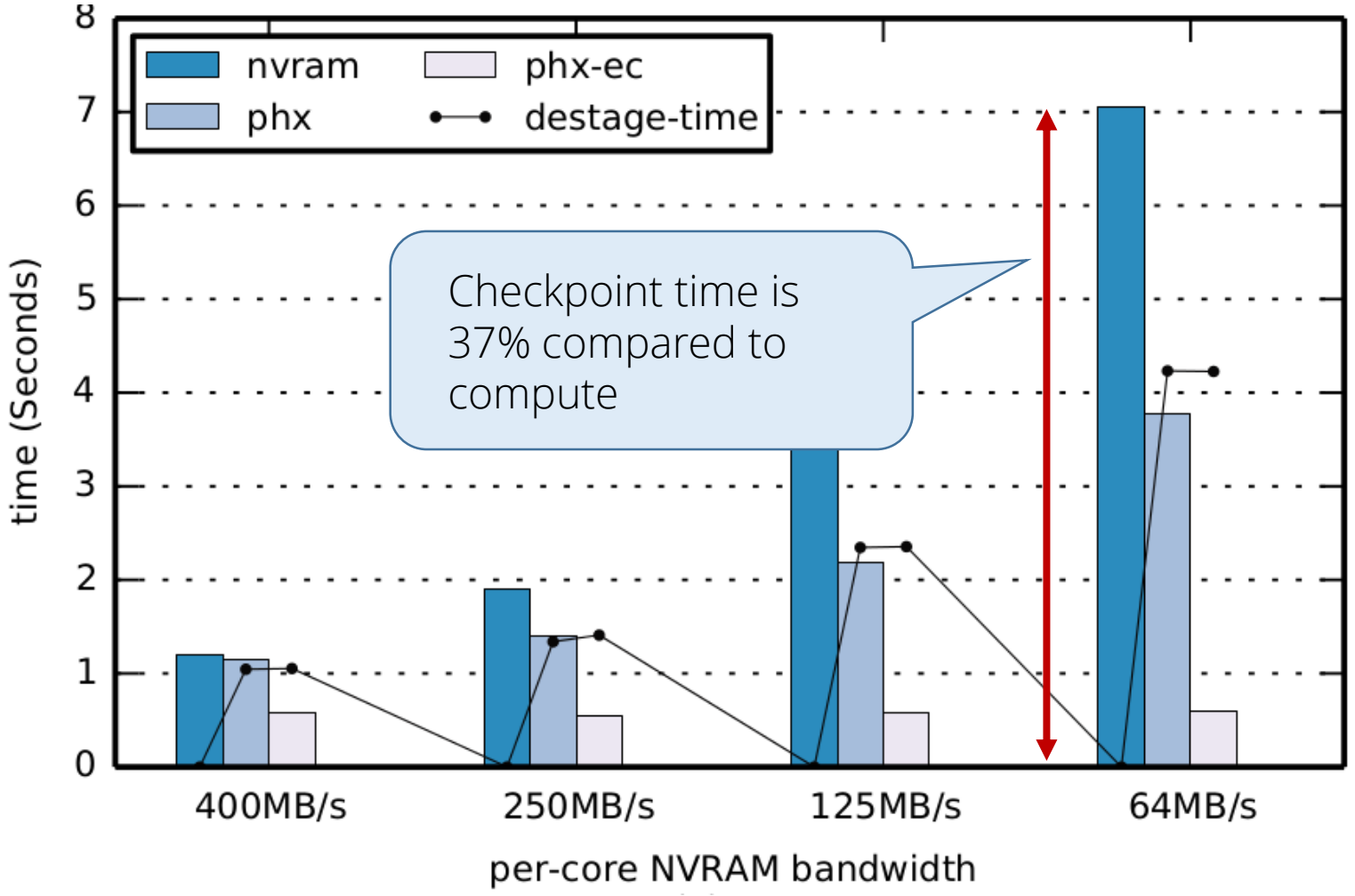

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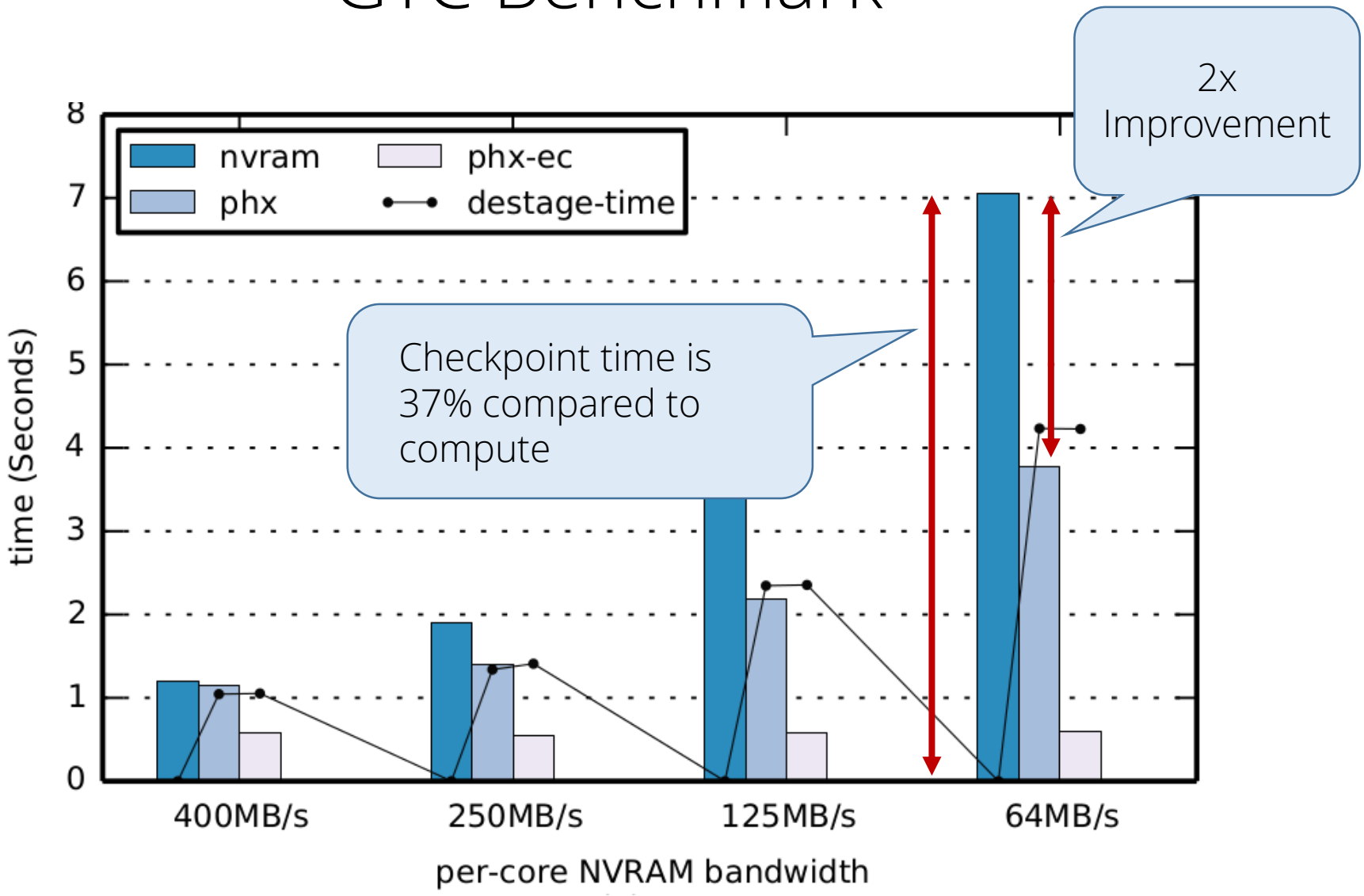

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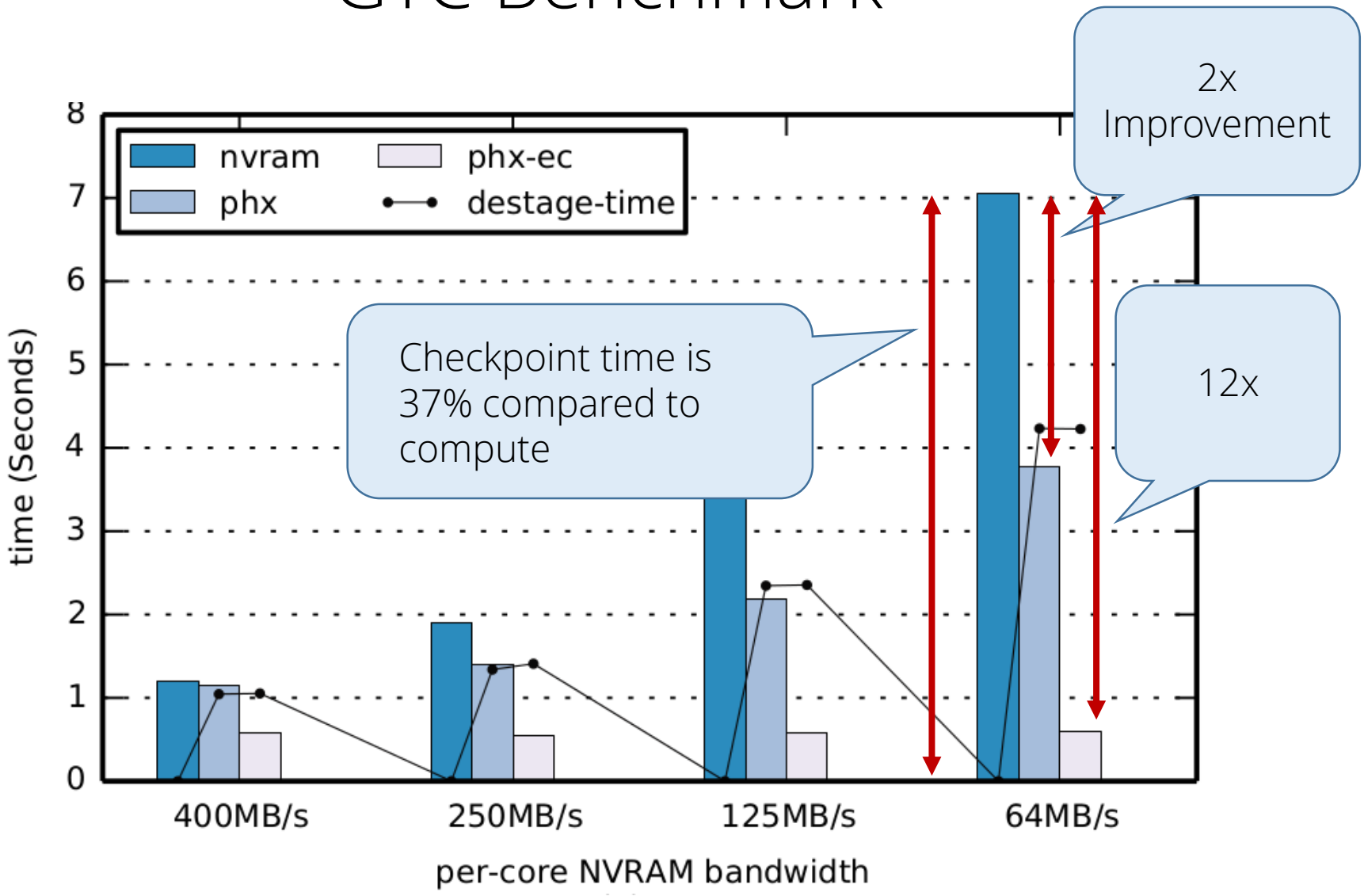

CM1 Benchmark

- Compute heavy application
- Staging buffer = 50% checkpoint data per interval
- No early access variables

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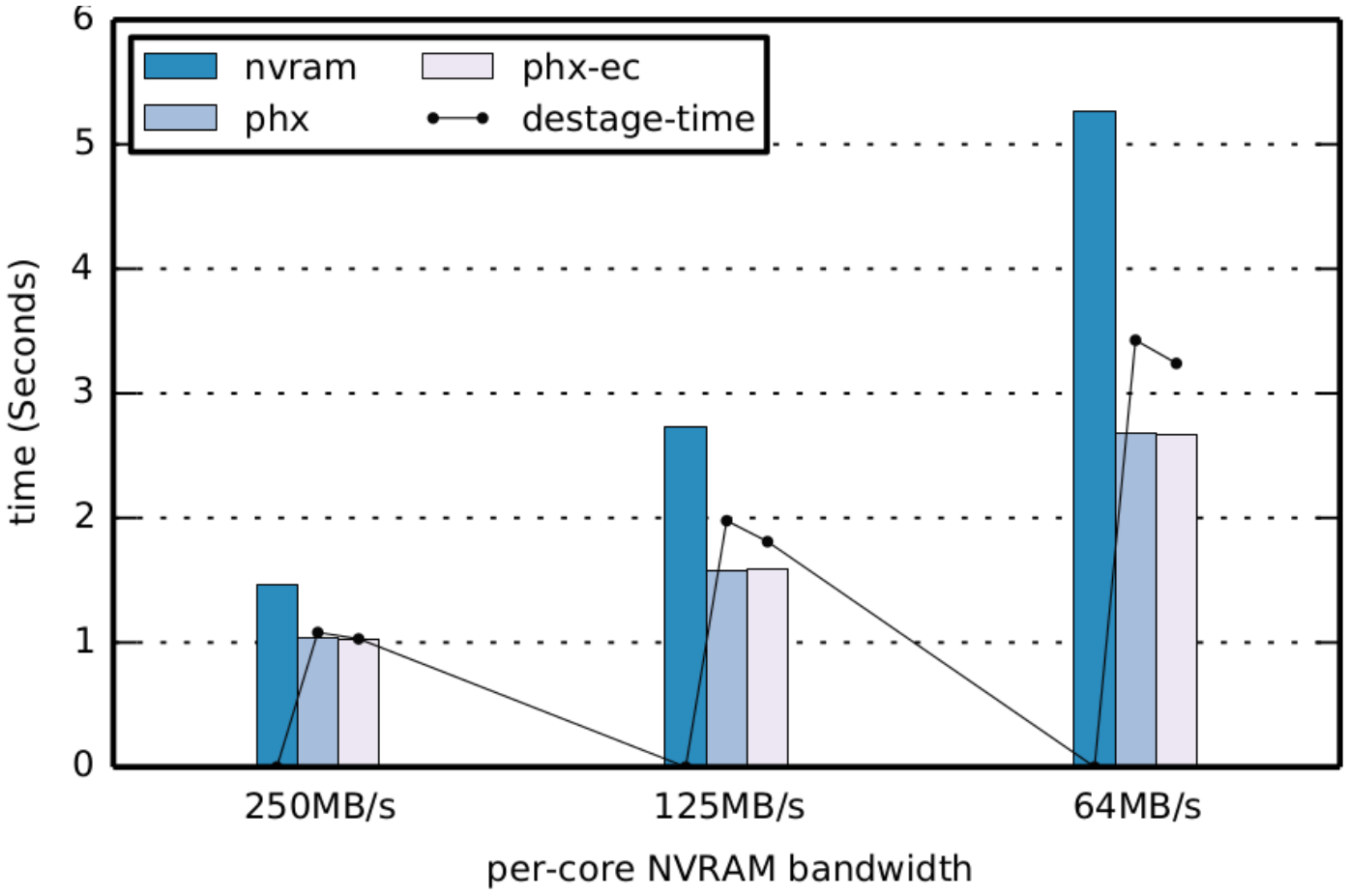

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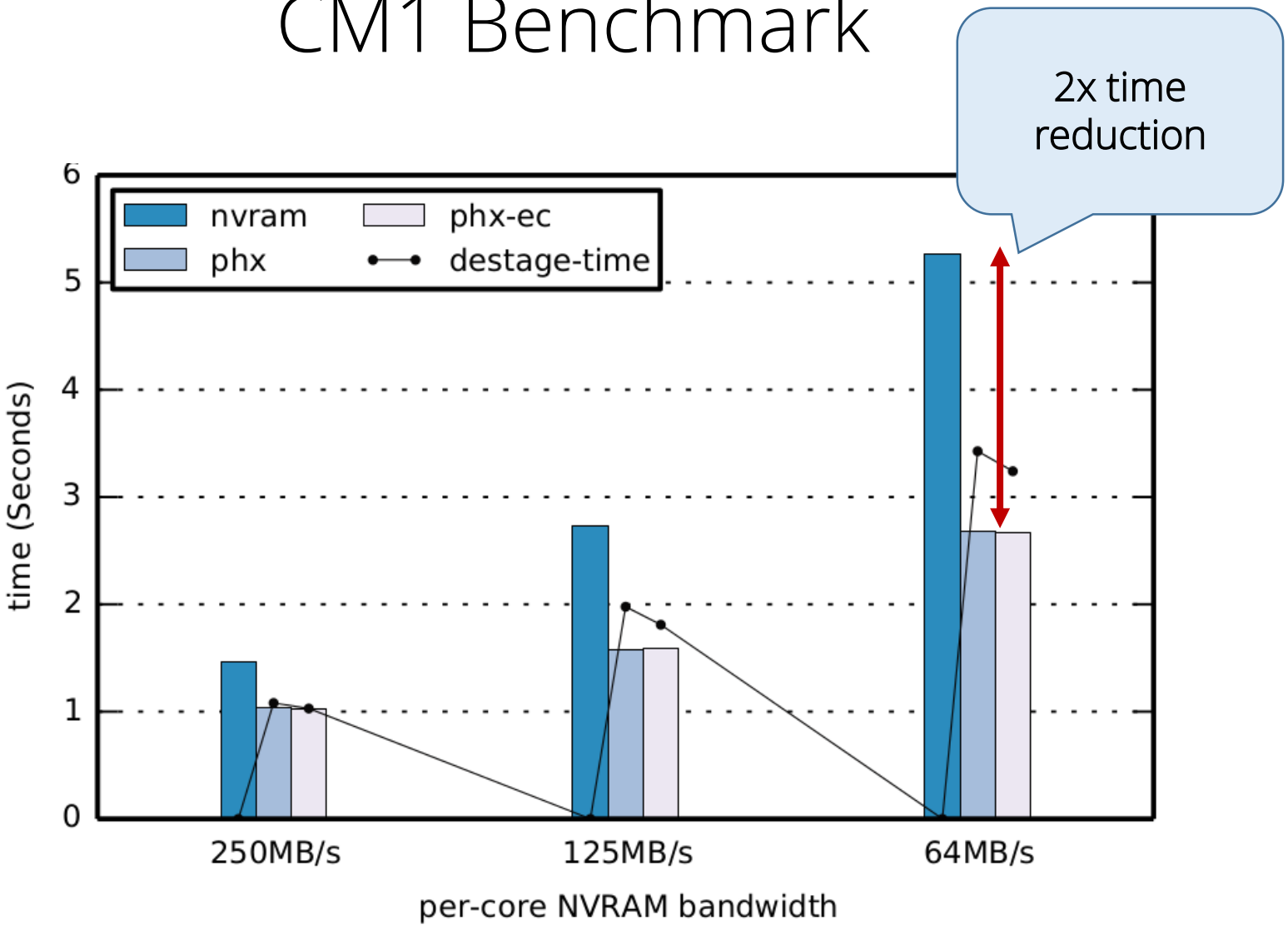
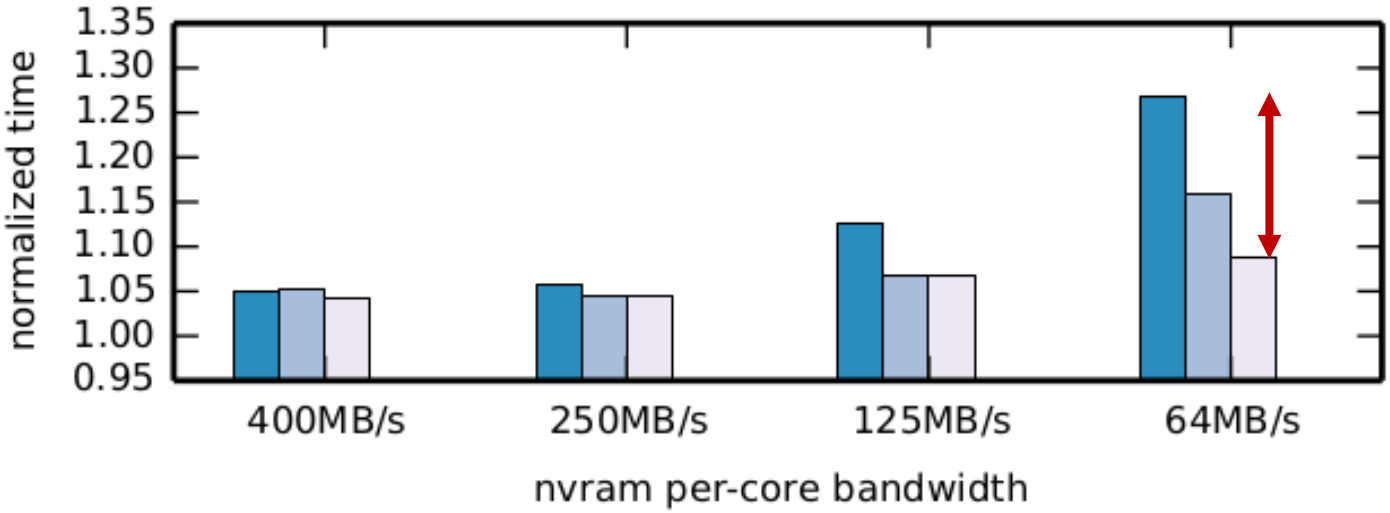


Total Simulation Time

- Application – GTC
- Total time over 10 compute iterations



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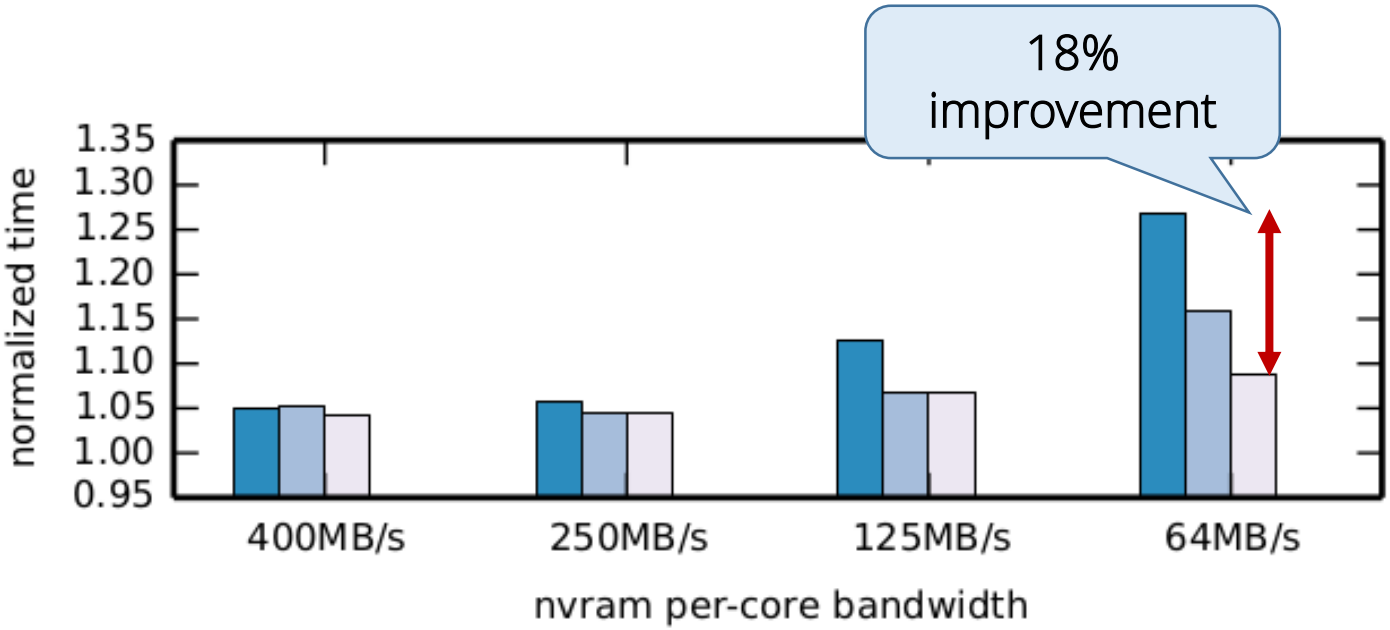

Summary

- PHX – a bandwidth aware checkpoint/ restart scheme for NVM
  - Reduce C/R time , accelerate simulation time
  - Reduce energy requirements
- The technique shows promising results in the evaluated scale
  - C/R costs will only increase with scale, so solutions like PHX will only gain importance
- Future work
  - Evaluate against analytics workloads
  - Deployment and evaluation at scale
  - Will be carried out as part of the UNITY SSIO/ SICM ECP projects, funder by US DoE

Thanks!

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Q&A