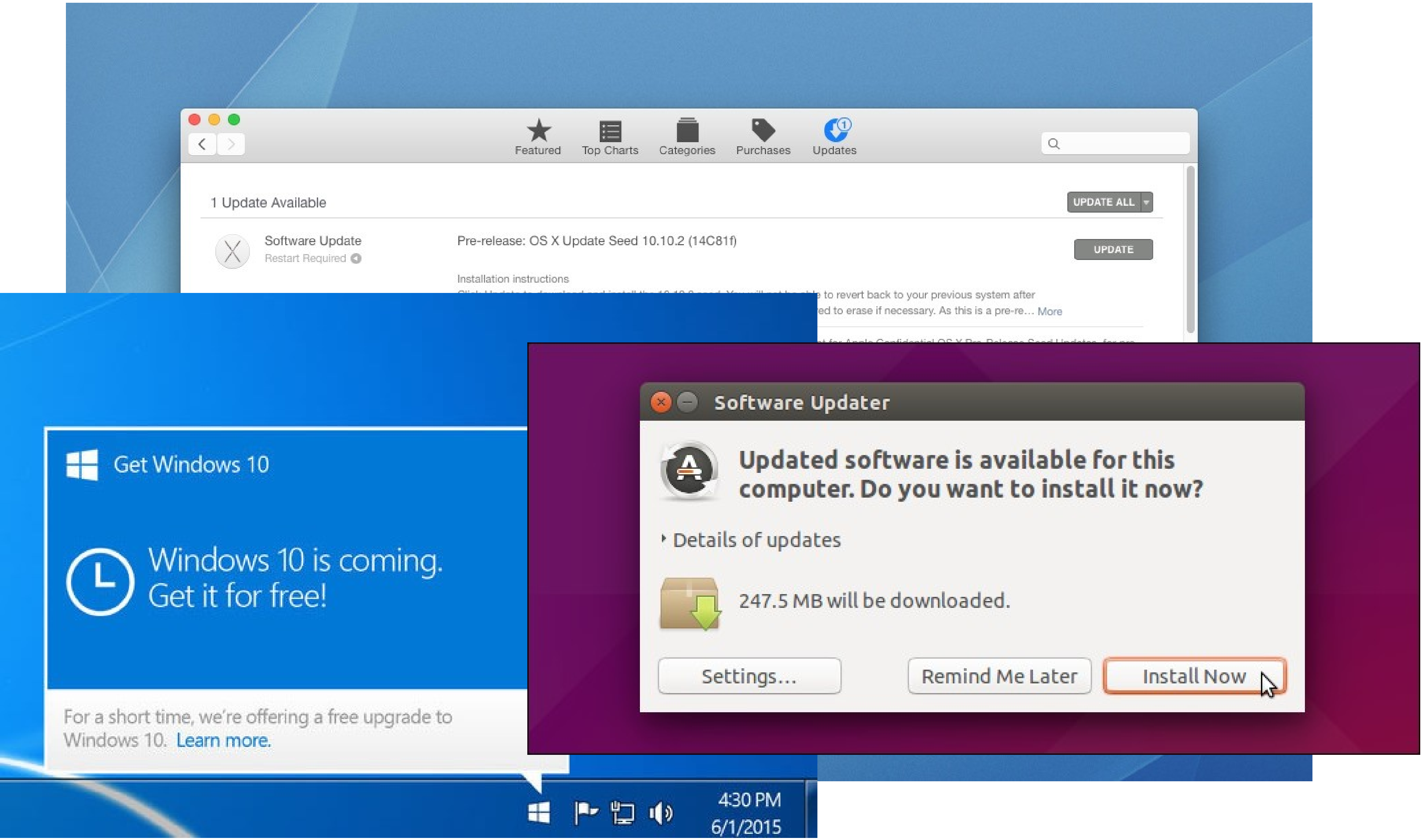
Instant OS Updates via Userspace Checkpoint-and-Restart

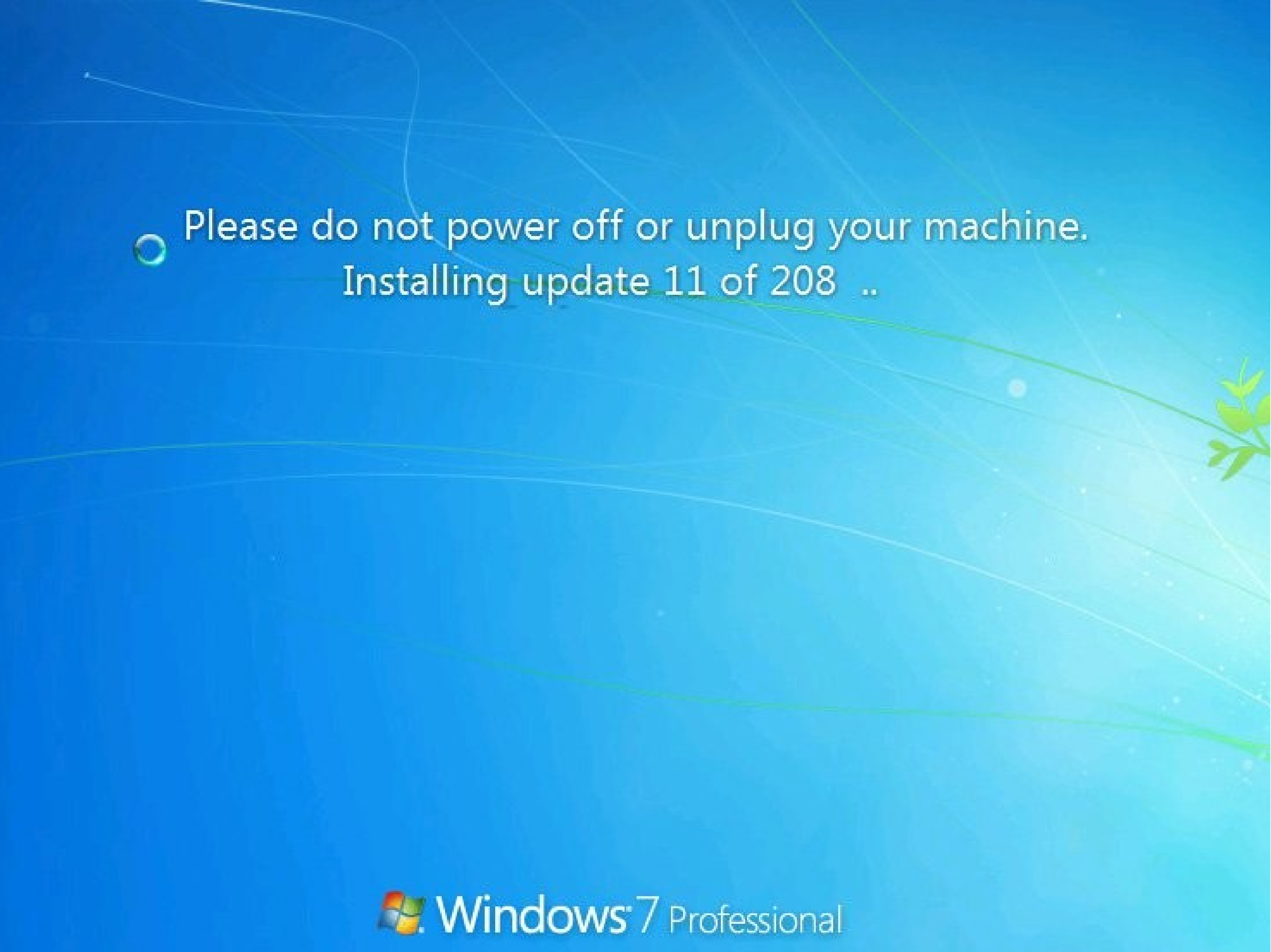
Sanidhya Kashyap, Changwoo Min, Byoungyoung Lee,
Taesoo Kim, Pavel Emelyanov

OS updates are prevalent



And OS updates are unavoidable

- Prevent known, state-of-the-art attacks
  - Security patches
- Adopt new features
  - New I/O scheduler features
- Improve performance
  - Performance patches


Please do not power off or unplug your machine.
Installing update 11 of 208 ..
Windows 7 Professional

Unfortunately, system updates come at a cost

- Unavoidable downtime
- Potential risk of system failure

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THE FINANCIAL AND OTHER COSTS OF DATA CENTER DOWNTIME

Posted on March 30, 2014 by Mary Hiers

...

Amazon had 49 minutes of downtime in Ja
an estimated $4 million in lost sales, or $8
minute of the outage. When Google went
2013, it cost an estimated $545,000 in
minute. Obviously, downtime costs big co
losses than small companies, but regardl
an expense nobody wants to face. Here are some other important facts and figures.

$109k per minute
Hidden costs (losing customers)

Example: memcached

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  - Warming cache (e.g., 120 GB) over the network

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Our approach updates OS in 3 secs for 32GB of data from v3.18 to v3.19 for Ubuntu / Fedora releases

Existing practices for OS updates

- Dynamic Kernel Patching (e.g., kpatch, ksplice)
  - **Problem:** only support minor patches
- Rolling Update (e.g., Google, Facebook, etc)
  - **Problem:** inevitable downtime and requires careful planning

Existing practices for OS updates

Losing application state is inevitable

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Goals of this work:

- **Support all types of patches**
- **Least downtime to update new OS**
- **No kernel source modification**

Problems of typical OS update

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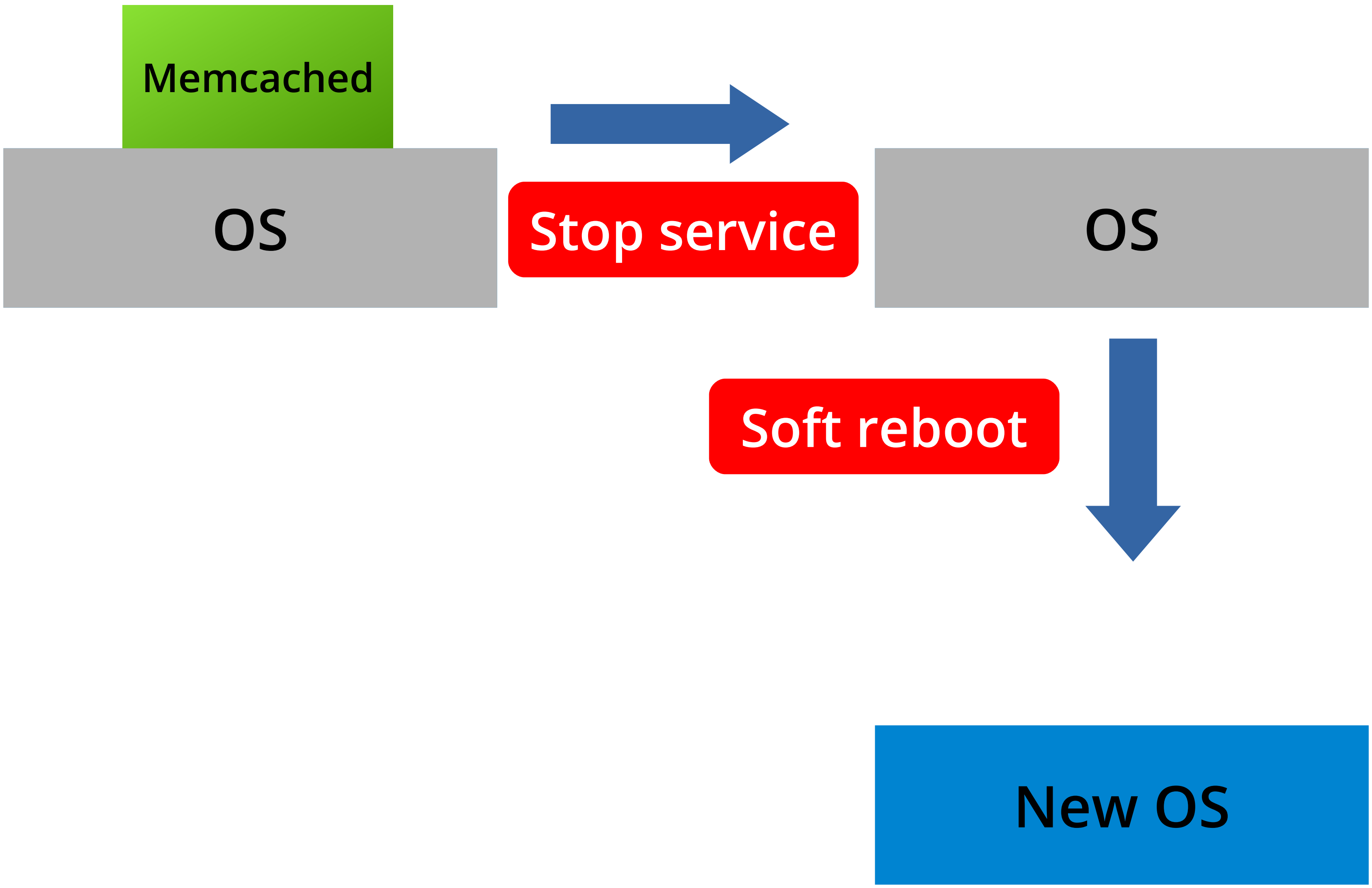

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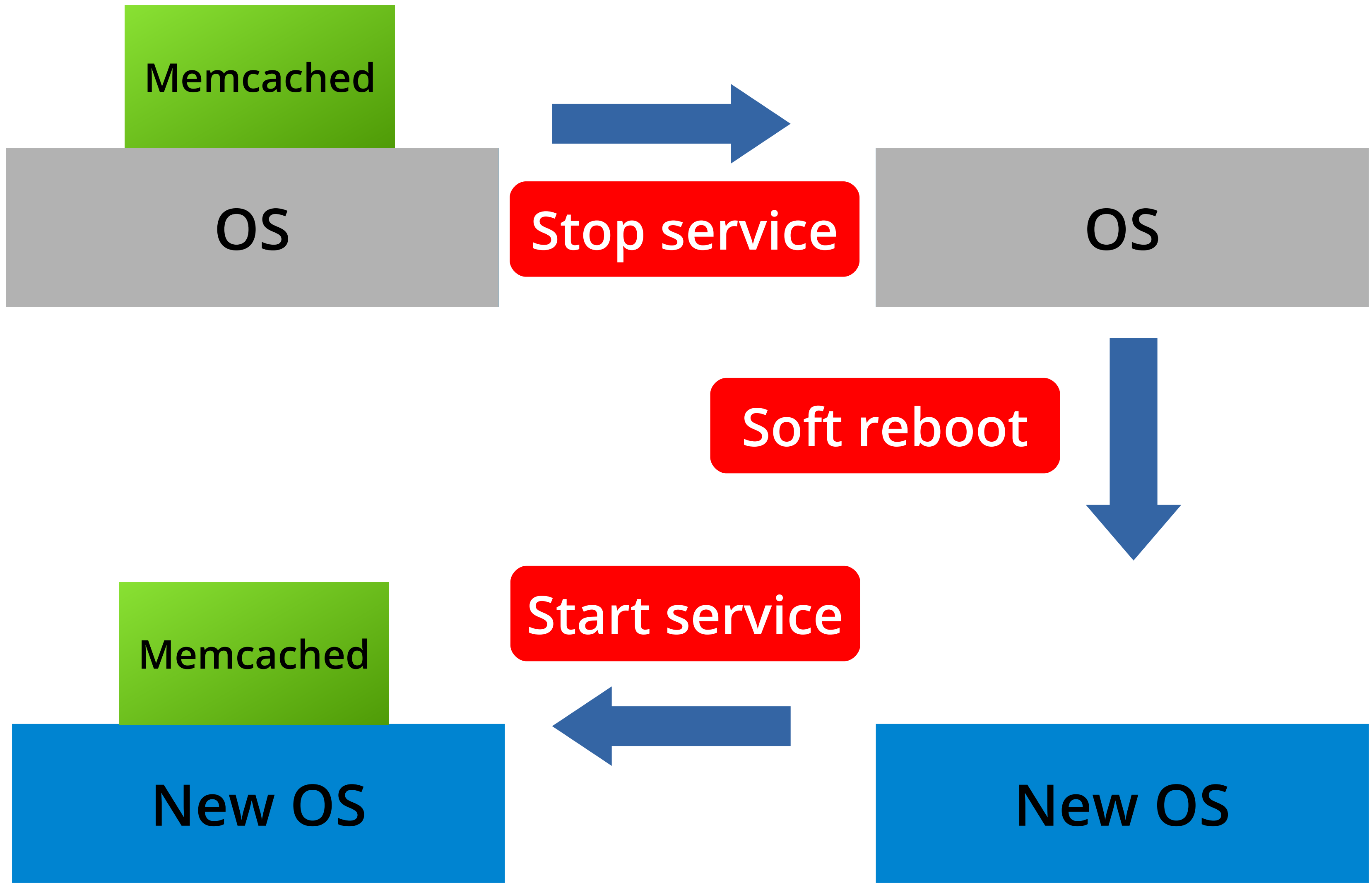

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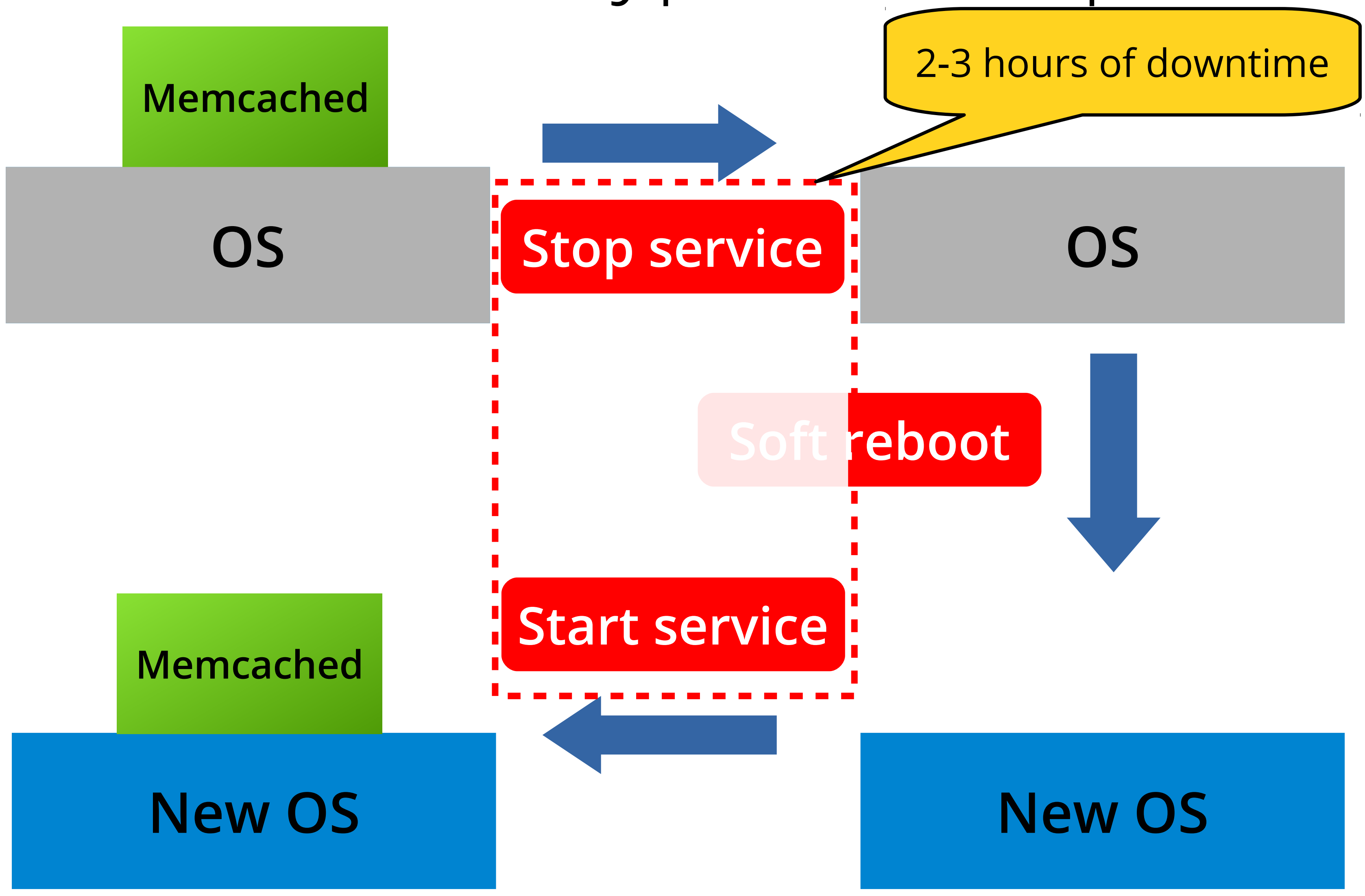

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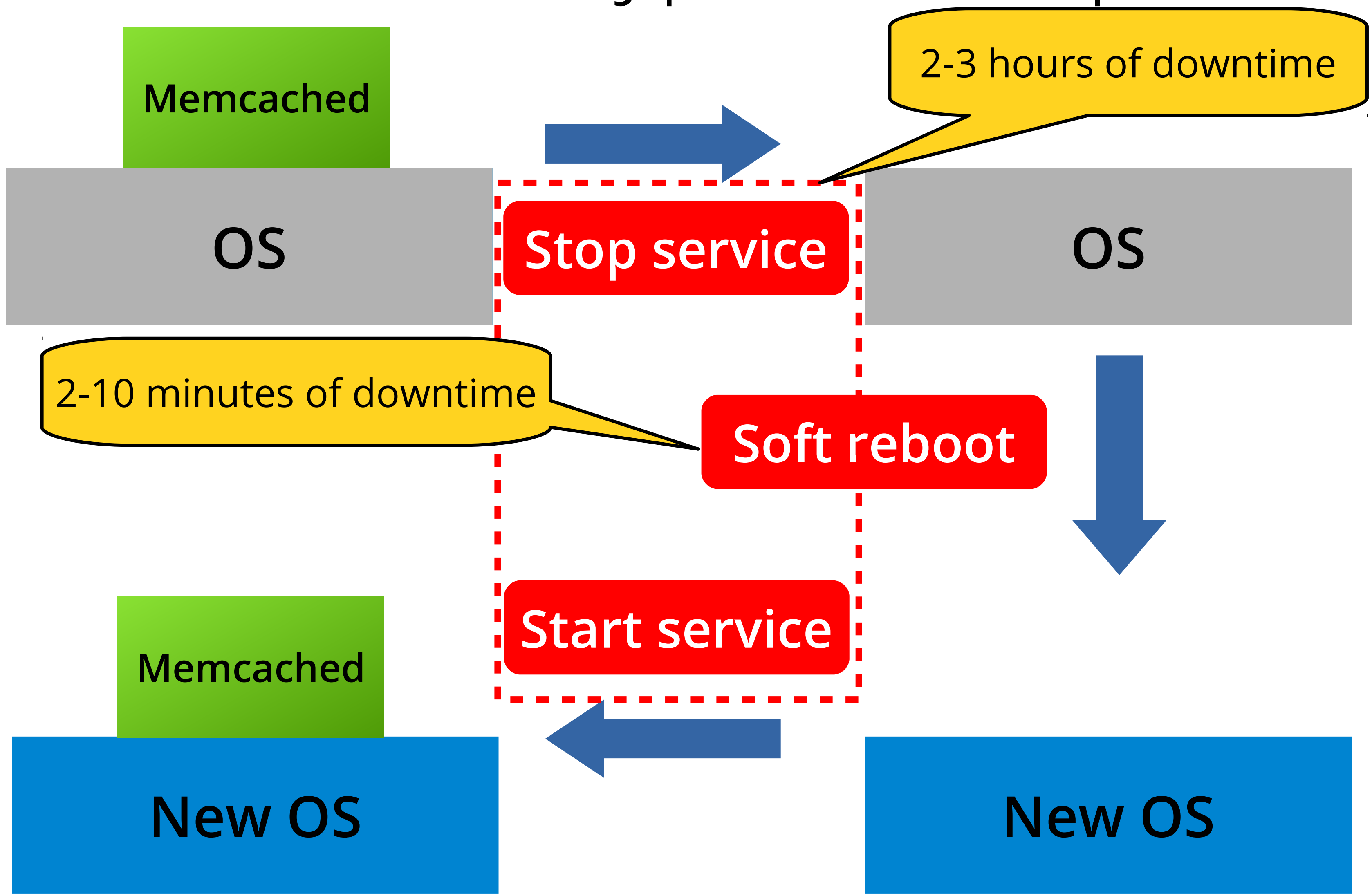

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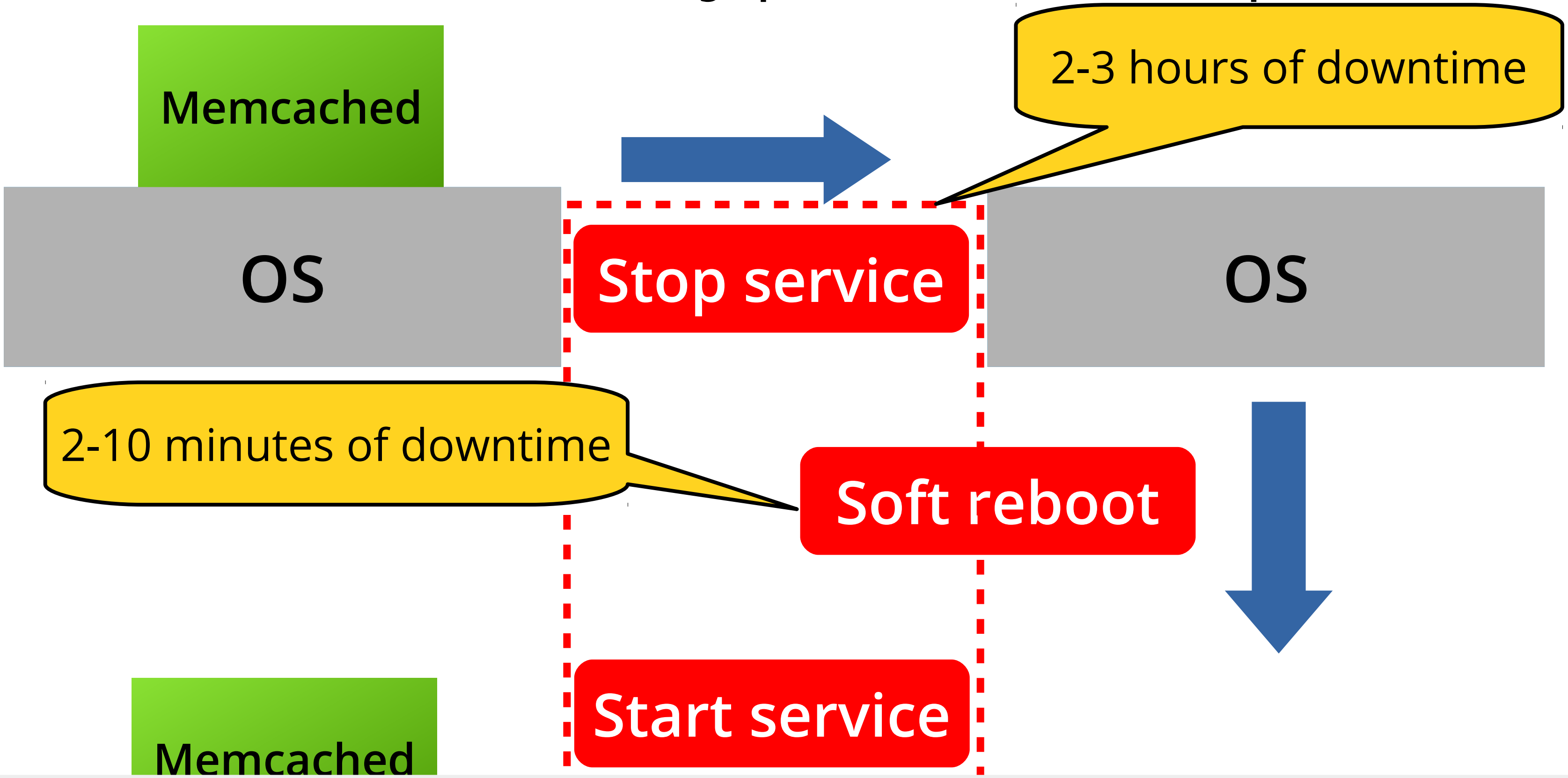
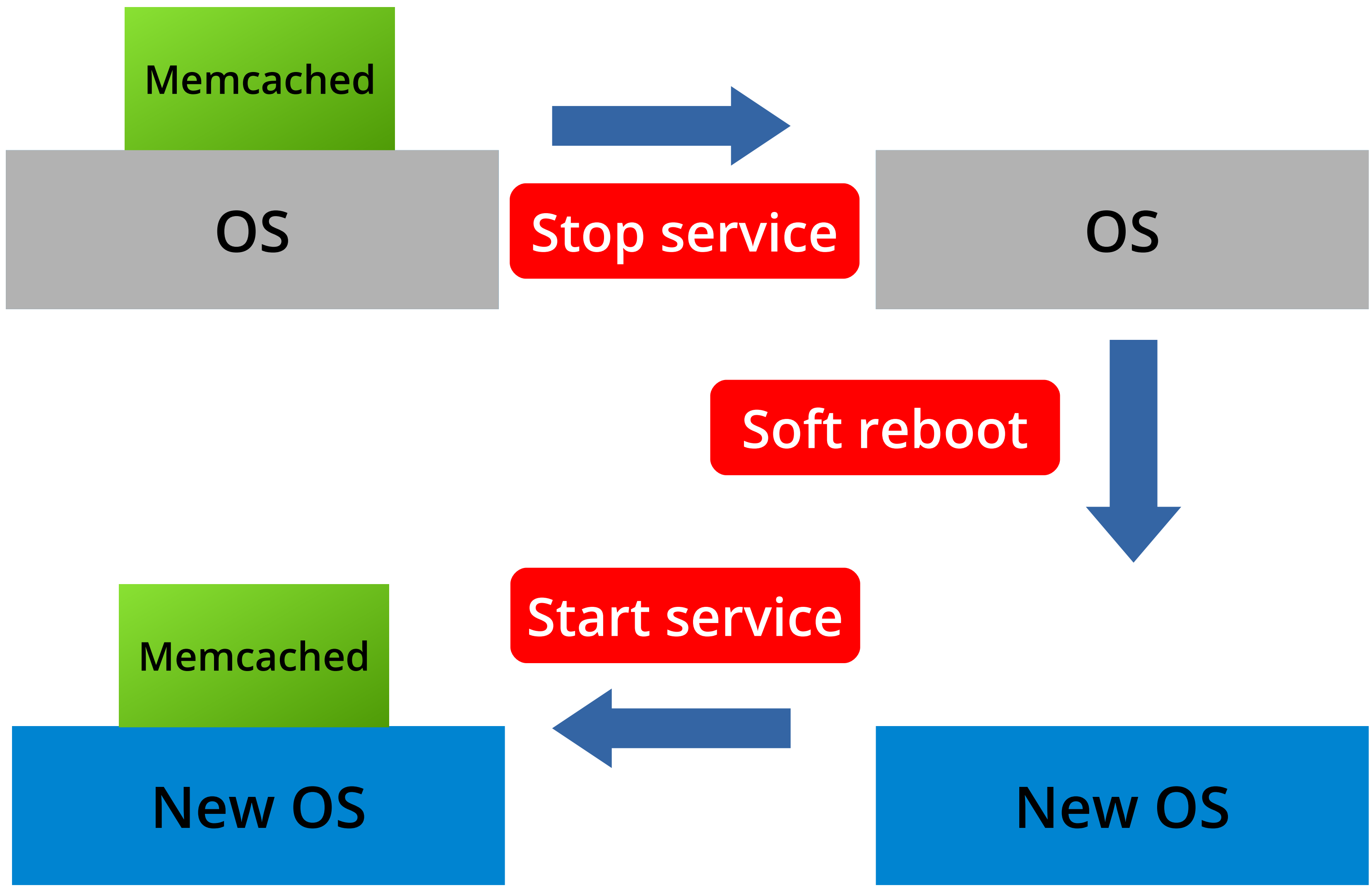


Is it possible to keep the application state?

KUP: Kernel update with application checkpoint-and-restore (C/R)



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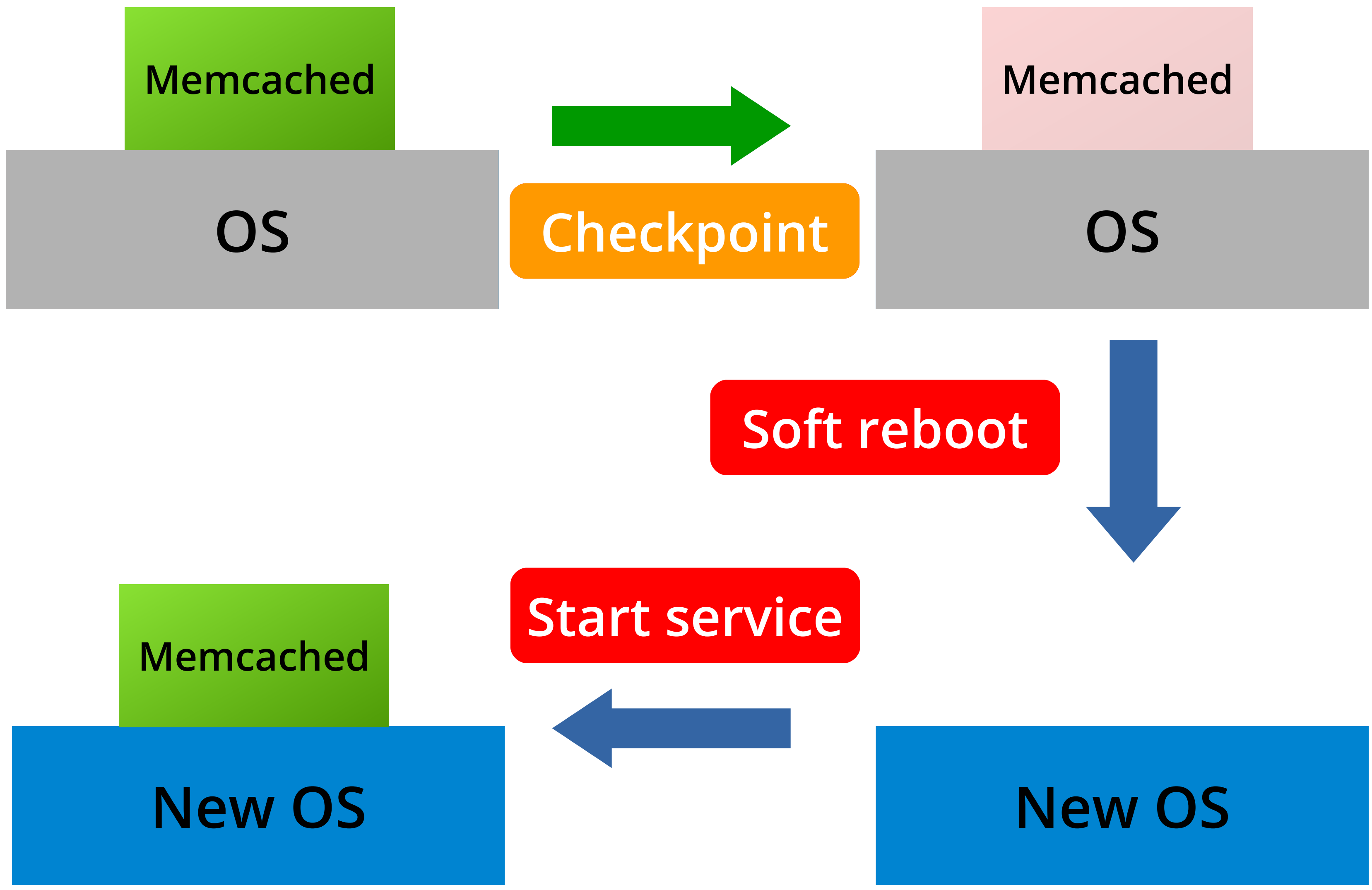

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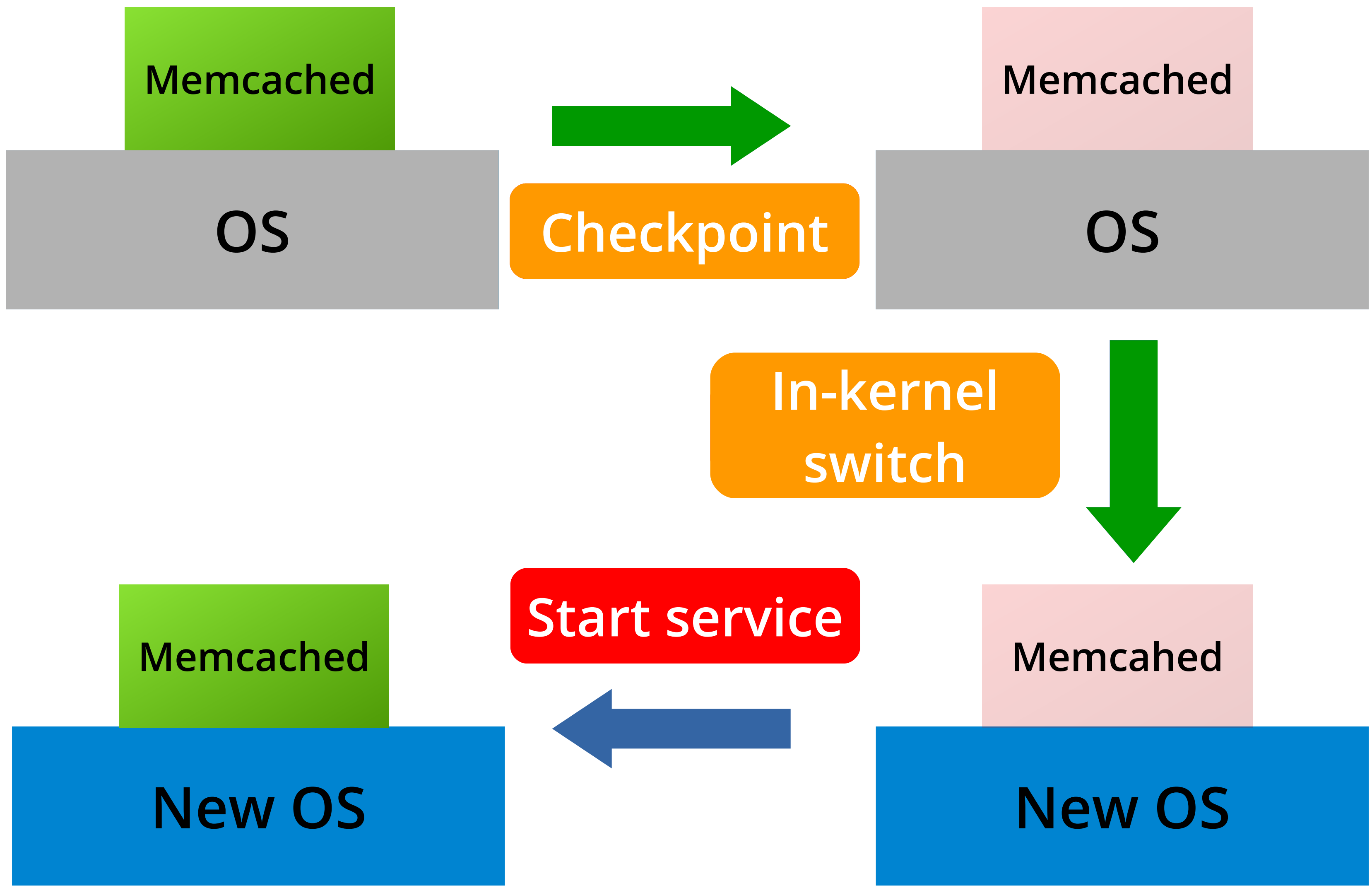

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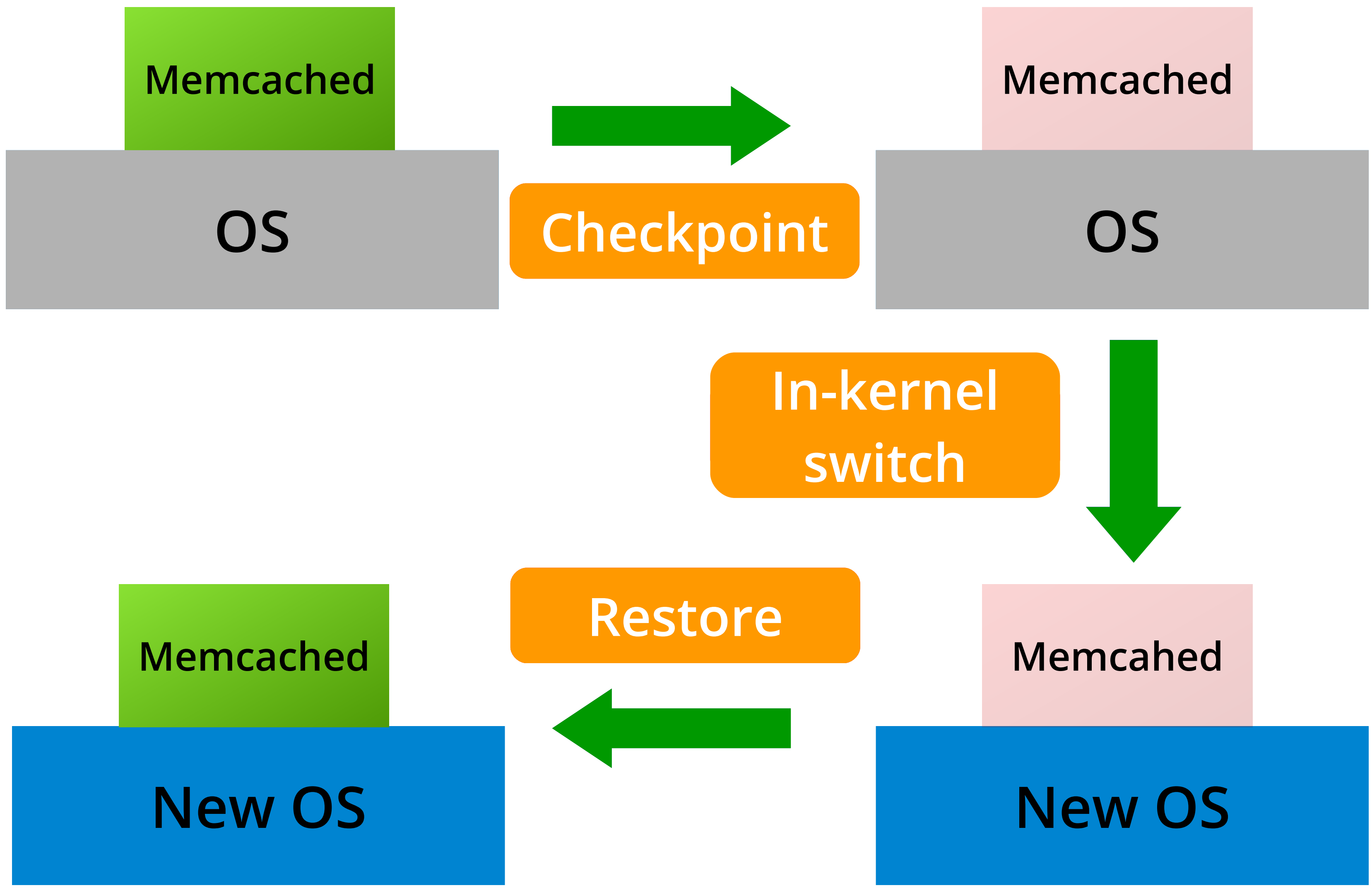

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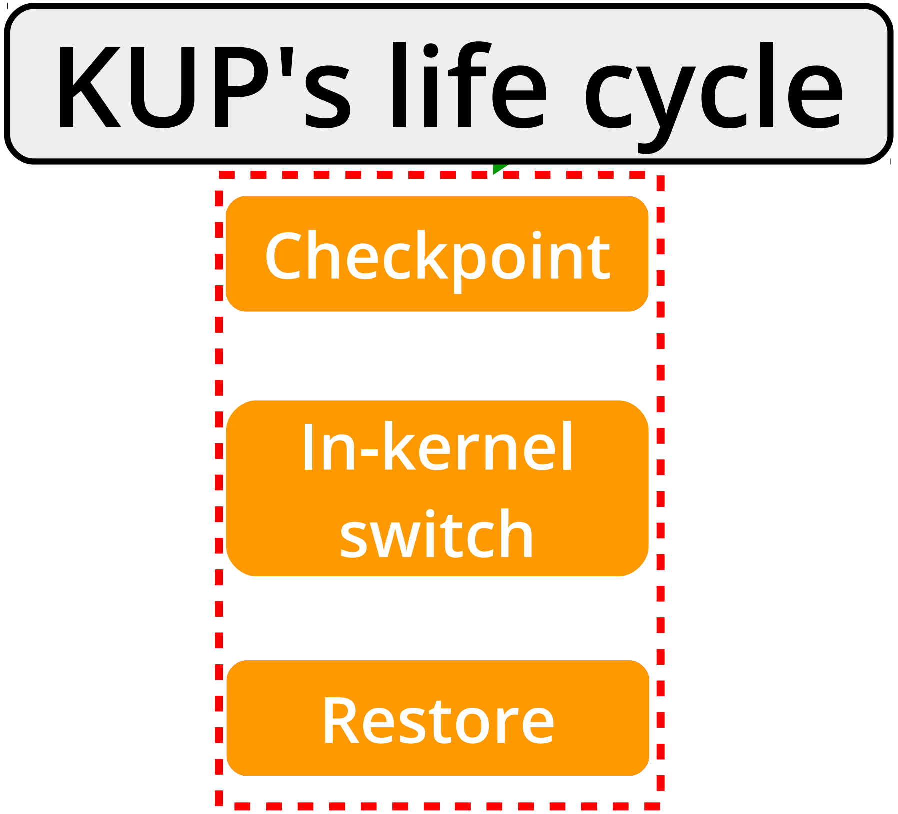

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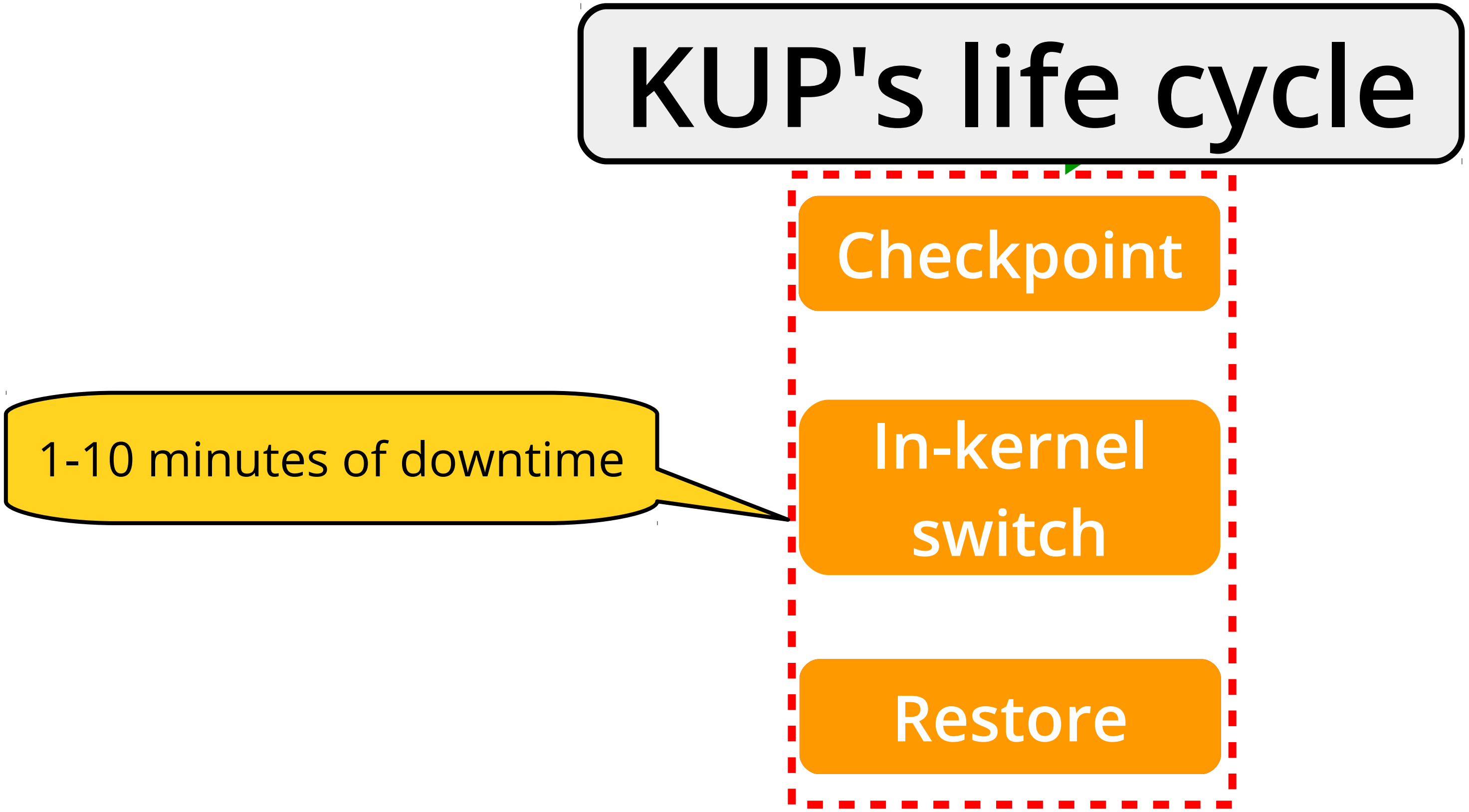

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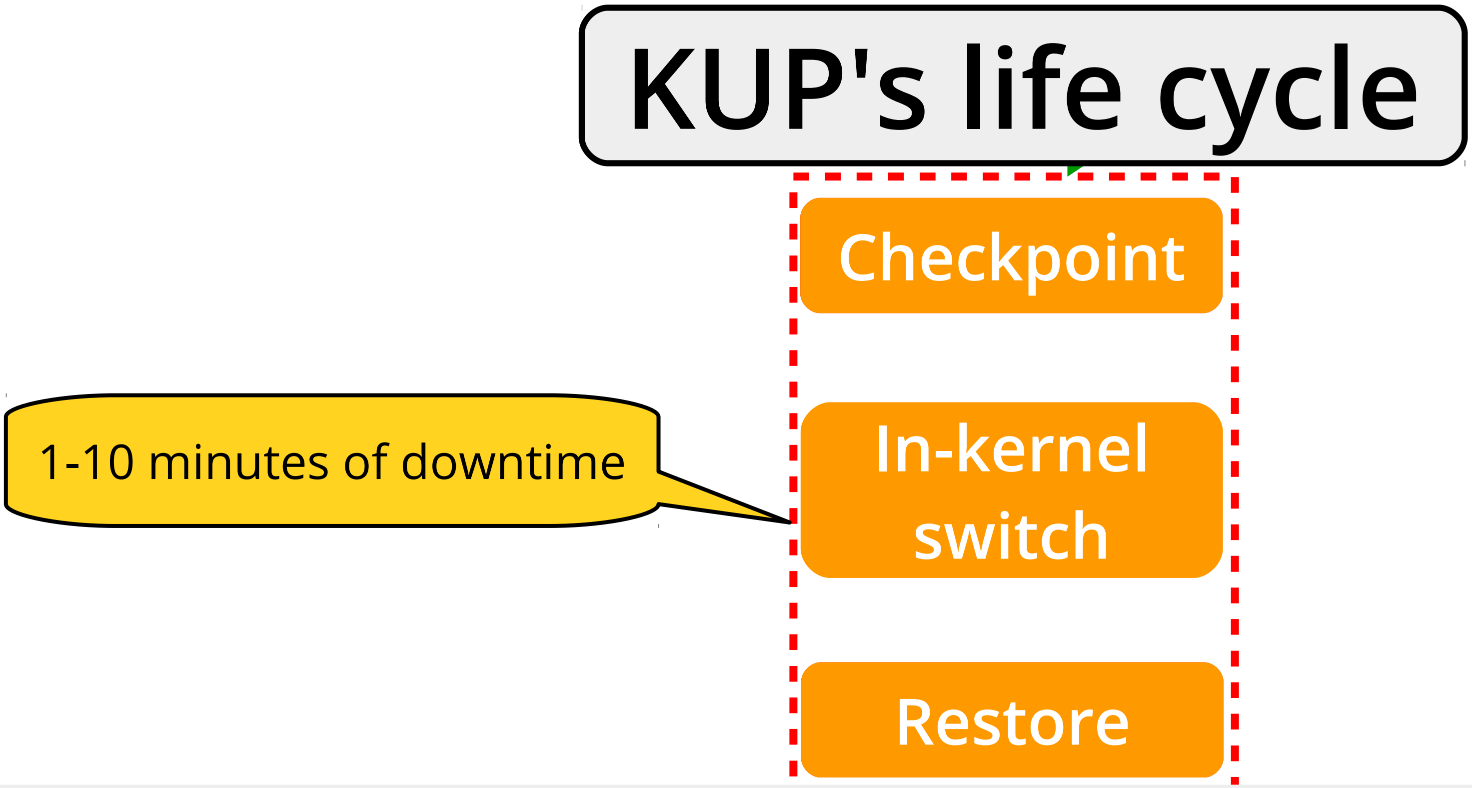
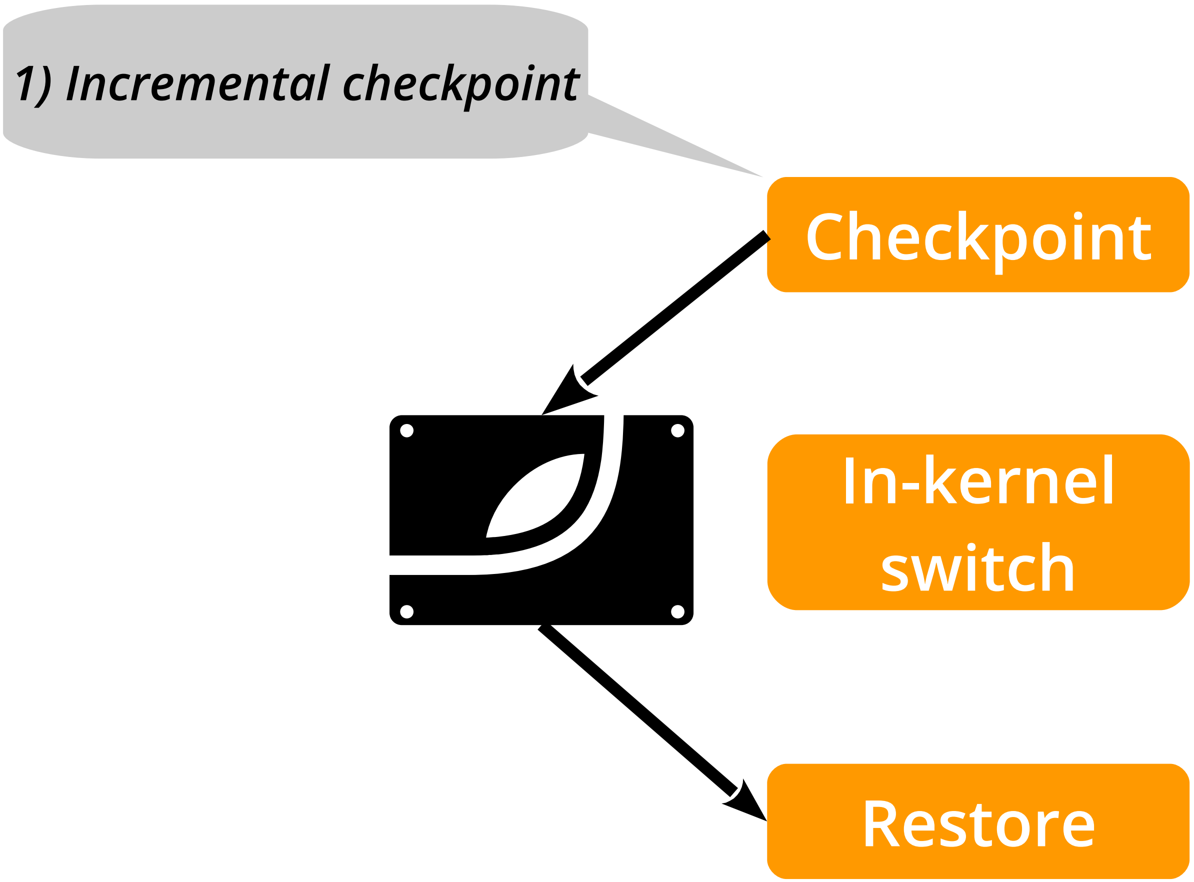


Challenge: how to further decrease the potential downtime?

Techniques to decrease the downtime



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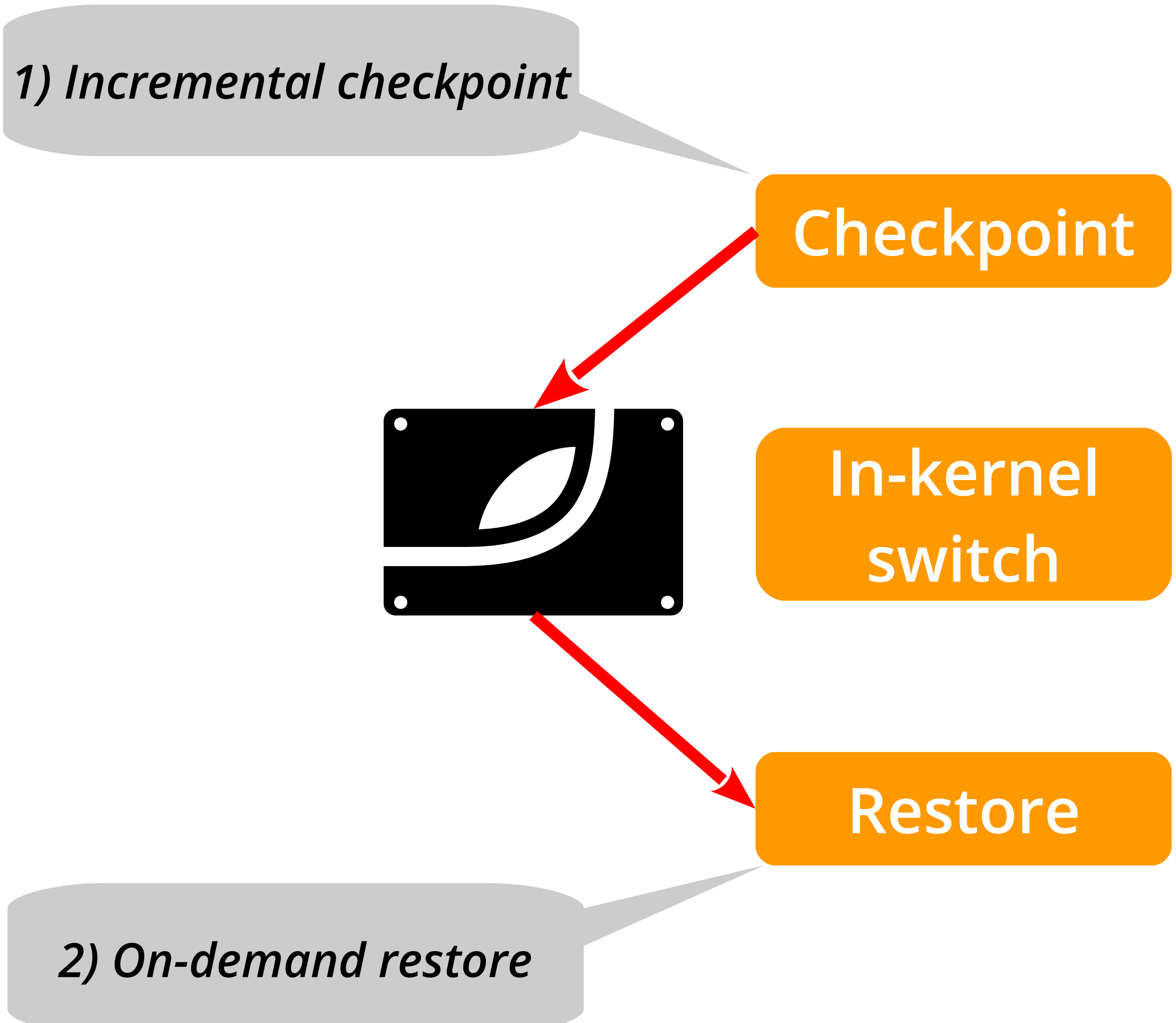

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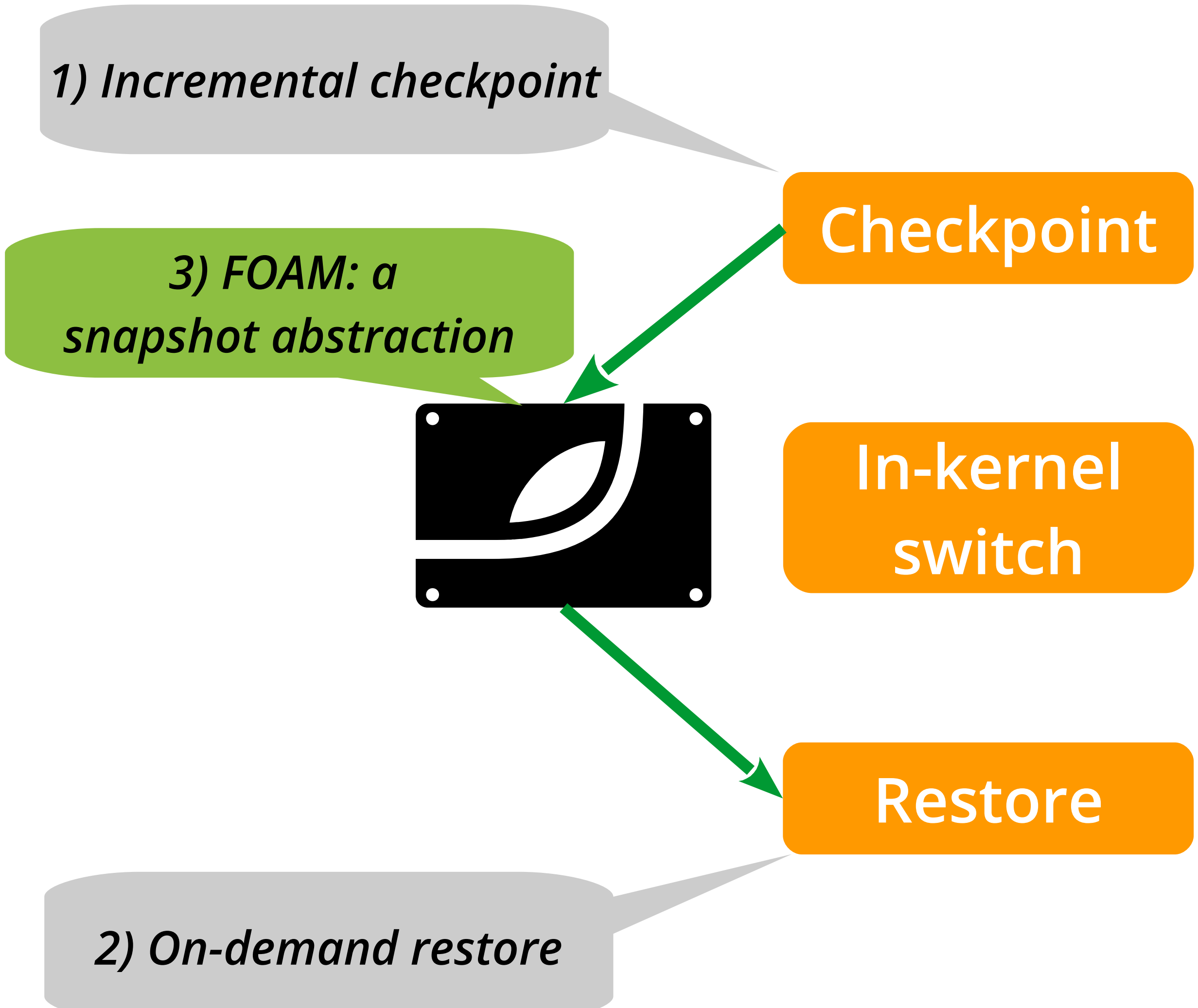

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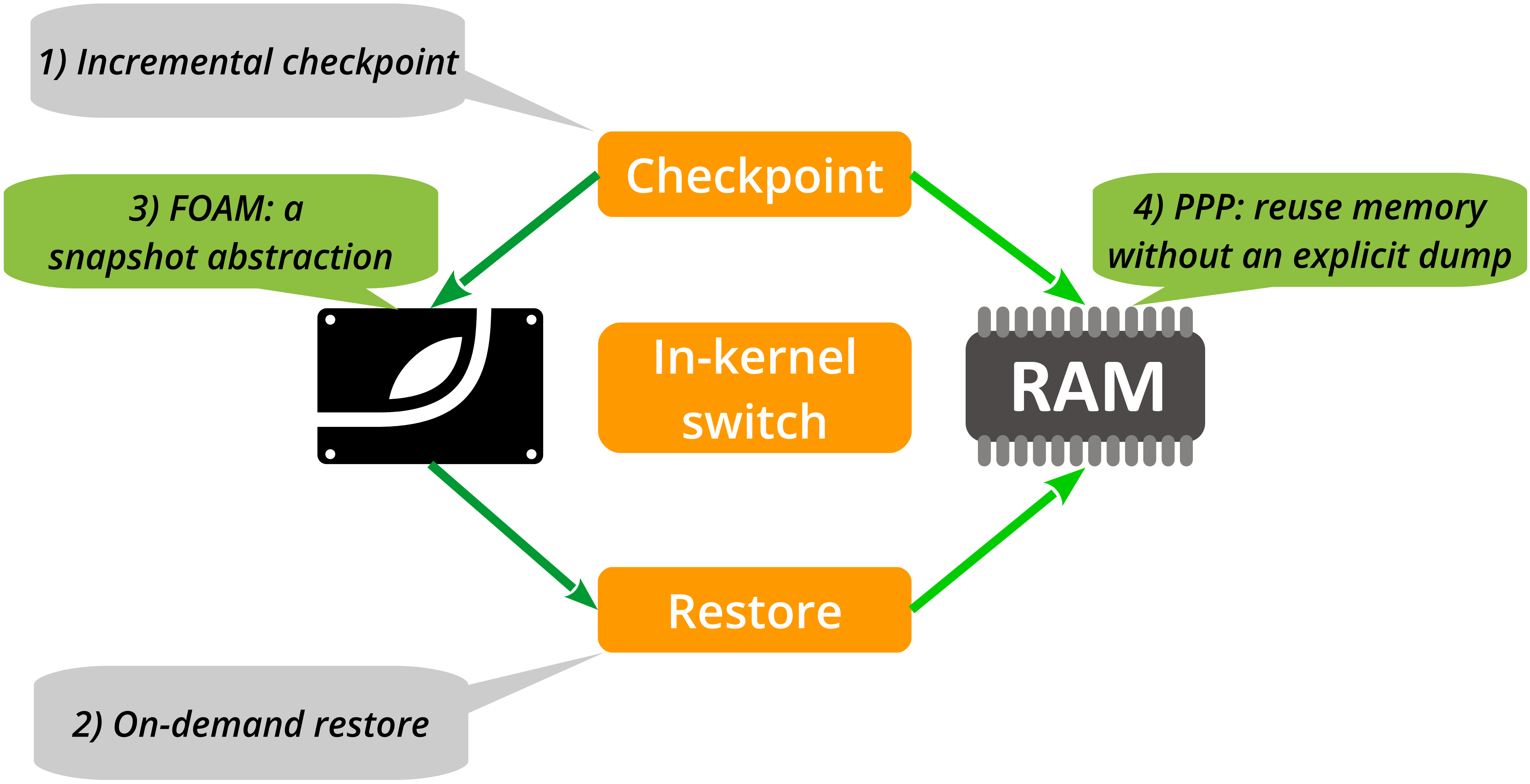

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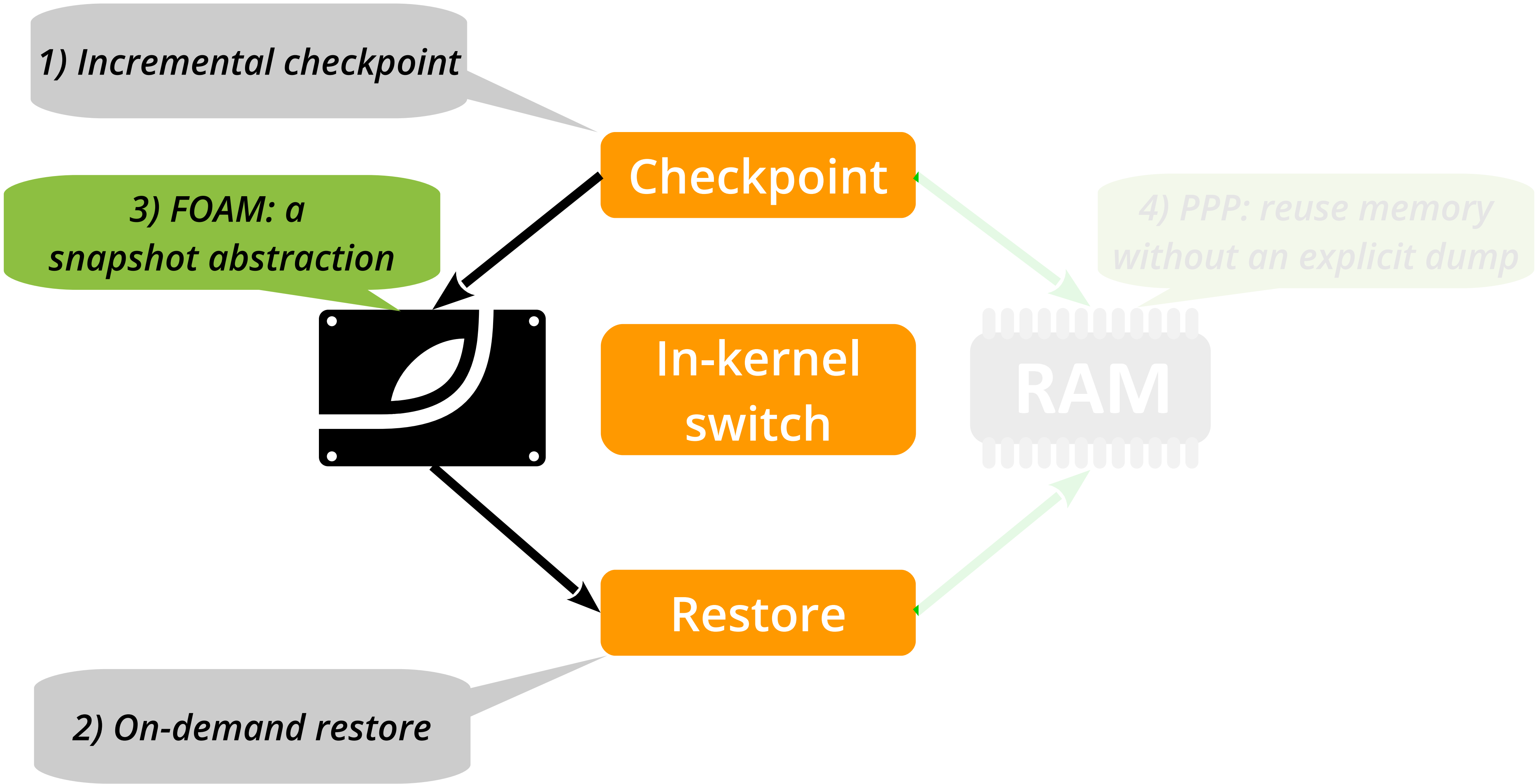
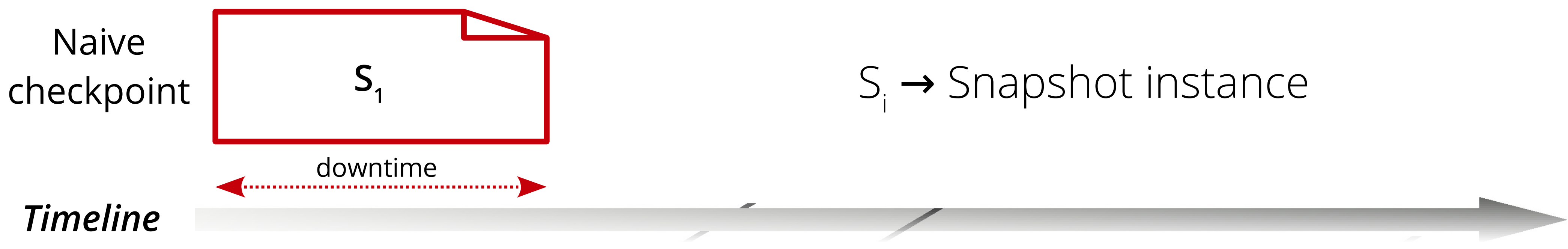


Incremental checkpoint

- Reduces downtime (up to 83.5%)
- **Problem**: Multiple snapshots increase the restore time



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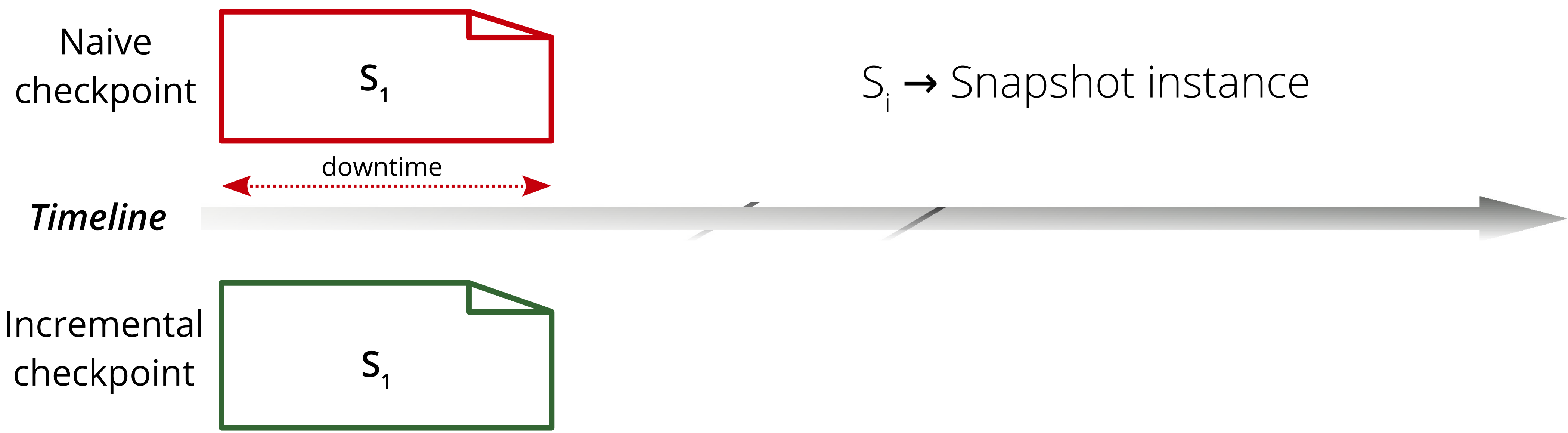

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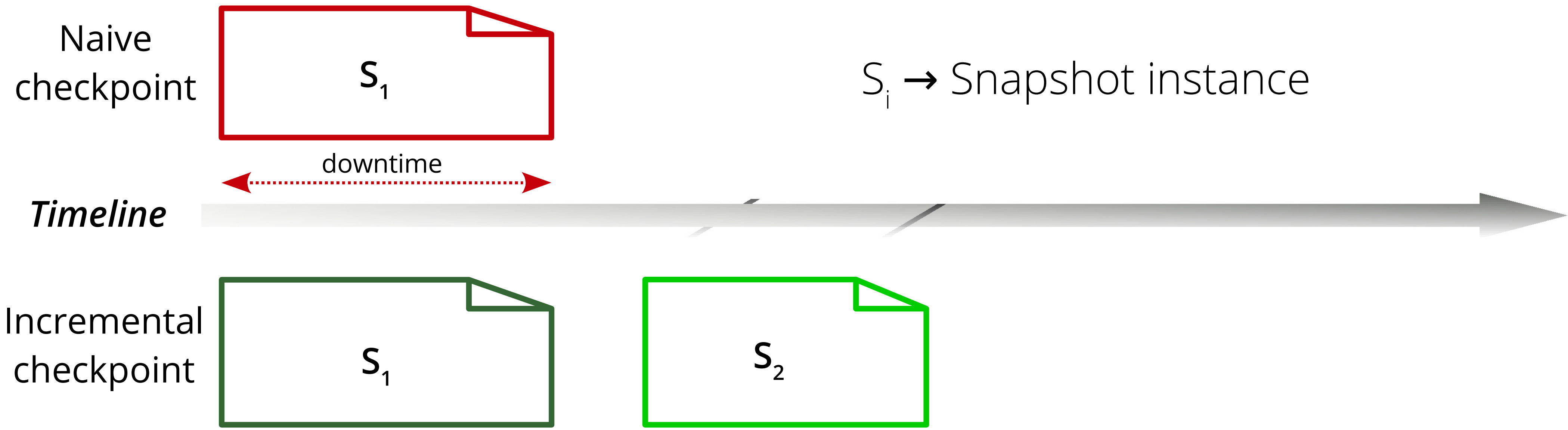

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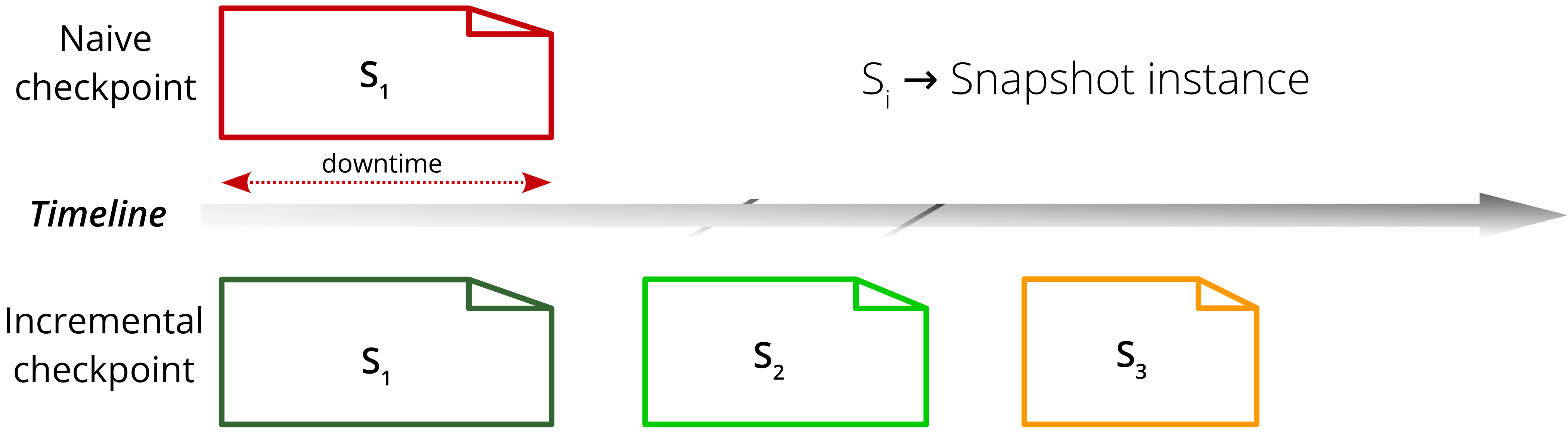

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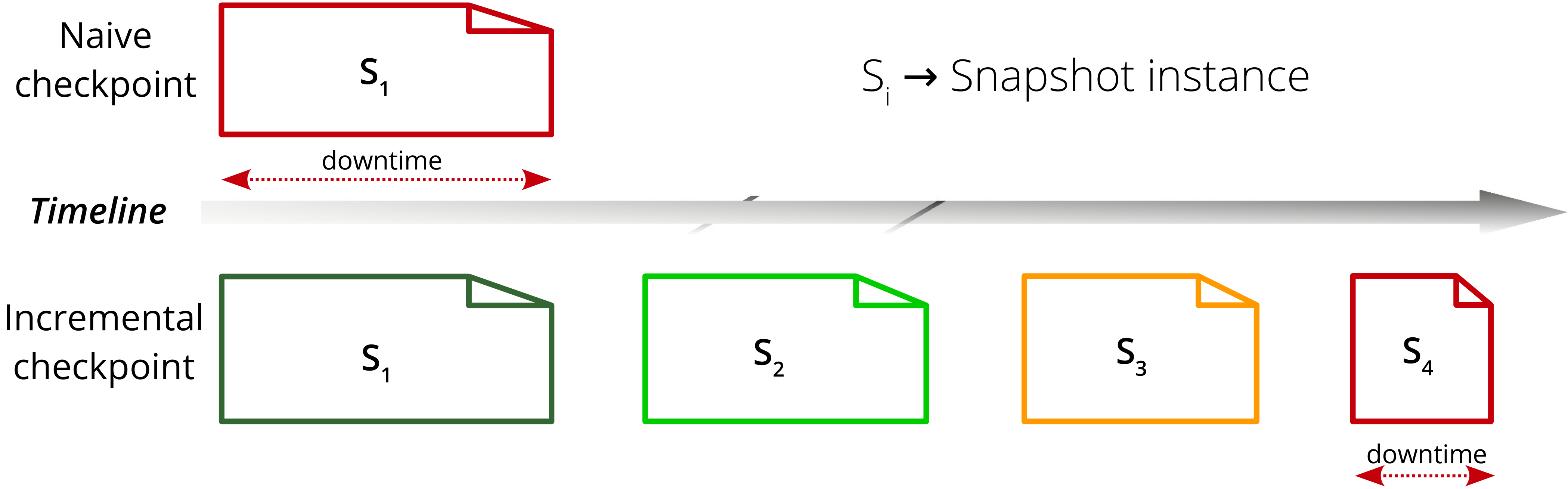
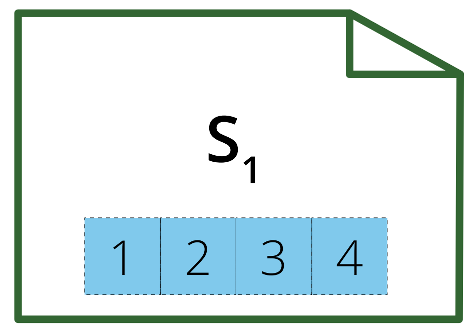


On-demand restore

- Rebind the memory once the application accesses it
  - Only map the memory region with snapshot and restart the application
- Decreases the downtime (up to 99.6%)
- **Problem**: Incompatible with incremental checkpoint

Problem: both techniques together result in inefficient application C/R

- During restore, need to map each pages individually
  - Individual lookups to find the relevant pages
  - Individual page mapping to enable on-demand restore



- An application has 4 pages as its working set size
- Incremental checkpoint has 2 iterations
  - 1st iteration → all 4 pages (1, 2, 3, 4) are dumped
  - 2nd iteration → 2 pages (2, 4) are dirtied

- Increases the restoration downtime (42.5%)

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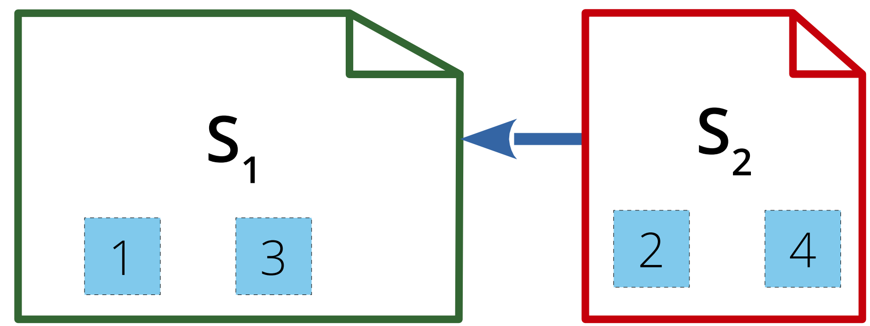

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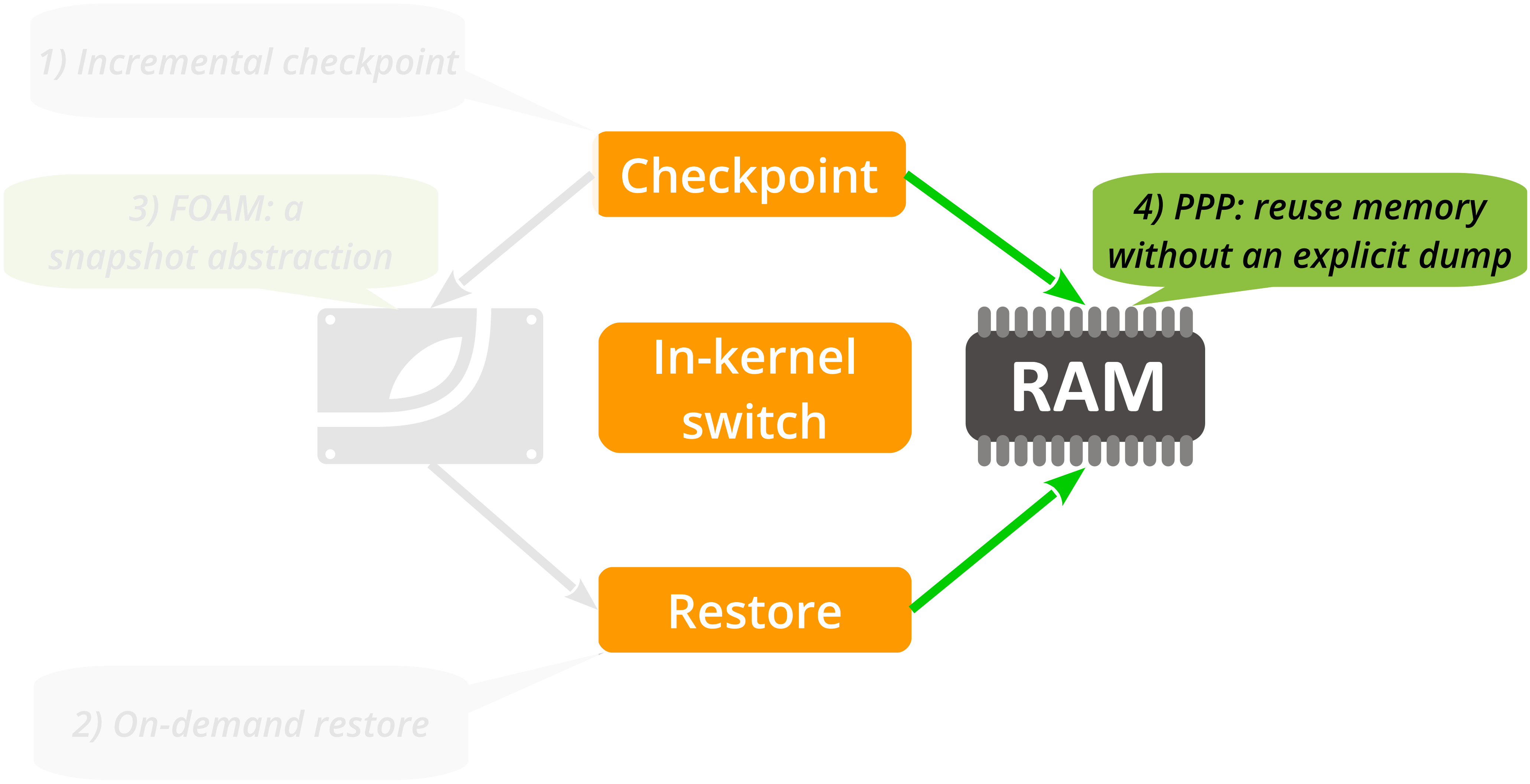
New abstraction: file-offset based address mapping (FOAM)

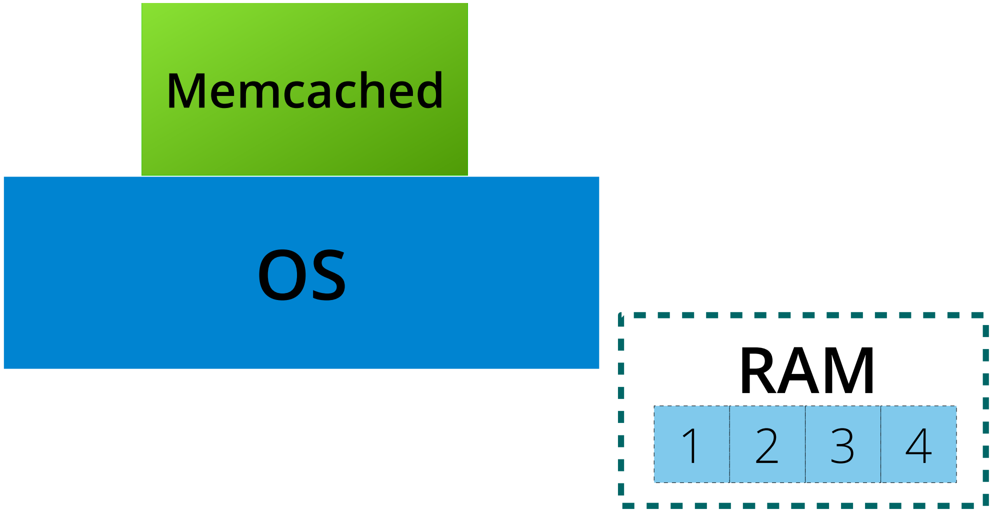
- Flat address space representation for the snapshot
  - One-to-one mapping between the address space and the snapshot
  - No explicit lookups for the pages across the snapshots
  - A few map operations to map the entire snapshot with address space
- Use sparse file representation
  - Rely on the concept of holes supported by modern file systems
- Simplifies incremental checkpoint and on-demand restore

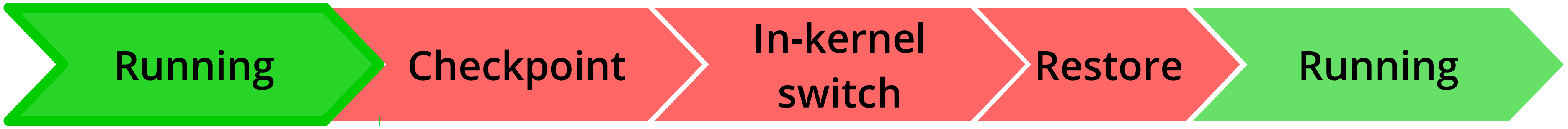
Techniques to decrease the downtime



Redundant data copy

- Application C/R copies data back and forth
- Not a good fit for applications with huge memory





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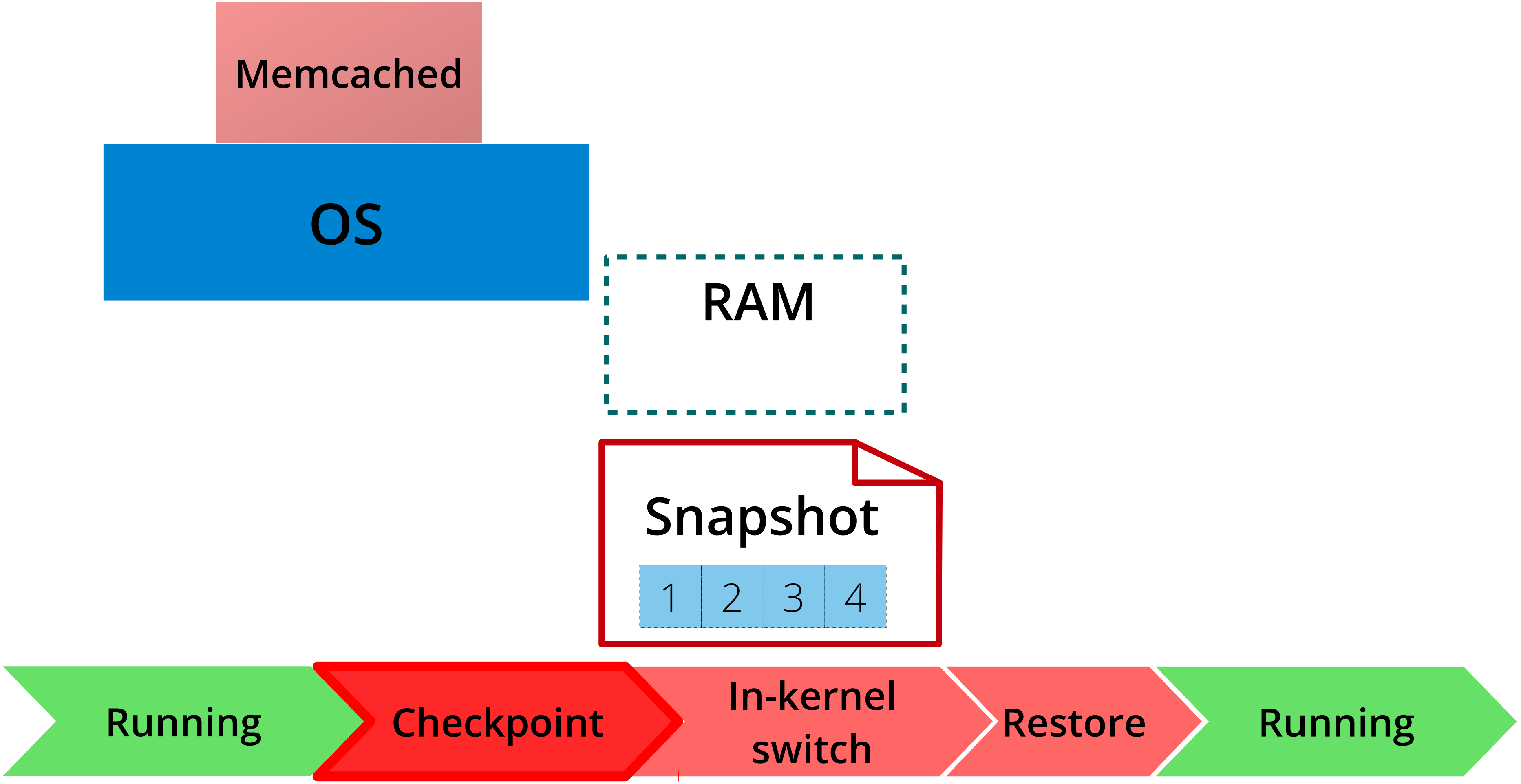

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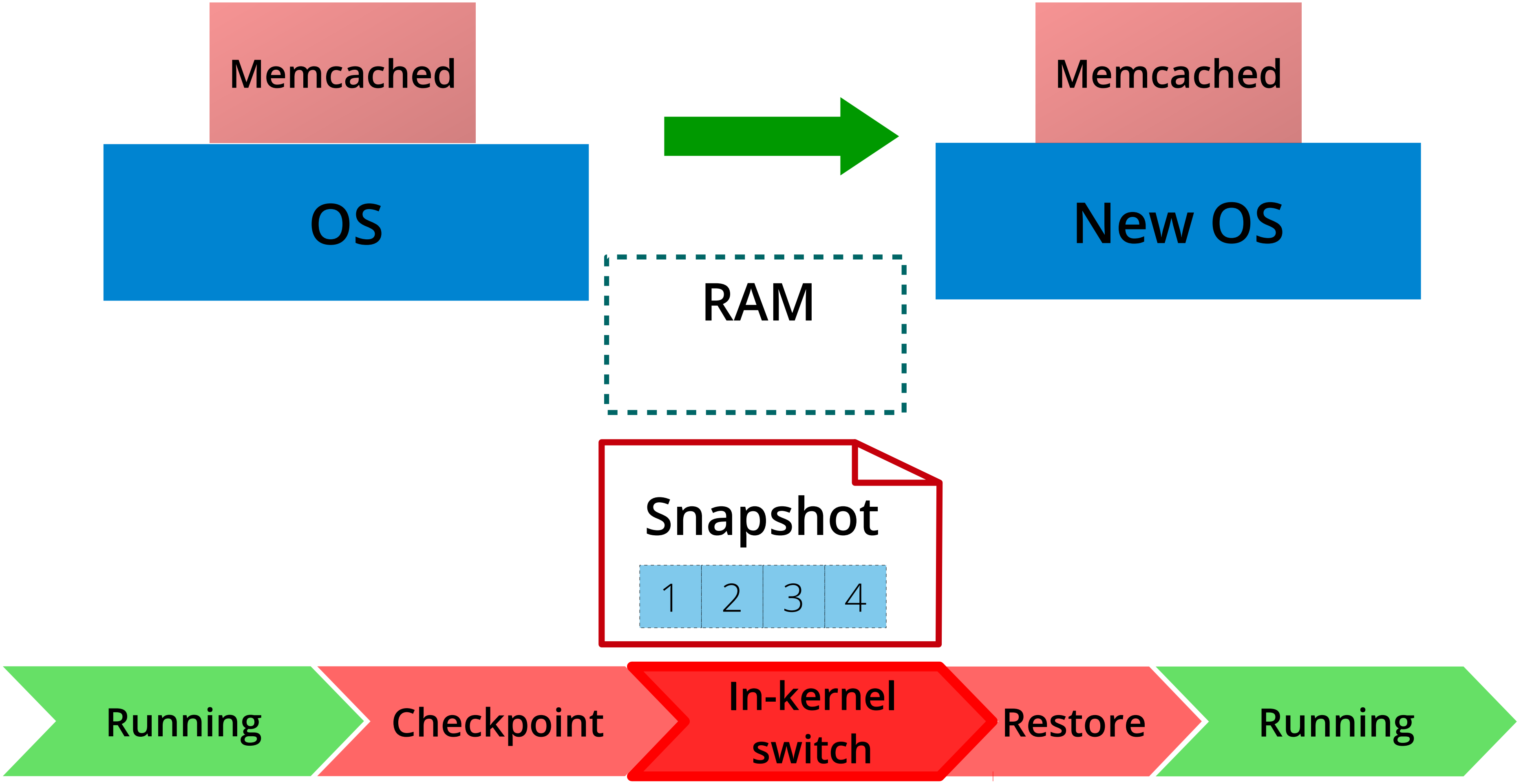

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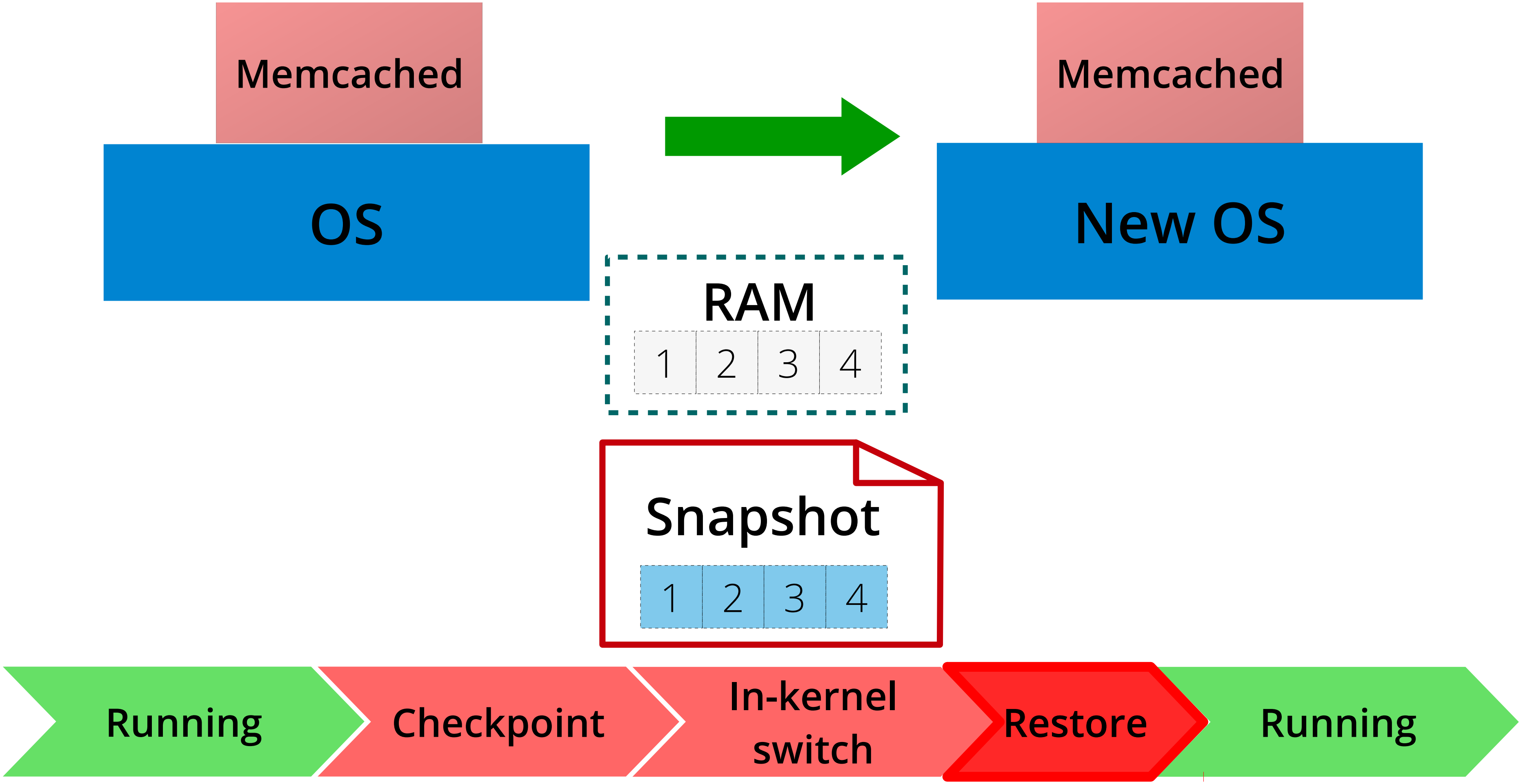

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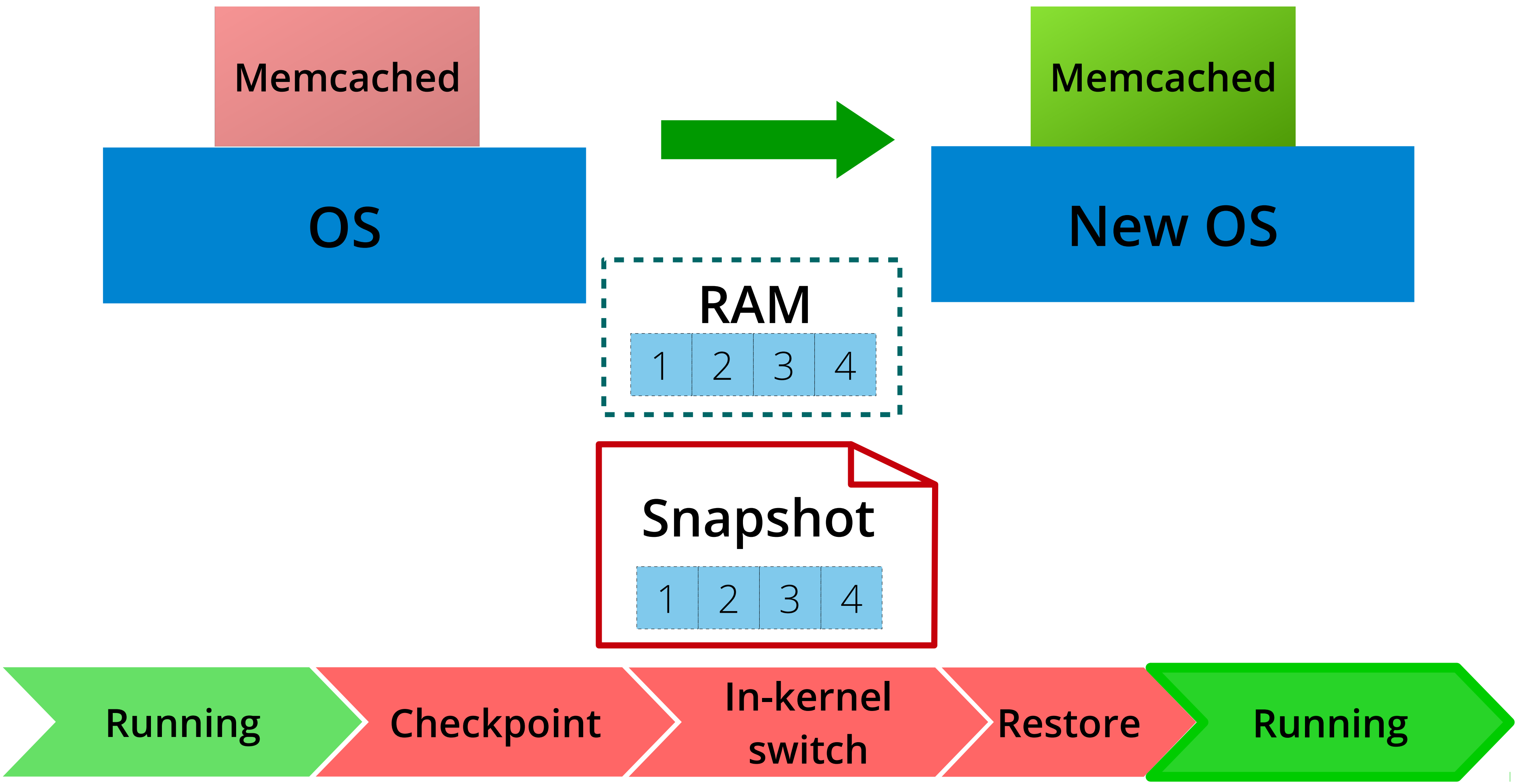

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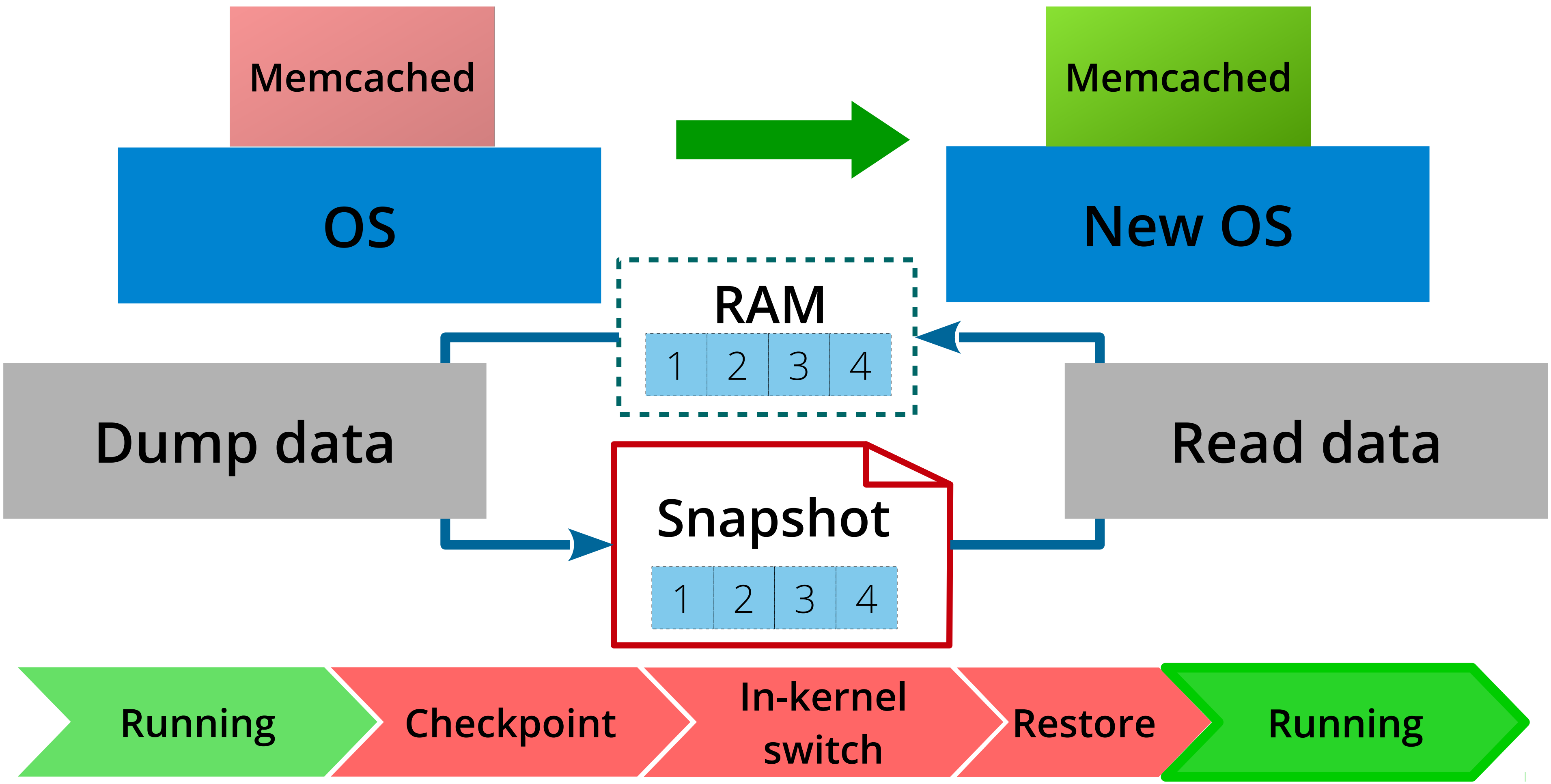

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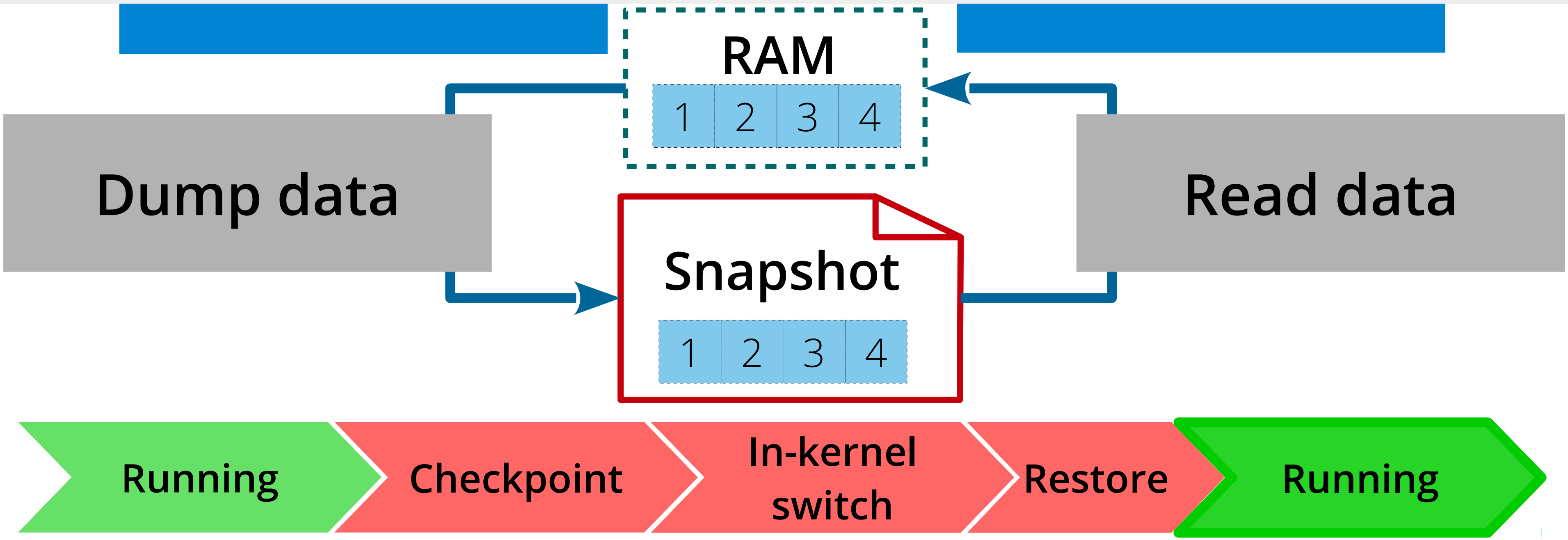
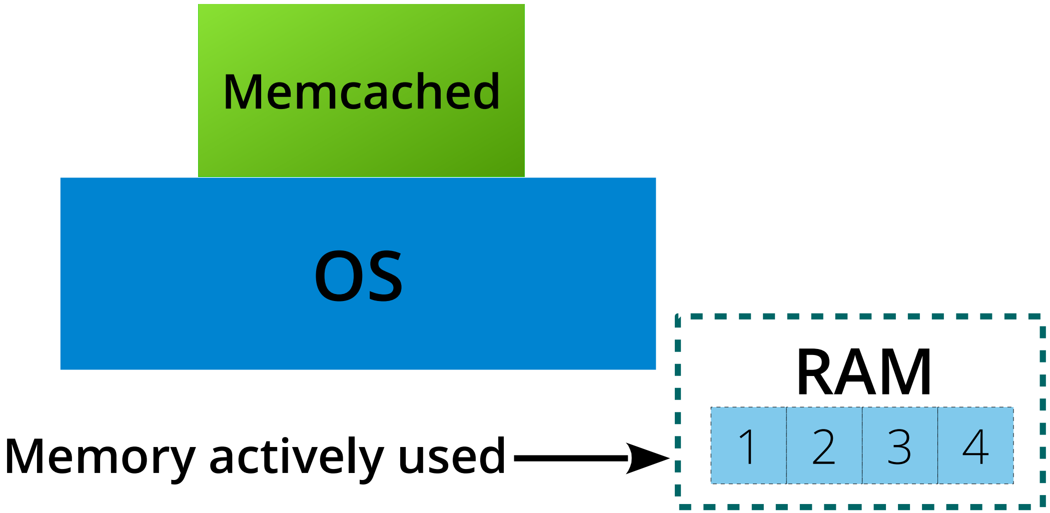
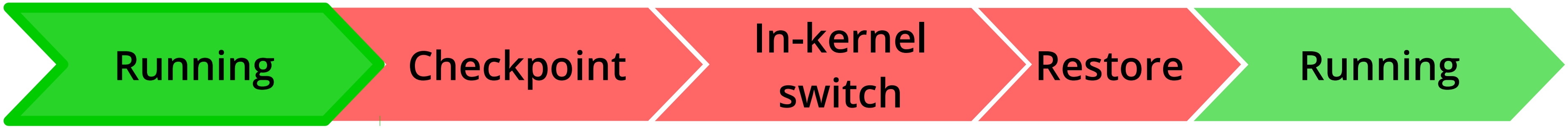
Is it possible to avoid memory copy?



Avoid redundant data copy across reboot

- Reserve the application's memory across reboot
- Inherently rebind the memory without any copy





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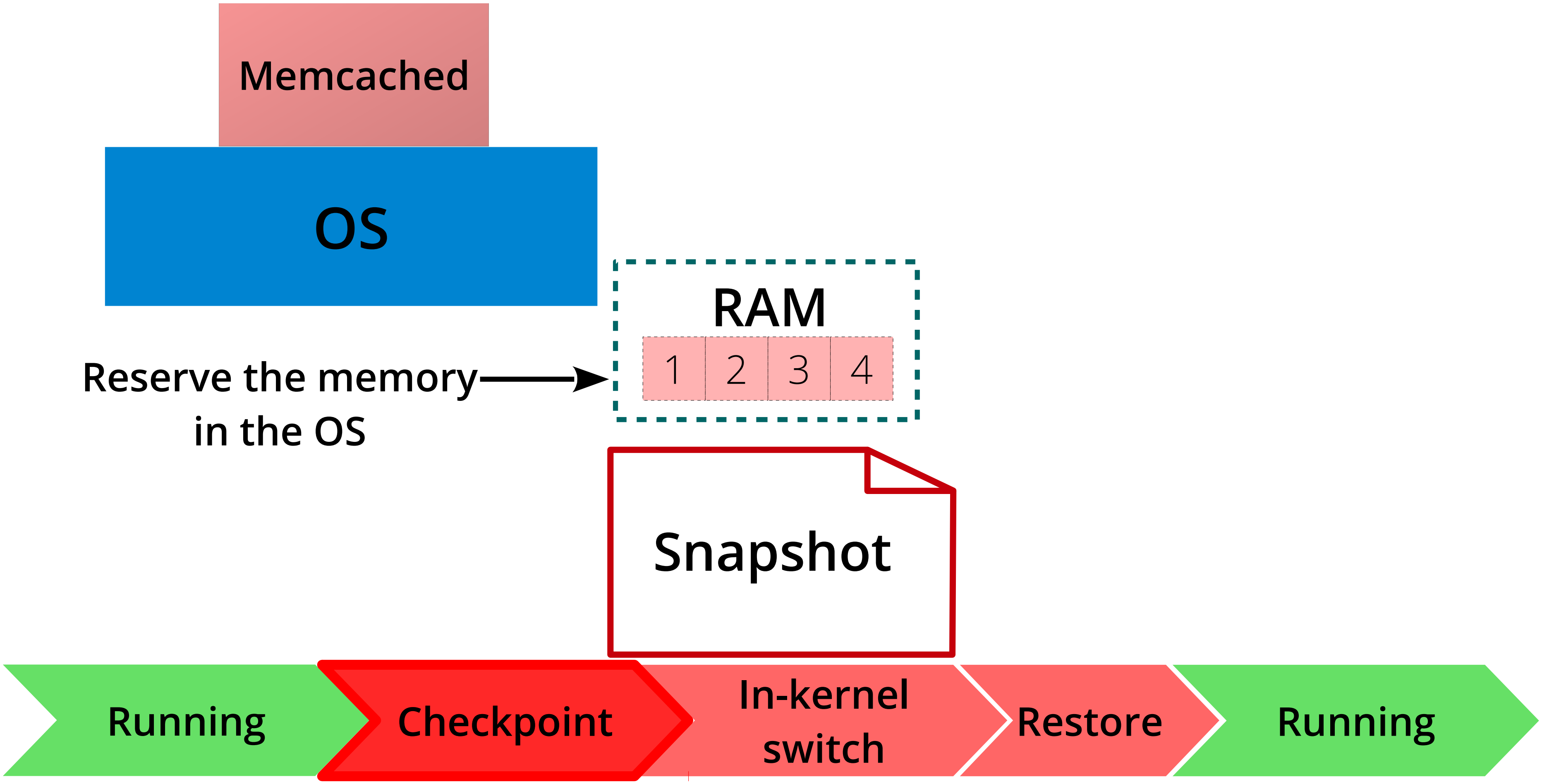

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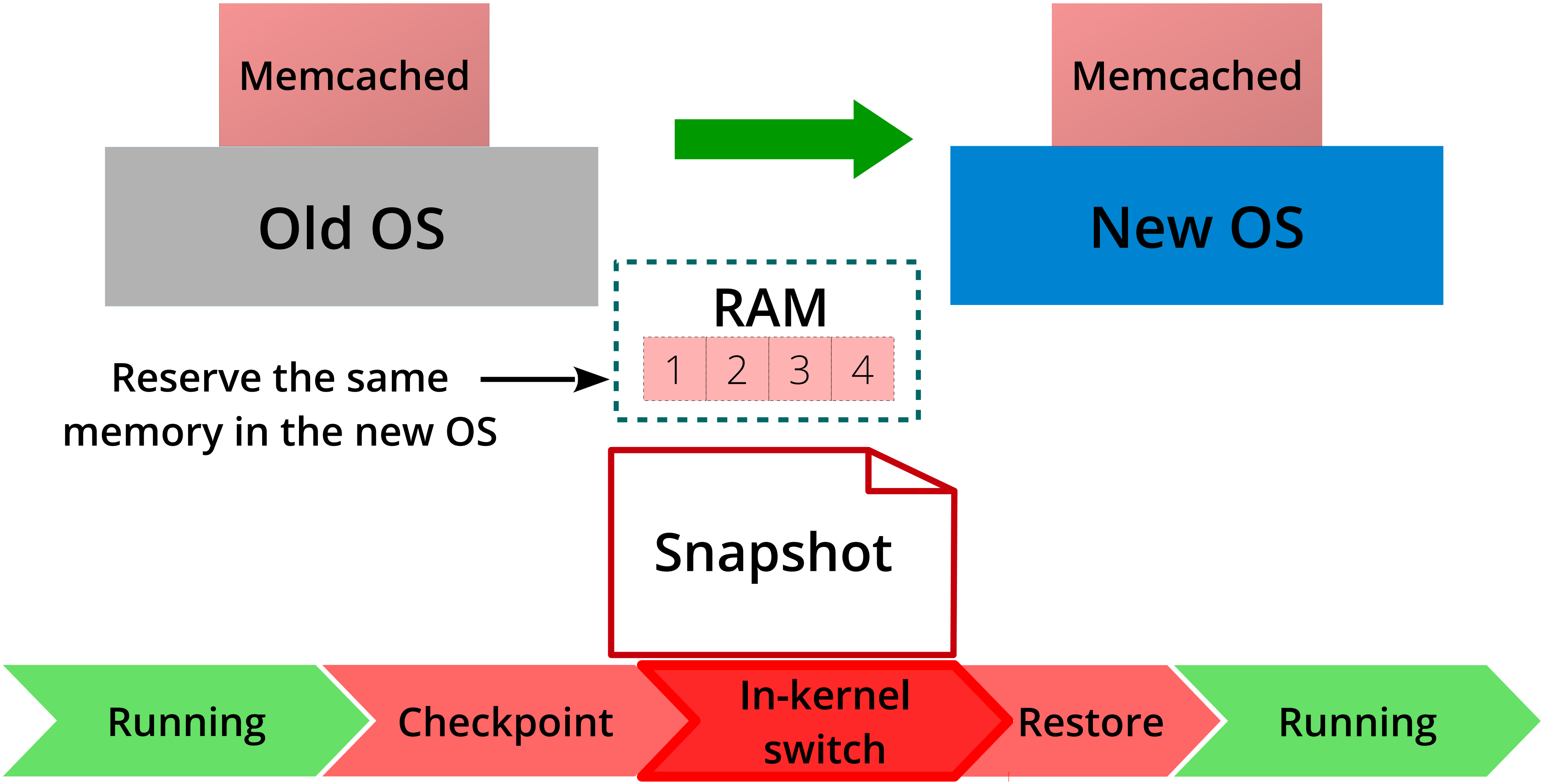

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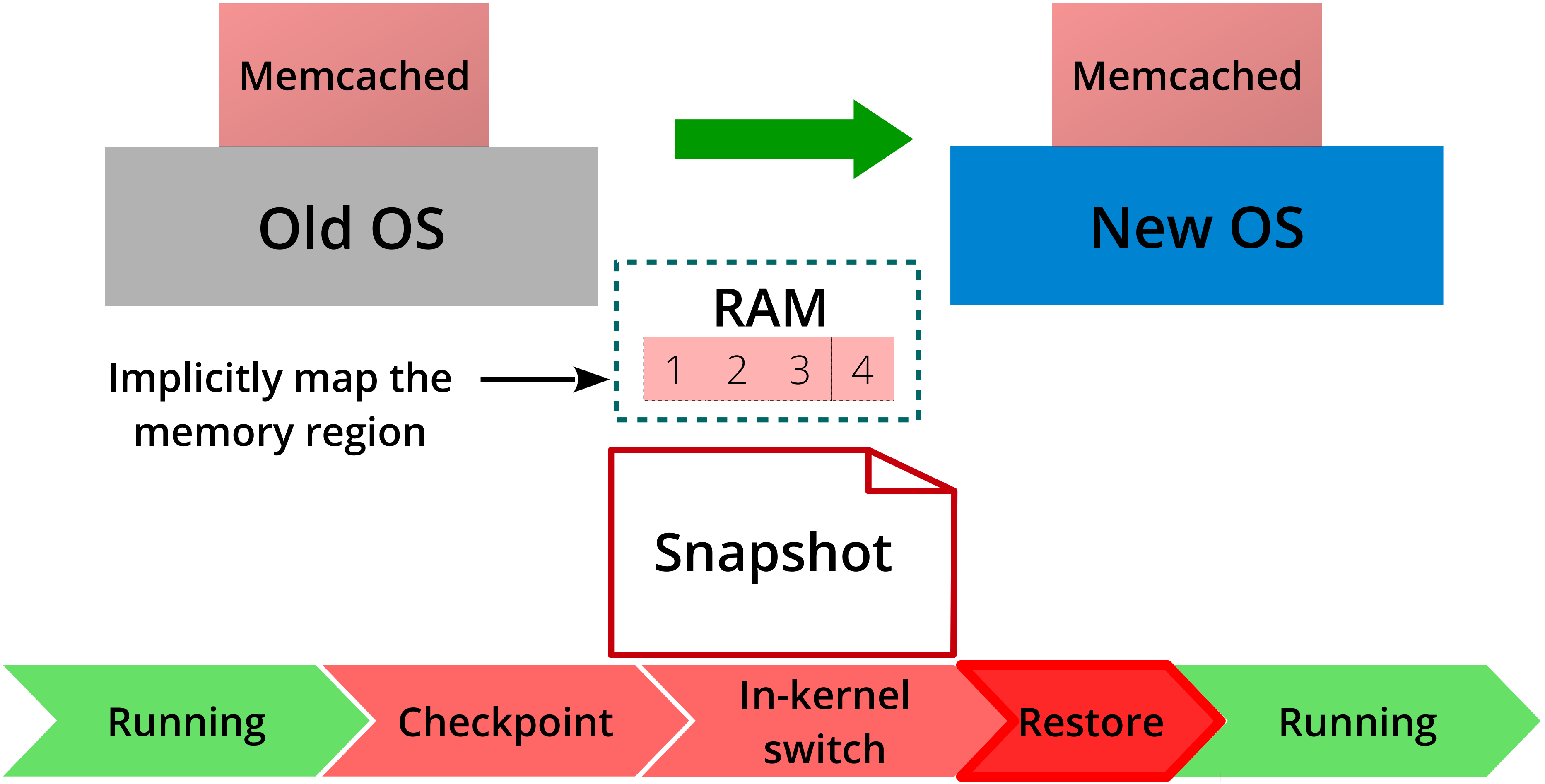

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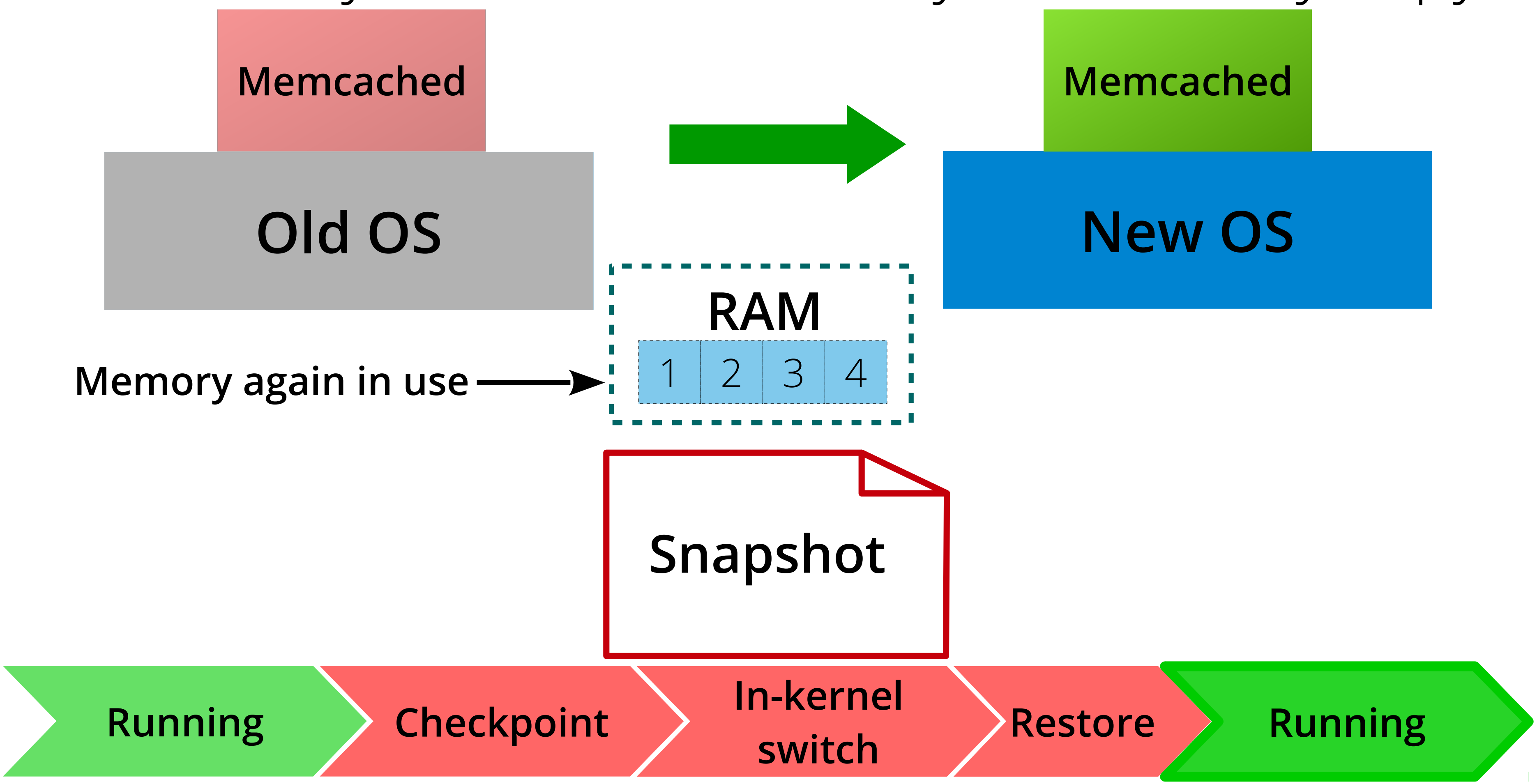

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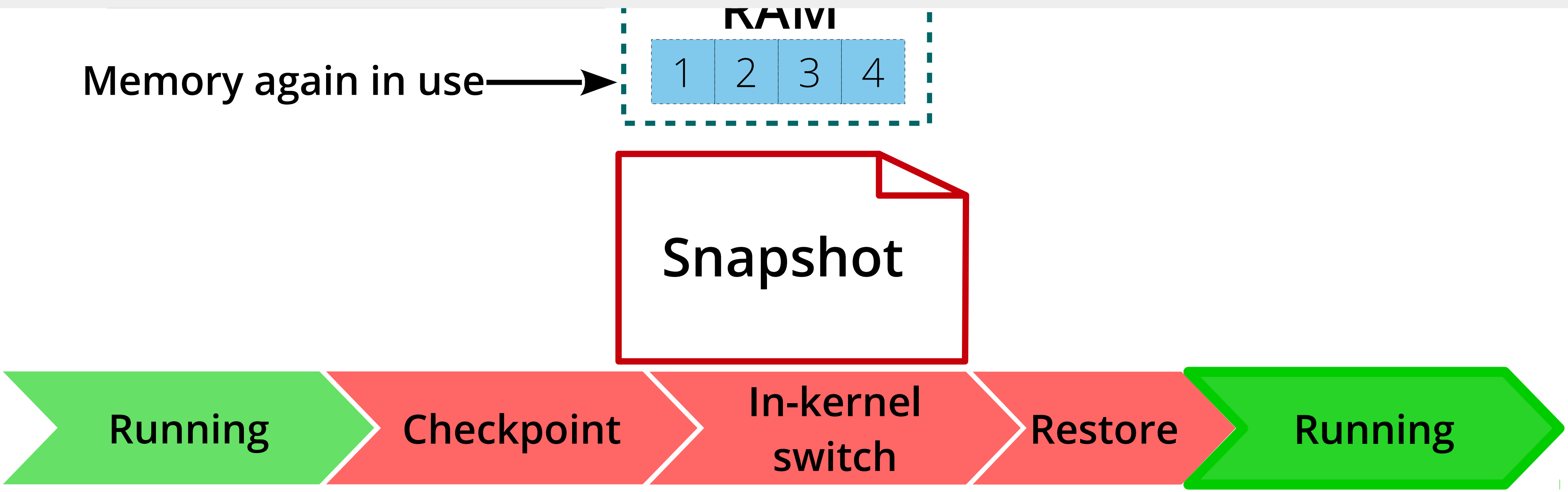
Challenge: how to notify the newer OS without modifying its source?



Persist physical pages (PPP) without OS modification

- Reserve virtual-to-physical mapping information
  - Static instrumentation of the OS binary
  - Inject our own memory reservation function, then further boot the OS
- Handle page-faults for the restored application
  - Dynamic kernel instrumentation
  - Inject our own page fault handler function for memory binding

Persist physical pages (PPP) without OS modification

- Reserve virtual-to-physical mapping information

- **No explicit memory copy**
- **Does not require any kernel source modification**

  - Dynamic kernel instrumentation
  - Inject our own page fault handler function for memory binding

Implementation

- Application C/R → *criu*
  - Works at the namespace level
- In-kernel switch → *kexec* system call
  - A mini boot loader that bypasses BIOS while booting

Component	**Lines of code**
`criu` / on-demand restore	810 lines of C
`criu` / `FOAM`	950 lines of C
`criu` / `PPP`	600 lines of C
KUP `systemd, init`	1040 lines of Python/Bash
`criu` / others, `kexec()`, etc.	150 lines of C
Total	3,550 lines of code

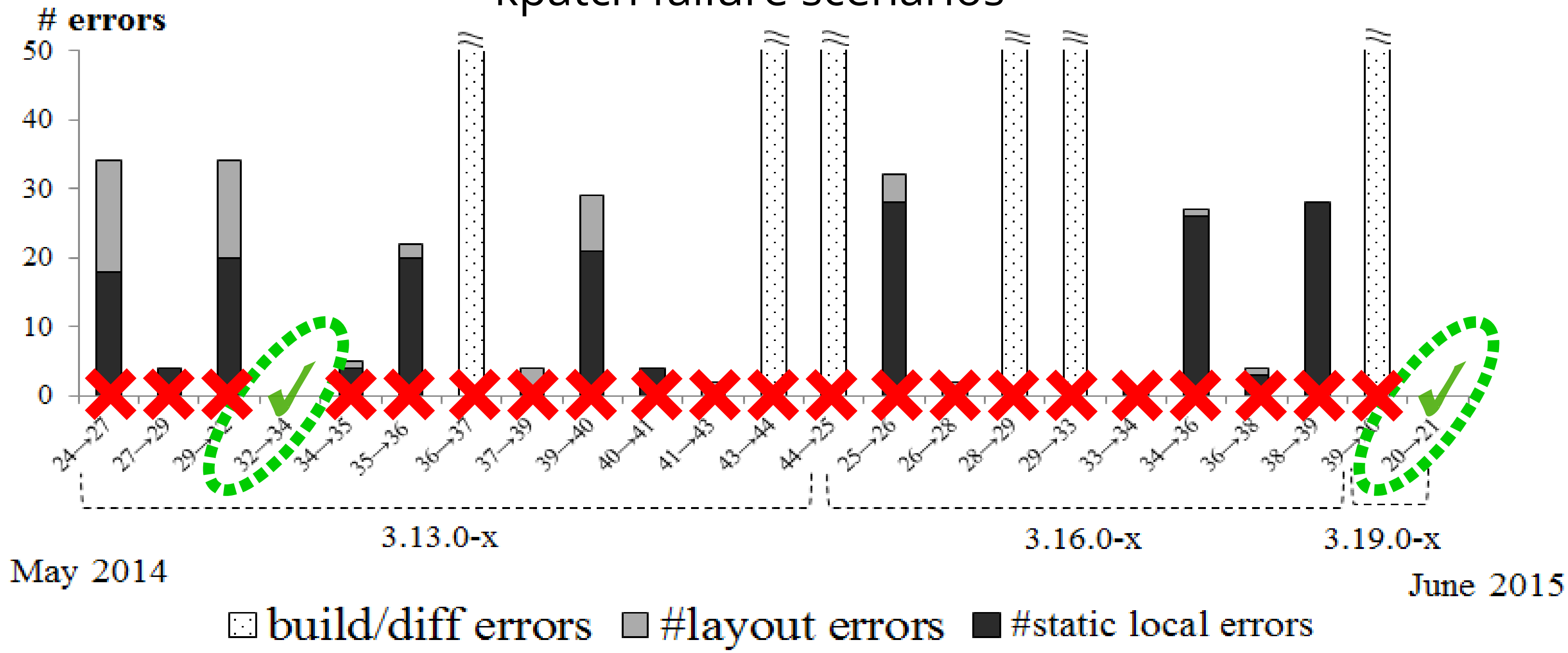
Evaluation

- How effective is KUP's approach compared to the in-kernel hot patching?
- What is the effective performance of each technique during the update?

KUP can support major and minor updates in Ubuntu

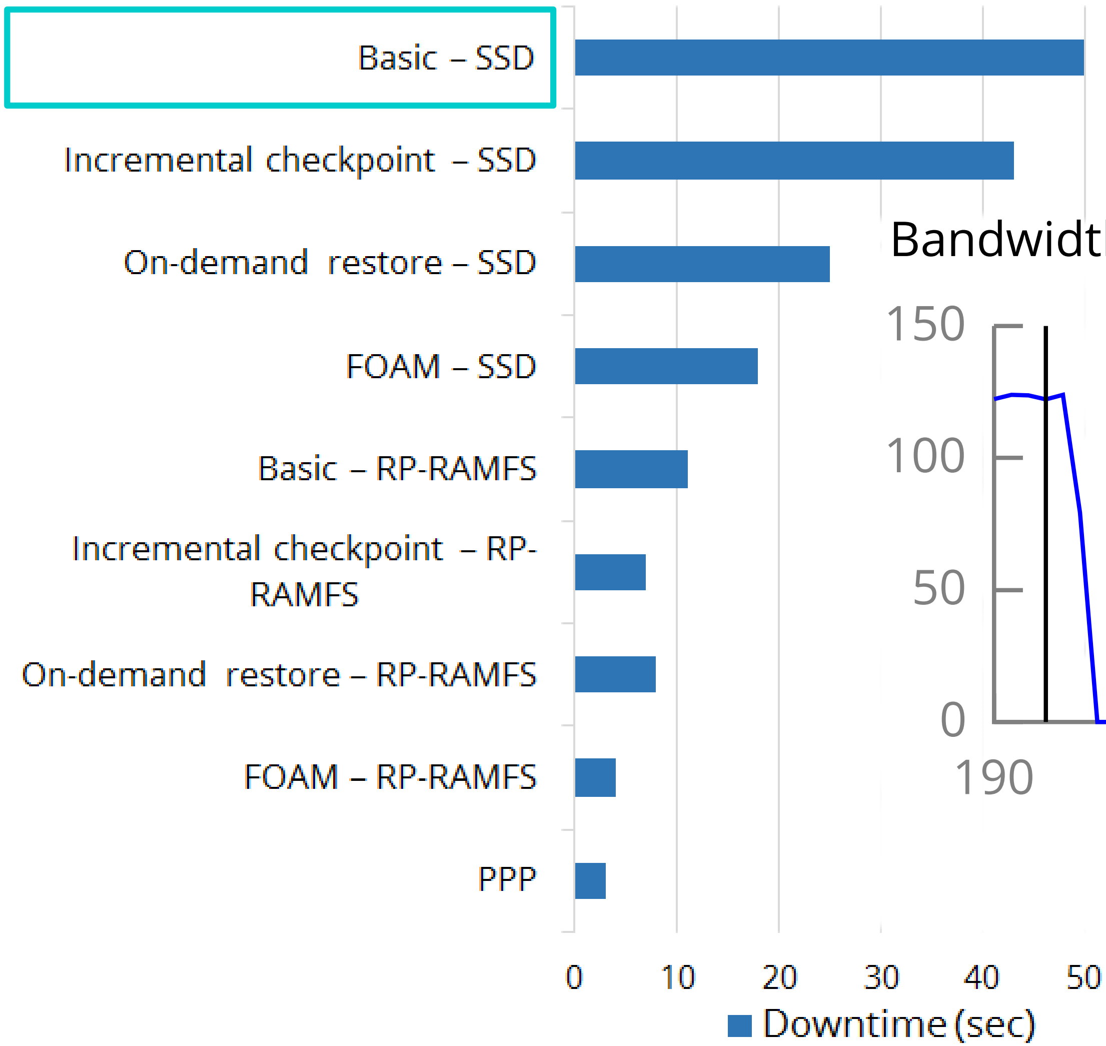
- KUP supports 23 minor/4 major updates (v3.17–v4.1)
- However, kpatch can only update 2 versions
  - e.g., layout change in data structure

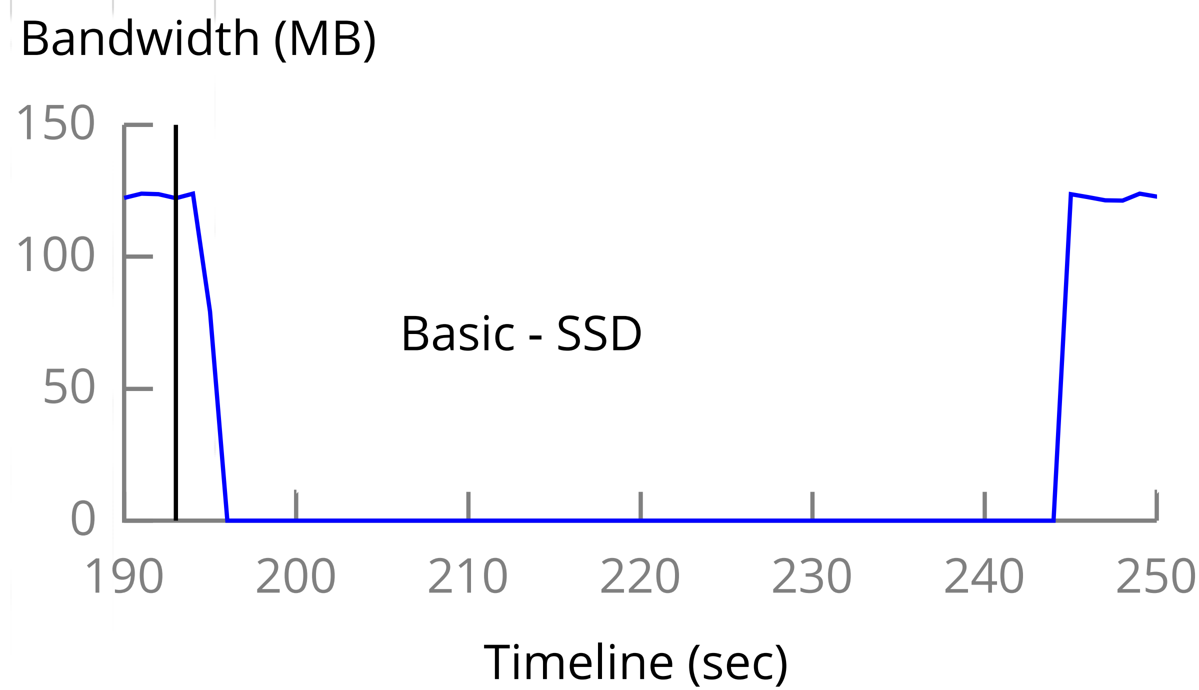
kpatch failure scenarios



Updating OS with memcached

- PPP has the least degradation
- Storage also affects the performance





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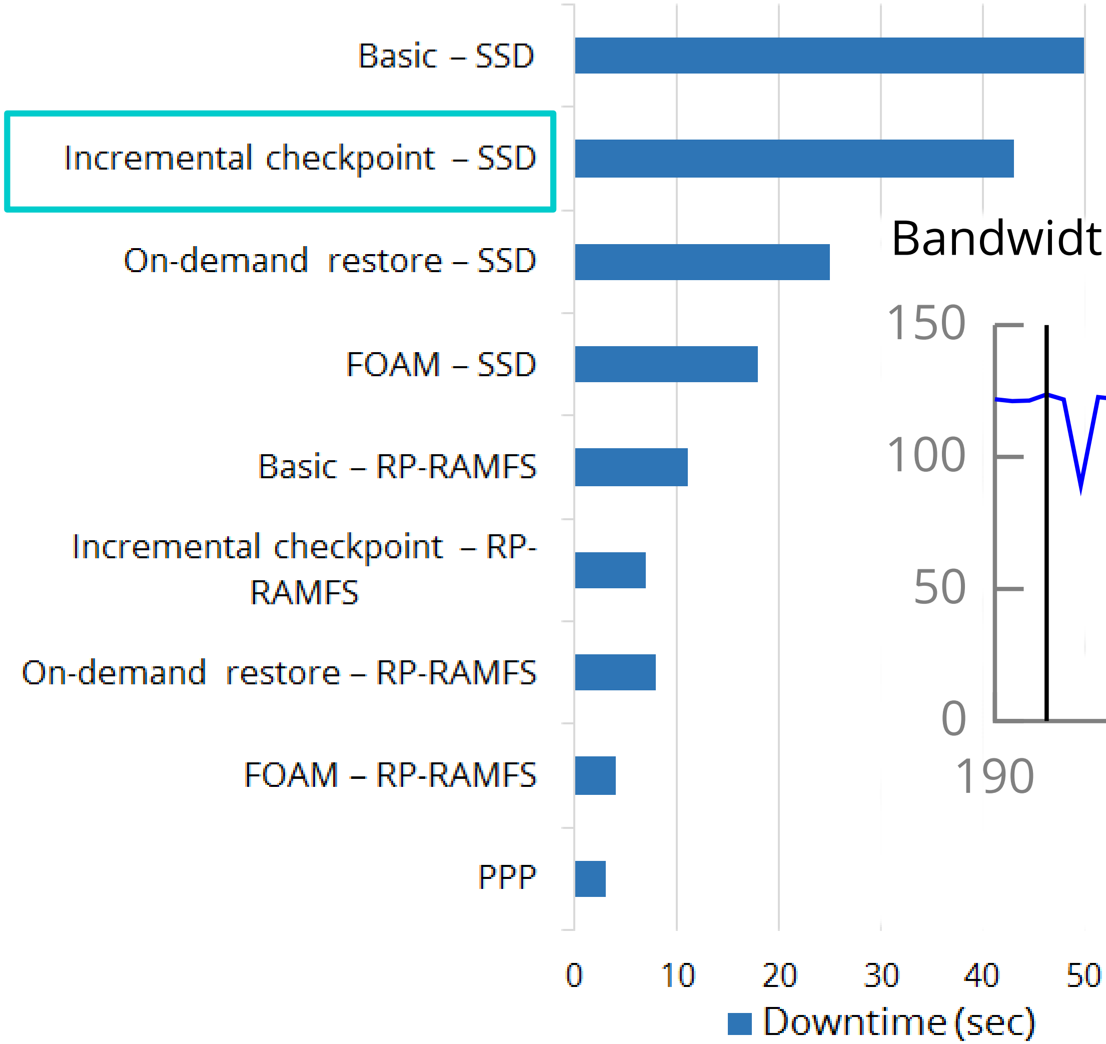

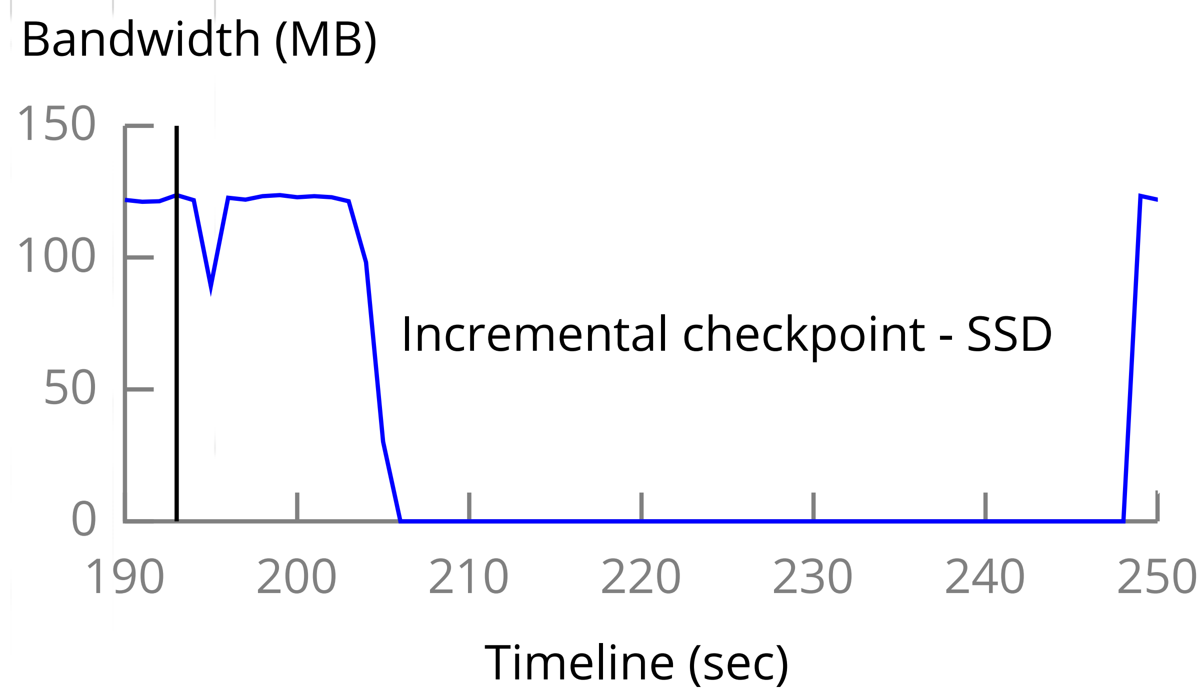

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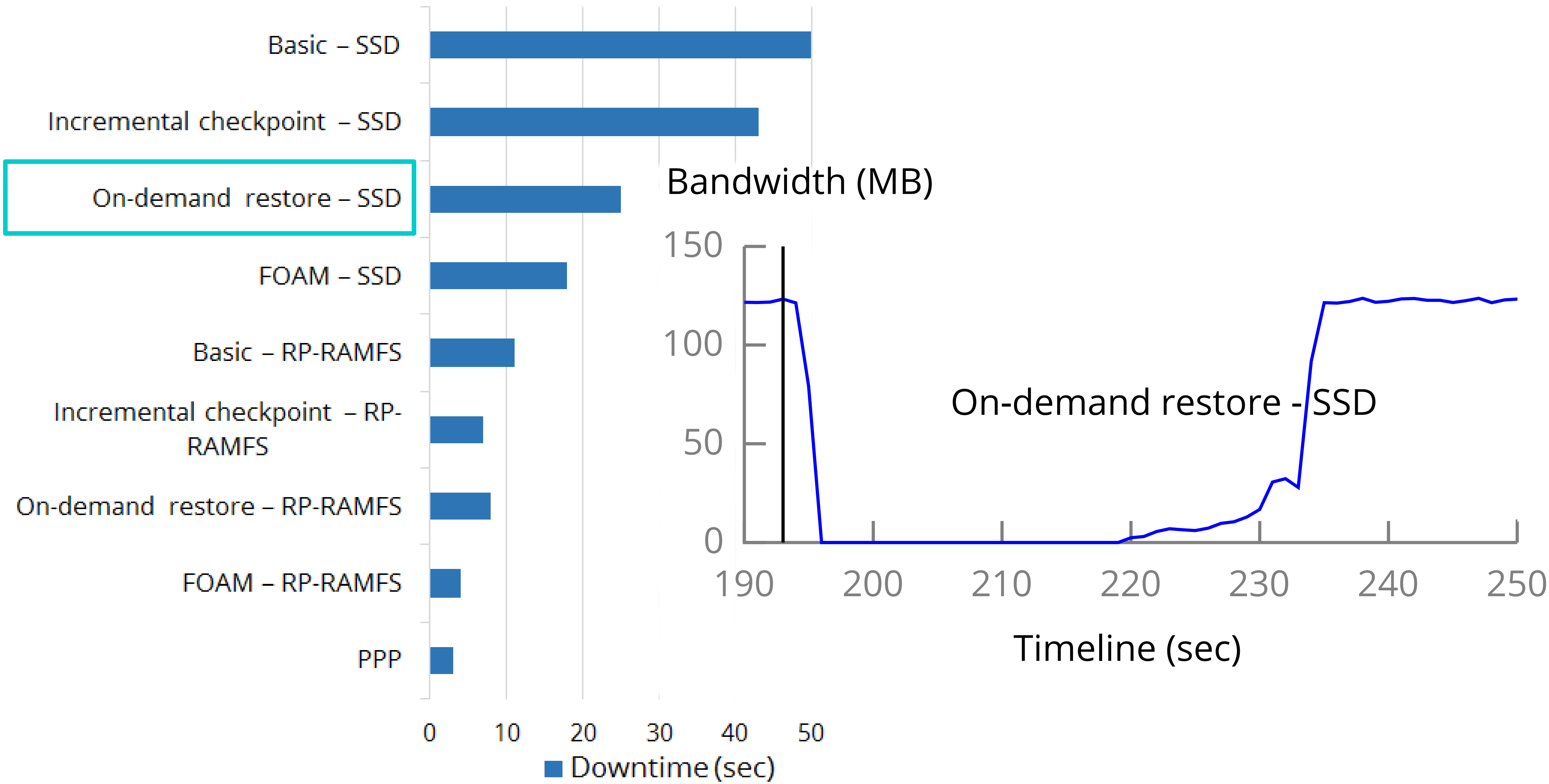

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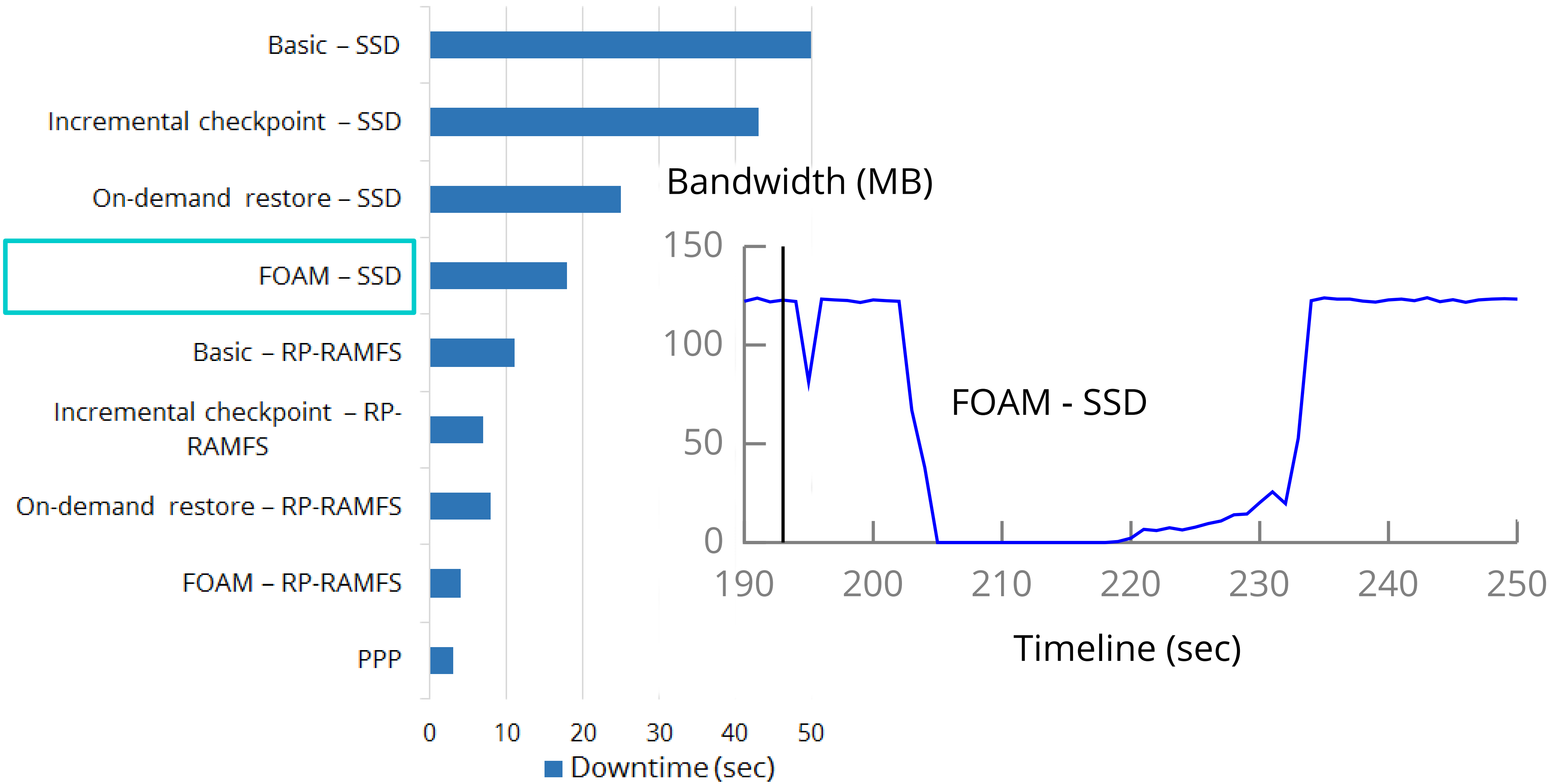

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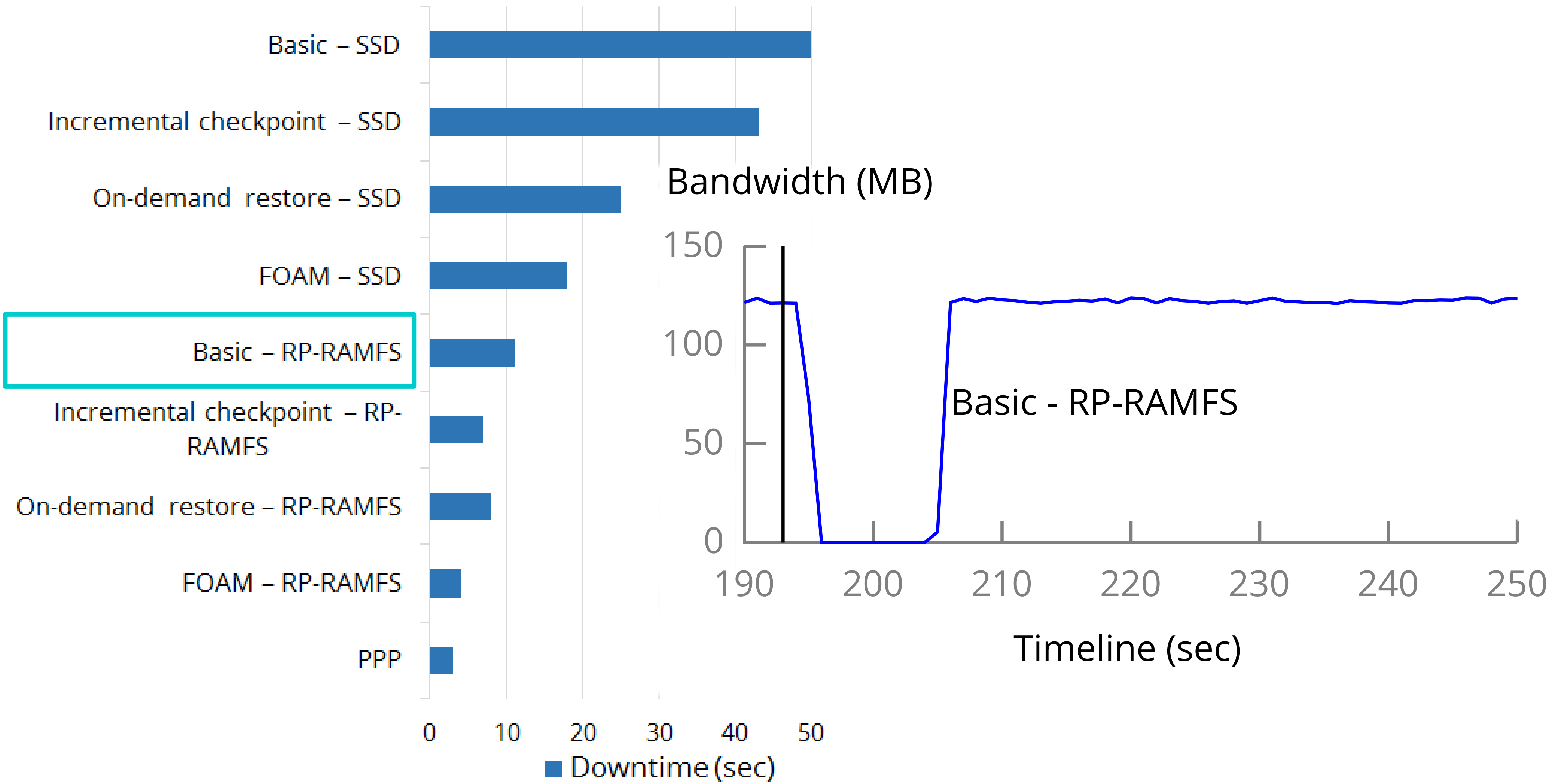

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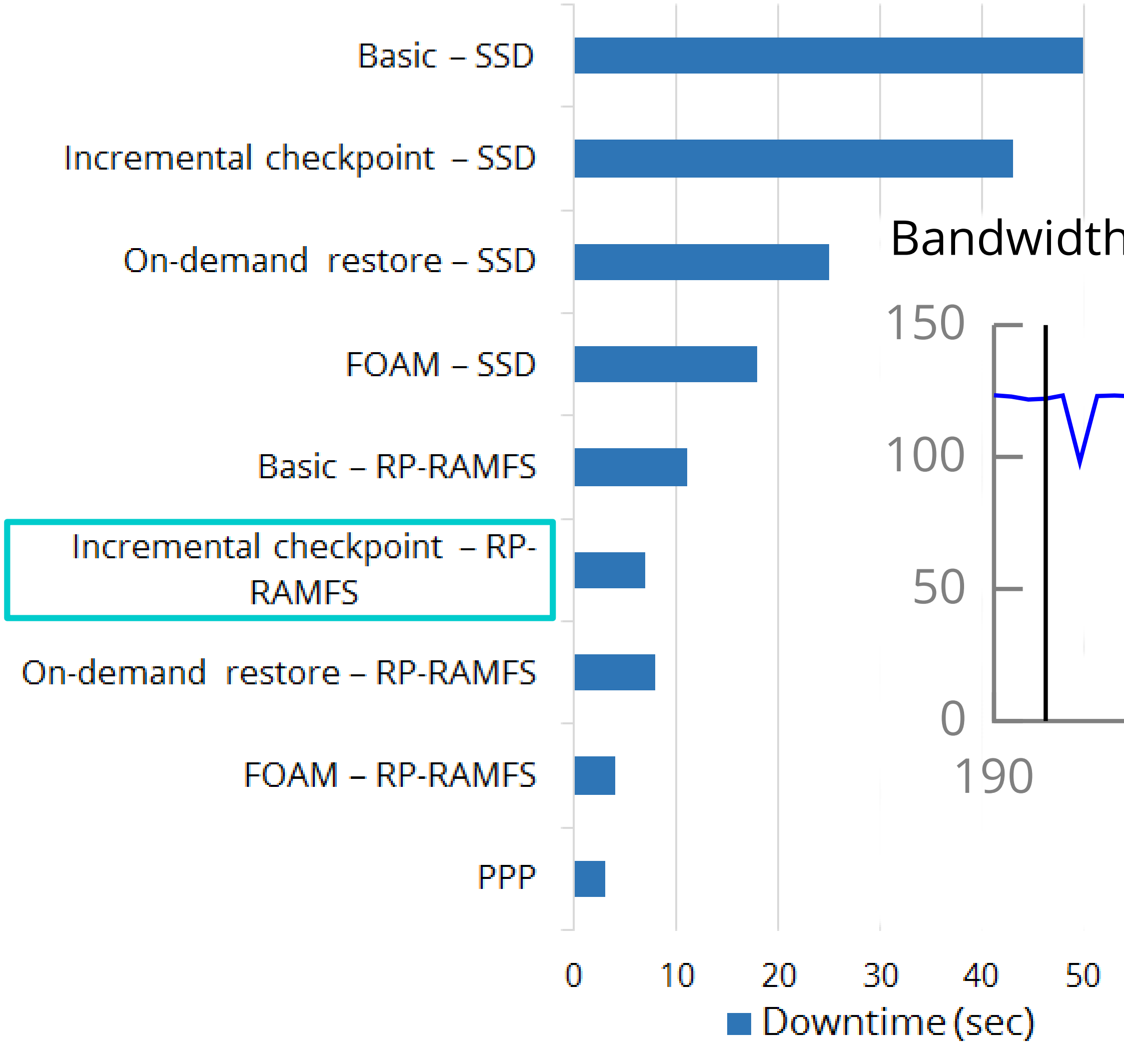

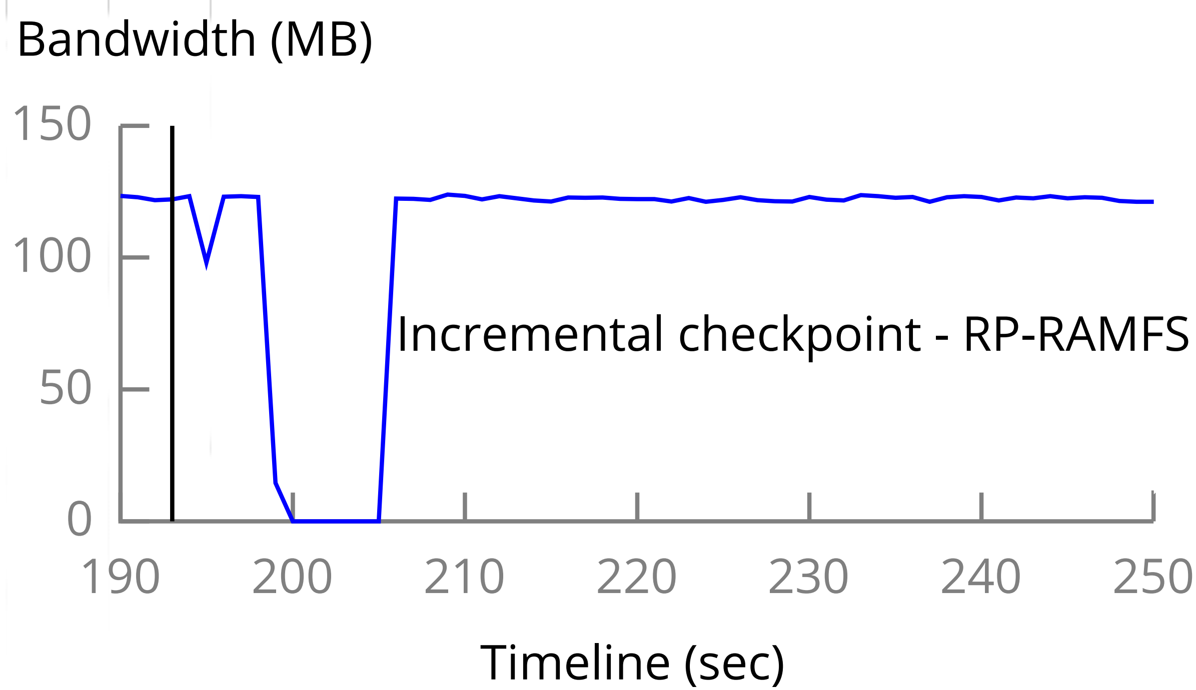

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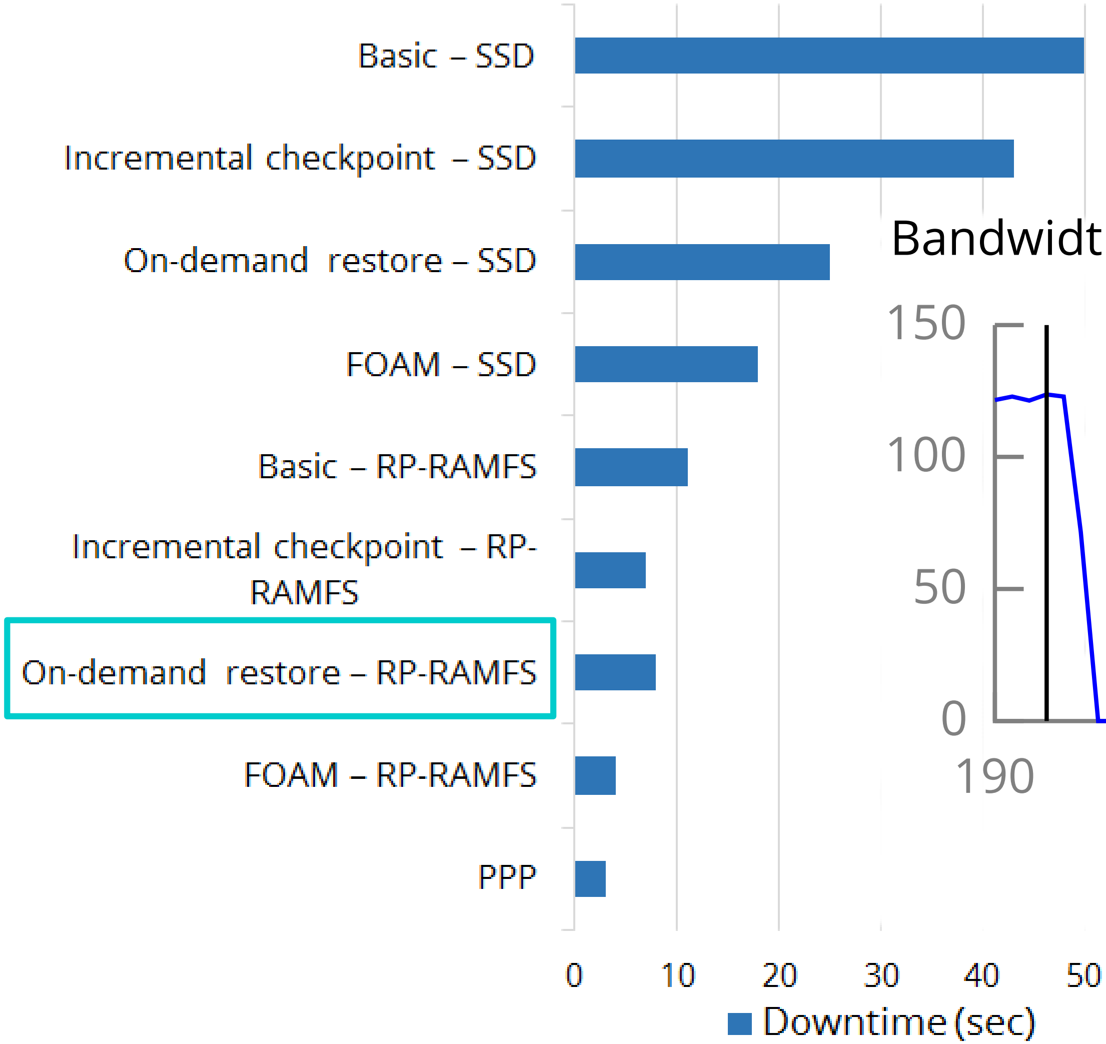

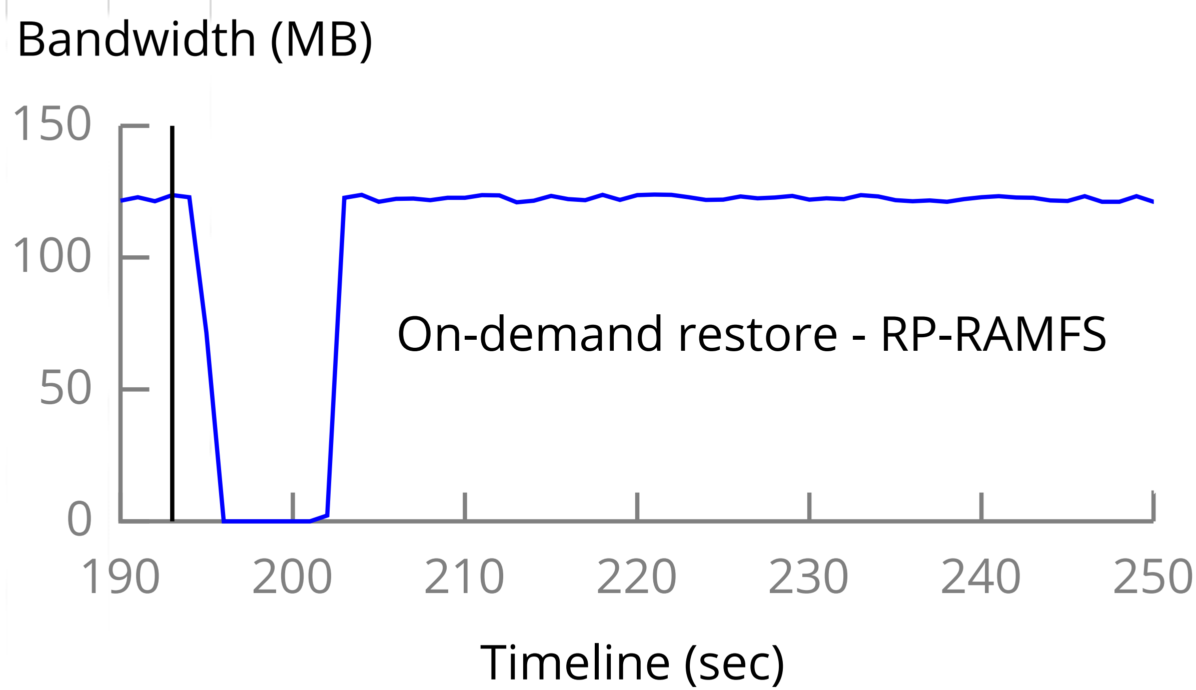

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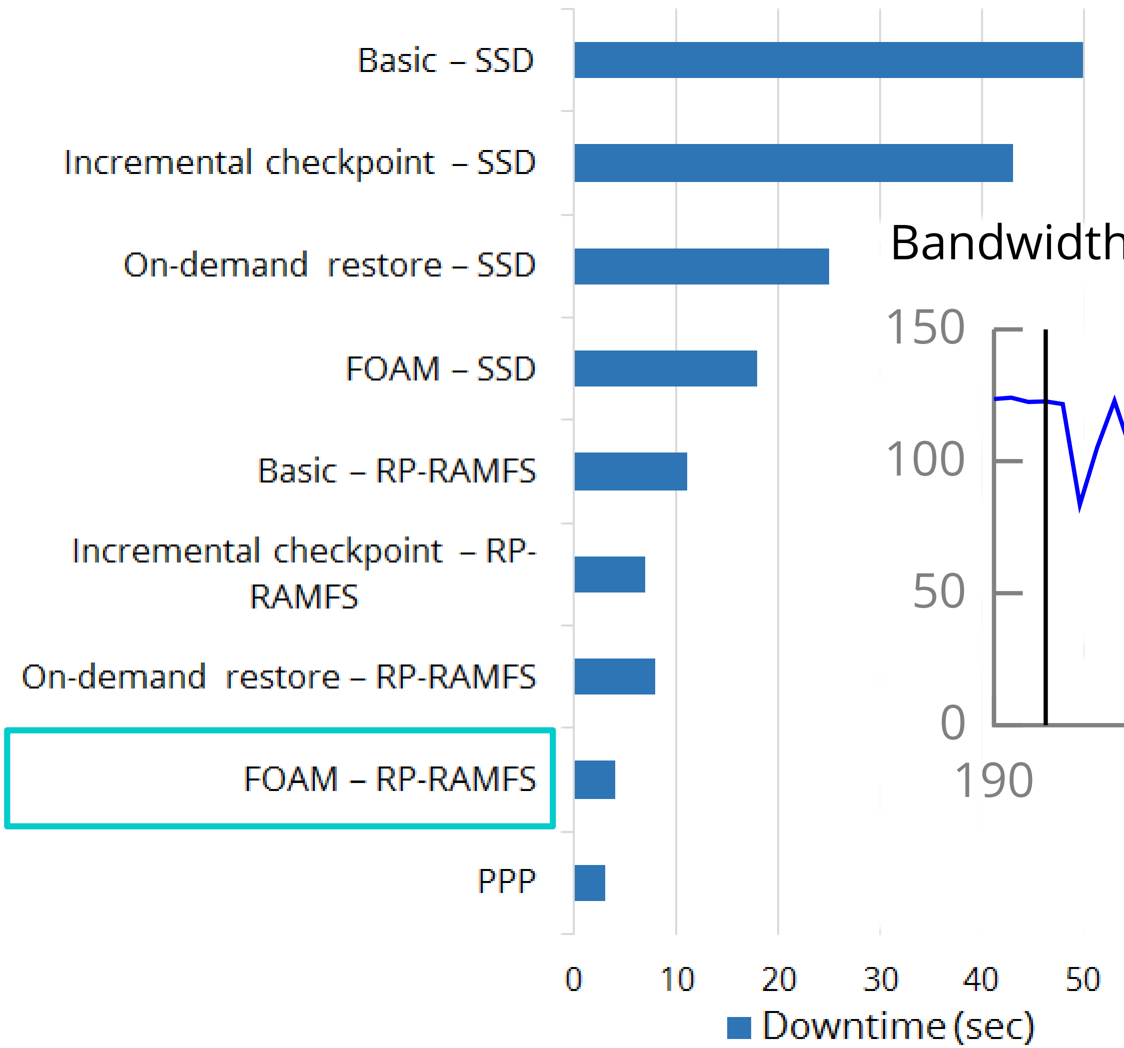

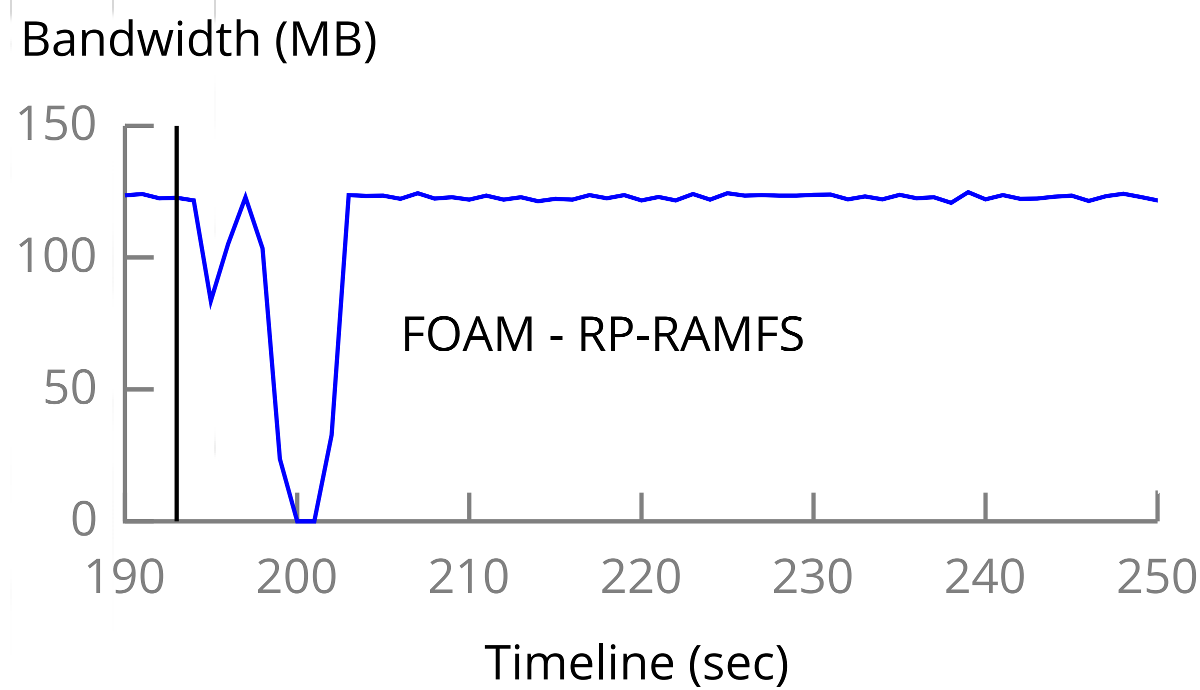

Updating OS with memcached

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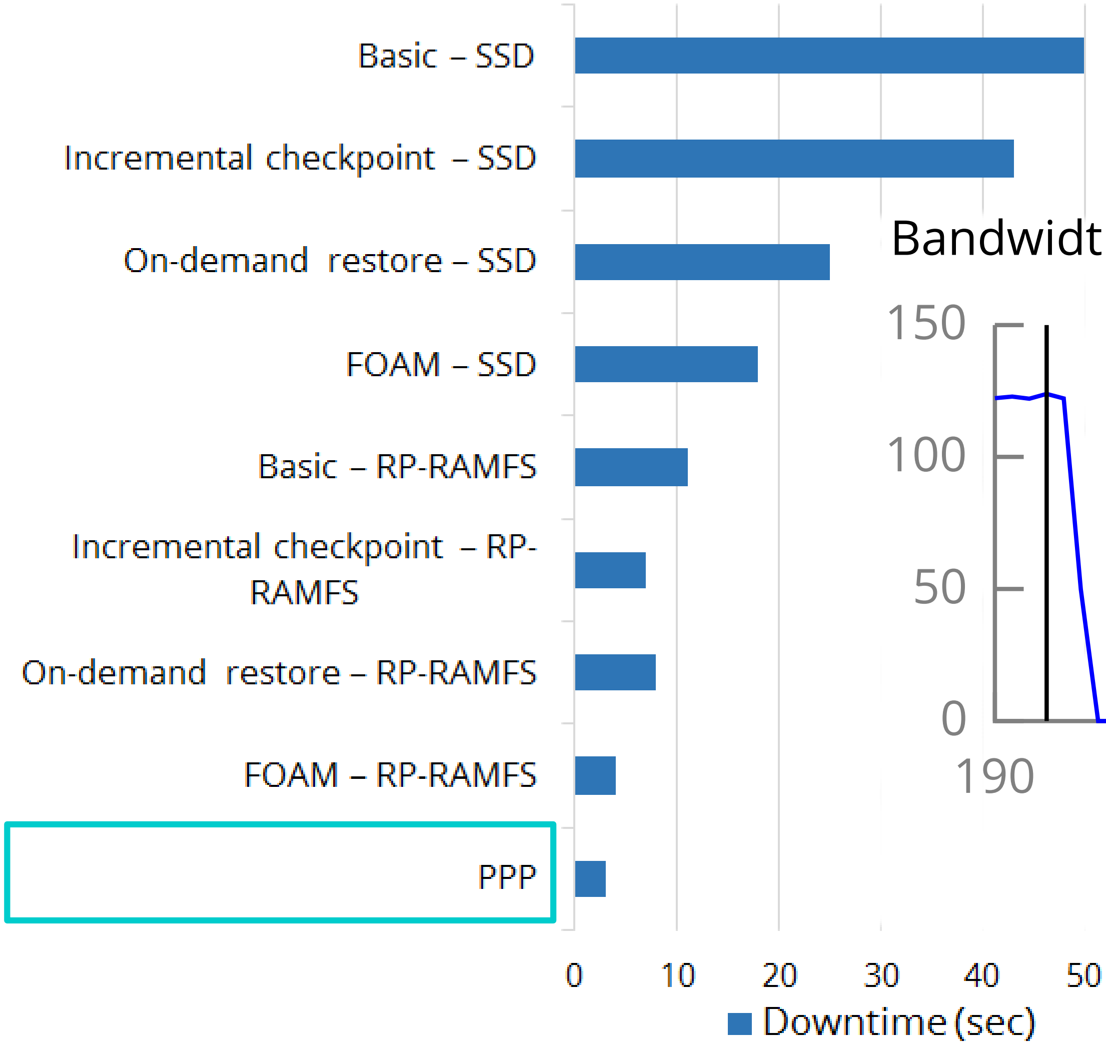

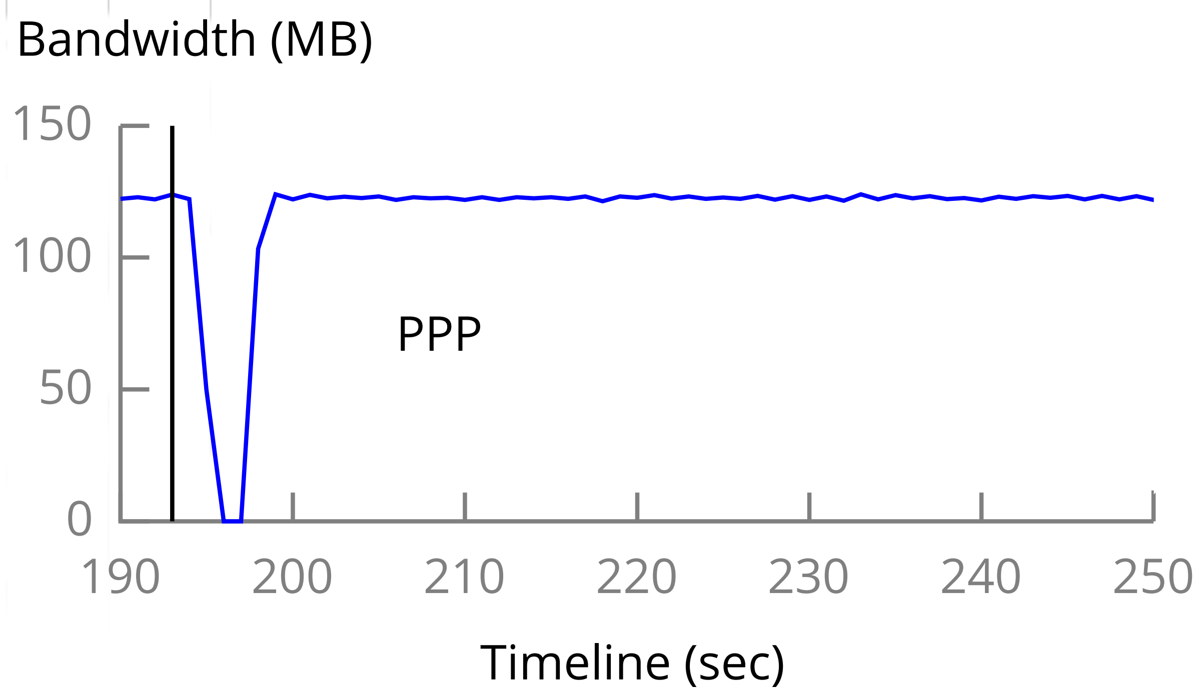

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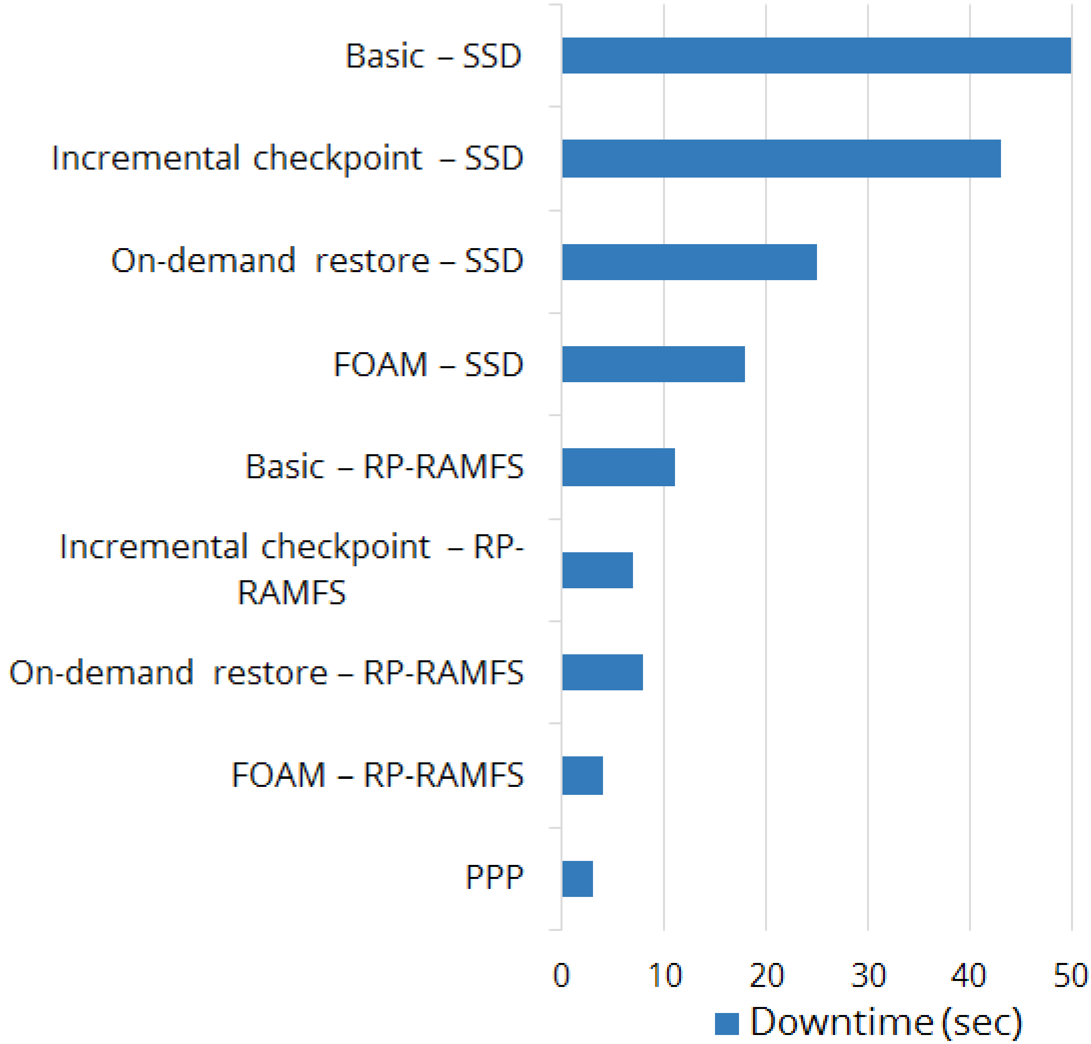

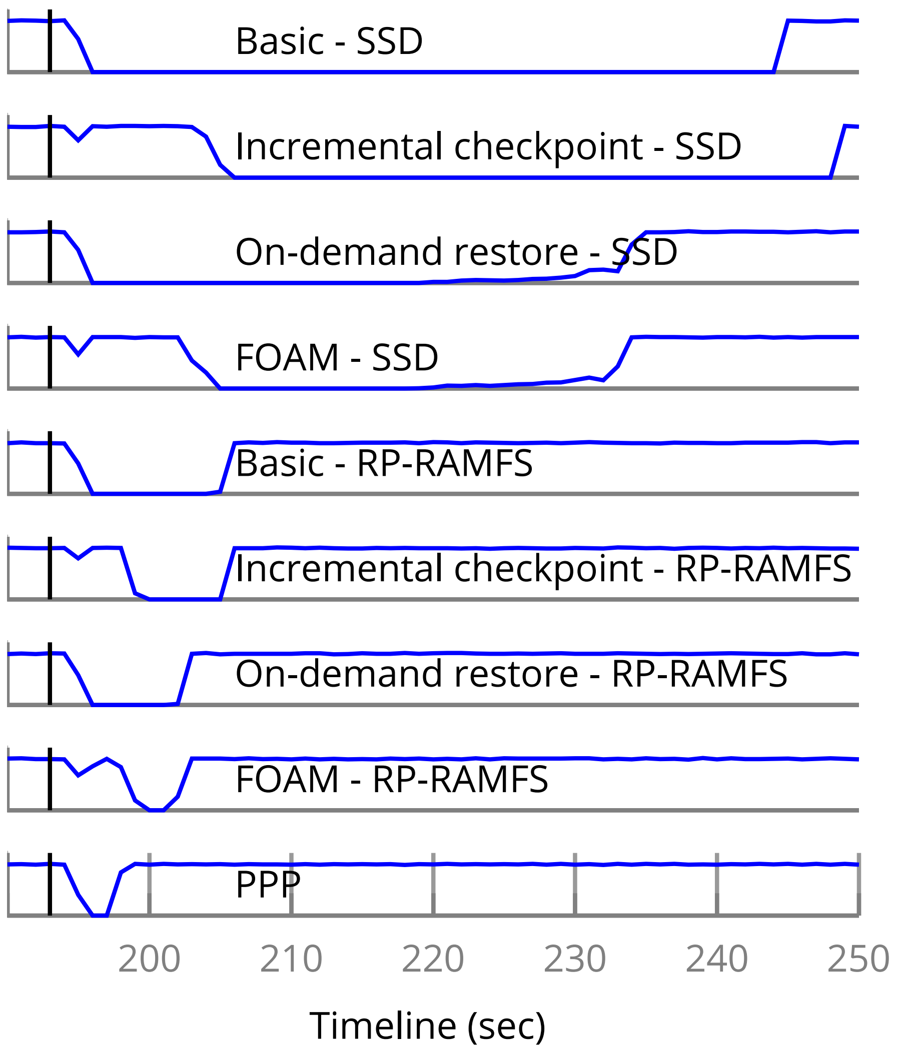

Limitations

- KUP does not support checkpoint and restore all socket implementations
  - TCP, UDP and netlink are supported
- Failure during restoration
  - System call is removal or interface modification

Demo

Summary

- KUP: a simple update mechanism with application checkpoint-and-restore (C/R)
- Employs various techniques:
  - New data abstraction for application C/R
  - Fast in-kernel switching technique
  - A simple mechanism to persist the memory

Summary

- KUP: a simple update mechanism with application checkpoint-and-restore (C/R)
- Employs various techniques:
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Thank you!

Backup Slides

Handling in-kernel states

- Handles namespace and cgroups
- ptrace() syscall to handle the blocking system calls , timers, registers etc.
- Parasite code to fetch / put the application's states
- /proc file system exposes the required information for application C/R
- A new mode (TCP_REPAIR) allows handling the TCP connections

What cannot be checkpointed

- X11 applications
- Tasks with debugger attached
- Tasks running in compat mode (32 bit)

Possible changes after application C/R

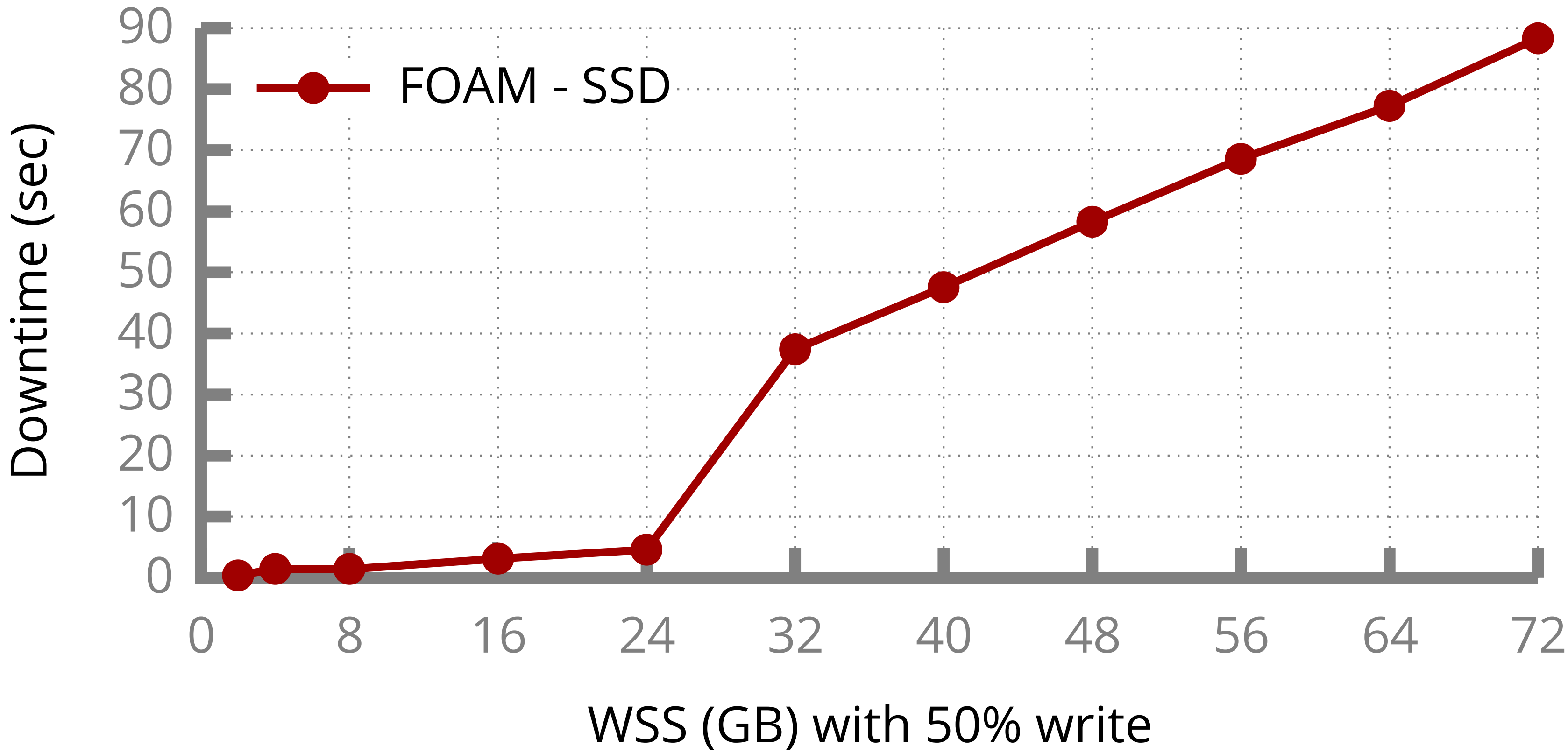
- Per-task statistics
- Namespace IDs
- Process start time
- Mount point IDs
- Socket IDs (st_ino)
- VDSO

Suitable applications

- Suitable for all kinds of applications
- PPP approach supports all types of applications
  - May fail to restore on the previous kernel
- FOAM is not a good candidate for write-intensive applications
  - More confidence in safely restoring the application on the previous kernel

PPP works effectively

- FOAM on SSD → slow
- FOAM on RP-RAMFS → space inefficient



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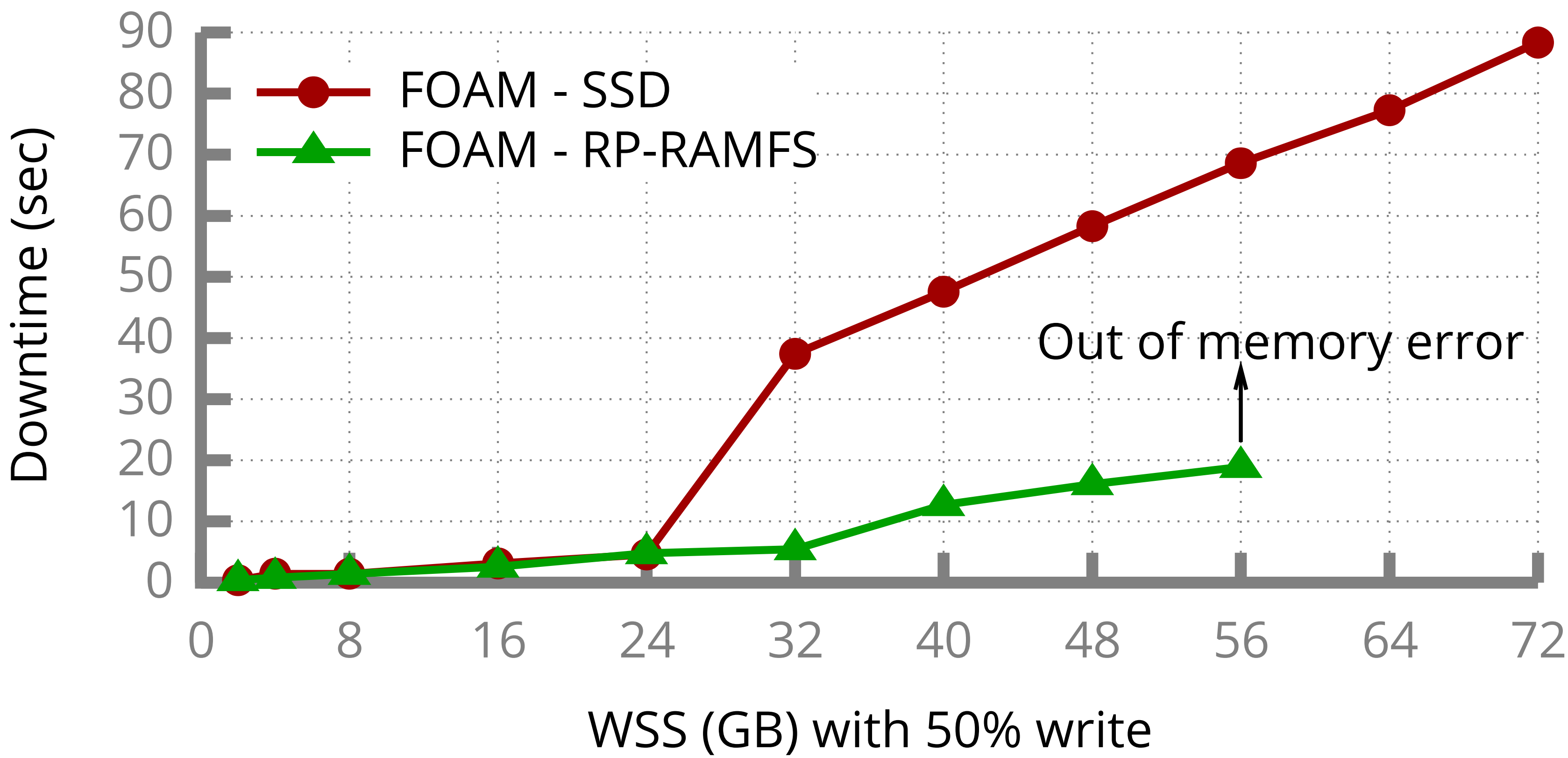

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