Distributed Snapshots with Virtual Machines

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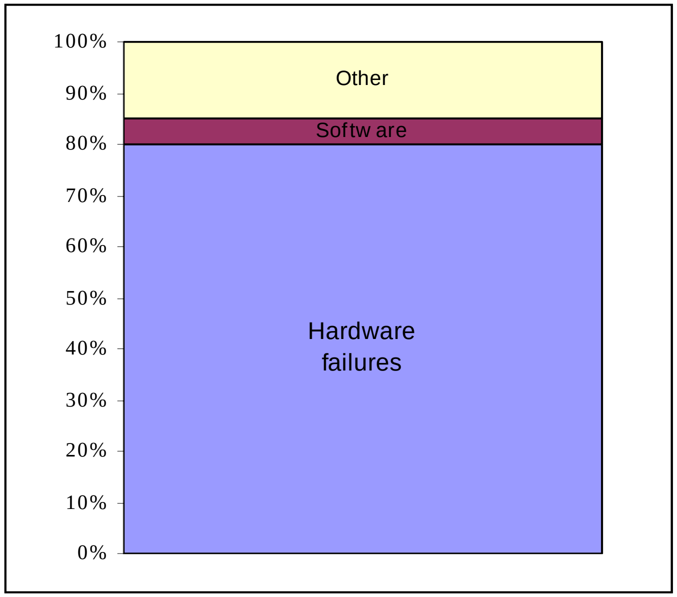
Motivation

- Single system: snapshots allow
  - ‘Time travel’
    - Reduce failure costs
    - Debugging
    - System audit
    - [Scalability studies]
  - Migration

- Distributed/parallel system:
  - All the above would be (even more) useful …
  - *… but we do not have an transparent & efficient snapshot mechanism*

Challenge problem (1): Parallel application checkpoint/restart

- Large parallel applications can expect multiple failures during a normal run
  - This situation is getting worse as we scale up
- Possible solutions
  - Buy reliable components (expensive!)
  - Reduce the cost of failures through checkpoint/restart mechanisms



Multiple component system

$$MTBF = \frac{1}{\sum_{i=1}^{N} \lambda_i} \cong \frac{1}{N\lambda}$$

- *Challenge*: checkpoint/restart a real application on a 1K nodes cluster with reasonable overhead

Challenge problem (2):
Migration of an e-commerce application

- Most e-commerce applications deployed on large clusters
- Scenario: the whole cluster is going down. What do we do?

- *Challenge*: <1s observable downtime while migrating an entire e-commerce application

A bit of distributed snapshots theory …

- Non-deterministic problem
    - Guarantee that: Snapshot state is reachable from initial state, final state is reachable from snapshot

- Main approaches
    - Coordinated snapshots
        - Assumes: synchronized clocks
        - But: Unrealistic
    - Uncoordinated snapshots [Chandi'85]
        - Assumes: communication channels with in-order delivery, bounded message propagation time
        - But: Memory expensive – not-bounded!

State of the art

Snapshots for parallel applications	Type
Application level	coord./uncoord.
Library level (modified MPI, OS support)	*uncoord*.
System level	*coord*.

Operations: most HPC centers do not provide any support

- Checkpointing left entirely to the application developer
- Some systems (Cray) do, but limited to single node
- Job management systems (e.g., LSF) have the appropriate plug-ins

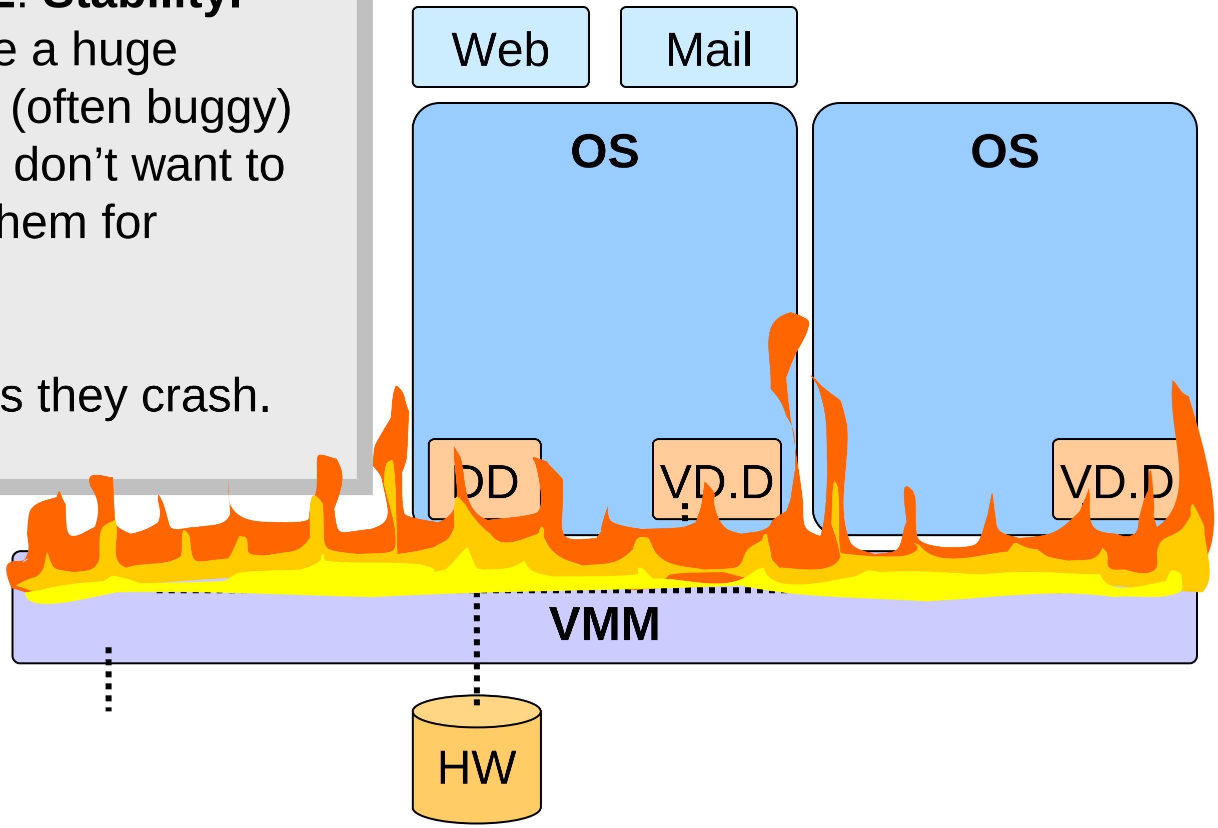
How can a platform based on VMs help?

- *Coordination backbone*
  - Application runs in a VM. Second VM on the same node for signaling/management.
- *High-level abstraction*
  - Bundles: memory, registers, file-descriptors, sockets
- *Time travel*
  - Can mask suspended state duration:
    - Applications that rely on timing can still work correctly
    - E.g., timing the core computation to determine progress, communication timers.
- *Delayed message delivery*
  - Enables network "flush"

Brief detour: Devices in Xen

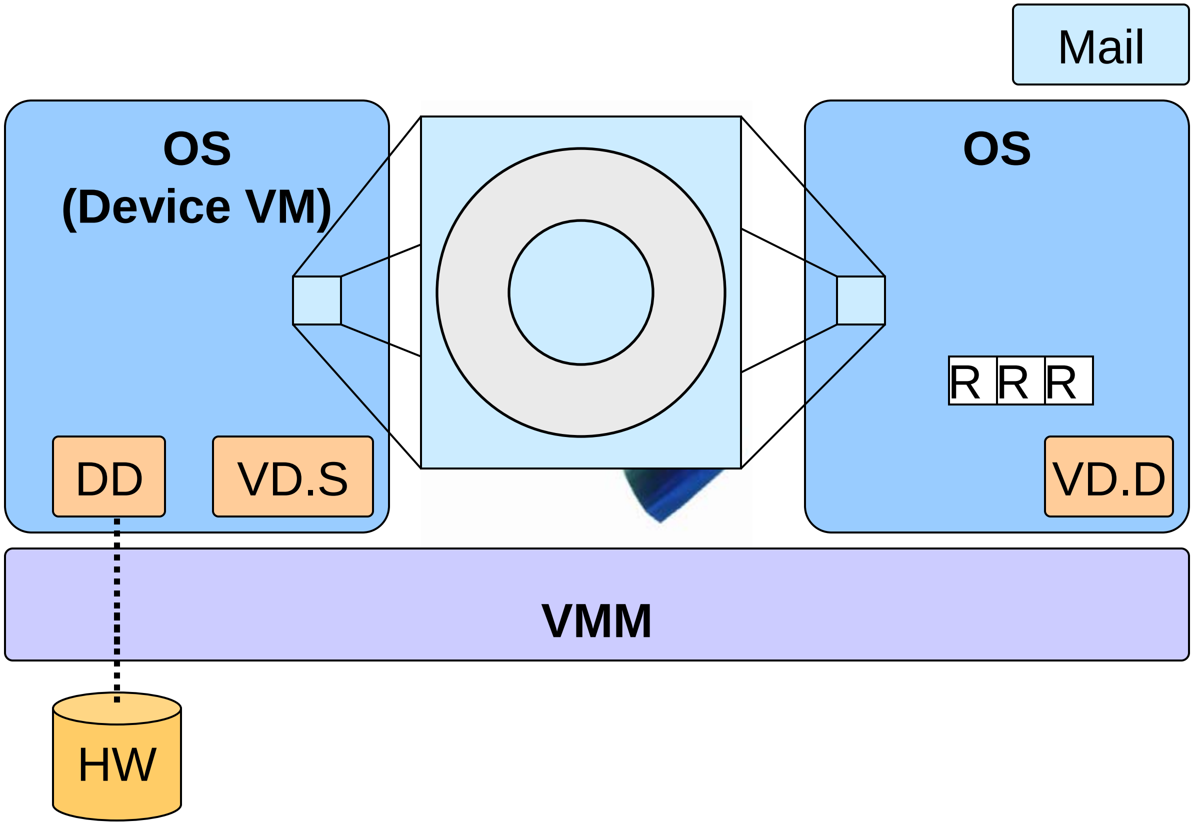
Problem 2: **Stability.** Drivers are a huge amount of (often buggy) code. We don't want to count on them for reliability.

Sometimes they crash.



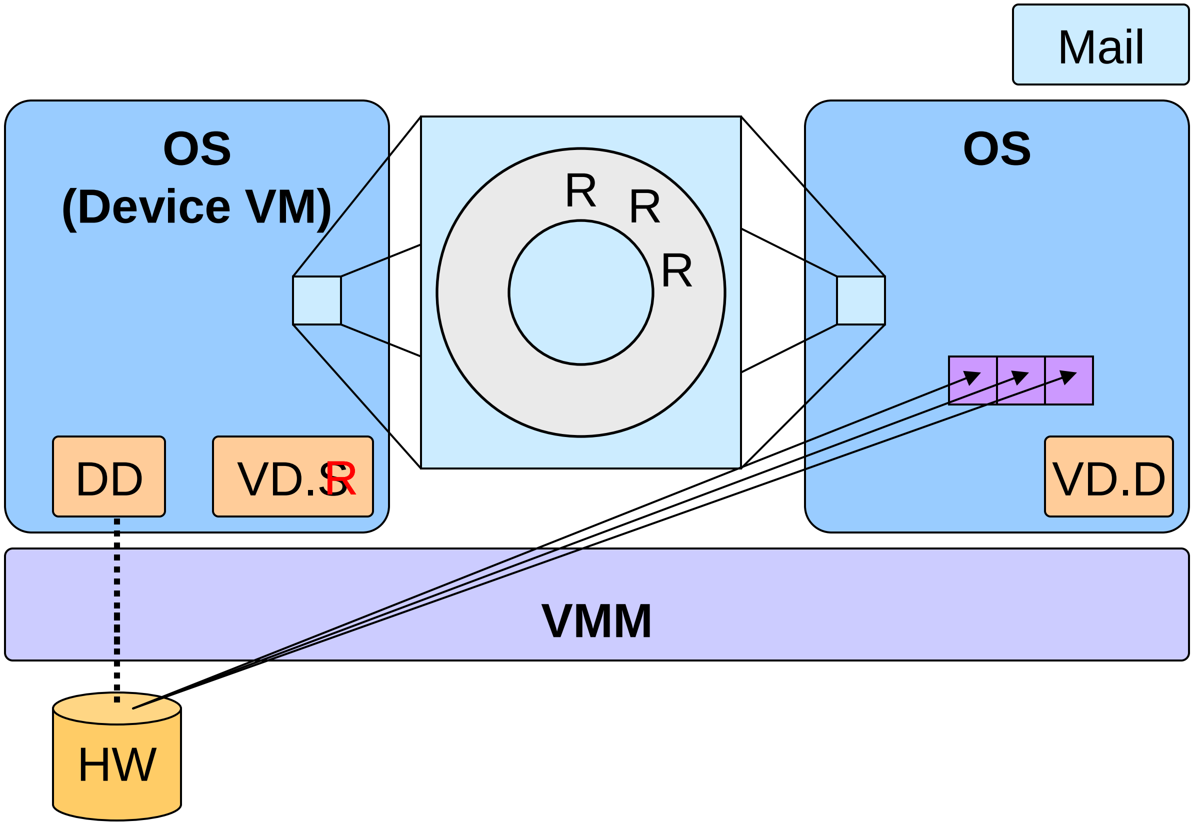
Option 1: VMM runs physical device driver. VM drivers for "virtual" device. Either real (emulated) HW, or idealized.

Brief detour: Devices in Xen.



Option2: VMM exports physical hardware to a device VM. Use OS driver, OS mechanisms (e.g. packet forwarding)

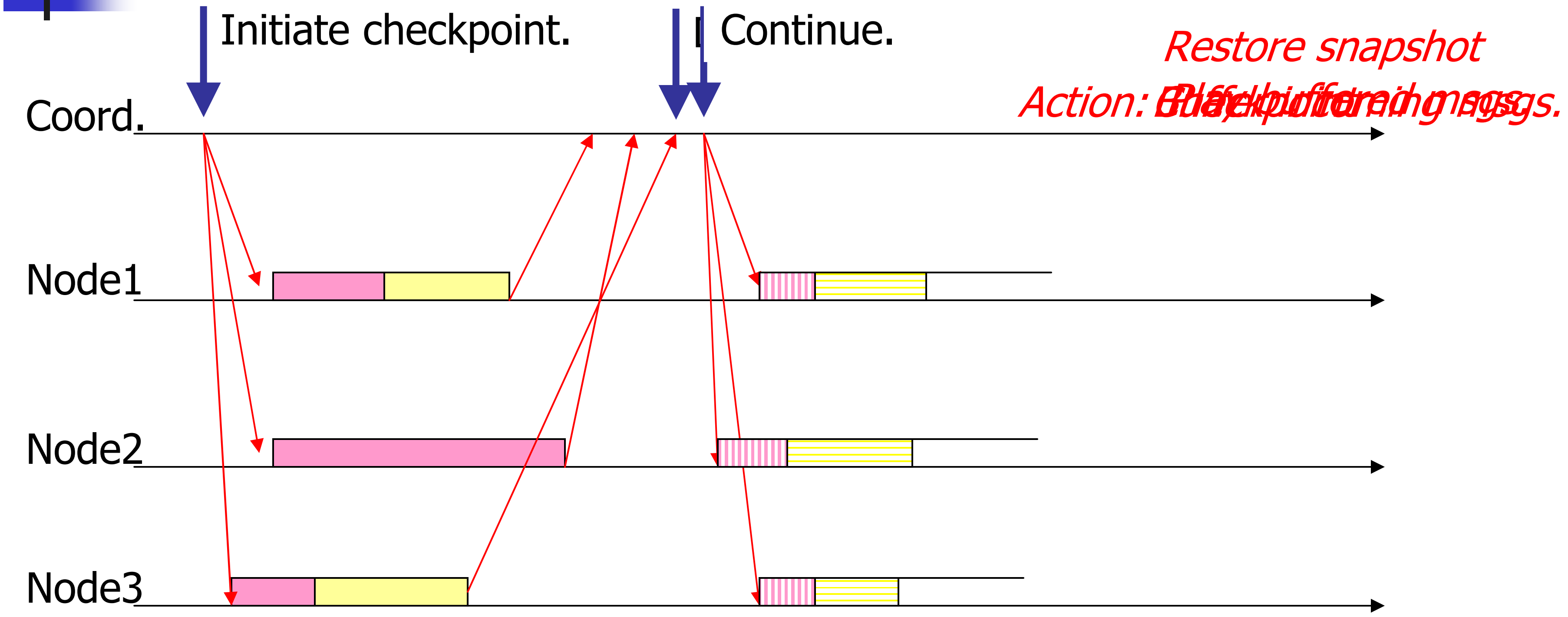
Brief detour: Devices in Xen



Option 2: VMM e
Use OS driver, OS

Exploit this architecture to queue messages while draining the network!

Putting everything together: Coordination protocol



Assumptions

- Bounded (known) message propagation time – to ‘flush’
- Bounded state saving time – to detect node failures at barrier

Status

Just starting:

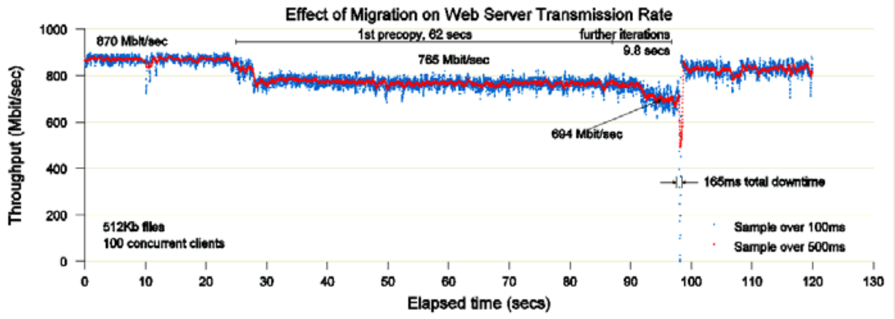
- Putting together an experimental platform
- Experimenting: How far unmodified Xen and the coordinated checkpoint algorithm takes us with real applications?

Discussion: potential stoppers

- Runtime overheads
  - New hardware allows proper virtualization (no more full- & para-virtualization)
  - Communication overheads: already accepted
- Checkpoint overheads: large snapshots to persist on disk
  - Incremental checkpoint techniques
  - To exploit: similar state at all machines
- Application correctness depends on wall-clock time
  - Parameterize the type of time the VMM provides?

Discussion: Interesting problems

- Data preservation problems
  - Reduce aggregate checkpoint state based on similarities
  - Optimized file system: multiple write / (maybe) one write (slow)
  - Improve scalability & snapshot availability by peering nodes
- What does it mean to ‘virtualize’ a distributed platform?
  - Snapshots
  - Clocks
  - Internal routing
- What does it take to scale to 1K/10k/100k nodes?
- Fast migration?



Summary

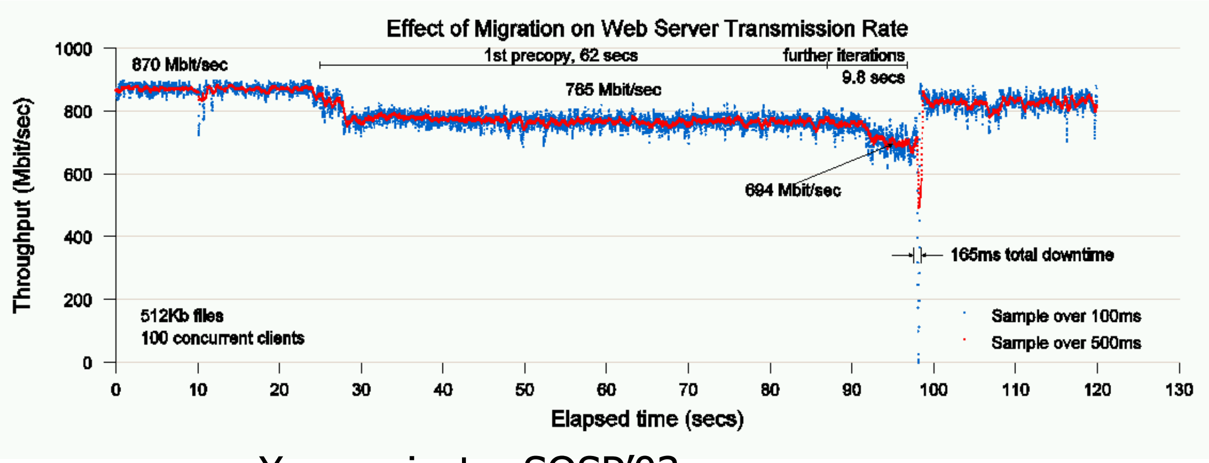
- VM-based platform natural match for distributed snapshots
  - Converging view: virtualization trend extends to distributed platforms
    - State collection (Snapshots) - basic functionality for virtualization platform
- Benefits
  - ‘time-travel’
  - Enables competitive compute resource market:
    - Migration enables detaching resource and application/service providers
  - Improve resource utilization of HPC clusters
  - Integrate with Virtual Clusters (ANL)

Thank you

- Questions

What’s the state of the art?

- Live (single) machine migration



Xen project – SOSP’03 paper

- Projects that reconfigure platform based on observed traffic (NWU, UFlorida, Purdue, others)
- Virtual playgrounds (ANL)