Hasso Plattner Institut

IT Systems Engineering | Universität Potsdam

Memory-Based Cloud Architectures

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Definition

Cloud Computing
=
Data Center + API

What to take home from this talk?

Answers to four questions:

- Why are memory based architectures great for cloud computing?
- How predictable is the behavior of an in-memory column database?
- Does virtualization have a negative impact on in-memory databases?
- How do I assign tenants to servers in order to manage fault-tolerance and scalability?

First question

Why are memory based architectures great for cloud computing?

Numbers everyone should know

L1 cache reference	0.5 ns
Branch mispredict	5 ns
L2 cache reference	7 ns
Mutex lock/unlock	25 ns
Main memory reference	100 ns (in 2008)
Compress 1K bytes with Zippy	3,000 ns
Send 2K bytes over 1 Gbps network	20,000 ns
Read 1 MB sequentially from memory	250,000 ns
Round trip within same datacenter	500,000 ns (in 2008)
Disk seek	10,000,000 ns
Read 1 MB sequentially from network	10,000,000 ns
Read 1 MB sequentially from disk	20,000,000 ns
Send packet CA → Netherlands → CA	150,000,000 ns

Source: Jeff Dean

Memory should be the system of record

- Typically disks have been the system of record
  - Slow → wrap them in complicated caching and distributed file systems to make them perform
  - Memory used as cache all over the place but it can be invalidated when something changes on disk
- Bandwidth:
  - Disk: 120 MB/s/controller
  - DRAM (x86 + FSB): 10.4 GB/s/board
  - DRAM (Nehalem): 25.6 GB/s/socket
- Latency:
  - Disk: 13 milliseconds (up to seconds when queuing)
  - InfiniBand: 1-2 microseconds
  - DRAM: 5 nanoseconds

High-end networks vs. disks

Maximum bandwidths:

Hard Disk	100-120 MB/s
SSD	250 MB/s
Serial ATA II	600 MB/s
10 GB Ethernet	**1204 MB/s**
InfiniBand	**1250 MB/s (4 channels)**
PCIe Flash Storage	1400 MB/s
PCIe 3.0	32 GB/s
DDR3-1600	25.6 GB/s (dual channel)

Designing a database for the cloud

- Disks are the limiting factor in contemporary database systems
  - Sharing a high performance disk on a machine/cluster/cloud is fine/troublesome/miserable
  - While one guy is fetching 100 MB/s, everyone else is waiting

- **Claim:** Two machines + network is better than one machine + disk
  - Log to disk on a single node:
    > 10,000 µs (not predictable)
  - Transactions only in memory but on two nodes:
    < 600 µs (more predictable)

- Concept: Design to the strengths of cloud (redundancy) rather than their weaknesses (shared anything)

Design choices for a cloud database

- No disks (in-memory delta tables + async snapshots)
- Multi-master replication
  - Two copies of the data
  - Load balancing both reads and (monotonic) writes
  - (Eventual) consistency achieved via MVCC (+ Paxos, later)
- High-end hardware
  - Nehalem for high memory bandwidth
  - Fast interconnect
- Virtualization
  - Ease of deployment/administration
  - Consolidation/multi-tenancy

Why consolidation?

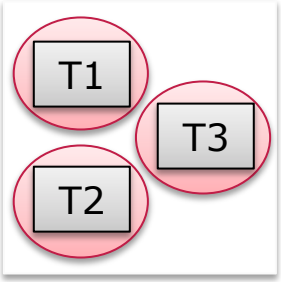
- In-memory column databases are ideal for mixed workload processing
- **But:** In a SaaS environment it seems costly to give everybody their private NewDB box

- How much consolidation is possible?
  - 3 years worth of sales records from our favorite Fortune 500 retail company
  - 360 million records
  - Less than 3 GB in compressed columns in memory
  - Next door is a machine with 1 TB of DRAM
  - (Beware of overhead)

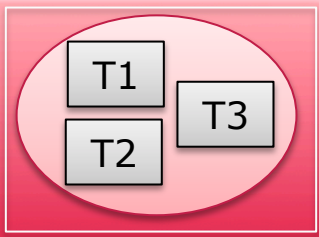
Multi-tenancy in the database – four different options

- **No multi-tenancy** – one VM per tenant
  - **Ex.:** RightNow has 3000 tenants in 200 databases (2007): 3000 vs. 200 Amazon VMs cost $2,628,000 vs. $175,200/year
  - Very strong isolation

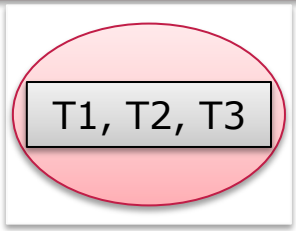
- **Shared machine** – one database process per tenant
  - Scheduler, session manager and transaction manager need live inside the individual DB processes: IPC for synchronization
  - Good for custom extensions, good isolation



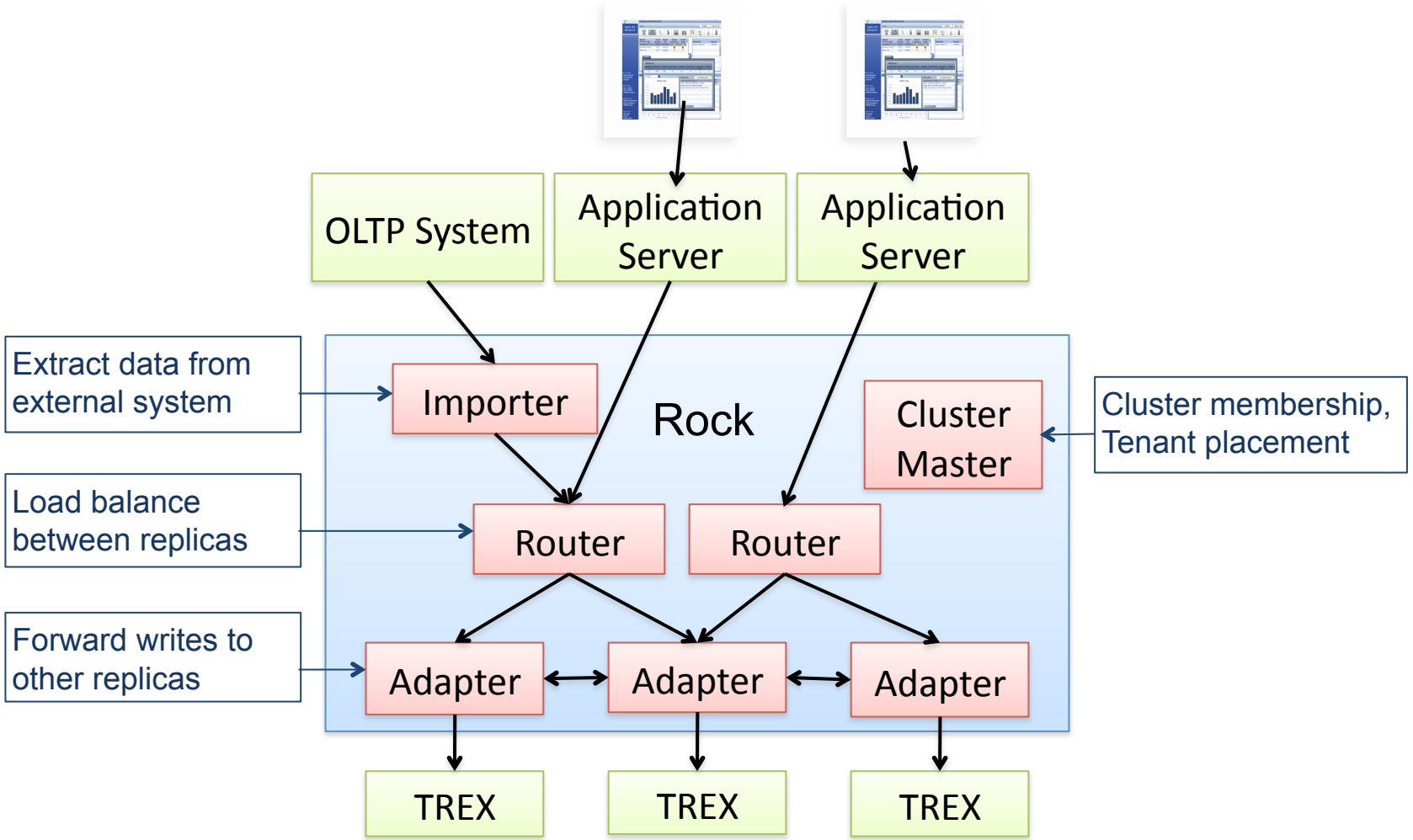
- **Shared process** – one schema instance per tenant
  - Must support large numbers of tables
  - Must support online schema extension and evolution



- **Shared table** – use a `tenant_id` column and partitioning
  - Bad for custom extensions, bad isolation
  - Hard to backup/restore/migrate individual tenants



Putting it all together: Rock cluster architecture



Second question

How predictable is the behavior of an in-memory column database?

What does "predictable" mean?

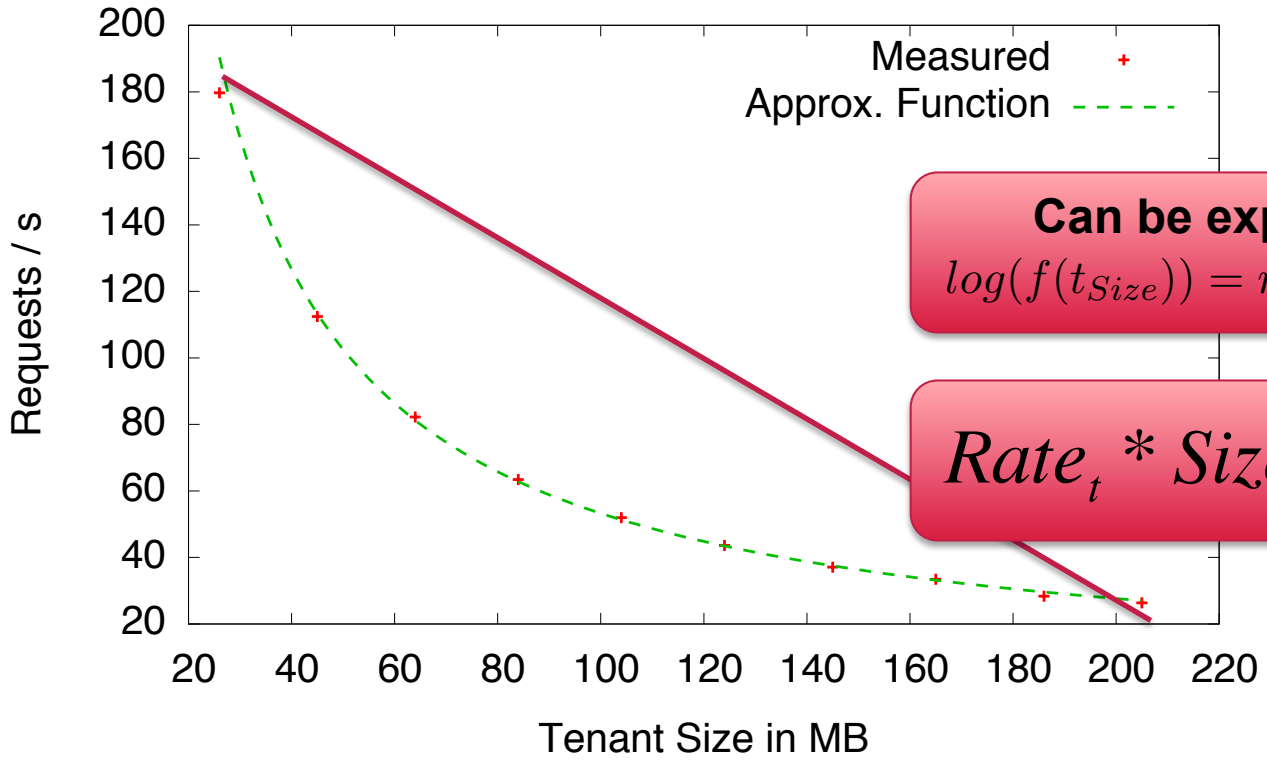
- Traditionally, database people are concerned with the questions of type "how do I make a query faster?"

- In a SaaS environment, the question is "how do I get a fixed (low) response time as cheap as possible?"
  - Look at throughput
  - Look at quantiles (e.g. 99-th percentile)

- Example formulation of desired performance:
  - Response time goal "1 second in the 99-th percentile"
  - Average response time around 200 ms
  - Less than 1% of all queries exceed 1,000 ms
  - Results in a maximum number of concurrent queries before response time goal is violated

System capacity

- Fixed amount of data split equally among all tenants



Can be expressed as:

$$log(f(t_{Size})) = m \cdot log(t_{Size}) + n$$

$$Rate_t * Size_t^{0.95} = 4144$$

- Capacity ≈ bytes scanned per second
  (there is a small overhead when processing more requests)
- In-memory databases behave very linearly!

Workload

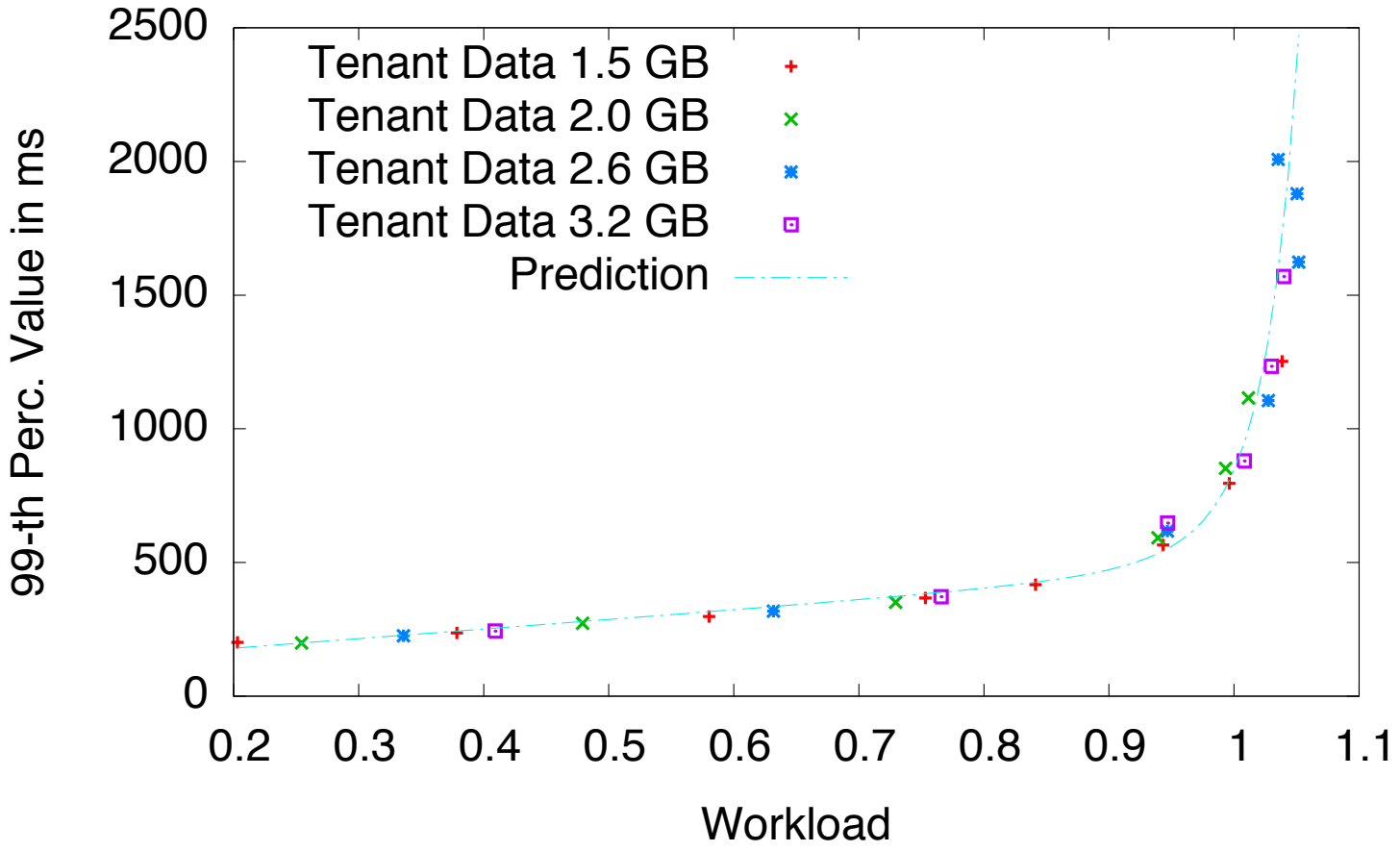
- Tenants generally have different rates and sizes
- For a given set of T tenants (on one server) define

$$Workload = \sum_{t \in T} \frac{Rate_t * Size_t^{0.95}}{4144}$$

- When Workload = 1
  - System runs at it's maximum throughput level
  - Further increase of workload will result in violation of response time goal

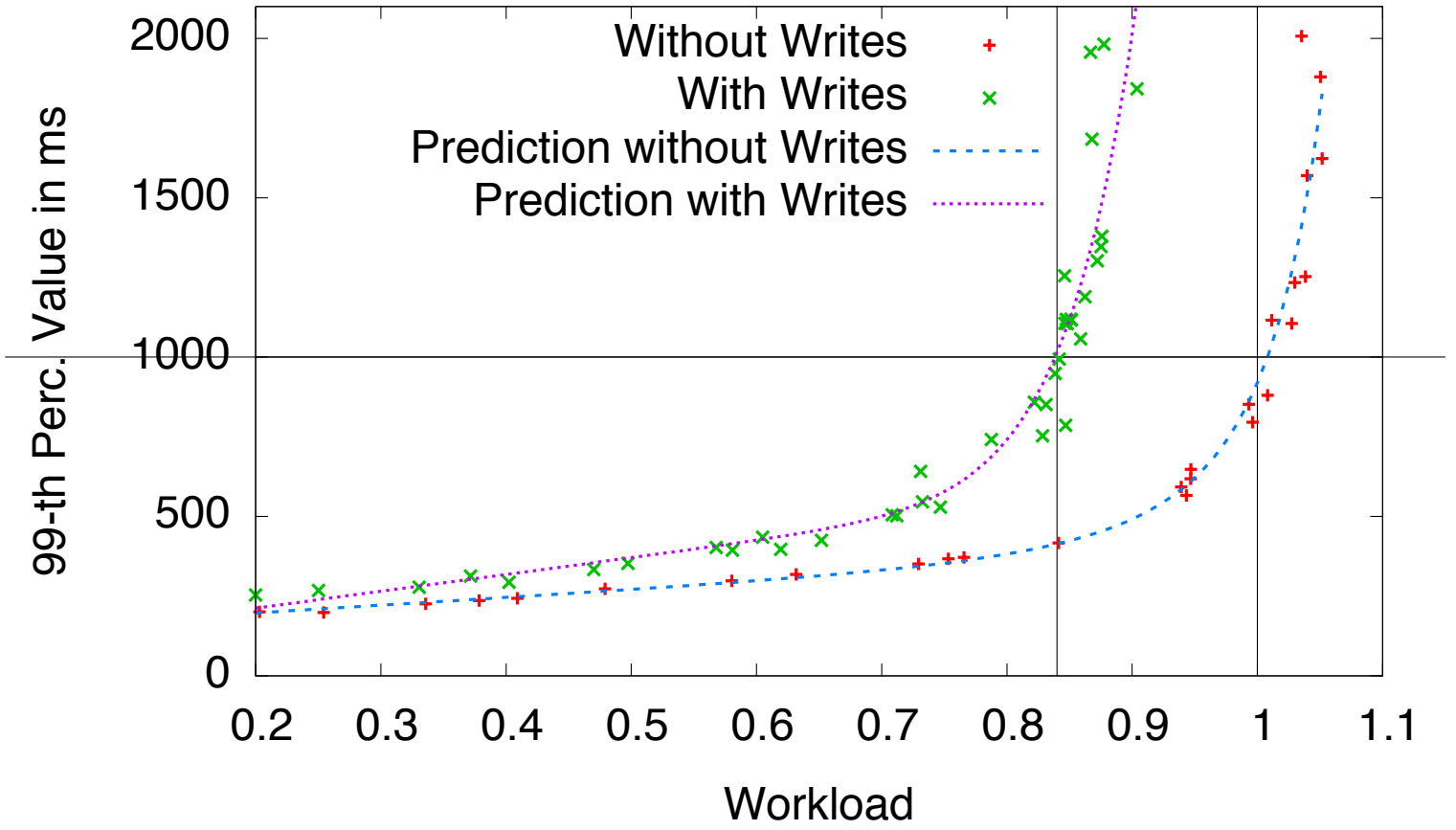
Response time

- Different amounts of data and different request rates (“assorted mix”)
- Workload is varied by scaling the request rates



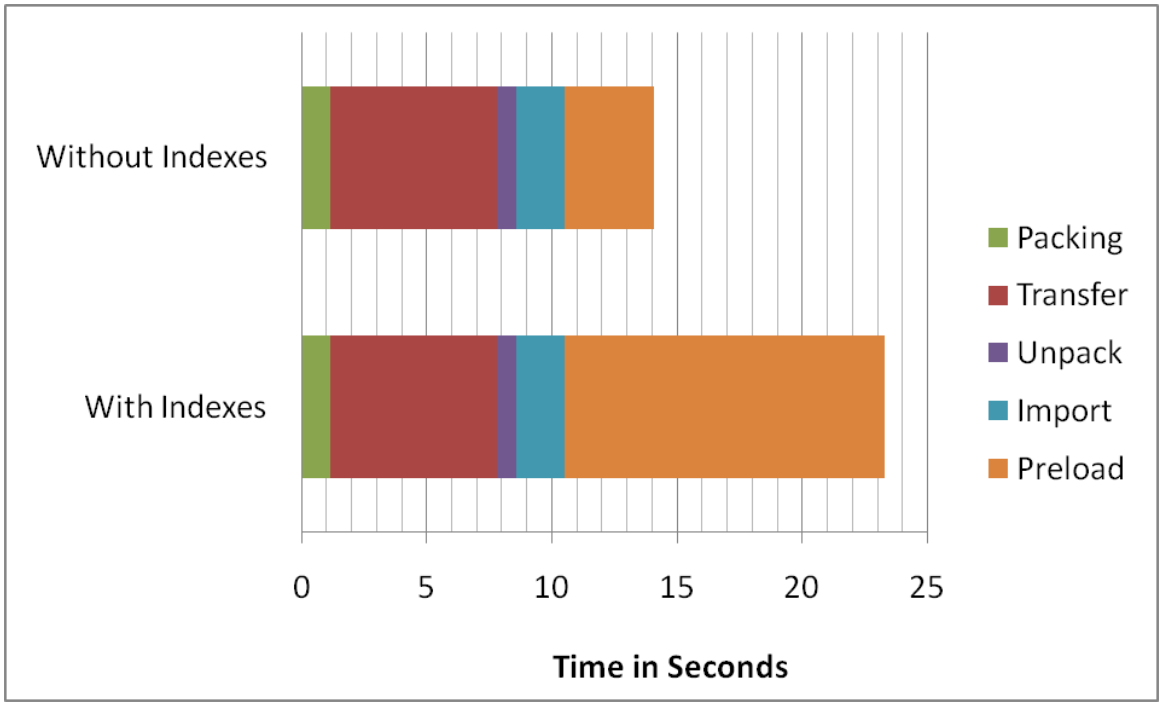
Impact of writes

- Added periodic batch writes (fact table grows by 0.5% every 5 minutes)



Why is predictability good?

- Ability to plan and perform resource intensive tasks during normal operations:
  - Upgrades
  - Merges
  - Migrations of tenants in the cluster (e.g. to dynamically re-balance the load situation in the cluster)



Cost breakdown for migration of tenants

Definition

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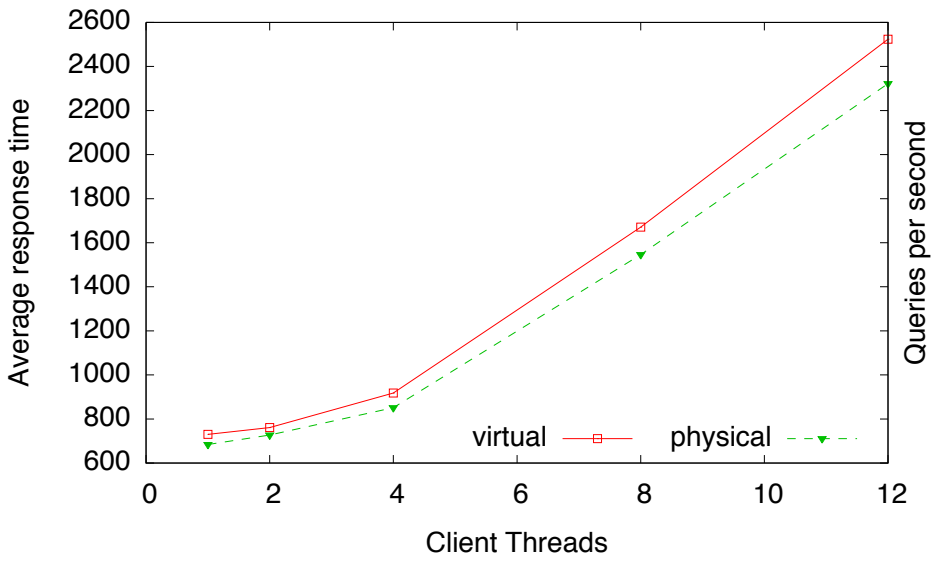
Third question

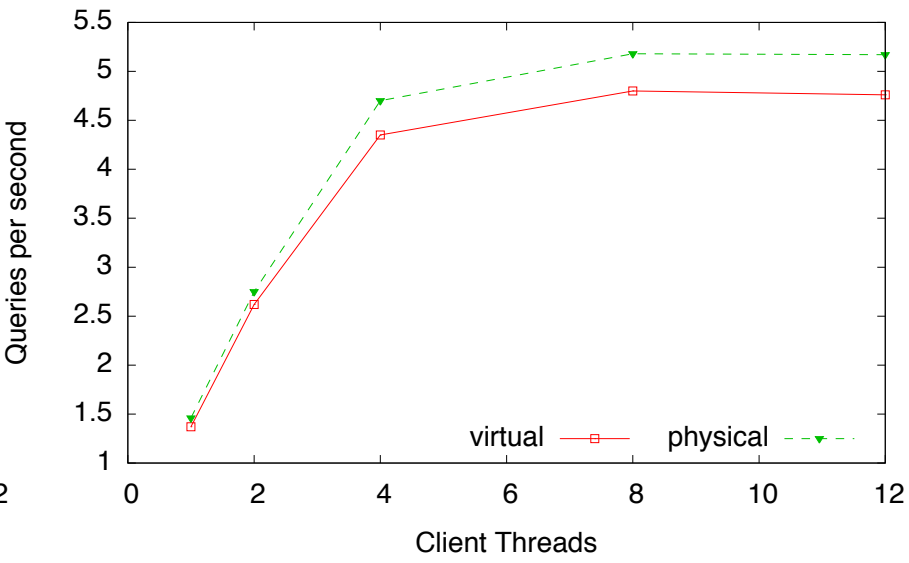
Does virtualization have a negative impact on in-memory databases?

Impact of virtualization

- Run multi-tenant OLAP benchmark on either:
  - one TREX instance directly on the physical host vs.
  - one TREX instance inside VM on the physical host

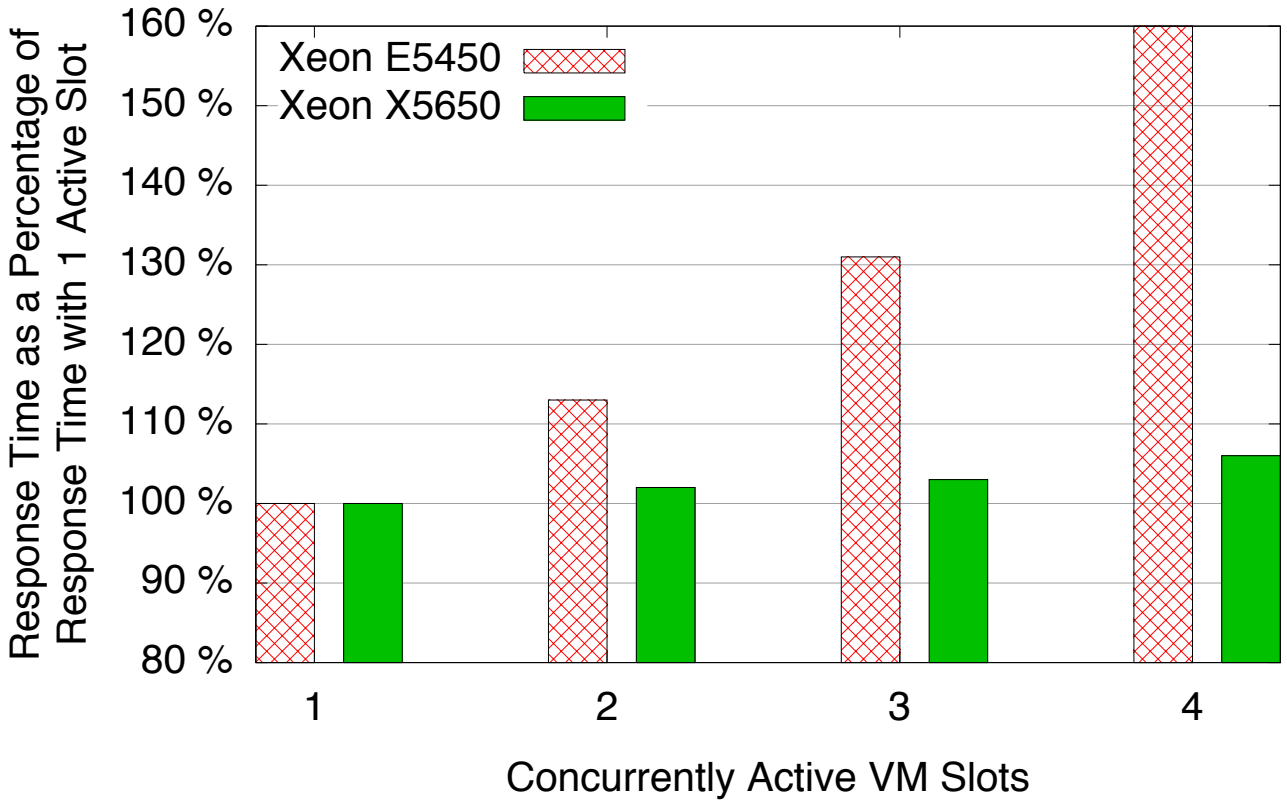
- Overhead is approximately 7% (both in response time and throughput)





Impact of virtualization (contd.)

- Virtualization is often used to get "better" system utilization
  - What happens when a physical machine is split into multiple VMs?
  - Burning CPU cycles does not hurt → memory bandwidth is the limiting factor



Fourth question

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How do I assign tenants to servers in order to manage fault-tolerance and scalability?

Why is it good to have multiple copies of the data?

- Scalability beyond a certain number of concurrently active users
- High availability during normal operations
- Alternating execution of resource-intensive operations (e.g. merge)
- Rolling upgrades without downtime
- Data migration without downtime

- *Reminder:* Two in-memory copies allow faster writes and are more predictable than one in-memory copy plus disk

- **Downsides:**
  - Response time goal might be violated during recovery
  - You need to plan for twice the capacity

Tenant placement

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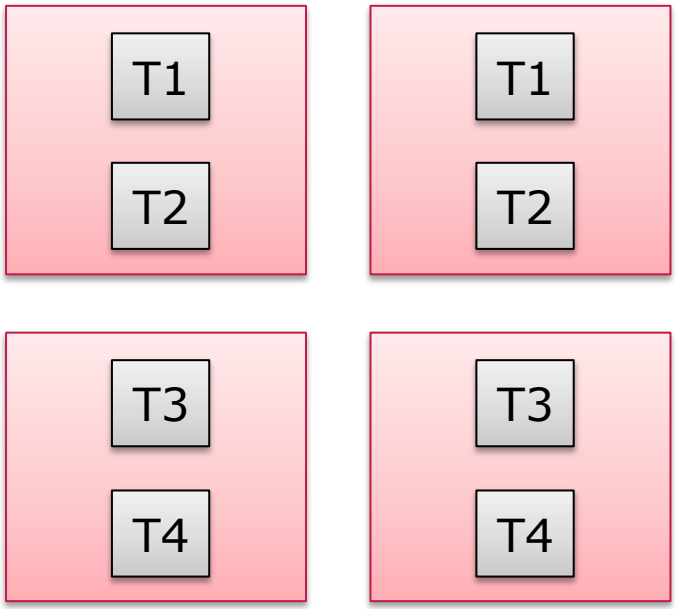
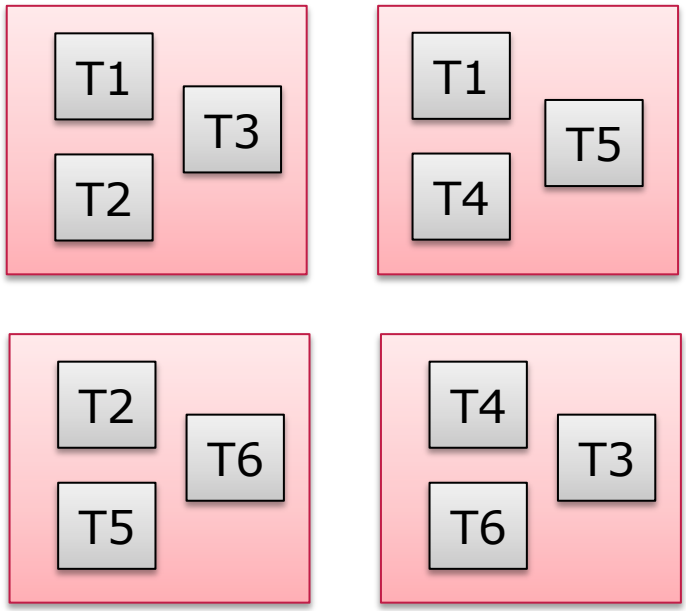
Conventional Mirrored Layout



If a node fails, all work moves to one other node. The system must be **100% over-provisioned**.

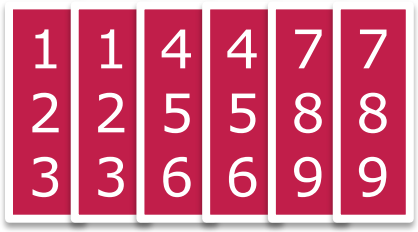
Interleaved Layout



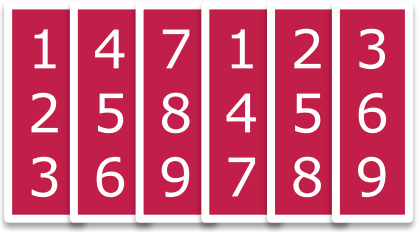
If a node fails, work moves to many other nodes. Allows **higher utilization** of nodes.

Handcrafted best case

- Perfect placement:
  - 100 tenants
  - 2 copies/tenant
  - All tenants have same size
  - 10 tenants/server



Mirrored



Interleaved

- Perfect balancing (same load on all tenants):
  - 6M rows (204 MB compressed) of data per tenant
  - The same (increasing) number of users per tenant
  - No writes

	Mirrored	Interleaved	Improvement
No failures	4218 users	4506 users	7%
Periodic single failures	2265 users	4250 users	88%

Throughput before violating response time goal

Requirements for placement algorithm

- An optimal placement algorithm needs to cope with multiple (conflicting) goals:
  - Balance load across servers
  - Achieve good interleaving
- Use migrations consciously for online layout improvements (no big bang cluster re-organization)
- Take usage patterns into account
  - Request rates double during last week before end of quarter
  - Time-zones, Christmas, etc.

Conclusion

- Answers to four questions:
  - ✓ Why are memory based architectures great for cloud computing?
  - ✓ How predictable is the behavior of an in-memory column database?
  - ✓ Does virtualization have a negative impact on in-memory databases?
  - ✓ How do I assign tenants to servers in order to manage fault-tolerance and scalability?

- **Questions?**