Characterizing Private Clouds: A Large-Scale Empirical Analysis of Enterprise Clusters

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University of Washington – Nutanix Inc.

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Private Clouds
Private Clouds

- Cloud computing that delivers service to a single organization, as opposed to public clouds, which service many.
- Direct control of infrastructure and data.
- Carry management and maintenance costs.
Motivation

• **Increasing trend** in the use of **private clouds** within companies.

• Private clouds **deployments** require **careful consideration** of what will happen in the future:
  – Capacity
  – Failures
  – ...
Motivation

• Research Questions:
  – What are the most common failures?
  – What type of workloads are typically run?
  – How is the storage used? What about CPU usage?
  – How do additional replicas impact data durability?
  – What causes companies to expand their clusters?

Need Measurement Data!
## Related Work

<table>
<thead>
<tr>
<th>Setting \ Study</th>
<th>Hardware Failures</th>
<th>Storage</th>
<th>Compute</th>
</tr>
</thead>
<tbody>
<tr>
<td>Desktops</td>
<td>• HW Failures in PCs [Nightingale et al., EuroSys’11]</td>
<td>• Metadata in Windows PCs [Agrawal et al., TOS’07]</td>
<td>• Disk/CPU Usage and Load [Bolosky et al., SIGMETRICS’00]</td>
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<tr>
<td></td>
<td>• HW reliability [Harter et al., SOSP’11]</td>
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<tr>
<td>Public Clouds</td>
<td>• HW reliability [Vishwanath et al., SoCC’11]</td>
<td>• Access Patterns [Liu et al., IEEE/ACM CCGrid’13]</td>
<td>• Workloads characterization [Mishra et al., SIGMETRICS’10]</td>
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**Limited prior work on Private Clouds!**
In this talk

• Large-Scale Measurement Study of Private Clouds
  – Lower hardware failure rates
  – Nodes overprovisioned
  – Stable storage and CPU usage

• Modeling based on the Measurements
  – Each extra replica provides substantial durability improvements
  – Storage needs drive growth more than compute
Outline

• Large-Scale Measurement Study of Private Clouds
  – Context
  – Cluster Profiles
  – Failure Analysis
  – Workload Characteristics

• Modeling based on the Measurements
  – Durability
  – Cluster Growth
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Nutanix Clusters

- Operations interposed at the hypervisor level and redirected to CVMs
- Global view of cluster state
- Random replication VMs migration
- Integrated Compute-Storage
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# Clusters

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6.18 Nodes/Cluster
# Clusters

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<td>Cluster Sizes</td>
<td>3 - 40</td>
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<tr>
<td># of Disks</td>
<td>~ 70K</td>
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# Node Configurations

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Storage</th>
<th>Compute</th>
<th>Memory (GB)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SSD (TB)</td>
<td>HDD (TB)</td>
<td>Cores</td>
</tr>
<tr>
<td>Config-1</td>
<td>1.6</td>
<td>8</td>
<td>24</td>
</tr>
<tr>
<td>Config-2</td>
<td>0.8</td>
<td>4</td>
<td>12</td>
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<tr>
<td>Config-3</td>
<td>0.8</td>
<td>30</td>
<td>16</td>
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**Storage-heavy**

**Compute-heavy**

Mostly homogeneous within a cluster
## Workloads

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<td>Hadoop</td>
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<tr>
<td>Others</td>
<td>IT Infrastructure Custom applications</td>
<td>Mix</td>
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Distribution of VMs per Node

- Median 21
- Most 2-4 vCPUs
- Highest density

Lowest density

Avg. # of VMs per Node vs Size of Cluster (# of Nodes)

- 1 vCPU
- 2-4 vCPUs
- > 4 vCPUs
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Failures

• We only consider failures that require manual intervention, i.e., human operators annotate the cause of the problem.
Hardware Failures

Top 3 account for around 50% of HW failures
## Annual Return Rate

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<th>ARR (%)</th>
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2-9 % prior studies
## Annual Return Rate

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<tr>
<td>SSD</td>
<td>0.72</td>
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Lower return rates

Enterprise-grade commodity HW

4% prior studies (4 years)
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Workload Characteristics

- **Usage over time** seems to be **stable/predictable:**
  - *Storage:* mean $\leq 50\%$, std $\leq 8\%$
  - *CPU:* mean $\leq 20\%$, std $\leq 5\%$

- **SSDs** can generally **maintain** the **working set**
  - 80% of nodes use $\leq 500$ GB for the working set
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Durability Model

• Estimate the **probability of data loss**.

• Assumptions:
  – **replication factor** of 2
  – **random replication** (replicate to a random node)

• The **time** required to **create a new replica** when a node goes down:

\[ \Delta t = \frac{d}{(n - 1)v} \]

- Data to be replicated
- Data transfer rate
- Remaining live nodes
Durability Model

• \( \rho(\Delta t) = \text{probability of node failure} \) in \( \Delta t \) time.
• We decompose the overall period over which we want to provide the durability guarantee into a sequence of intervals, each of length \( \Delta t \).
• \( Q = \text{data loss event} \) where two failures occur within \( \Delta t \) time, i.e. data could not be replicated.
Durability Model

- Then the **probability** that there is **no data loss** in an interval $\Delta t$:

$$P(\neg Q, \Delta t) \leq (1 - p(\Delta t))^n + np(\Delta t)(1 - p(\Delta t))^{n-1}(1 - p(\Delta t))^{n-1}$$

- **No failures**
- **Exactly one node fails**
- **The remaining n-1 nodes do not fail within $\Delta t$ time**
Durability Model

• On a yearly-basis, we consider all $\Delta t$ intervals in a year.

• Probability of no data loss within a year is:

$$P_{durability} = P(\neg Q, \Delta t)^N(\Delta t)$$

# of intervals of $\Delta t$ time in a year
Durability in Private Clouds

Most clusters have 5 9’s with RF2, and 10 9’s with RF3

Rule of Thumb: each additional replica provides an additional 5 9's of durability
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Cluster Growth Analysis

• **Customers** periodically **add nodes** to their existing clusters.
• What **drives** such **growth**?
• We resort to **machine learning**
  – **Binary classification** problem
  – **Logistic Regression** with L1 regularization
Cluster Growth Analysis

• Use **200 clusters** than grew at least once in a period of 8 months.

• **15K examples** (70% train, 10% val, 20% test).

• Train with **different combination of features** to understand which are important.
# Features

<table>
<thead>
<tr>
<th>Cluster Features $F^c$</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$n(\text{nodes})$</td>
<td>discretized # of nodes</td>
</tr>
<tr>
<td>$n(\text{vms})$</td>
<td># of vms per node</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Storage Features $F^s$</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$r(\text{ssd})$</td>
<td>ssd usage to ssd capacity ratio</td>
</tr>
<tr>
<td>$r(\text{hdd})$</td>
<td>hdd usage to hdd capacity ratio</td>
</tr>
<tr>
<td>$r(\text{store})$</td>
<td>storage usage to total capacity ratio</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Performance Features $F^p$</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$n(\text{vcpus})$</td>
<td># of virtual cpus</td>
</tr>
<tr>
<td>$n(\text{iops})$</td>
<td># of iops per node</td>
</tr>
</tbody>
</table>
What drives cluster growth?

1. Cluster Size
2. Storage Needs
3. Compute Needs

- Upgrades from 3-4 node clusters
- HDD usage
- Number of VMs

Storage more than compute!
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Conclusions

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Thanks!