Application Performance Management in the Cloud using Learning, Optimization, and Control

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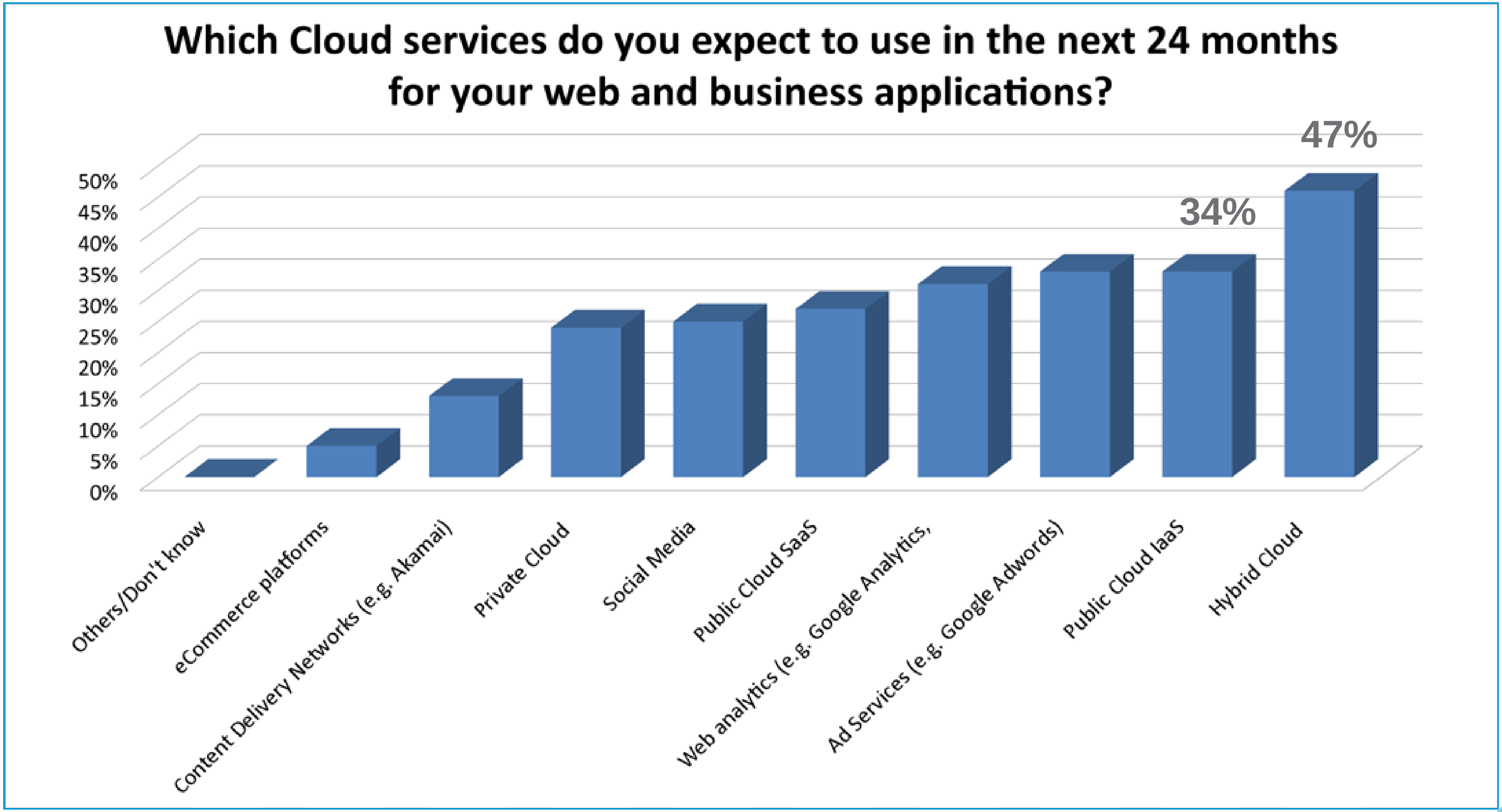
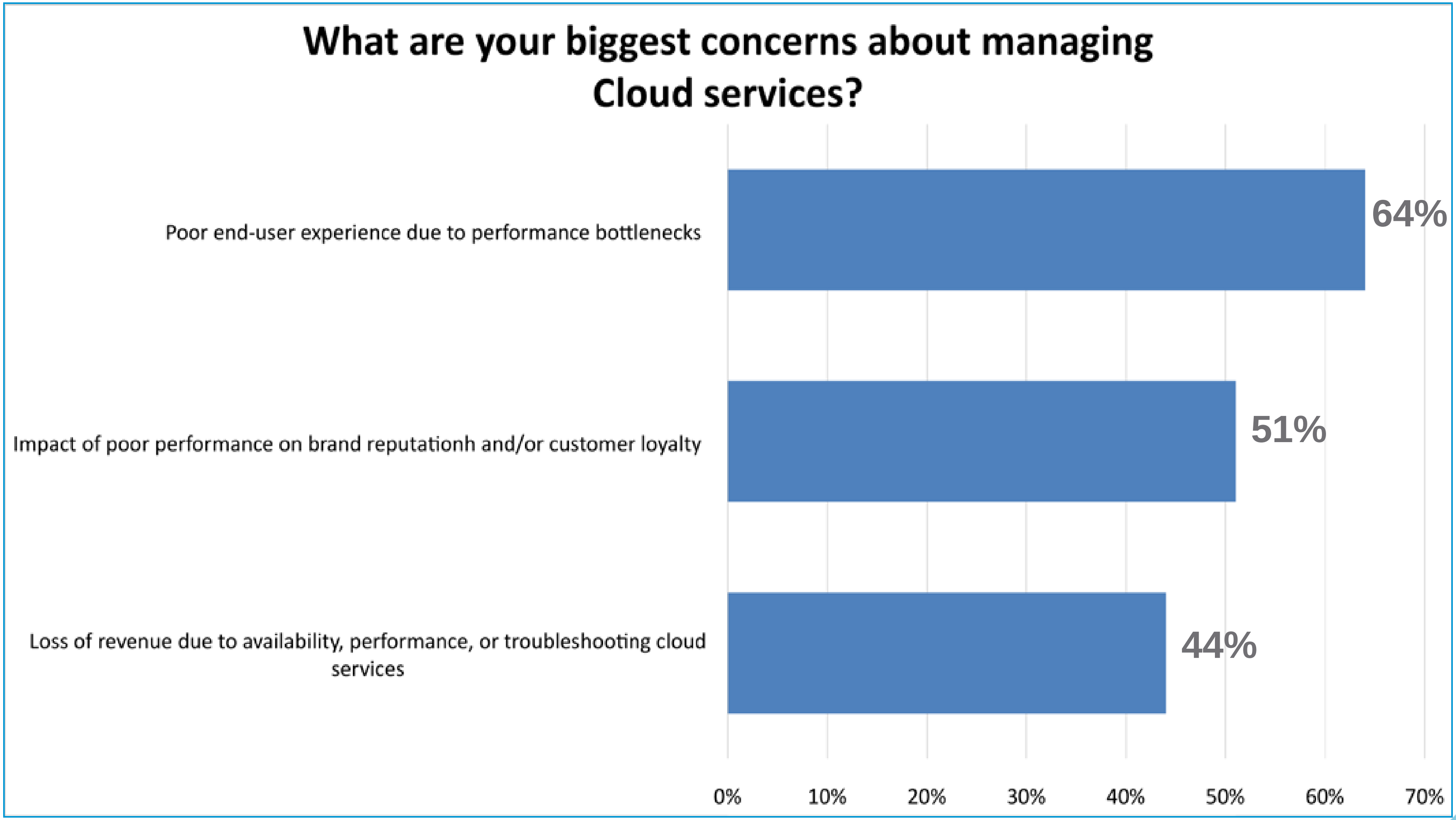
Rising adoption of cloud-based services



Source: "The hidden costs of managing applications in the cloud," Compuware/Research In Action White Paper, Dec. 2012, based on survey results from 468 CIOs in Americas, Europe, and Asia.

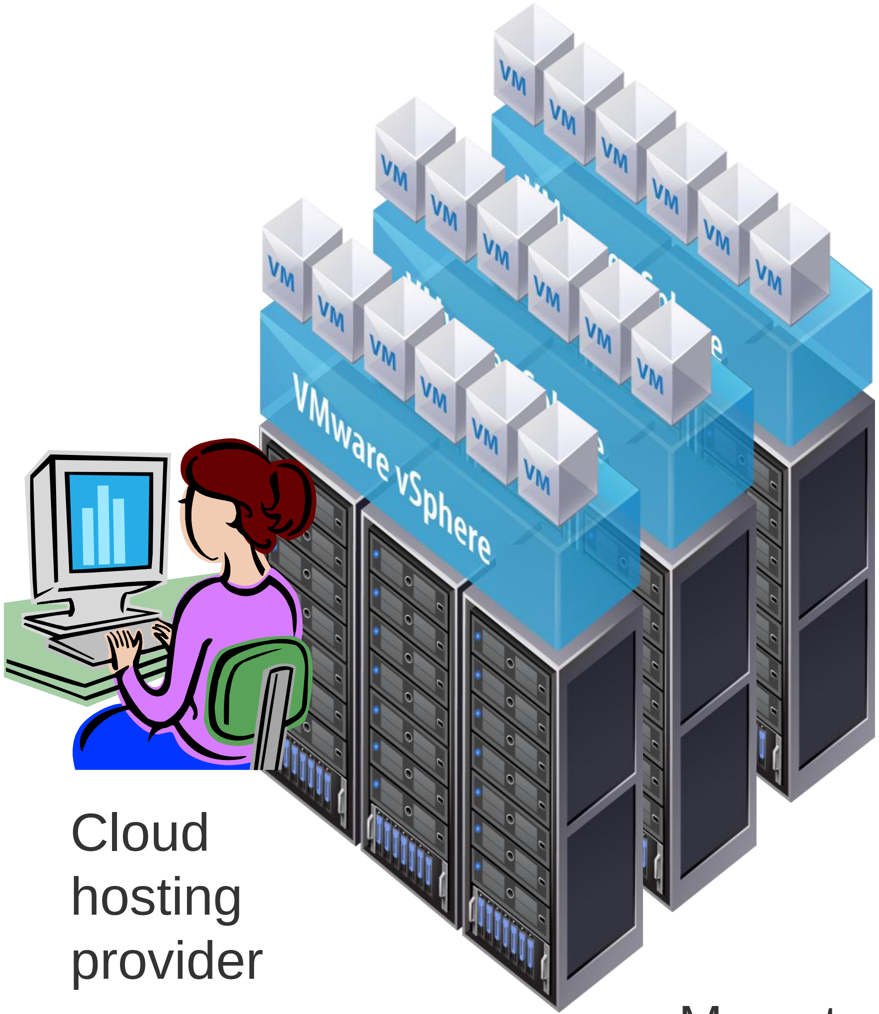
Application performance – a real concern



Source: "The hidden costs of managing applications in the cloud," Compuware/Research In Action White Paper, Dec. 2012, based on survey results from 468 CIOs in Americas, Europe, and Asia.

Application performance management is hard

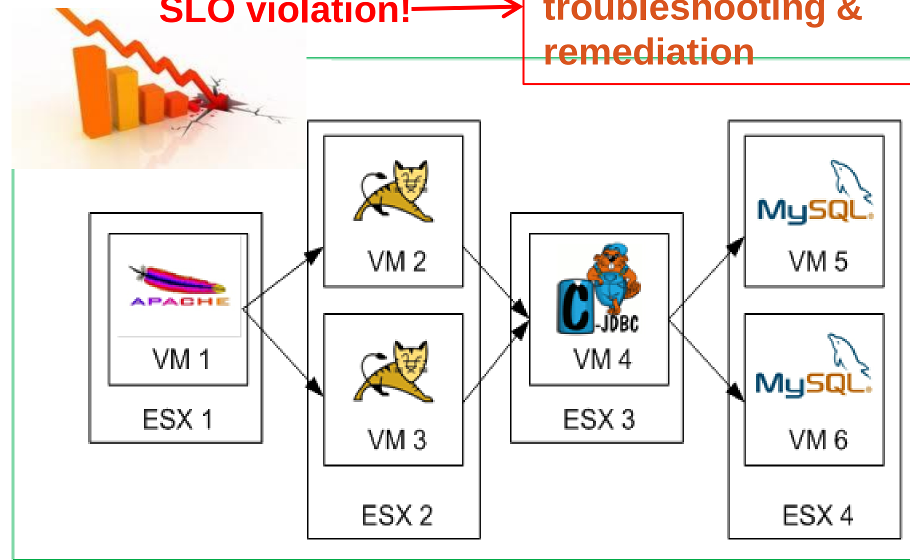
Service Level Objective: 95% of all transactions should be completed within 500ms

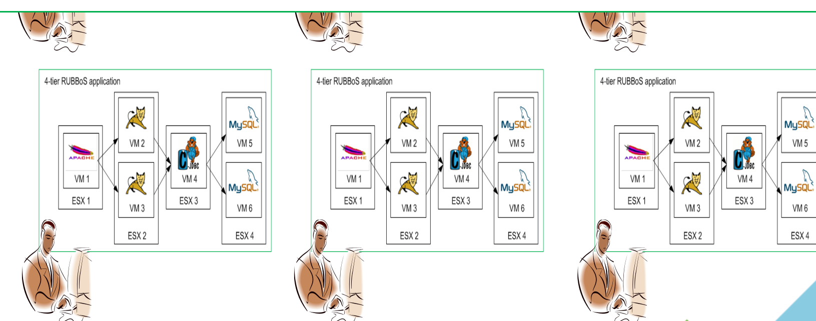


Cloud hosting provider

SLO violation!

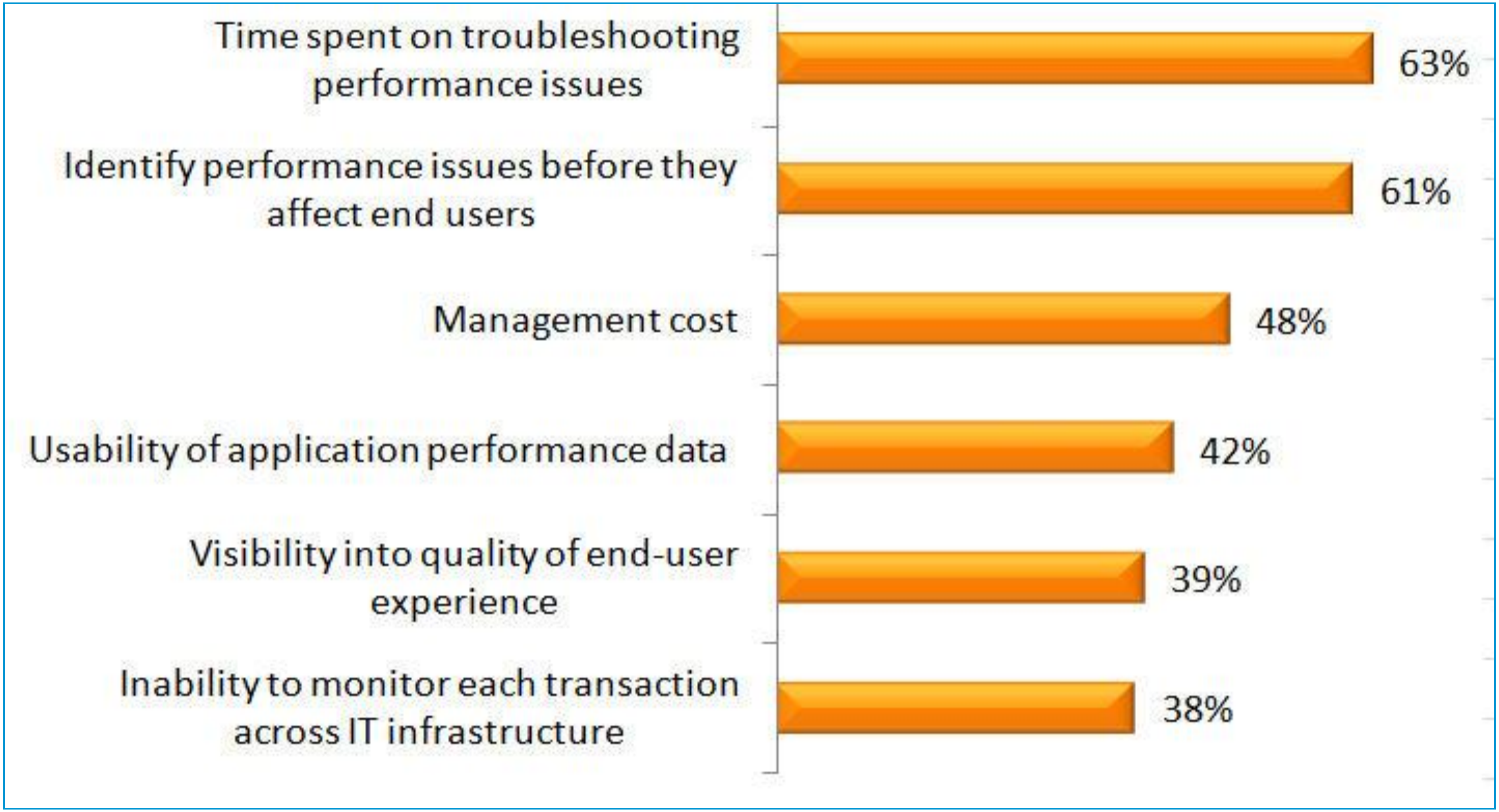
Performance troubleshooting & remediation





Many tenant applications

Challenges in managing application performance



- On average, **46.2 hours** spend in "**war-room**" scenarios each month

Source: Improving the usability of APM data: Essential capabilities and benefits. TRAC Research, June 2012, based on survey data from 400 IT organizations worldwide

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APM-related problems we're working on

- Real-time performance monitoring
  - Infrastructure-level vs. application-level monitoring
- Automated performance modeling
  - Knowledge-driven vs. data-driven
  - Linear vs. nonlinear models
  - Offline vs. online modeling
- Computer-assisted performance troubleshooting
  - Correlation & model based problem localization
- Service level remediation via auto-scaling
  - Horizontal vs. vertical scaling

Infrastructure-level performance monitoring

Physical host metrics

- System-level stats collected by the hypervisor
  - *e.g.*, `esxtop` – CPU, memory, disk, network, interrupt
- CPU stats
  - *%USED, %RUN, %RDY, %SYS, %OVRLP, %CSTP, %WAIT, %IDLE, %SWPWT*
- ~100s-1000s metrics per host!

VM metrics

- Resource usage stats collected by the guest OS
  - *e.g.*, `dstat, iostat`
- ~10s metrics per VM

- Widely available on most platforms
- Available at a time scale of seconds to minutes

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Application-level performance monitoring

Metrics reflecting end user experience

- Response times
- Throughput (or errors such as timed out requests)

VMware Hyperic monitoring tool

- Agents deployed in VMs
- Auto-discovers types of applications running
- Plugins to extract application-related performance stats
- Stats available at a time scale of minutes
- Stats aggregated in Hyperic server
- Supports over 80 different application components
- Extensible framework to allow customized plugins

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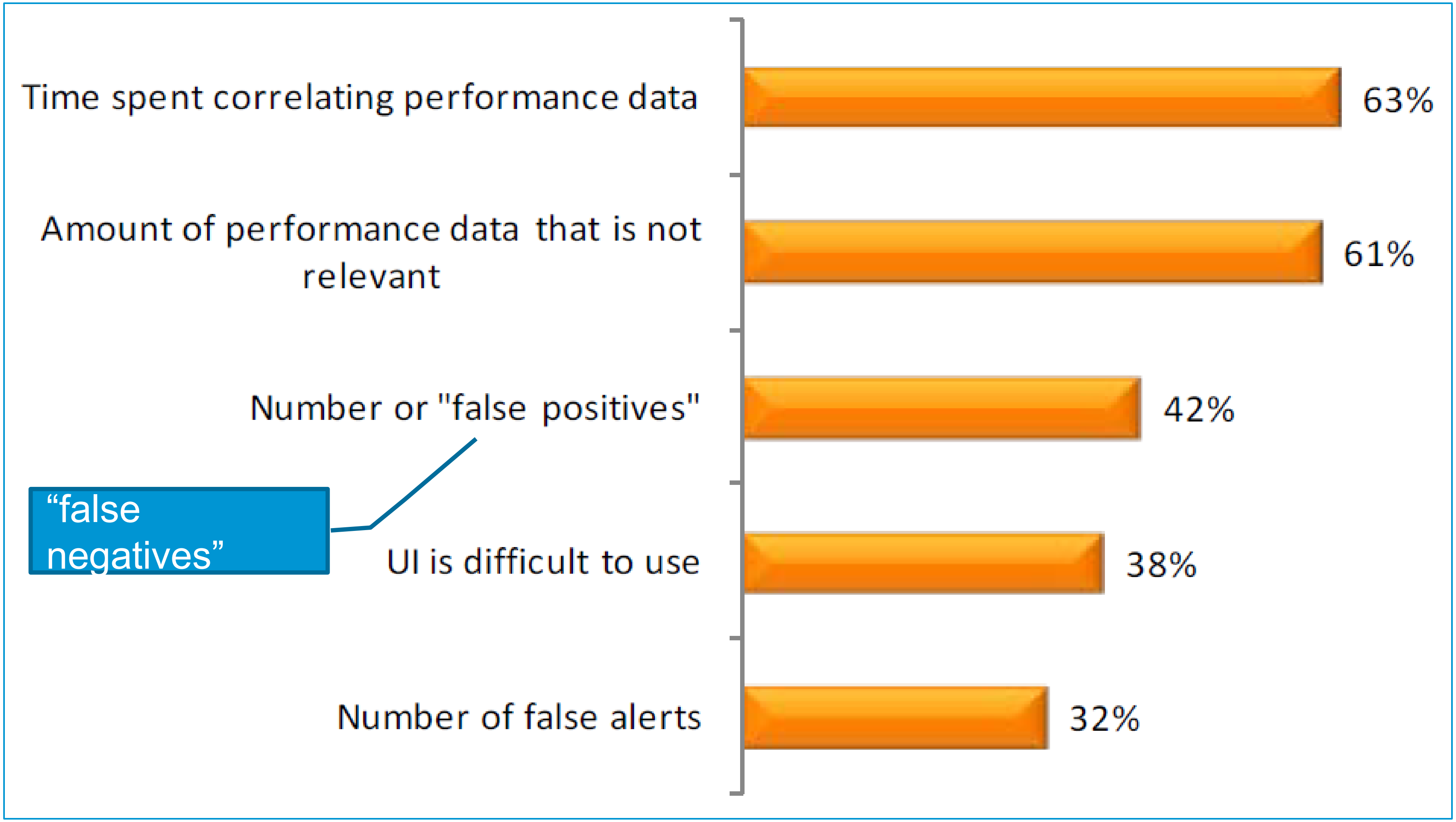
APM-generated big data

- "APM tools were part of the huge explosion in metric collection, generating thousands of KPIs per application."
- "83% of respondents agreed that metric data collection has grown >300% in the last 4 years alone."
- "88% of companies are only able to analyze less than half of the metric data they collect… 45% analyze less than a quarter of the data."
- "77% of respondents cannot effectively correlate business, customer experience, and IT metrics."

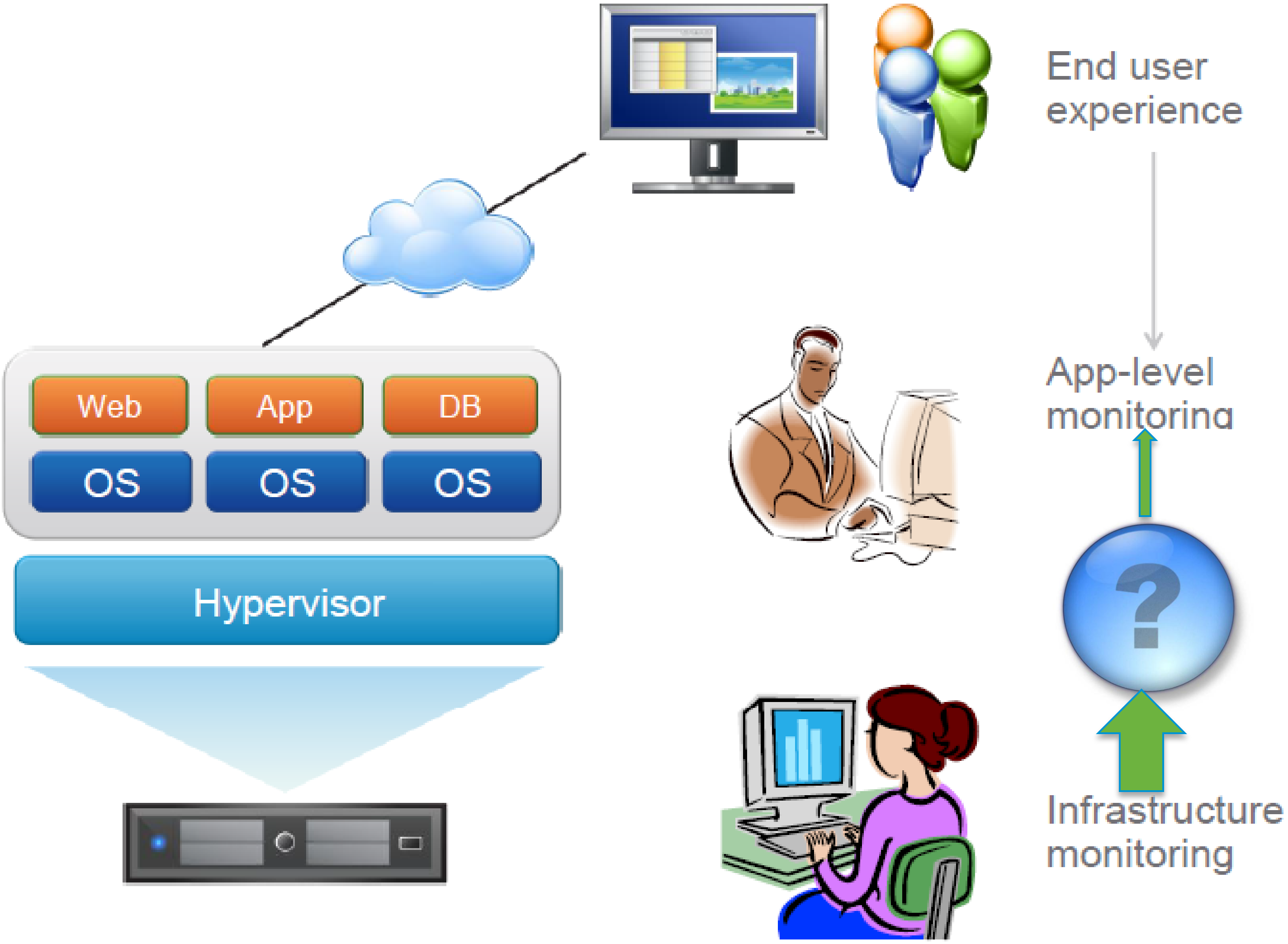
Source: "APM-generated big data boom." Netuitive & APMDigest, July 2012, based on survey of US & UK IT professionals.

Challenges in usability of performance data

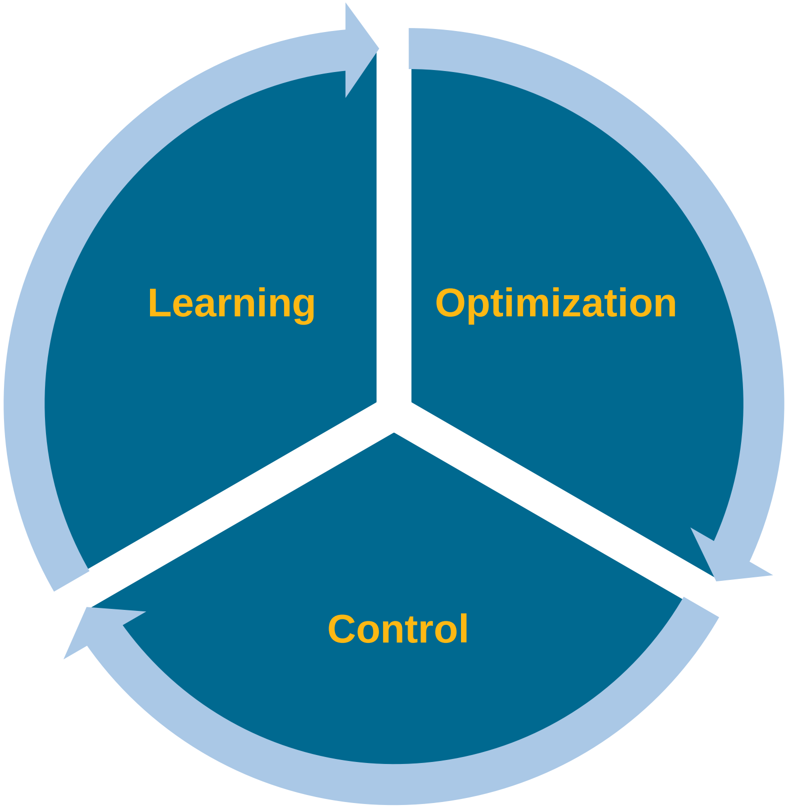


Source: Improving the usability of APM data: Essential capabilities and benefits. TRAC Research, June 2012, based on survey data from 400 IT organizations worldwide

The Semantic Gap challenge
Correlating performance data from different sources



Better IT analytics for APM automation
Three-pronged approach



Semantic gap filled by performance models
Leaning-based approach

Traditional models harder to apply

- **First-principle models**: Only exist for special cases (e.g., flow models)
- **Queuing models**: More suitable for aggregate/average behavior
- **Architectural models**: Require domain knowledge, harder to automate

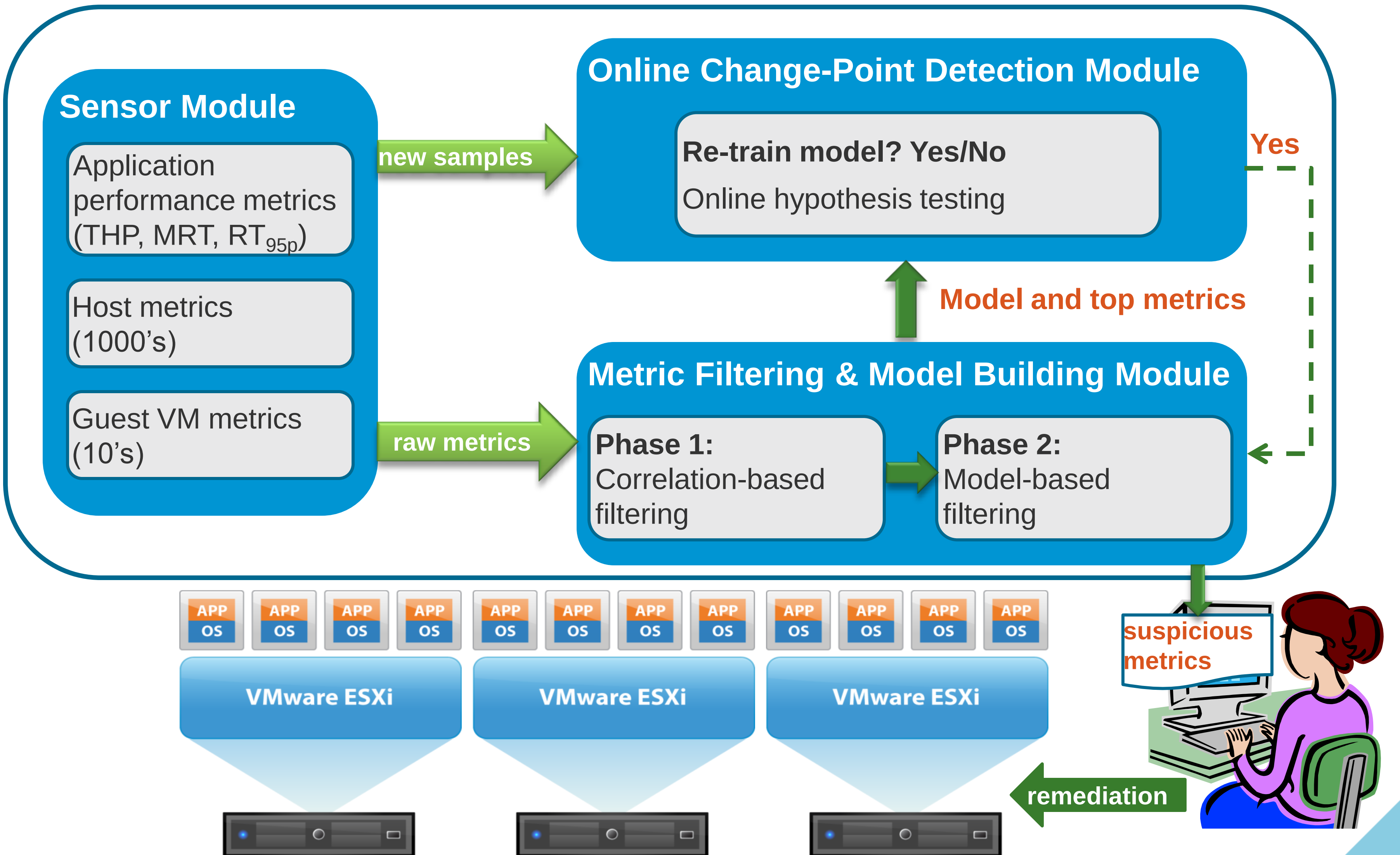
Empirical models via statistical learning

- Data driven, easier to automate and scale
- **Offline modeling** usually insufficient
  - Time-varying workloads
  - Changing system/software configurations
- **Online modeling** (models updated on demand)
  - Need to be low overhead and adaptive

Three key questions

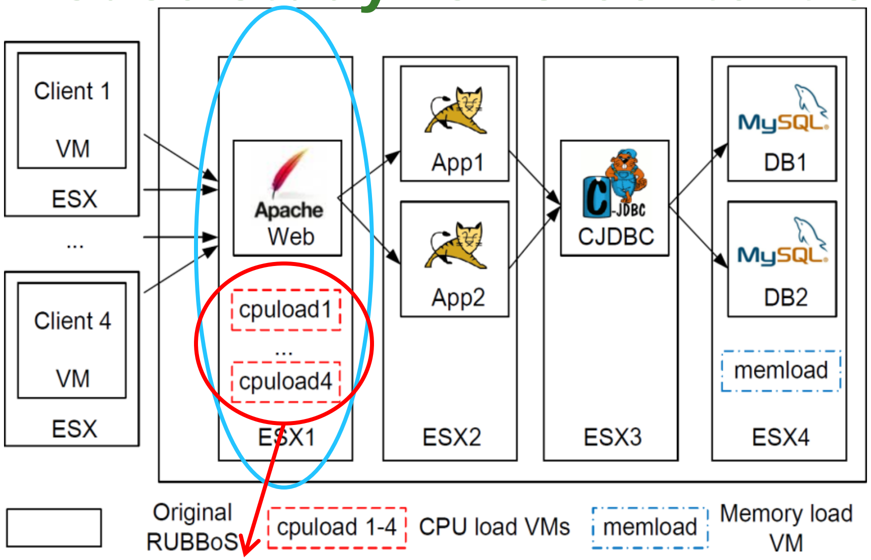
- **Q1: Which variables go into the model?**
  - Which system resources or parameters affect application performance the most?
  - Correlation-based analysis to provide hints
- **Q2:** What kind of model should we use?
  - Nonlinear models - better accuracy in general
  - Linear regression models - cheaper to compute and easier to interpret
- **Q3:** How do we know our model is (still) accurate?
  - Online change-point detection

Correlation and model based metric selection

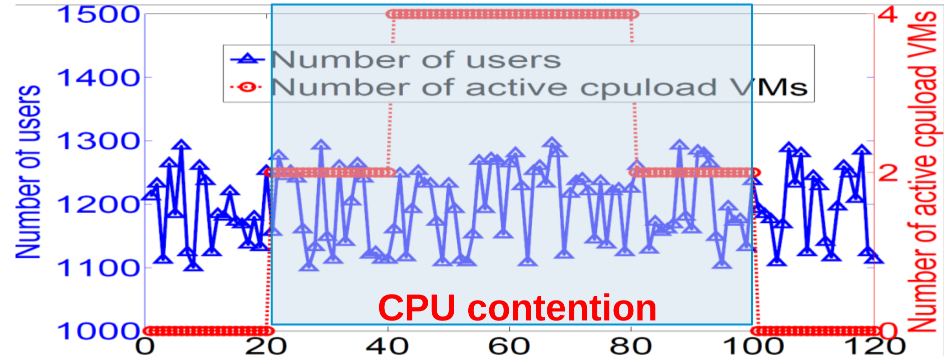


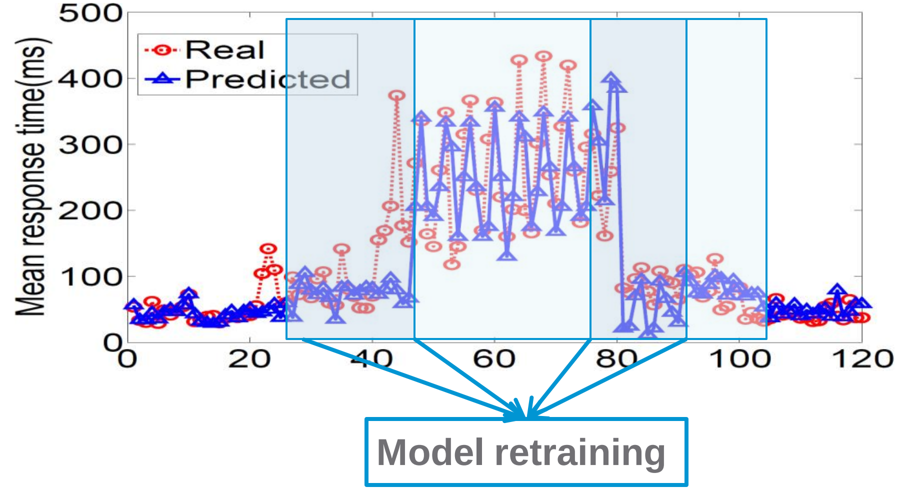
** P. Xiong et al. "vPerfGuard: An automated model-driven framework for application performance diagnosis in consolidated cloud environments." ICPE 2013.*

Case study: CPU contention with co-located VMs



noisy neighbors





Intervals	MRT Model
27 – 45	MRT = 1.13 H_**ESX1_CPU_Util** + 1.97 H_ESX4_Mem_Active – 89.7
46 – 74	MRT = 752.8 H_**ESX1_CPULoad**_1MinAvg – 562.9
75 – 89	MRT = 12.5 H_**ESX1_Web_vCPU_Ready** – 25.0
90 – 102	MRT = -7.70 H_**ESX1_vCPU_Idle** + 410.3

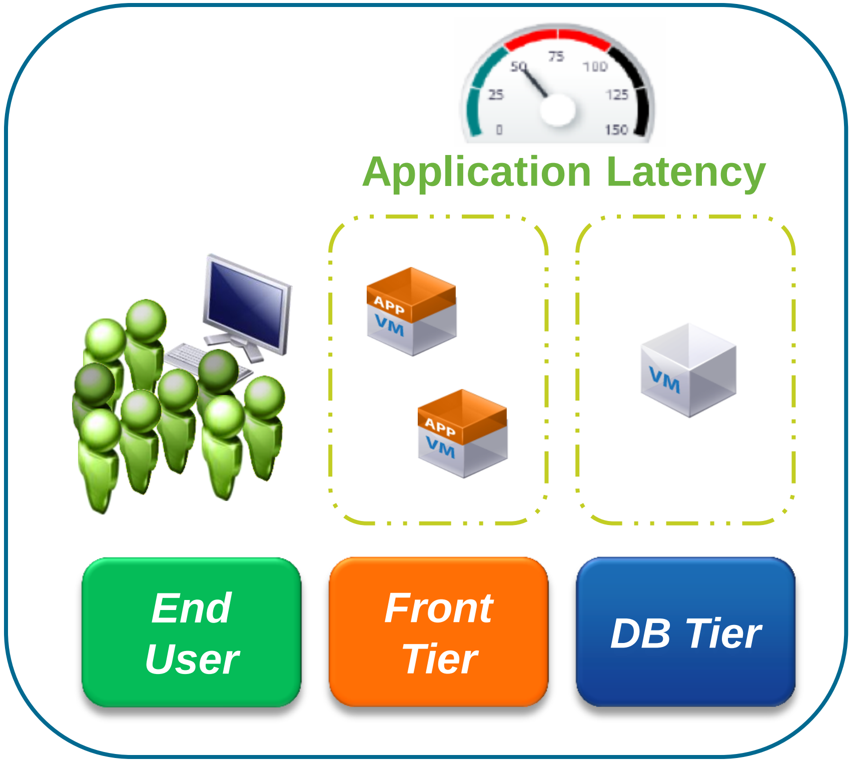
Note: **All models** during the contention period show **CPU** on **ESX1** as the top metric affecting application latency!

Performance remediation via auto-scaling

Challenges to ensure application performance

- Enterprise applications are distributed or multi-tiered
- App-level performance depends on access to many resources
  - HW: CPU, memory, cache, network, storage
  - SW: threads, connection pool, locks
- Time-varying application behavior
- Dynamic and bursty workload demands
- Performance interference among co-hosted applications

Auto-Scaling to maintain application SLO



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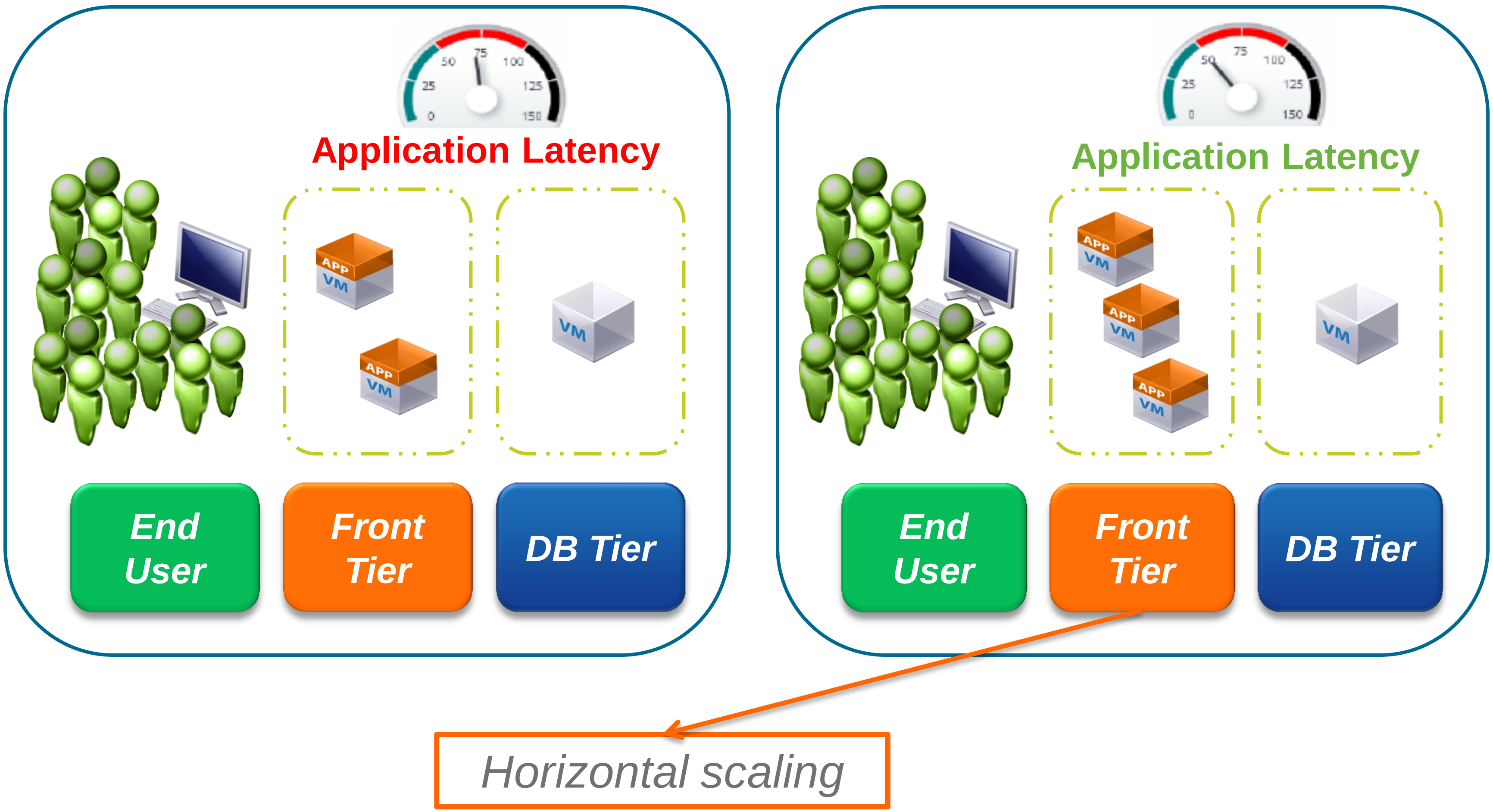
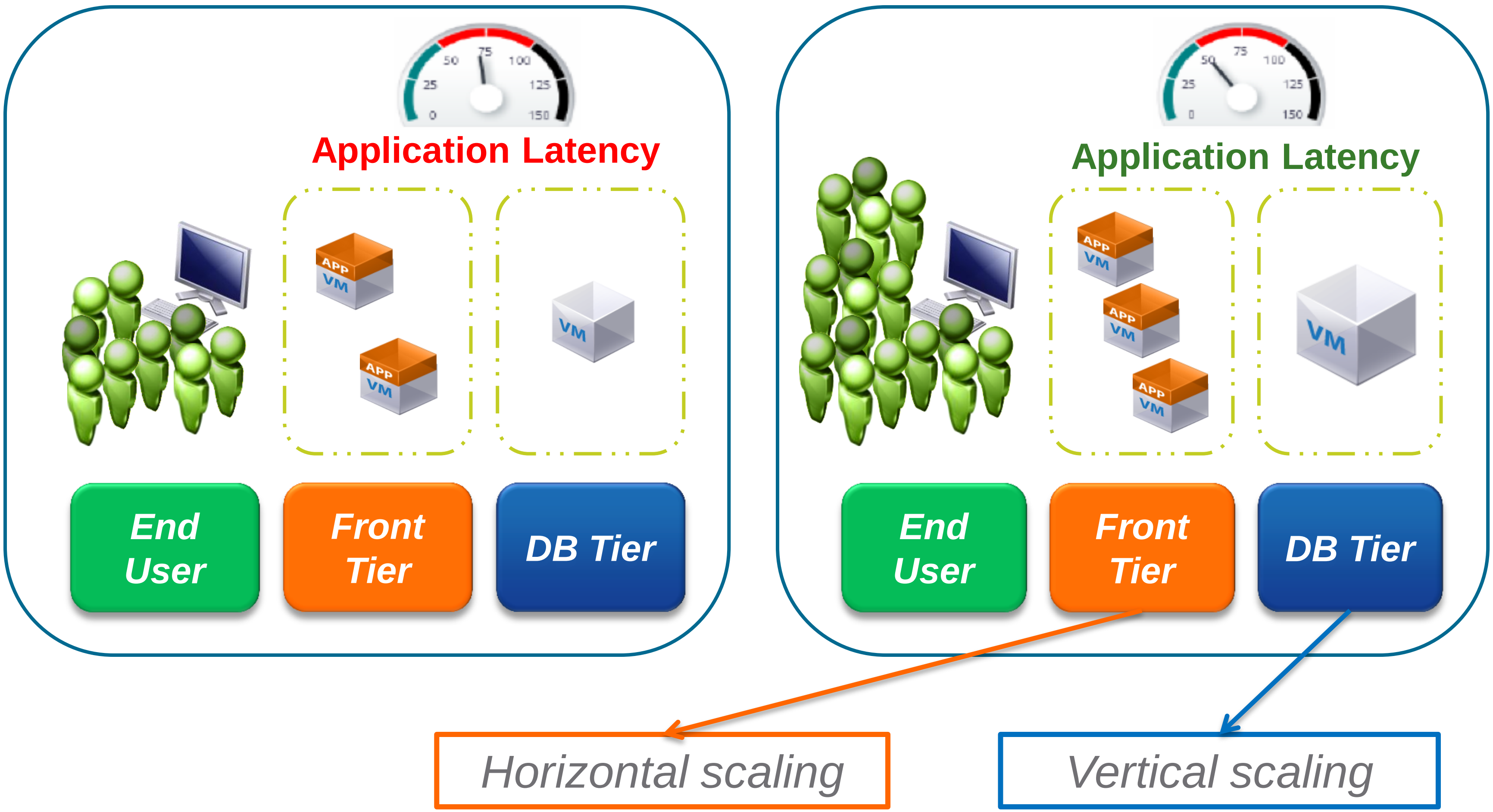
Auto-Scaling to Maintain Application SLO



Auto-Scaling to Maintain Application SLO



Horizontal scaling of applications

Academic research

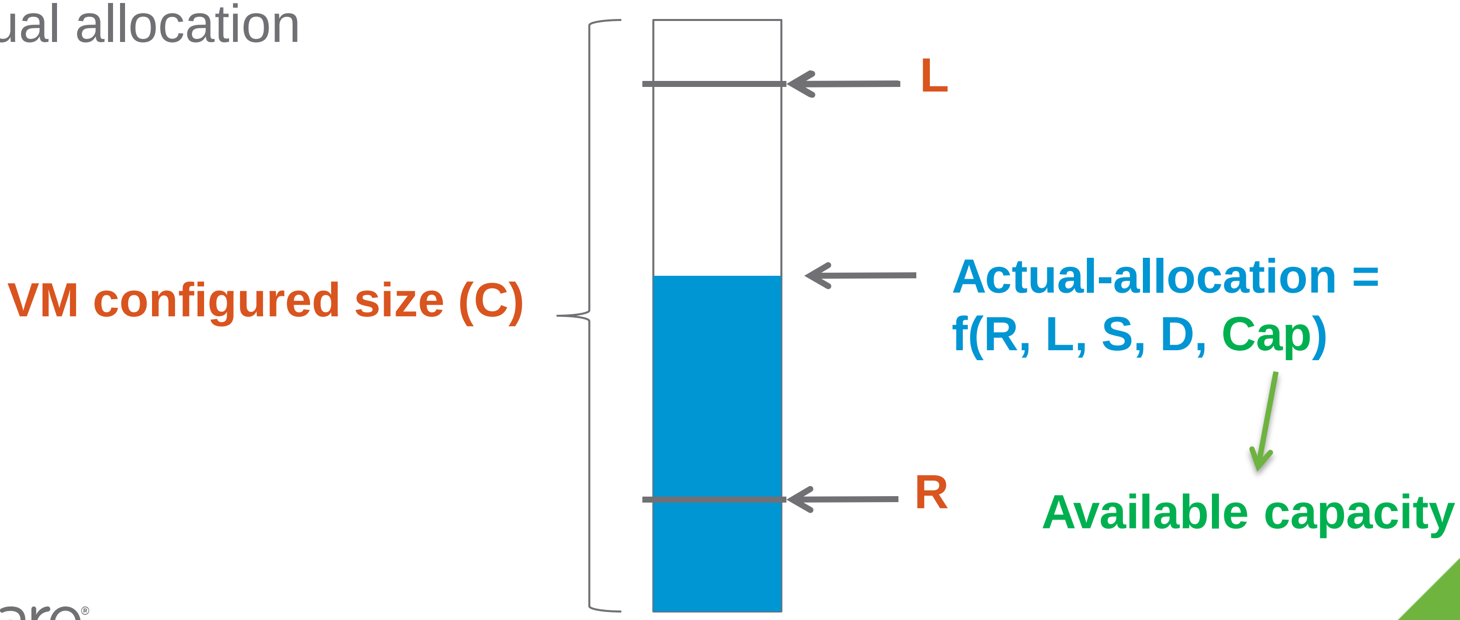
- Muse: Managing energy and server resources in hosting centers (SOSP'01)
- A hybrid reinforcement learning approach to autonomic resource allocation (ICAC'05)
- A lot of recent work scaling clusters of VMs

Commercial systems

- **Amazon Web Services**: http://aws.amazon.com/autoscaling/
- **RightScale**: http://www.rightscale.com
- **Rule-based:** User-set thresholds/alerts on resource utilization or load metrics
- **Learning-based:** Ongoing work at VMware

Vertical scaling of resource containers
Method 1: Dynamic resource control settings

- Available on various virtualization platforms
- For shared CPU, memory, disk I/O*, network I/O*:
  - ***Reservation (R)**** – minimum guaranteed amount of resources
  - ***Limit (L)*** – upper bound on resource consumption (non-work-conserving)
  - ***Shares (S)*** – relative priority during resource contention
- VM's CPU/memory *demand (D)*: estimated by hypervisor, critical to actual allocation



Vertical scaling of resource containers
Related work (not exhaustive)

- **Tuning resource *limits* (aka. *caps*)**
  - Adaptive control of virtualized resources in utility computing environments (Eurosys'07)
  - Autonomic resource management in virtualized data centers using fuzzy-logic-based applications (Cluster Computing Journal 2008)
  - Memory overbooking and dynamic control for Xen virtual machines in consolidated environment (IM'09, memory limit)
  - Vertical scaling of prioritized VMs provisioning (CGC'12)
  - Agile: Elastic distributed resources scaling for infrastructure-as-a-service (ICAC'13)
- **Tuning resource *shares* (aka. *weights*)**
  - *Maximizing server utilization while meeting critical SLAs via weight-based collocation management (IM'13)*
- **Tuning resource *reservations* (aka. *min)***
  - Application-driven dynamic vertical scaling of virtual machines in resource pools (NOMS'14)

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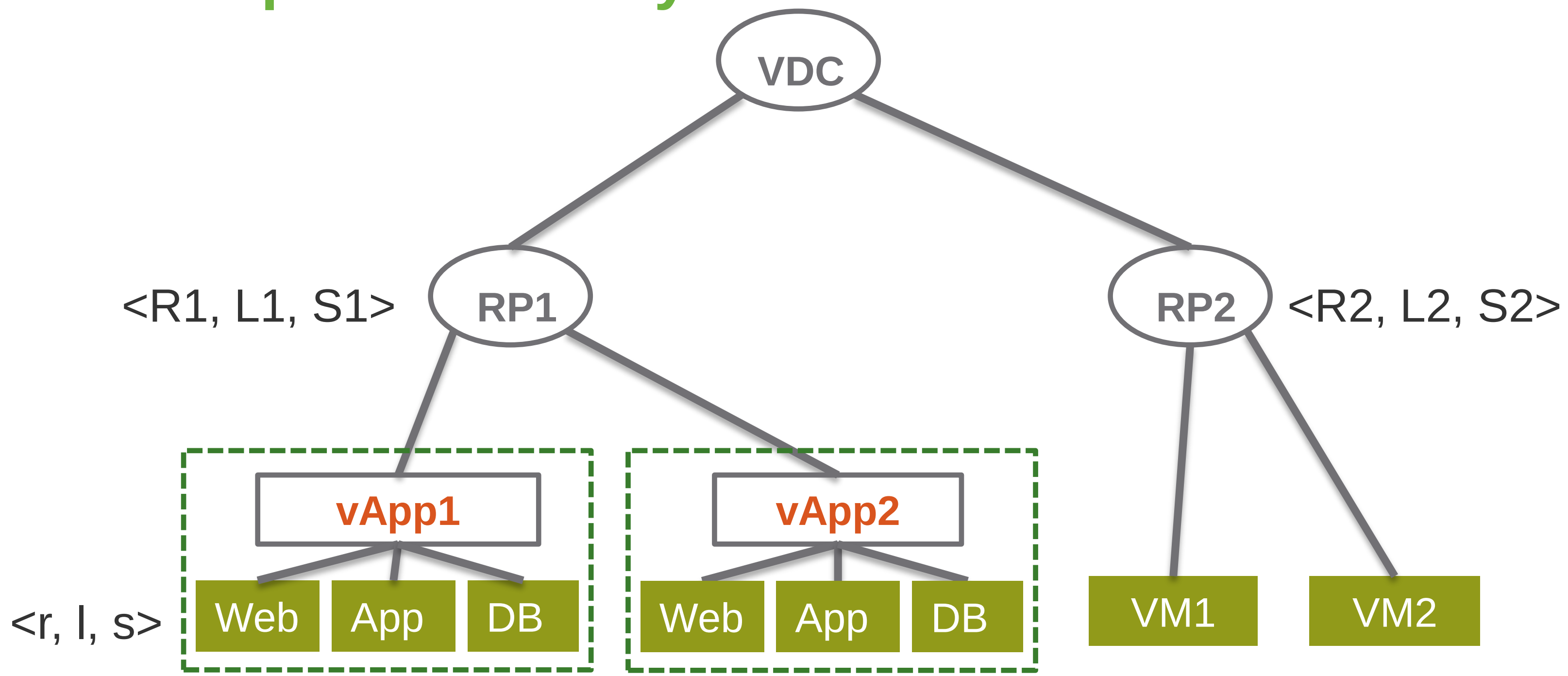
DRS (Distributed Resource Scheduler)
Resource pool hierarchy

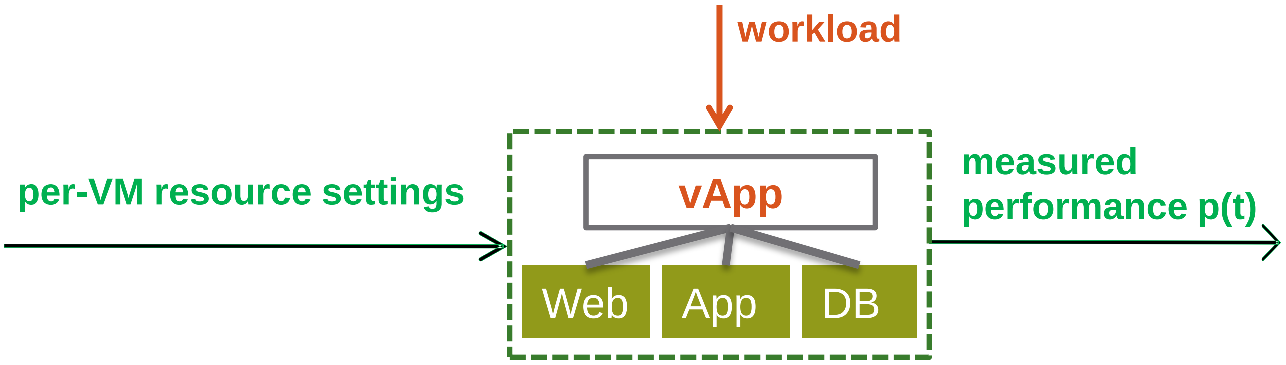


- Capacity of an RP divvied hierarchically based on resource settings
- Sibling RPs share capacity of the VDC
- Sibling VMs share capacity of the parent RP

** VMware distributed resource management: Design, implementation, and lessons learned, VMware Technical Journal, April 2012.*

Powerful knobs, hard to use

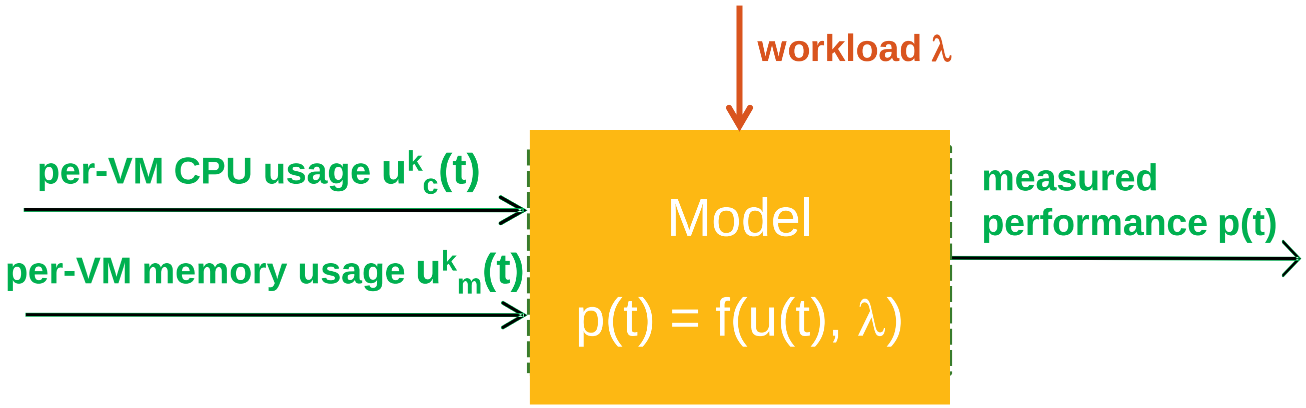
- How do VM-level settings impact application performance?
- How to set RP-level settings to protect high priority applications within the RP?
- Fully reserved (R=L=C) for critical applications
  - Leads to lower consolidation ratio due to admission control
- Others left at default (R=0, L=C) until performance problem arises
  - Increases reservation for the bottleneck resource (which one? by how much?)



Performance model learned for each vApp

Maps VM-level resource allocations to app-level performance

- Captures multiple tiers and multiple resource types
- Choose a linear regression model (easy to compute)
- Workload indirectly captured in model parameters
- Model parameters updated online in each interval (tracks nonlinearity)



Rule-based vs. model-based feedback control

Rule-based	Model-based
often involves no analytical model	requires an analytical model
driven by intuition and domain knowledge	driven by quantitative relationships
hard to control multiple knobs at the same time	captures interactions between multiple metrics
no concern of dynamics	considers dynamics and transient responses
threshold and heuristics based	standard control methods as building blocks
no systematic consideration of stability	systematically handles tradeoff between stability & performance

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Use optimization to handle design tradeoff

- An example cost function

$$J(\mathbf{u}(t+1)) = (p(t+1) - p_{SLO})^2 + \beta \|\mathbf{u}(t+1) - \mathbf{u}(t)\|^2$$

performance cost

Tradeoff between performance and stability

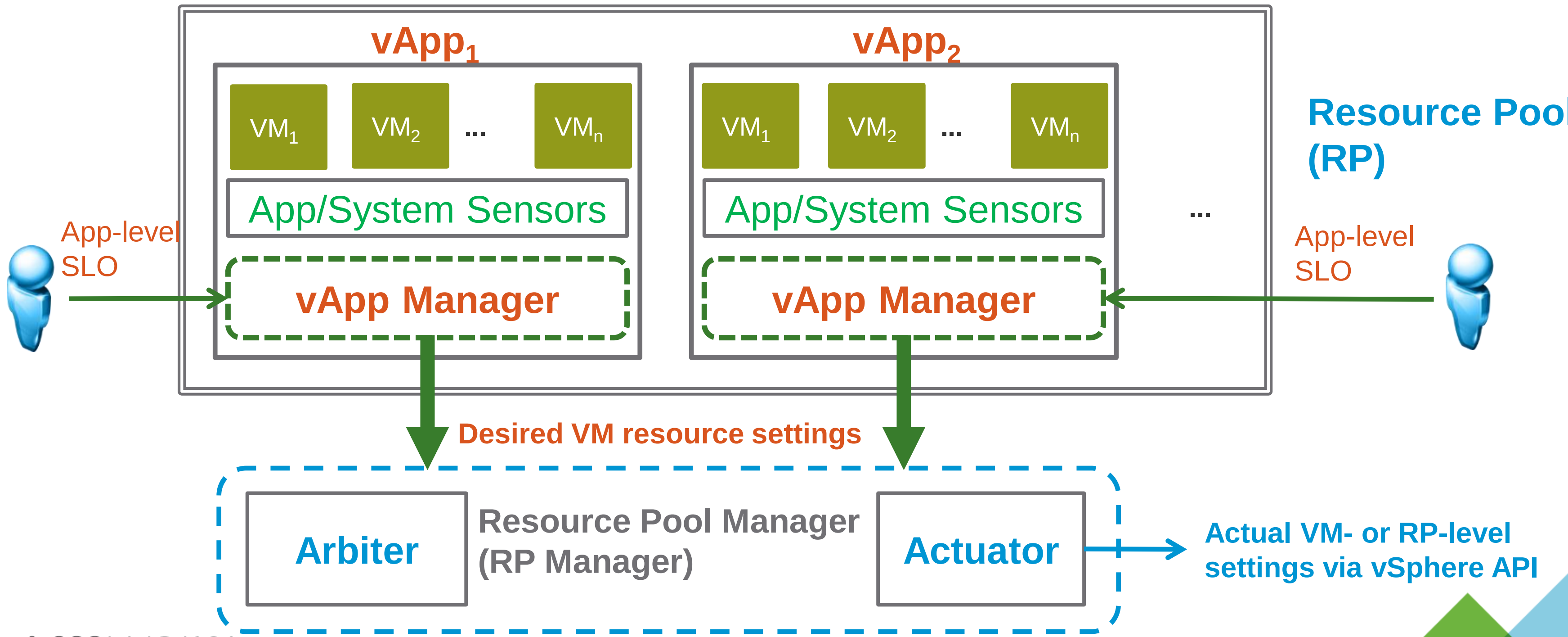
control cost

- Solve for optimal resource allocations

$$\boxed{u^*(t+1) = g(p(t), p_{SLO}, \mathbf{u}(t), \lambda, \beta)}$$

AppRM: Model-based vertical scaling

- Auto-tunes VM-level and RP-level resource control settings to meet application SLOs
  - For each application, **vApp Manager** translates its SLO into ***desired*** resource control settings at individual VM level
  - For each resource pool, **RP Manager** computes the ***actual*** VM- and RP-level resource settings to satisfy all critical applications

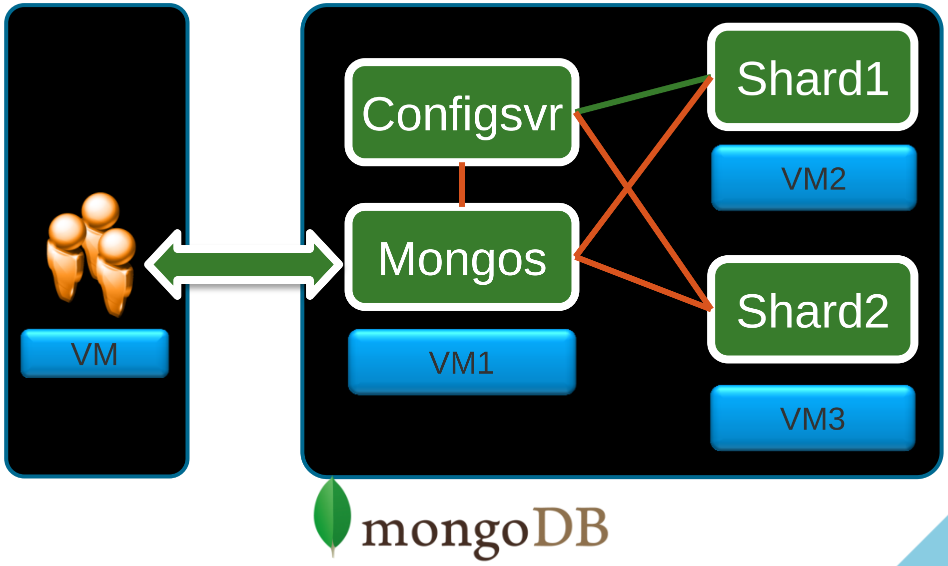


Performance evaluation

- Application
  - **MongoDB** – distributed data processing application with sharding
  - **Rain** – workload generation tool to generate dynamic workload

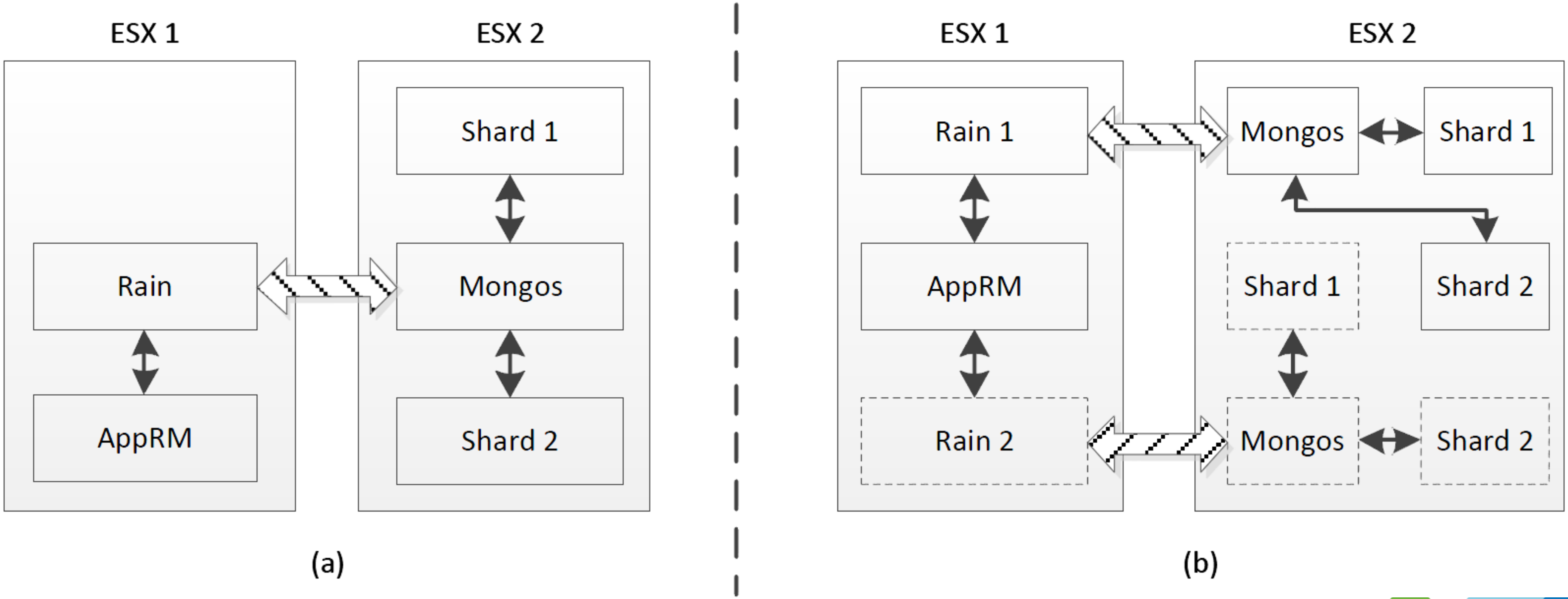
- Workload
  - Number of clients
  - Read/write mix

- Evaluation questions
  - Can the vApp Manager meet individual application SLO?
  - Can the RP Manager meet SLOs of multiple applications?



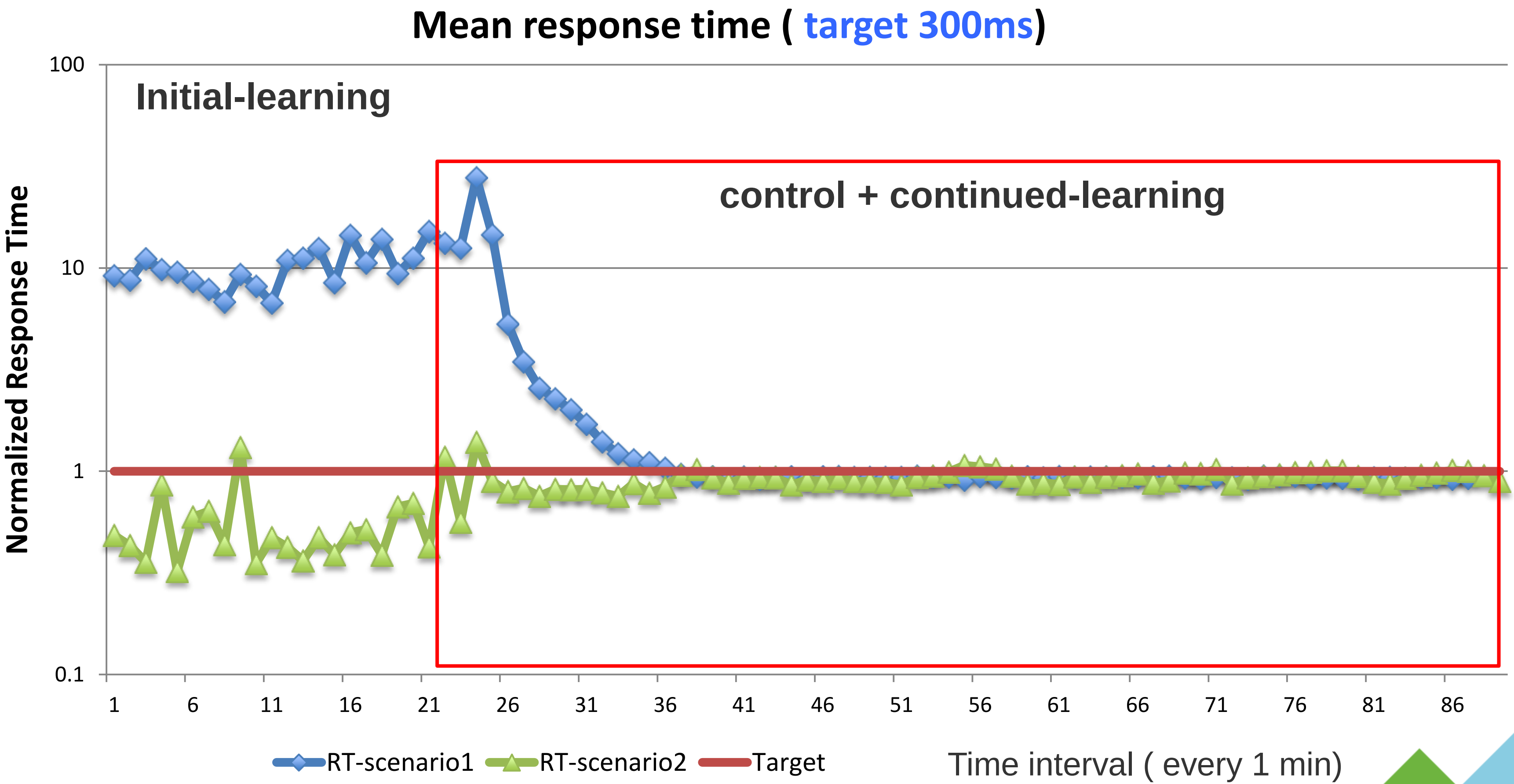
Testbed setup

- Two ESX 5.0 GA hosts
- ESX2 (12 cores, 96 GB) to emulate the capacity of a VDC
- Three VMs per MongoDB instance (2 vCPUs, 4 GB)
- One VM per instance of Rain, one VM for AppRM



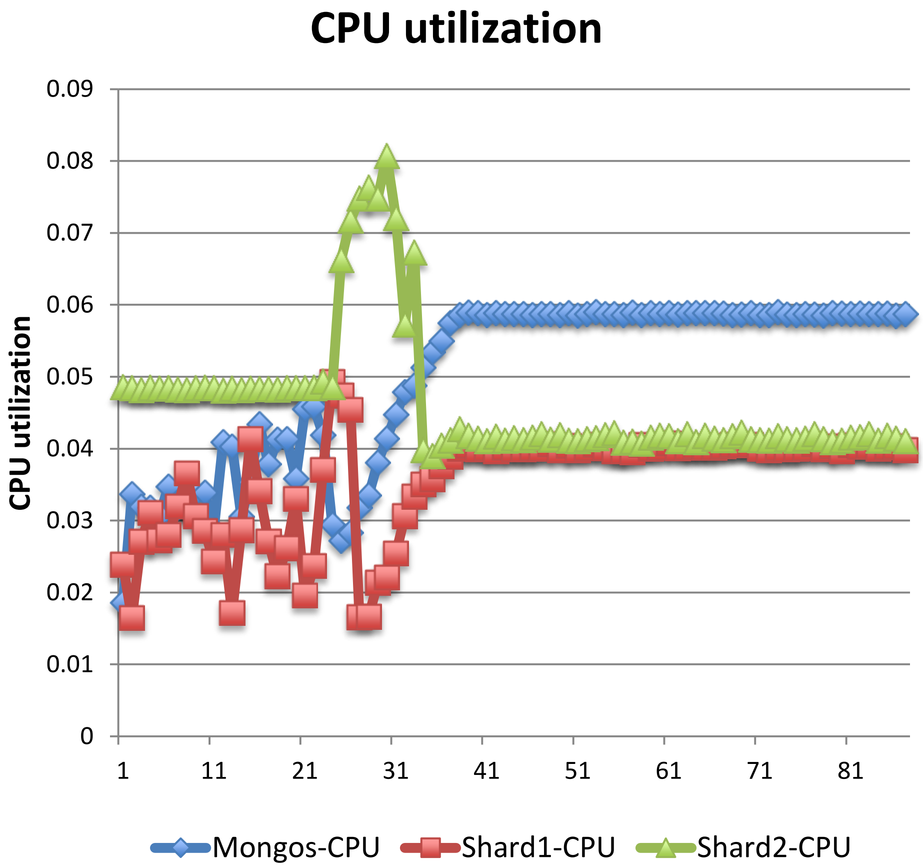
Result: Meeting mean response time target

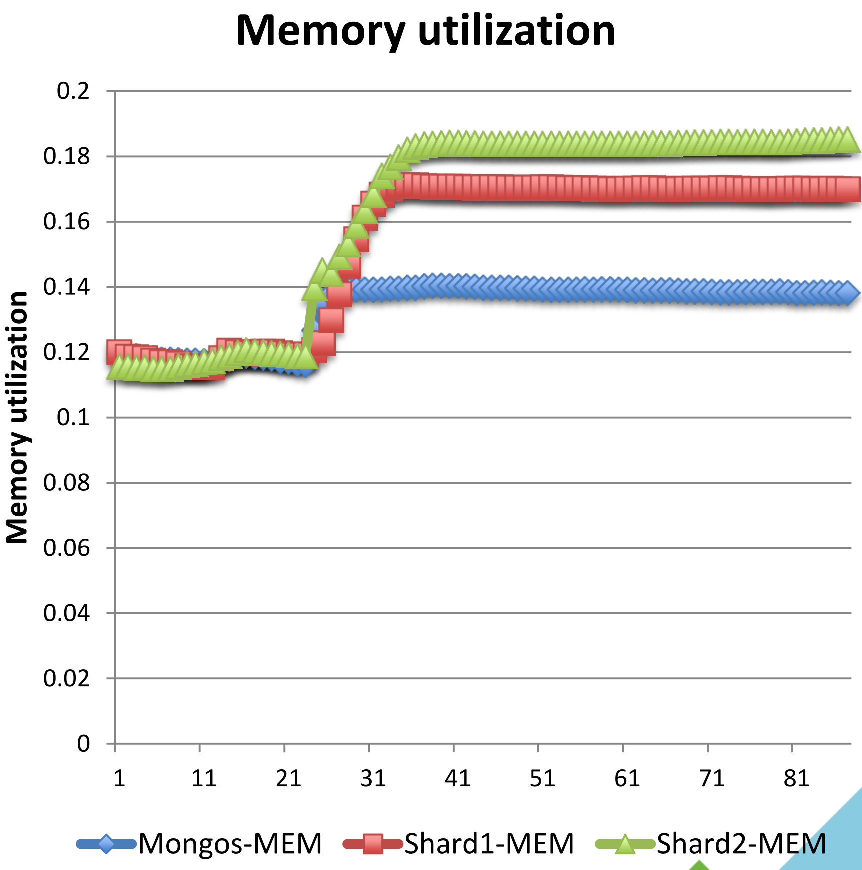
- Scenario1 - Initial settings: R = 0, Limit = 512 (MHz, MB)
- Scenario2 – Initial settings: R = 0, L = unlimited (cpu, mem)



Resource utilization (under-provisioned case)

- Target response time = 300 ms
- Initial setting R = 0, L = 512 MHz/MB (under-provisioned)

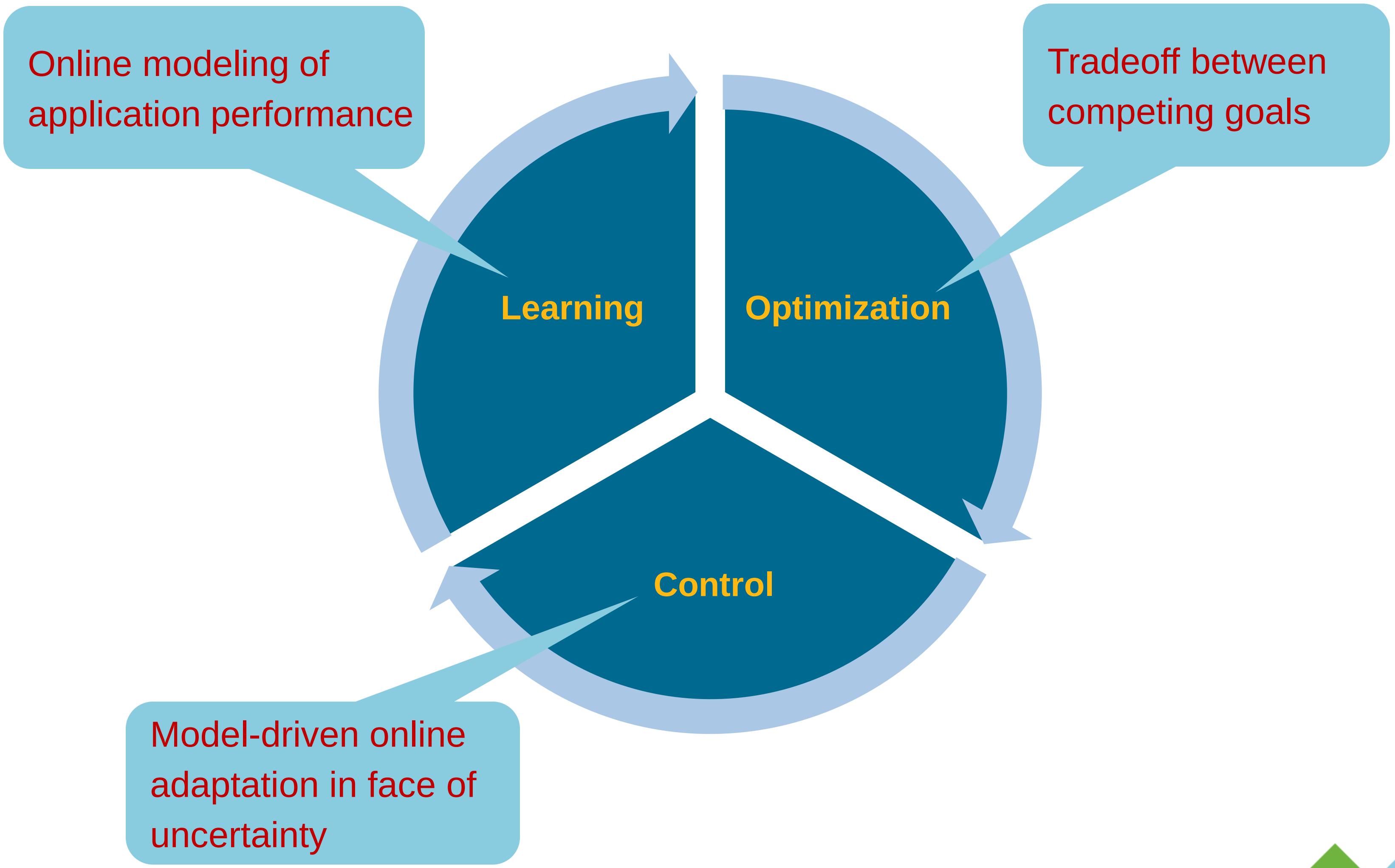




Vertical scaling of resource containers
Method 2: Runtime reconfiguration of VM sizes

- Configured size for a VM
  - *#vCPUs*
  - *Memory size*
  - *#virtual disks, disk sizes*
  - *#vNICs*
- ESX allows over-commitment of CPU and memory
  - Sum(VM-size) >= host-capacity
- CPU/memory Hot-add supported by most recent OS's
  - Can be used to scale up a VM at runtime – work-in-progress
  - Need application support to leverage additional resources
- CPU/memory Hot-remove unsupported by most OS's
  - Requires VM reboot (undesirable)

Recap:
APM automation requires better analytics



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