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Virtualization, Elasticity and Performance for Distributed Applications

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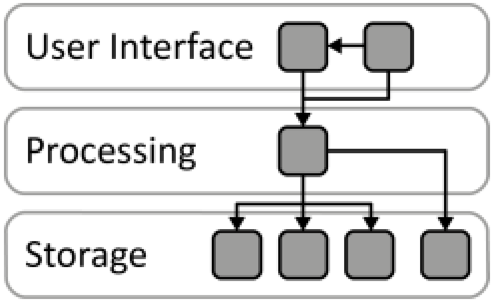
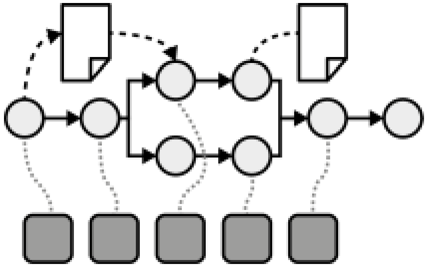
What this lecture is about?

- Resources and their impact on distributed systems and applications
- Virtualization
  - Resource virtualization
- Elasticity
  - Key concepts and techniques
- Performance
  - Utilizing virtualization and elasticity for some performance patterns

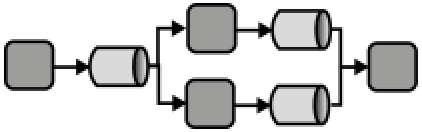
Impact of resources on Distributed applications

Types of distributed applications





Workflow/process style



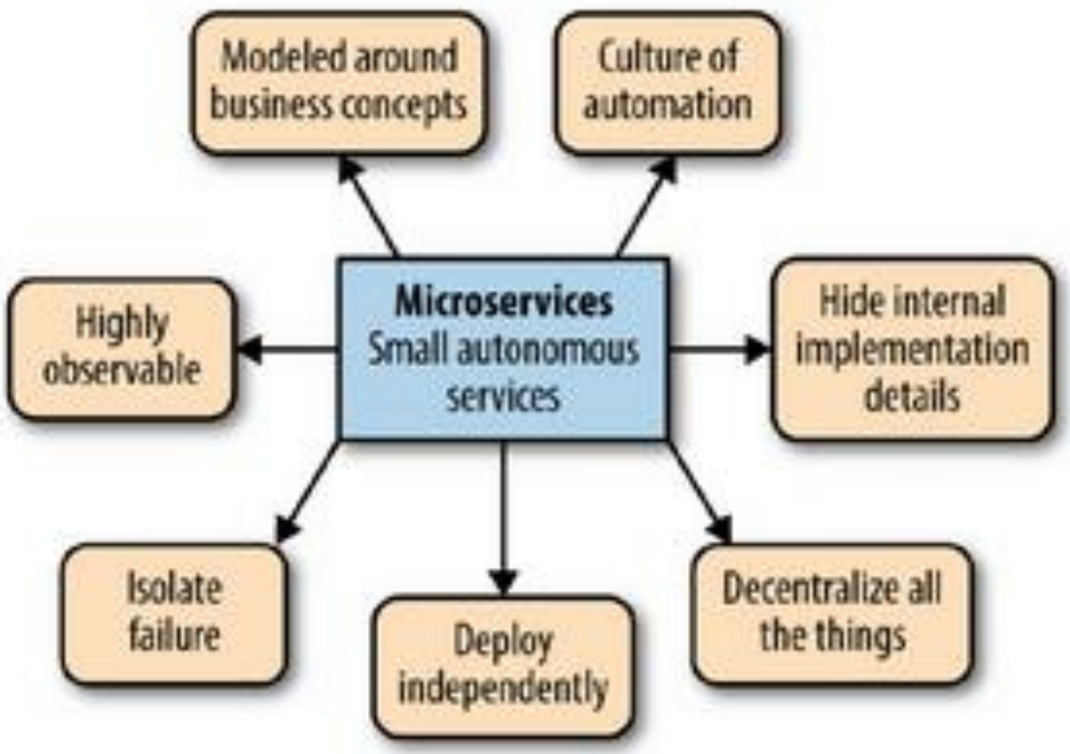
Data-centric pipeline style

Figure sources: http://www.cloudcomputingpatterns.org/Distributed_Application

- Some questions for DevOps
  - How to have a development environment that is similar to the operational one?
  - How to utilize computing resources in the best way?
  - How to achieve the best performance?

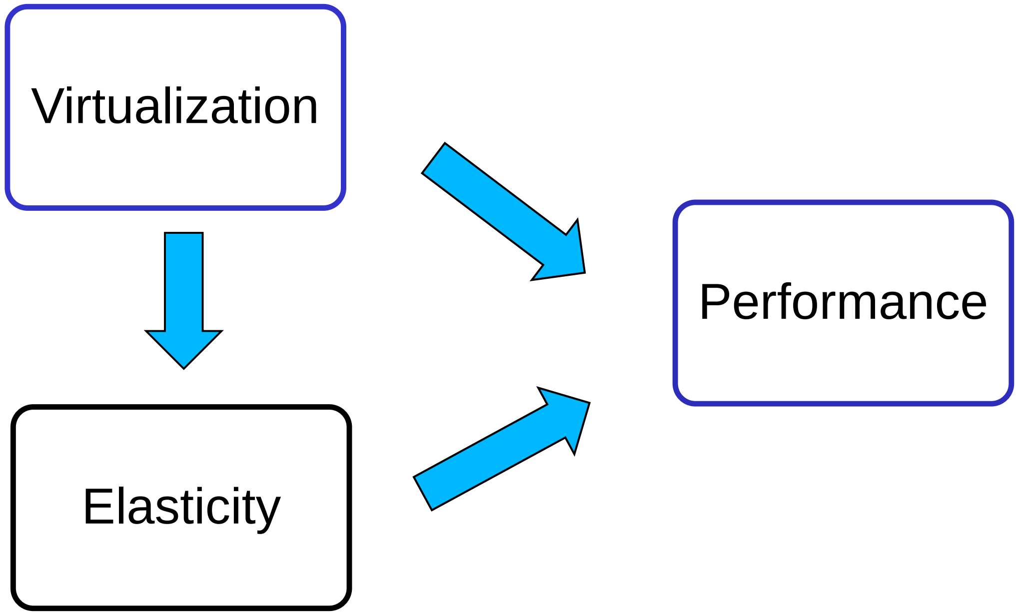
Recall – Breakdown the complexity

Figure source:Sam Newman, Building Microservices, 2015



How to make sure that the underlying resources and infrastructures are suitable for „small autonomous services"?

Concepts of today‘s lecture



VIRTUALIZATION

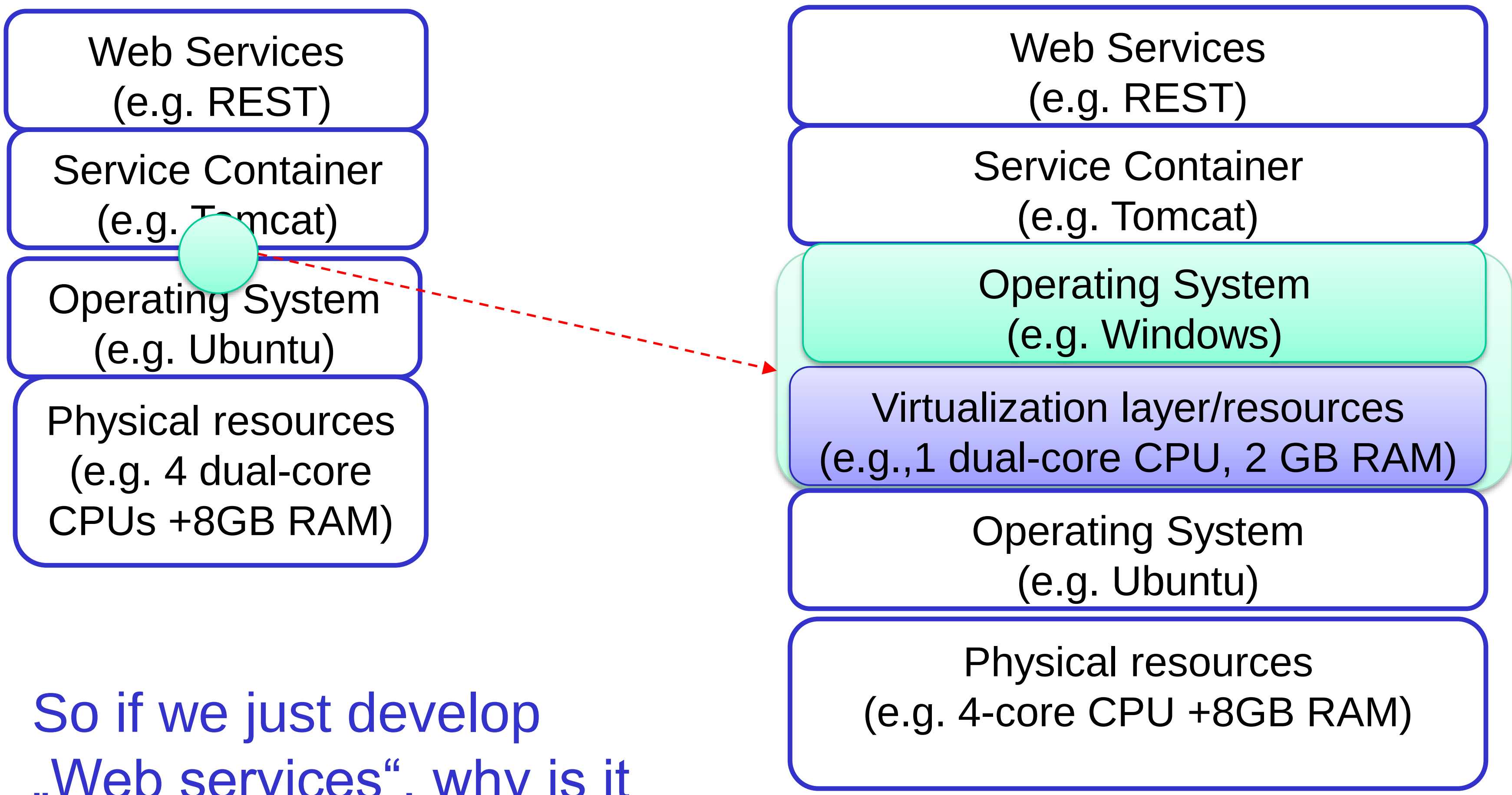
What is virtualization? A bird view

- Virtualization:
  - To abstract low-level compute, data and network resources to create *virtual version* of these resources
- Virtualization software creates and manages "virtual resources" isolated from physical resources

→ Virtualization is a powerful concept: we can apply virtualization techniques virtually for everything!

→Virtualization is a key enabling technology for cloud computing and modern computer networks.

Virtualizing physical resources



So if we just develop „Web services“, why is it important to us?

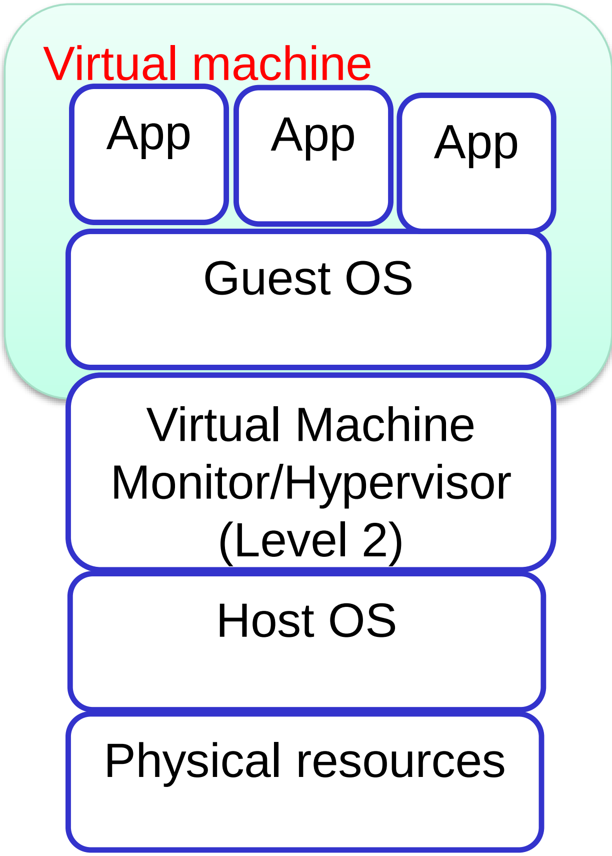
Main types of virtualization of infrastructures for distributed apps

- Compute resource virtualization
  - Compute resources: CPU, memory, I/O, etc.
  - To provide virtual resources for „virtual machines“
- Storage virtualization
  - Resources: storage devices, harddisk, etc.
  - To optimize the usage and management of data storage
- Network Function Virtualization
  - Network resources: network equipment & functions
  - To consolidate network equipment and dynamically provision and manage network functions

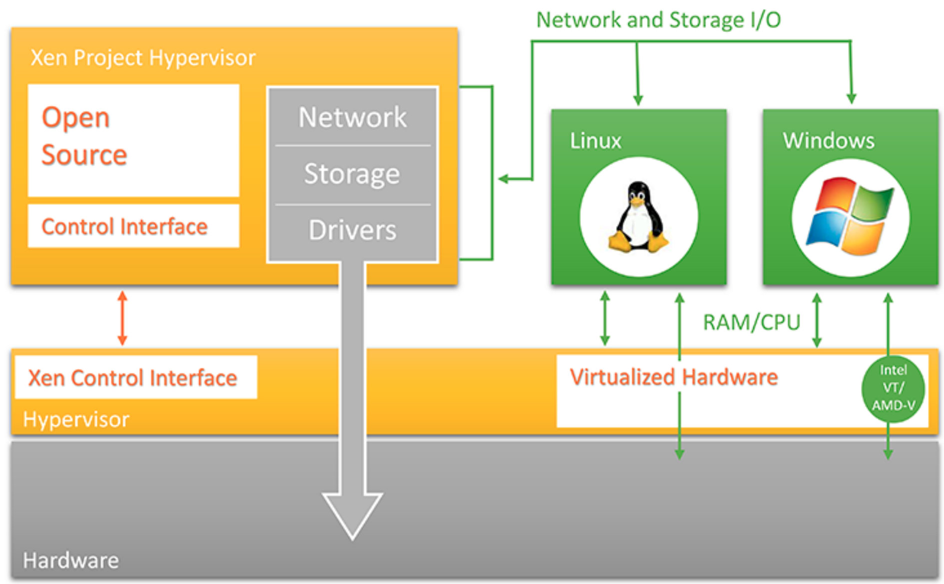
Compute Resource Virtualization Technologies

- Physical compute resources:
  - Individual physical hosts/servers (CPU, memory, I/O),
  - Clusters and data centers
- At the low-level: two main streams
  - Hypervisor/Virtual Machine monitor
    - Virtual machines (VirtualBox, VMWare, Zen, etc.)
  - Containterlization
    - Containers (Linux Containers, Docker, Warden Container, OpenVZ, etc.)

Hypervisor/Virtual Machine Monitor

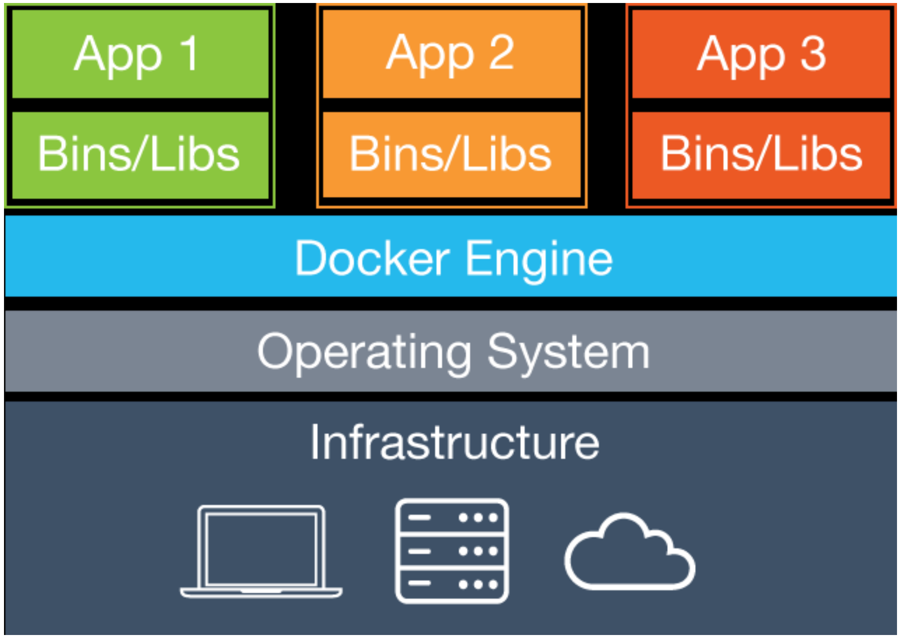


Another model (Hypervisor level 1)

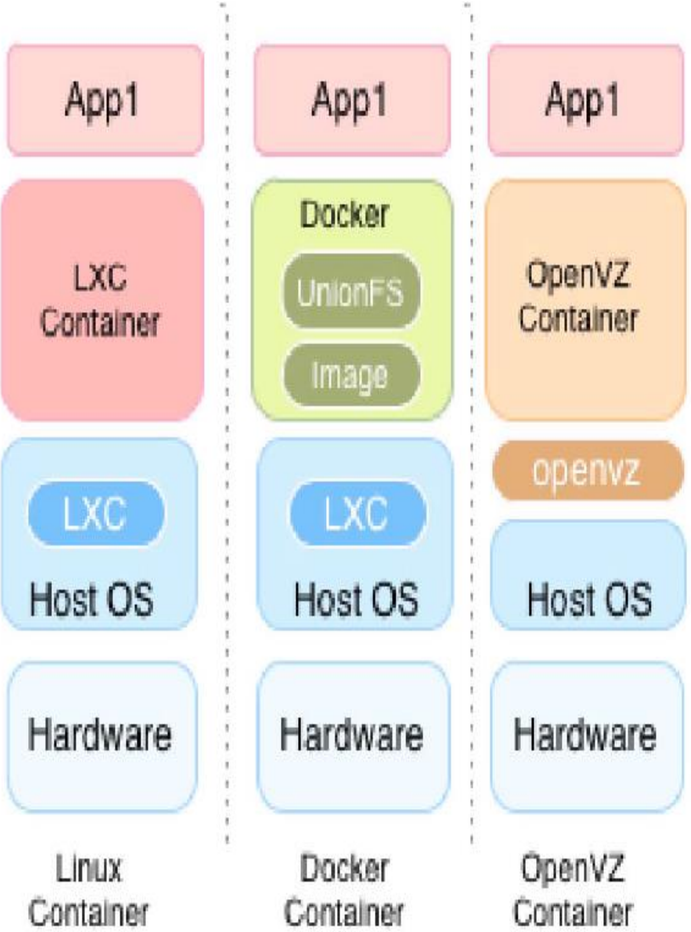


https://www.citrix.de/products/xenserver/tech-info.html

Containers



https://www.docker.com/what-docker



Source: Rajdeep Dua, A. Reddy Raja, Dharmesh Kakadia: Virtualization vs Containerization to Support PaaS. IC2E 2014: 610-614 http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=6903537

We do not dig into low-level techniques in virtualization, but examine

- How would virtualization techniques enable us to acquire, utilize and manage resources for our Devs and Ops of distributed applications and systems?

- How would such techniques change our software design?

- How to align resources/infrastructures with software using them

Virtual machines versus containers

App	App
Guest OS	Container

Parameter	Virtual Machines	Containers
Guest OS	Each VM runs on virtual hardware and Kernel is loaded into in its own memory region	All the guests share same OS and Kernel. Kernel image is loaded into the physical memory
Communication	Will be through Ethernet Devices	Standard IPC mechanisms like Signals, pipes, sockets etc.
Security	Depends on the implementation of Hypervisor	Mandatory access control can be leveraged
Performance	Virtual Machines suffer from a small overhead as the Machine instructions are translated from Guest to Host OS.	Containers provide near native performance as compared to the underlying Host OS.
Isolation	Sharing libraries, files etc between guests and between guests hosts not possible.	Subdirectories can be transparently mounted and can be shared.
Startup time	VMs take a few mins to boot up	Containers can be booted up in a few secs as compared to VMs.
Storage	VMs take much more storage as the whole OS kernel and its associated programs have to be installed and run	Containers take lower amount of storage as the base OS is shared

TABLE I
VM AND CONTAINER FEATURE COMPARISION

Source: Rajdeep Dua, A. Reddy Raja, Dharmesh Kakadia: Virtualization vs Containerization to Support PaaS. IC2E 2014: 610-614 http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=6903537

VM versus containers

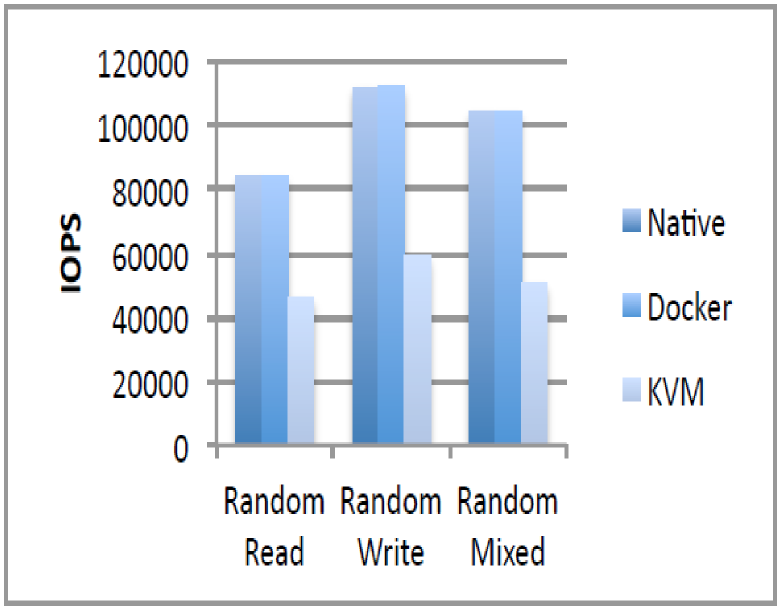


Fig. 6. Random I/O throughput (IOPS).

Source: Wes Felter, Alexandre Ferreira, Ram Rajamony, Juan Rubio:
An updated performance comparison of virtual machines and Linux containers. ISPASS 2015: 171-172
http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=7095802

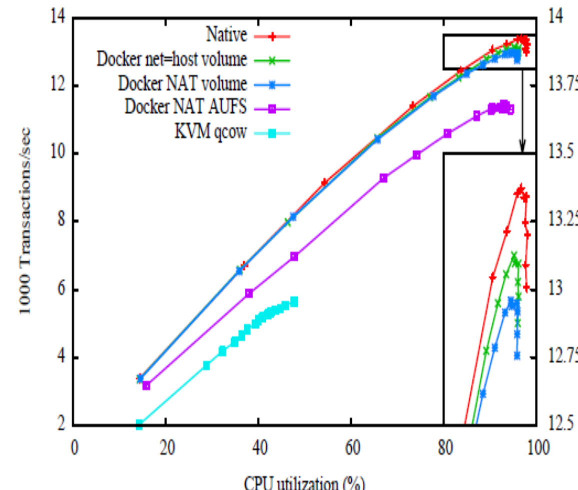


Fig. 11. MySQL throughput (transactions/s) vs. CPU utilization.

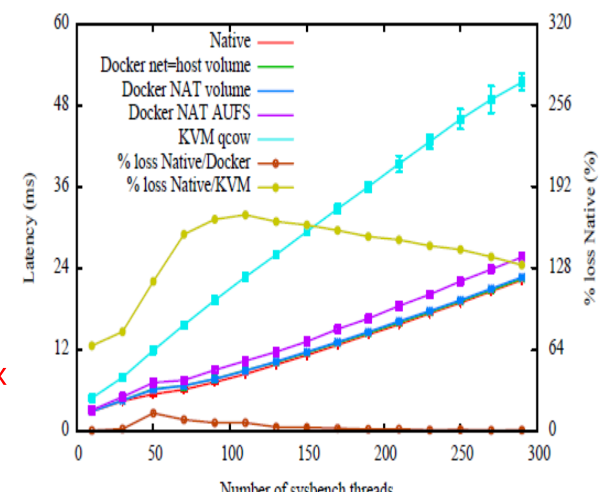


Fig. 12. MySQL latency (in ms) vs. concurrency.

Examples of performance

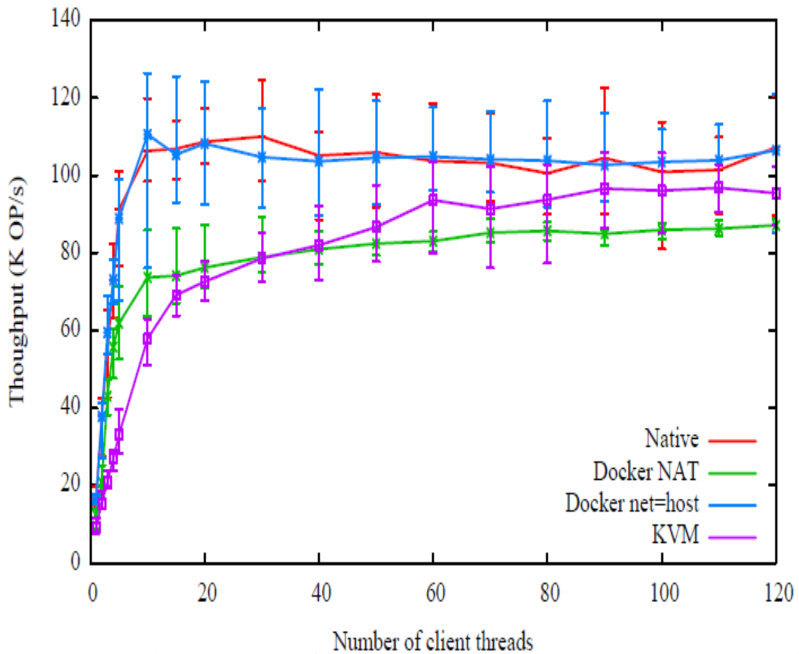


Fig. 8. Evaluation of NoSQL Redis performance (requests/s) on multiple deployment scenarios. Each data point is the arithmetic mean obtained from 10 runs.

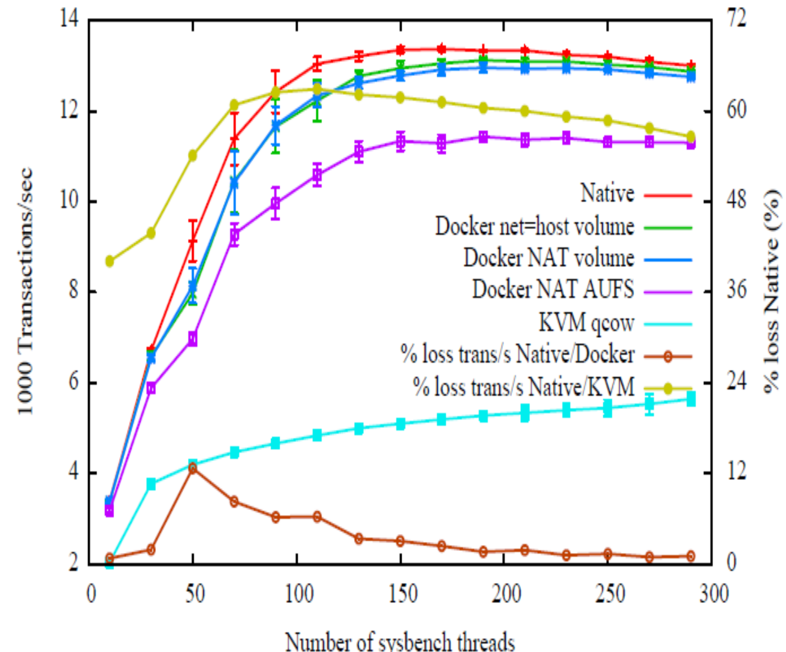


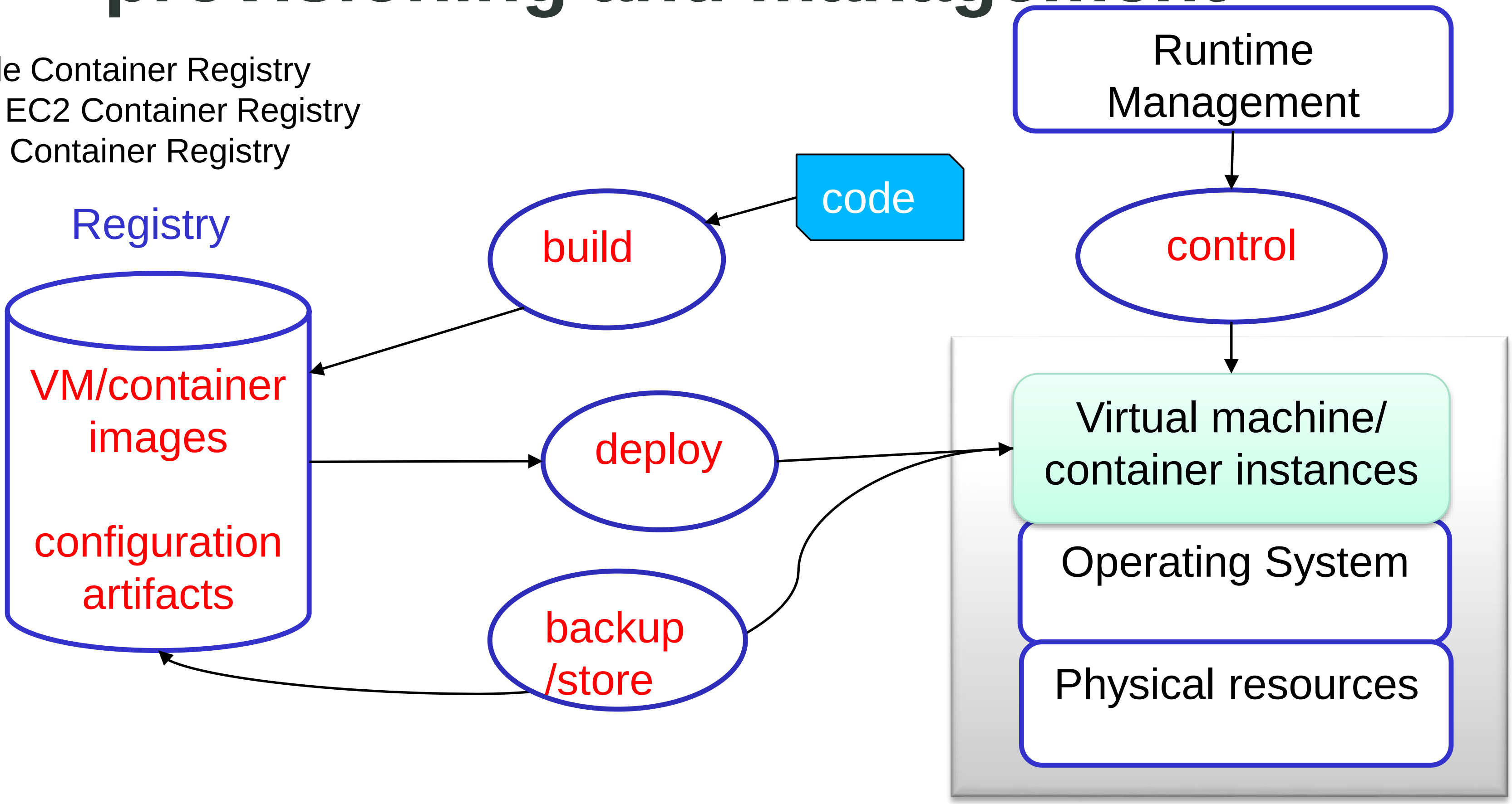
Fig. 10. MySQL throughput (transactions/s) vs. concurrency.

Wes Felter, Alexandre Ferreira, Ram Rajamony, Juan Rubio:
An updated performance comparison of virtual machines and Linux containers. ISPASS 2015: 171-172
http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=7095802

Tools, frameworks and providers: Chef, Vagrant, Amazon, Google, Microsoft, OpenStack, …

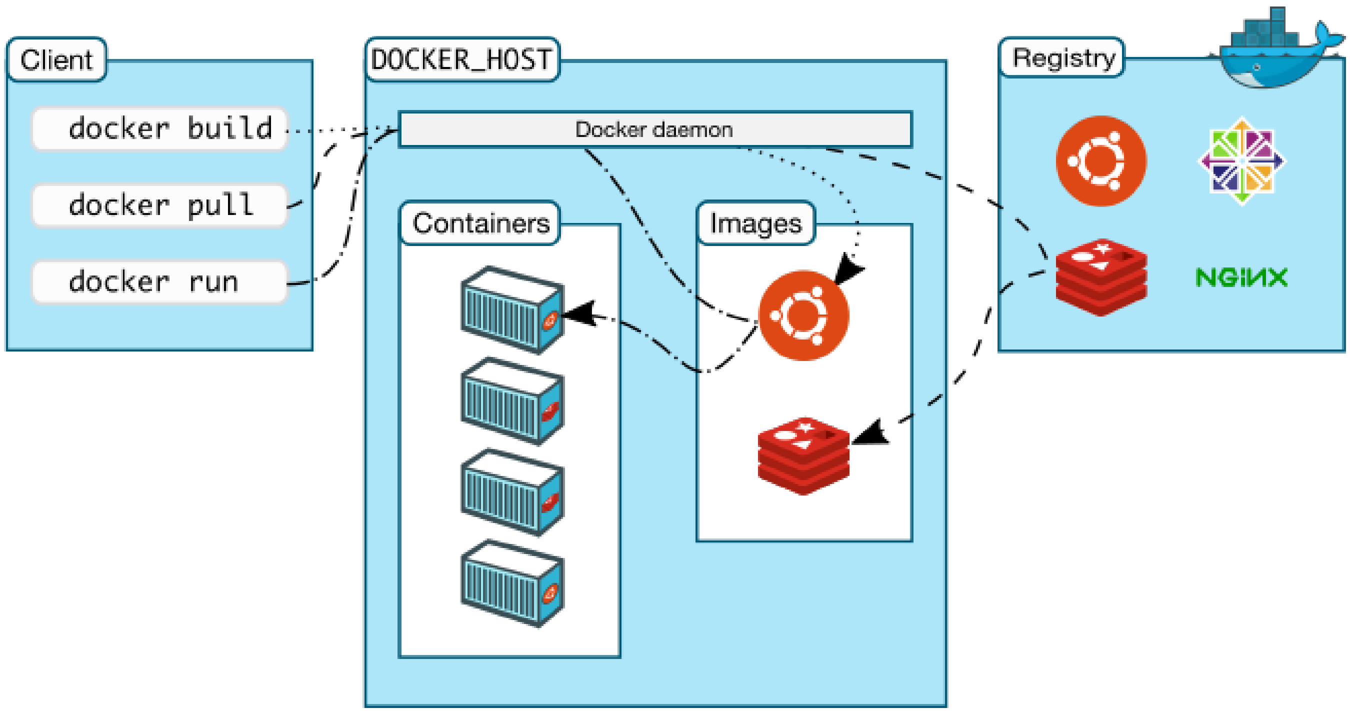
Interactions in VMs/containers provisioning and management

Google Container Registry
AWS EC2 Container Registry
Azure Container Registry



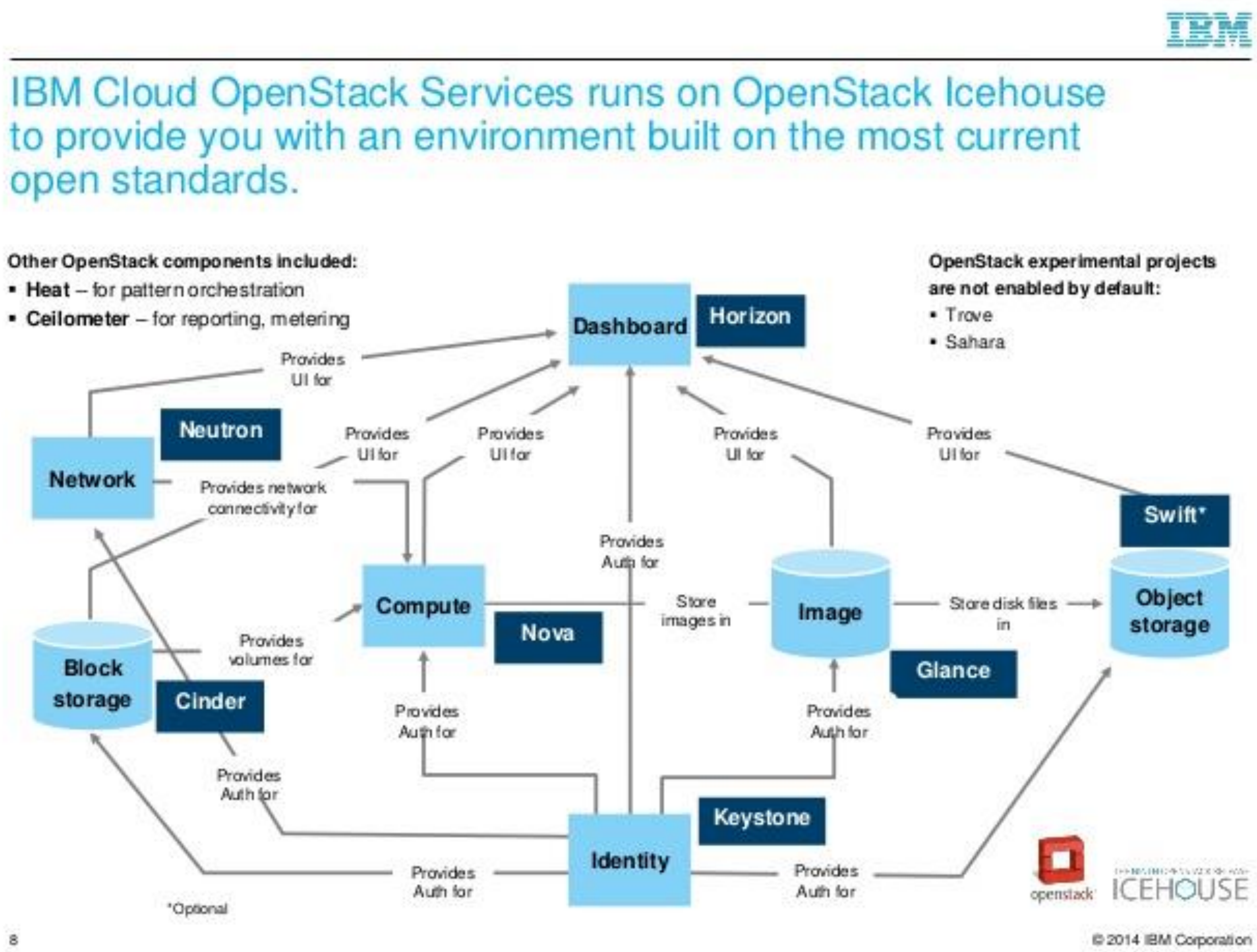
You focus on application development, how does it impact your work?

Examples



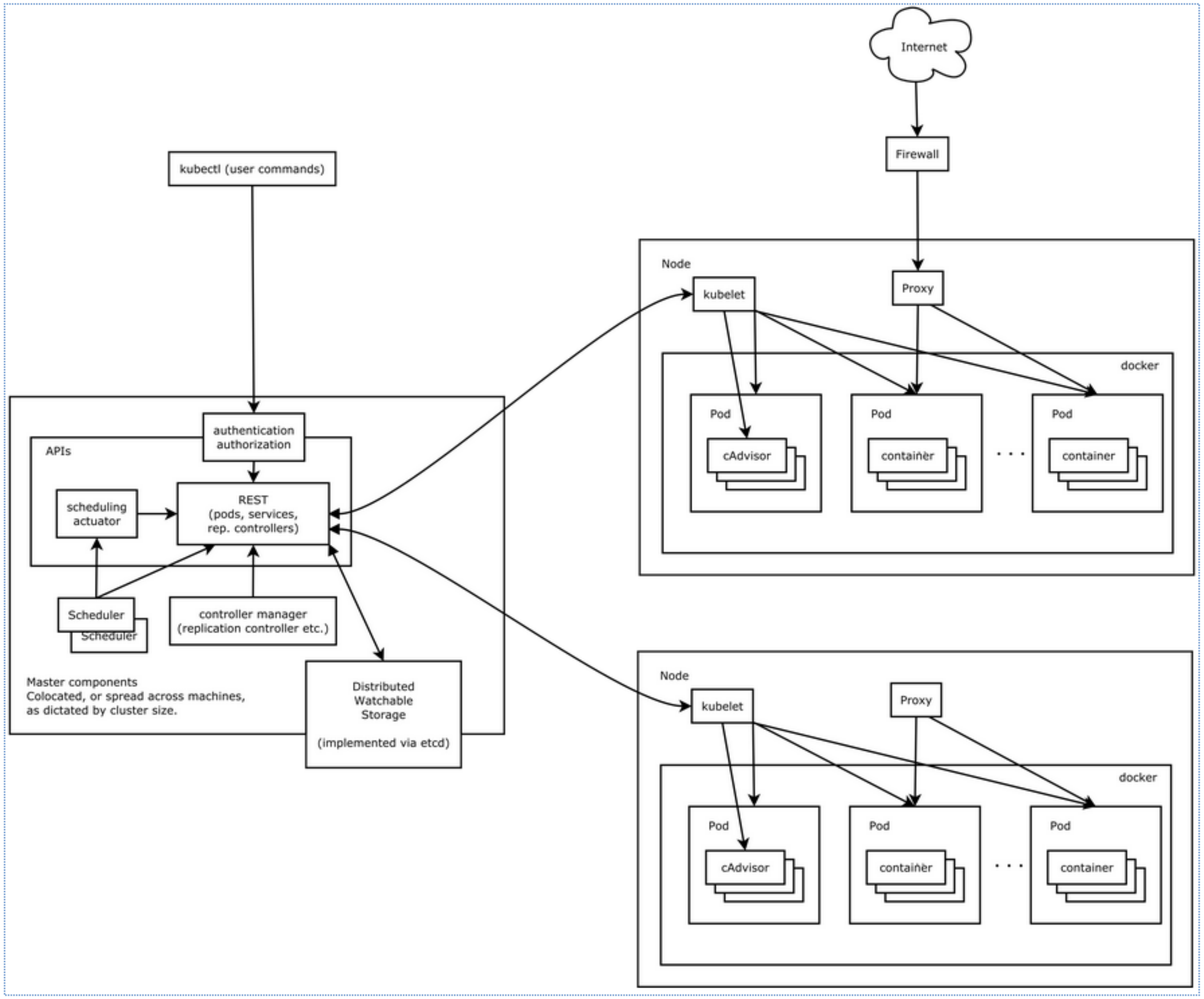
Source: https://docs.docker.com/engine/understanding-docker/

Examples



Source: http://www.slideshare.net/OpenStack_Online/ibm-cloud-open-stack-services

Cluster of VMs/containers



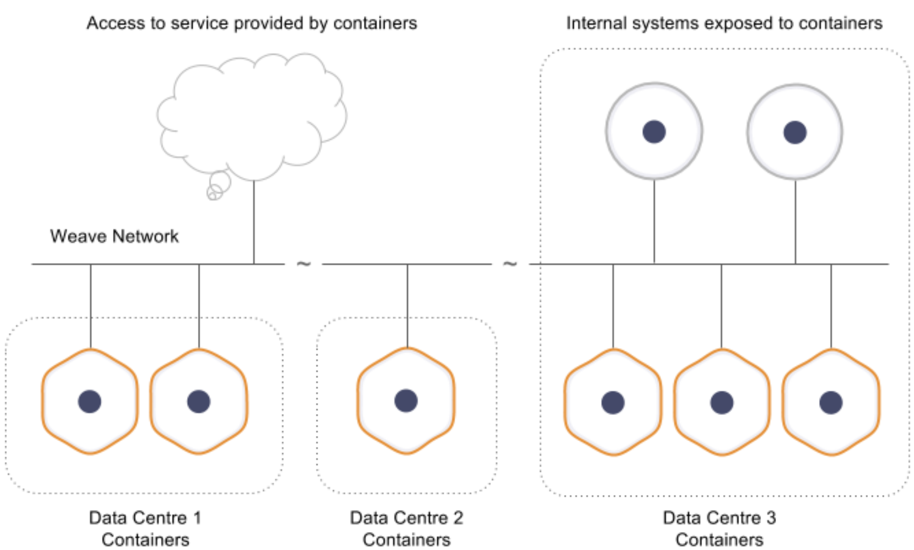
https://github.com/kubernetes/kubernetes/blob/release-1.2/docs/design/architecture.md

Virtual data centers

- On-demand virtual data centers
  - Compute nodes, storage, communication, etc.
  - Virtual data centers work like a single distributed system (e.g., a cluster)
- Challenges
  - Provision resources/nodes (using VMs or containers)
  - Configure networks within virtual data centers
  - Configure networks between virtual data centers and the outside systems
  - Deploy software into the virtual data centers

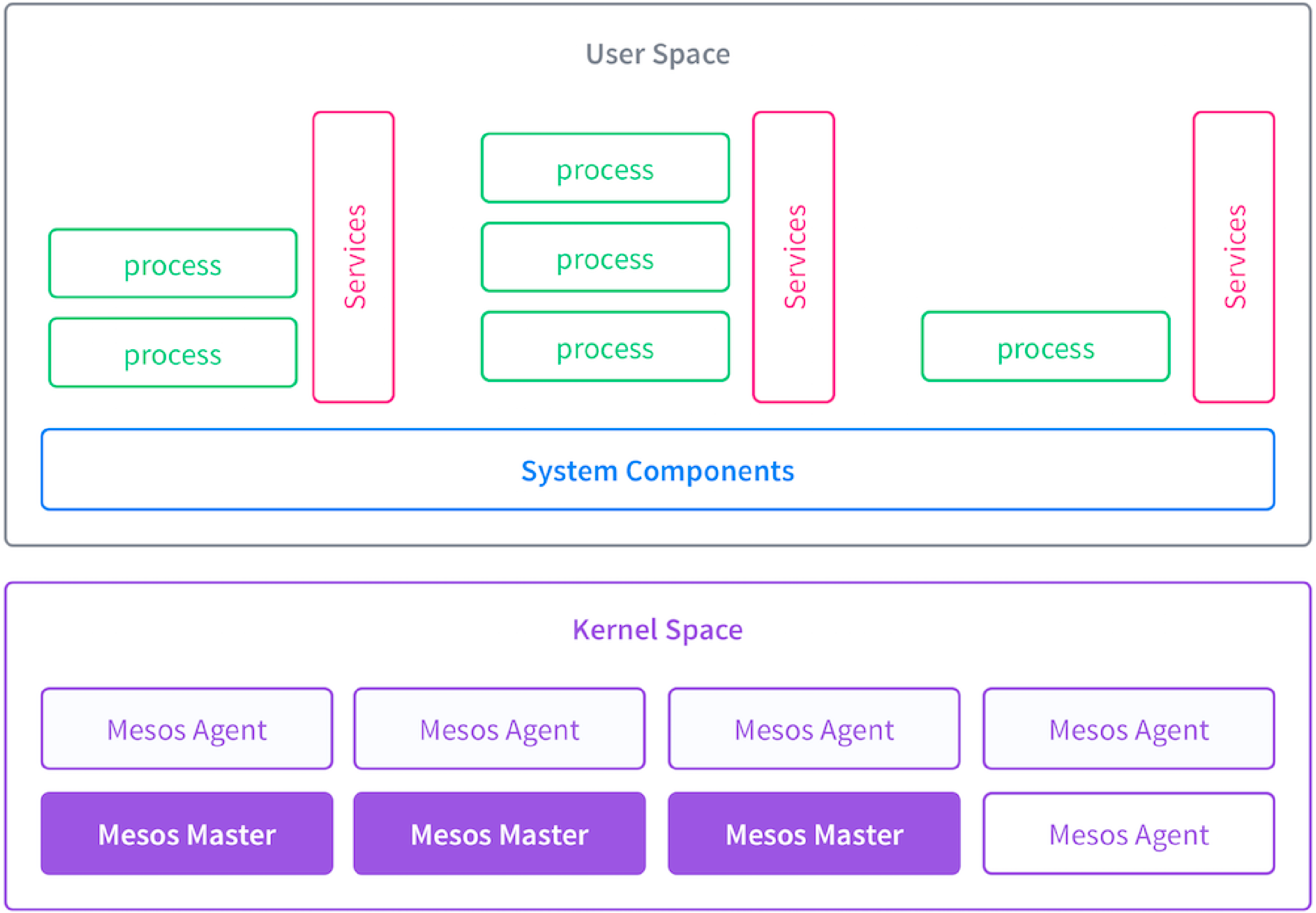
Example - Weave Net and docker

- Work with Kubernetes & Mesos as well
- Key idea: using network plug-in for containers + P2P overlay of routers in the host



Source: https://www.weave.works/docs/net/latest/introducing-weave/

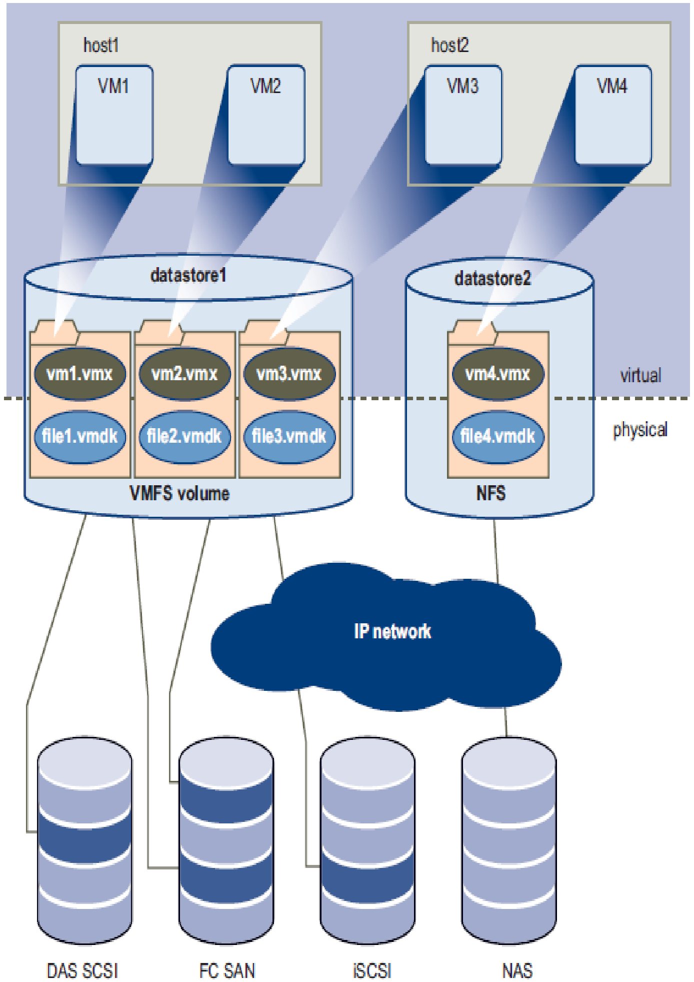
Example -- DC/OS



Source: https://docs.mesosphere.com/1.8/overview/architecture/

Storage Virtualization

- Low-level storage
  - e.g., RAID (redundant arry of independent disks)
- High-level, e.g., database
  - MySQL Cluster + auto-sharding



Source: https://www.vmware.com/pdf/vi_architecture_wp.pdf

- Why is it relevant to you?
- What changes should we make in our apps?

Network Function Virtualization

- Consolidate network equipment and services
- On-demand provisioning of network functions

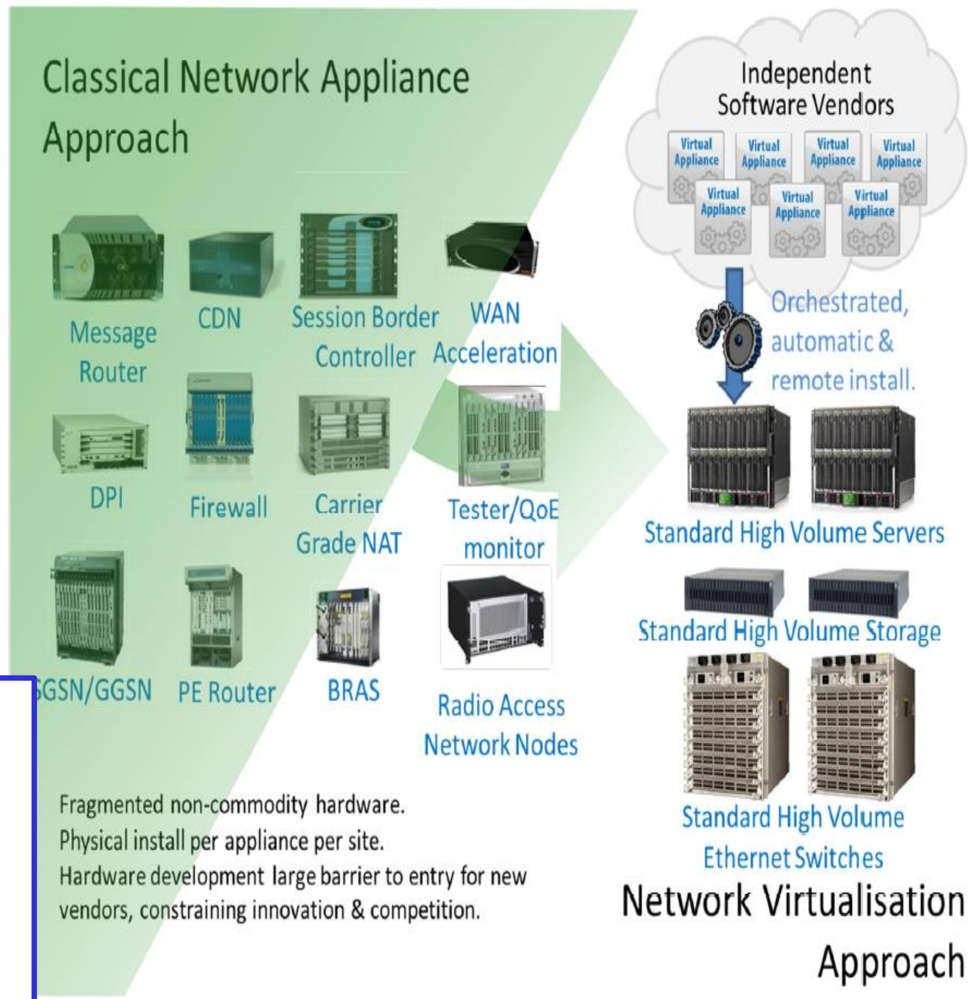


Figure source: https://portal.etsi.org/NFV/NFV_White_Paper.pdf

Is it the sysadmin task? I never see the network part in my apps. So why is it relevant to the software developer?

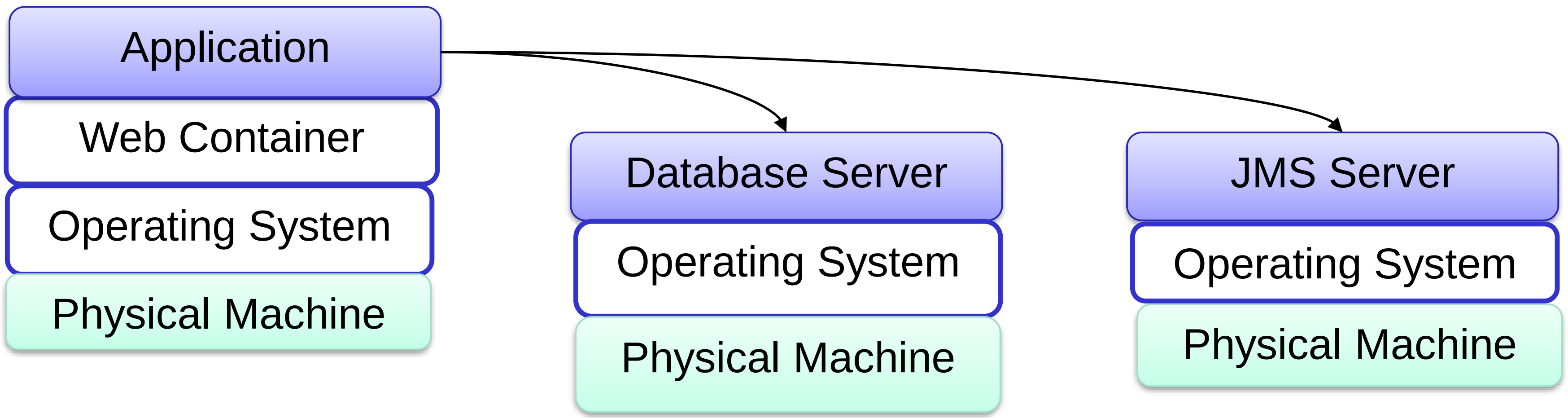
Why is resource virtualization interesting for distributed applications?

What are impacts of virtualization on the development and operation of distributed applications?

List of why and impact

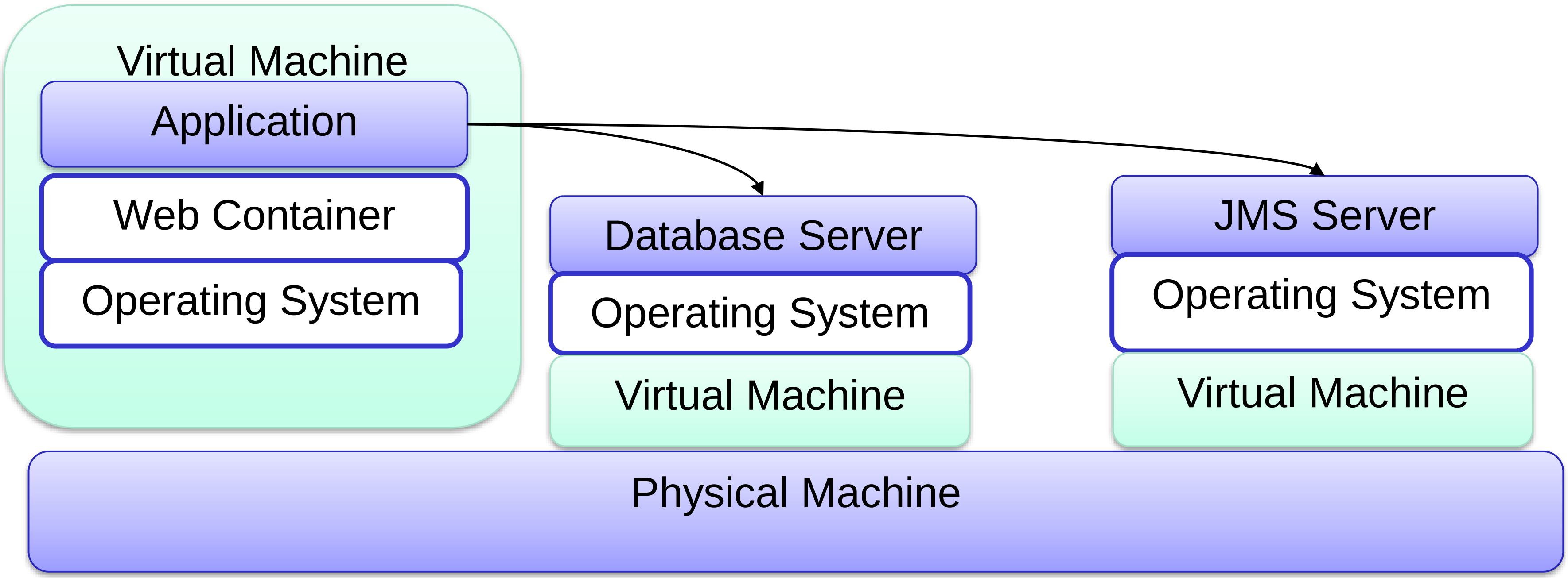
- Server consolidation
  - Consolidating compute capabilities
- Security, fault tolerance and performance
  - Through dynamic provisioning and auto-scaling
- Cost/optimization
  - elasticity, hot deployment, etc.
- Compatibility issues
- DevOps
  - Closing the gap between real and development environments

Server Consolidation



- Cost, complexity (management)
  - Infrastructures (cooling, spaces), human resources
- Resources under utilization

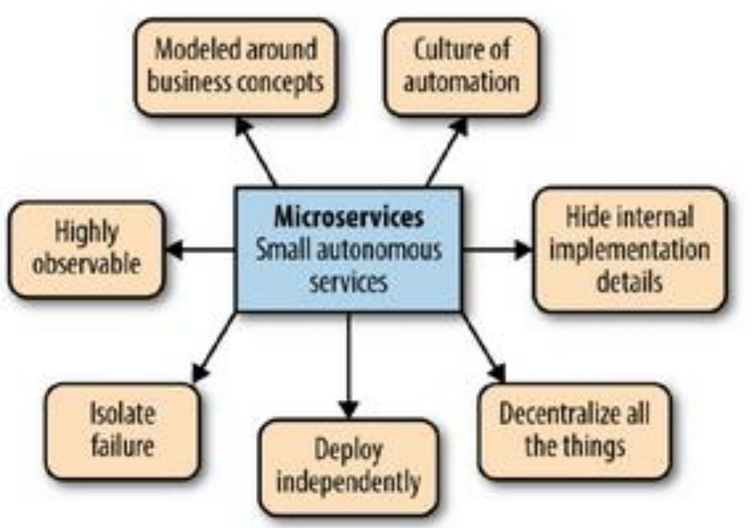
Server Consolidation

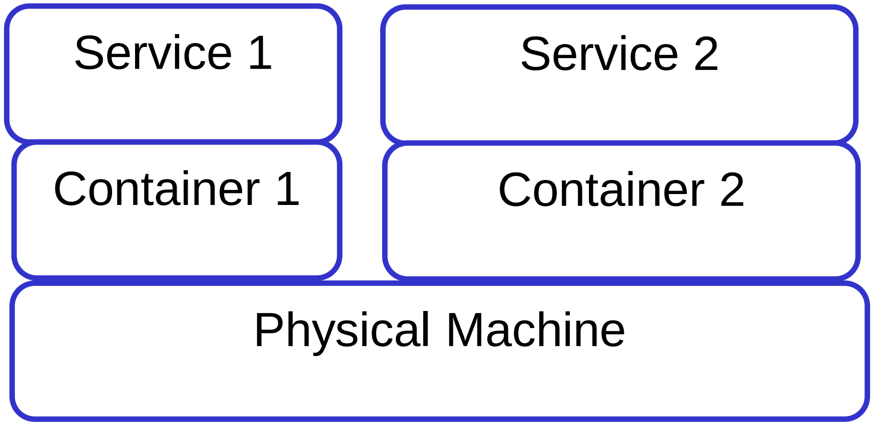


How does it help me? Consolidation looks good for the sysadmin but not relevant to the software developer?

What changes the developer has to do?

Microservices + partitioning

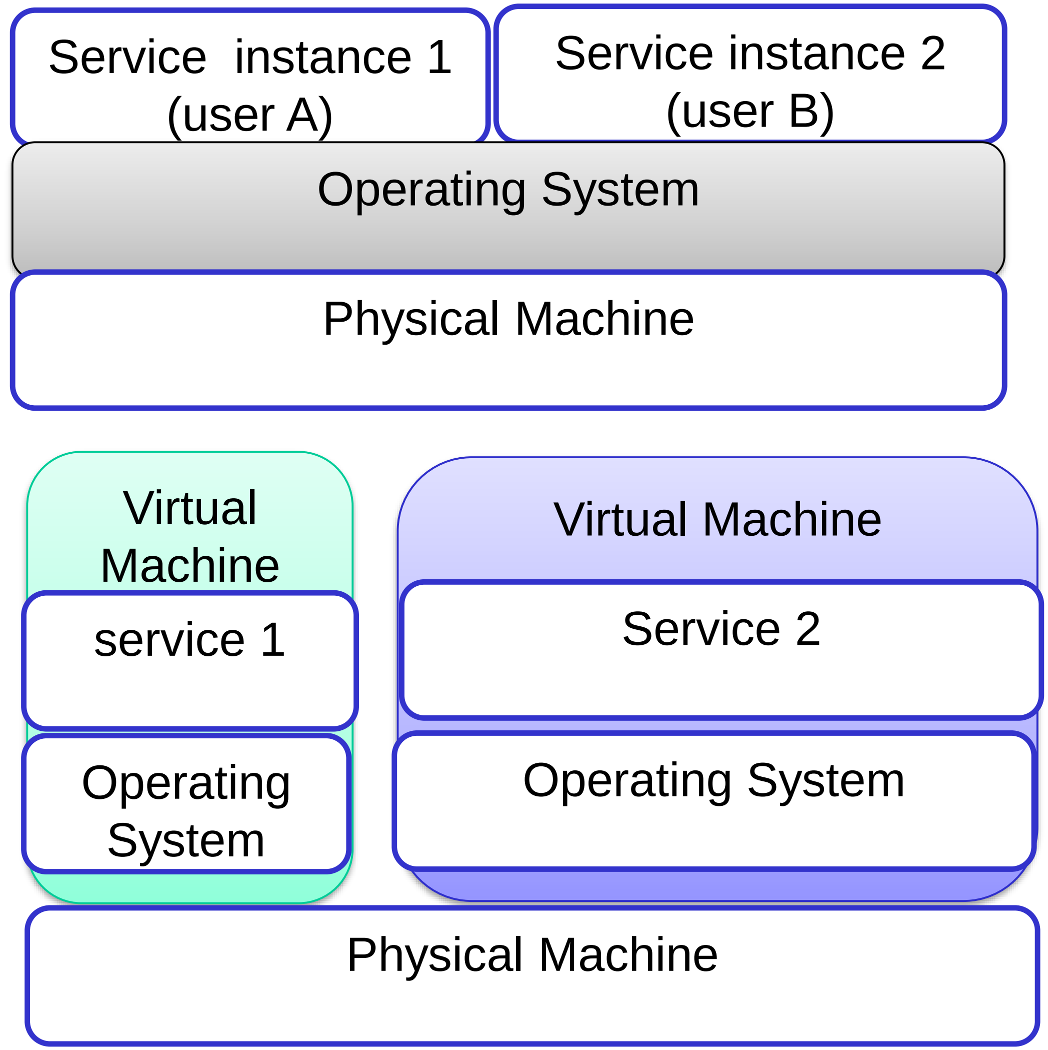




- Partition complex code into different services → easy configuration and maintenance
- But this has to be in sync with underlying resources provisioning

Security improvement

(Virtual) server and service isolation



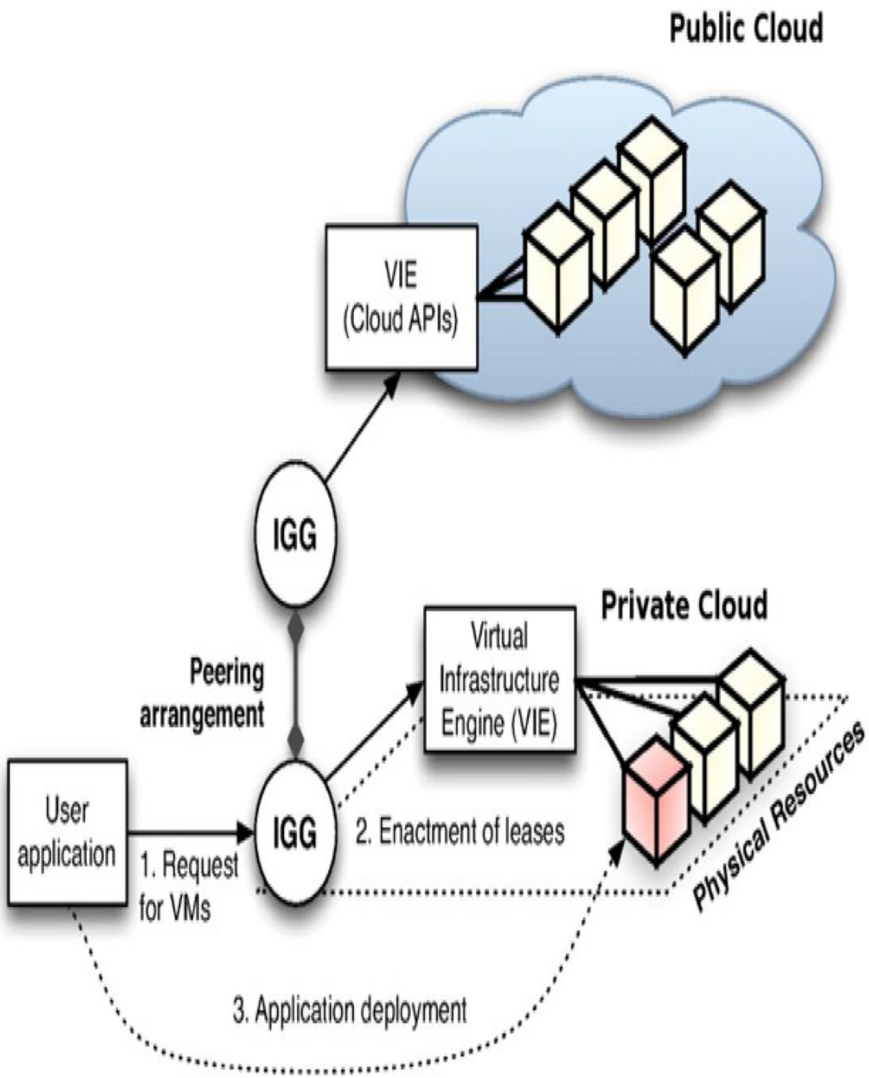
Fault tolerance and performance

How does resource virtualization help improving fault tolerance and performance?

- Possible benefits
  - Failure masking
  - Cost/optimization
    - Elasticity, hot deployment, etc.
    - Cloud bursting (combining private + public resources)
  - Improving service performance in incident management
    - E.g., spend time to fix a machine or just quickly relaunch a new one (and fix the old one later) ?

Examples of cloud bursting/hybrid clouds

Bahman Javadi, Jemal Abawajy, Rajkumar Buyya, Failure-aware resource provisioning for hybrid Cloud infrastructure, Journal of Parallel and Distributed Computing, Volume 72, Issue 10, October 2012, Pages 1318-1331, ISSN 0743-7315,



Development and deployment

- Compatibility and support legacy application
- Maintenance
- Close the gap between development/test environment and real/production environments
- Simplify testing, emulating real environments, etc.

ELASTICITY

Elasticity in physics

"elasticity (or stretchiness) is the physical property of a material that **returns to its original shape** after the stress (e.g. external forces) that made it deform or distort is removed" – http://en.wikipedia.org/wiki/Elasticity_(physics)

- It is related to the form (the structure) of something
  - "Stress" causes the elasticity (structure deformation)
  - "Strain" measures what has been changed (amount of deformation)
- In the context of computing: given a process or a system
  - What can be used to represent "Stress" and "Strain"?
  - When does a "strain" signals a "dangerous situation"?
  - How to be elastic under dynamic "stress"?

Elasticity in computing

"Elastic computing is the use of computer resources which vary dynamically to meet a variable workload" –

http://en.wikipedia.org/wiki/Elastic_computing

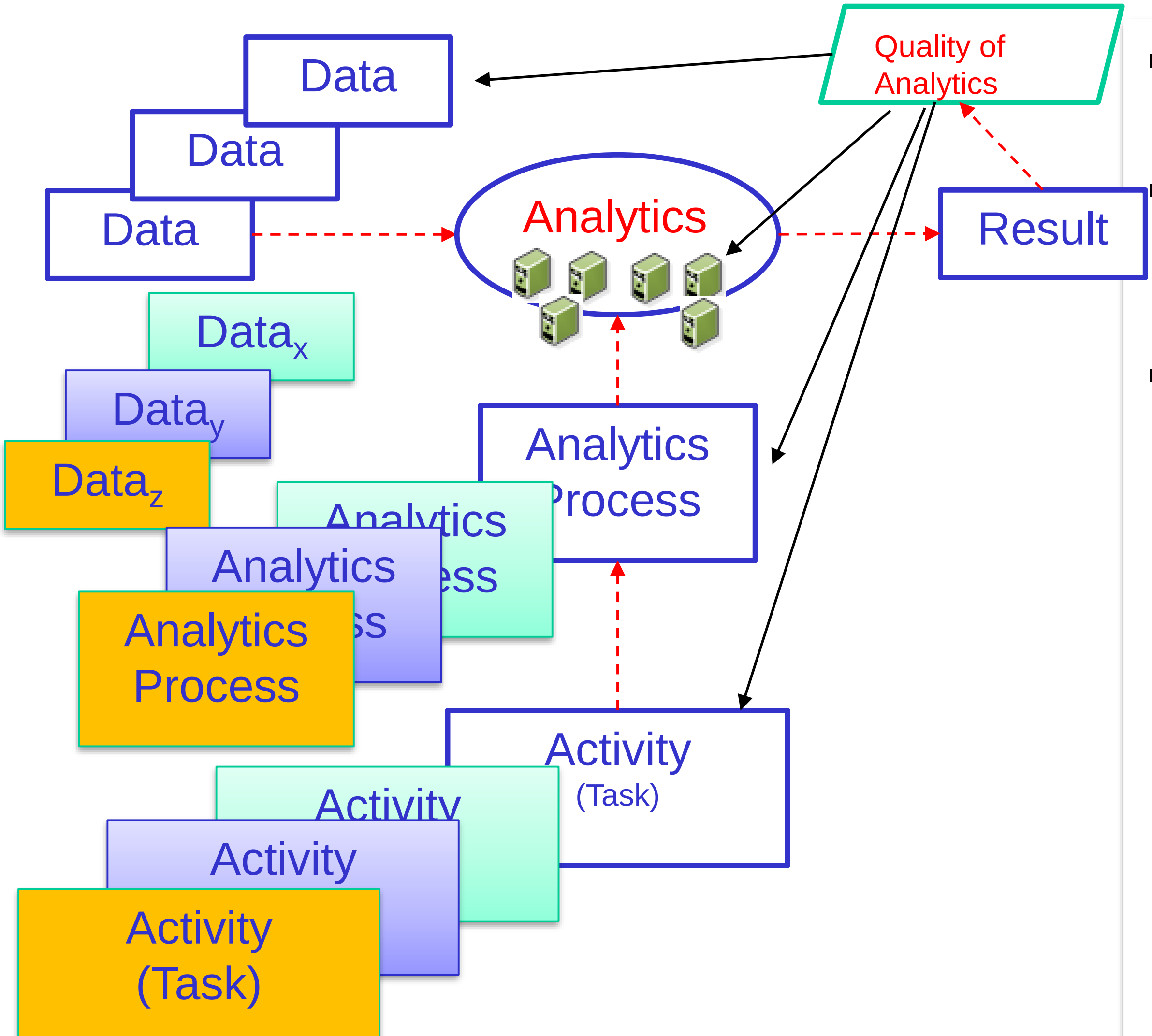
"Clustering elasticity is the ease of adding or removing nodes from the distributed data store" –

http://en.wikipedia.org/wiki/Elasticity_(data_store)

"What elasticity means to cloud users is that they should **design their applications to scale their resource requirements up and down** whenever possible.", David Chiu –

http://xrds.acm.org/article.cfm?aid=1734162

Elasticity in (big) data analytics



- **More data** → more compute resources (e.g. more VMs)
- **More types of data** → more activities → more analytics processes
- Change **quality of analytics**
  - Change quality of data
  - Change response time
  - Change cost
  - Change types of result (form of the data output, e.g. tree, table, story)

Elasticity in computing – broad view

1. Demand elasticity

   Elastic demands from consumers

2. Output elasticity

   Multiple outputs with different price and quality

3. Input elasticity

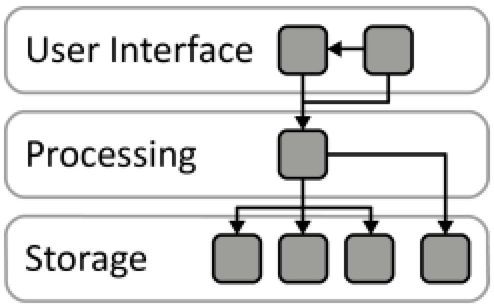
   Elastic data inputs, e.g., deal with opportunistic data

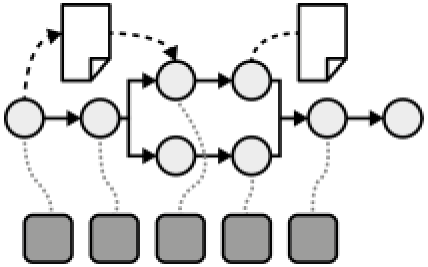
4. Elastic pricing and quality models associated resources

Diverse types of elasticity requirements

- ***Application user***: “If the cost is greater than 800 Euro, there should be a scale-in action for keeping costs in acceptable limits”
- ***Software provider***: “Response time should be less than amount X varying with the number of users.”
- ***Developer***: “The result from the data analytics algorithm must reach a certain data accuracy under a cost constraint. I don’t care about how many resources should be used for executing this code.”
- ***Cloud provider***: “When availability is higher than 99% for a period of time, and the cost is the same as for availability 80%, the cost should increase with 10%.”

Our focus in this course: elasticity of compute resources for distributed applications





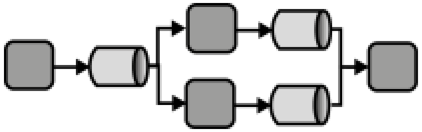


Figure source: http://www.cloudcomputingpatterns.org/Distributed_Application

Q1: Where can elasticity play a role in these application models?

Q2: How does virtualization help implementing elasticity of resources

Elasticity implementation

- Elasticity specification
  - Constraints/Rules
- Elasticity monitoring and prediction
- Elasticity controller/adjustment:
  - Interpret specifications and monitoring data
  - Control
    - Reactive scale versus proactive scale
    - Vertical scaling (scale up/down) versus Horizontal scaling (scale out/in)

Elasticity constraints

Table 1 Summary of the reviewed literature about threshold-based rules

Ref	Auto-scaling Techniques	H/V	R/P	Metric	Monitoring	SLA	Workloads	Experimental Platform
[63]	Rules	Both	R	CPU, memory, I/O	Custom tool. 1 minute	Response time	Synthetic. Browsing and ordering behavior of customers.	Custom testbed (called IC Cloud) + TPC
[72]	Rules	H	R	Average waiting time in queue, CPU load	Custom tool.	–	Synthetic	Public cloud. FutureGrid, Eucalyptus India cluster
[64]	Rules	Both	R	CPU load, response time, network link load, jitter and delay.	–	–	Only algorithm is described, no experimentation is carried out.	
[48]	Rules + QT	H	P	Request rate	Amazon Cloud-Watch. 1–5 minutes	Response time	Real. Wikipedia traces	Real provider. Amazon EC2 + Httperf + MediaWiki
[52]	RightScale + MA to performance metric	H	R	Number of active sessions	Custom tool	–	Synthetic. Different number of HTTP clients	Custom testbed. Xen + custom collaborative web application
[73]	RightScale + TS: LR and AR(1)	H	R/P	Request rate, CPU load	Simulated.	–	Synthetic. Three traffic patterns: weekly oscillation, large spike and random	Custom simulator, tuned after some real experiments.
[59]	RightScale	H	R	CPU load	Amazon CloudWatch	–	Real. World Cup 98	Real provider. Amazon EC2 + RightScale (PaaS) + a simple web application
[96]	RightScale + Strategy-tree	H	R	Number of sessions, CPU idle	Custom tool. 4 minutes.	–	Real. World Cup 98	Real provider. Amazon EC2 + RightScale (PaaS) + a simple web application.
[81]	Rules	V	R	CPU load, memory, bandwidth, storage	Simulated.	–	Synthetic	Custom simulator, plus Java rule engine Drools
[77]	Rules	V	R	CPU load	Simulated. 1 minute	Response time	Real. ClarkNet	Custom simulator

Table rows are as follow. (1) The reference to the reviewed paper. (2) A short description of the proposed technique. (3) The type of auto-scaling: horizontal (H) or vertical (V). (4) The reactive (R) and/or proactive (P) nature of the proposal. (5) The performance metric or metrics driving auto-scaling. (6) The monitoring tool used to gather the metrics. The remaining three fields are related to the environment in which the technique is tested. (7) The metric used to verify SLA compliance. (8) The workload applied to the application managed by the auto-scaler. (9) The platform on which the technique is tested

Source: A Review of Auto-scaling Techniques for Elastic Applications in Cloud Environments, Tania Lorido-Botran , Jose Miguel-Alonso, Jose A. Lozano, http://link.springer.com/article/10.1007%2Fs10723-014-9314-7

Microsoft Azure Elasticity Rules

XML

```xml
<rules
  xmlns=http://schemas.microsoft.com/practices/2011/entlib/autoscaling/rules
  enabled="true">
  <constraintRules>
    <rule name="Default" description="Always active"
          enabled="true" rank="1">
      <actions>
        <range min="2" max="5" target="RoleA"/>
      </actions>
    </rule>

    <rule name="Peak" description="Active at peak times"
          enabled="true" rank="100">
      <actions>
        <range min="4" max="6" target="RoleA"/>
      </actions>
      <timetable startTime="08:00:00" duration="02:00:00">
        <daily/>
      </timetable>
    </rule>
  </constraintRules>

  <reactiveRules>
    <rule name="ScaleUp" description="Increases instance count"
          enabled="true" rank="10">
      <when>
        <greater operand="Avg_CPU_RoleA" than="80"/>
      </when>
      <actions>
        <scale target="RoleA" by="1"/>
      </actions>
    </rule>
    <rule name="ScaleDown" description="Decreases instance count"
          enabled="true" rank="10">
      <when>
        <less operand="Avg_CPU_RoleA" than="20"/>
      </when>
      <actions>
        <scale target="RoleA" by="-1"/>
      </actions>
    </rule>
  </reactiveRules>

  <operands>
    <performanceCounter alias="Avg_CPU_RoleA"
      performanceCounterName="\Processor(_Total)\% Processor Time"
      aggregate="Average" source="RoleA" timespan="00:45:00"/>
  </operands>
</rules>
```

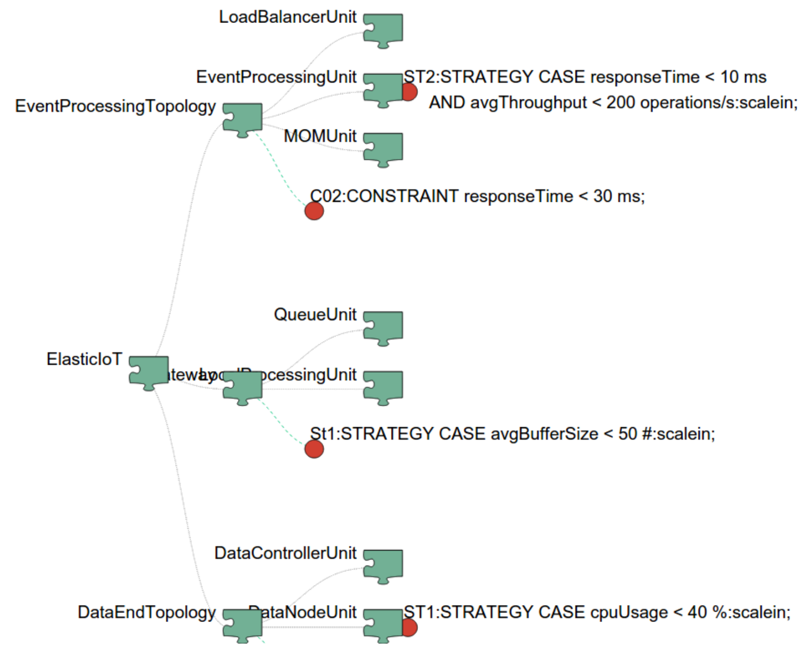
Source: https://msdn.microsoft.com/en-us/library/hh680881%28v=pandp.50%29.aspx

High level elasticity control in SYBL (http://tuwiendsg.github.io/iCOMOT/

#SYBL.CloudServiceLevel
Cons1: CONSTRAINT responseTime < 5 ms
Cons2: CONSTRAINT responseTime < 10 ms WHEN nbOfUsers > 10000
Str1: STRATEGY CASE fulfilled(Cons1) OR fulfilled(Cons2): minimize(cost)

#SYBL.ServiceUnitLevel
Str2: STRATEGY CASE ioCost < 3 Euro : maximize(dataFreshness)

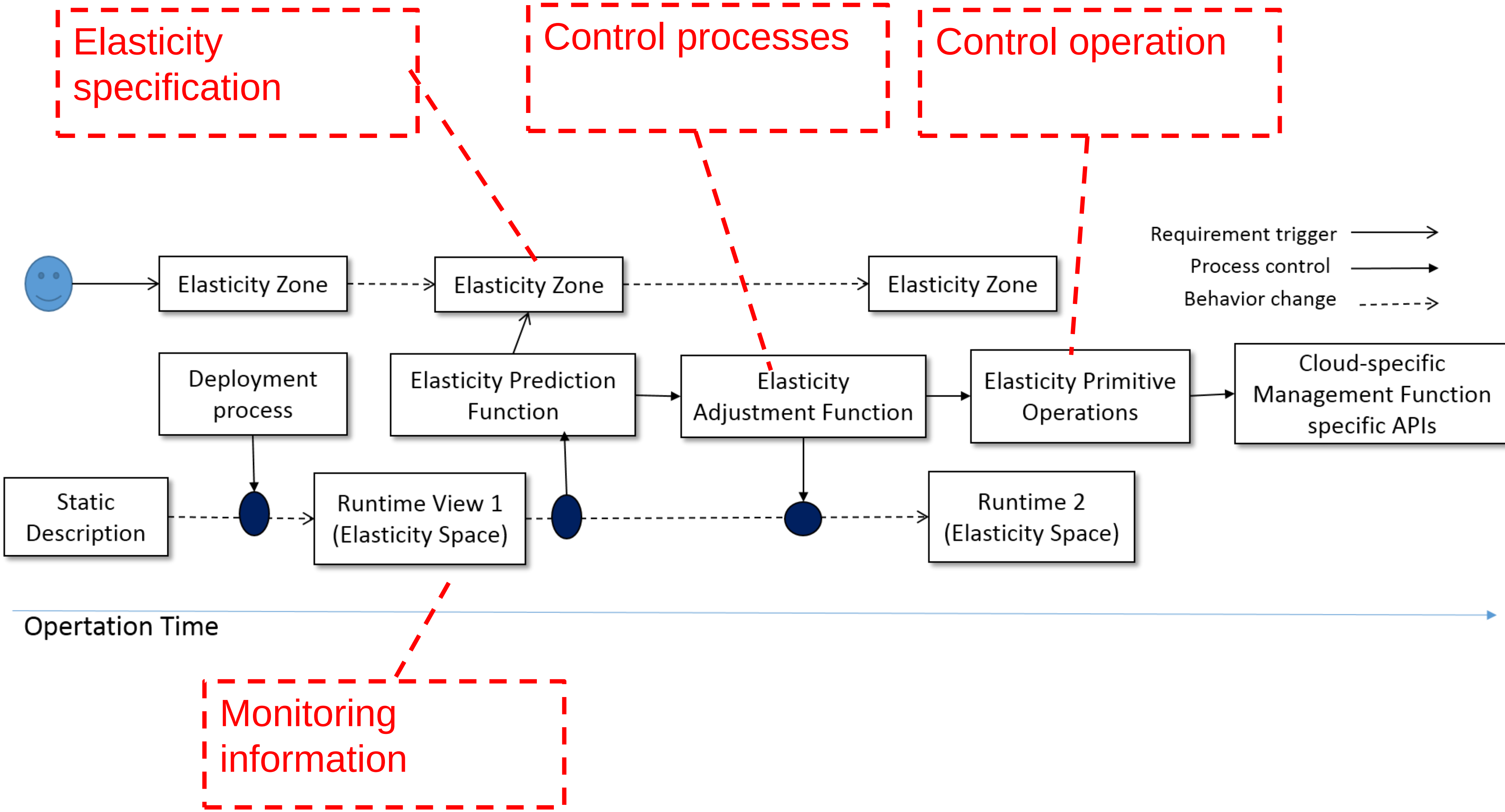
#SYBL.CodeRegionLevel
Cons4: CONSTRAINT dataAccuracy>90% AND cost<4 Euro



Georgiana Copil, Daniel Moldovan, Hong-Linh Truong, Schahram Dustdar, **"SYBL: an Extensible Language for Controlling Elasticity in Cloud Applications"**, 13th IEEE/ACM International Symposium on Cluster, Cloud and Grid Computing (CCGrid), May 14-16, 2013, Delft, Netherlands

A quick check: if you want to allow the developer to specify elasticity in his/her source code, e.g., Java, what would be your solution?

General concept: Lifecycle of applications and elasticity



VIRTUALIZATION AND ELASTICITY FOR IMPLEMENTING PERFORMANCE PATTERNS

Design for handling failures

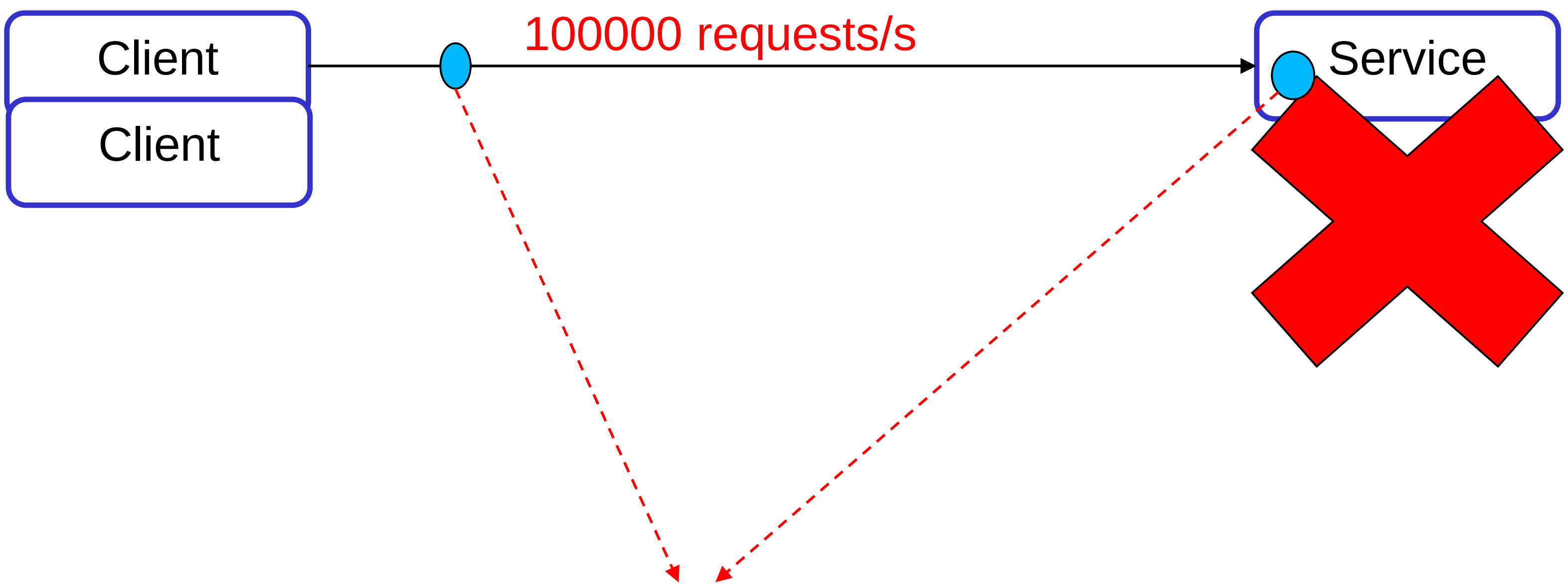
- Resource failures
  - Problems with CPUs, networks, machines, etc.
  - → other dependent services failures
  - Scopes: with an enterprise, within a data center, across multiple sites, across multiple infrastructures provided by different providers, etc.
- Our design must be ready to handle such failures
- Using virtualization and elasticity techniques to deal with issues
- Relying on best practices

Examples of best practices when using Amazon services

Source: https://media.amazonwebservices.com/AWS_Cloud_Best_Practices.pdf

- Using Elastic IPs
- Utilize resources from multiple zones
- Maintain Amazon virtual machines
- Use Amazon Cloudwatch for monitoring
- Automatically make snapshots of VMs
- Automatically backups

Recall this case



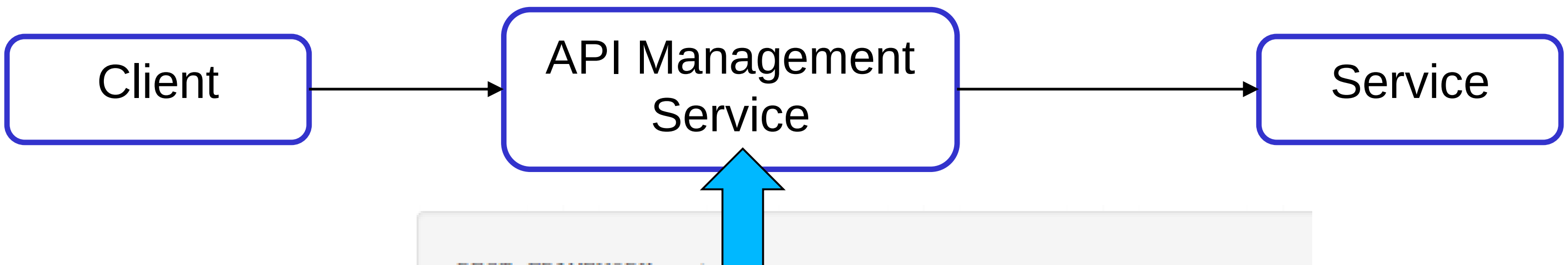
Change the way to handle client requests outside the service and within the service

Which are possible solutions?

- Throttling
- Queue-based load leveling within the service
- Multiple instances and queues
- Multiple instances and elastic resources
- Circuit breaker to deal with failures
- You name it

Throttling

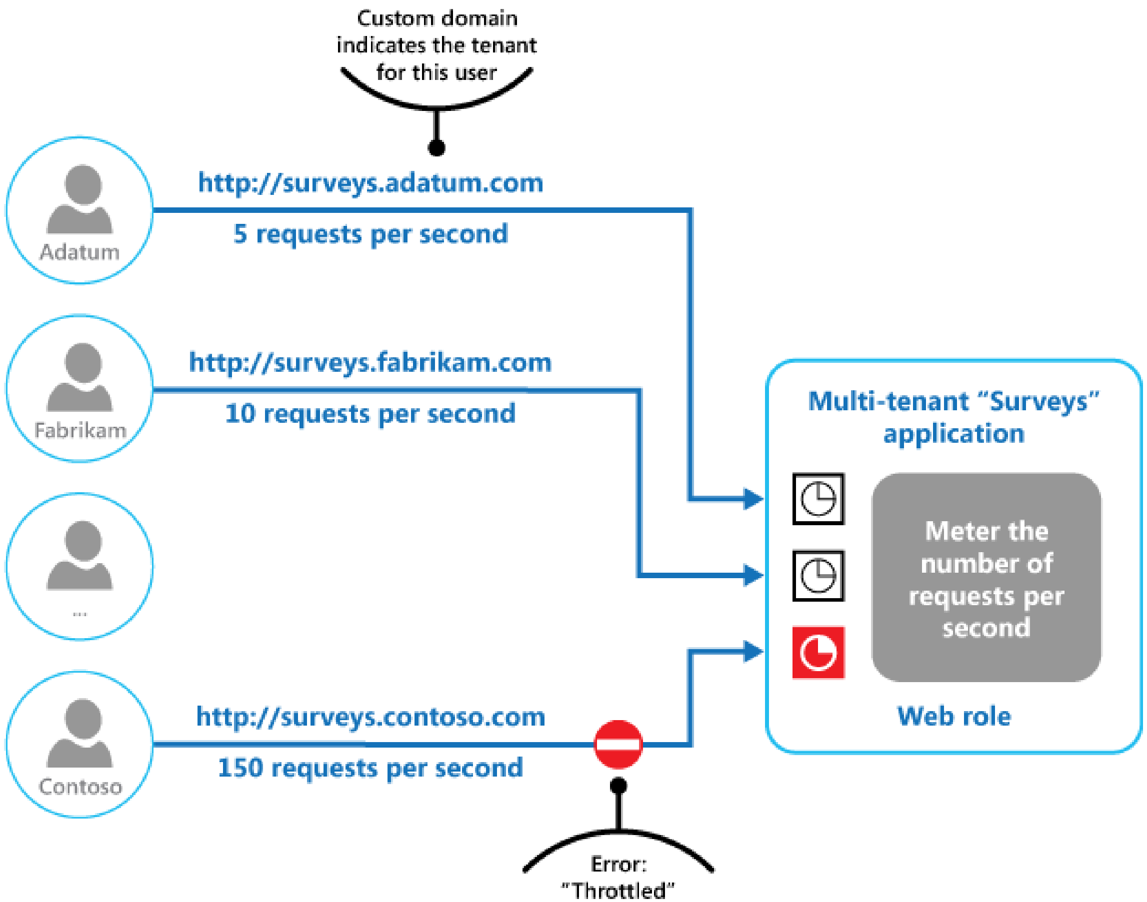
Disable too many access and disable unessential services




```
REST_FRAMEWORK = {
    'DEFAULT_THROTTLE_CLASSES': (
        'rest_framework.throttling.AnonRateThrottle',
        'rest_framework.throttling.UserRateThrottle'
    ),
    'DEFAULT_THROTTLE_RATES': {
        'anon': '100/day',
        'user': '1000/day'
    }
}
```

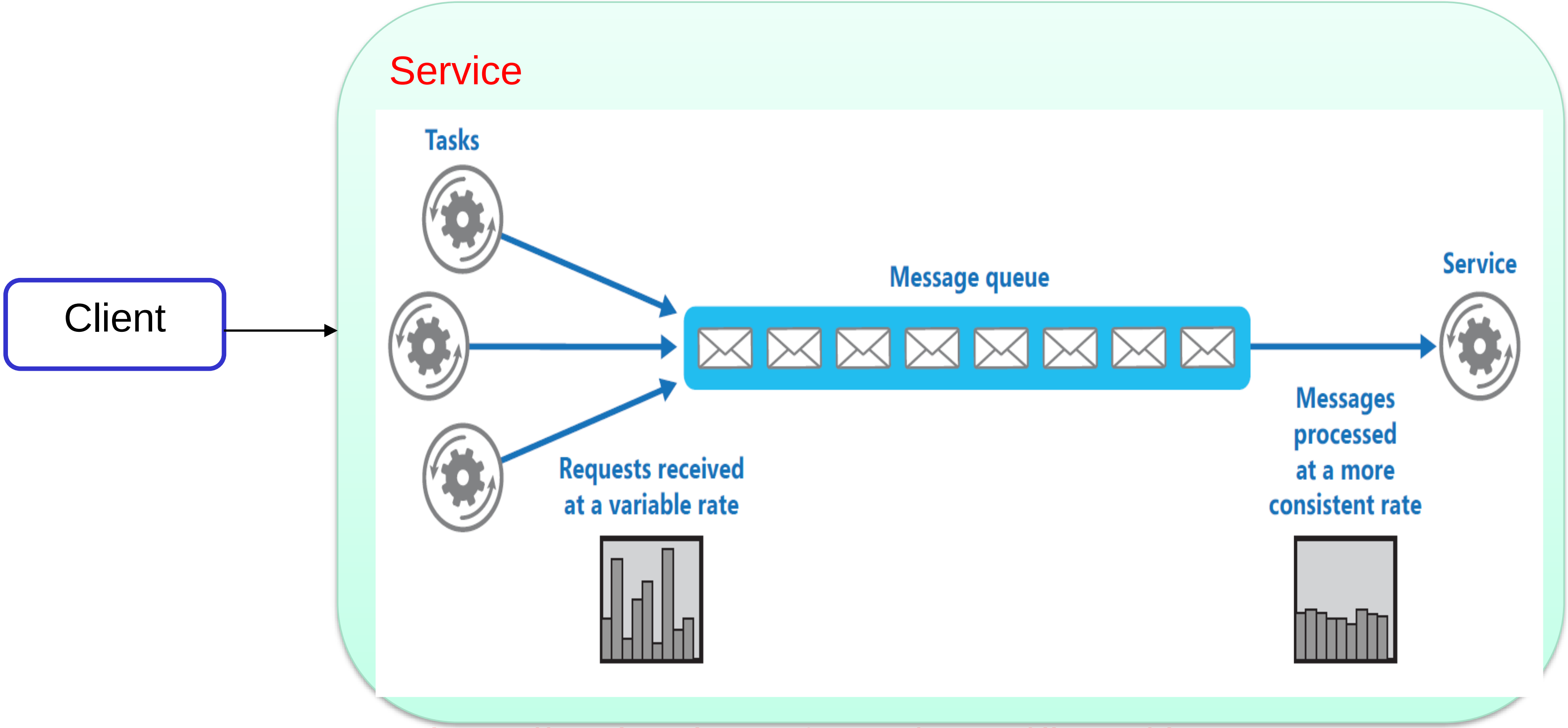
Code: http://www.django-rest-framework.org/api-guide/throttling/#how-throttling-is-determined

Example



Source: https://msdn.microsoft.com/en-us/library/dn589798.aspx

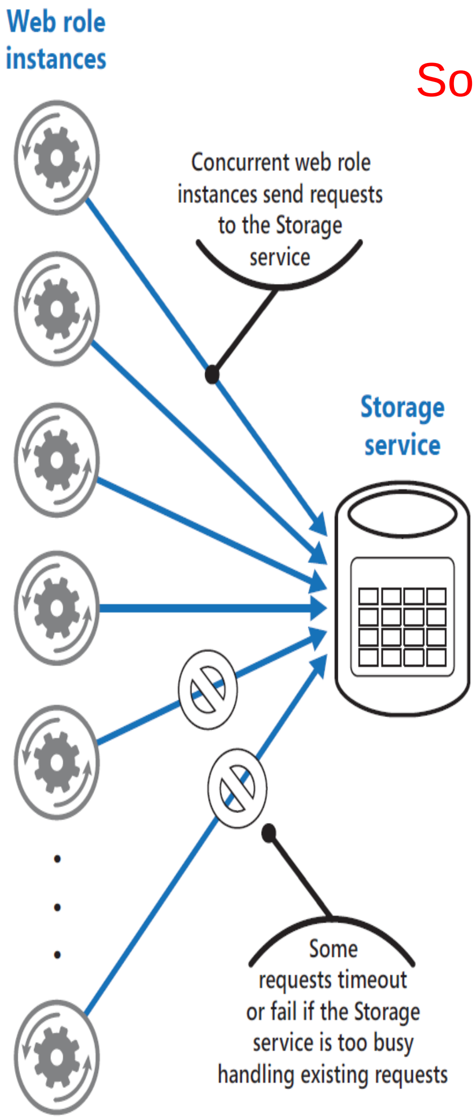
Using tasks and queue-based load leveling pattern

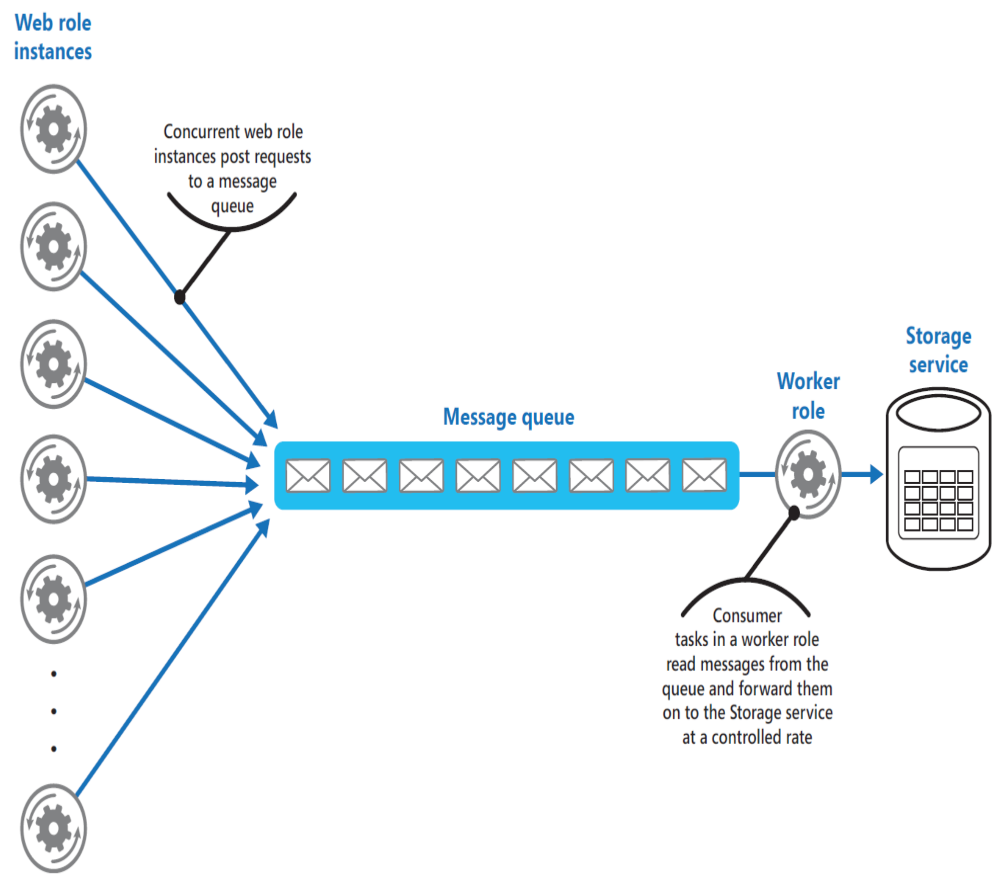


https://msdn.microsoft.com/en-us/library/dn589783.aspx

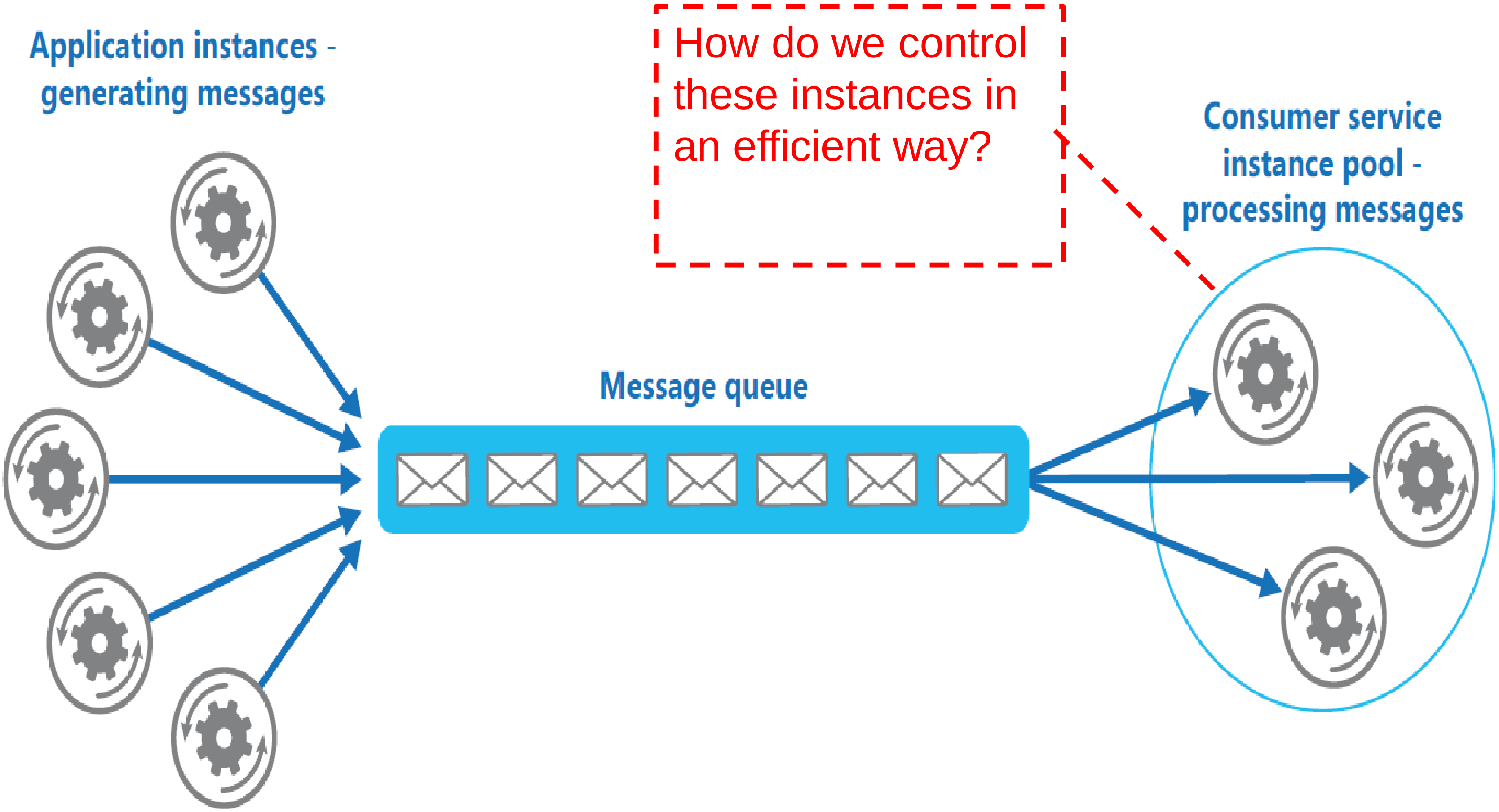
Examples of queue-based load leveling pattern

Source: https://msdn.microsoft.com/en-us/library/dn589783.aspx





Using multiple instances of services and queues



Source: https://msdn.microsoft.com/en-us/library/dn568101.aspx

Load balancing and elastic resources -- recall

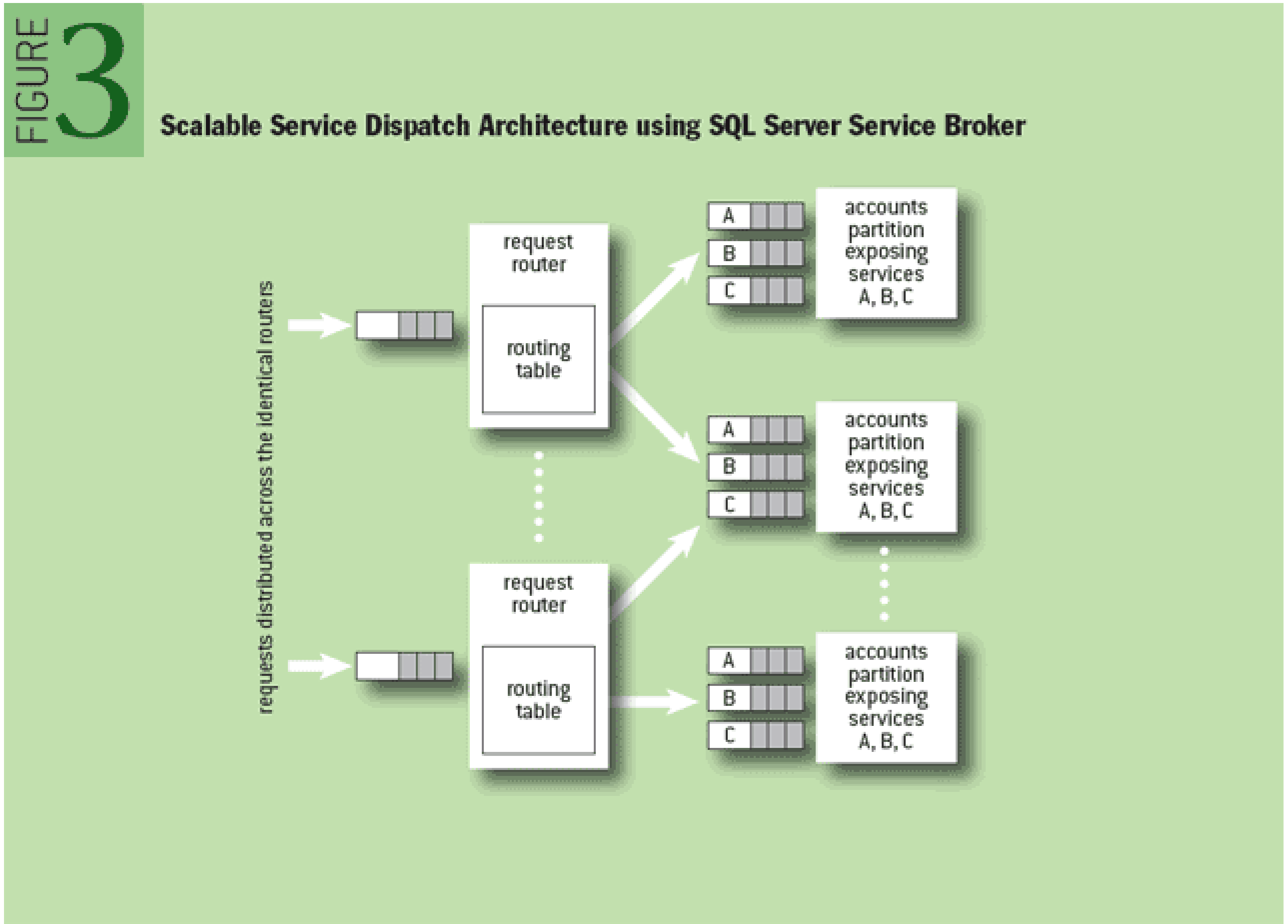
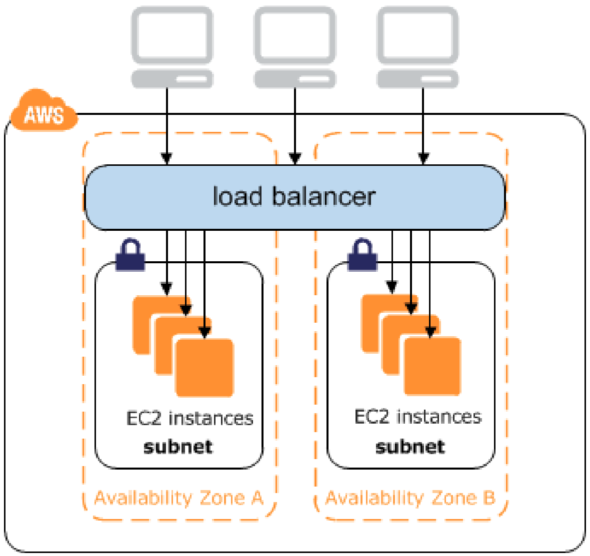
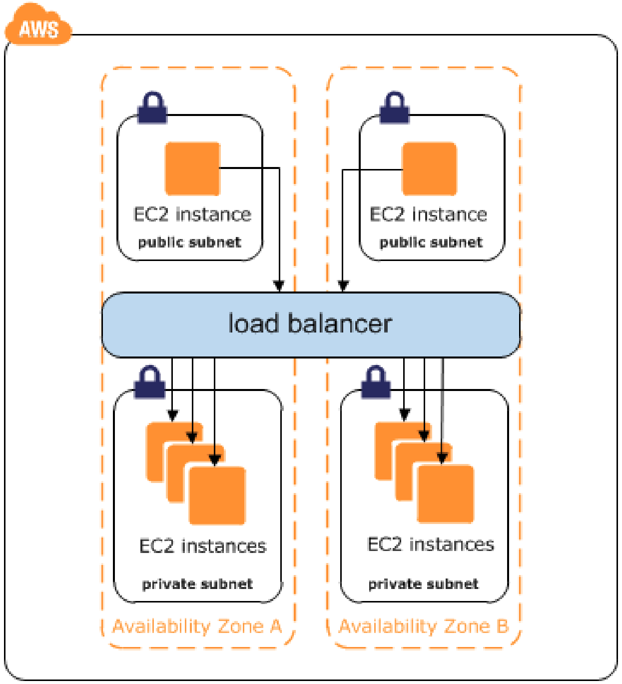


Figure source: http://queue.acm.org/detail.cfm?id=1971597

Load balancing and elastic resources -- Concepts

- Using loadbalancer for a group of resources



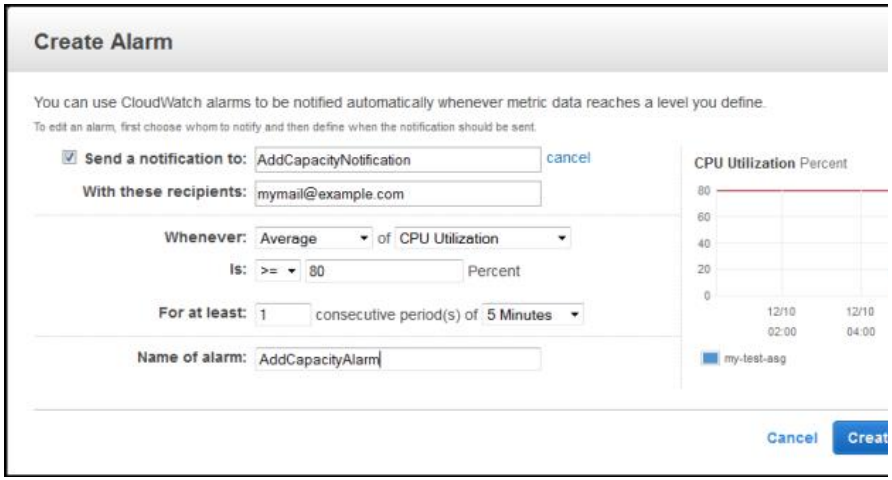


Source: http://docs.aws.amazon.com/ElasticLoadBalancing/latest/DeveloperGuide/elb-internal-load-balancers.html

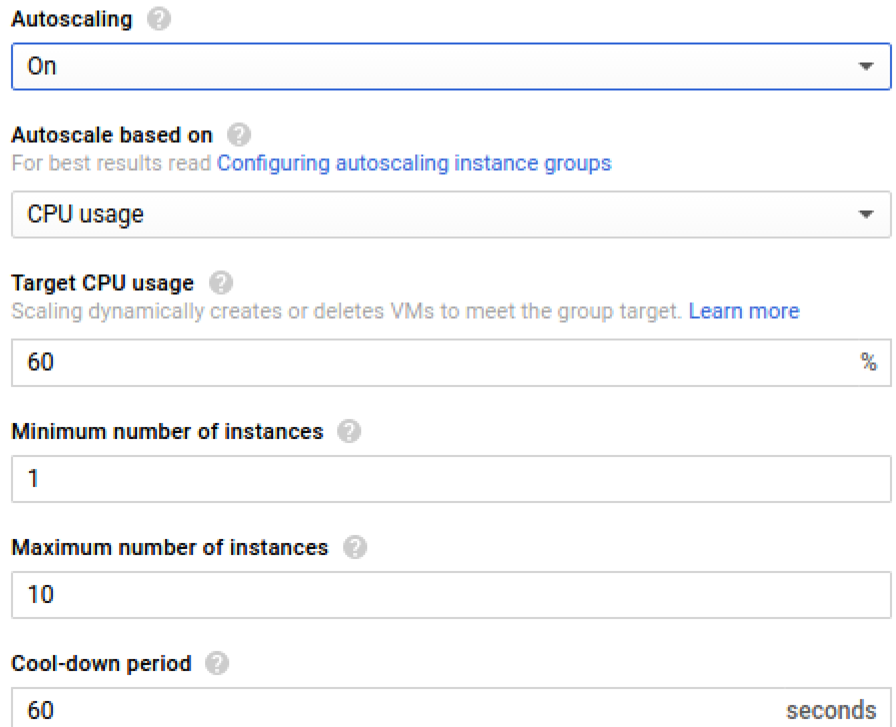
- Load balancer can monitor instances and send request to healthy instances but what if we still need more instances?
- Auto-scaling

Examples

Amazon services



Google (from console.cloud.google.com)



They are programming tasks

Sources: http://docs.aws.amazon.com/autoscaling/latest/userguide/policy_creating.html
http://docs.aws.amazon.com/autoscaling/latest/userguide/attach-load-balancer-asg.html

Examples from Amazon services

Increase Group Size

Name: AddCapacity

Execute policy when: AddCapacityAlarm Edit Remove
breaches the alarm threshold: CPUUtilization >= 80 for 300 seconds
for the metric dimensions AutoScalingGroupName = my-asg

Take the action: Add 30 percent of group when 80 <= CPUUtilization < +infinity

Add step

Add instances in increments of at least 1 instance(s)

Instances need: 300 seconds to warm up after each step

Create a simple scaling policy

Decrease Group Size

Name: DecreaseCapacity

Execute policy when: DecreaseCapacityAlarm Edit Remove
breaches the alarm threshold: CPUUtilization <= 40 for 300 seconds
for the metric dimensions AutoScalingGroupName = my-asg

Take the action: Remove 2 instances when 40 >= CPUUtilization > -infinity

Add step

Create a simple scaling policy

```
aws autoscaling attach-load-balancers --auto-scaling-group-name my-asg --load-balancer-names my-lb
```

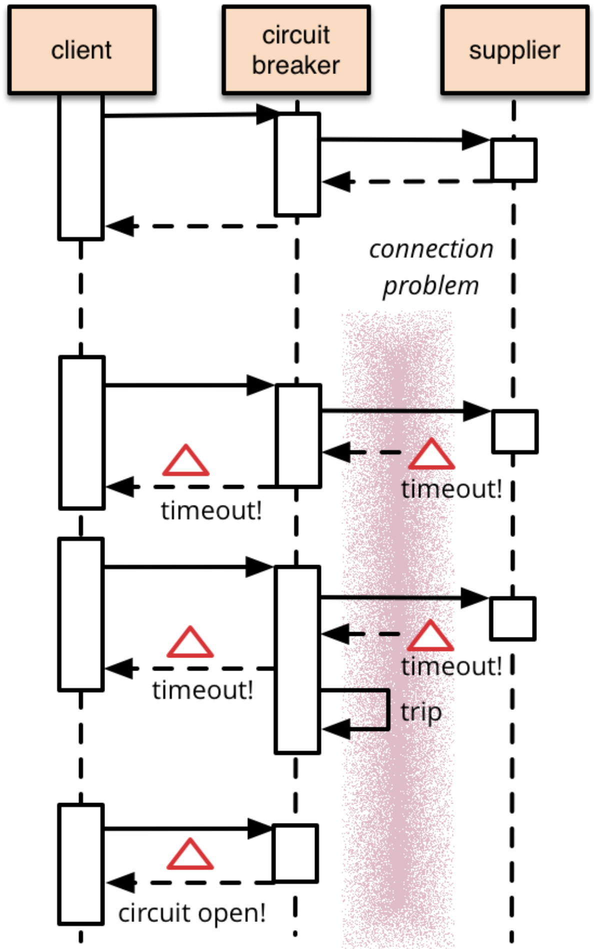
Sources: http://docs.aws.amazon.com/autoscaling/latest/userguide/policy_creating.html
http://docs.aws.amazon.com/autoscaling/latest/userguide/attach-load-balancer-asg.html

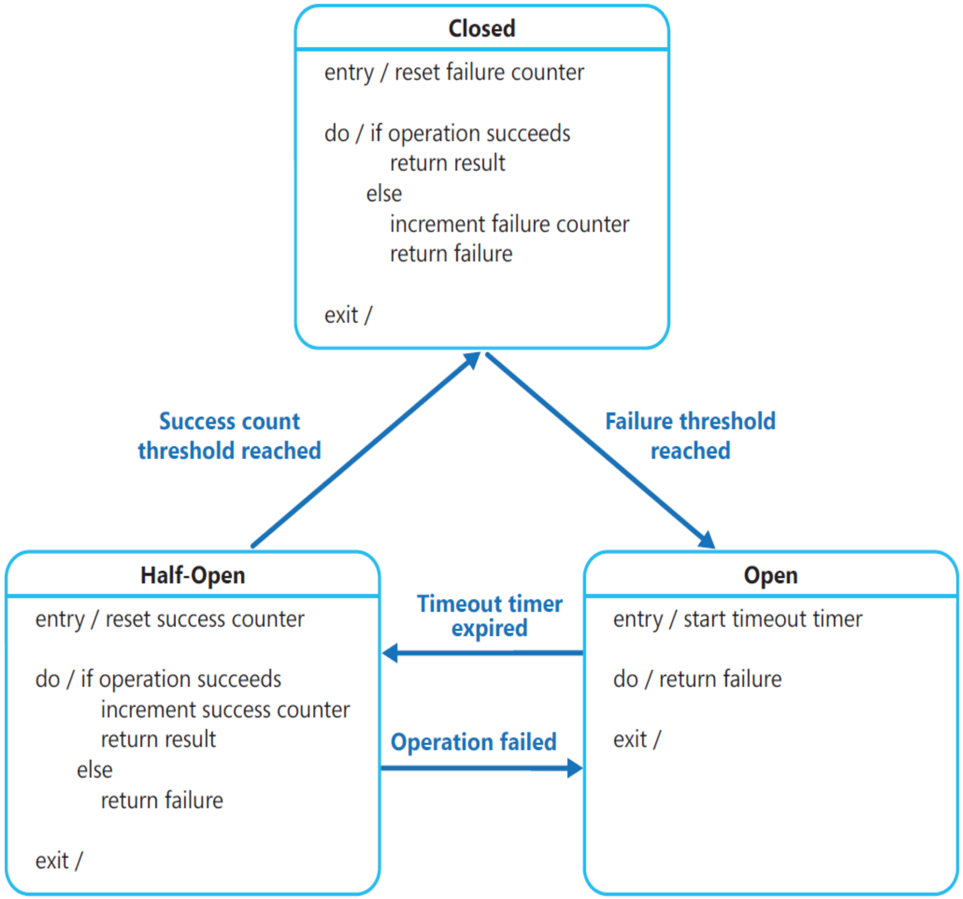
Circuit breaker pattern

- What if service operations fail due to unexpected problems or cascade failures (e.g. busy → timeout)
  - Let the client retry and serve their requests may not be good

→ Circuit breaker pattern prevents clients to retry an operation that would likely fail anyway and to detect when the operation failure is resolved.

Circuit breaker patterm



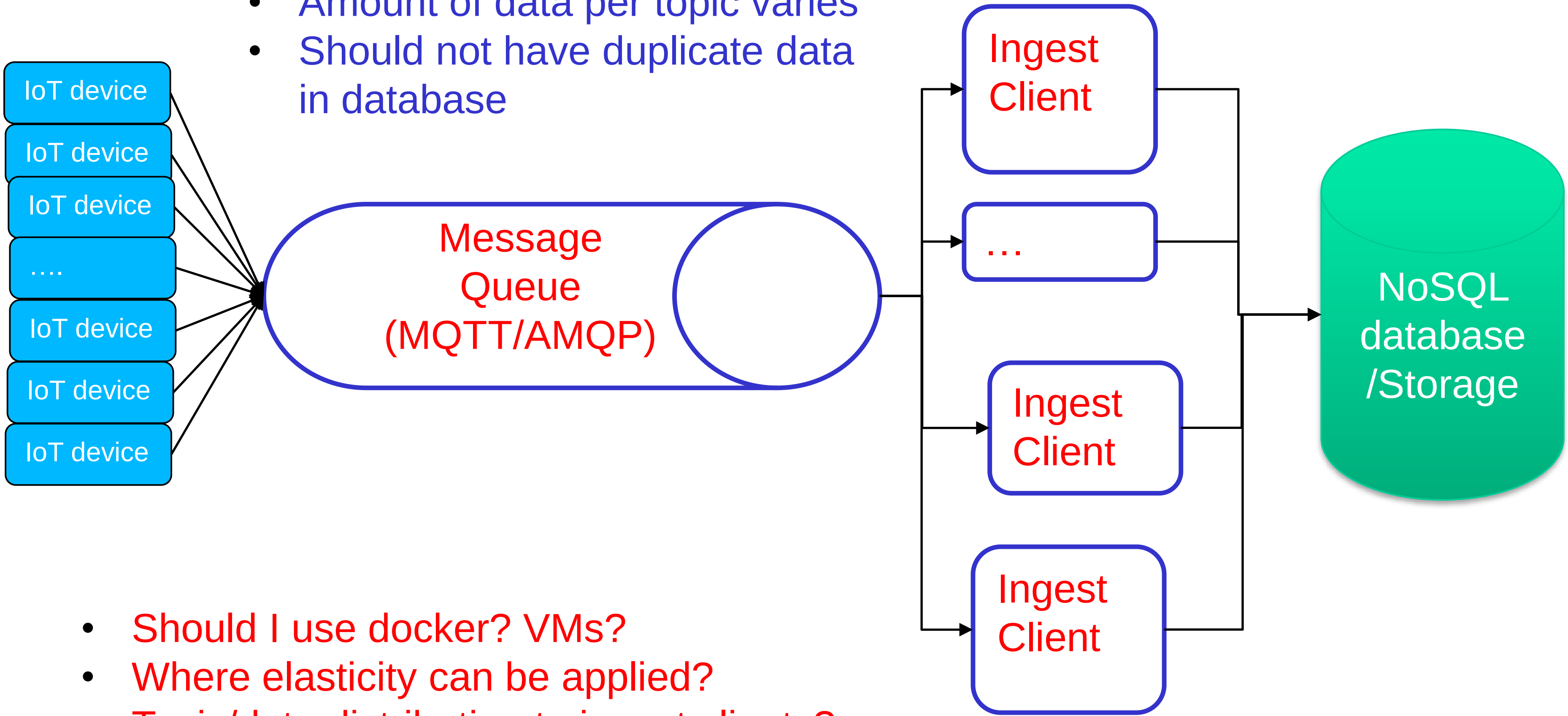


http://martinfowler.com/bliki/CircuitBreaker.html

https://msdn.microsoft.com/en-us/library/dn58978

Open Case Study for recap

- Multiple topics
- Amount of data per topic varies
- Should not have duplicate data in database



- Should I use docker? VMs?
- Where elasticity can be applied?
- Topic/data distribution to ingest clients?

Summary

- Modern distributed applications should consider underlying computing resources
  - Incorporate features to leverage virtualization and elasticity at runtime through programming tasks
- Elasticity and virtualization enable robust, efficient and reliable distributed applications
- They can also simplify the development and operation activities.
- Do exercises by examining examples in this lecture → e.g., providing your dockers for next year students

Further materials

- https://www.computer.org/web/the-clear-cloud/content?g=7477973&type=blogpost&urlTitle=performance-patterns-in-microservices-based-integrations
- Daniel Cukier. 2013. DevOps patterns to scale web applications using cloud services. In Proceedings of the 2013 companion publication for conference on Systems, programming, & applications: software for humanity (SPLASH '13). ACM, New York, NY, USA, 143-152. DOI=http://dx.doi.org/10.1145/2508075.2508432
- https://msdn.microsoft.com/en-us/library/dn600224.aspx

Thanks for your attention

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