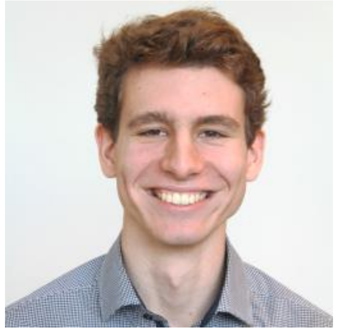
An Introduction to #CloudComputing

Tim
Hegeman



Georgios
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Fabian
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Prof. dr. ir. Alexandru Iosup

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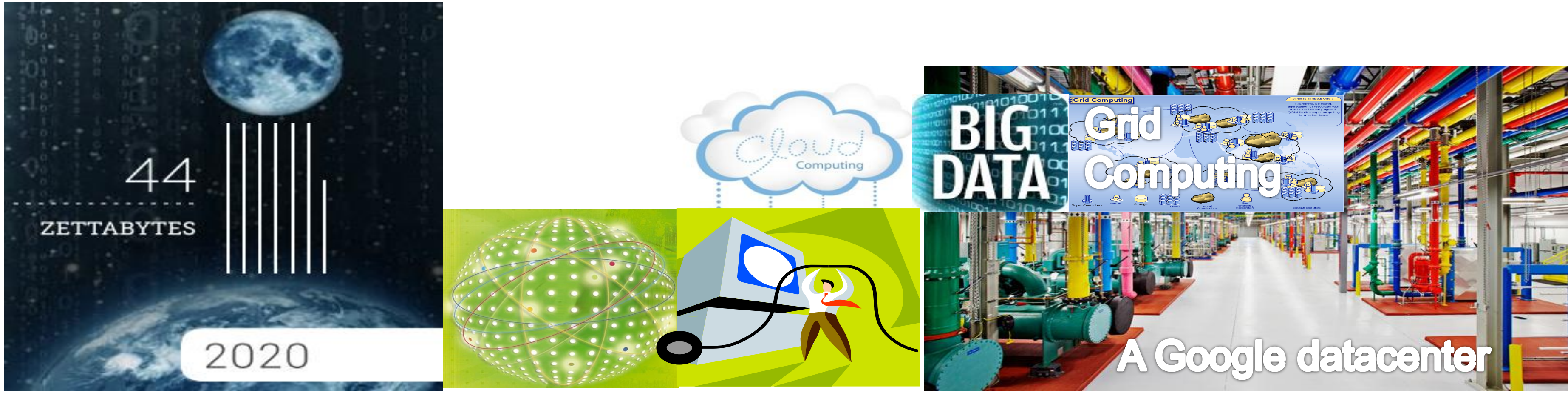
NWO STW COMMIT/

ICT Addresses Major Societal Challenges



The quadruple helix: prosperous society & blooming economy & inventive academia & wise governance depend on ICT

- Enable data access & processing as a fundamental right in Europe
- Enable big science and engineering (2020: €100 bn., 1 mil. jobs)
- “To out-compute is to out-compete”, but with energy footprint <5%
- Keep Internet-services affordable yet high quality in Europe
- The Schiphol of computation: Netherlands as a world-wide ICT hub

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Societal Challenges, A Concrete Example: Graph Processing for Everyone

LinkedIn

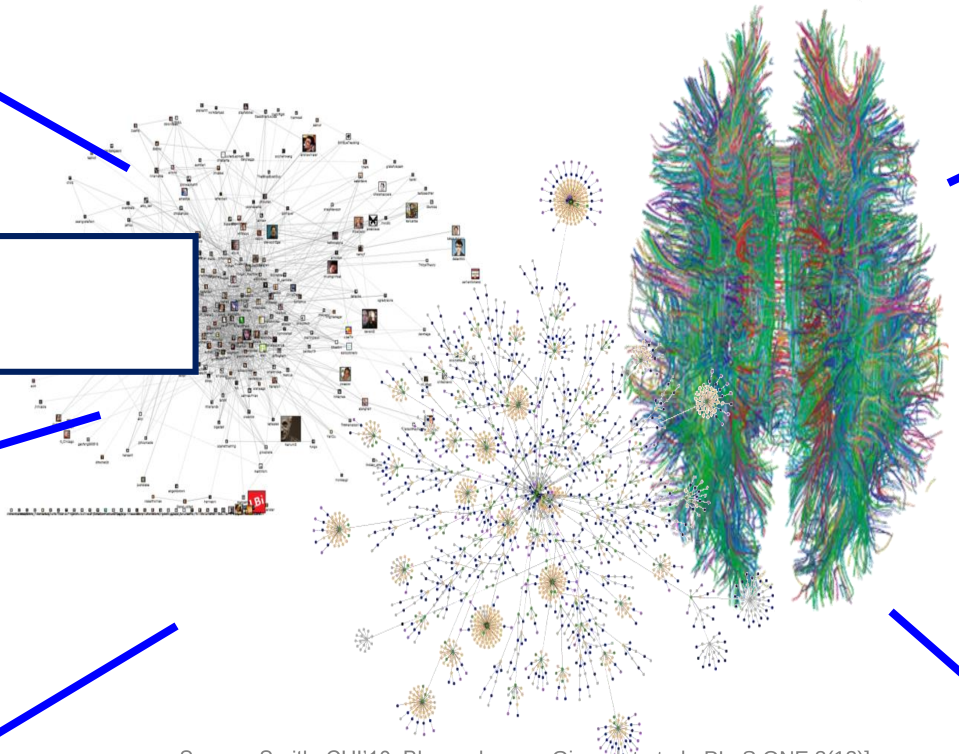
Oracle 1.2M followers,
132k employees

company/day:
40-60 posts, 500-700 comments

YAHOO!

friendster

(SME*)



Source: Smith, CHI'10; Blog webpage; Gigandet et al., PLoS ONE 3(12)]

270M MAU
200+ avg followers

>54B edges

1.2B MAU 0.8B DAU
200+ avg followers

>240B edges

(SME*)

XFIRE

* SMEs in EU/NL= 60% gross value added, little to no ICT expertise

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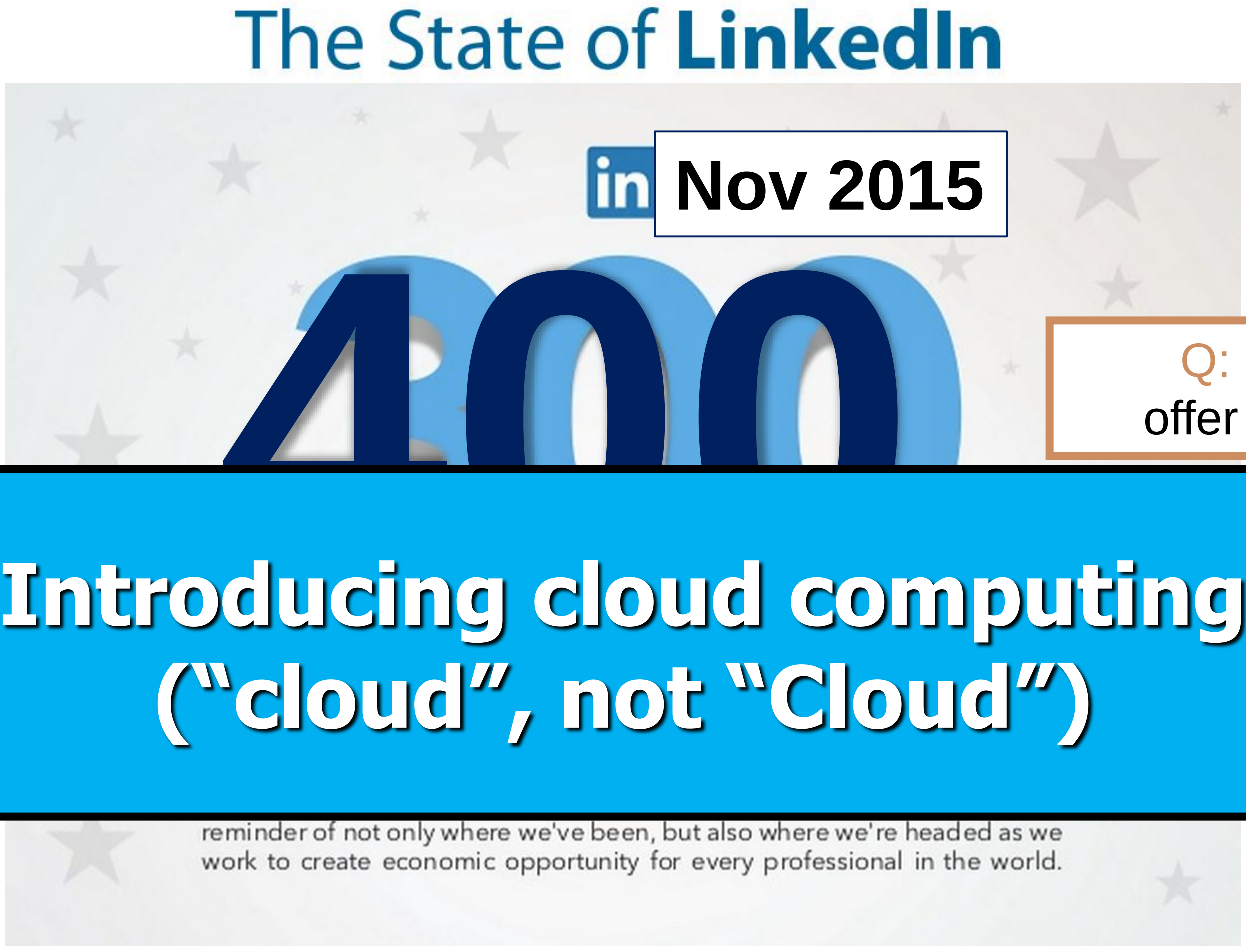
LinkedIn: Job-Seeker & Job-Creator Match



Nov 2015

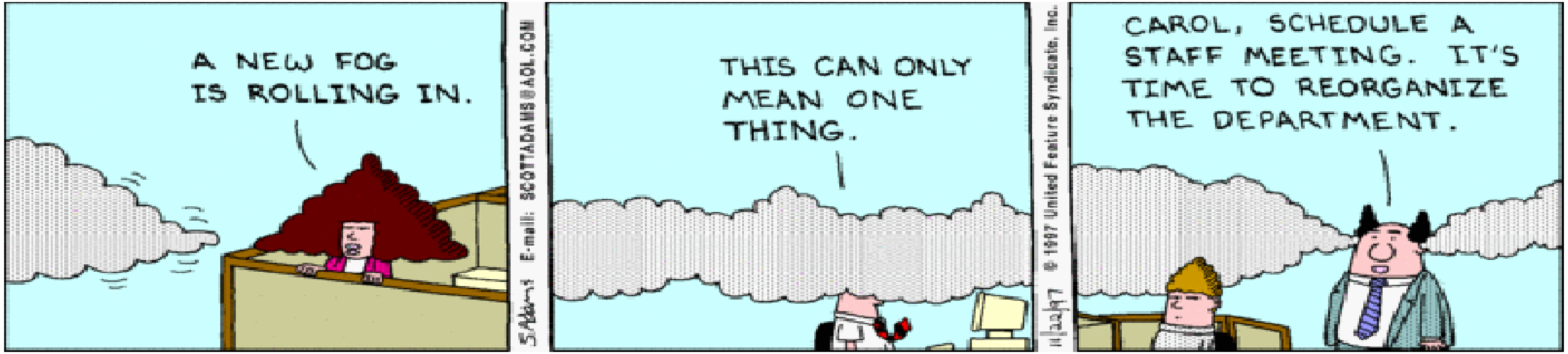
Q: How can LinkedIn offer this service to you?

Introducing cloud computing ("cloud", not "Cloud")

Sources: Vincenzo Cosenza, The State of LinkedIn, http://vincos.it/the-state-of-linkedin/
via Christopher Penn, http://www.shiftcomm.com/2014/02/state-linkedin-social-media-dark-horse/

What is Cloud Computing?
1. A Cloudy Buzzword

- 18 definitions in computer science (ECIS’10). NIST has one. Cal has one. We have one.
- “We have redefined cloud computing to include everything that we already do.” Larry Ellison, Oracle, 2009



Source: http://dilbert.com/strips/comic/1997-11-22/

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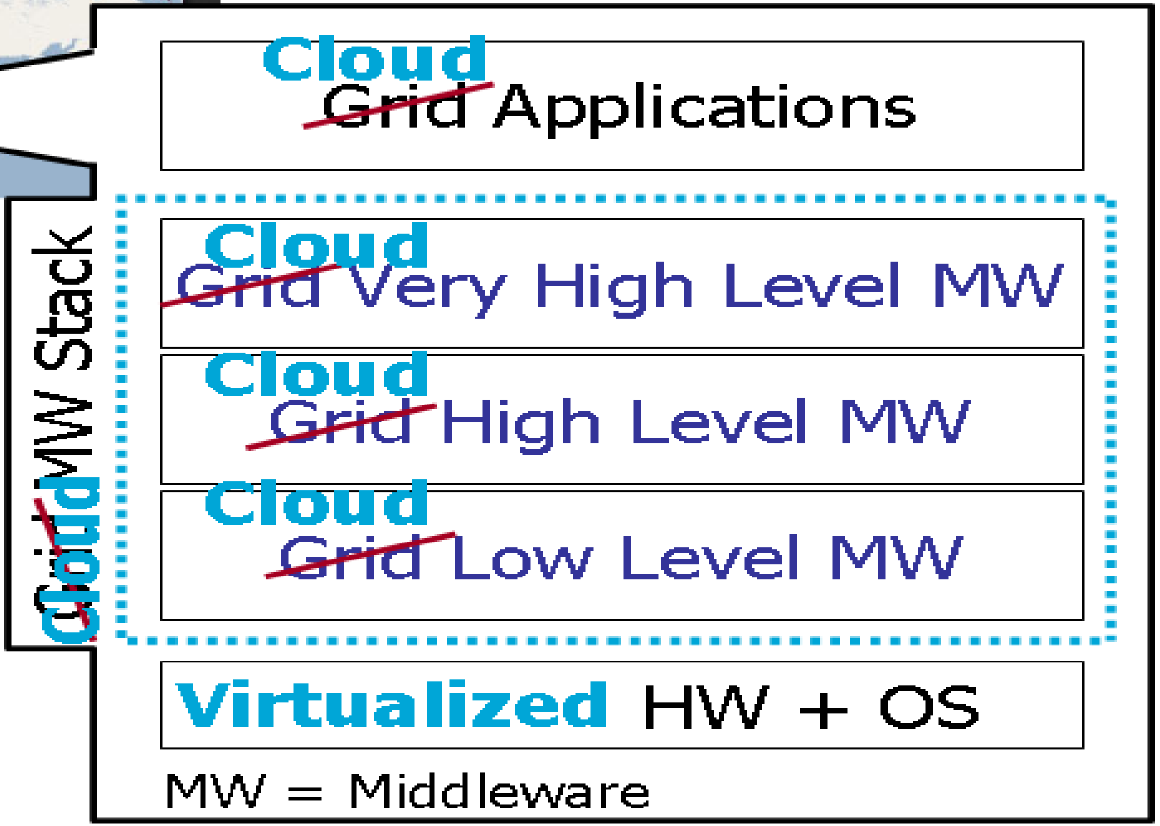
What is Cloud Computing?
2. A Descendant* of the Grid Idea

* Subset.

Source: http://royal.pingdom.com/2008/04/11/map-of-all-google-data-center-locations/

"A computational grid is a hardware and software infrastructure that provides dependable, consistent, pervasive, and inexpensive access to high-end computational capabilities [+ for] nontrivial QoS." I. Foster, 1998 + 1999



Have you noticed "QoS"? What is that?

What is Cloud Computing?
3. A Useful IT Service

"Use only when you want! Pay only for what you use!"

Main Characteristics of IaaS Clouds

1. On-Demand Pay-per-Use
2. Elasticity (cloud concept of Scalability)
3. Resource Pooling
4. Fully automated IT services
5. Quality of Service

Q: Sounds great, but …
How can we make
all this stuff happen?

**Introducing datacenters &
datacenter-based clouds =
ICT service creation
for everyone**

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Intro to Cloud Computing

TU: 1 — Pitch on Datacenter-Based Cloud Computing

Here or @home

Interactive

1 — The Golden Age of Datacenters

4 — A Delft View on Datacenters

- The core idea of datacenter computing
- The main enabling technologies for datacenter computing
- The main challenges and techniques

7 — Making Clouds Tick

- Addressing the Scheduling challenge
- Addressing the Ecosystem Navigation challenge
- Addressing the Big Cake challenge
- Addressing the Efficiency challenge

— Reality Check

This Is the Golden Age of Datacenters

Factories Powering the Goods Economy and Better Living Standards

Creator

Factory (1980)

Consumer

Datacenters = Digital Factories Powering the Digital Economy and Better Living Standards

Creator

Datacenter (2010)

Consumer

We want more of this

"15% ICT market is simple DC services"

"Already 60+ bn.€/year"

"Consume more energy than the transport industry"

We want less of this (and other issues raised by DCs)

Intro to Cloud Computing

Here or @home | Interactive

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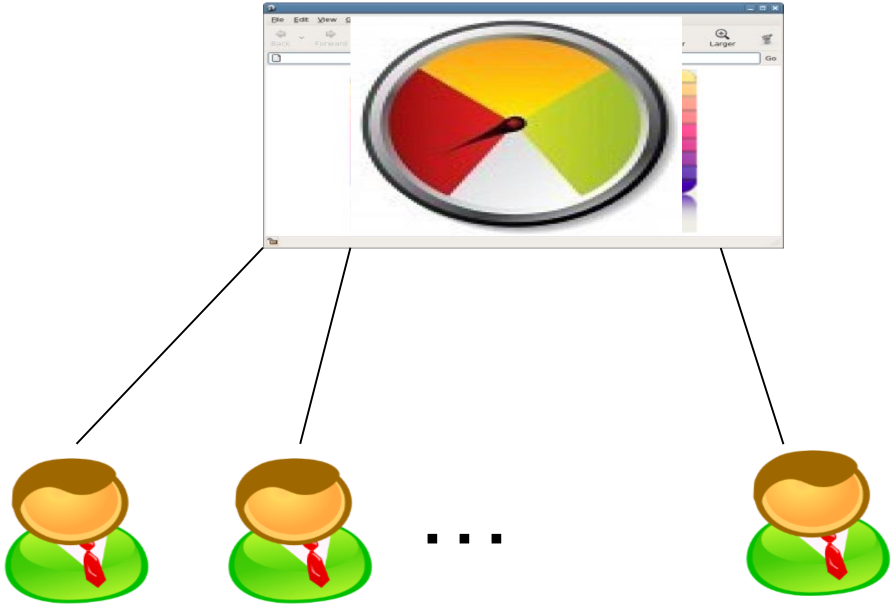
10' — Reality Check

Joe Has an Idea ($$$)

[A. Antoniou, MSc Thesis, TU Delft, 2012]

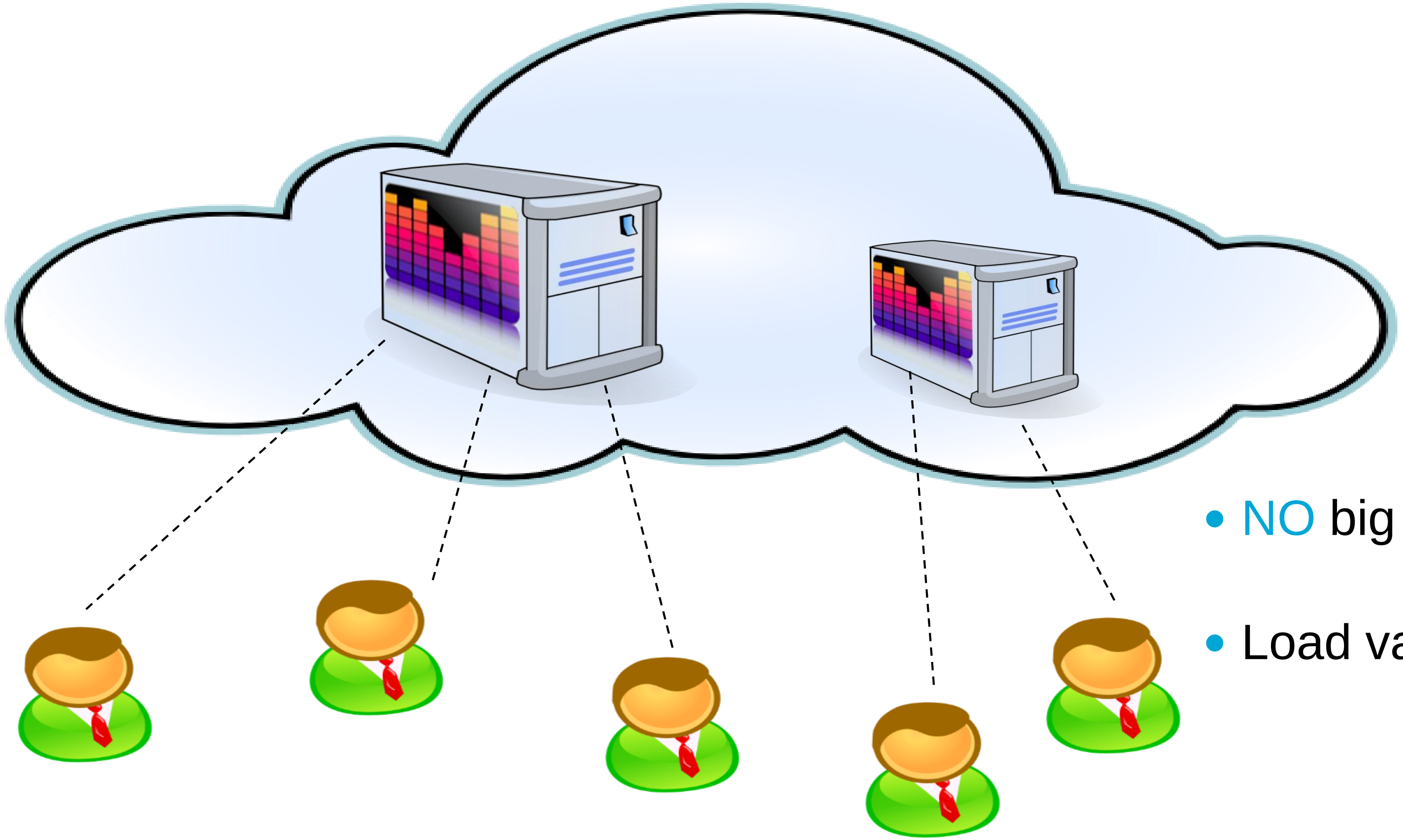
Solution #1 Buy then Maintain

- Big up-front commitment
- Load variability: NOT supported



[A. Antoniou, MSc Thesis, TU Delft, 2012]

Solution #2   Deploy on IaaS Cloud

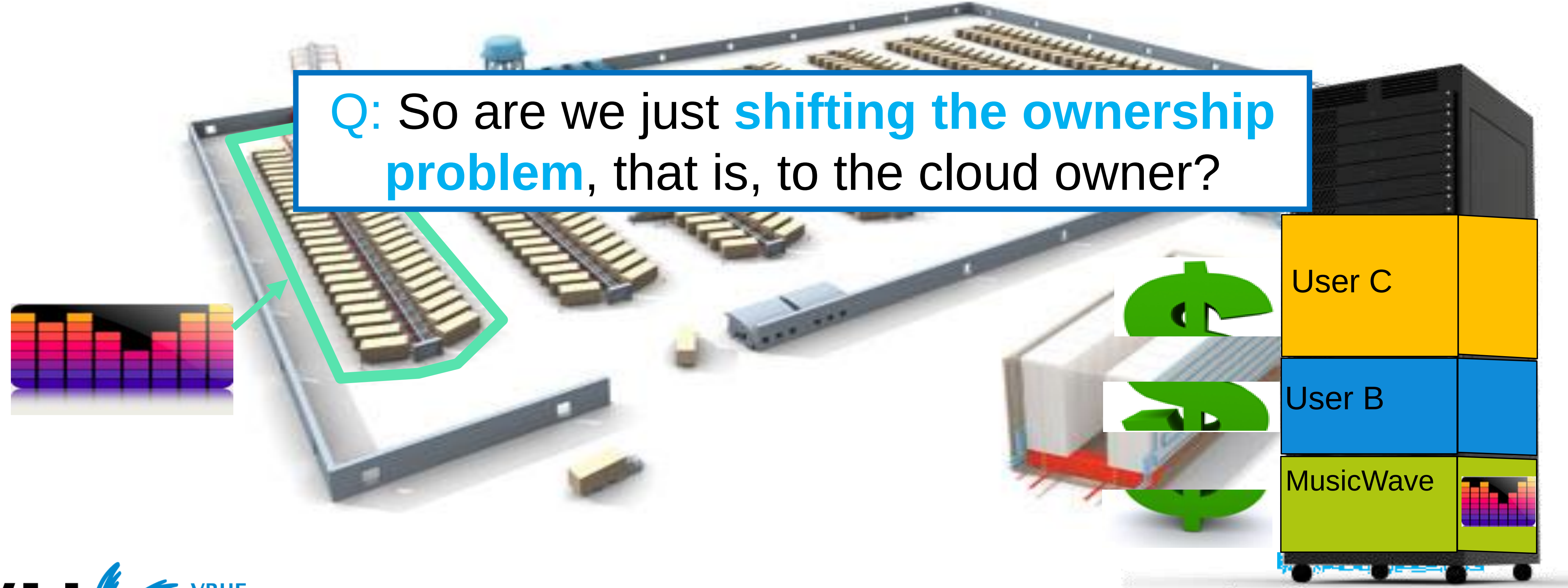


- NO big up-front commitment
- Load variability: supported

[A. Antoniou, MSc Thesis, TU Delft, 2012]

Inside a Cloud Datacenter: Infrastructure as a Service

Q: So are we just **shifting the ownership problem**, that is, to the cloud owner?



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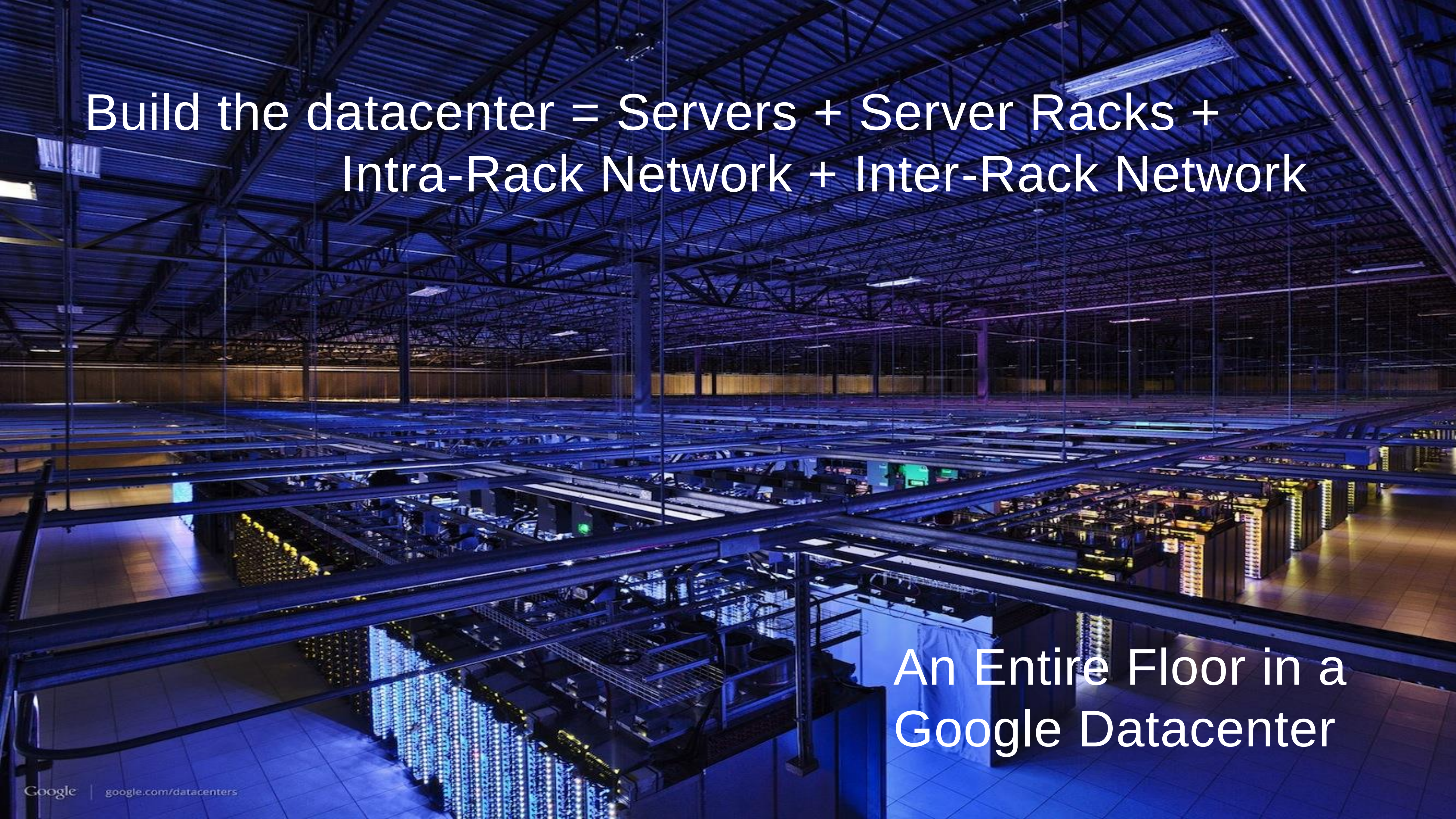
10' — Reality Check

The Cloud Owner Perspective

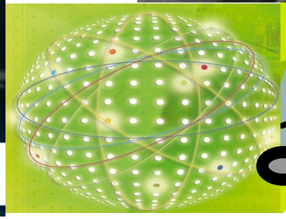
- Build the datacenter
- Operate the datacenter

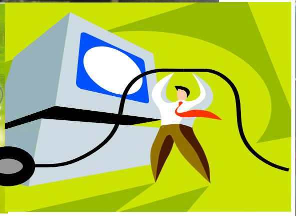
Build the datacenter = Servers + Server Racks + Intra-Rack Network + Inter-Rack Network

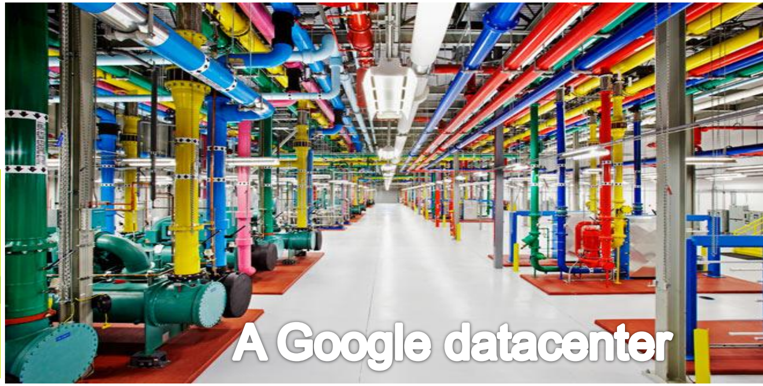


An Entire Floor in a Google Datacenter

Datacenter = commodity high-performance ICT







- Large-scale infrastructure
- High-tech automated software to manage
- Inter-connected computer clusters
- High-end computation, storage, network
- Large memory capacity
- “my other computer is a datacenter”

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The Pizza-Box Stack

- The 1U server

The Pizza-Box Stack

- The 1U server

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The Pizza-Box Stack

- The 1U server

The Pizza-Box Stack

- The 1U server
- The 19” server rack (42U is r
  - Half-racks also common

Q: What is a **half-rack**,
and why is it useful?

The Data Center Network

- Network bandwidth per rack
  - 1 x 48 port GigE switch = 40 UP, 8 DOWN links

Q: What is are the characteristics of **research**, **enterprise**, and **consumer** hardware (and other services)?

  - (consumer) 100 Mbps for 1 GigE rack switch
  - (enterprise) 1 Gbps for 10 GigE rack switch
  - (enterprise) 10 GBps for ncHT3 (supercomputing class)
  - (research) 1 Tbps!~100 GBps optical (not yet production-ready)

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Source: Dennis Abts (Google, Inc.) and John Kim (KAIST), High Performance Data Center Networks, 2011.

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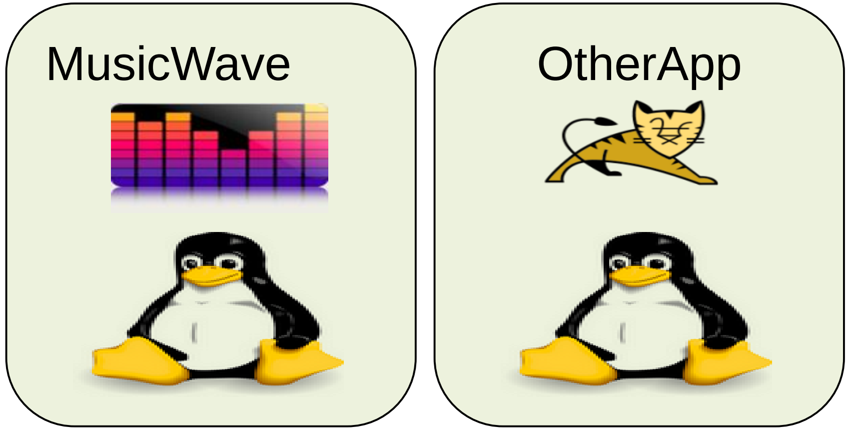
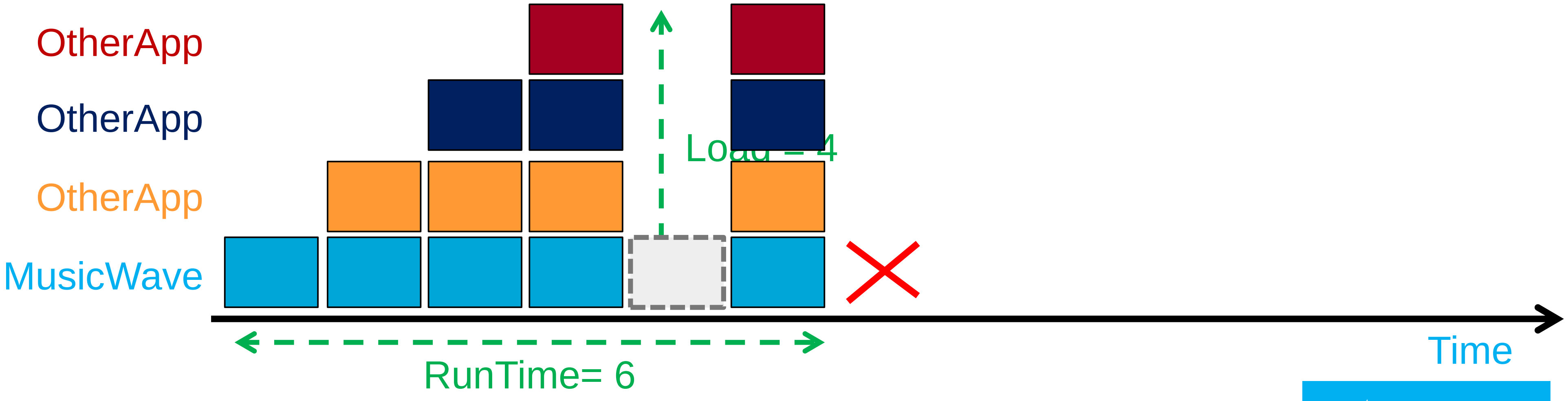
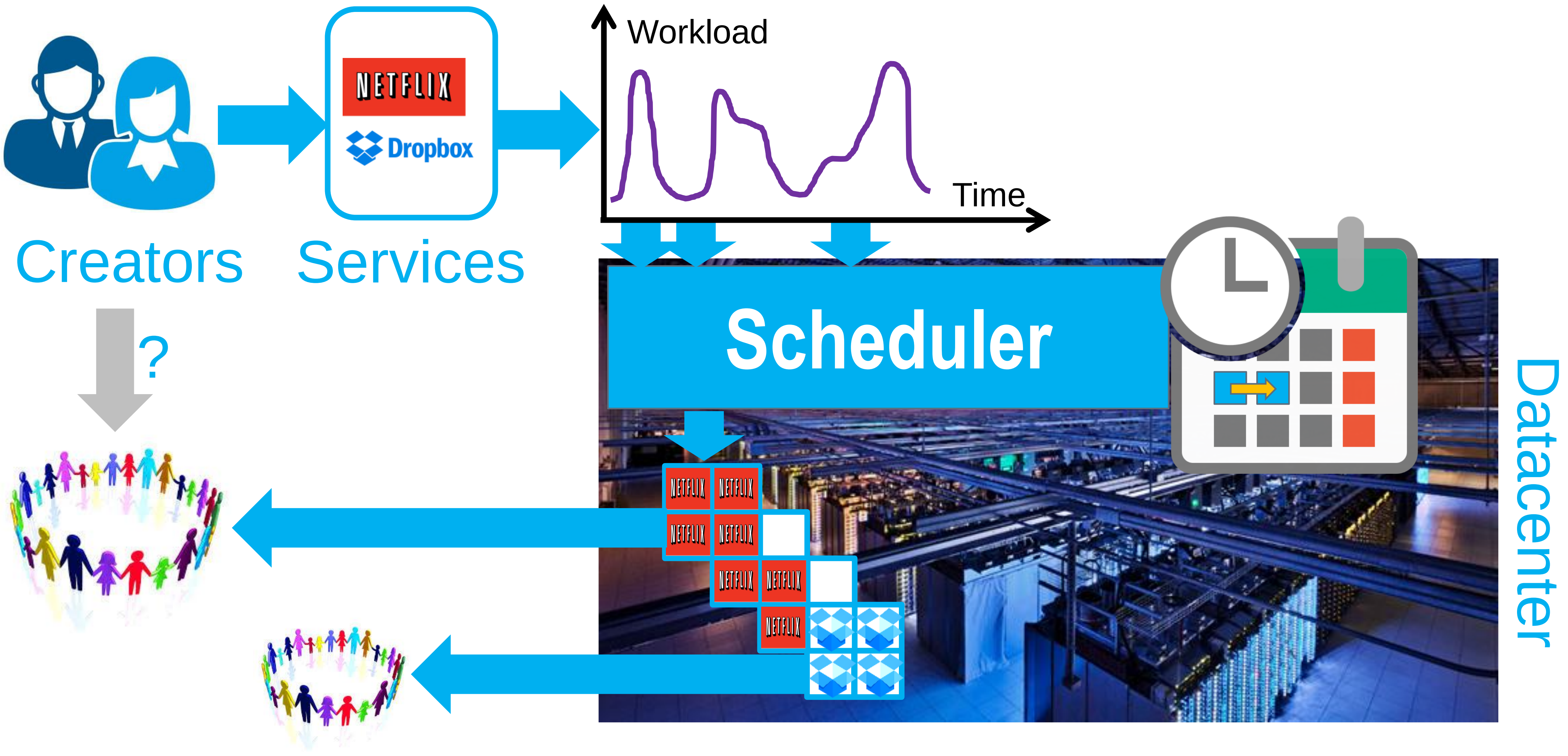
What does it mean to operate the DC? Running Workloads





Using a Scheduler to Run Workload

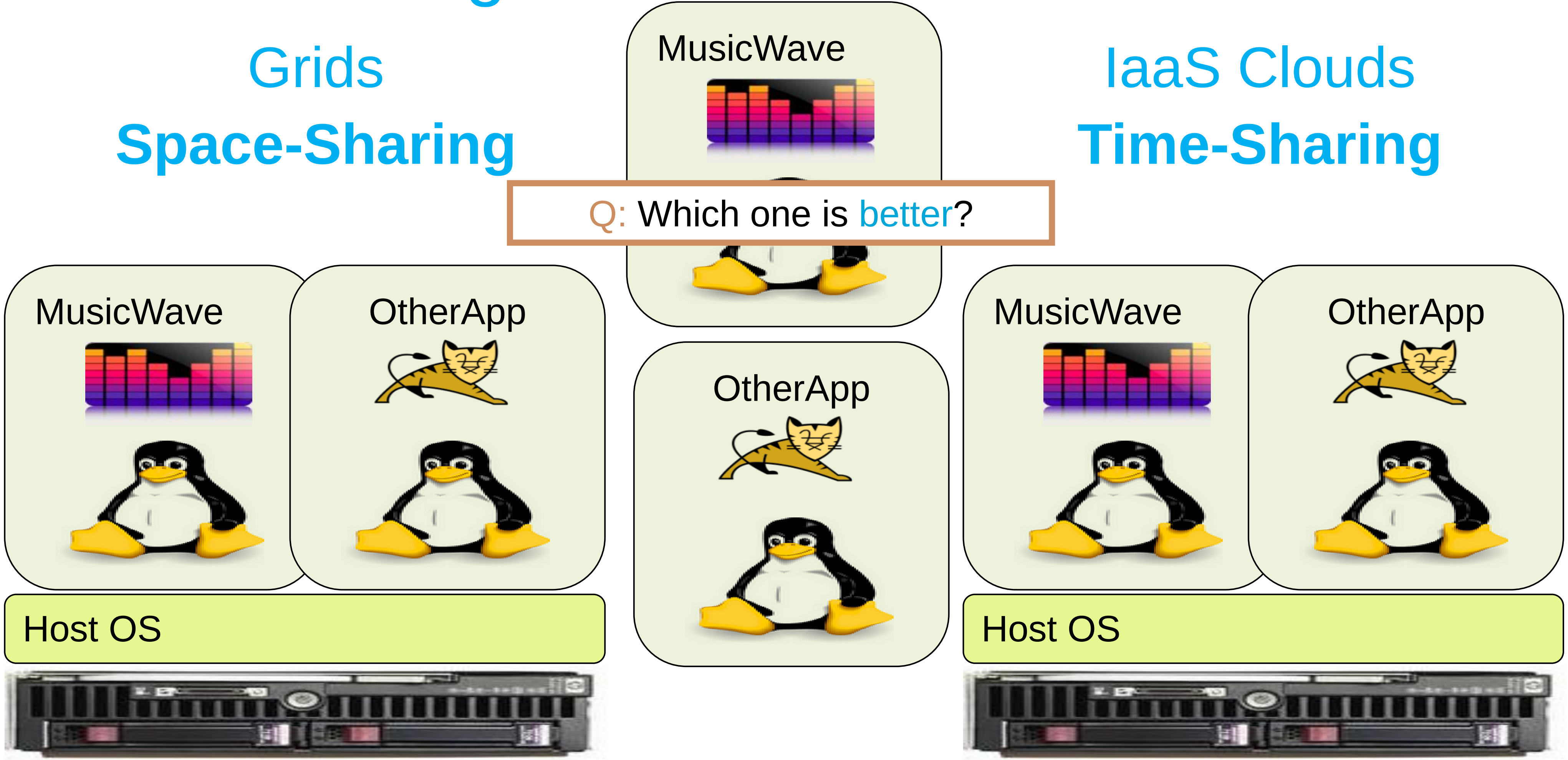


Resource Sharing Models

Grids
Space-Sharing

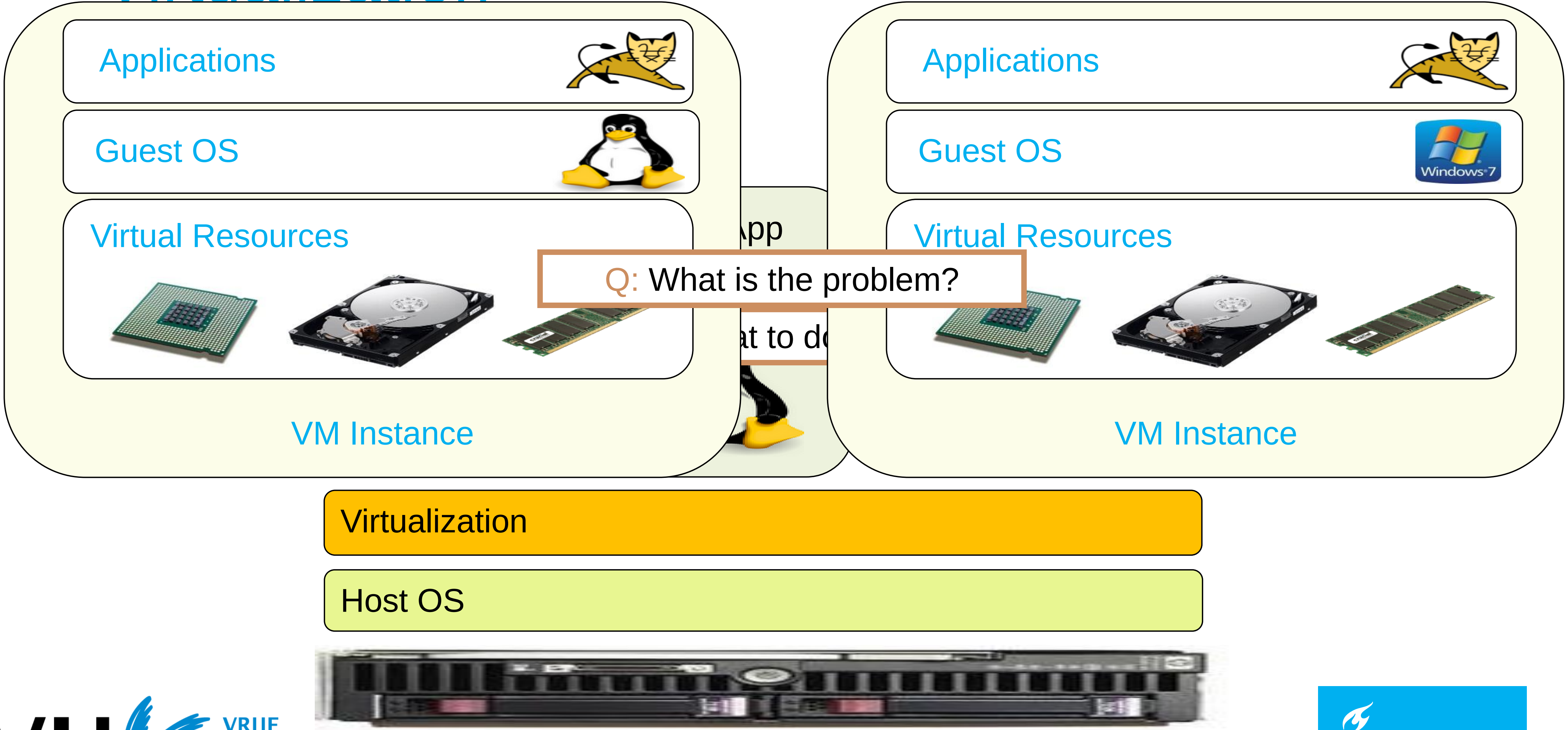
IaaS Clouds
Time-Sharing

Q: Which one is better?



(Source: A. Iosup, Course IN4392, TU Delft, 2014)

Virtualization

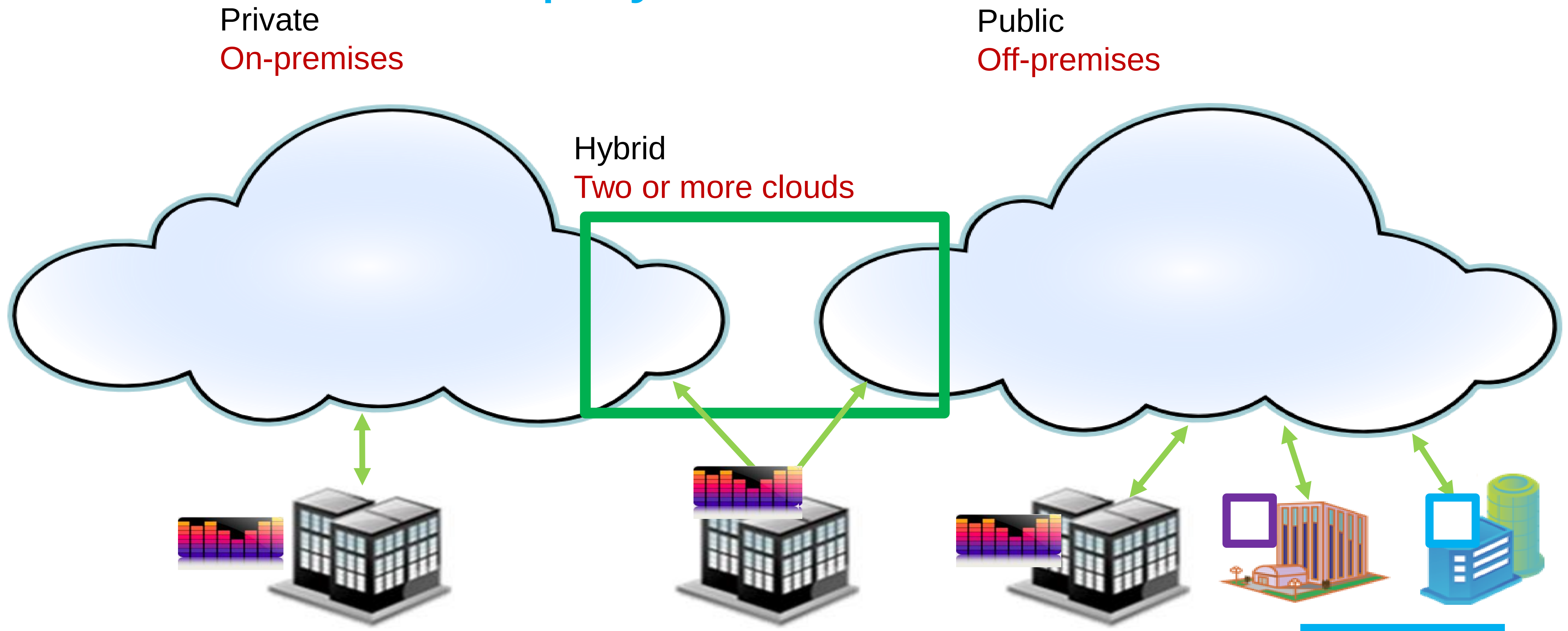


(Source: A. Iosup, Course IN4392, TU Delft, 2014)

The Cloud User Perspective

- Lease the resources
- Use the resources

Where to Lease Resources From? IaaS Cloud Deployment Models

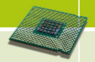
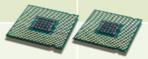
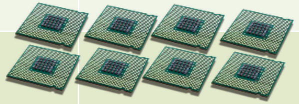


(Source: A. Antoniou, MSc Defense, TU Delft, 2012. Original idea: Mell and Grance, NIST Spec.Pub. 800-145, Sep 2011.)

Use Case:
Amazon Elastic Compute Cloud (EC2)

- Prominent IaaS provider
  (also Microsoft, Google, Alibaba)
- Datacenters all over the world
- Many VM instance types
- Per-hour **charging**
- **Auto-scaling with simple policies**

amazon web services™

Instance	Capacity	US$/hour
m1.small		0.10
m1.large		0.38
c1.xlarge		0.76

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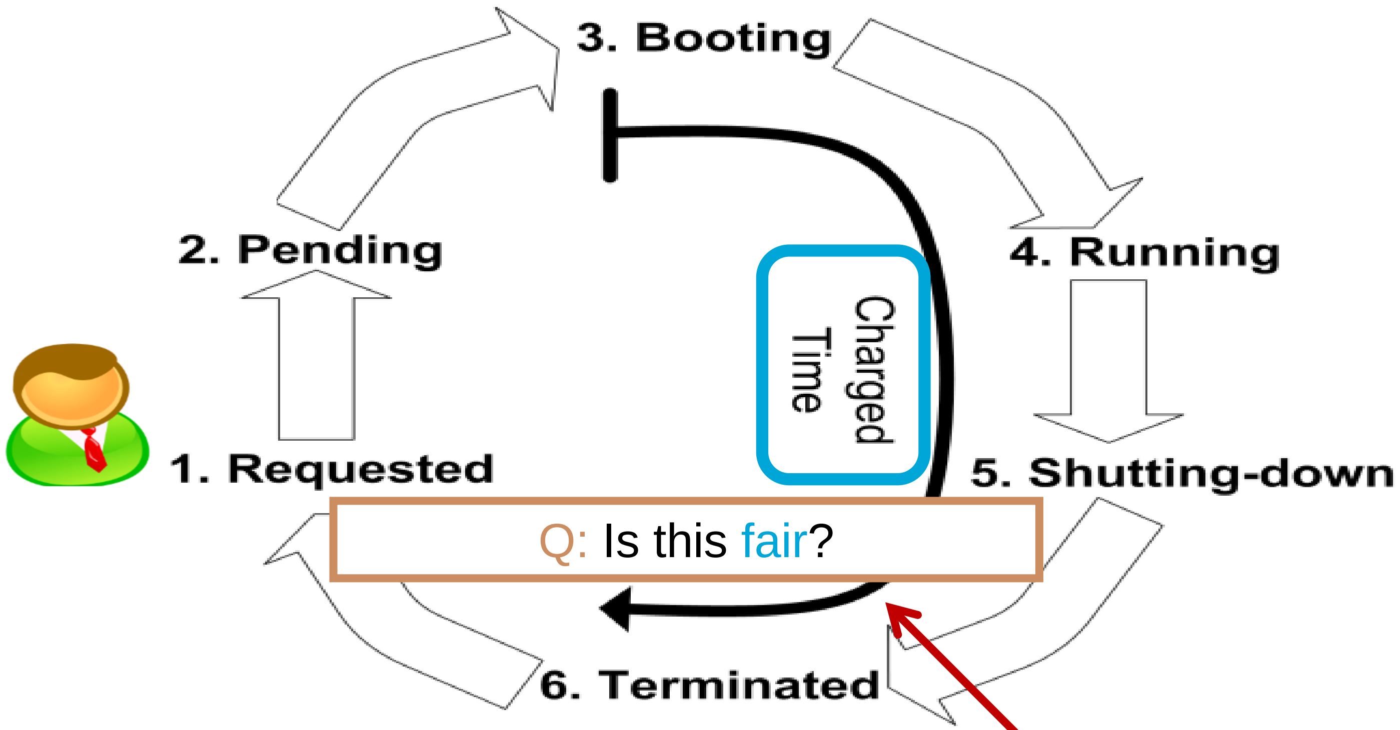
What Does It Mean To Lease A Resource?
The Virtual Machine Lifecycle



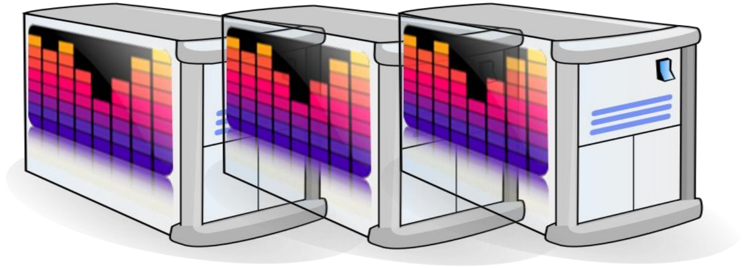
At this scale, computer science is also about ethics, law, society, etc.

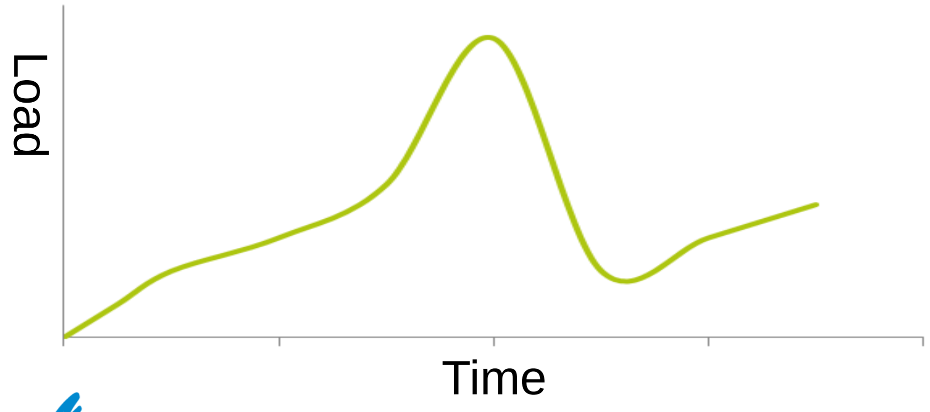
(Source: A. Antoniou, MSc Defense, TU Delft, 2012.)

Provisioning and Allocation of Resources

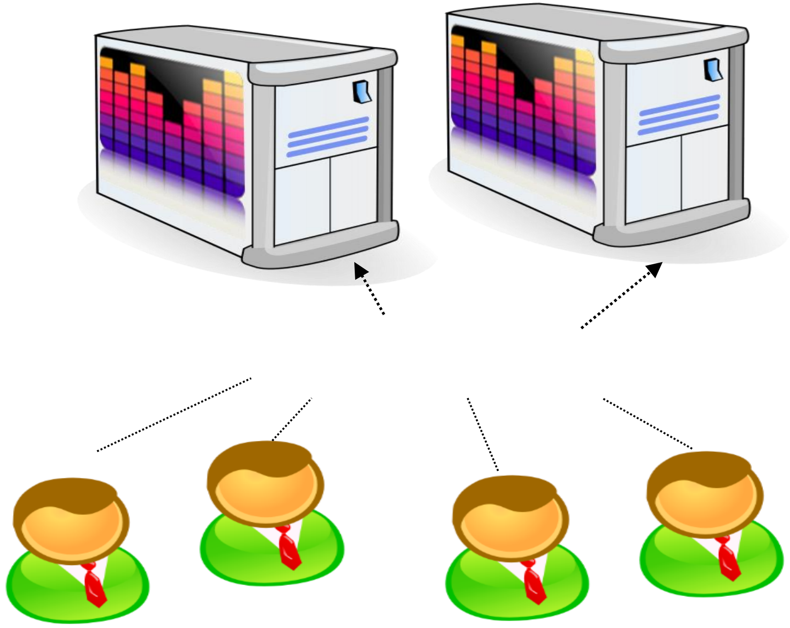
Q: How do service creators get resources?

Provisioning





Allocation

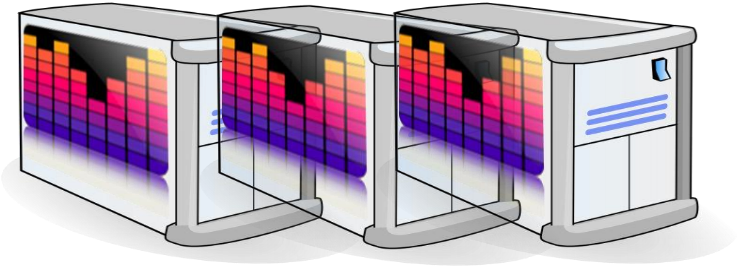


Provisioning and Allocation *Policies*

Q: How many policies exist?

Q: How to select a policy?

Provisioning



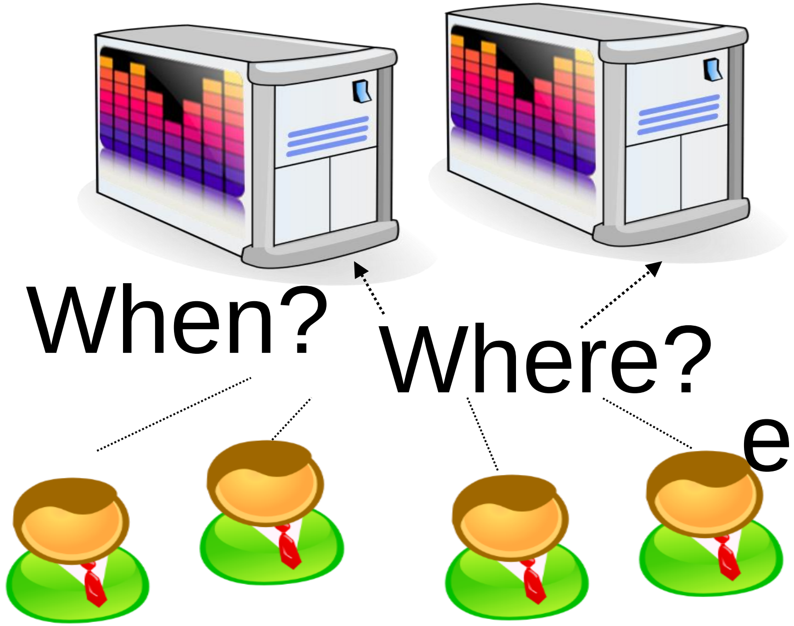
When? From where?

How many?

Which type?

etc.

Allocation



When? Where?

etc.

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(Source: A. Antoniou, MSc Defense, TU Delft, 2012.)

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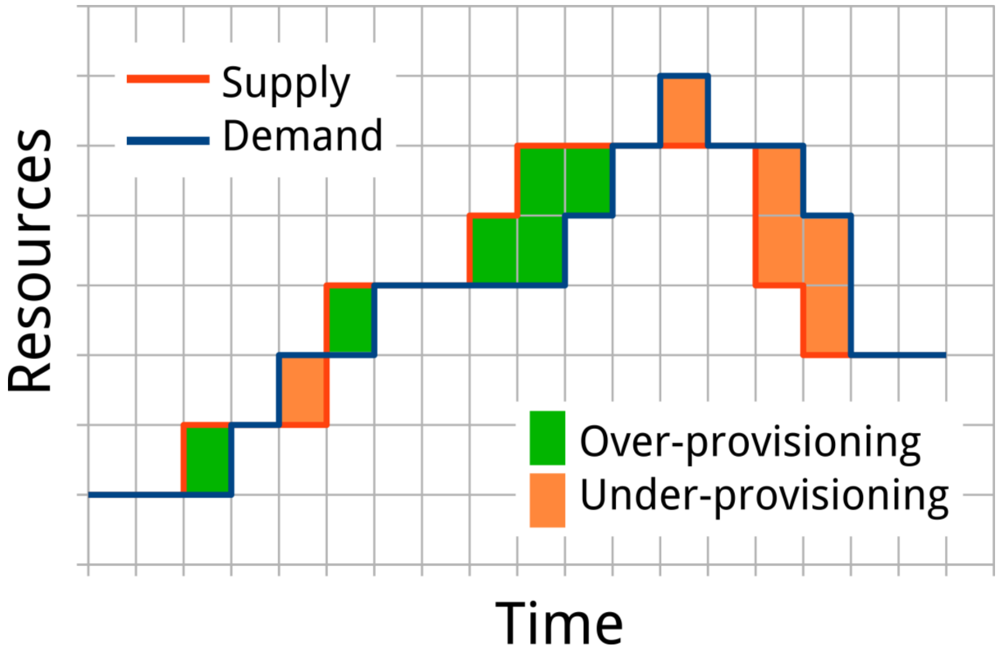
Auto-Scalers = automatically provision resources, on-demand



(Source: A. Ilyushkin, N. Herbst, A. Ali El Din, SPEC RG Cloud Group, 2016)

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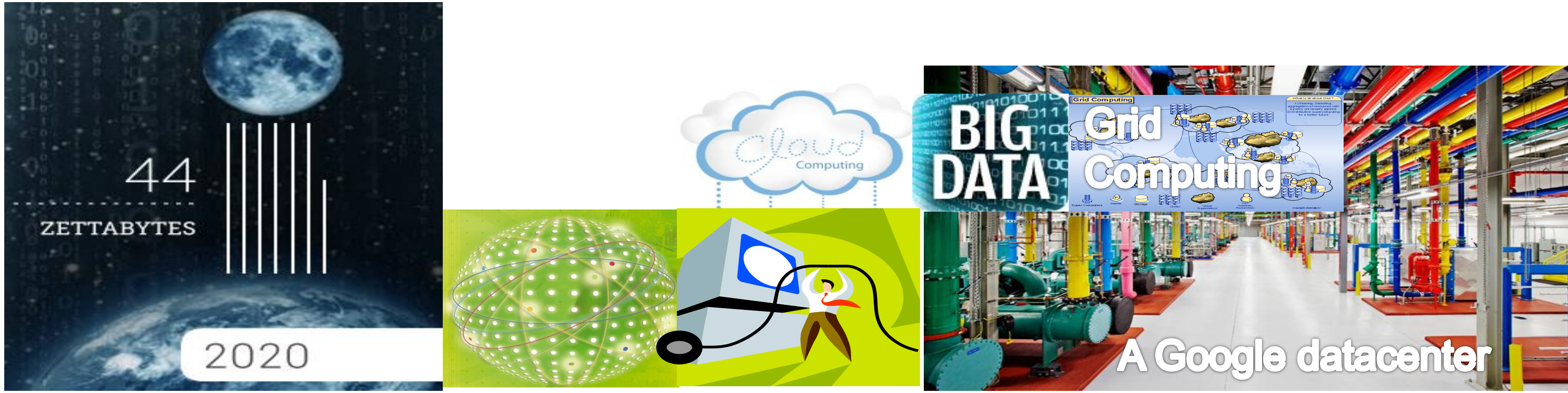
10' —— Reality Check

Scientific Challenges to Get This Done



How to massivize?

- Super-scalable, super-flexible, yet efficient ICT infrastructure
- End-to-end automation of large-scale, simple and complex processes
- Dynamic, compute- and data-intensive workloads
- Evolving, heterogeneous hardware and software
- Strict performance, cost, energy, reliability, and fairness requirements
- … all these, without needing much expertise from customers

↖ There's a lot we don't know how to do yet…you can help!

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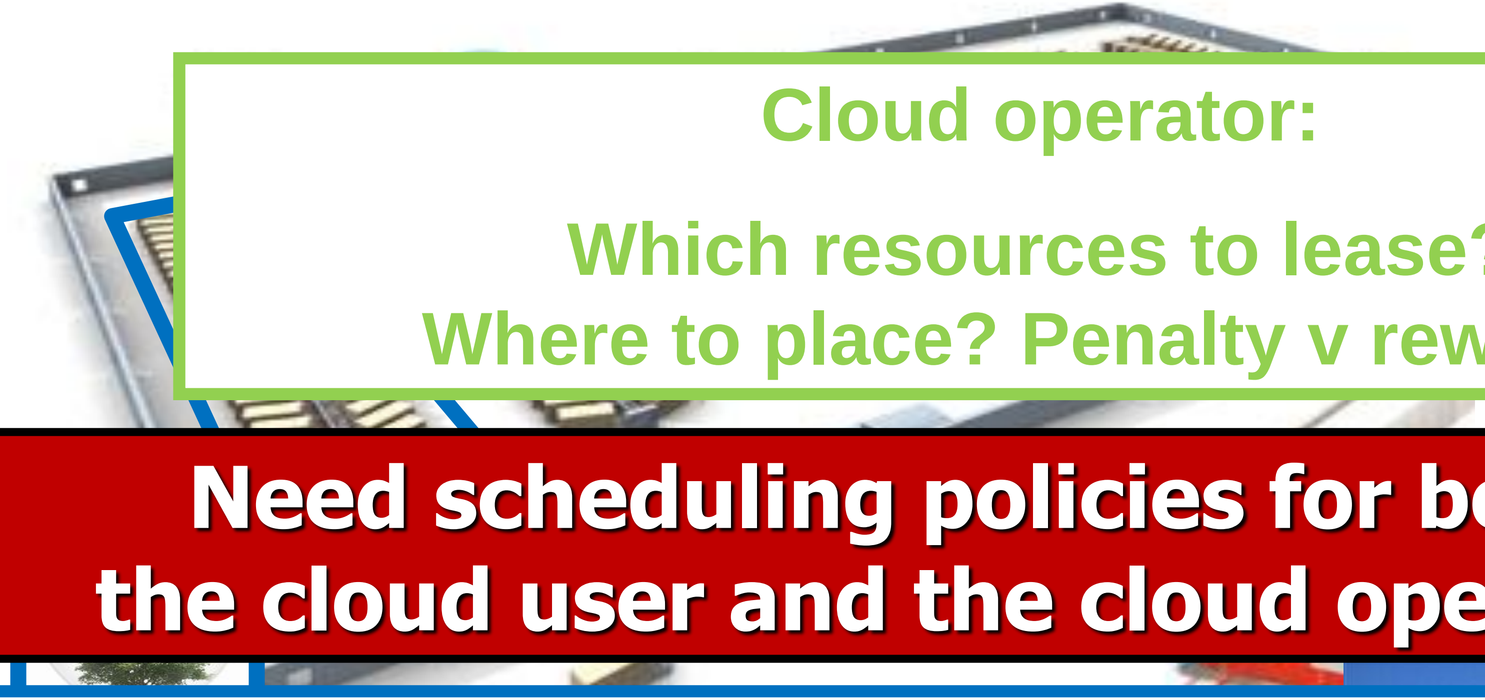
The Scheduling Challenge



Cloud operator:

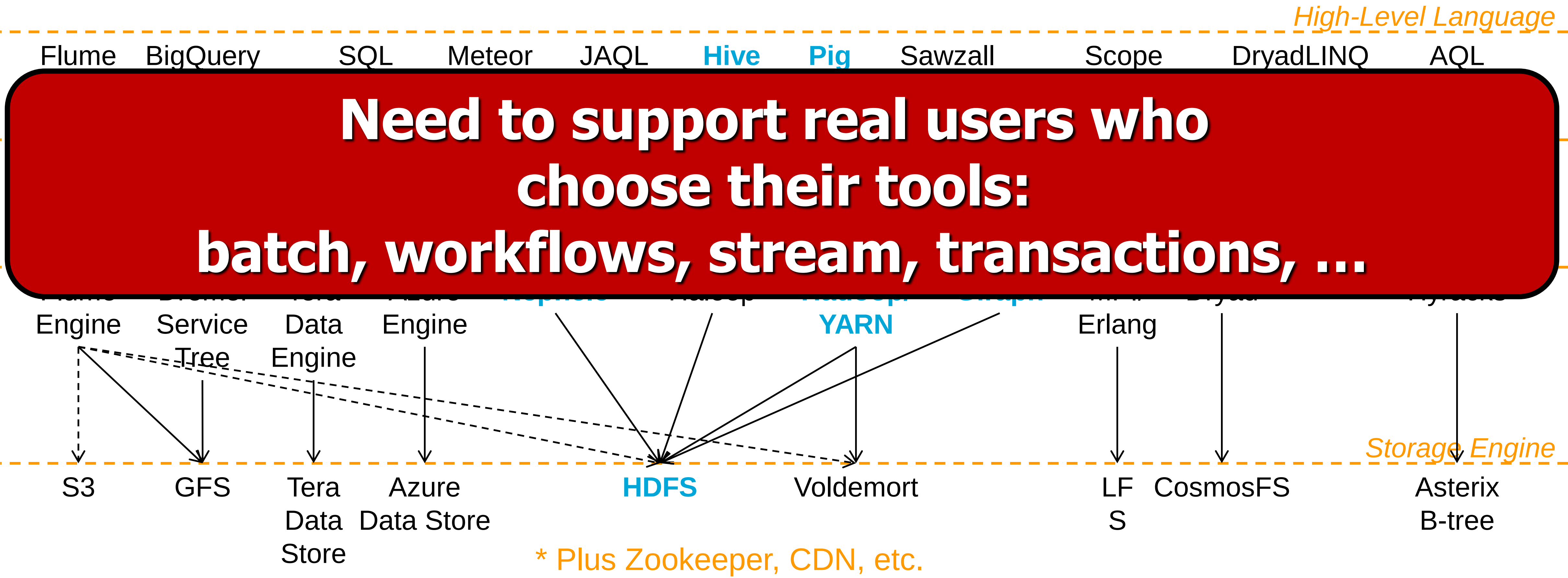
Which resources to lease?
Where to place? Penalty v reward?

Need scheduling policies for both the cloud user and the cloud operator

Cloud customer:

Which resources to lease?
When? How many? When stop?
Utility functions?

The Ecosystem Navigation Challenge

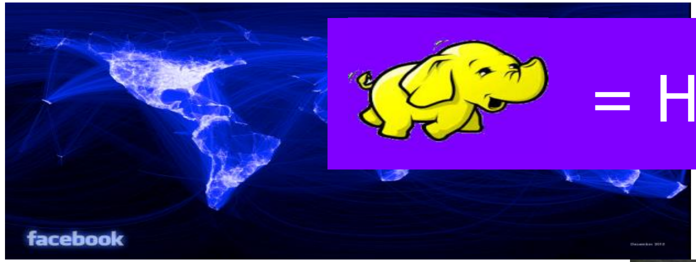


Need to support real users who choose their tools: batch, workflows, stream, transactions, …

* Plus Zookeeper, CDN, etc.

The “Big Cake” Challenge In the Datacenter

Online Social Networks



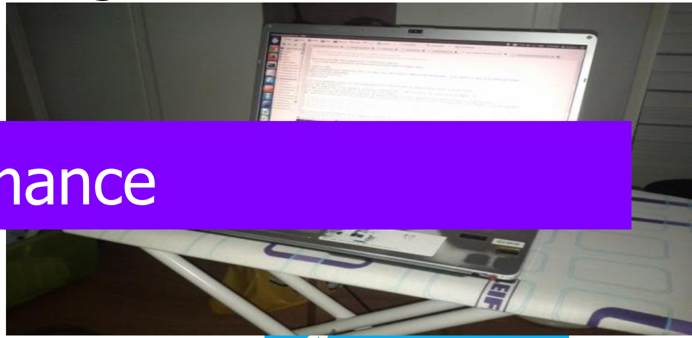
Financial Analysts

= Hadoop / MapReduce framework

Need multi-tenant, self-aware schedulers and resource managers

Universe Explorers

Big Data Enthusiast



Multiple frameworks = Isolation, especially performance

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(Source: B. Ghit et al., SIGMETRICS 2014)

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Jevons Effect: More Efficient, Less Capable?

Over 500 YouTube videos have at least 100,000,000 viewers each.

Need to be more efficient in how we use our resources, (also educate others to not abuse "infinite" capacity)

PSY Gangnam consumed ~500GWh

= more than entire countries* in a year (*41 countries),
= over 50MW of 24/7/365 diesel, 135M liters of oil,
= 100,000 cars running for a year, ...

Source: Ian Bitterlin and Jon Summers, UoL, UK, Jul 2013.
Note: Psy has >3 billion views (Nov 2015).

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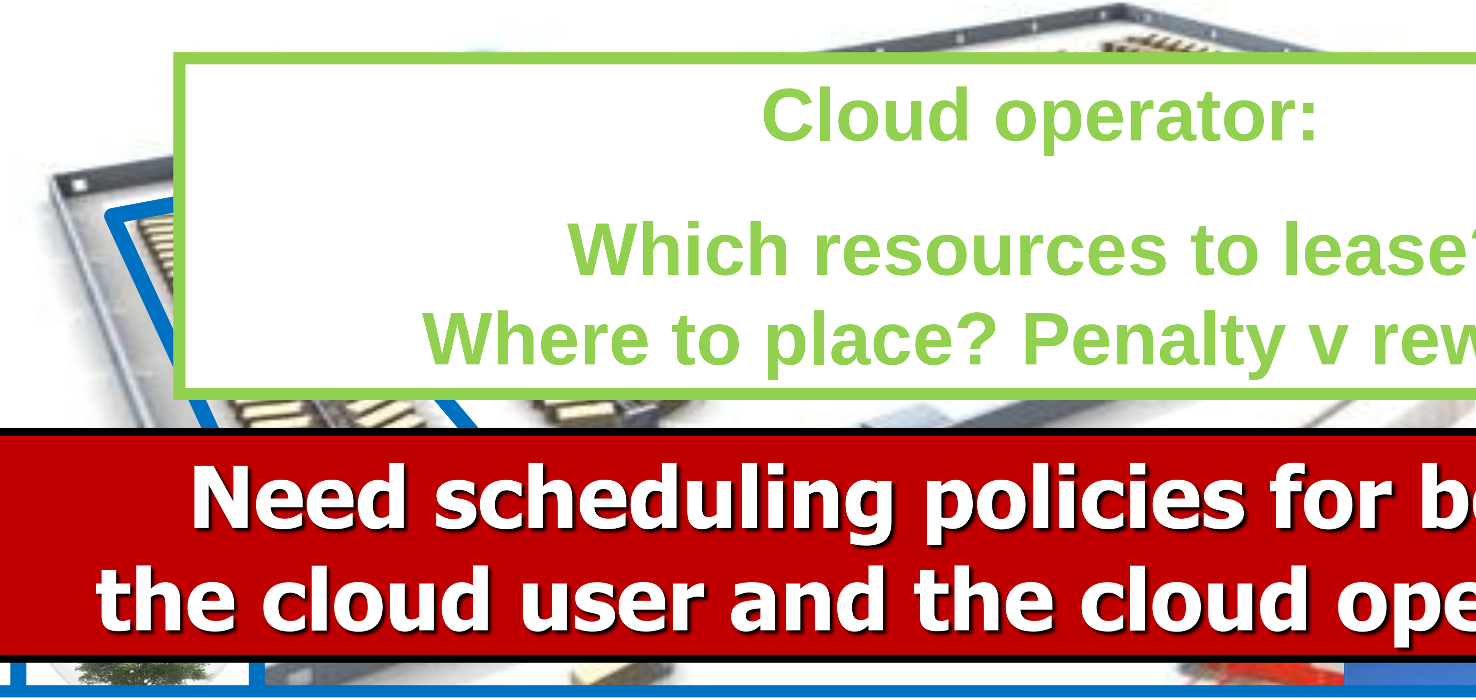
The Scheduling Challenge



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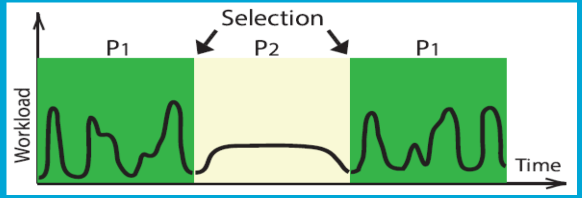
Vincent
van Beek

Tim
Hegeman

Jesse
Donkervliet

Alexandru
Iosup



Portfolio Scheduling for DCs

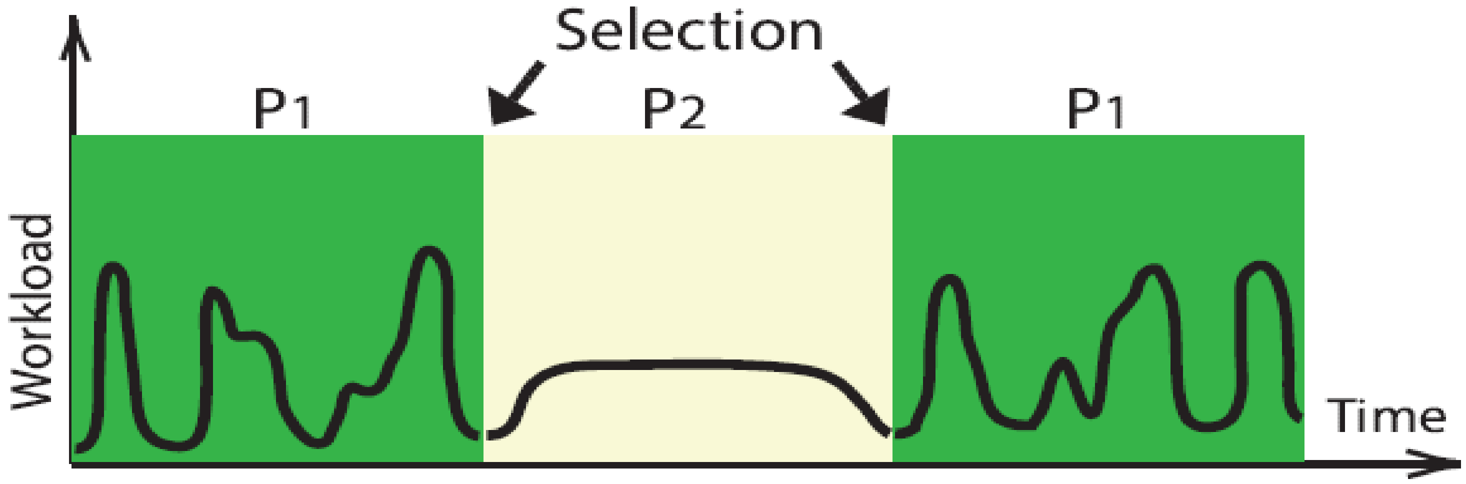
Self-Expressive Management of Business-Critical Workloads in Virtualized Datacenters

van Beek, Donkervliet, Hegeman, Hugtenburg, Iosup. Self-Expressive Management of Business-Critical Workloads in Virtualized Datacenters. IEEE Computer 48(7): 46-54 (2015)

Deng, Song, Ren, Iosup. Exploring portfolio scheduling for long-term execution of scientific workloads in IaaS clouds. SC 2013: 55:1-55:12

Portfolio Scheduling, In A Nutshell

- Datacenters cannot work without one or even several schedulers
- Instead of ephemeral, risky schedulers, we propose to



1. Create a set of schedulers (resource provisioning and allocation policies)
2. Select active scheduler online, apply for the next period, analyze results

(Repeat)

K. Deng et al. Exploring portfolio scheduling for long-term execution of scientific workloads in IaaS clouds. SC|13

Portfolio Scheduling

Portfolio Scheduling for Computer Systems

Portfolio Creation

- Configure schedulers
- 10s-100s+ schedulers

Scheduler Selection + Explanation

- Define new metrics, risk
- Consider data in the process

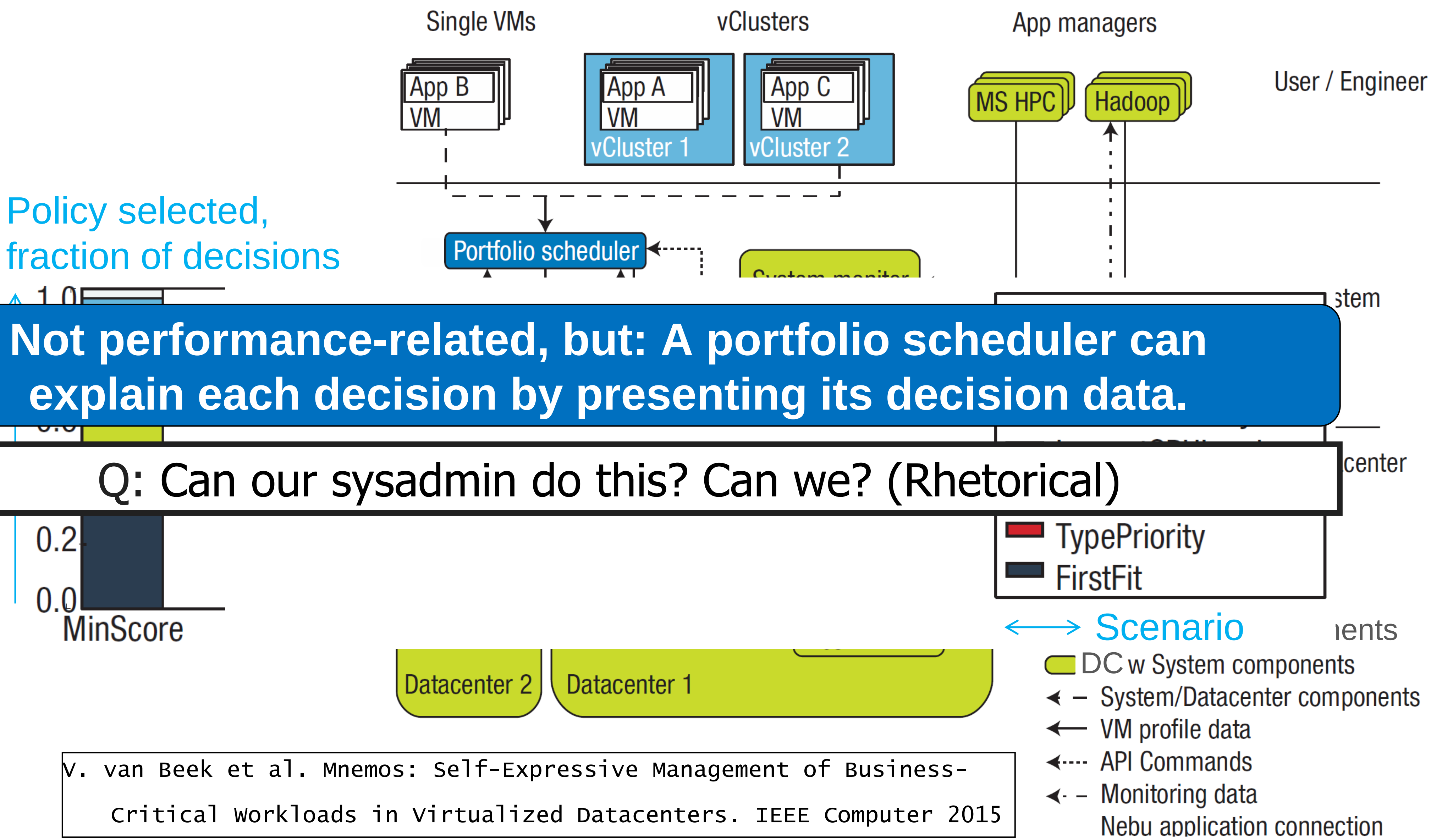
Application of Selected Scheduler

- Monitor system for issues

Self-Reflection on Portfolio + Scheduler

- Reflect and Adapt portfolio

Portfolio Scheduling in Practice: Massive Datacenters



Not performance-related, but: A portfolio scheduler can explain each decision by presenting its decision data.

Q: Can our sysadmin do this? Can we? (Rhetorical)

V. van Beek et al. Mnemos: Self-Expressive Management of Business-Critical Workloads in Virtualized Datacenters. IEEE Computer 2015

Intro to Cloud Computing

Here or @home

Interactive

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- The core idea of datacenter computing
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10' — Reality Check

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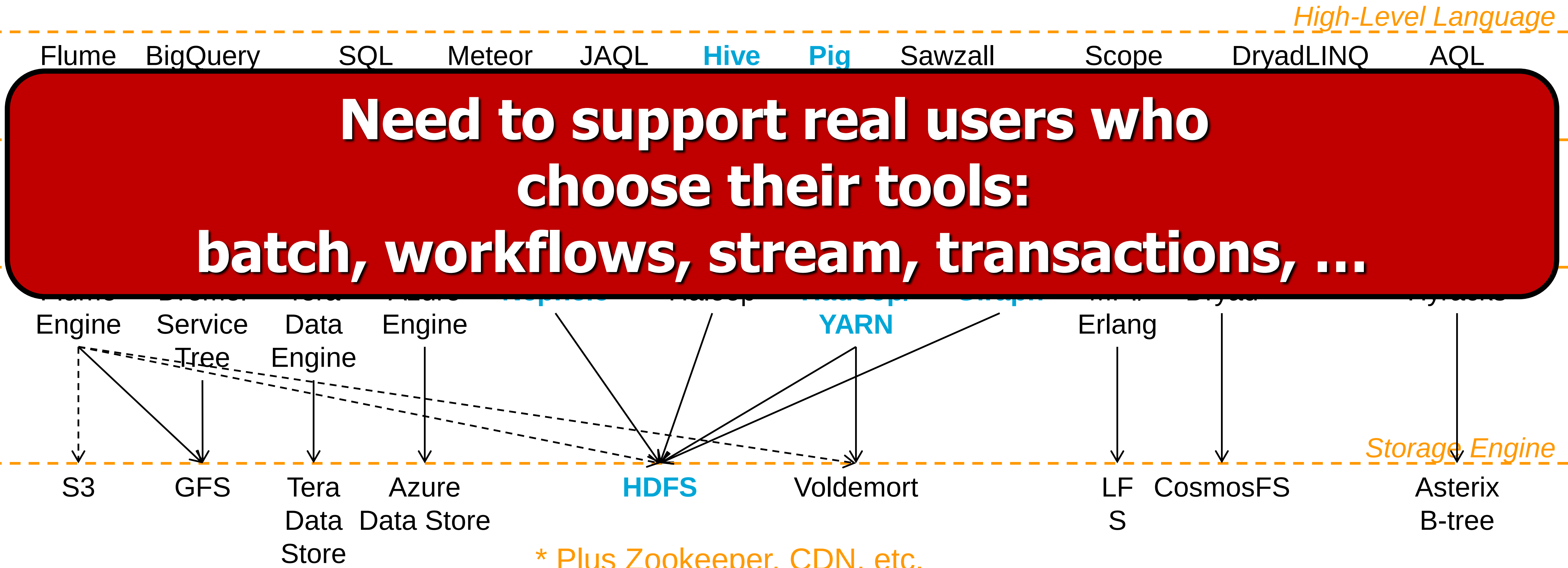
The Ecosystem Navigation Challenge



Need to support real users who choose their tools: batch, workflows, stream, transactions, …

* Plus Zookeeper, CDN, etc.




David Villegas
FIU/IBM

Athanasios
Antoniou

Alexandru
Iosup

Dick
Epema

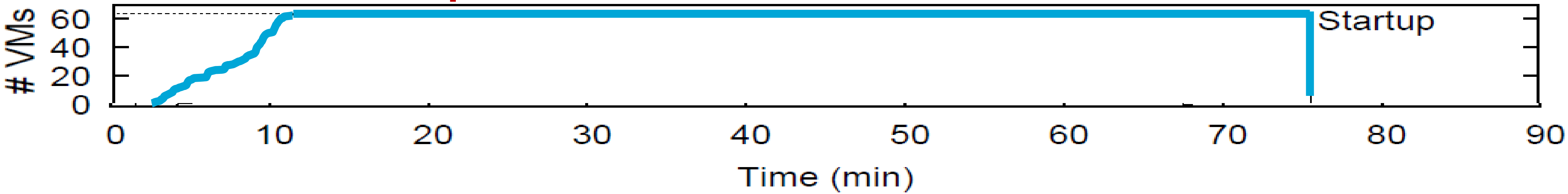
IaaS Provisioning and Allocation

Design of new policies and real-world experiments to compare with alternatives

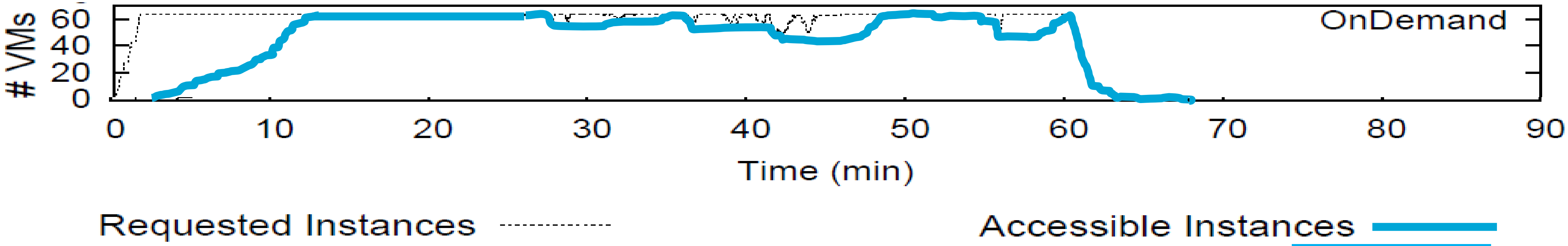
Villegas, Antoniou, Sadjadi, Iosup. An Analysis of Provisioning and Allocation Policies for Infrastructure-as-a-Service Clouds, CCGrid 2012.

Use Case: Provisioning Policies, Compared

Startup



OnDemand



Villegas, Antoniou, Sadjadi, Iosup. An Analysis of Provisioning and Allocation Policies for Infrastructure-as-a-Service Clouds, CCGRID'12

Use Case:
Provisioning Policies, Compared

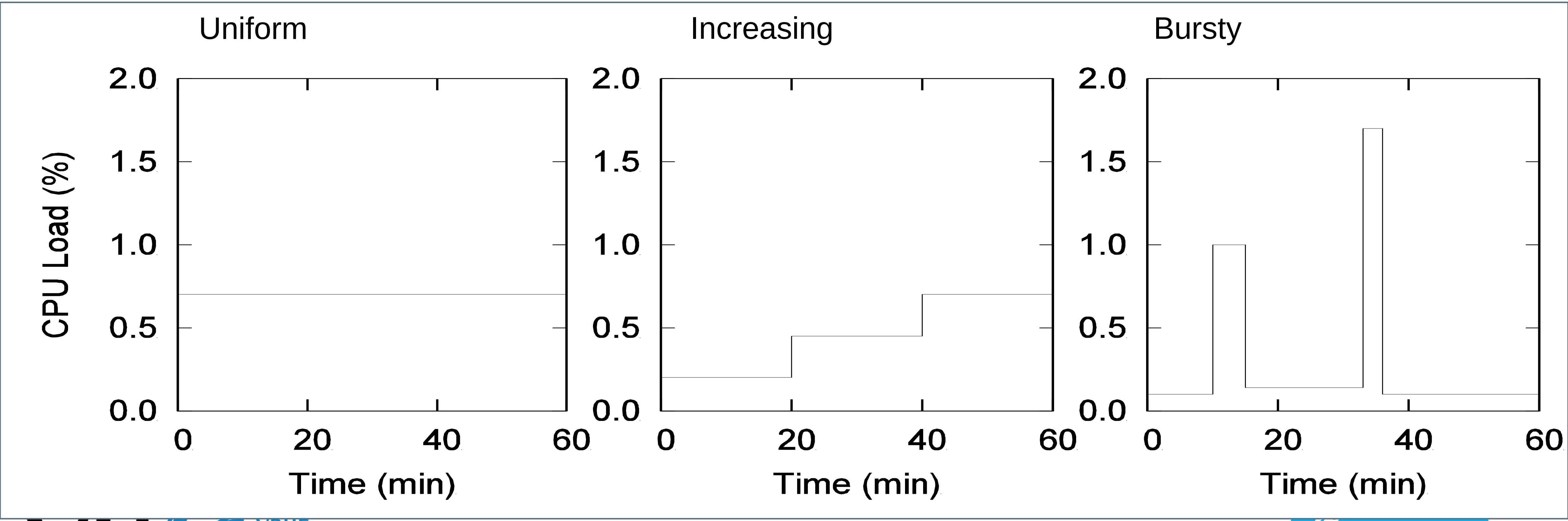
Environments (values for 2012 study, 2016 study much larger)

System	Hardware	VIM	Hypervisor	Max VMs
DAS4/Delft	20 Dual quad-core 2.4 GHz 24 GB RAM 2x1 TB storage	OpenNebula	KVM	64
FIU	7 Pentium 4 3.0 GHz 5 GB RAM 340 GB Storage	OpenNebula	Xen	7
Amazon EC2	unkown/various	-	Xen	20

Villegas, Antoniou, Sadjadi, Iosup. An Analysis of Provisioning and Allocation Policies for Infrastructure-as-a-Service Clouds, CCGRID'12

Use Case:
Two Provisioning Policies, Compared

Workloads



Villegas, Antoniou, Sadjadi, Iosup. An Analysis of Provisioning and Allocation Policies for Infrastructure-as-a-Service Clouds, CCGRID'12

Use Case:
Two Provisioning Policies, Compared

Metrics for comparison

- Job Slowdown (***JSD***): Ratio of actual runtime in the cloud and the runtime in a dedicated non-virtualized environment

- Charged Cost (***C_c***)

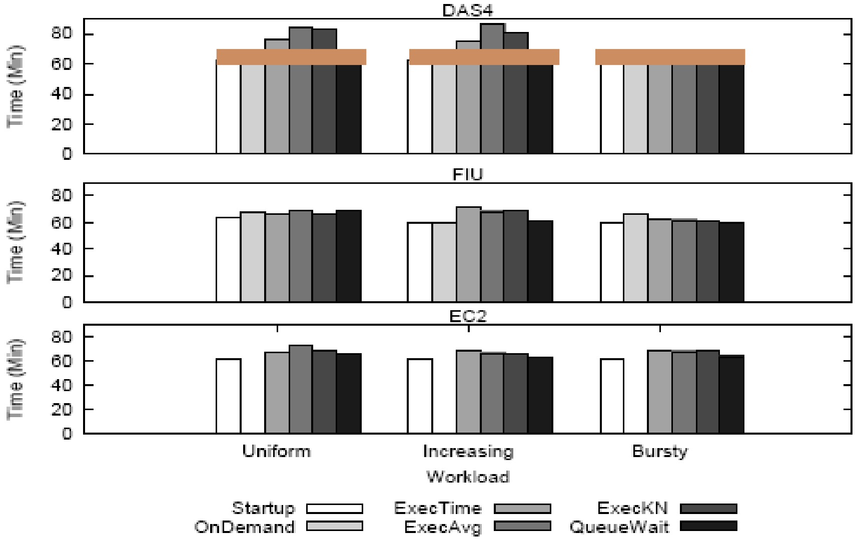
Q: Charged cost vs Total RunTime?

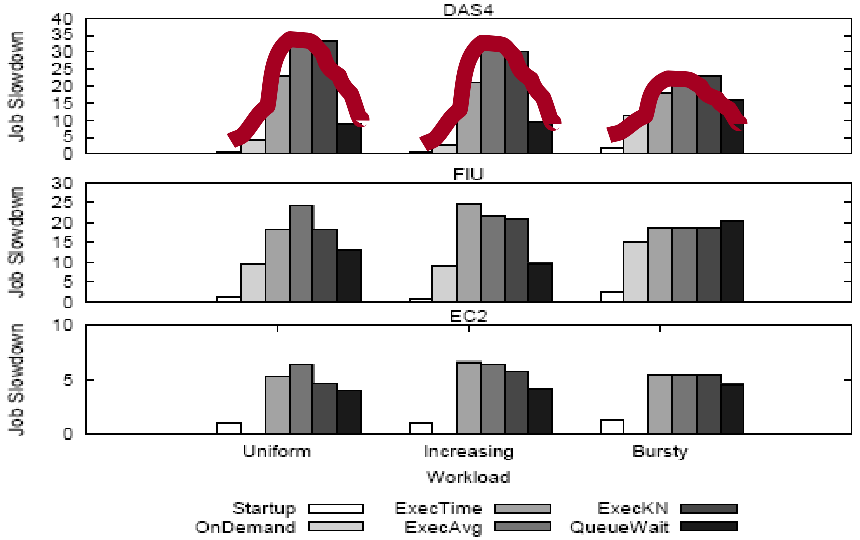
$$C_c(W) = \sum_{i \in leased\ VMs} \lceil t_{stop}(i) - t_{start}(i) \rceil$$

- Utility (***U***)

$$U(W) = \frac{SU_1(W)}{C_c(W)}$$

Performance Metrics



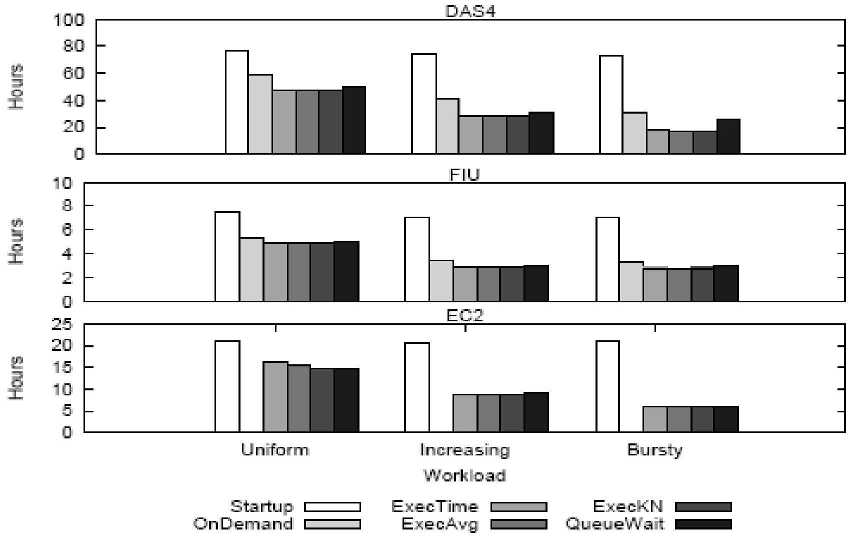


- Makespan very similar
- Very different job slowdown

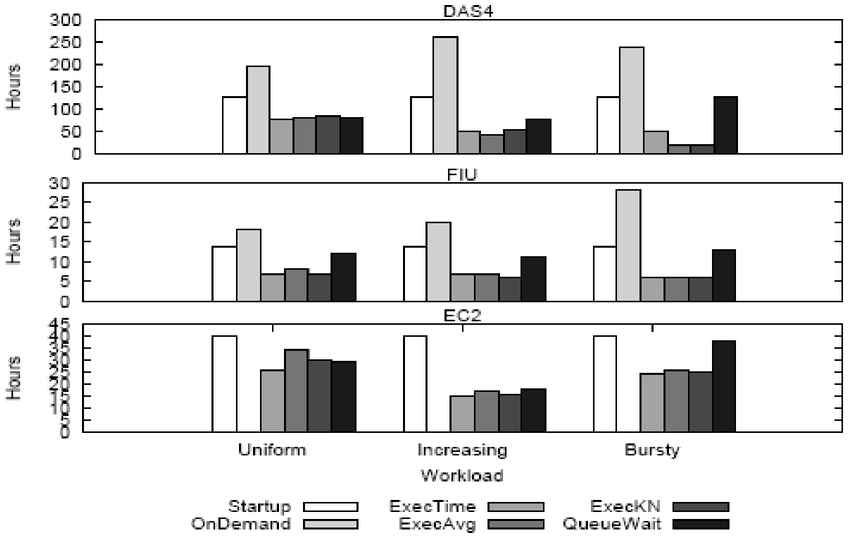
Villegas, Antoniou, Sadjadi, Iosup. An Analysis of Provisioning and Allocation Policies for Infrastructure-as-a-Service Clouds, CCGrid 2012

Cost Metrics

Actual Cost



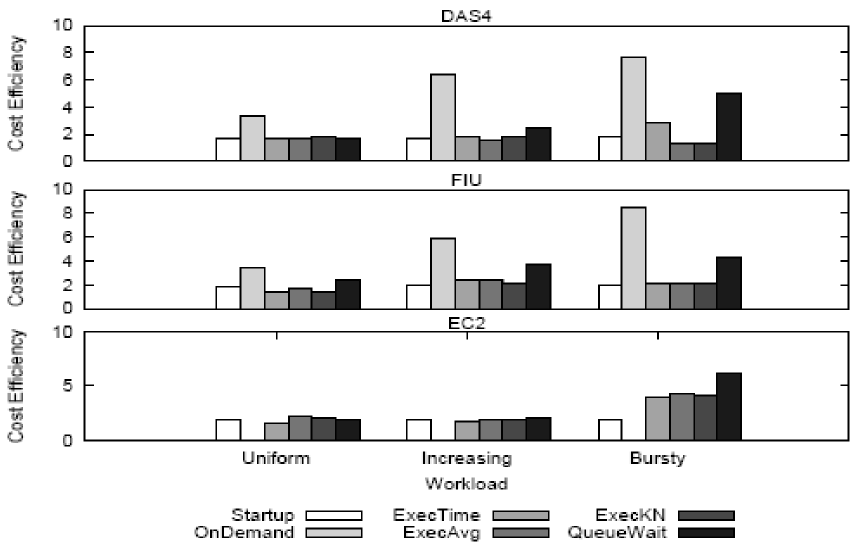
Charged Cost

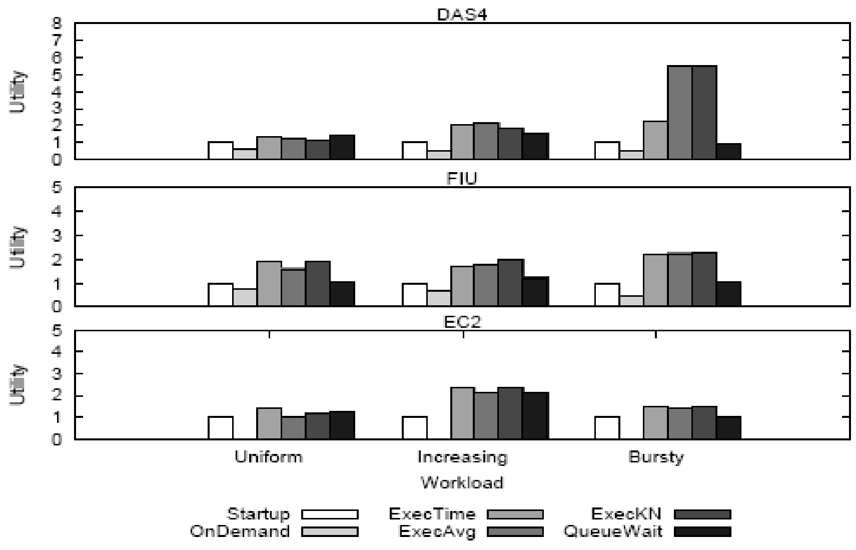


- Very different results between actual and charged
  - Cloud charging function an important selection criterion
- All policies better than Startup in actual cost
- Policies much better/worse than Startup in charged cost

Villegas, Antoniou, Sadjadi, Iosup. An Analysis of Provisioning and Allocation Policies for Infrastructure-as-a-Service Clouds, CCGrid 2012

Compound Metrics





- Trade-off Utility-Cost still needs investigation
- **Performance or Cost, not both:**
  the policies we have studied improve one, but not both

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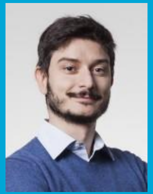
Villegas, Antoniou, Sadjadi, Iosup. An Analysis of Provisioning and Allocation Policies for Infrastructure-as-a-Service Clouds, CCGrid 2012

TU Delft

Alexey Ilyushkin

Ahmed Ali-Eldin

Nikolas Herbst



Alessandro Papadopoulos

Bogdan Ghiț

Dick Epema

Alexandru Iosup

Auto-Scaling

Experimental Performance Evaluation of Autoscaling Policies for Complex Workflows

Best Paper Candidate

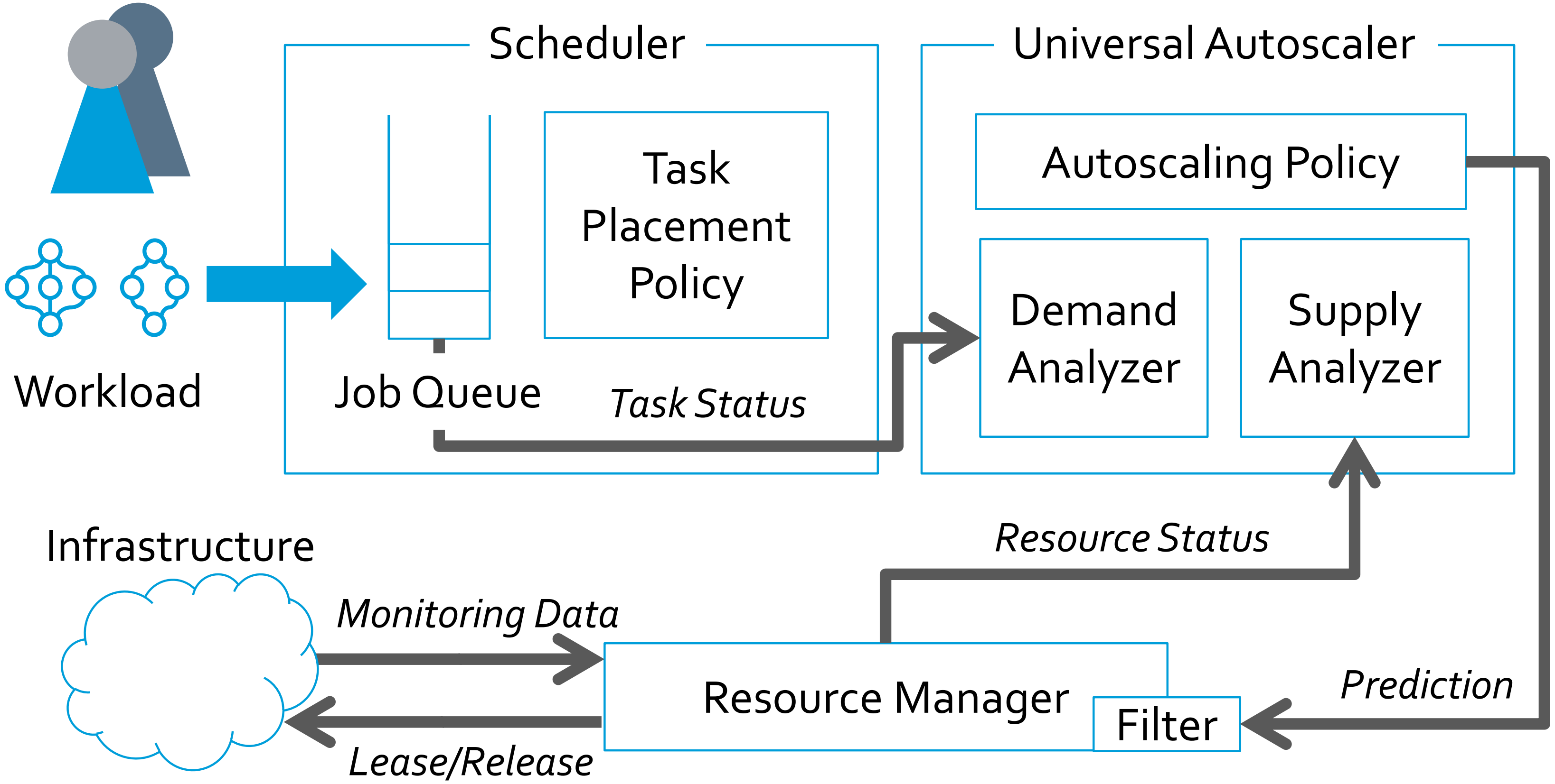
Ilyushkin, Ali-Eldin, Herbst, Papadopoulos, Ghit, Epema, Iosup. An Experimental Performance Evaluation of Autoscaling Policies for Complex Workflows. ICPE 2017

Our Approach

A comprehensive method for evaluating and comparing autoscalers

- A **model** for elastic cloud platform
- A set of relevant **metrics** for assessing autoscaler performance
- A set of general and workflow-specific **autoscalers**
- Three **comparison methods** for autoscalers
- **Real experiments** with up to 50 VMs in OpenNebula on DAS supercomputer

Elastic Cloud Platform



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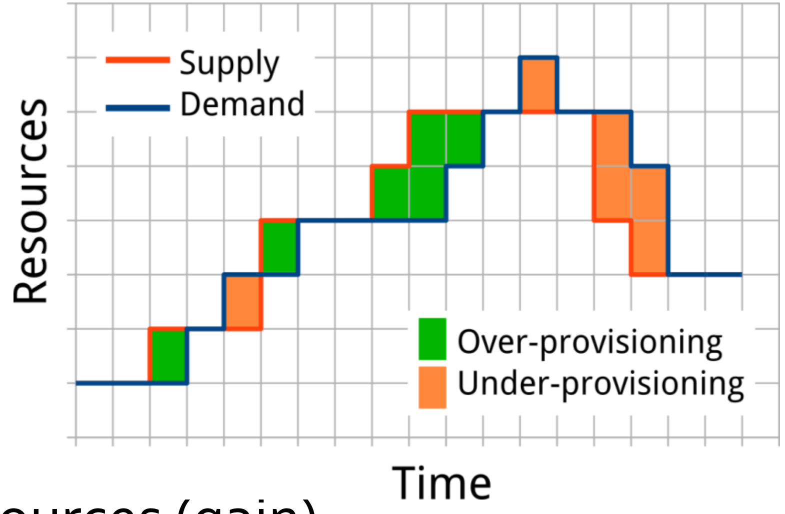
Performance Metrics

System-oriented elasticity metrics

- Accuracy (also normalized by actual demand)
- Wrong-Provisioning Timeshare
- Instability



User-oriented metrics

- Elastic Slowdown
- Average Number of Utilized Resources (gain)
- Average Throughput (tasks/h)

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Autoscaling Policies

Timeliness of the Information

	Long-term	Current/Recent
Server	Hist, Reg, ConPaaS	React, Adapt
Job	Plan	Token

Information Source

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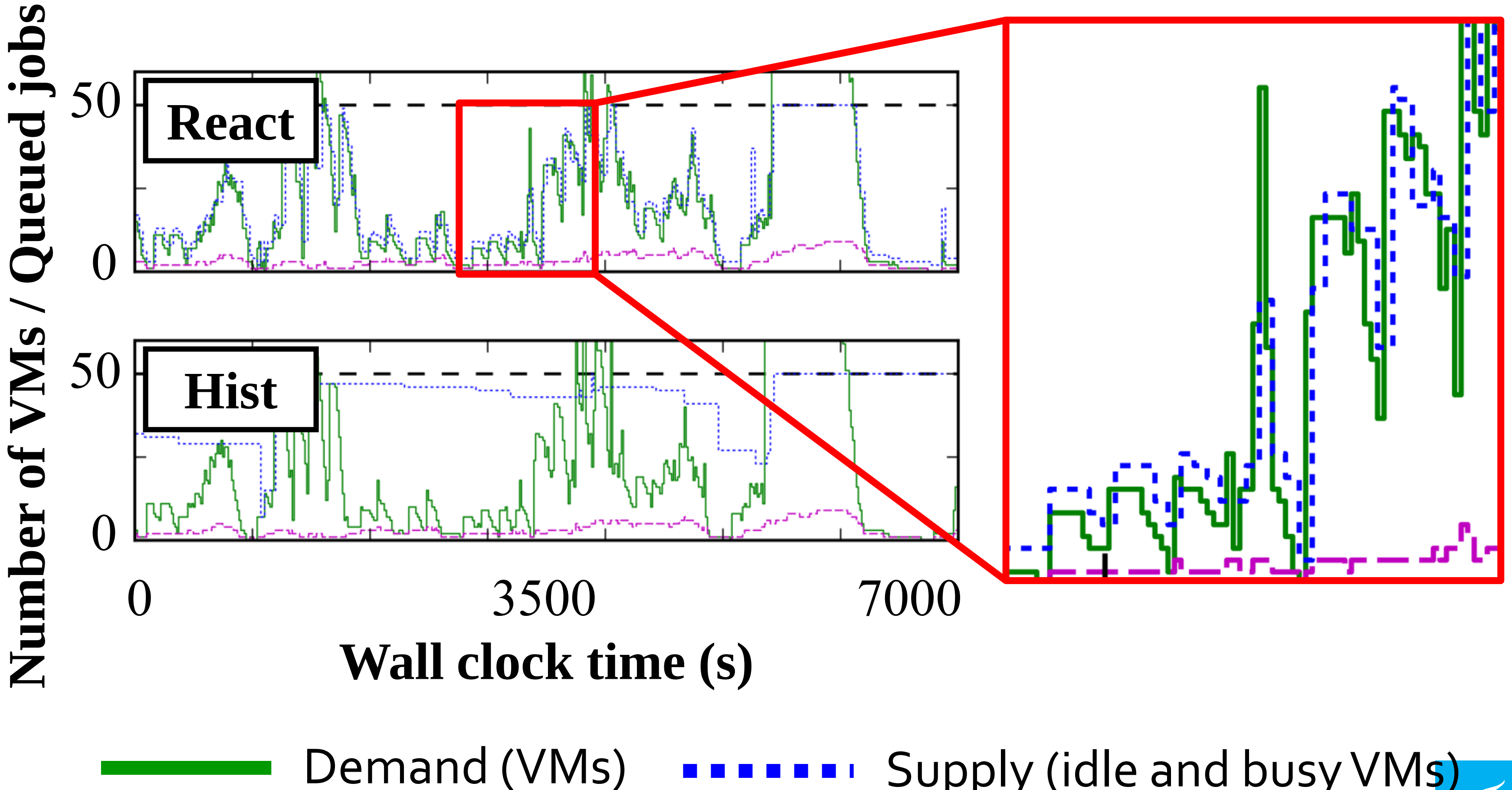
Experimental Results



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Which Policy is the Best?

Methods for aggregation of metrics

- **Pairwise Comparison** – pairwise compare metrics between autoscalers
- **Fractional Difference Comparison** – compare autoscalers with an ideal case based on the experimental results
- **Aggregated System-oriented Elasticity and User Metrics** (by Fleming et al.)
  Compute speedup ratios and then average the speedups using an unweighted geometric mean

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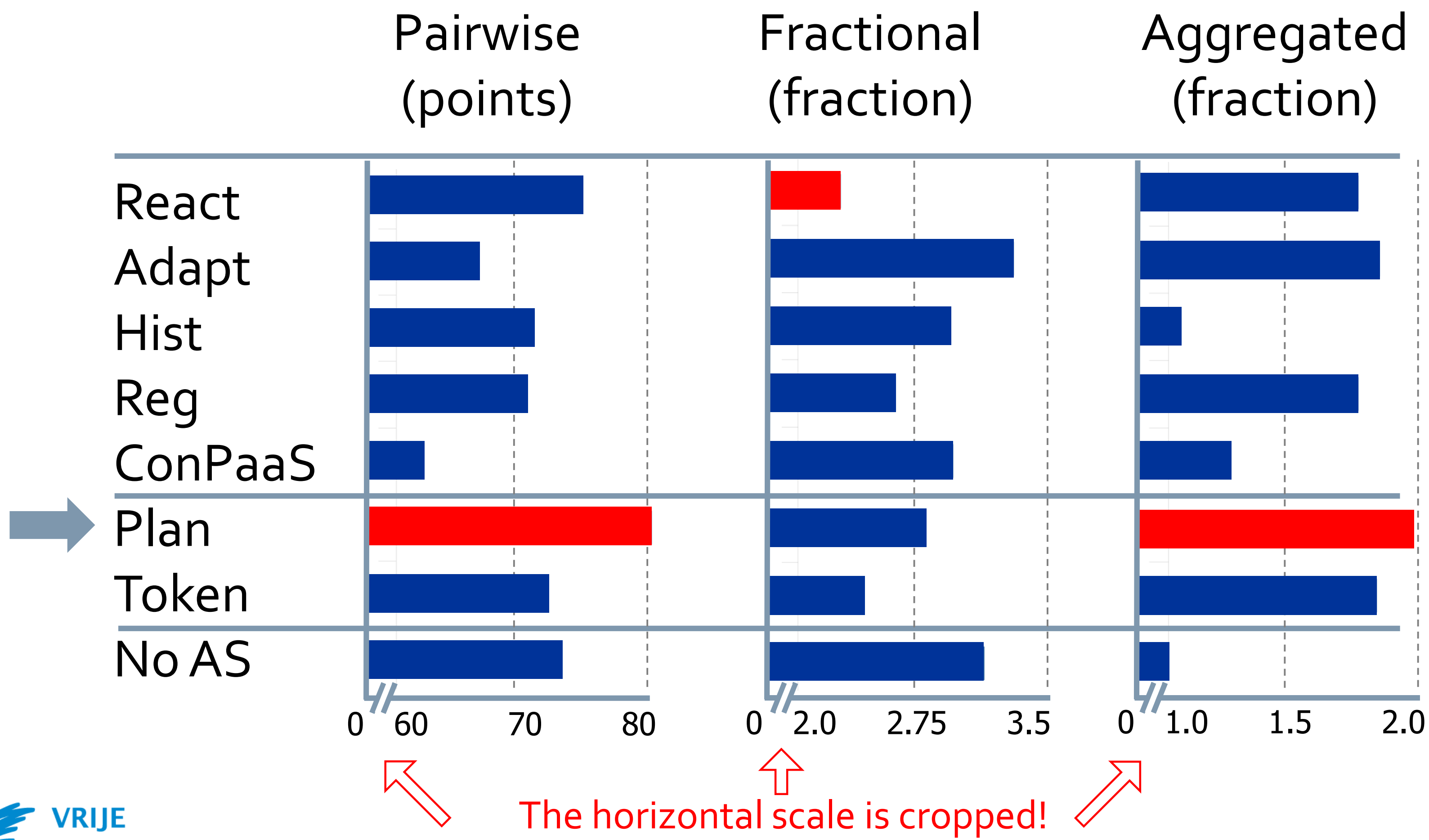
Which Policy is the Best?



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Conclusion

1. We developed a method to compare different autoscalers
2. General autoscalers can achieve similar performance as workflow-specific autoscalers (surprising)
3. No autoscaler is the best:
   Our workflow-specific Plan autoscaler wins 4 out of 5 competitions but is not the best overall
4. The correct choice of an autoscaler is important but significantly depends on the application type
5. Correct parameterization of general autoscalers is very important

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Intro to Cloud Computing

Here or @home | Interactive

5' — Pitch on Datacenter-Based Cloud Computing

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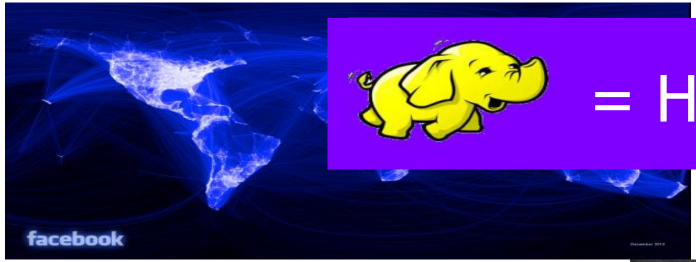
10' — Reality Check

The "Big Cake" Challenge In the Datacenter

Online Social Networks



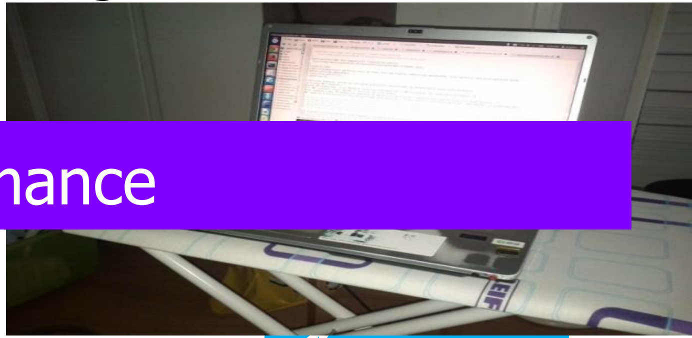
Financial Analysts

= Hadoop / MapReduce framework

Need multi-tenant, self-aware schedulers and resource managers

Universe Explorers

Big Data Enthusiast



Multiple frameworks = Isolation, especially performance

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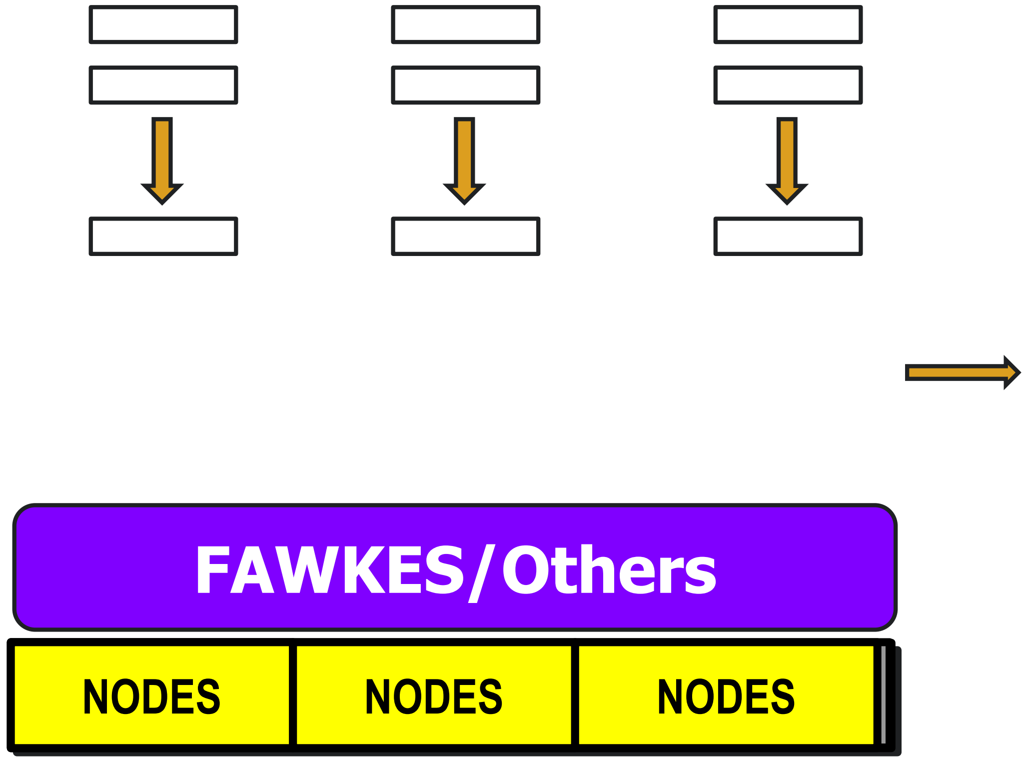
Dynamic Big Data Processing

Fawkes = Elastic MapReduce



FAWKES

Job submissions

Frameworks

Resource manager

Infrastructure

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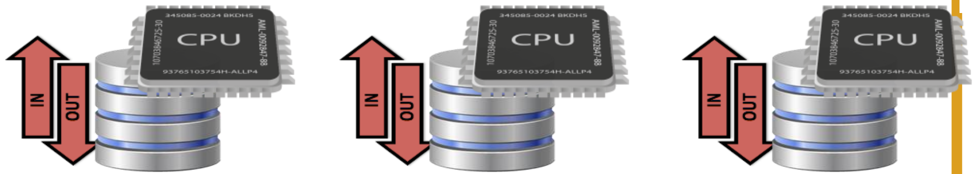
Elasticity for MapReduce Frameworrks

Core nodes



INPUT/OUTPUT DATA

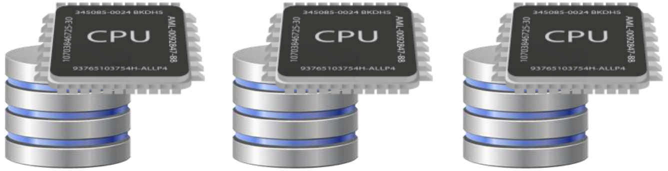
- Classical deployment
- Uniform data distribution
- **No removal**

Transient nodes (TR)

NO DATA

- No local storage
- R/W from/to core nodes
- **Instant removal**

Trans-core nodes (TC)



OUTPUT DATA

- Local storage, no input
- Only R from core nodes
- **Delayed removal**

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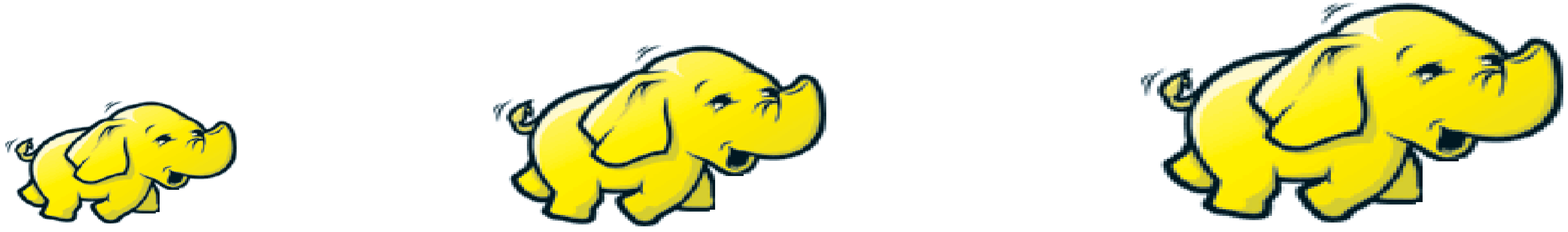
Fawkes in a Nutshell [1/2]

Because workloads may be time-varying:

- Poor resource utilization
- Imbalanced service levels



w_1 $<$ w_2 $<$ w_3

1. Fair framework size:

$$s_i = \frac{w_i}{w_1 + w_2 + w_3}, \quad i = 1,2,3$$

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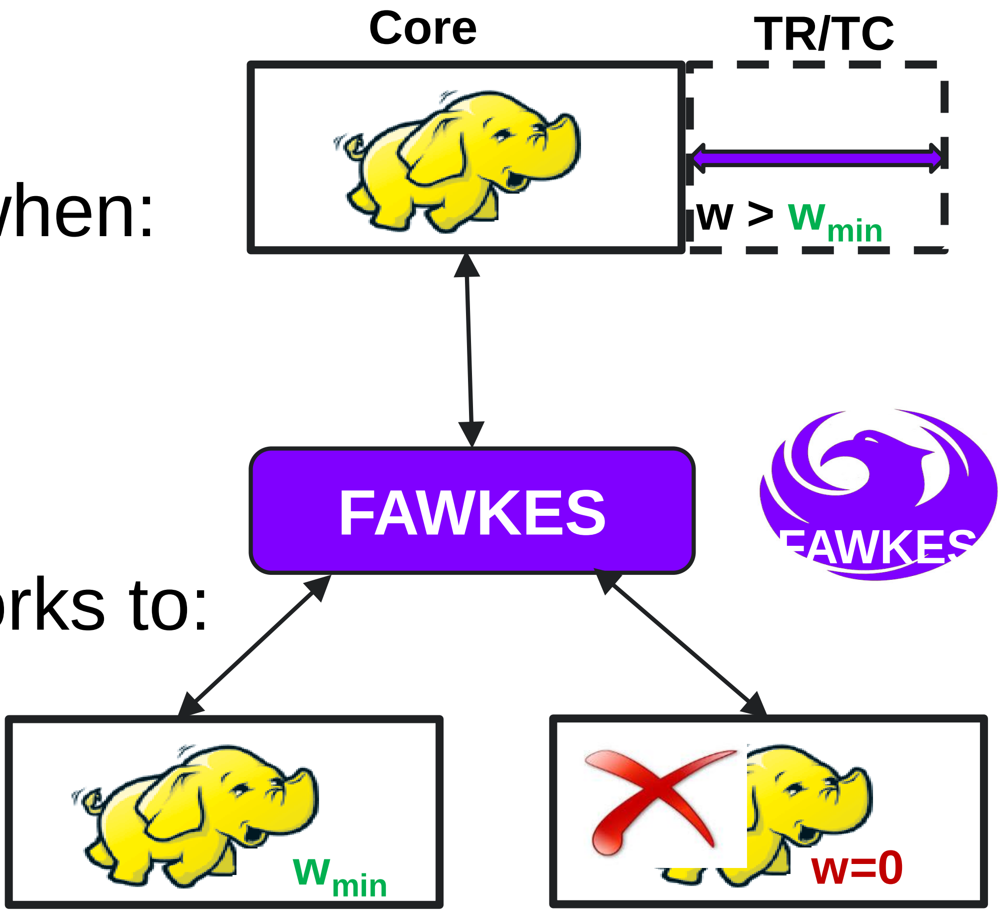
Fawkes in a Nutshell [2/2]

2. Updates dynamic weights when:
   - New frameworks arrive
   - Framework states change

3. Shrinks and grows frameworks to:
   - Allocate new frameworks
   - Give fair shares to existing frameworks
   - Eliminate unused frameworks



MapReduce Applications Tested with Fawkes

Application	Type	Input	Output
Wordcount (WC)	CPU	200 GB	5.5 MB
Sort (ST)	Disk	200 GB	200 GB
PageRank (PR)	CPU	50 GB	1.5 MB
K-Means (KM)	Both	70 GB	72 GB
TrackerOverTime (TT)	CPU	100 GB	3.9 MB
ActiveHashes (AH)	Both	100 GB	90 KB
BTWorld (BT)	Both	100 GB	73 GB

Synthetic benchmarks:

- HiBench suite
- Single applications
- Random datasets

Real-world applications:

- BTWorld workflow
- 14 Pig queries
- BitTorrent monitoring data

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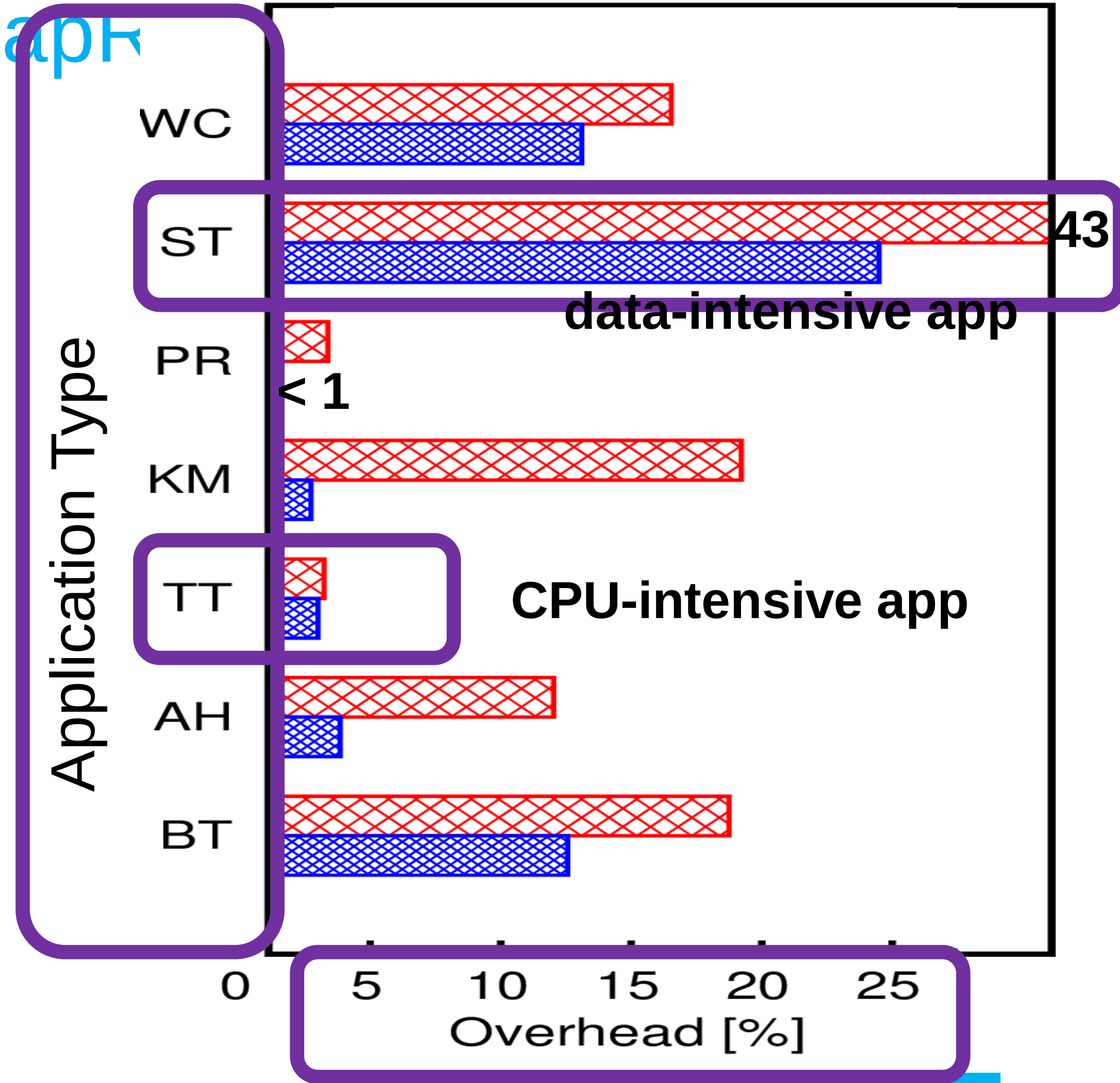
Performance of dynamic MapR

10 core +10xTR
10 core +10xTC
vs.
20 core nodes (baseline)



TRansient - **good** for compute-intensive workloads.

TCore - **needed** for disk-intensive workloads.

Dynamic MapReduce:
< 25% overhead

Fawkes also reduces imbalance

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Jevons Effect: More Efficient, Less Capable

Over 500 YouTube videos have at least 100,000,000 viewers each.

Need to be more efficient in how we use our resources, (also educate others to not abuse "infinite" capacity)

PSY Gangnam consumed ~500GWh

= more than entire countries* in a year (*41 countries),
= over 50MW of 24/7/365 diesel, 135M liters of oil,
= 100,000 cars running for a year, ...

Source: Ian Bitterlin and Jon Summers, UoL, UK, Jul 2013.
Note: Psy has >3 billion views (Nov 2015).

Existing Graph-Processing Systems: *Either* Distributed *or* Heterogeneous

- Distributed CPU-based systems cannot use additional computational power of accelerators

Oracle Labs PGX

APACHE GIRAPH

GraphLab

GraphX

YARN

- GPU-enabled systems are (mostly) single-machine systems, cannot handle large-s

NetSysLab

medusa-gpu
Medusa: Simplified Graph Processing on GPUs

mapgraph Beta
Massively Parallel Graph processing on GPUs

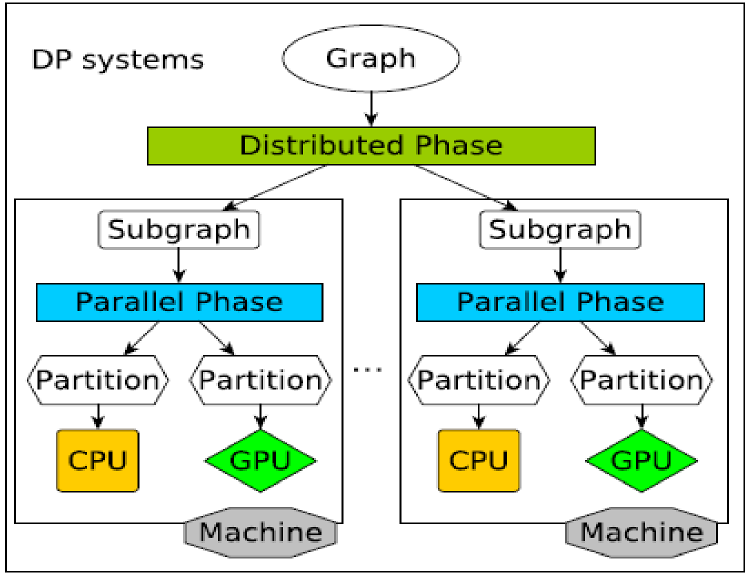
TOTEM

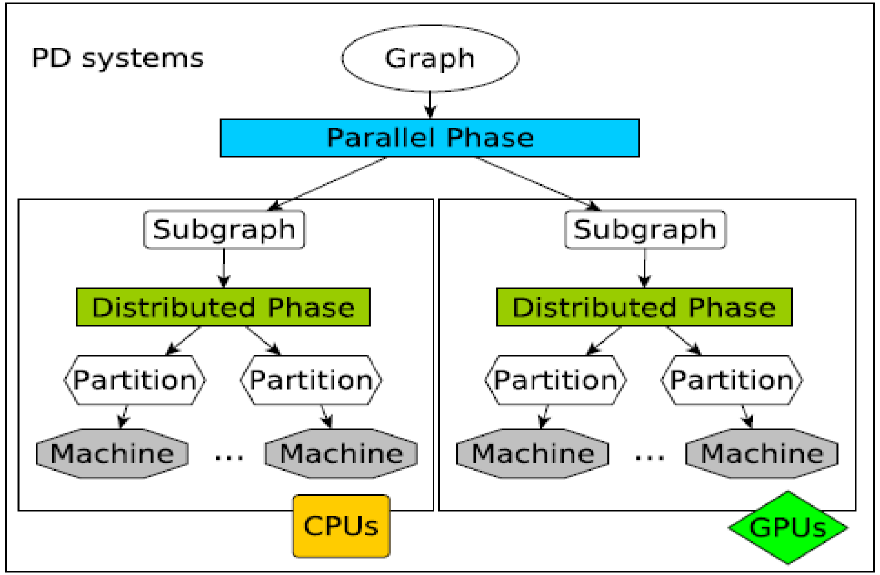
Gunrock
High-performance Graph Primitives on GPU

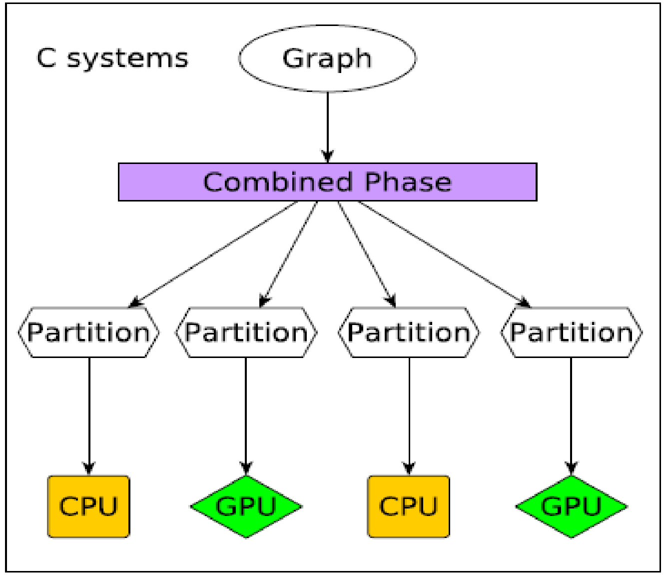
VertexAPI2

Y. Guo, A. L. Varbanescu, D. Epema, and A. Iosup, "Design and Experimental Evaluation of Distributed Heterogeneous Graph-Processing Systems," Submission to *CCGrid, 2016.*

Our approach: 3 Families of Distributed *and* Heterogeneous (CPU+GPU) Graph-Processing Systems







Distributed-then-Parallel (DP) Systems

Parallel-then-Distributed (PD) Systems

(Combined Par.-and-Distributed (C) Systems

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Y. Guo, A. L. Varbanescu, D. Epema, and A. Iosup, "Design and Experimental Evaluation of Distributed Heterogeneous Graph-Processing Systems," Submission to *CCGrid, 2016.*

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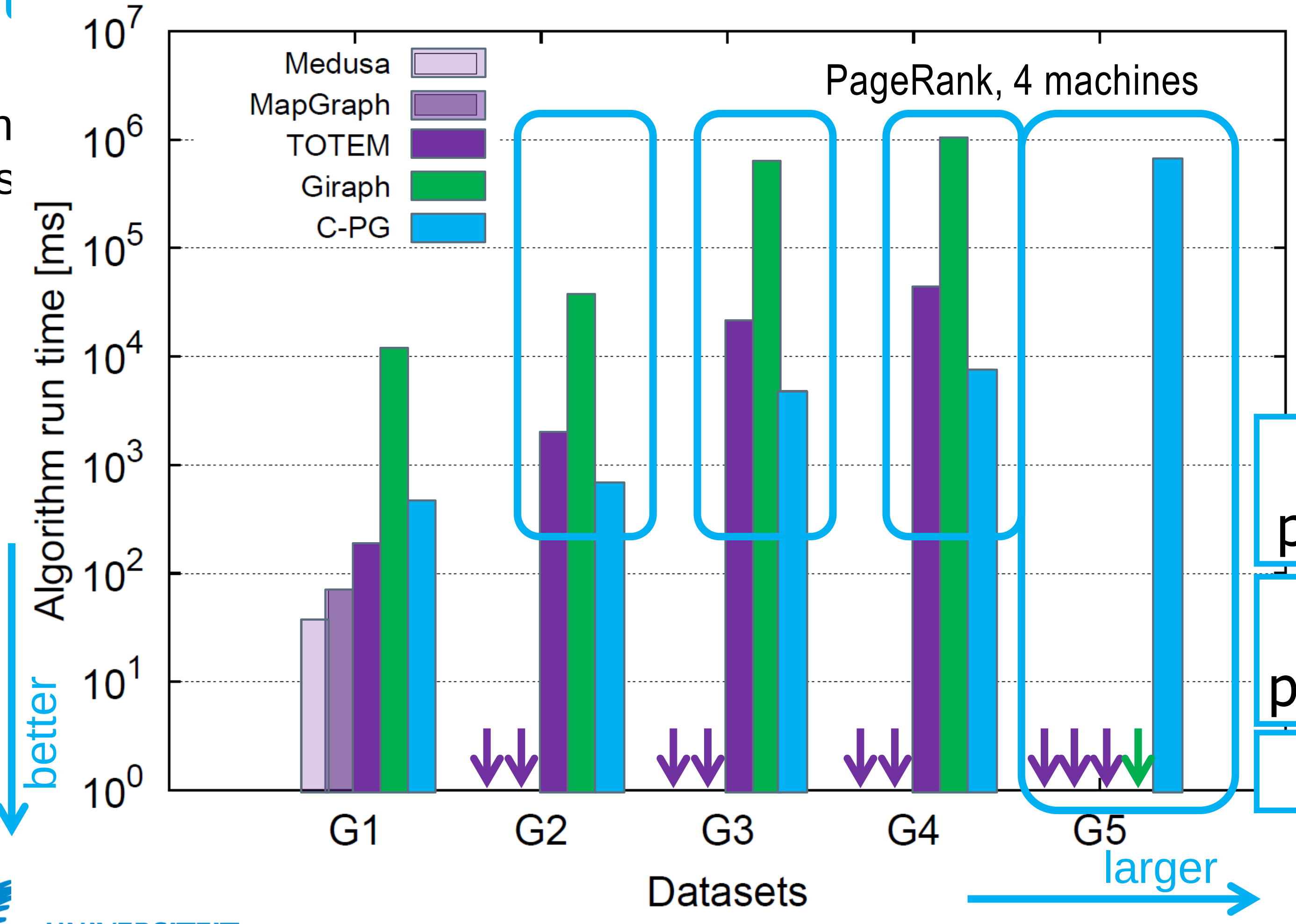
Promising Results for Distributed *and* Heterogeneous Graph Processing Systems

Missin
sys



Distributed *and* Heterogeneous

Distributed only

Heterogeneous only

→

C-PG system has good performance iff. large data

TOTEM has good performance iff. in-memory

C-PG system scales

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Y. Guo, A. L. Varbanescu, D. Epema, and A. Iosup, “Design and Experimental Evaluation of Distributed Heterogeneous Graph-Processing Systems,” Submission to *CCGrid, 2016.*

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Interactive Masterclass

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The Real IaaS Cloud

“The path to abundance”

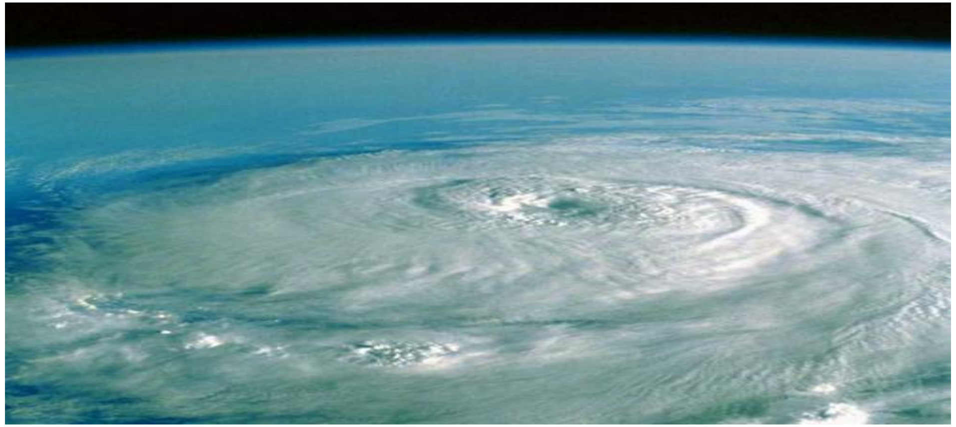
On-der

Cheap

Great f

http://www.flickr.com/photos/dimitrisotiropoulos/4204766418/

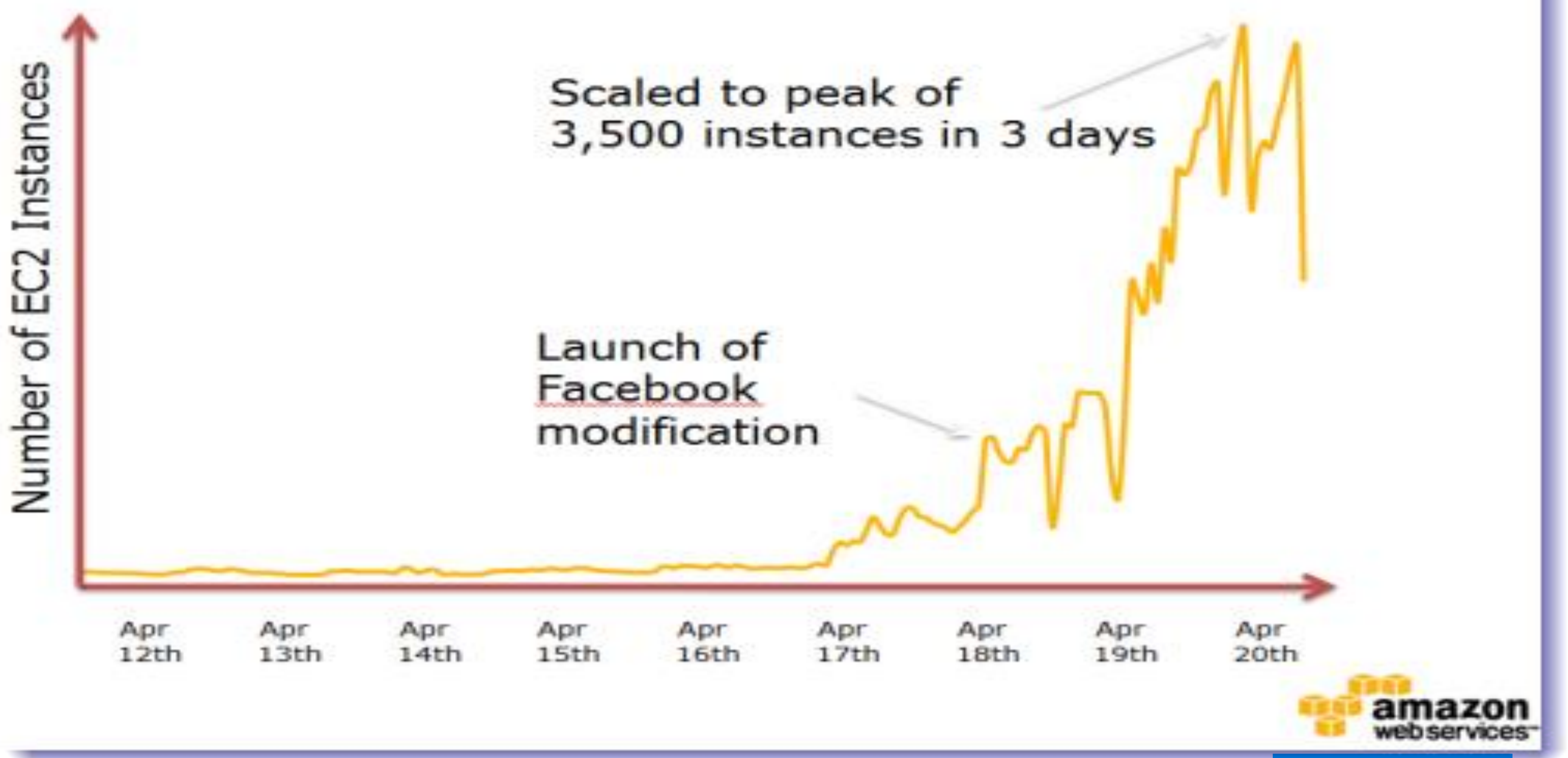
VS



Tropical Cyclone Nargis (NASA, ISSS, 04/29/08)

- “The killer cyclone”
- Not so great performance for scientific applications (compute- or data-intensive)

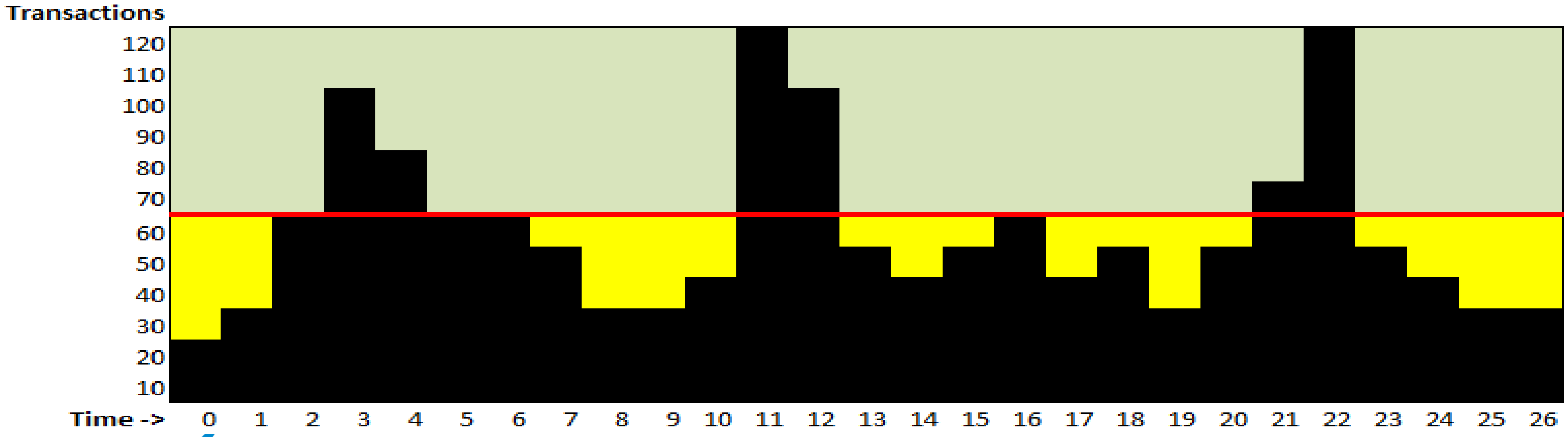
Animoto: Video App on Amazon EC2



(Source: http://www.cca08.org/files/slides/w_vogel.pdf)

Zynga zCloud: Hybrid Self-Hosted/EC2

- After Zynga had large scale
- More efficient self-hosted servers



(Sources: http://seekingalpha.com/article/609141-how-amazon-s-aws-can-attract-ugly-economics and http://www.undertheradarblog.com/blog/3-reasons-zynga-is-moving-to-a-private-cloud/)

Other Cloud Customers

reddit

- 218 virtual CPUs
- 9TB/2TB block/S3 storage
- 6.5TB/2TB I/O per month

Dropbox

(Source: http://markbuhagiar.com/technical/businessinthecloud/)

Our Industry Collaborators



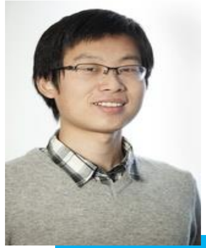
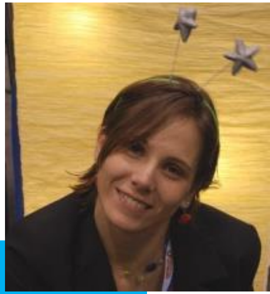
Take-Home Message
The Golden Age of Datacenters


Cloud computing = lease vs self-own

- On-Demand, Pay-per-Use, Elastic, Pooled, Automated, QoS
- Owner vs User perspective


Important New Challenges

1. The scheduling challenge
2. The ecosystem navigation challenge
3. The big cake & 4. Jevons (Efficiency) challenges

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Recommended Reading

http://atlarge.science

Elastic Big Data and Computing

- van Beek et al.: Self-Expressive Management of Business-Critical Workloads in Virtualized Datacenters. IEEE Computer 48(7): 46-54 (2015)
- B. Ghit, N. Yigitbasi (Intel Research Labs, Portland), A. Iosup, and D. Epema. Balanced Resource Allocations Across Multiple Dynamic MapReduce Clusters. SIGMETRICS 2014
- L. Fei, B. Ghit, A. Iosup, D. H. J. Epema: KOALA-C: A task allocator for integrated multicluster and multicloud environments. CLUSTER 2014: 57-65
- K. Deng, J. Song, K. Ren, A. Iosup: Exploring portfolio scheduling for long-term execution of scientific workloads in IaaS clouds. SC 2013: 55
- Iosup et al.: On the Performance Variability of Production Cloud Services. CCGRID 2011: 104-113
- Iosup et al.: Performance Analysis of Cloud Computing Services for Many-Tasks Scientific Computing. IEEE Trans. Parallel Distrib. Syst. 22(6): 931-945 (2011)

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- Many thanks!