System Support for **Managing Risk** in Cloud Computing Platforms

PhD oral defense

Supreeth Shastri

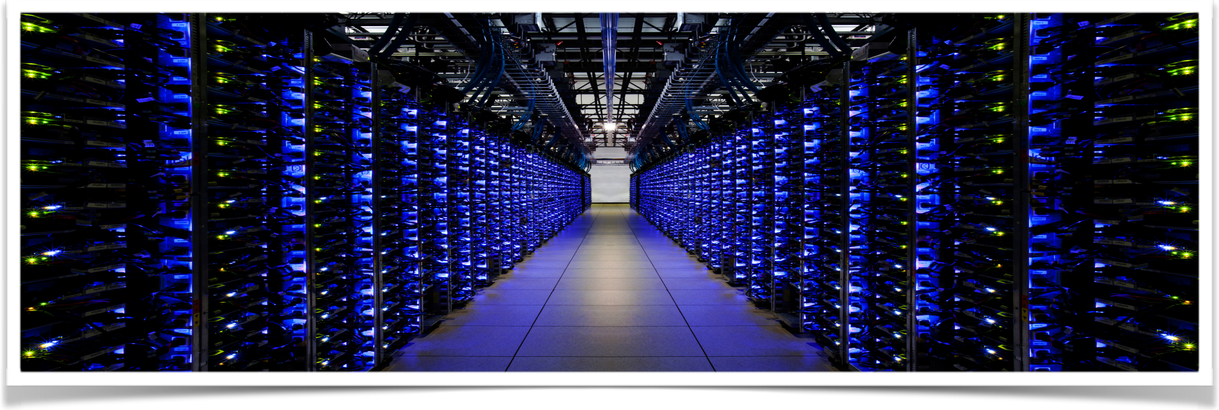
University of Massachusetts Amherst

Compute server

Static characteristics that do not change in the lifetime of an application

“A rose by any other name would smell as sweet ”

Compute server



Compute Servers in the Cloud

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"A rose by any other name ~~would~~ *may not* smell as sweet"

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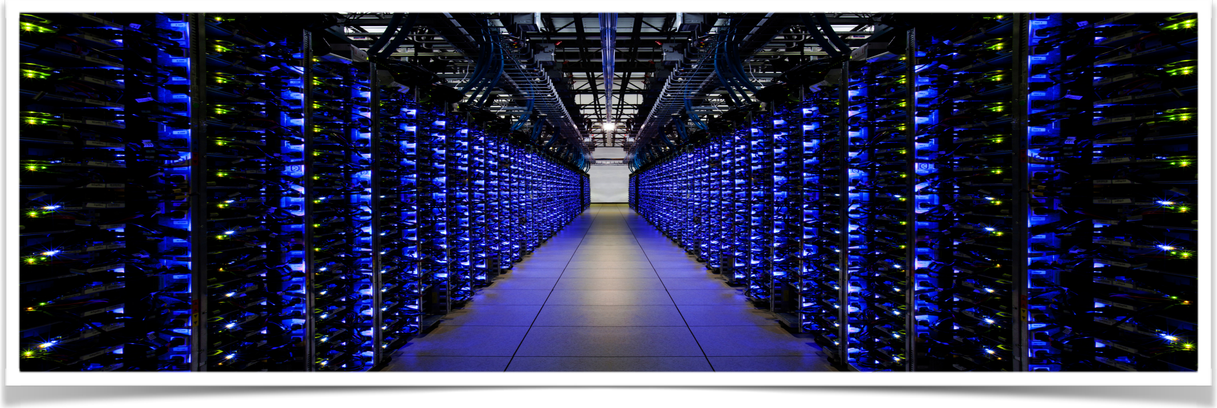

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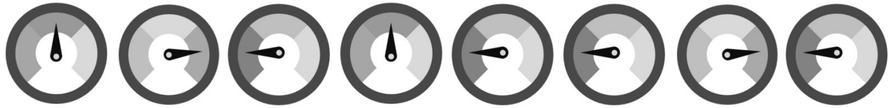

Static characteristics that do not change in the lifetime of an application

All service-level characteristics are **controlled** in fine granularity

What has the Cloud Done to Our Good Old Servers?

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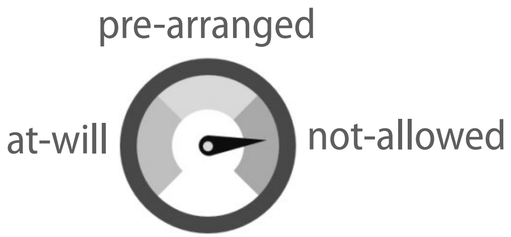

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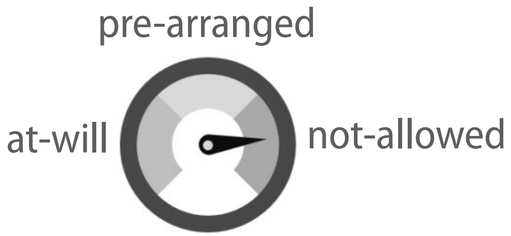

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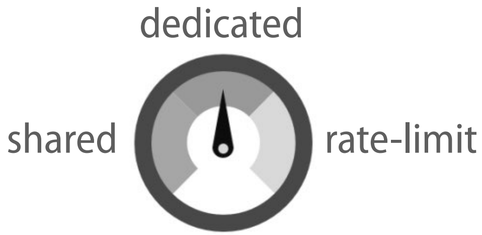

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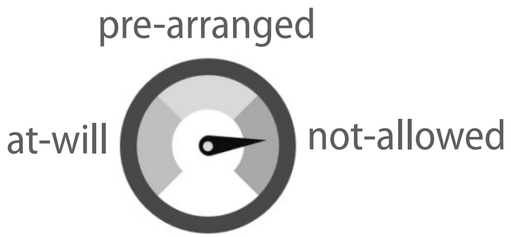
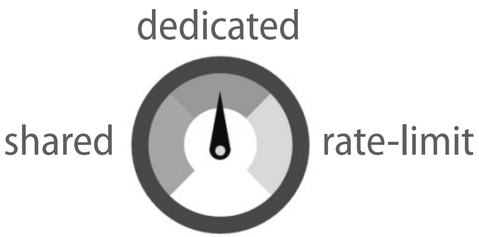


Revocability

Pricing Model



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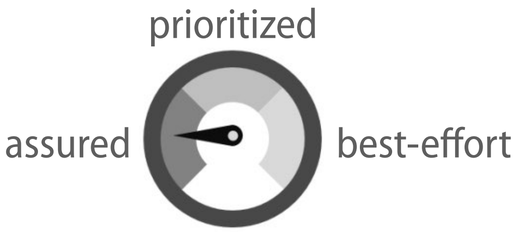
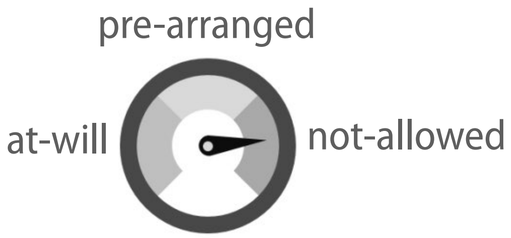


Availability



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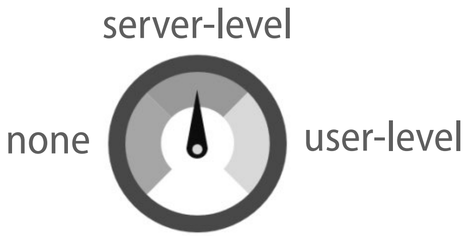
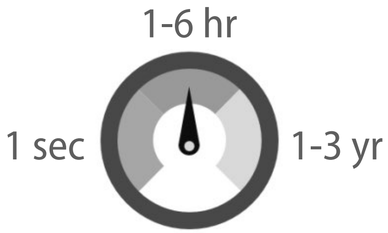
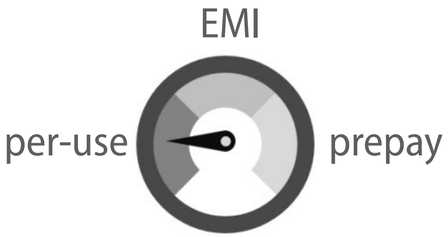


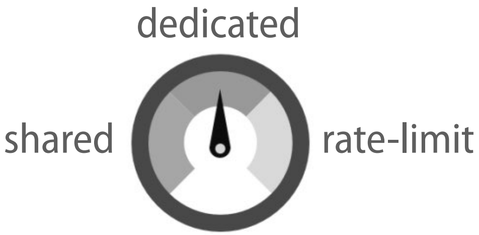
Isolation



Time Commitment



Billing Frequency



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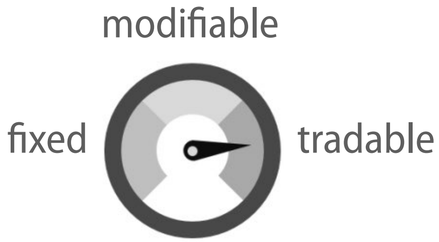
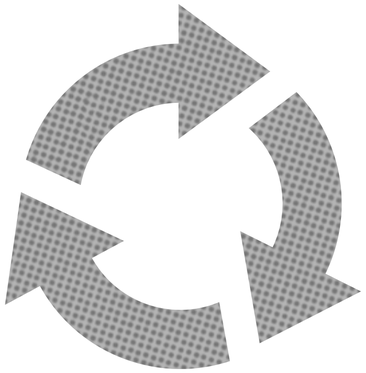


Terms of Contract

Cloud risks are exposed throughout the computing lifecycle



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Rejection Risk

When users request for resources,
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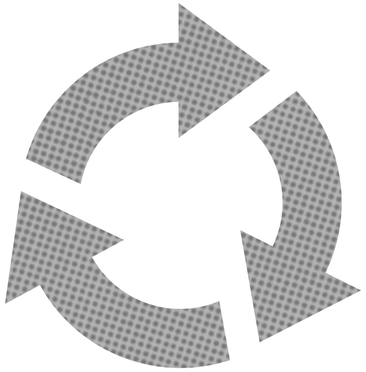

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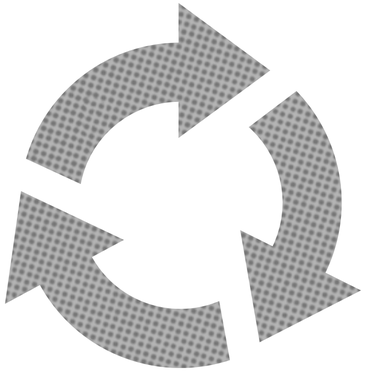

Revocation Risk

Allocated resources may become
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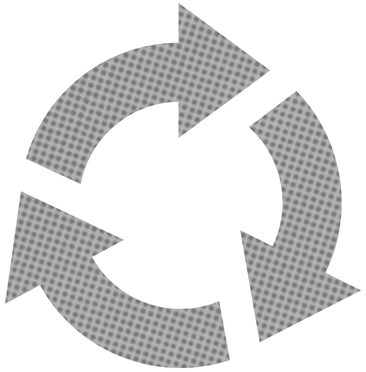

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Acquired server's price
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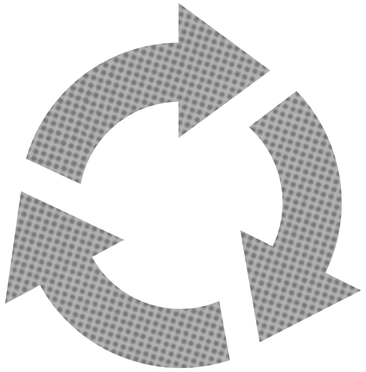
Valuation Risk

Users may not be able to value a
server's utility for their application



Revocation Risk

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Workload Risk

Workload requirements do not
match the acquired servers

Price Risk

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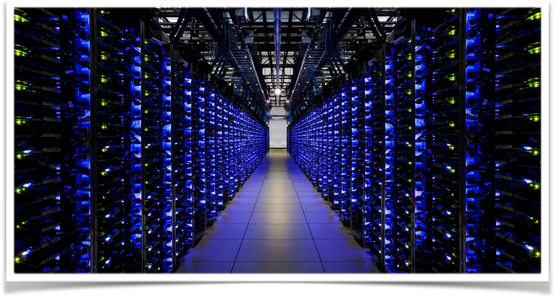
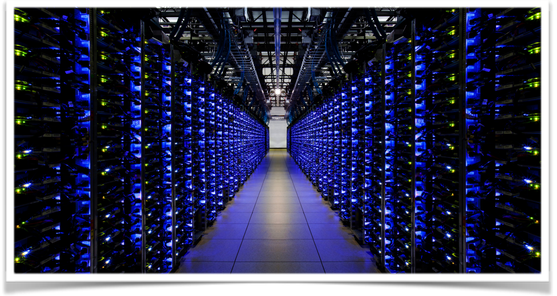
Uncertainty Risk

Price or performance variability
that makes planning difficult

Find in  = **Cloud Nirvana?**

Find in  = Cloud Nirvana?

There is No Such Thing as a Risk-free Cloud Contract

	Rejection	Revocation	Price	Uncertainty	Workload	Valuation
EC2/GCE On-demand	Yes	No	No	Yes	No	No
EC2/GCE Reserved	No	No	Yes	Yes	Yes	No
EC2 Spot	Yes	Yes	Yes	Yes	No	Yes
GCE Preemptible	Yes	Yes	No	Yes	No	Yes
EC2 Defined-Duration	Yes	No	Yes	Yes	Yes	Yes
EC2/GCE Burstable	Yes	No	No	Yes	No	Yes

Image source: www.freepik.com

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Short-term rental	Assisted living	Long-term room share	Lease-to-own

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Contract diversity is omnipresent in the real world

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Limitations of Current Systems

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Apache Spark and Hadoop

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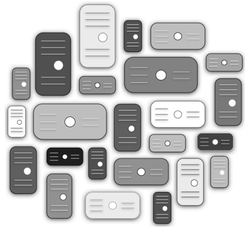

+

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RESERVED SPOT MARKET
Preemptible Dedicated

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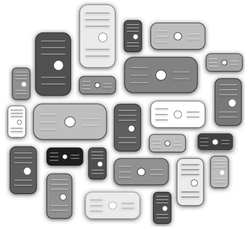

+ **On-Demand** BURSTABLE
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1. Current system software **ignore the risks** exposed by the cloud contracts
2. In turn, **pass the burden** of risk management to the applications
3. Unprepared applications incur **potential losses** due to unmanaged cloud risks

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Then, we **hypothesize** that by ***adapting and extending*** techniques from ***economics and finance***, we can effectively manage the cloud risks.

Financializing Cloud Computing

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Translate cloud server's characteristics and system software's actions into *financial value for the application*

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Analyze risk-reward tradeoffs, and **rationalize** decision making

Financializing Cloud Computing

1. **Translate** cloud server's characteristics and system software's actions into *financial value for the application*

2. **Analyze** risk-reward tradeoffs, and **rationalize** decision making

3. Build system software that manages the risks **autonomously**

Structure for the rest of the talk…

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Mitigating Revocation Risk with Insurance	Minimizing Valuation Risk via Asset Pricing	Reducing Price Risk thru' Active Trading	Eliminating Uncertainty Risk by Index Tracking
SpotOn [SoCC 2015]	Transient Guarantee [SC 2016]	HotSpot [SoCC 2017]	Cloud Index [In submission]

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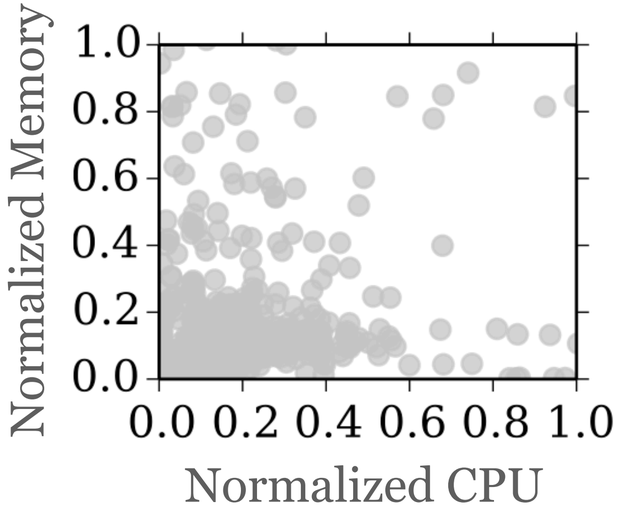
Jobs from Google cluster traces



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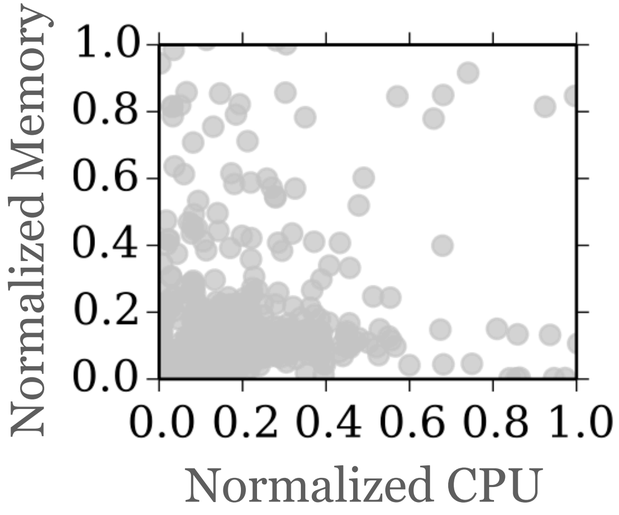
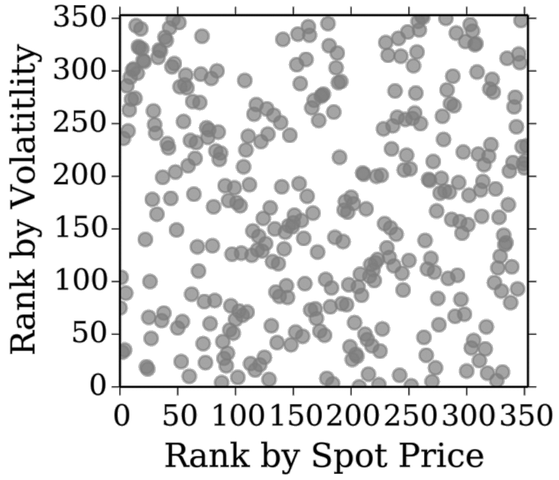


Linux spot markets in US-East-1



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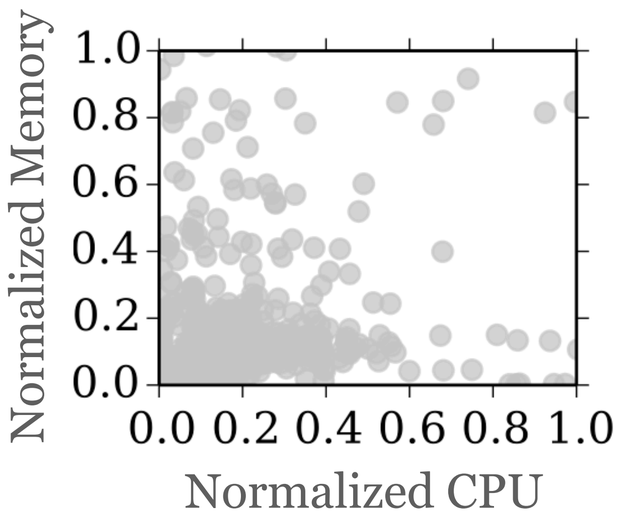

Proactive Checkpointing

Proactive Replication

Reactive Migration

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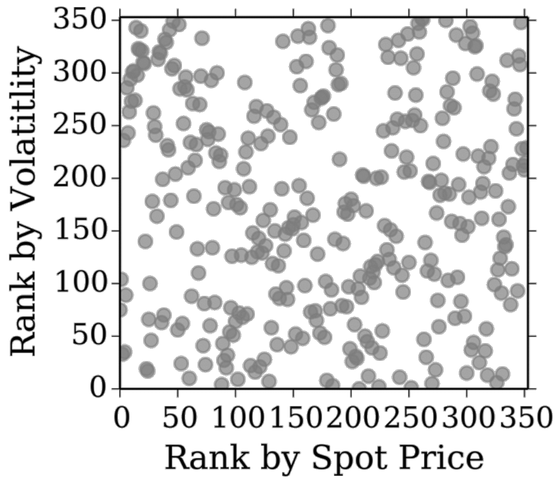

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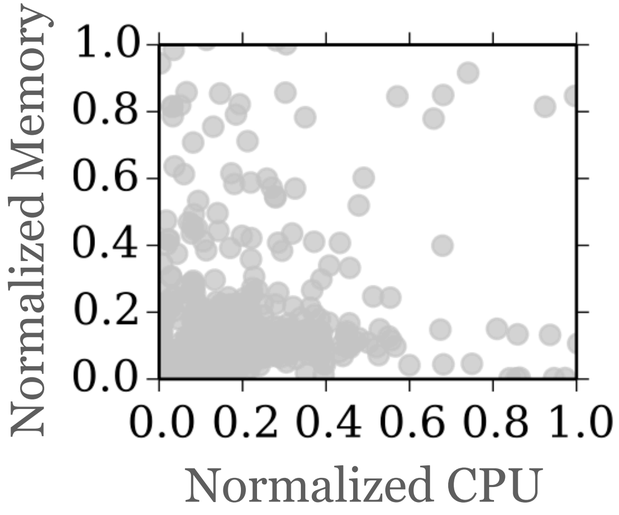

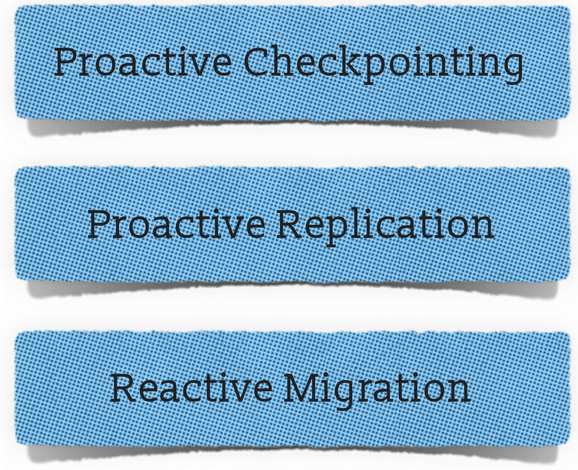

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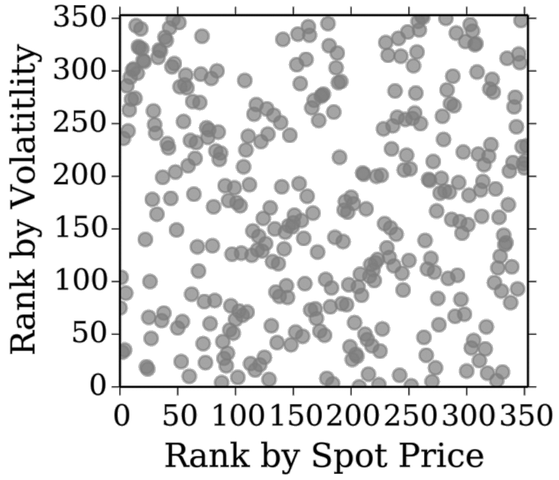

Applications, fault-tolerance mechanisms and spot servers exhibit **diverse characteristics**

Modeling Fault-tolerance Overhead

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Reactive **Migration**

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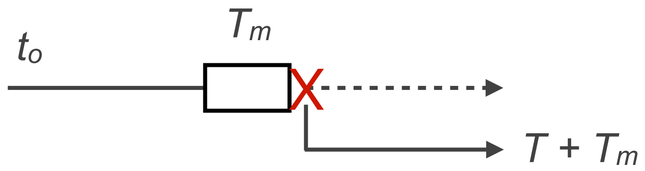

Overhead

f (job's resource usage, market characteristics)

Proactive **Checkpointing**

Replication

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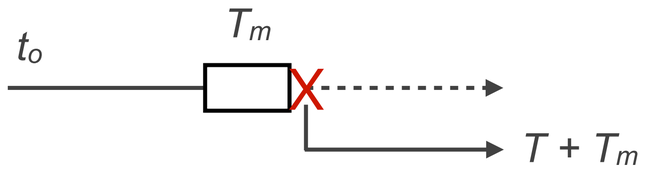

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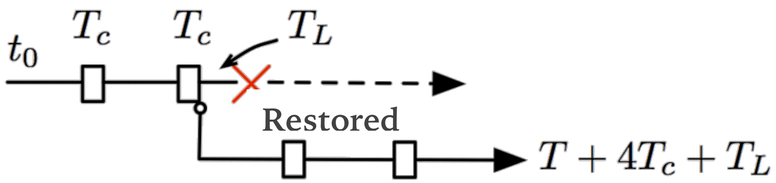

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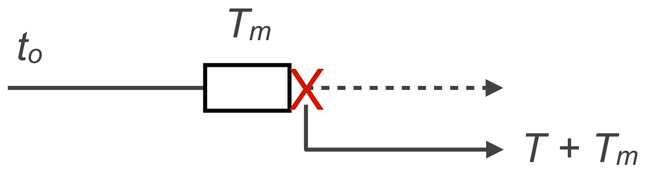

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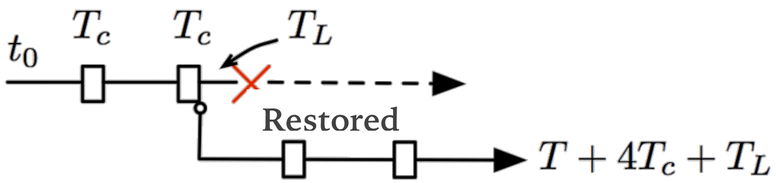

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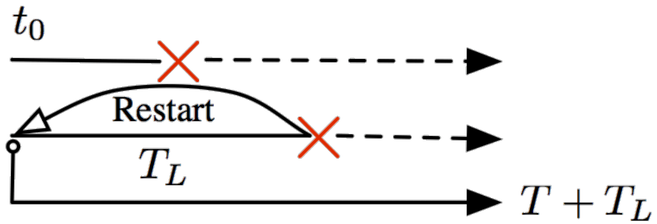

Overhead

f (market characteristics, replication factor)

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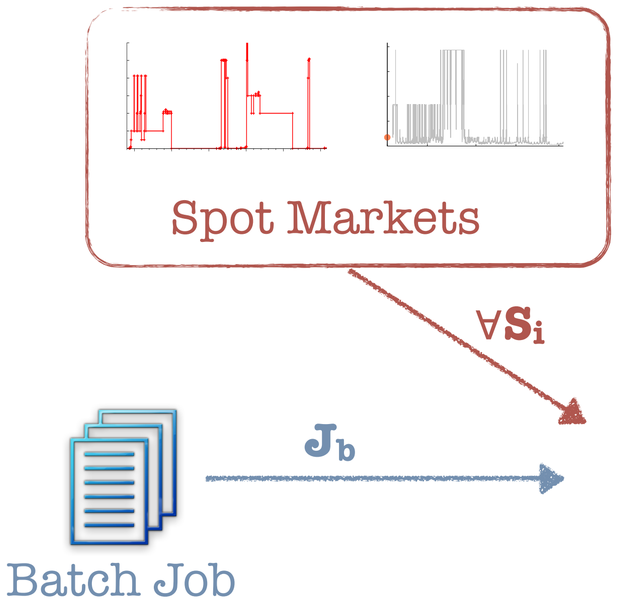

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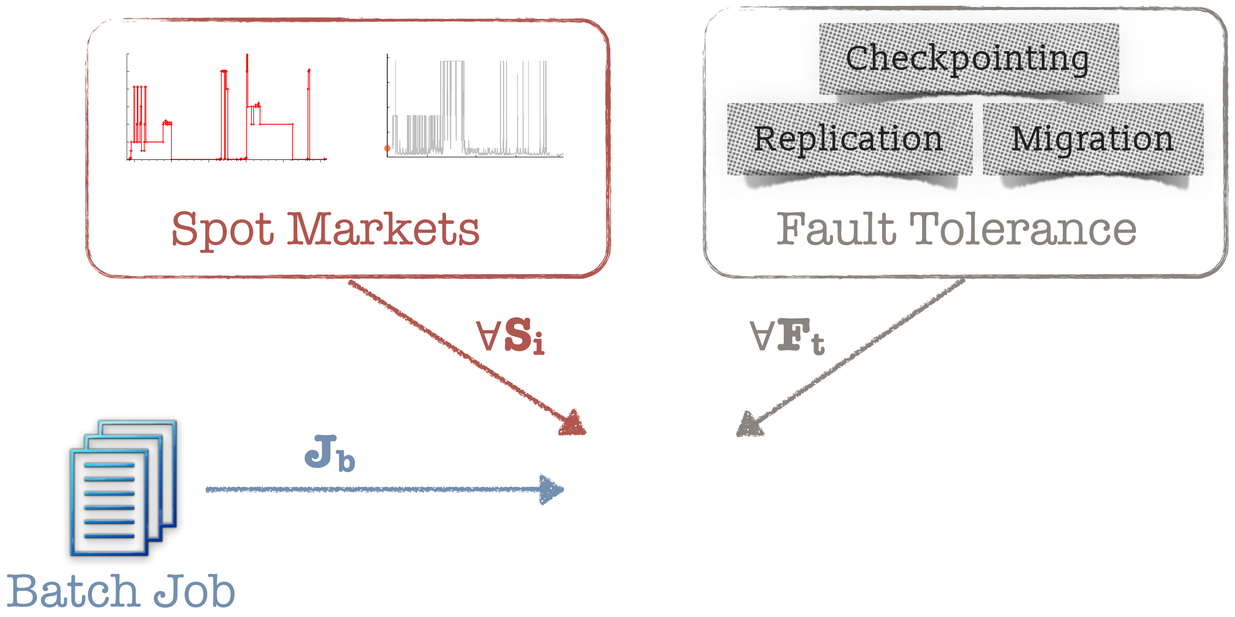

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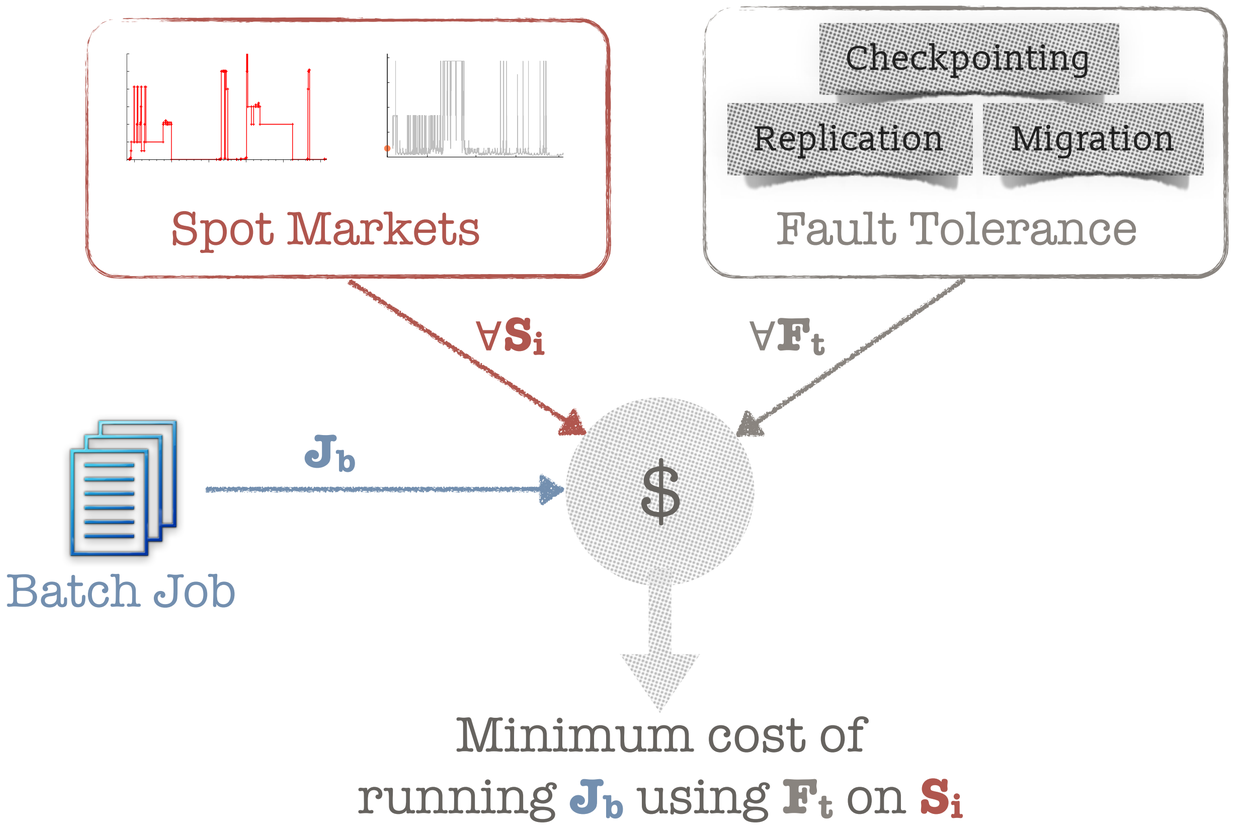

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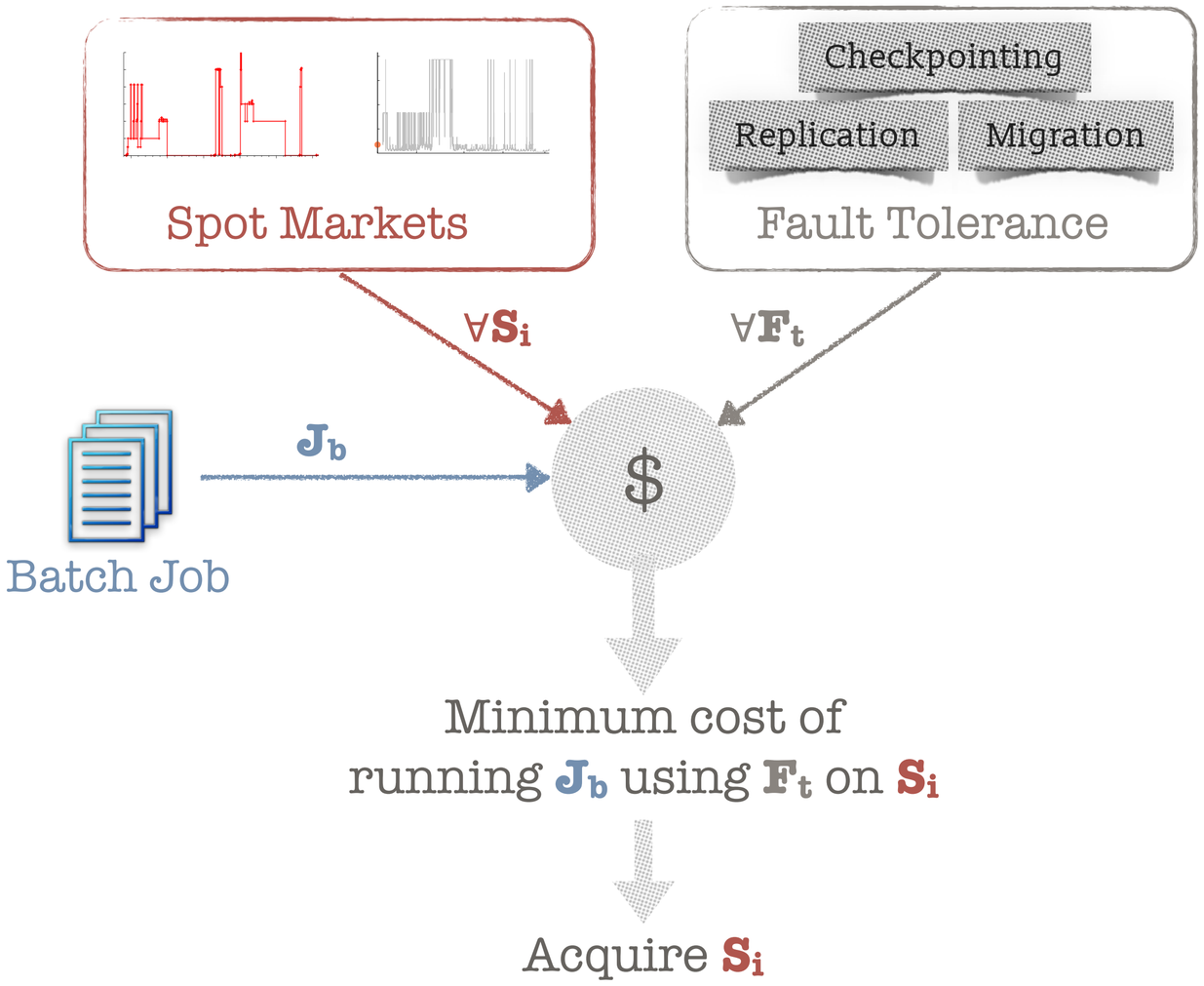

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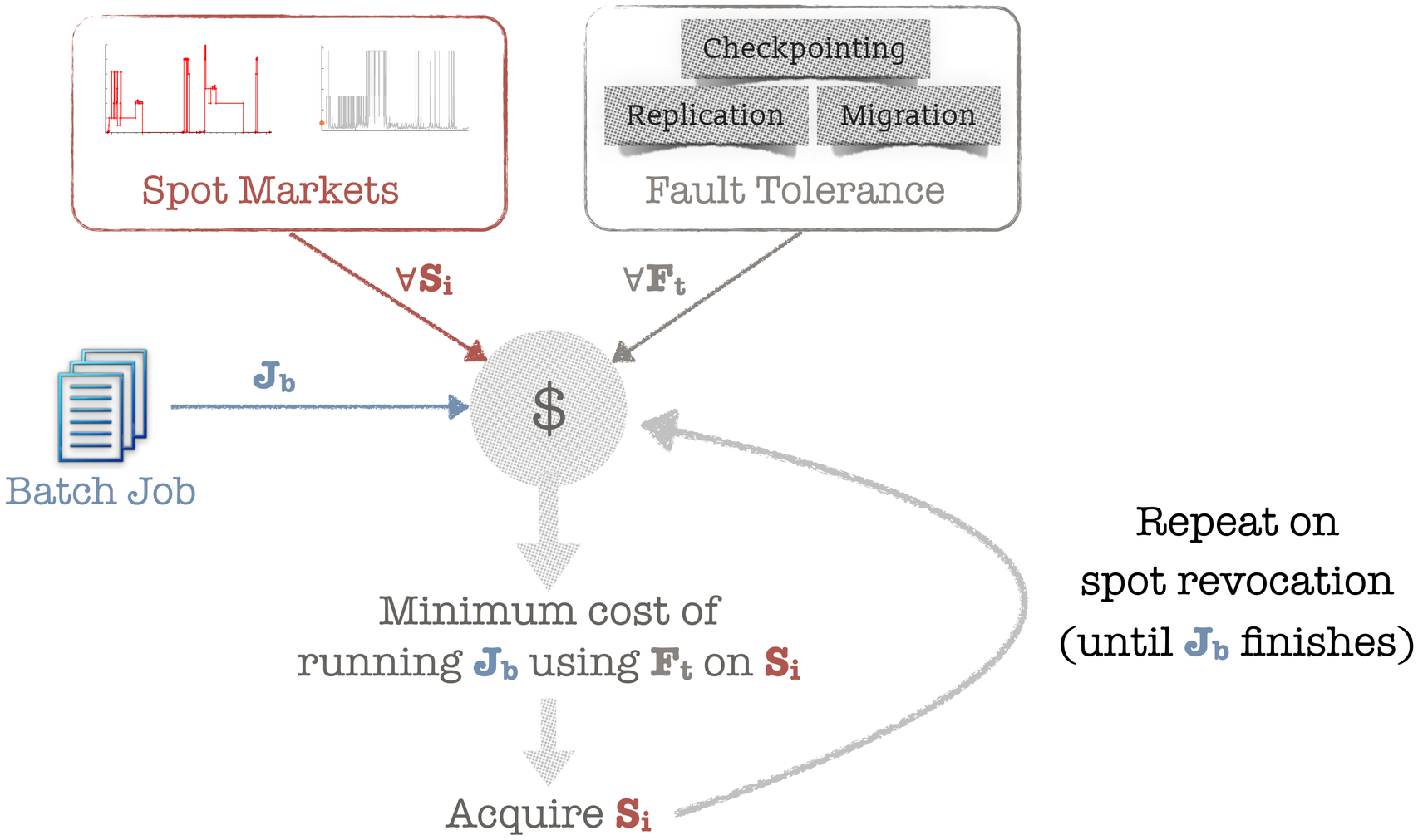

SpotOn: Design and Implementation

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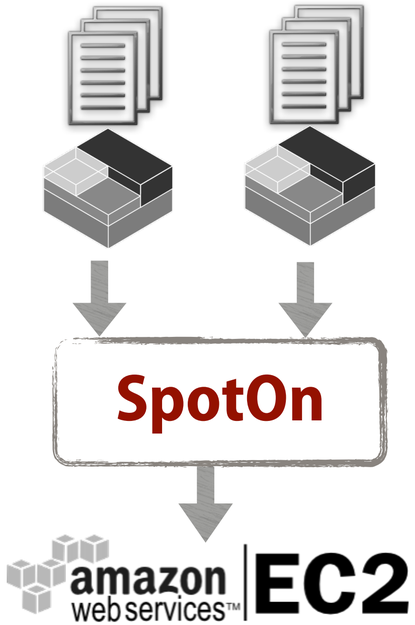

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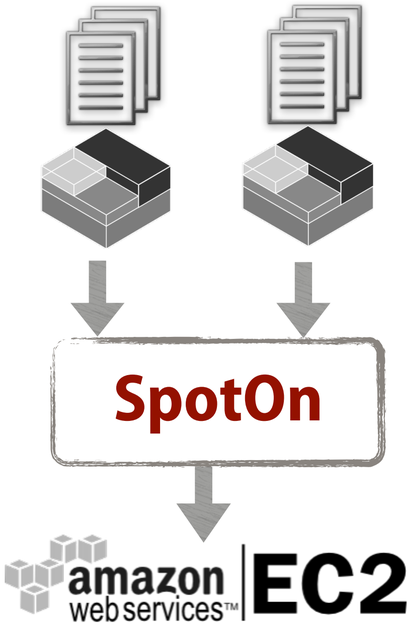

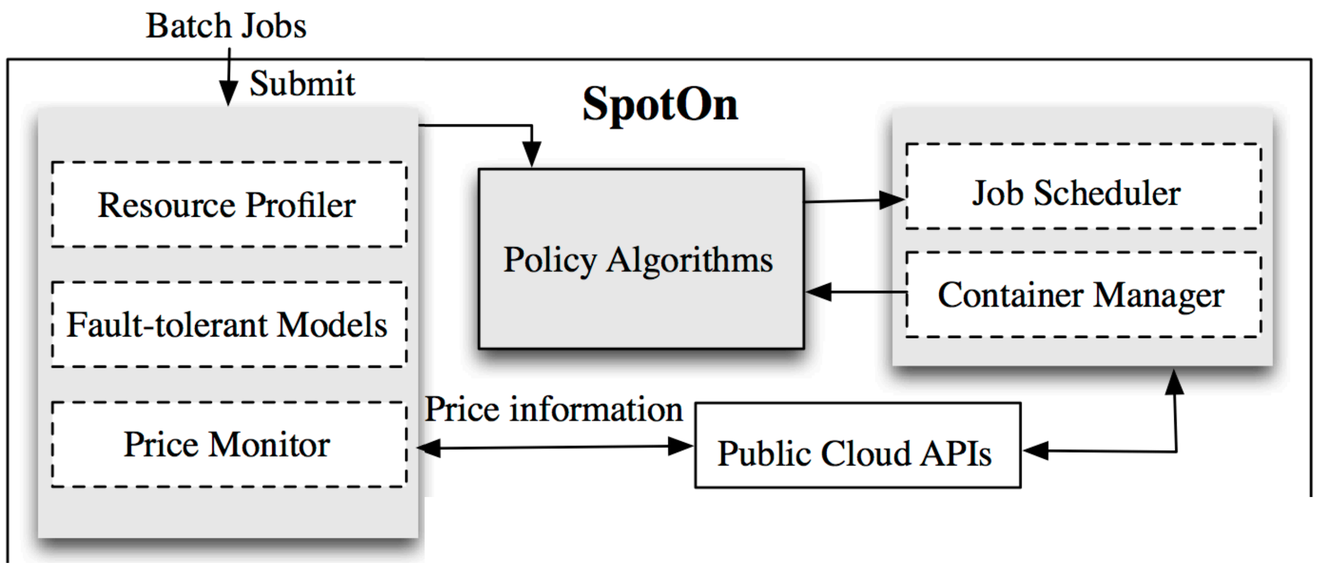

SpotOn's architectural components

Evaluation: Cost-efficient Insurance Policy

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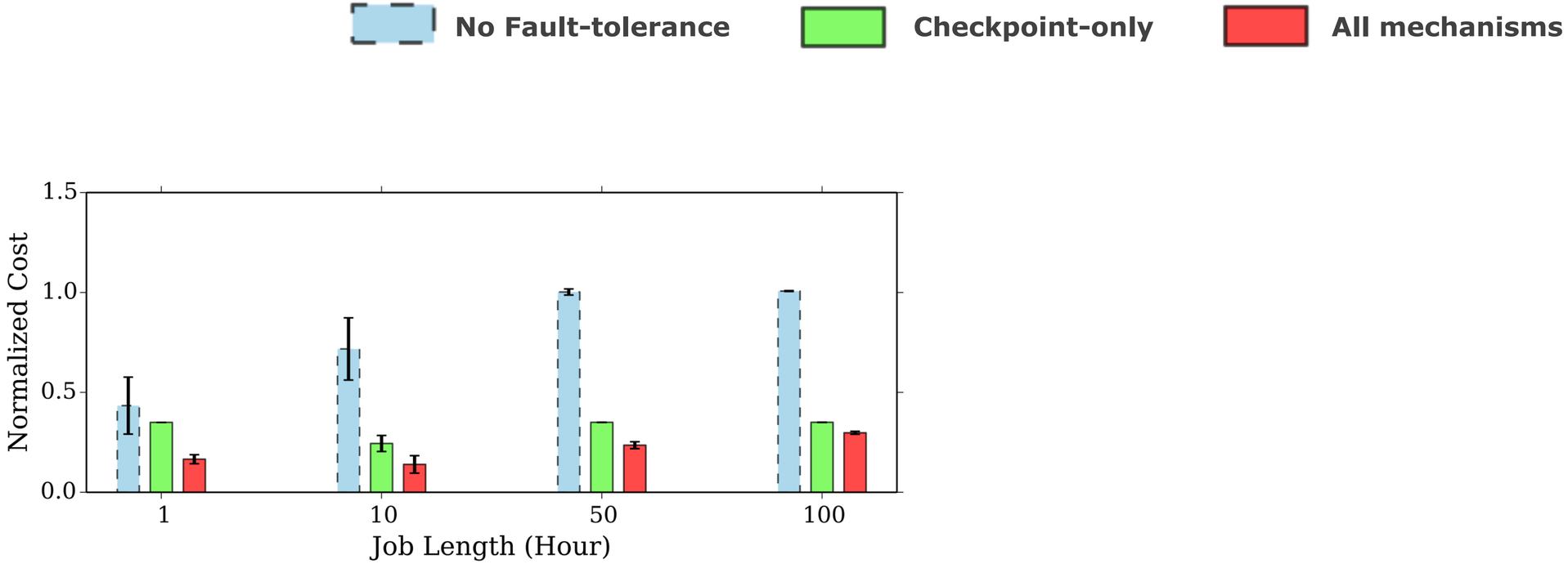

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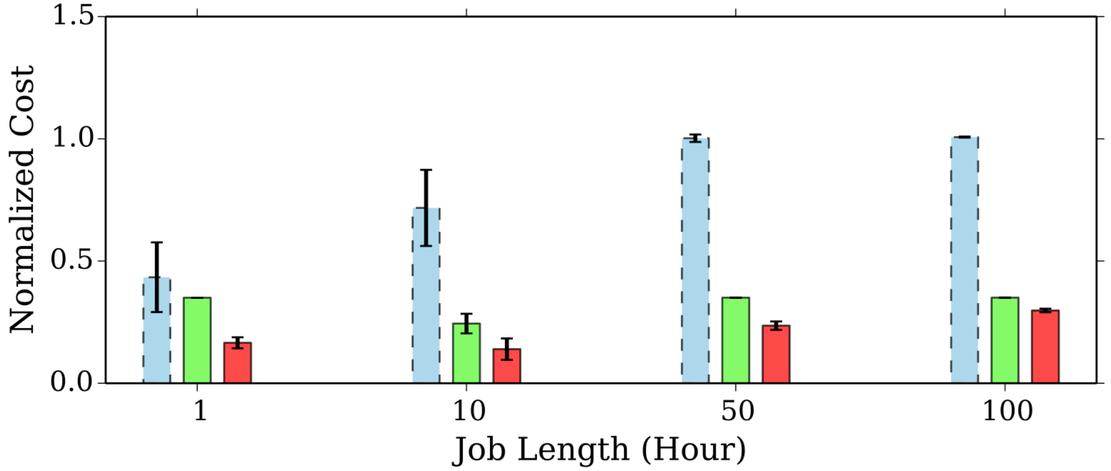

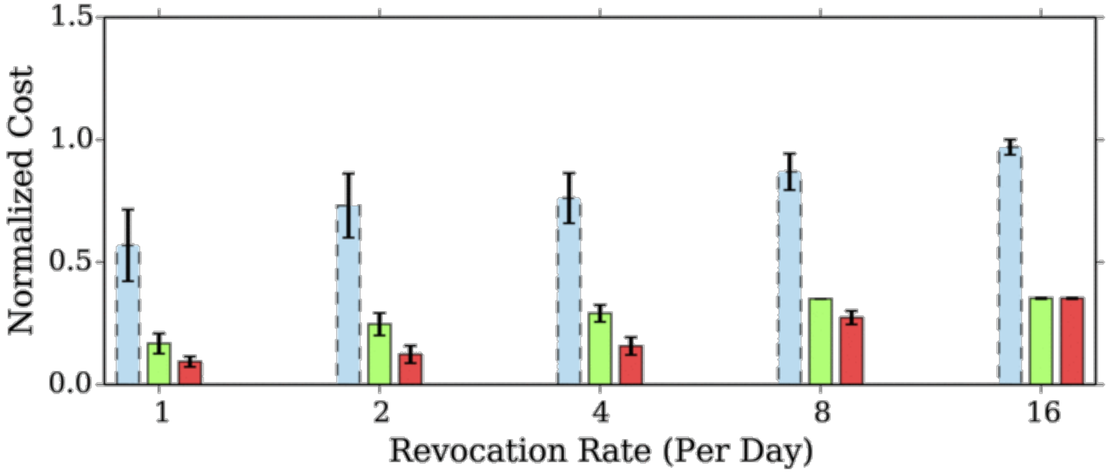

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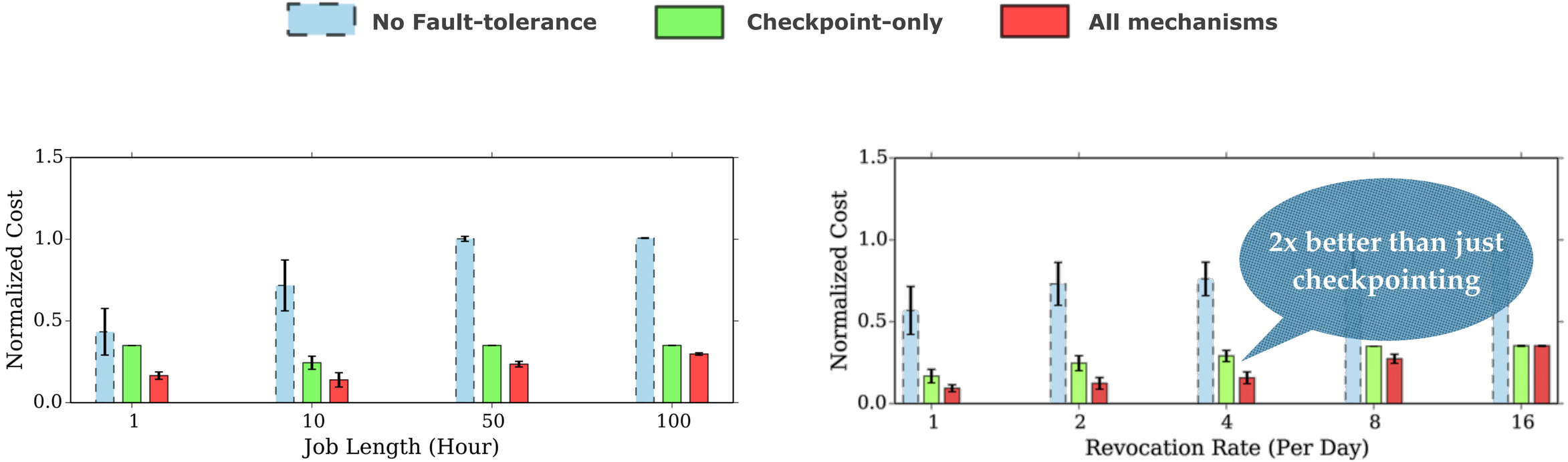

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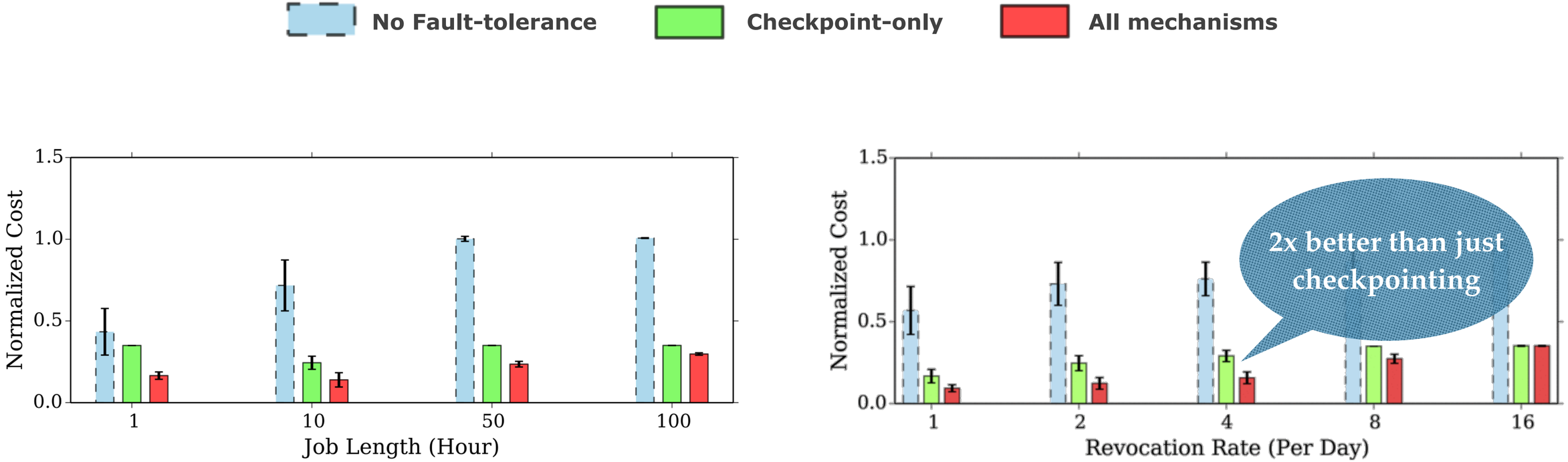

On Google cluster traces, SpotOn achieved **91.9% savings** compared to on-demand with little impact on performance

Transient server contracts do not reveal precise transiency information.

This opacity makes it difficult to **gauge** their **true value**.

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Transient Servers are Intrinsically Less Valuable!

Equilibrium Price of Transient Server
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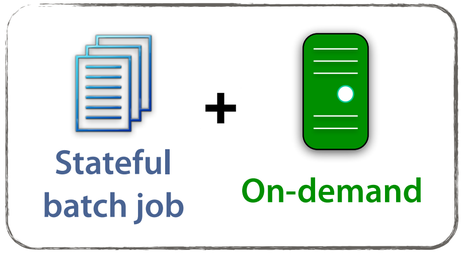
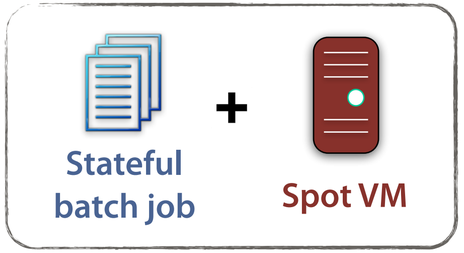


Completion time
12 hours



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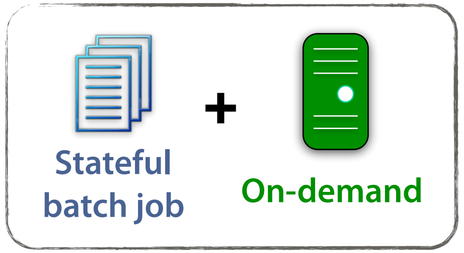

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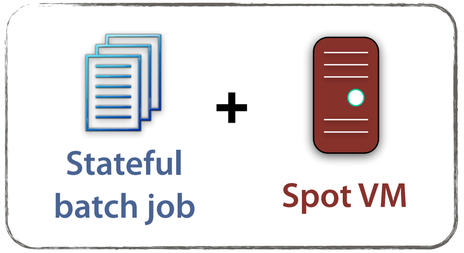
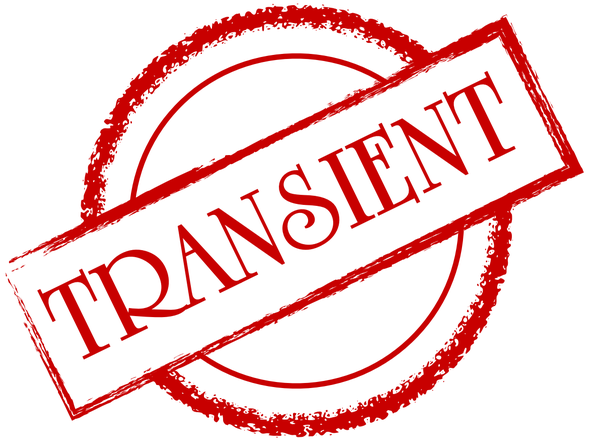


Completion time
20 hours

❝ For this application, a spot server with **40%** *discount, provides* **no savings at all** *❞*

Transient Guarantees



“ Uncertainty is more stressful than knowing for sure something bad will happen ”

nature COMMUNICATIONS

de Berker, Archy O., et al. *“Computations of uncertainty mediate acute stress responses in humans.”* Nature communications 7 (2016)

Not All Transient Servers are Alike

. . . and there are many ways to sell them

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Max Performance
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Every server sold with its unique revocability characteristics

Transient Guarantees

Providing probabilistic assurances on *availability, volatility and predictability* of transient servers

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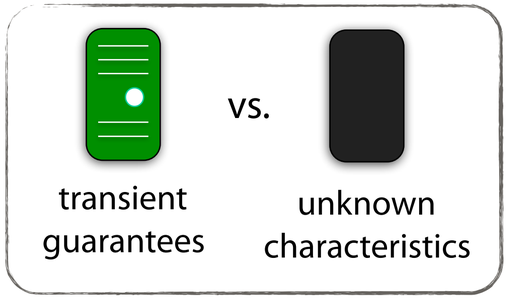

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Price the servers correctly
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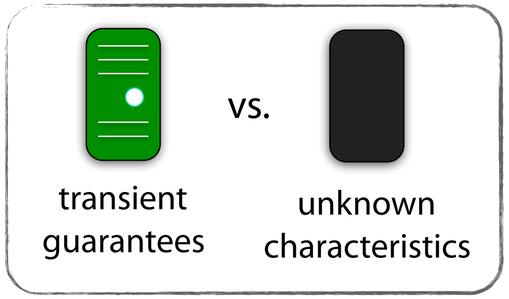

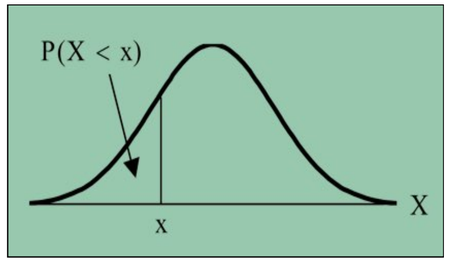

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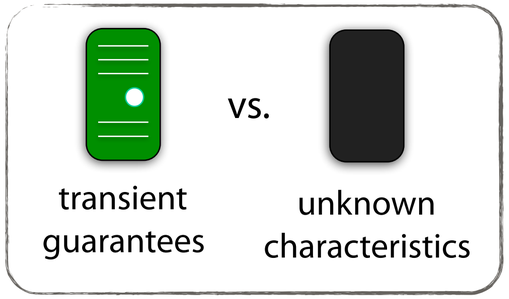

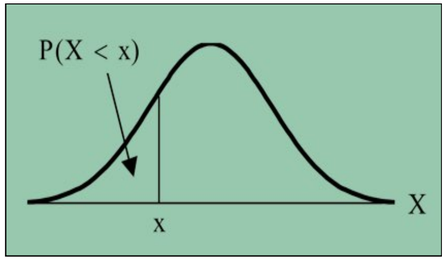

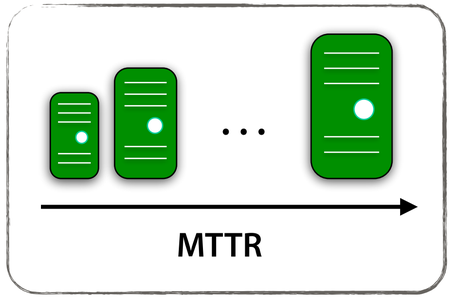

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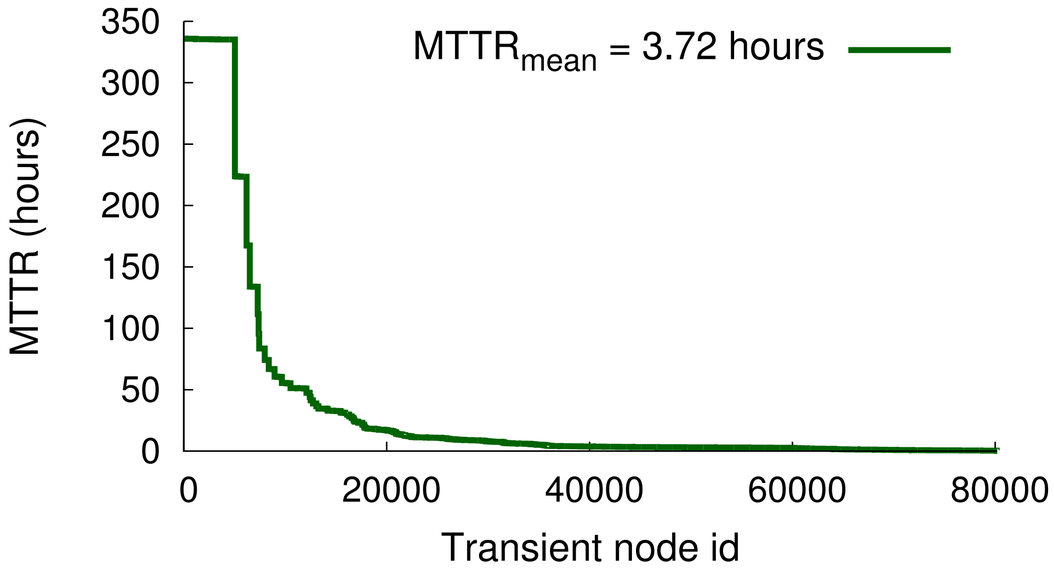
Differentiated offering

Higher revenue (providers)
Better choice (users)

Evaluation: Transient Server Characteristics



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Server characteristics are modeled from a production cluster at Google

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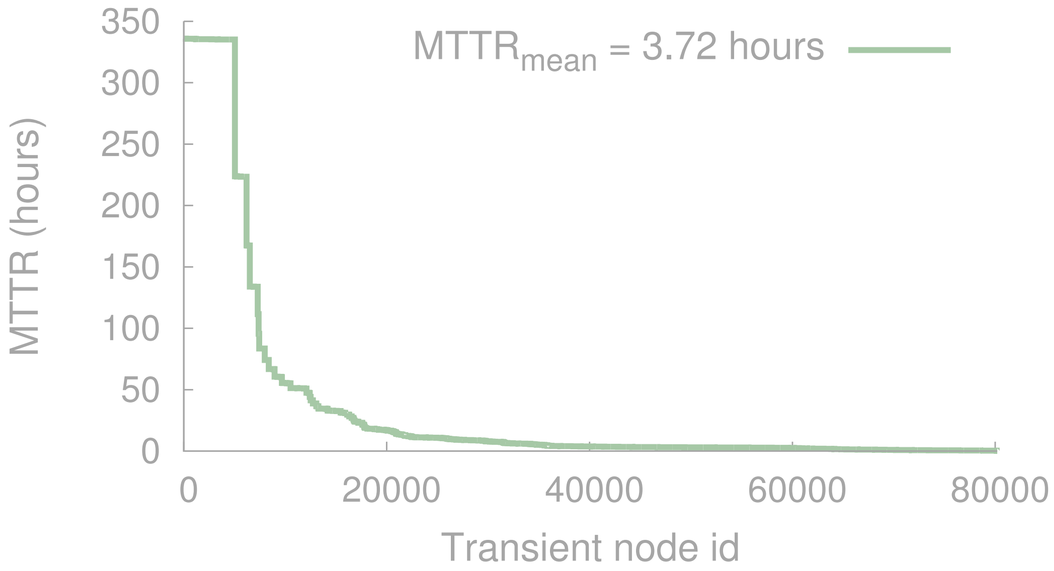

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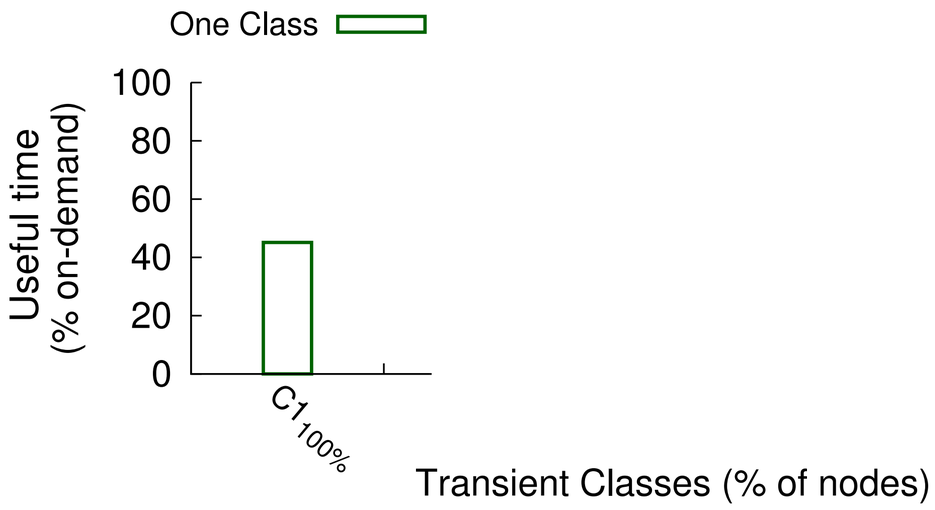

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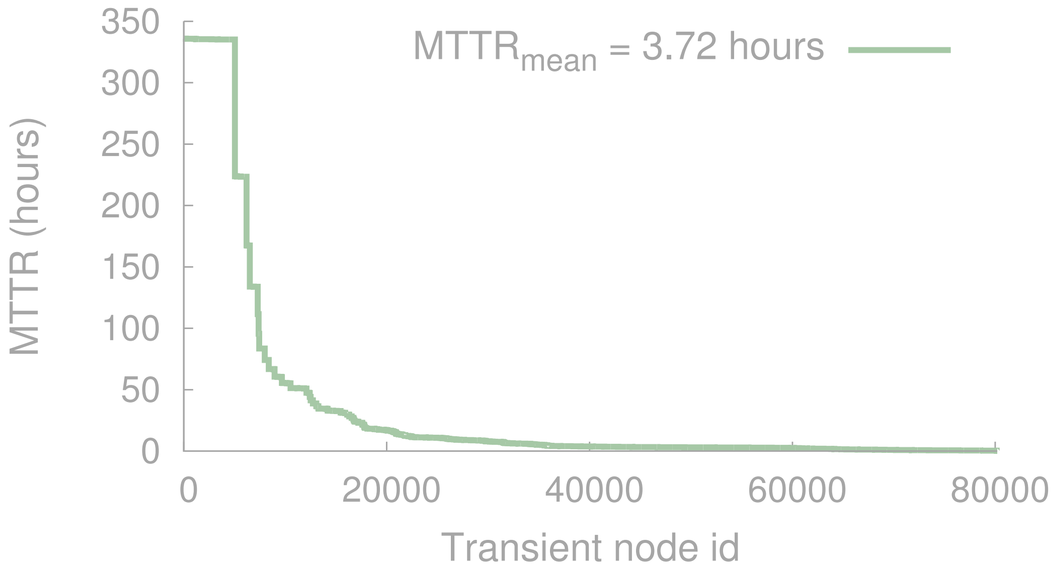

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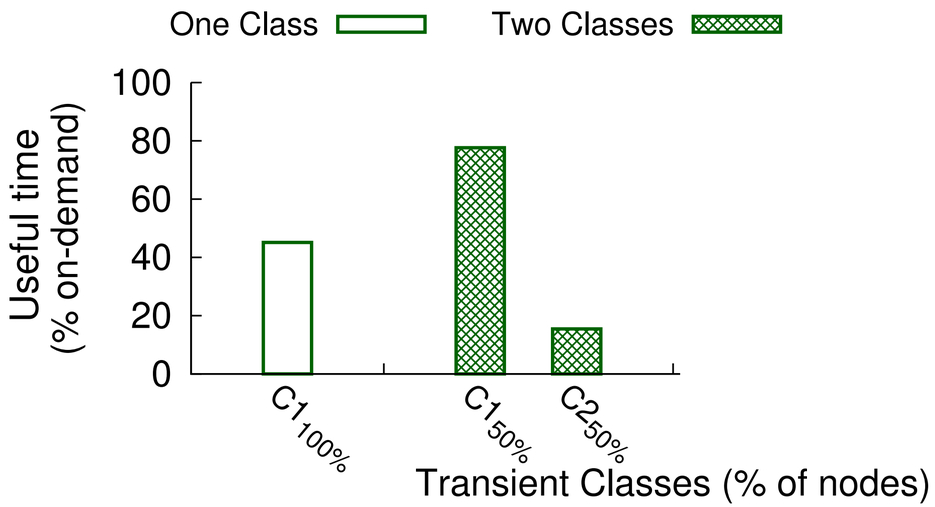

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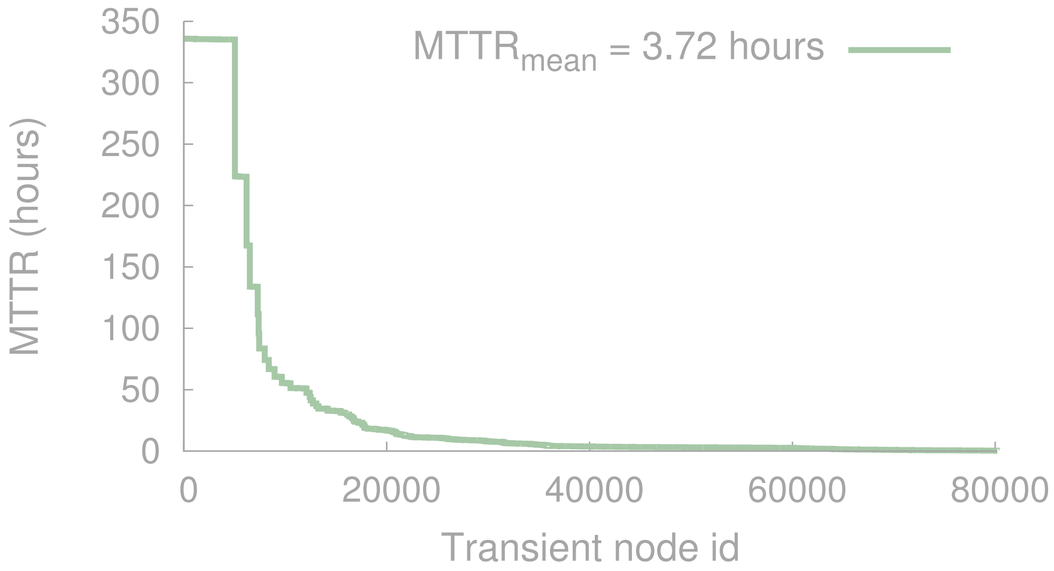

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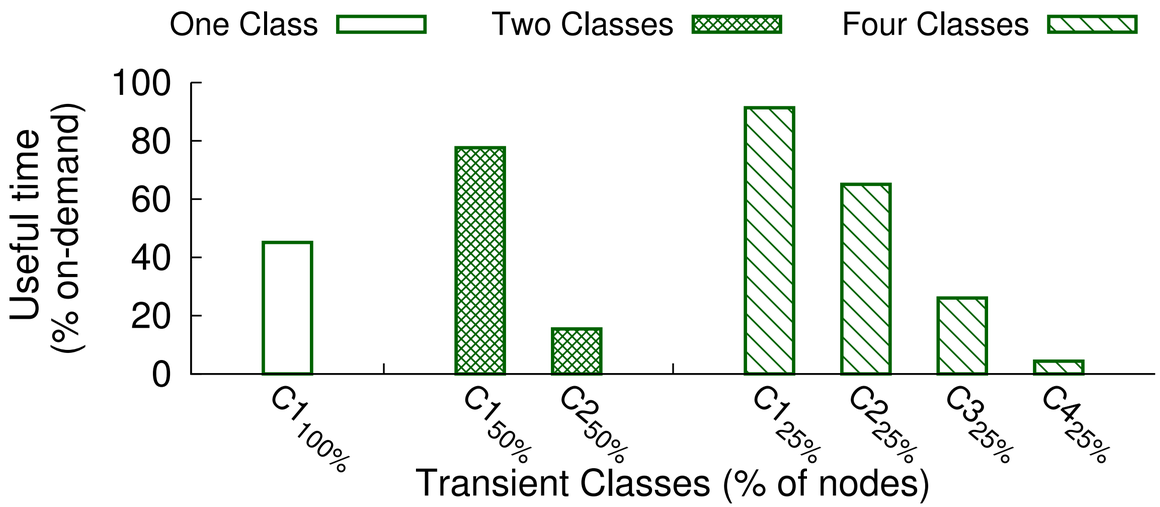

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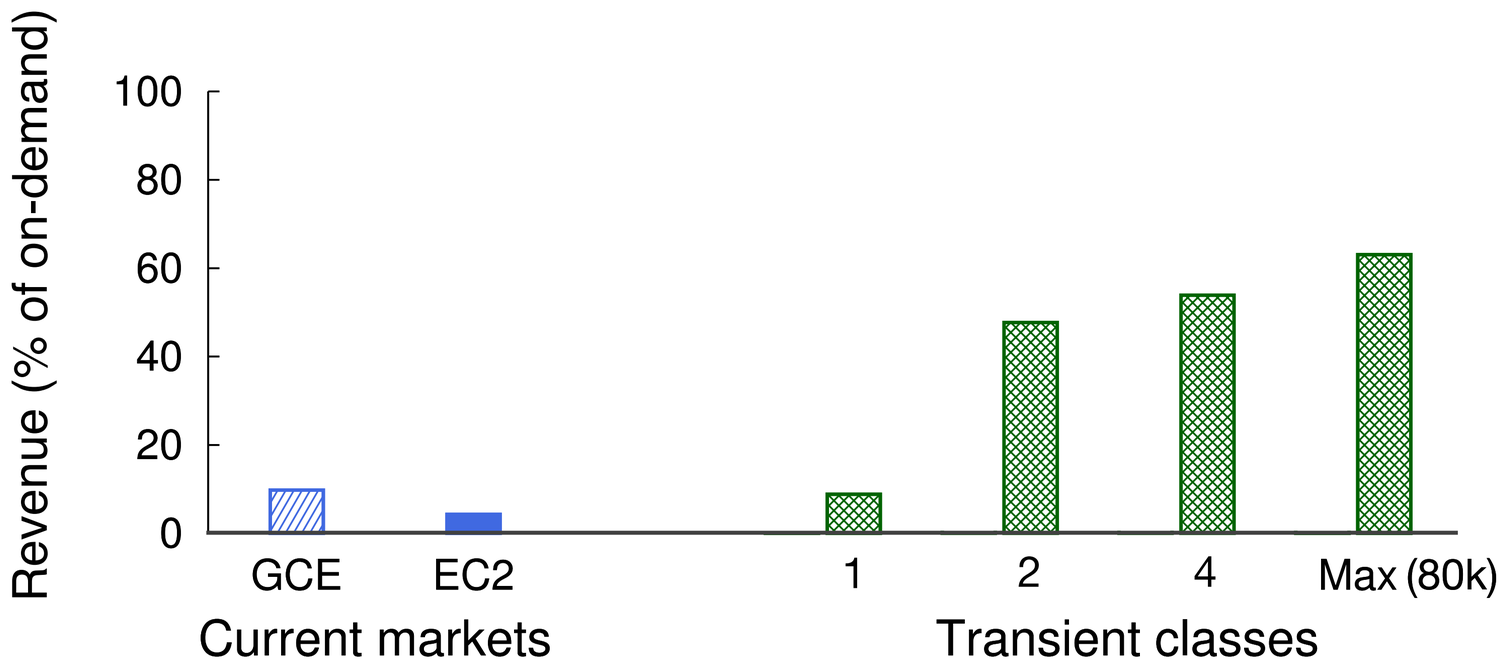

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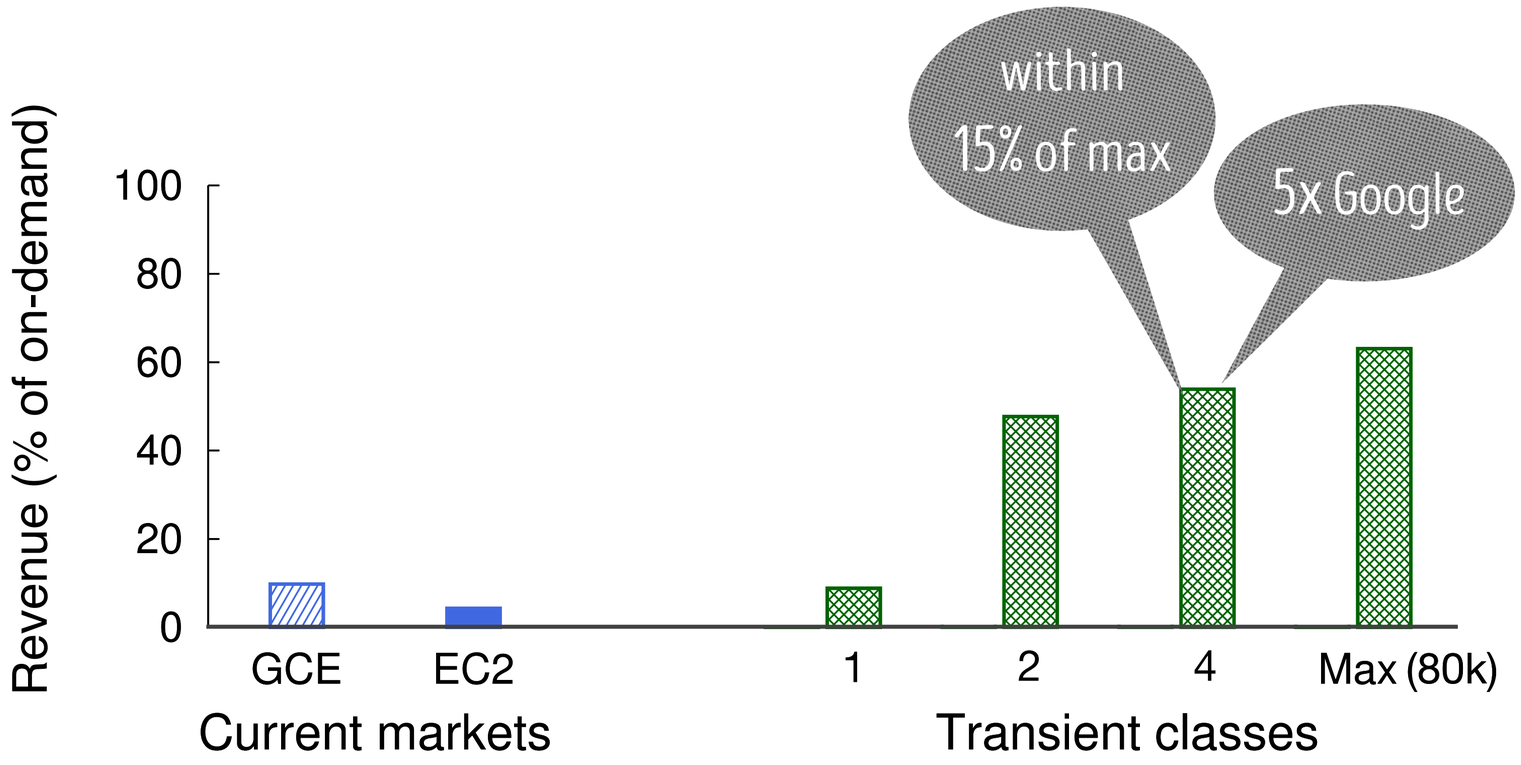

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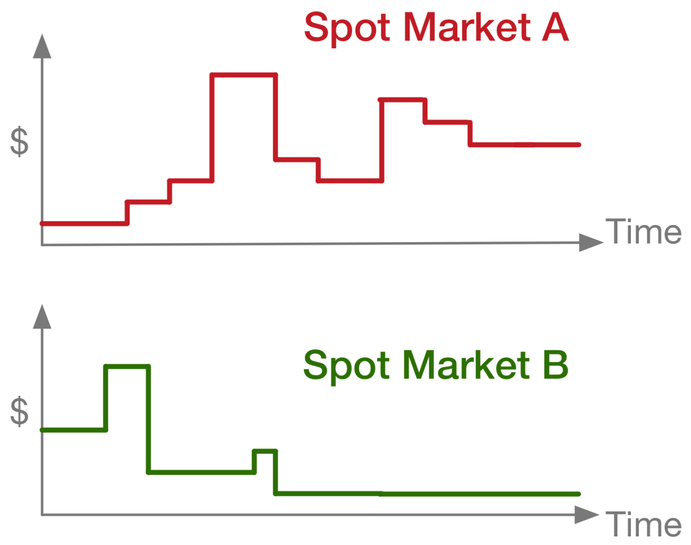

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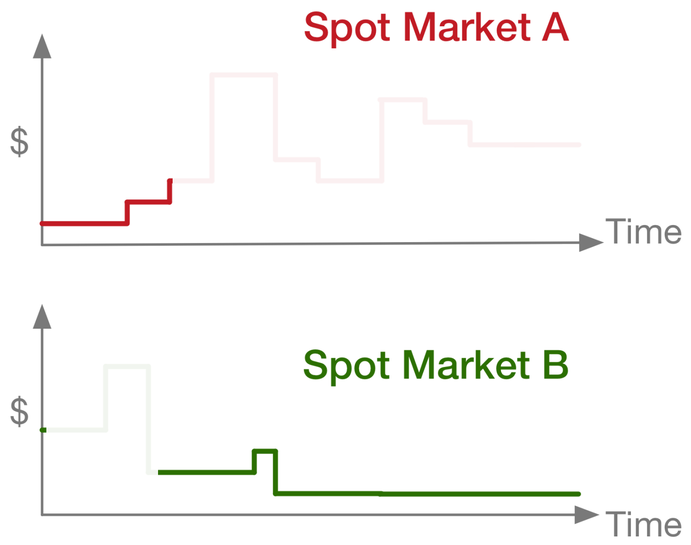

Price Risk >> Revocation Risk

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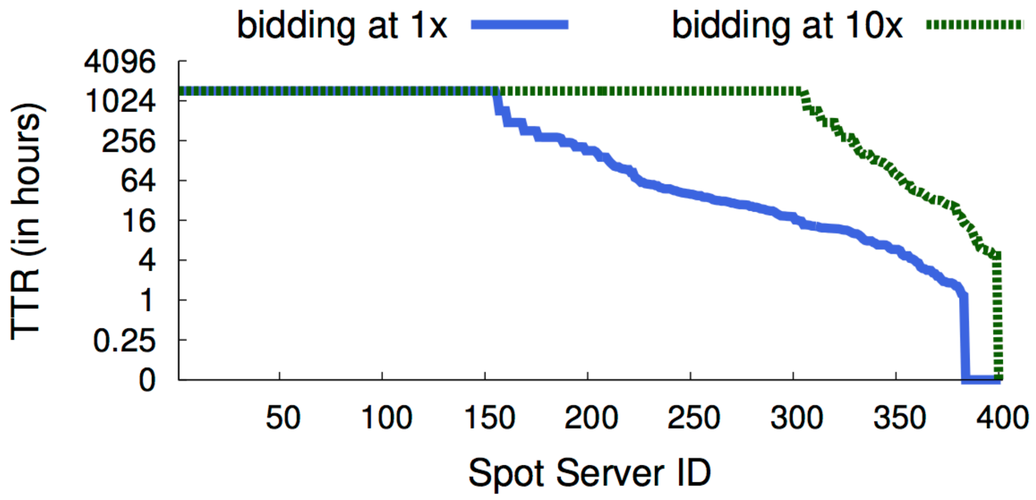

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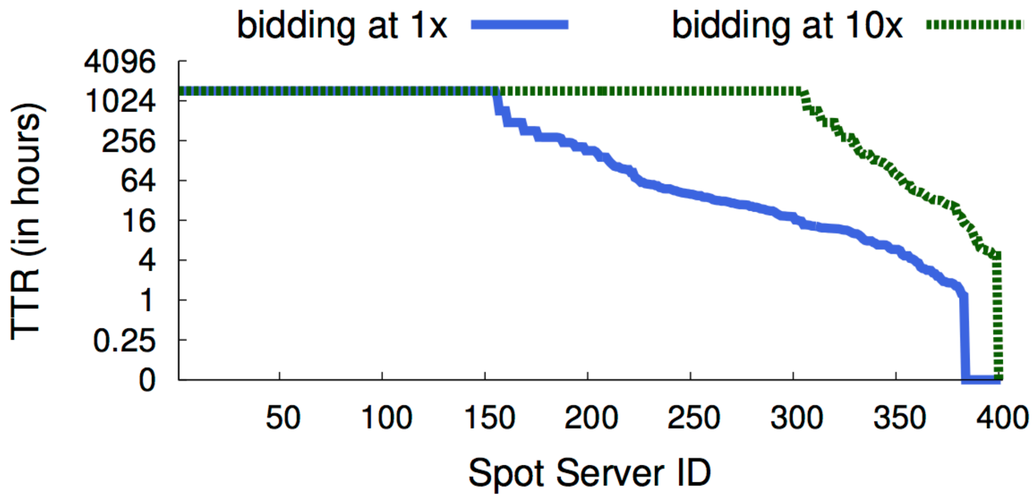

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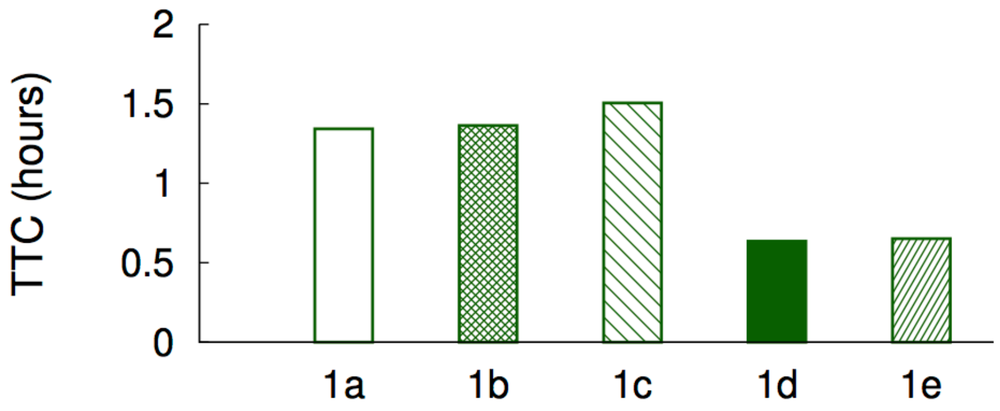

Time-to-Change (TTC) for the cheapest VM is 1.1 hours

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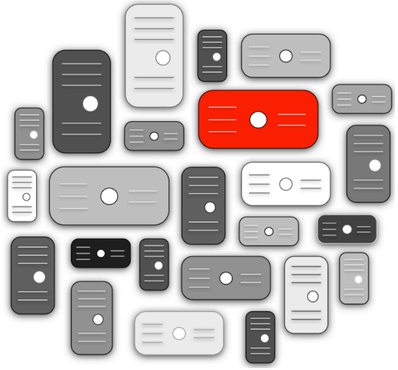

HotSpot: Automated Server Hopping

Automated Server Hopping

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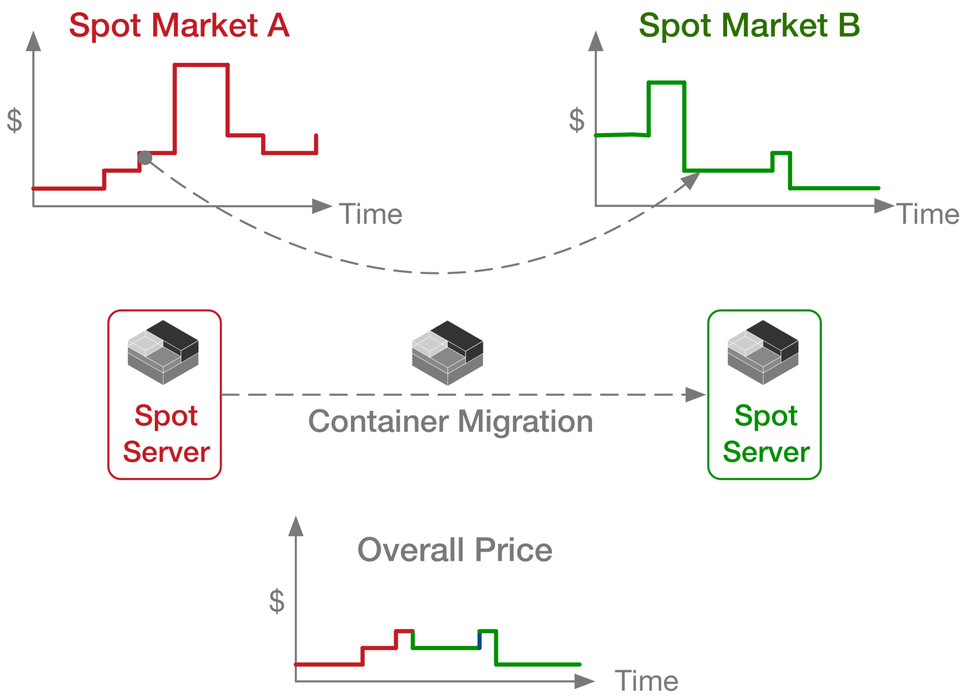

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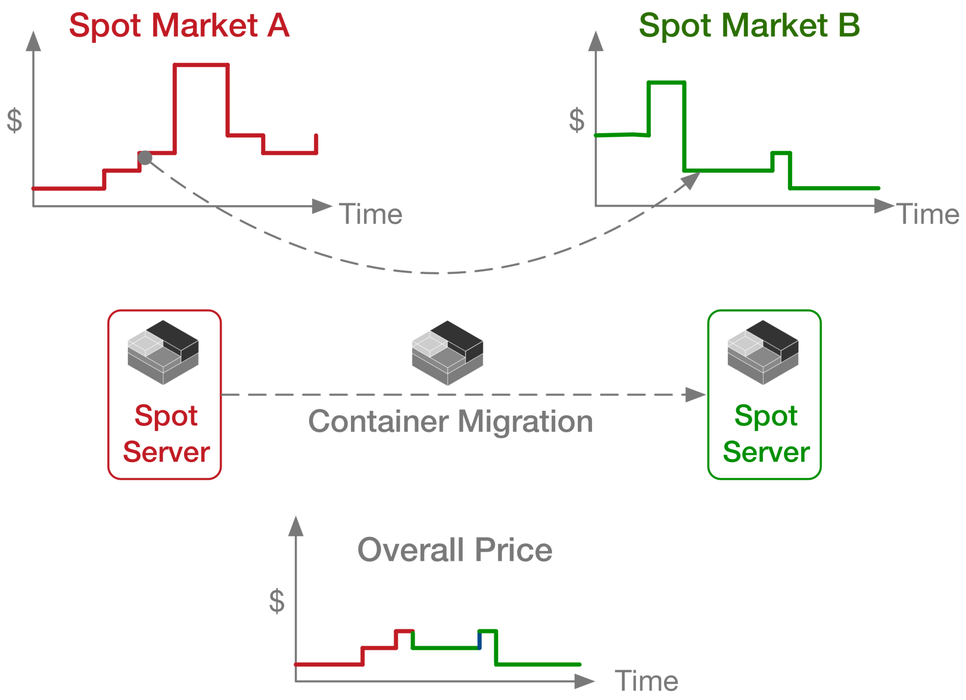

Benefits of Server Hopping

US-East-1 markets (3/1/2017 - 5/1/2017)

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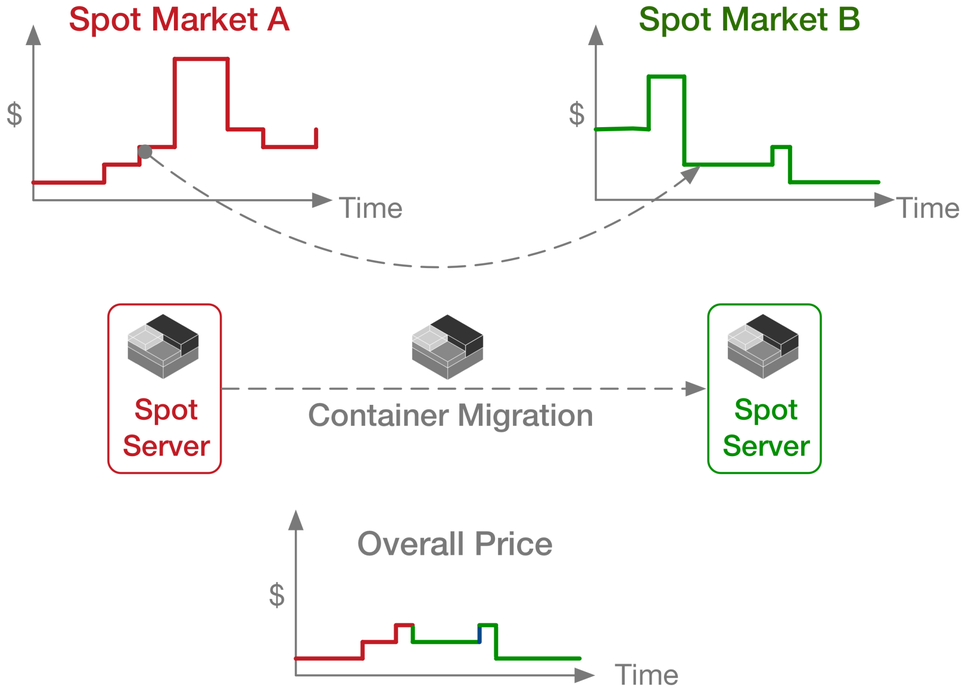
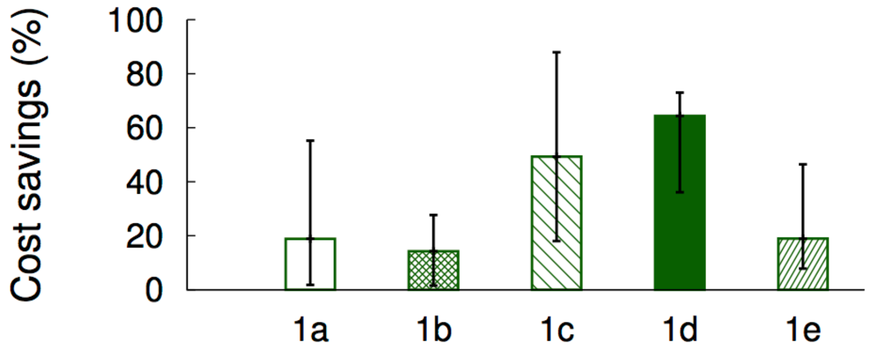


Benefits of Server Hopping

US-East-1 markets (3/1/2017 - 5/1/2017)



Ideal savings from **hopping** vs. **staying** for a long-running job (30 days)

Quote from Jack Welch, former CEO of General Electric

Effect on Revocation Risk

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Highly discounted servers tend to have lower revocation risk

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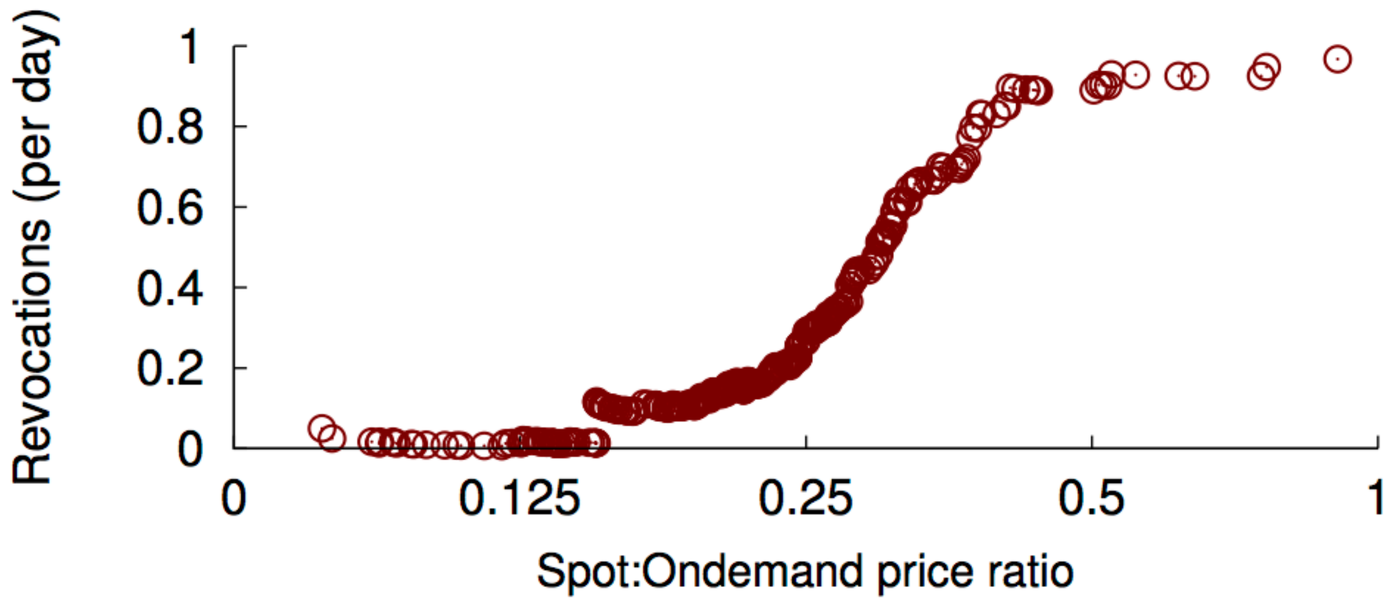

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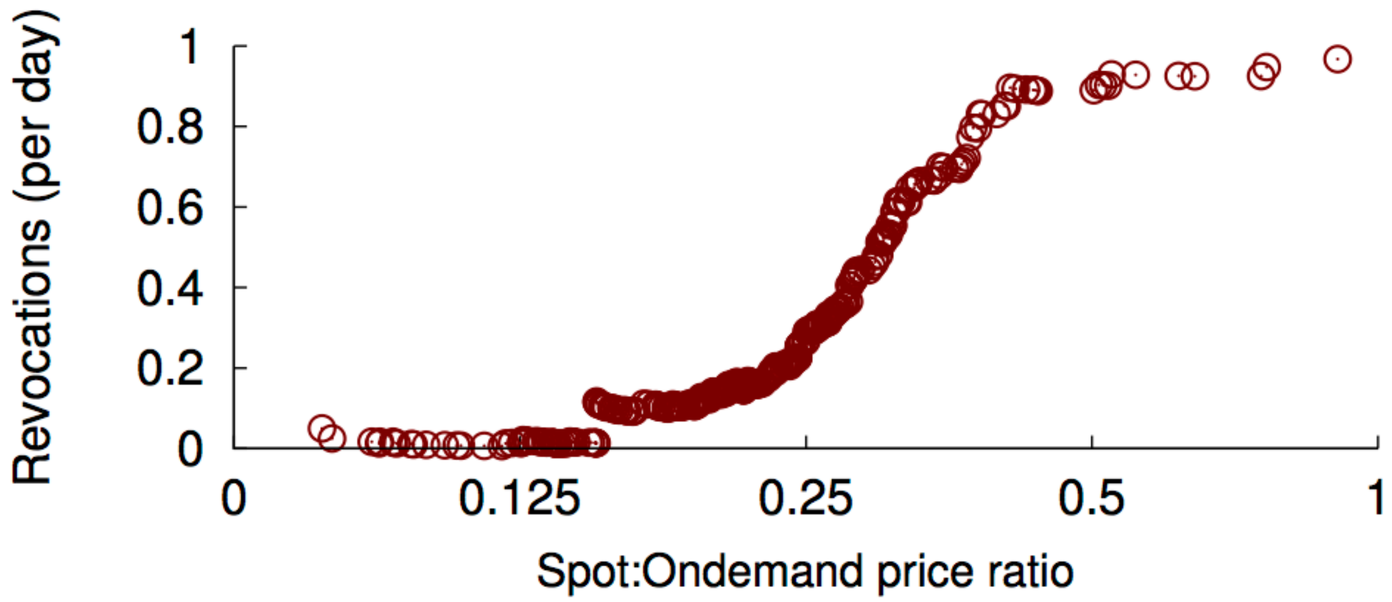

Server hopping lowers revocations along with improving cost-efficiency

HotSpot: Design and Implementation

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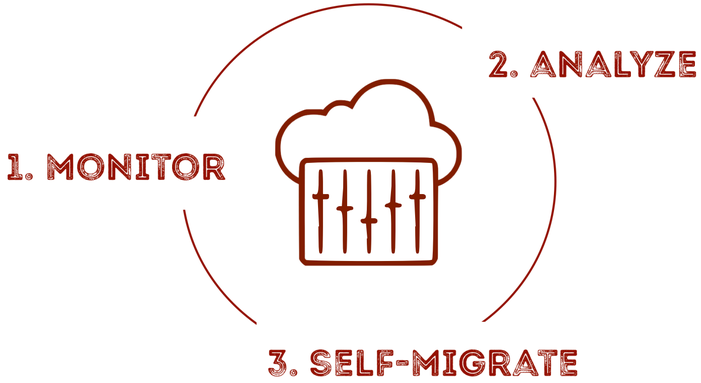

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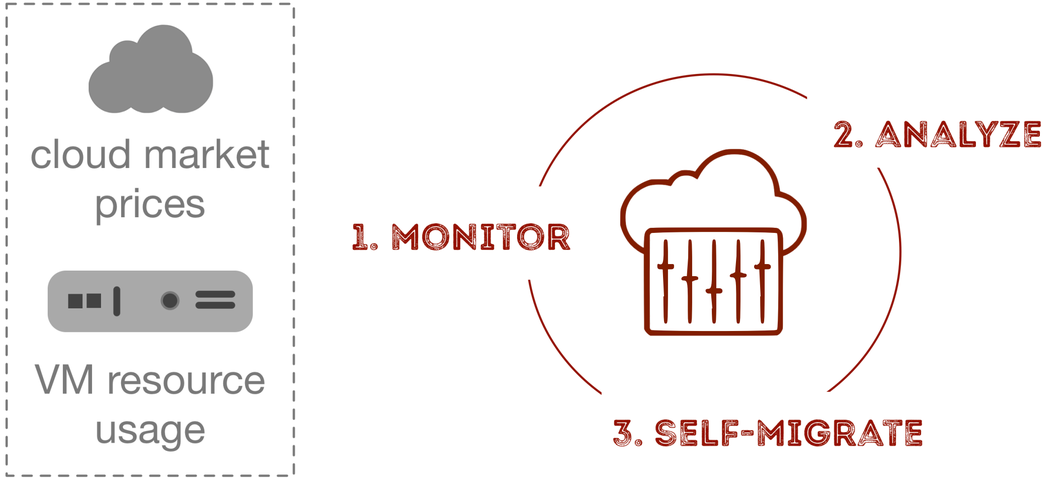

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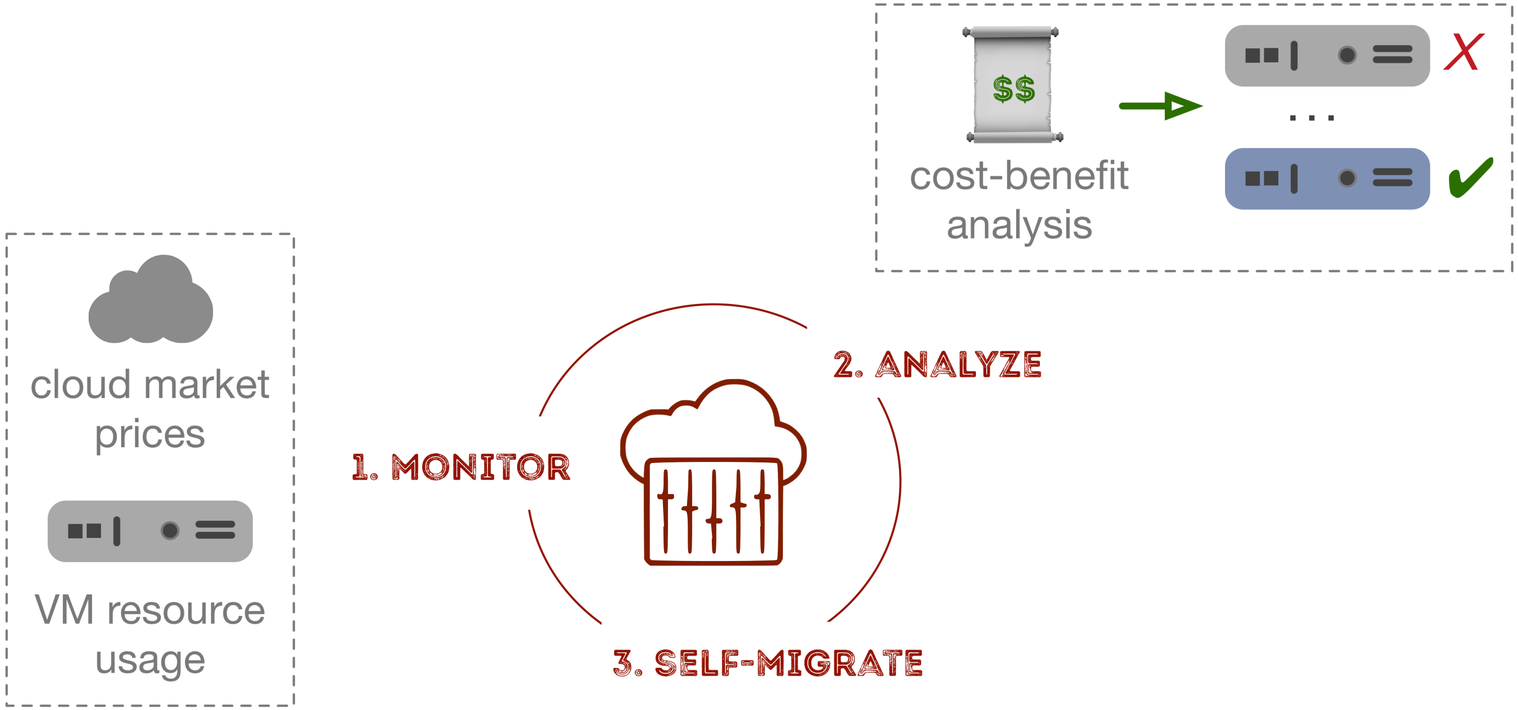

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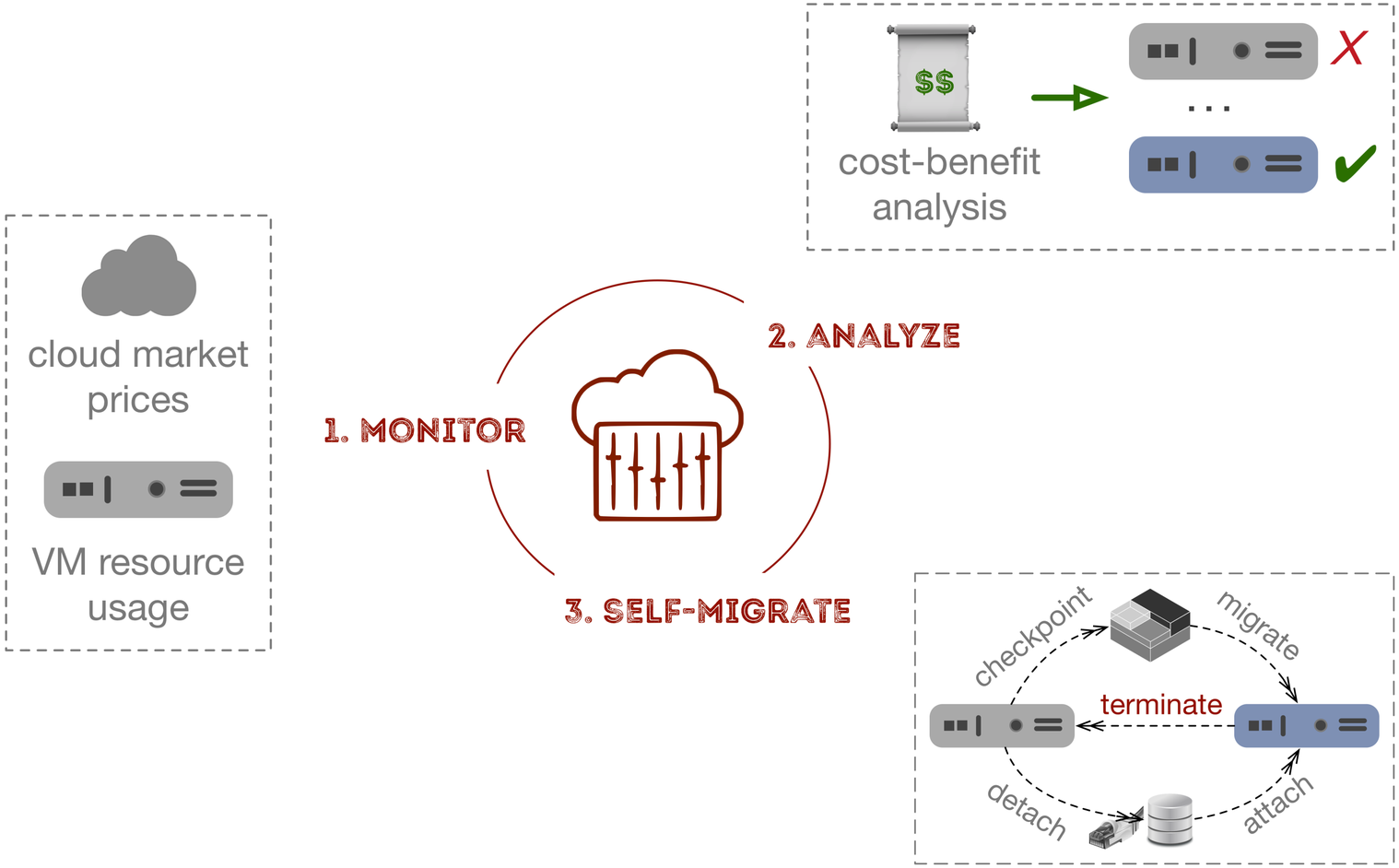

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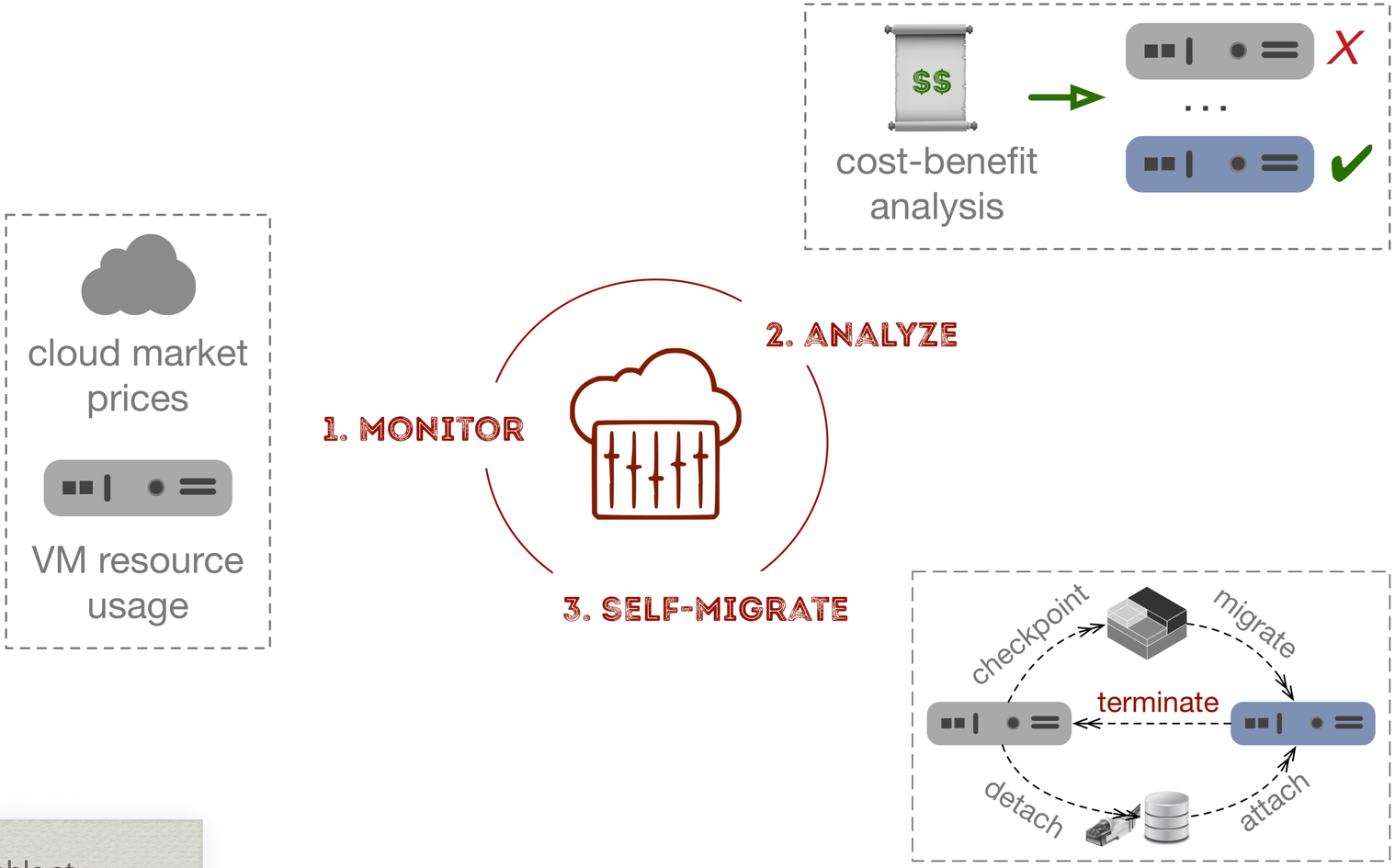

Fully functional prototype available at:

https://sustainablecomputinglab.github.io/hotspot/

Design of Server Hopping Logic

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(Run on a server that has the **best cost-efficiency** in $/utilized-resource without hindering the performance)

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- Double-paying for servers
- f(application footprint)

$$\text{Benefit} = (P_{current} - P_{new}) * E[T_{new}]$$

- Gain in cost-efficiency
- f(market characteristics)

Evaluation

Compare **cost, performance, revocations** of running a flexible batch application on

Spot server with **no protection** (SpotFleet)	vs.	Spot server with **fault-tolerance** (SpotOn)	vs.	Spot server with **server hopping** (HotSpot)

Google Cluster Jobs on EC2 Spot Markets

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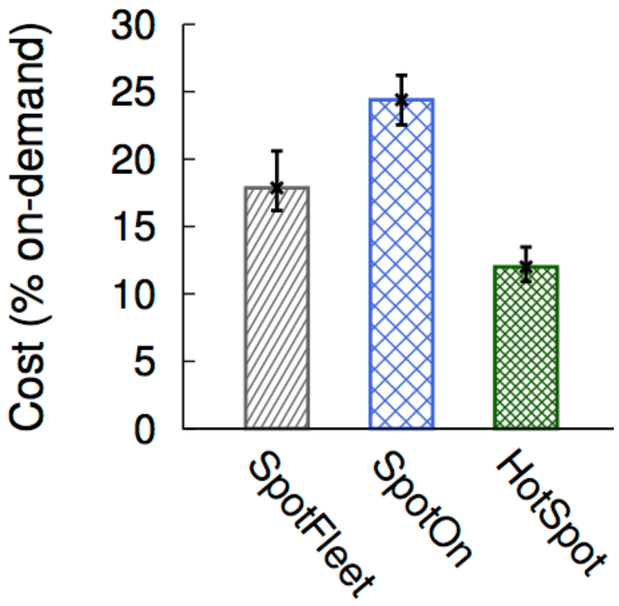

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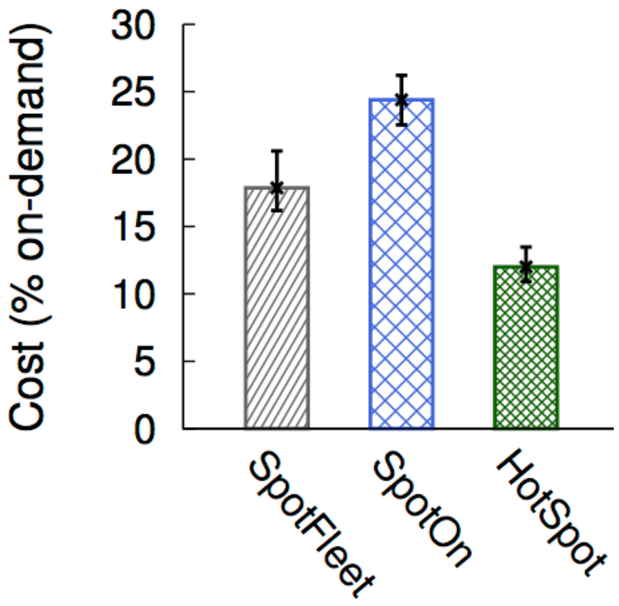

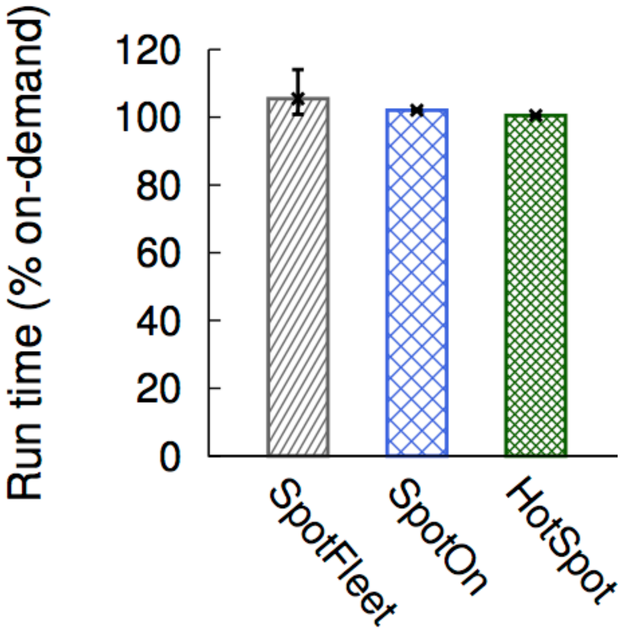

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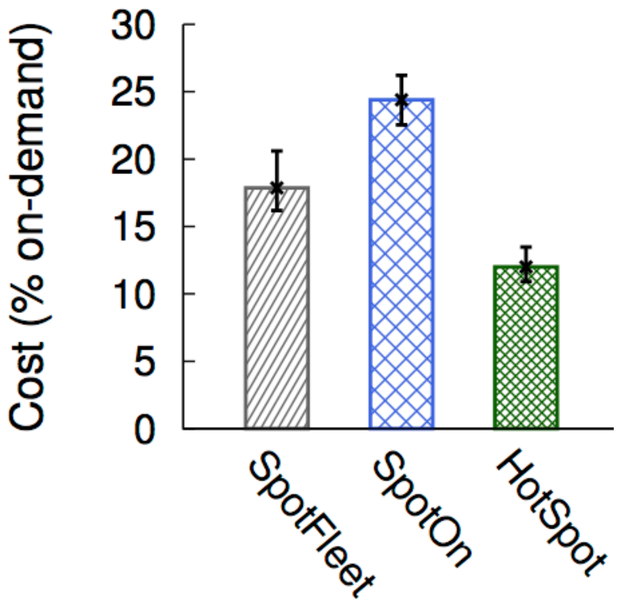

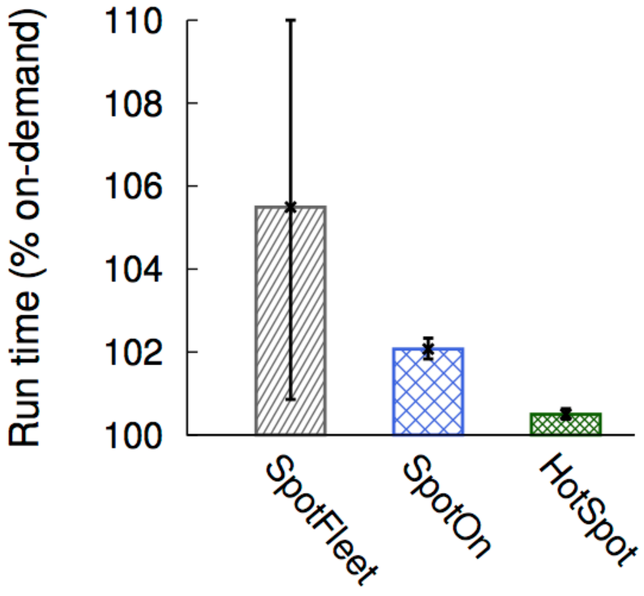

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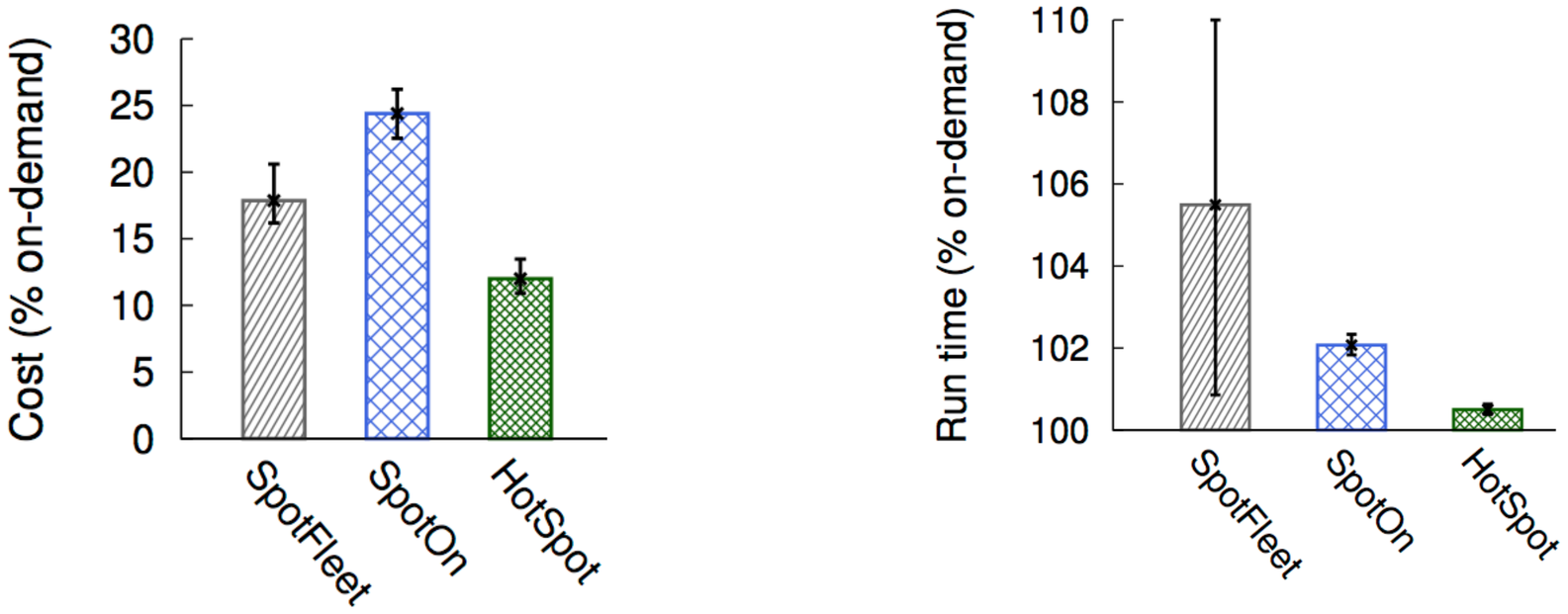

Even in the current EC2 spot markets (with low revocation rates),

optimizing for price-risk results in ***30-50% additional savings*** without degrading performance

Applications using variable-priced servers suffer from cost **uncertainty**.

This makes it hard for customers to **plan** their IT expenses.

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Mitigating Revocation Risk with Insurance	Minimizing Valuation Risk via Asset Pricing	Reducing Price Risk thru' Active Trading	Eliminating Uncertainty Risk by Index Tracking
SpotOn [SoCC 2015]	Transient Guarantee [SC 2016]	HotSpot [SoCC 2017]	Cloud Index [In submission]

Predicting Spot Prices is Important

Predicting Spot Prices is ~~Important~~ Accurately Difficult

68 • 2 • 2-5 • 14 • 2 = 7600+

Hardware config | OS types | Zones (datacenters) | Regions (country, state) | Time commitments | worldwide markets

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One size fits all model is unlikely

No visibility into market internals

Limited correlation with external variables

Market Properties from First Principles

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PROPERTY-1

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SUMMARY: we should model the behavior of **groups of spot markets** at family- and datacenter-levels

A Market-based Index

Image credit: www.cnbc.com/mad-money/

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A Market-based Index *for CLOUD*

Rather than focusing **exclusively** on predicting **individual servers**, cloud users should make decisions based on **broader market indices**

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vs.

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A Market-based Index *for CLOUD*

Characterizing an individual server i

Price = P_i , *Memory* = M_i *GB*

Compute = C_i *ECUs*

$$P_i^{norm} = \frac{P_i}{\sqrt{(C_i * M_i)}}$$

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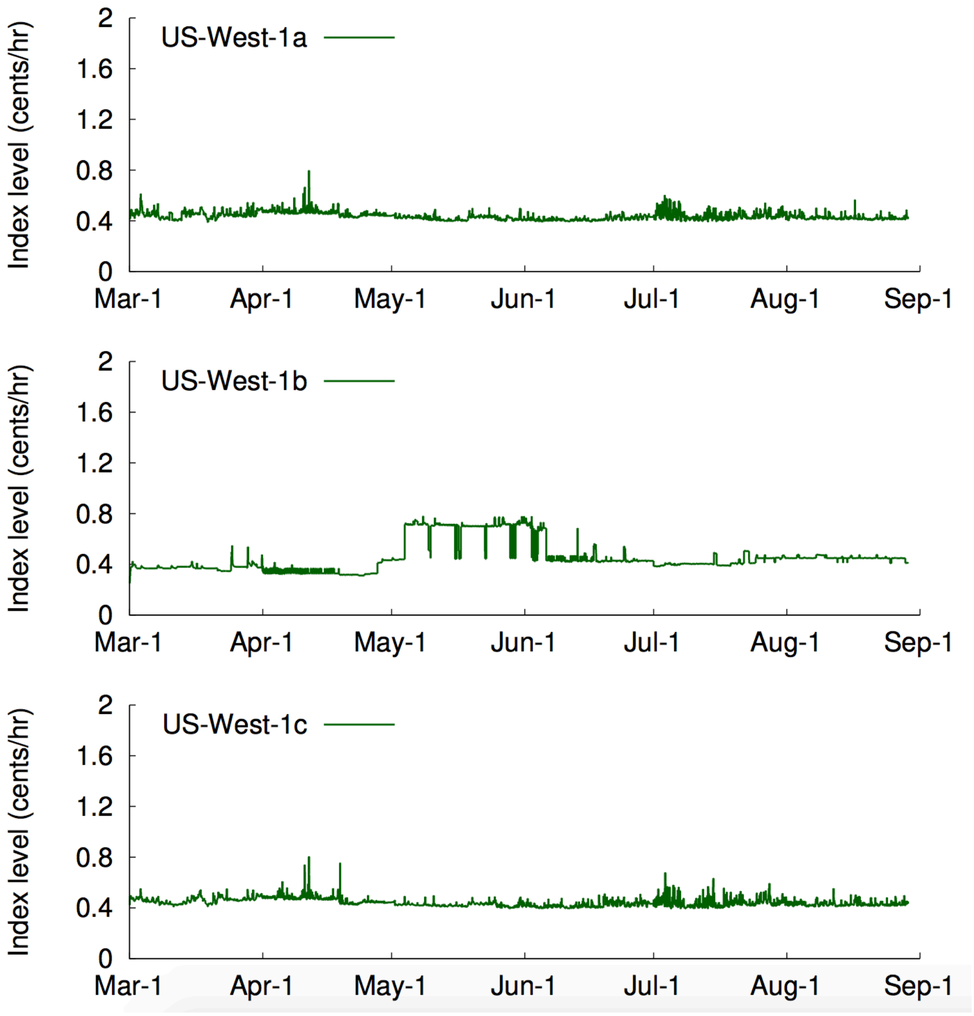
Cloud index value represents the **average price per unit of compute time** for the selected group of servers

Datacenter Level (US-West-1a/b/c)



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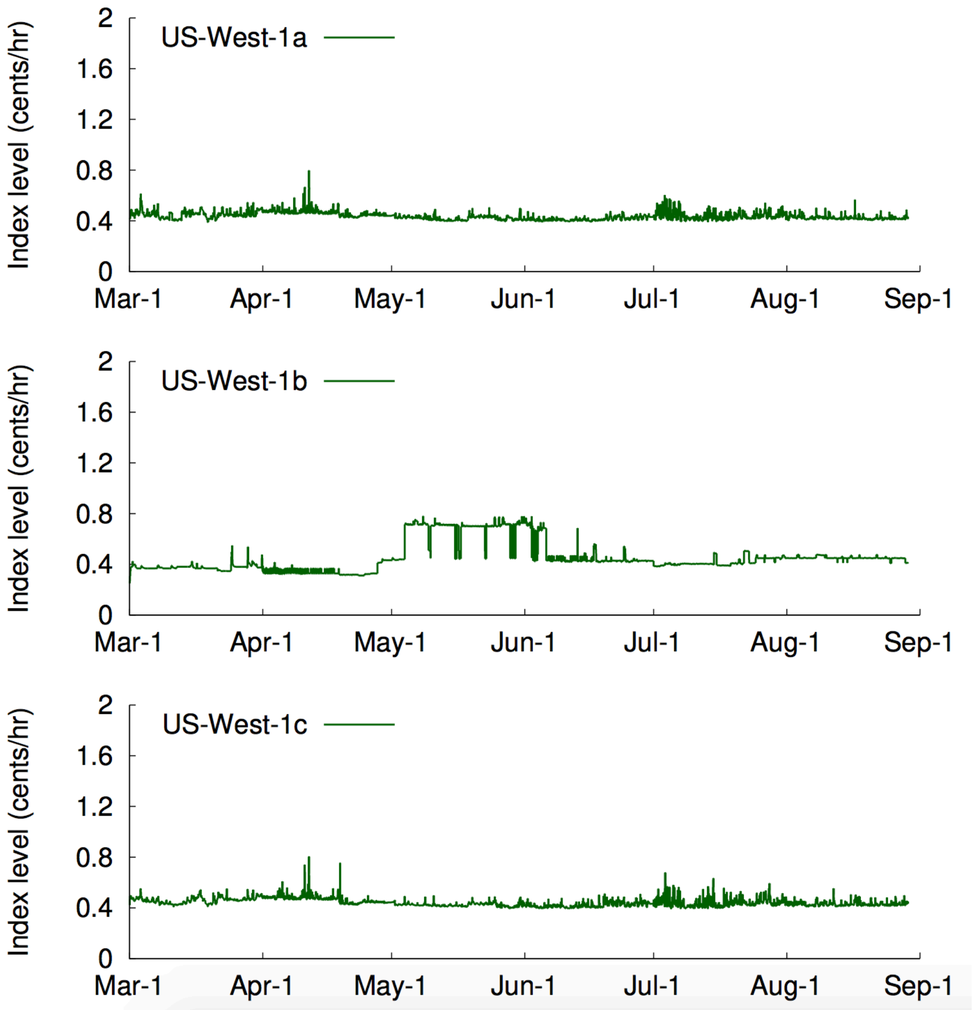
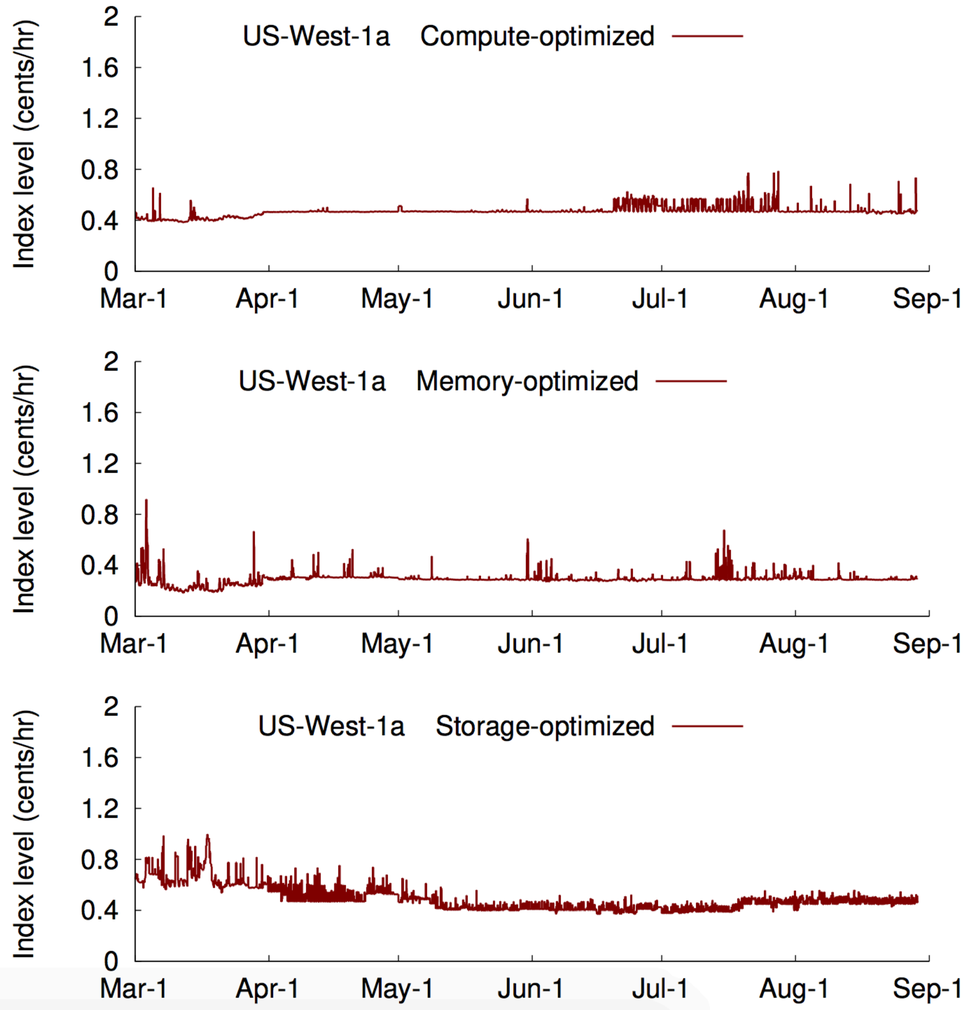


Server Family Level (US-West-1a)



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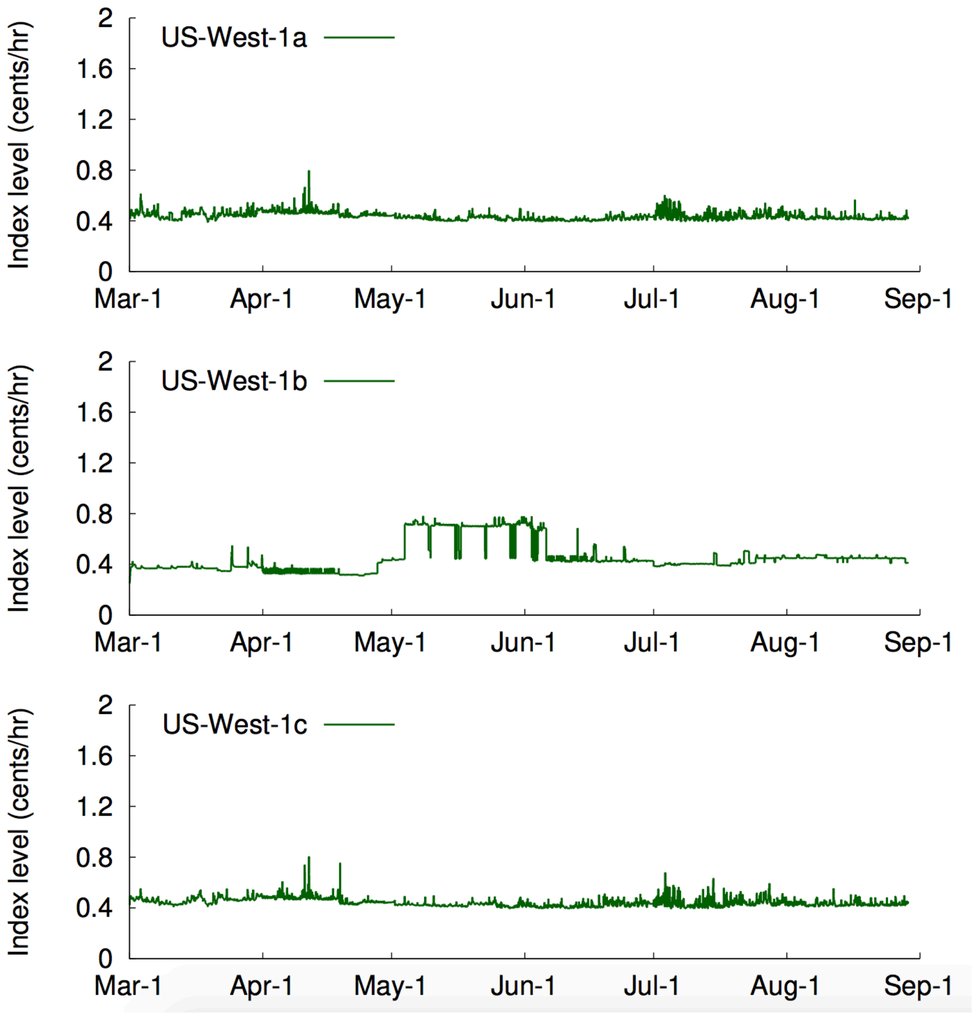

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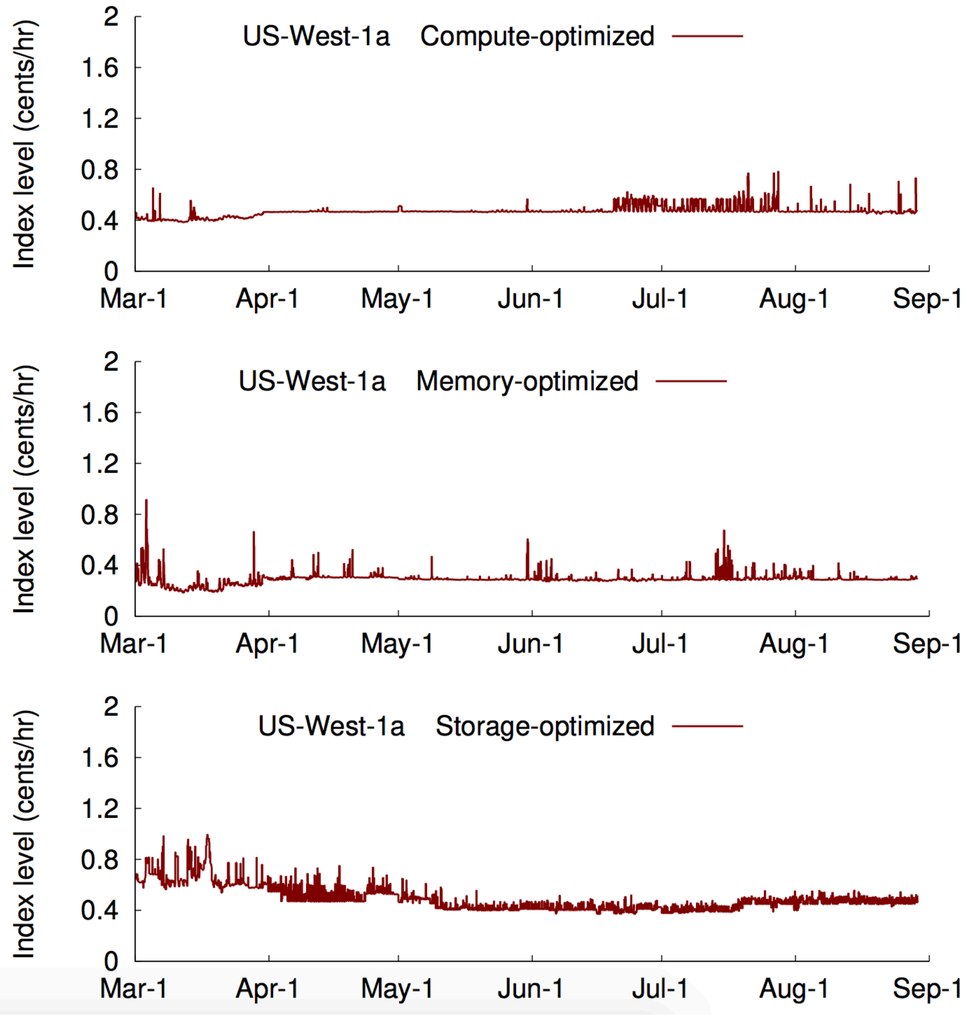

Price prediction is more accurate and stable at **datacenter-** and **server family level** than **individual** level

Cost-Predictive Server Hosting

(Host a flexible application on variable-priced servers such that it incurs predictable cost-efficiency)

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3. If application or market conditions violate index invariant, then transparently hop to a better server

Properties of Index-Tracking-by-Server-Hopping

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Scales well with increased adaptation

If everyone targets index-level efficiency ==> the market becomes less volatile ==> reduces the number of hopping needed ==> stability and cost-efficiency increases for all

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Better than fully-predictive and purely-reactive approaches

Index-based predictions are stable and more resilient to market changes

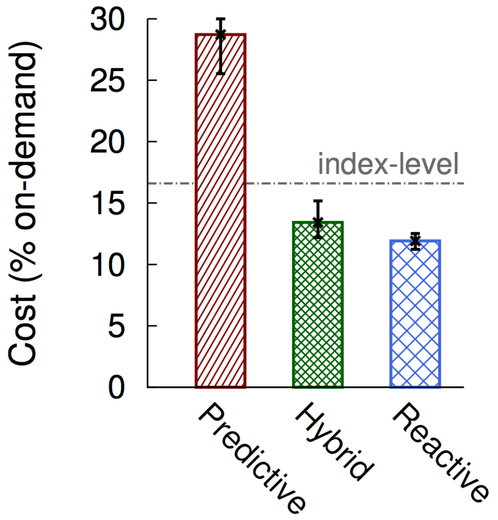
Hybrid technique naturally rate-limits the frequent hopping of reactive approaches

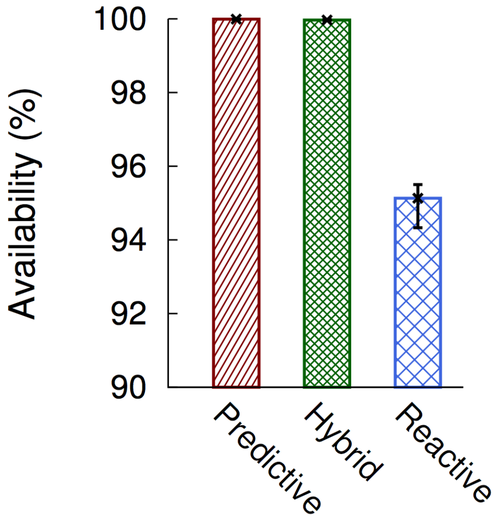
Evaluation

Compare **cost-predictability** and **cost-availability tradeoff** of running a flexible batch application on

Spot server with **predictive technique** (SpotFleet)	vs.	Spot server with **reactive technique** (HotSpot)	vs.	Spot server with **hybrid technique** (Index Tracking)

Long-running Application





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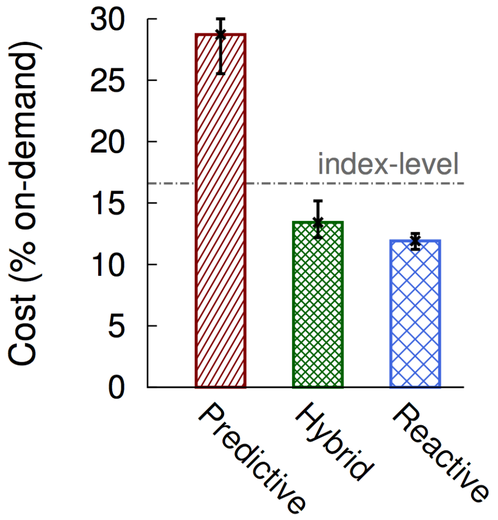
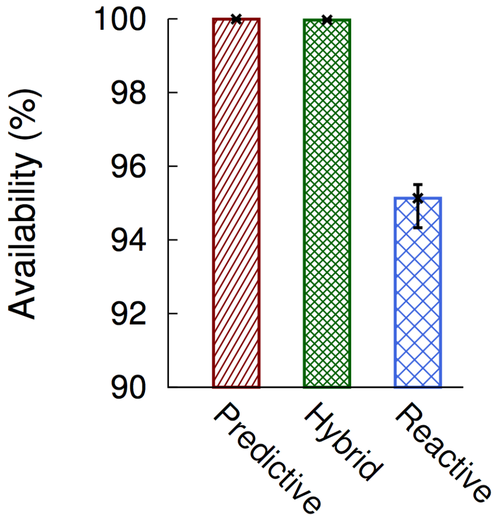
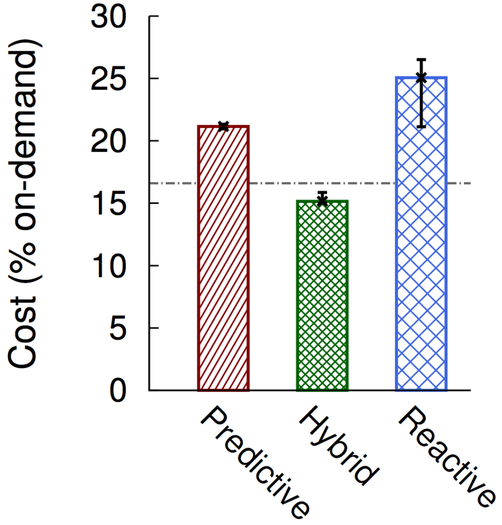
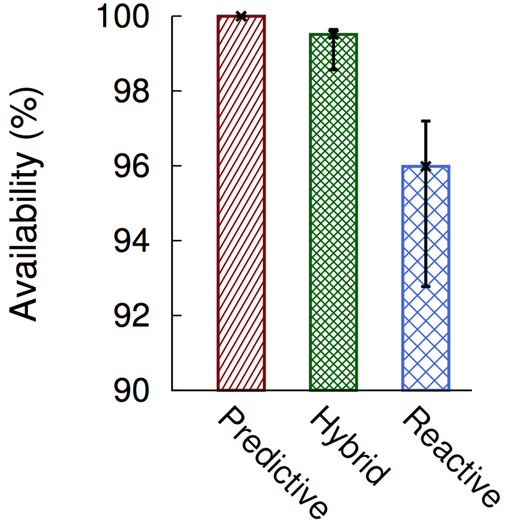




Parallel Applications





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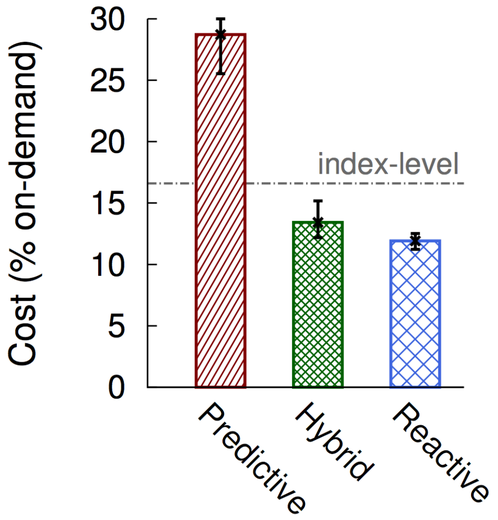

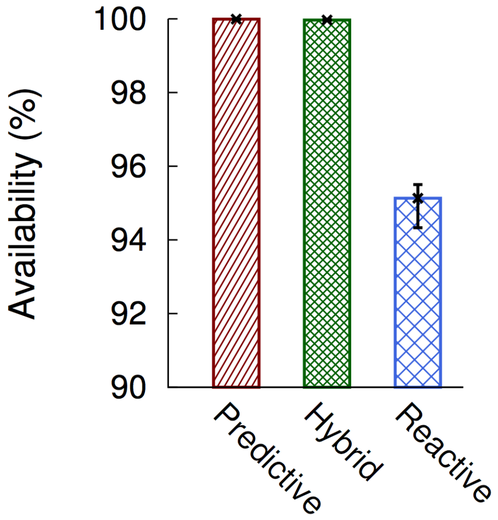

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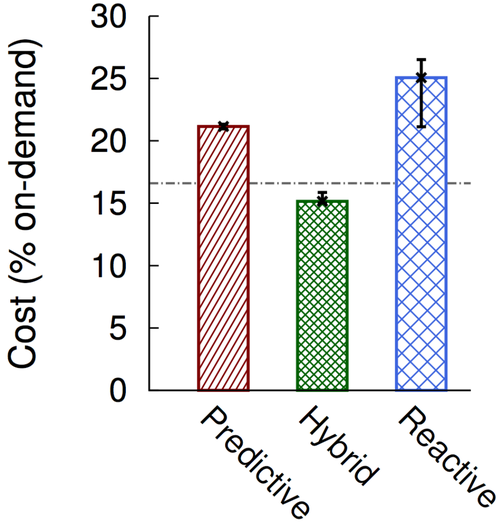

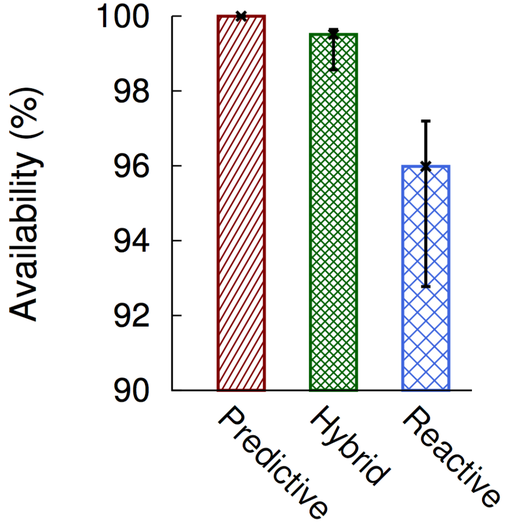

The hybrid approach of Index-Tracking not only meets the **predicted cost-efficiency** but also achieves the **best cost-availability tradeoff** compared to other approaches.

Thesis Contributions

Risks	Problems	Proposed Solution	Result
Revocation	Revocations pose a new fault-model that undermines the benefit of using transient servers	Cost-efficient insurance via *SpotOn*	91% cost-savings over on-demand
Price	Applications may pay higher price for less efficient servers in variable-priced cloud markets	Active server trading via *HotSpot*	50% cost reduction over insurance schemes
Uncertainty	Applications deployed on variable-priced cloud markets suffer from cost uncertainty	Server hosting that tracks *Cloud Indices*	Predictable costs that match the index-level
Valuation	Transient servers are difficult to price (for providers) and to value (for consumers)	Asset pricing via *Transient Guarantees*	5x increase in the overall value

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Future Directions: Managing Risks in Emerging Computing Landscape

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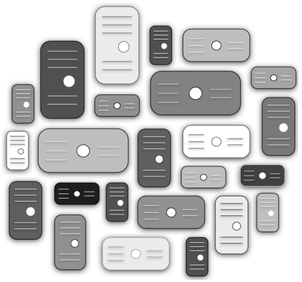

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On-Demand BURSTABLE
RESERVED **SPOT MARKET**
Preemptible Dedicated

Future Directions: Managing Risks in Emerging Computing Landscape

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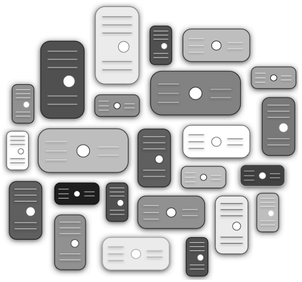

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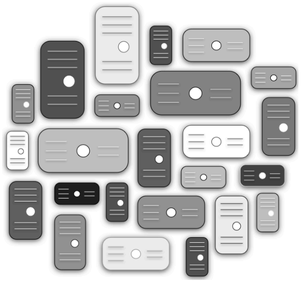
Batch | Iterative | Interactive | Real-time

Future Directions: Managing Risks in Emerging Computing Landscape

Not all compute is **created** equal



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On-Demand BURSTABLE
RESERVED **SPOT MARKET**
Preemptible Dedicated

Financialized system software

Not all compute is **consumed** equal

Batch | Iterative | Interactive | Real-time

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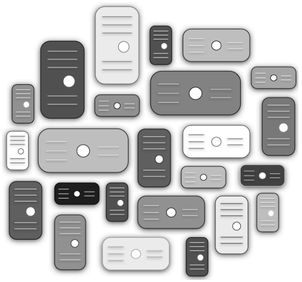

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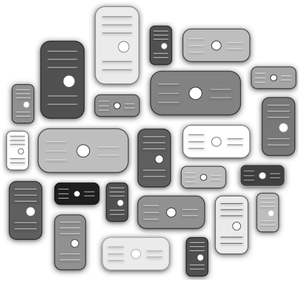

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On-Demand BURSTABLE
RESERVED SPOT MA
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NEW contracts

Financialized system software

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NEW categories

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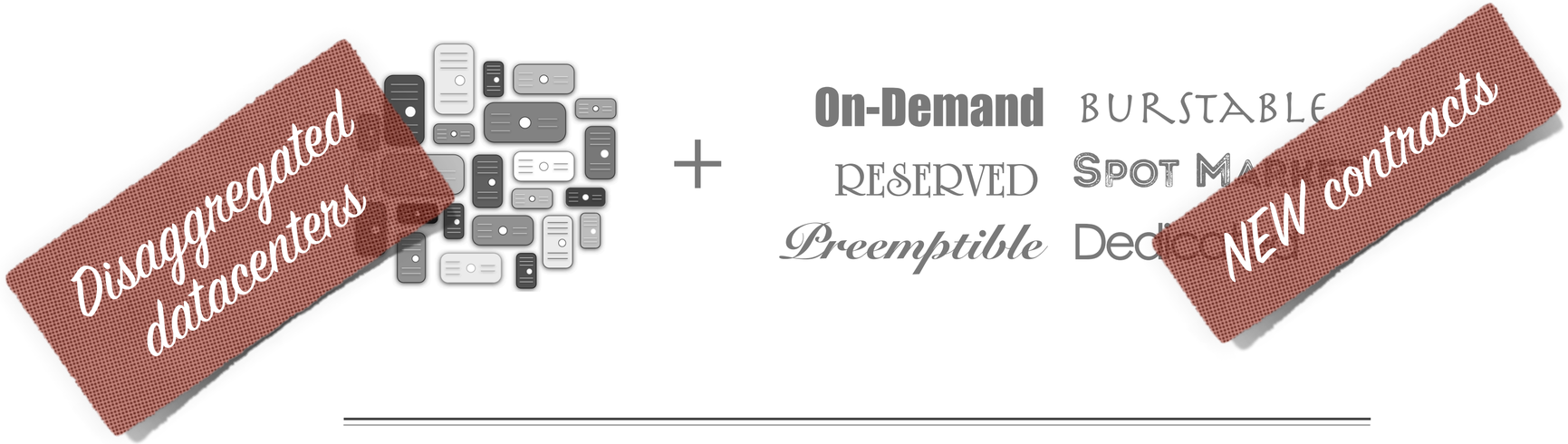

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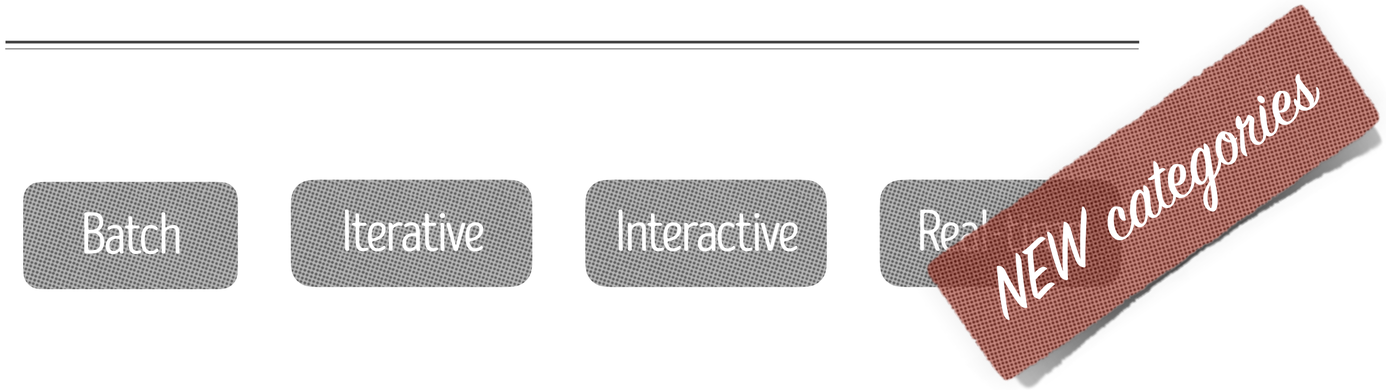

List of Publications

1. ***Supreeth Subramanya***, Zain Mustafa, David Irwin, and Prashant Shenoy. Energy-agility: A new grid-centric metric for evaluating system performance. In ***LIMITS***, June 2015.
2. ***Supreeth Subramanya***, Tian Guo, Prateek Sharma, David Irwin, and Prashant Shenoy. SpotOn: A Batch Computing Service for the Spot Market. In ***SoCC***, August 2015.
3. ***Supreeth Subramanya***, Zain Mustafa, David Irwin, and Prashant Shenoy. Beyond Energy-Efficiency: Evaluating Green Datacenter Applications for Energy-Agility. In ***ICPE***, March 2016.
4. ***Supreeth Subramanya***, Amr Rizk, and David Irwin. Cloud Spot Markets are Not Sustainable: The Case for Transient Guarantees. In ***HotCloud***, June 2016.
5. ***Supreeth Shastri***, Amr Rizk, and David Irwin. Transient Guarantees: Maximizing the Value of Idle Cloud Capacity. In ***SC***, November 2016.
6. David Irwin, Prateek Sharma, ***Supreeth Shastri***, and Prashant Shenoy. Financialization of Cloud Computing: Opportunities and Challenges. In ***ICCCN***, July 2017.
7. ***Supreeth Shastri*** and David Irwin. Towards Index-based Global Trading in Cloud Spot Markets. In ***HotCloud***, July 2017.
8. ***Supreeth Shastri*** and David Irwin. Automaton: Active Server Trading in the Cloud. In ***SoCC***, September 2017.
9. ***Supreeth Shastri*** and David Irwin. IndeX Marks the Spot: Cost-Predictive Server Hosting in Spot Markets. In ***Submission***.

Backup Slides

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Case Study for Cloud Risks: *Transient Cloud Servers*

Idle Cloud Capacity

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amazon web services™ | **EC2**

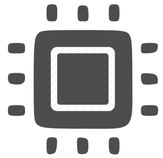
Spot servers in a nutshell

1

The users bid for VMs in a second price auction

2

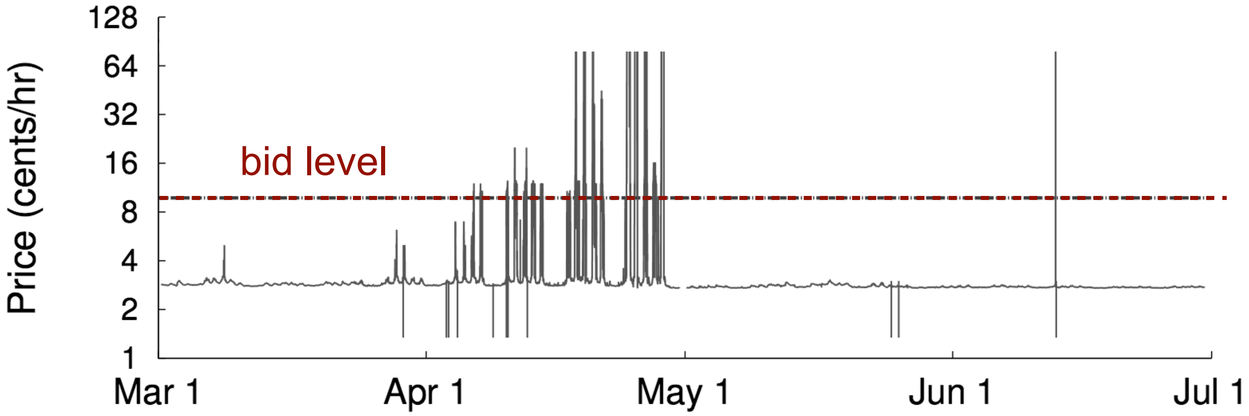
EC2 evaluates supply-demand dynamic to price spot servers



3

EC2 allocates if bid price ≥ spot price; Revokes when not.

Applications Hate Spot Servers… but Can't Live Without Them



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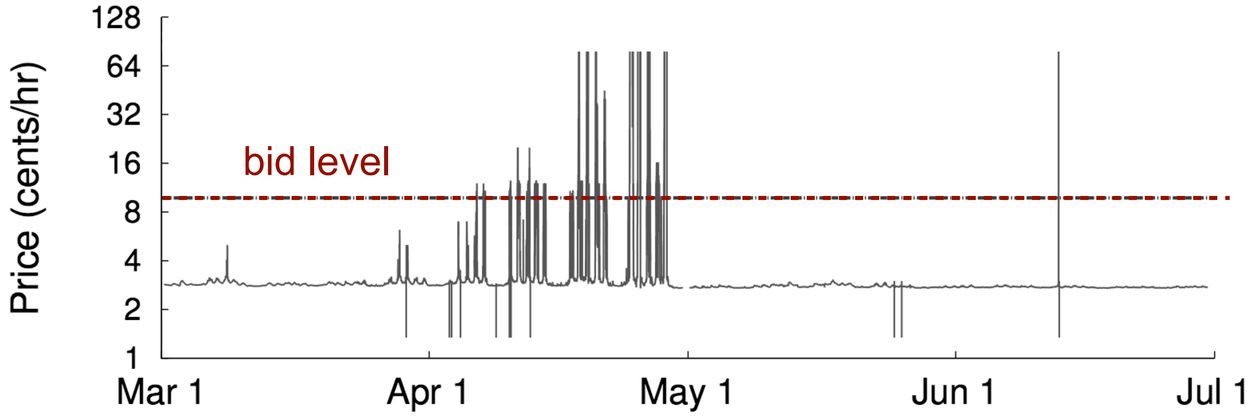

Low average price

50-90% discount over on-demand price

Deliberate revocations

when spot price rises above the bid level

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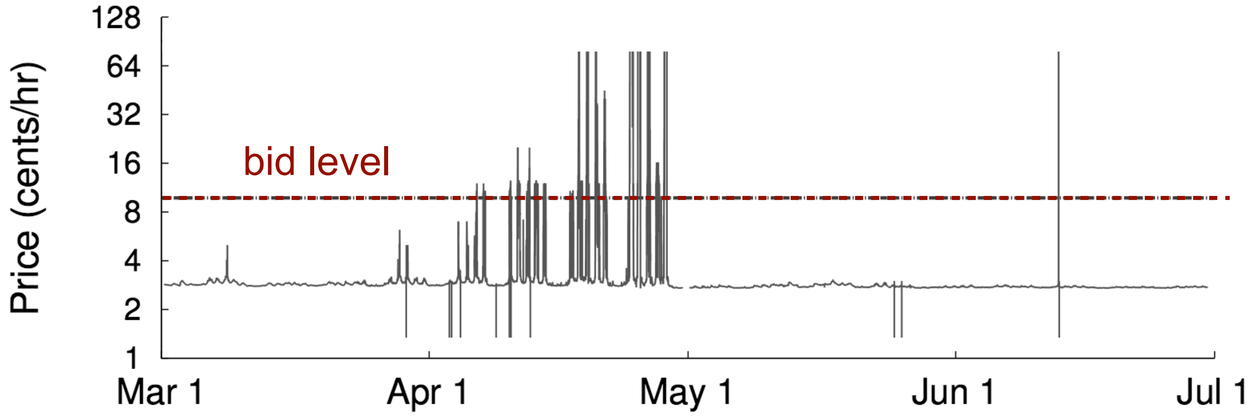

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Fermilab

"Spot instances helped scale our clusters up by **4X** during the discovery of the Higgs Boson"

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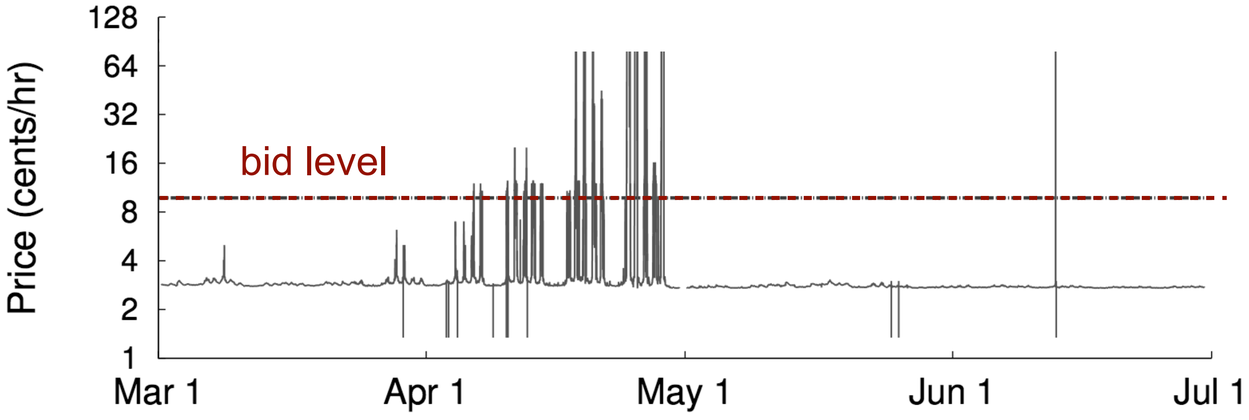

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Fermilab

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Spot compute consumed in 2016 > All EC2 compute consumed in 2012

https://aws.amazon.com/10year/

When "*Just Throw in Some Fault-tolerance*" Does Not Help!

Spot server behavior comprises of **three** key characteristics:

Availability, **VOLATILITY**, *Predictability*

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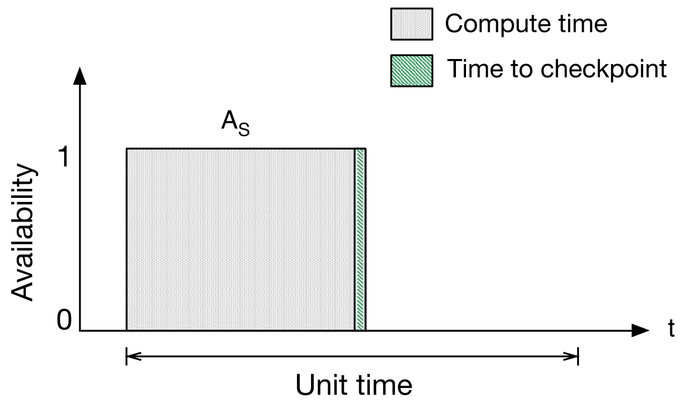

Limited Availability

Checkpoints = 1

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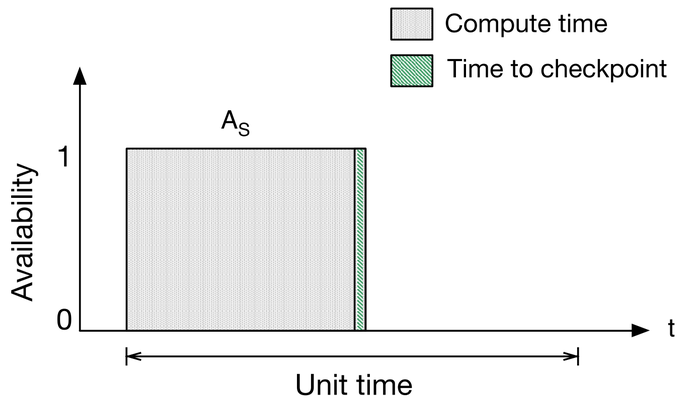

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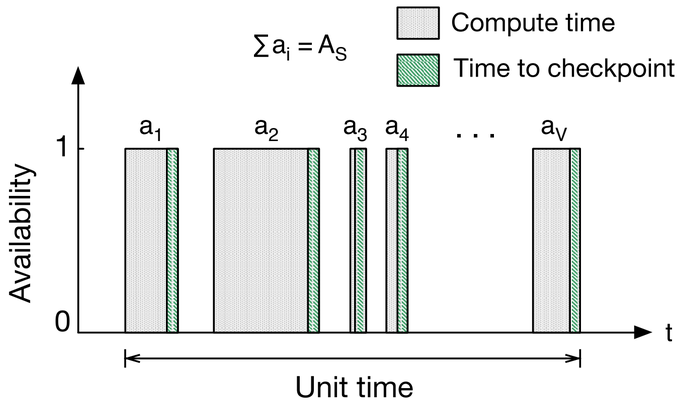

Limited Availability
+ **Volatility**

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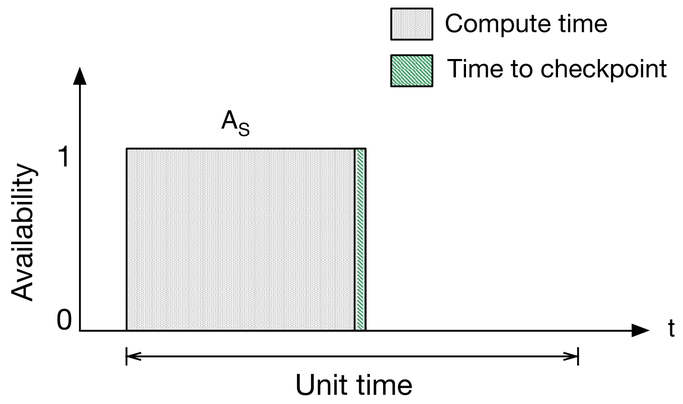

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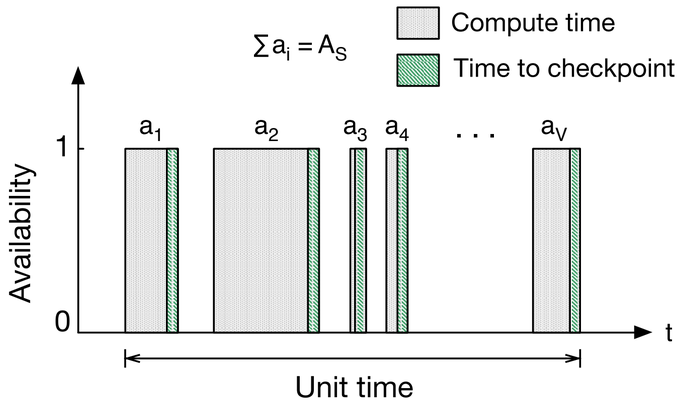

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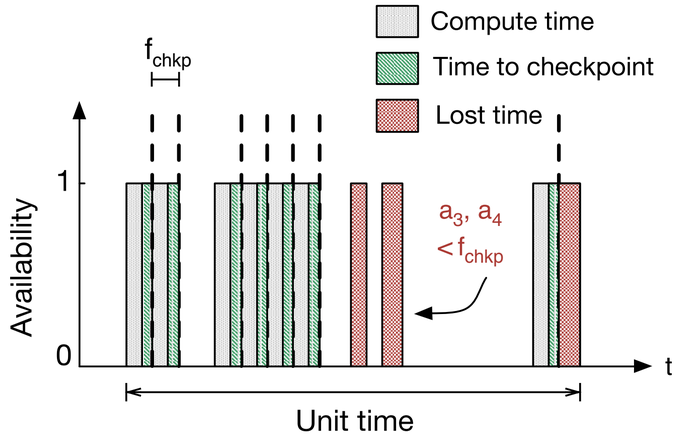

Limited Availability + Volatility
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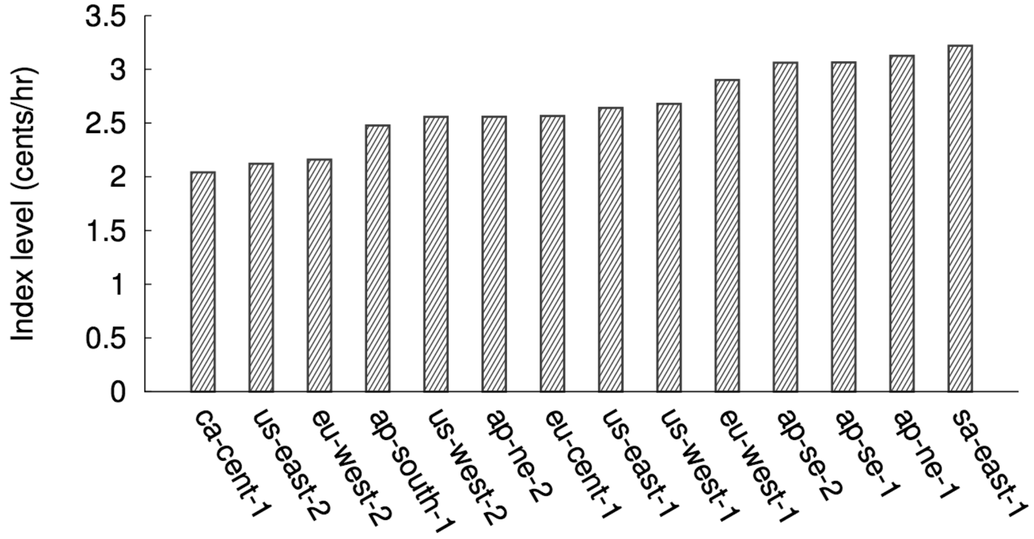
Periodic checkpointing

Worldwide On-demand (Linux)



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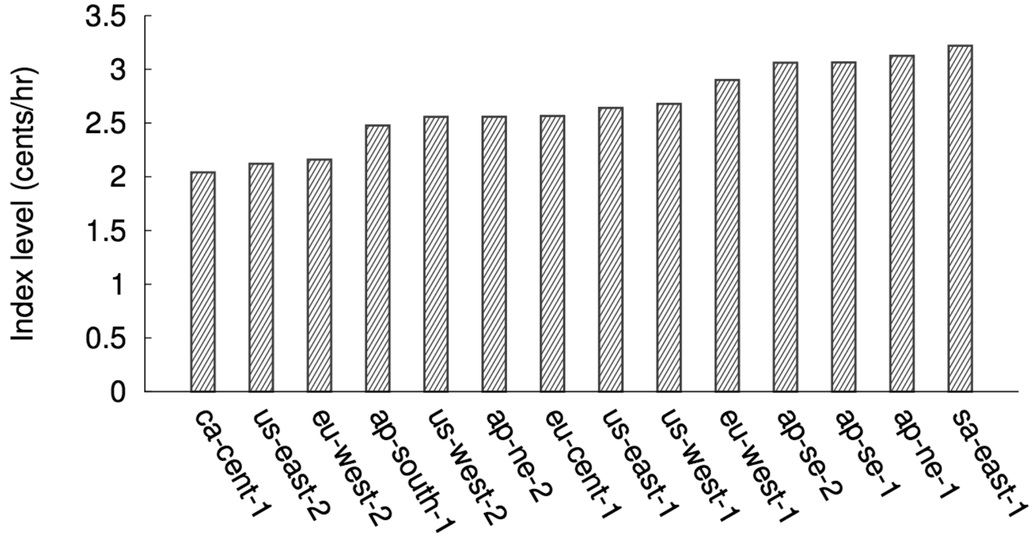

Compute-time is 50% more expensive

in Brazil than Canada

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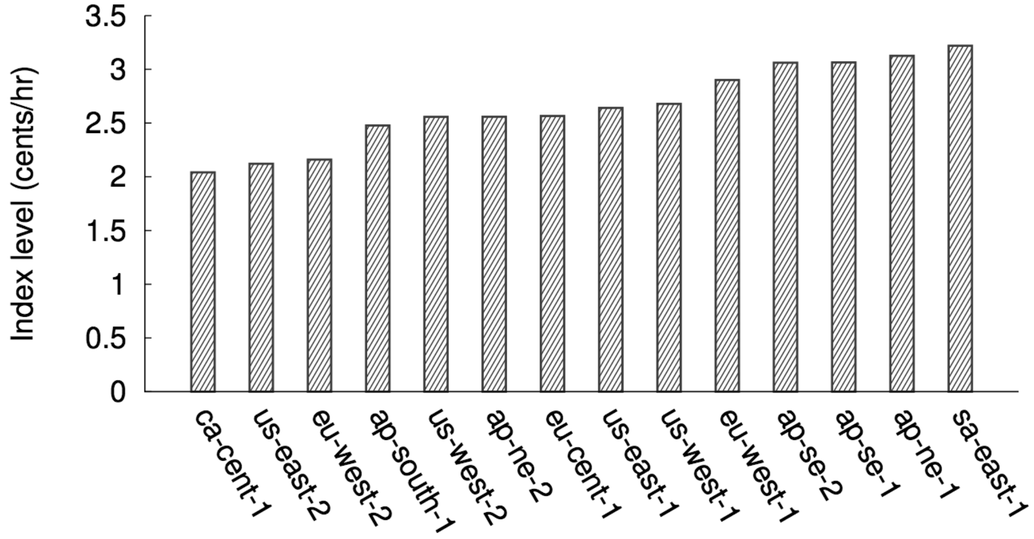

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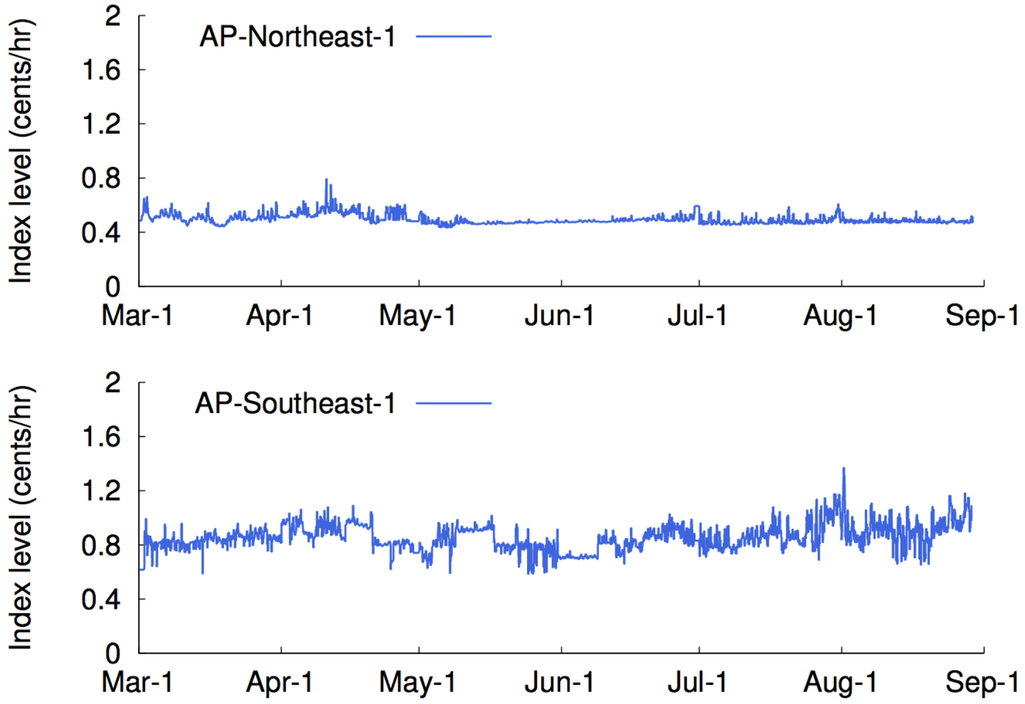
Identifying Price Inversions



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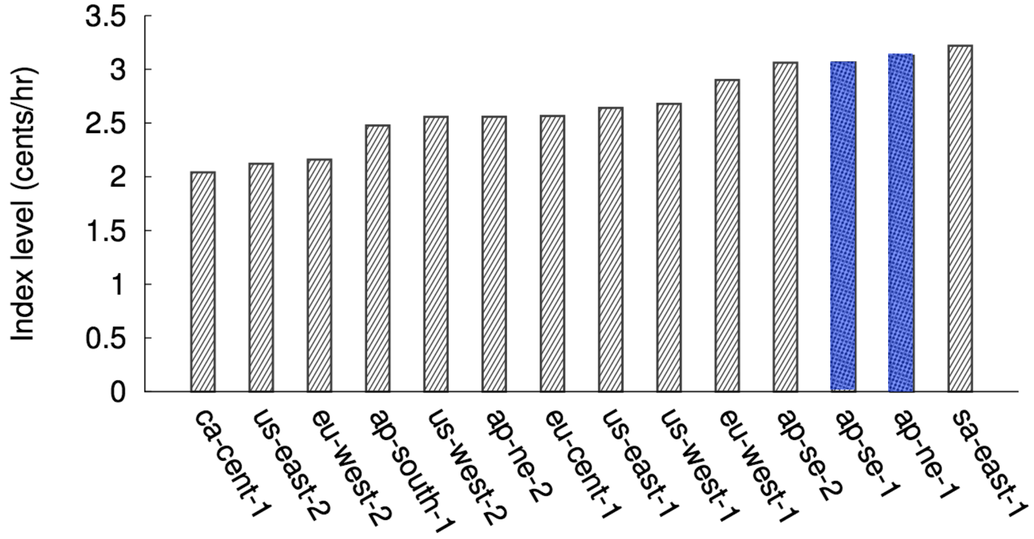

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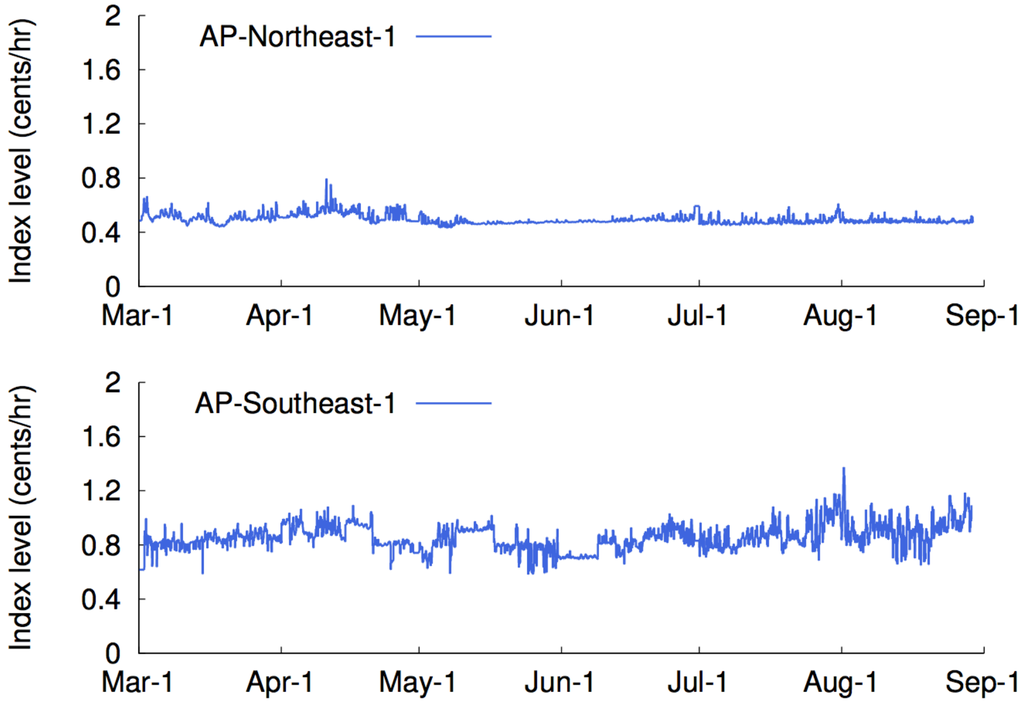

Indices allow us to readily identify systematic price differentials and arbitrages