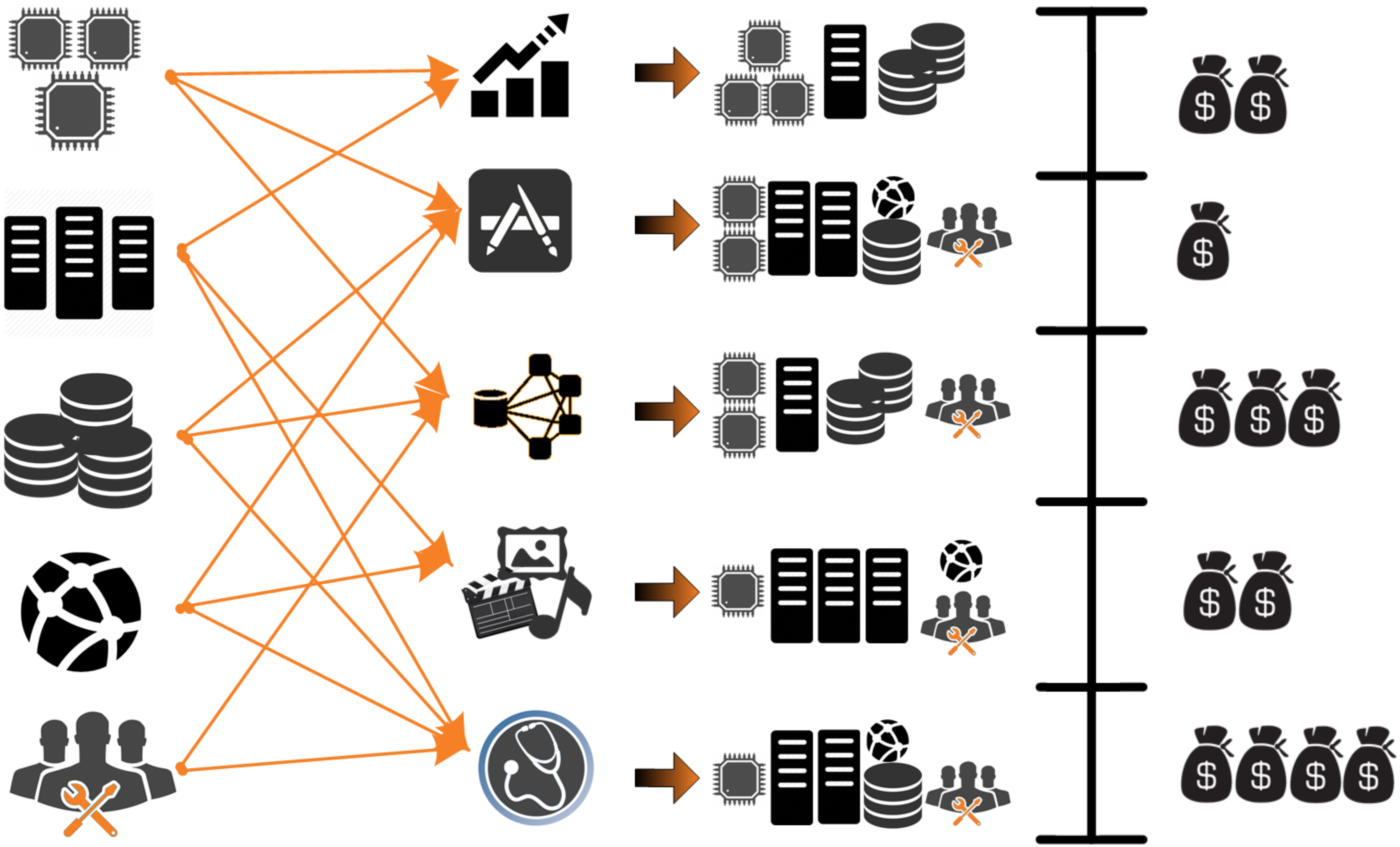
How to Bid the Cloud

SIGCOMM 2015

Cloud Resource Allocation and Pricing



Cloud pricing

Usage-based cloud pricing

Auction-based cloud pricing

Amazon’s Elastic Compute Cloud (EC2) spot instance

Spot instance

Step 1: Choose the instance type

Amazon Linux
Free tier eligible

Red Hat
Free tier eligible

SUSE Linux
Free tier eligible

Memory optimized	r3.large	2	15	1 x 32 (SSD)	-	Moderate
Memory optimized	r3.xlarge	4	30.5	1 x 80 (SSD)	Yes	Moderate
Memory optimized	r3.2xlarge	8	61	1 x 160 (SSD)	Yes	High
Memory optimized	r3.4xlarge	16	122	1 x 320 (SSD)	Yes	High
Memory optimized	r3.8xlarge	32	244	2 x 320 (SSD)	-	10 Gigabit

Step 2: Configure the instance details
– Number of instances & bid price

Number of instances 1

Purchasing option ☑ Request Spot Instances

Current price

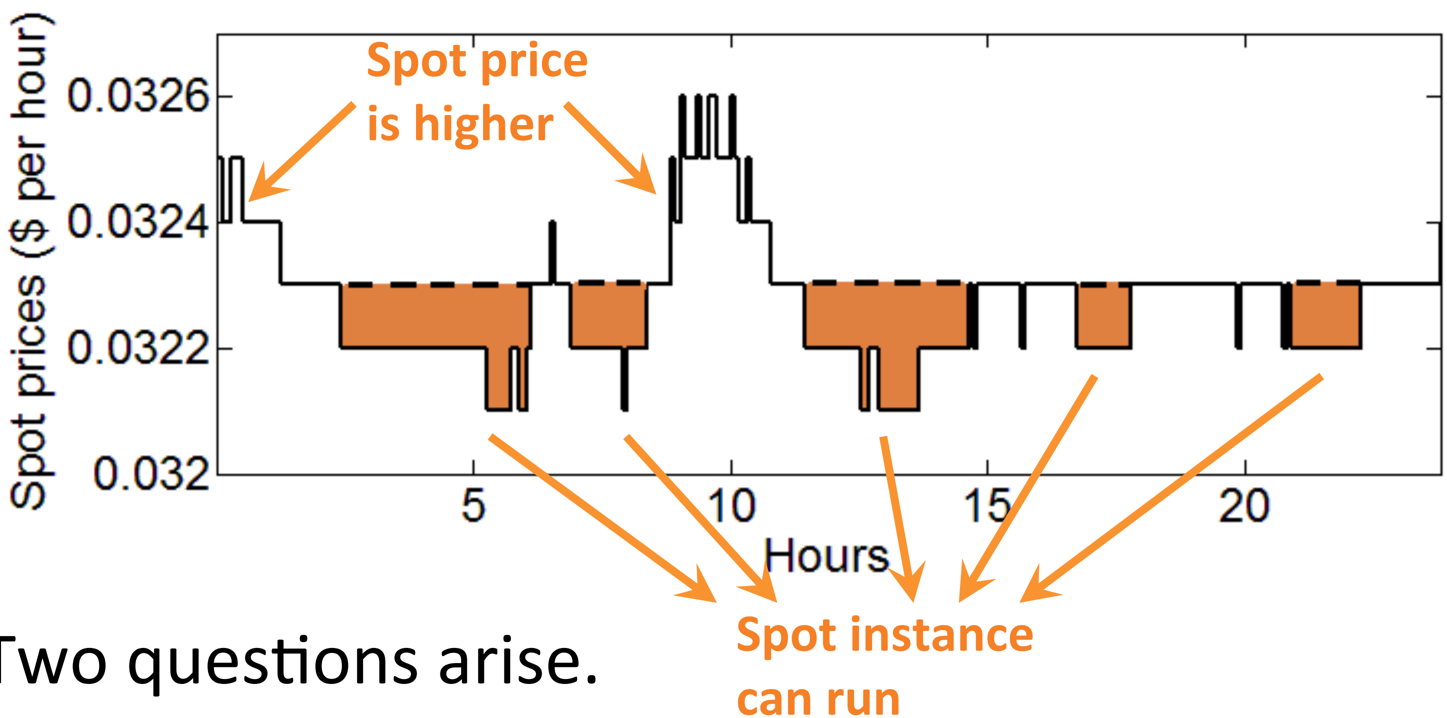
us-east-1a	0.1582
us-east-1b	0.1587
us-east-1d	0.1821
us-east-1e	0.1856

Maximum price $ (e.g. 0.045 = 4.5 cents/hour)

Name the price YOURSELF!

Spot pricing

Spot price history for an r3.xlarge instance in the US Eastern region on September 09, 2014



Two questions arise.

Our questions

- Question #1

  How might the cloud provider set the price?

- Question #2

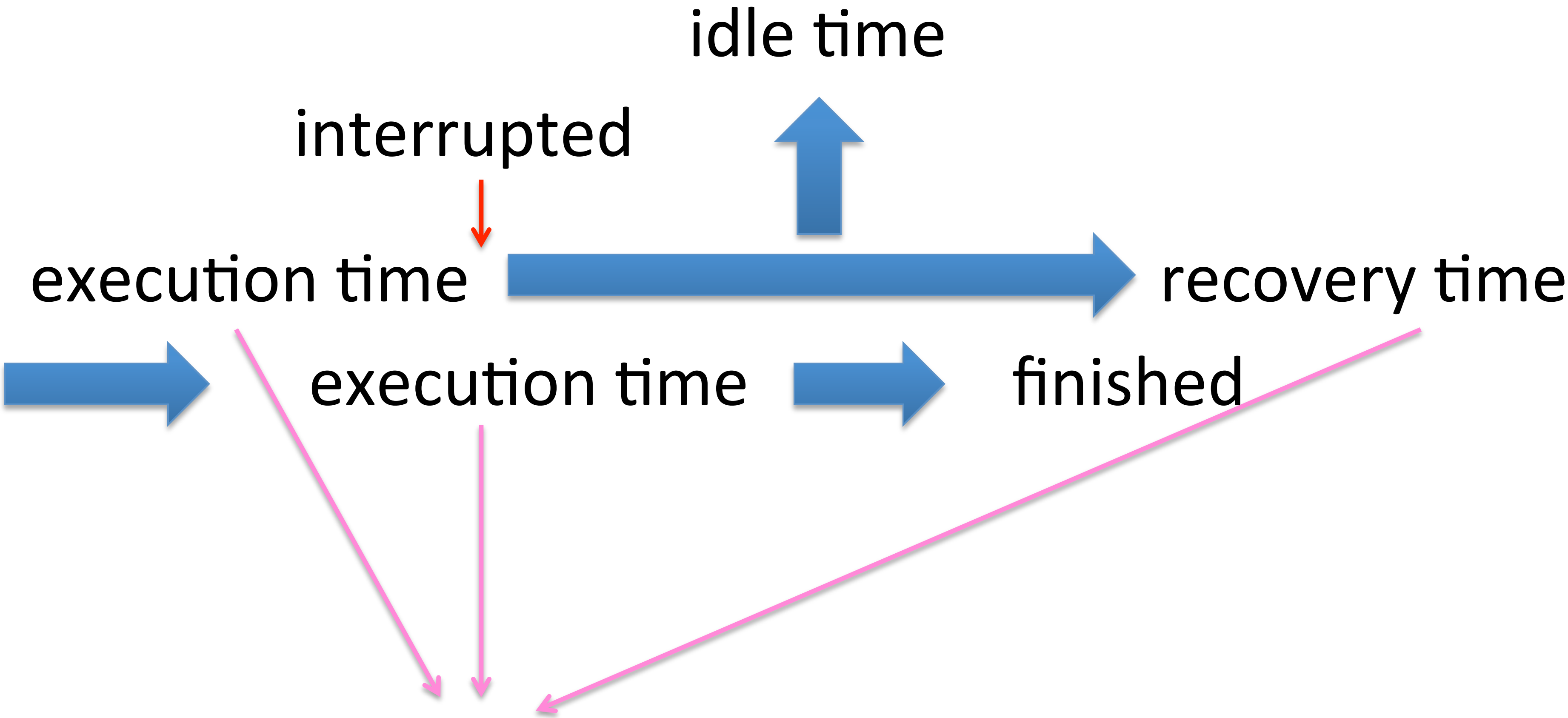
  What prices should users bid?

Differences

1. User-oriented
2. Jobs could be interrupted
3. Bid prices are dependent on spot prices

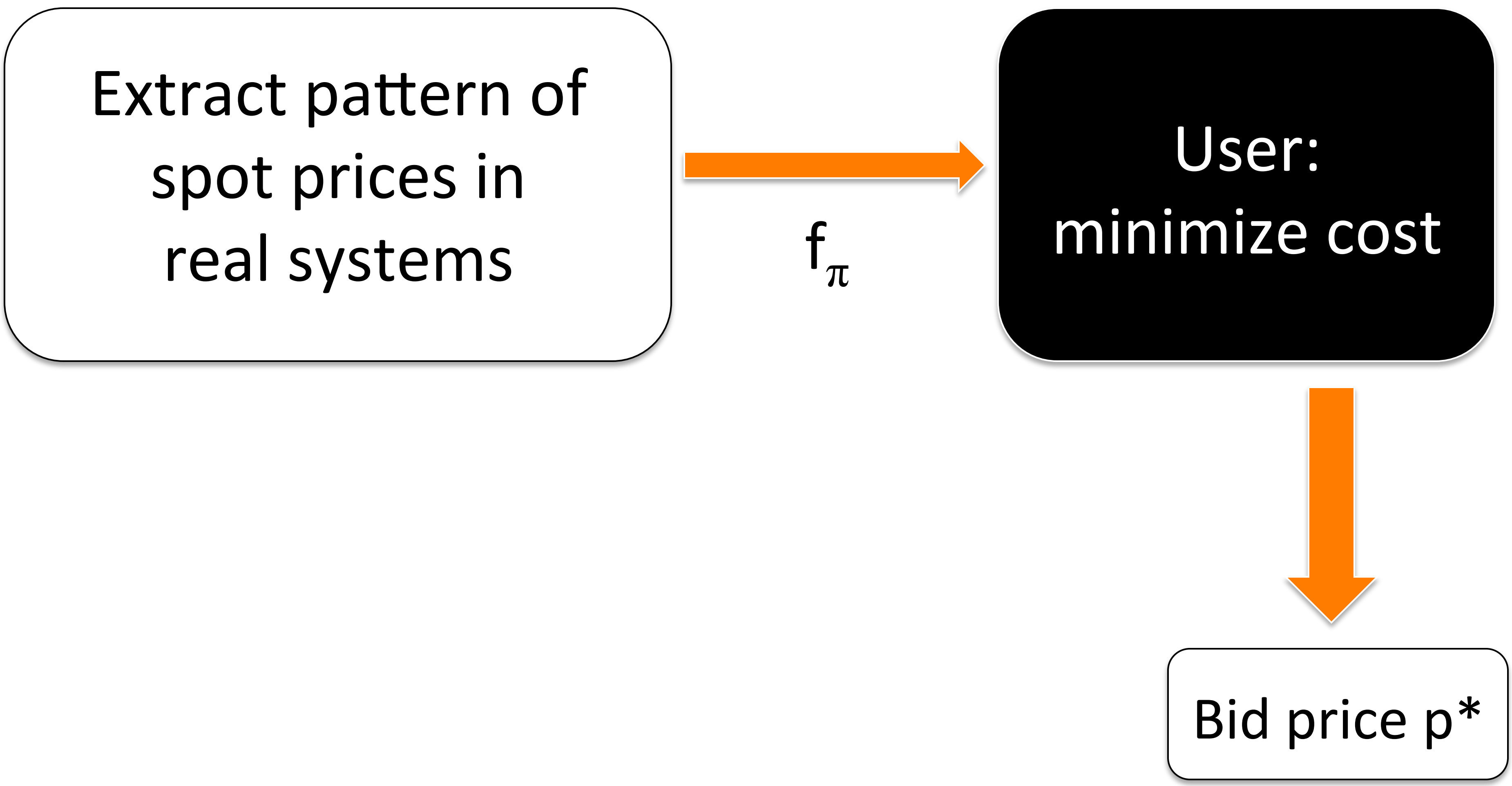
4. Goals: satisfy interruptibility requirement
   minimize user cost (payment);

What is user cost? Runtime * spot price

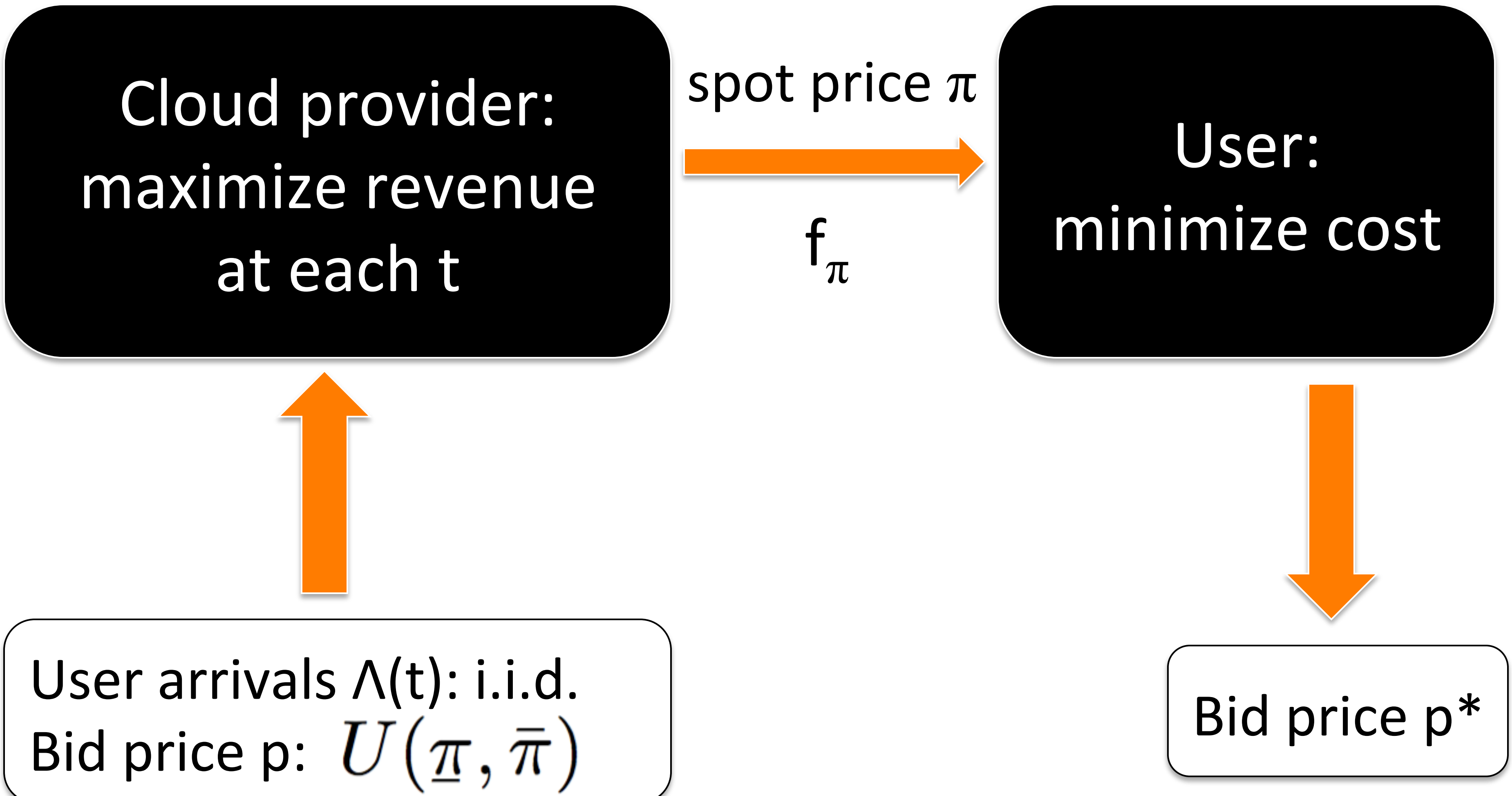


The user is get charged in job's running time

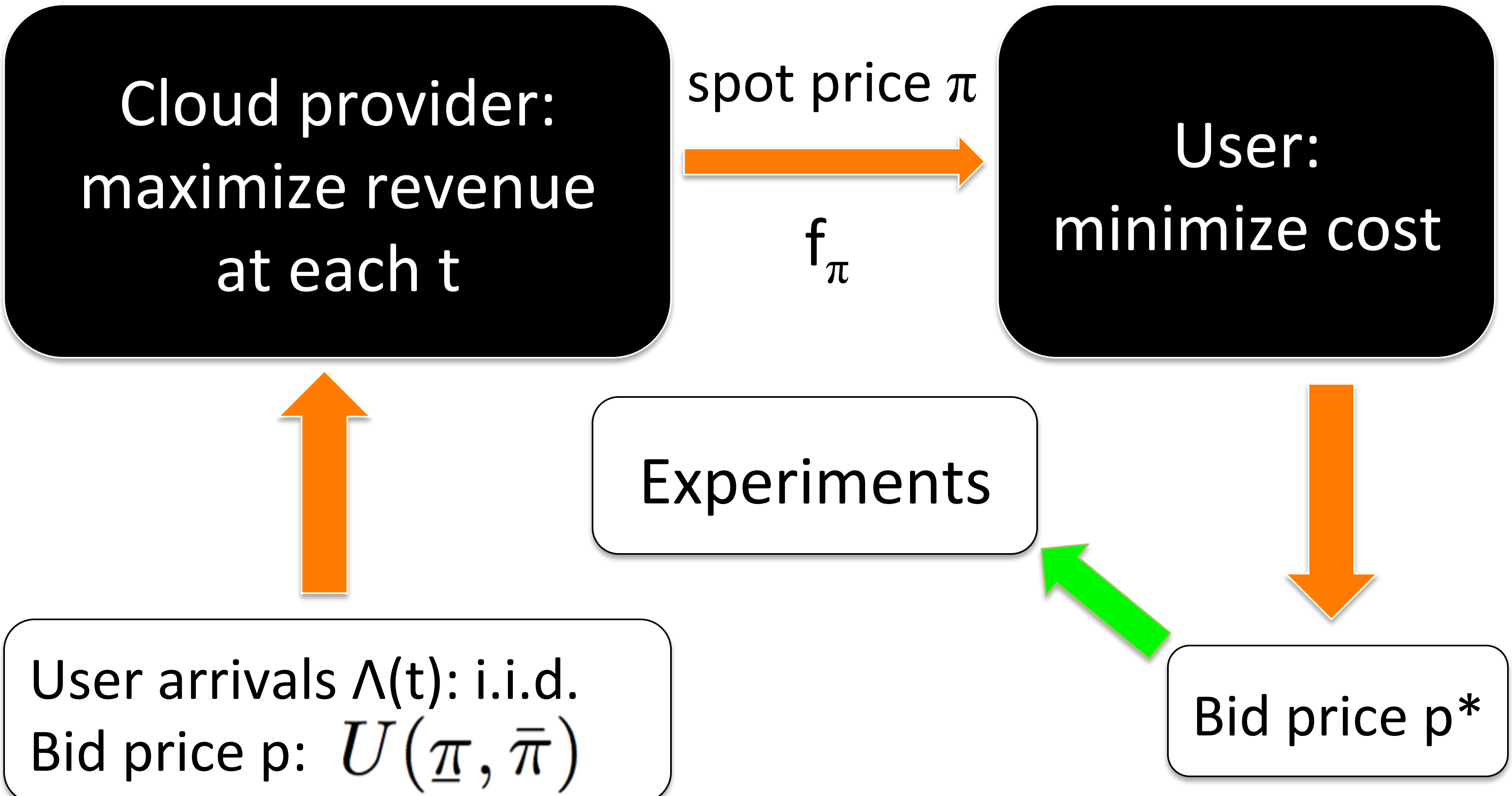
Outline


Extract pattern of spot prices in real systems
f_π
User: minimize cost
Bid price p*

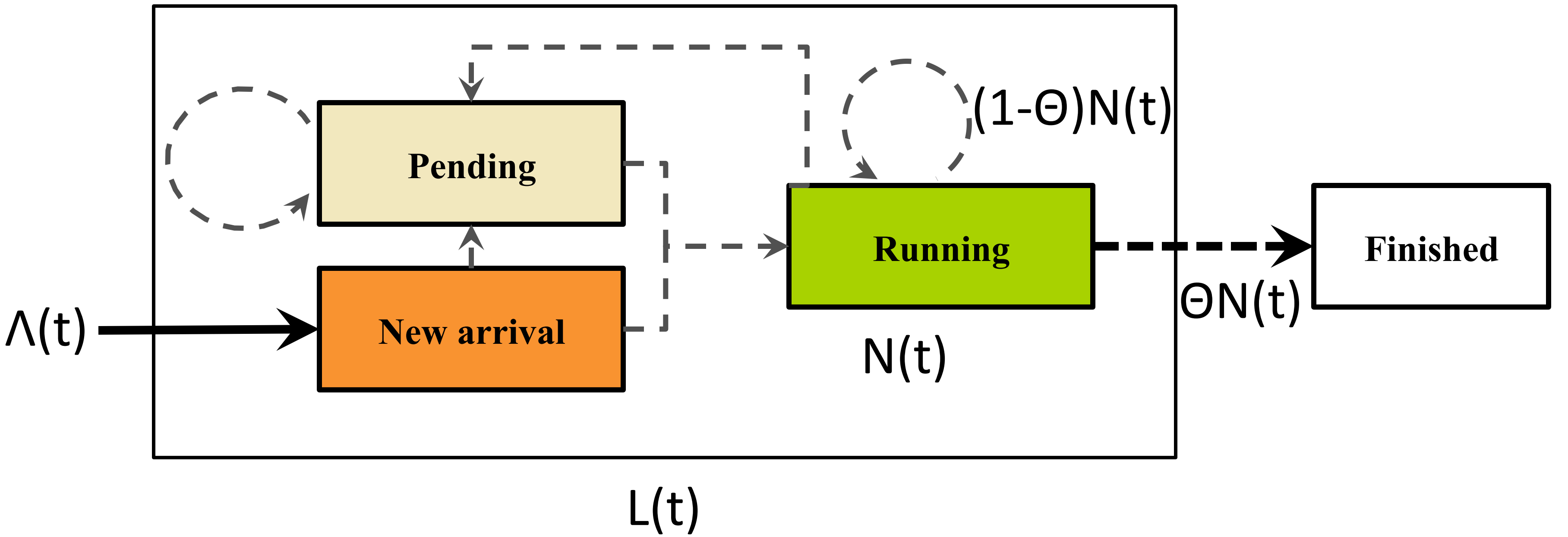
Outline


Cloud provider: maximize revenue at each t
spot price π
f_π
User: minimize cost
User arrivals $\Lambda(t)$: i.i.d.
Bid price p: $U(\underline{\pi}, \bar{\pi})$
Bid price p*

Outline


Cloud provider: maximize revenue at each t
spot price π
f_π
User: minimize cost
Experiments
User arrivals Λ(t): i.i.d.
Bid price p: $U(\underline{\pi}, \bar{\pi})$
Bid price p*

Cloud provider model



$$f_p(x) = 1/(\bar{\pi} - \underline{\pi}) \longrightarrow N(t) = L(t)\frac{\bar{\pi} - \pi(t)}{\bar{\pi} - \underline{\pi}}$$

Cloud provider revenue maximization

$$f_p(x) = 1/(\bar{\pi} - \underline{\pi}) \longrightarrow N(t) = L(t)\,\frac{\bar{\pi}-\pi(t)}{\bar{\pi}-\underline{\pi}}$$

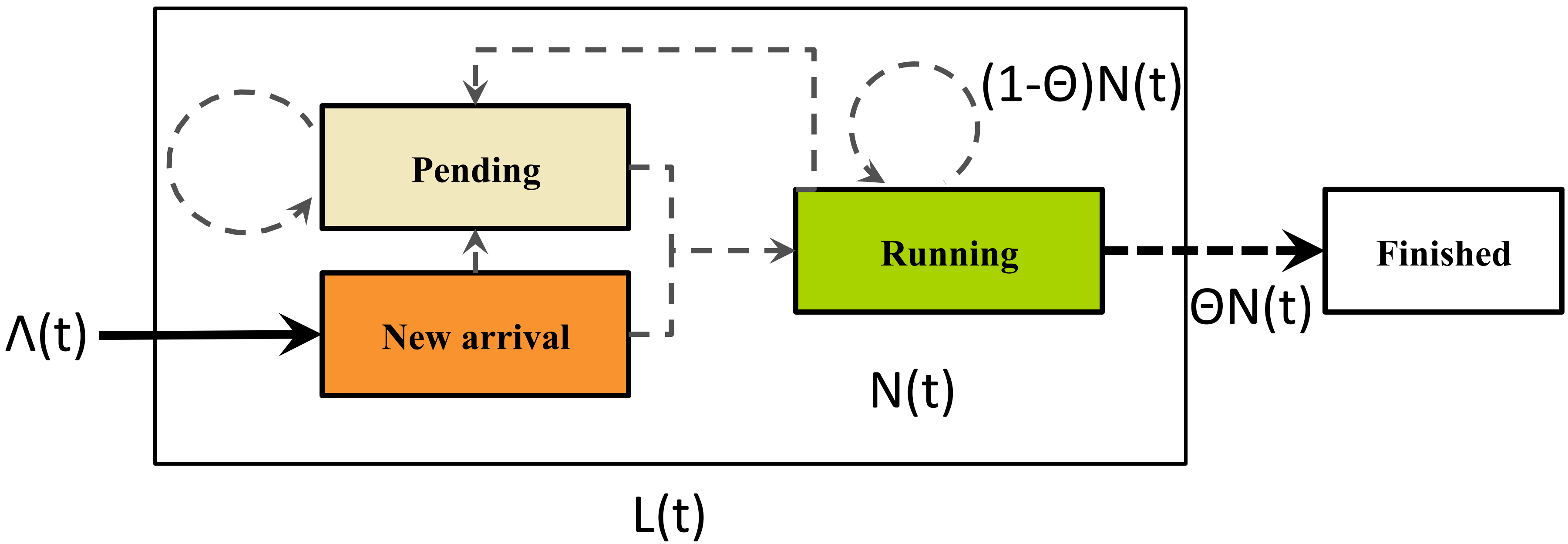
$$\begin{aligned}
\underset{\pi(t)}{\text{maximize}} \quad & \beta \log\left(1 + \boxed{L(t)\,\frac{\bar{\pi}-\pi(t)}{\bar{\pi}-\underline{\pi}}}\right) \\
& +\pi(t)L(t)\,\frac{\bar{\pi}-\pi(t)}{\bar{\pi}-\underline{\pi}} \\
\text{subject to} \quad & \underline{\pi} \le \pi(t) \le \bar{\pi}.
\end{aligned}$$

$$\begin{aligned}
\pi^{\star}(t) = \max\Bigg\{ & \underline{\pi},\ \frac{3}{4}\bar{\pi} + \frac{1}{2}(\bar{\pi}-\underline{\pi})\frac{1}{L(t)} \\
& -\frac{1}{4}\sqrt{\left(\bar{\pi} + 2(\bar{\pi}-\underline{\pi})\frac{1}{L(t)}\right)^2 + 8\beta(\bar{\pi}-\underline{\pi})\frac{1}{L(t)}}\Bigg\}
\end{aligned}$$

Stable job queues

$$f_p(x) = 1/(\bar{\pi} - \underline{\pi}) \longrightarrow N(t) = L(t)\frac{\bar{\pi} - \pi(t)}{\bar{\pi} - \underline{\pi}}$$

$$L(t+1) = \left(1 - \theta\frac{\bar{\pi} - \pi^\star(t)}{\bar{\pi} - \underline{\pi}}\right) L(t) + \Lambda(t).$$



Stable job queues

Proposition 1. The time-averaged queue size at any time t is uniformly bounded.

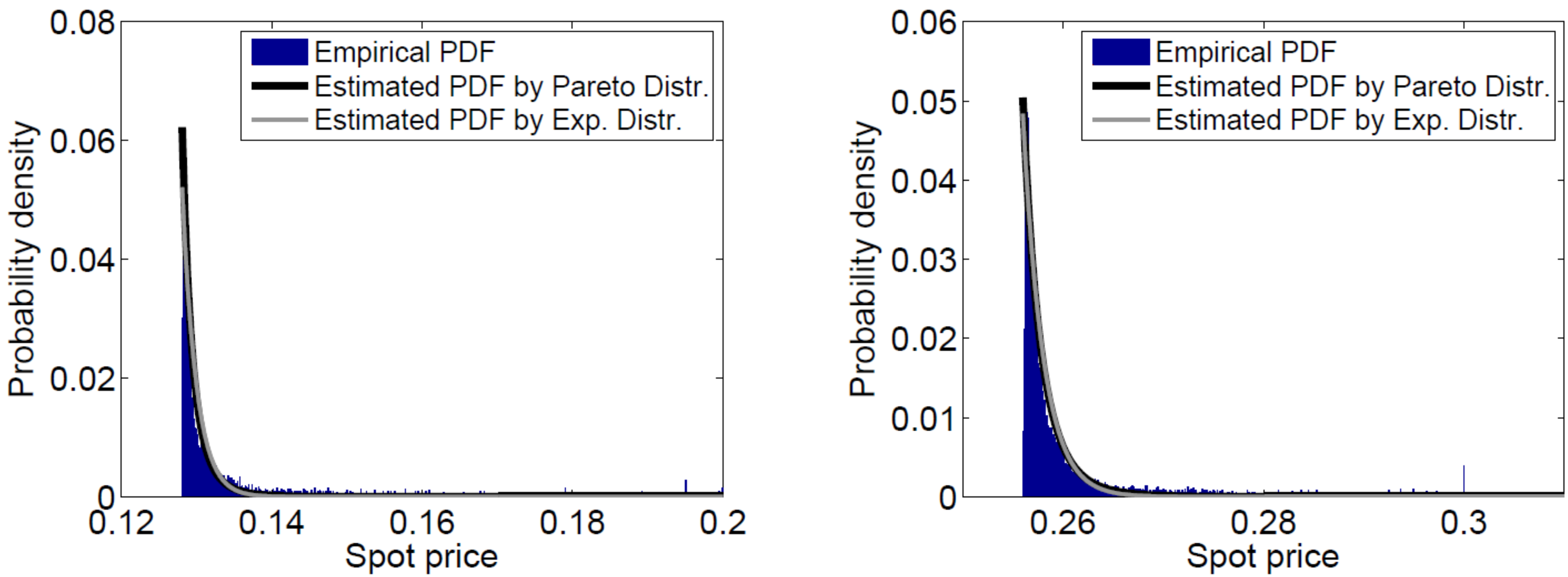
Proposition 2. Let L(t)=L(t+1), the optimal spot prices should satisfy:

$$\pi^\star(t) = h(\Lambda(t)) = \frac{1}{2}\left(\bar{\pi} - \frac{\beta}{1+\frac{1}{\theta}\Lambda(t)}\right). \qquad (6)$$

Proposition 3. The predicted PDF of the spot price is:

$$f_\pi(\pi) \simeq f_\Lambda(h^{-1}(\pi))$$

Validation from historical spot prices



$$f_\Lambda(\Lambda) = \frac{\alpha \Lambda_{min}^{\alpha}}{\Lambda^{\alpha+1}}, \quad \text{for } \Lambda \geq \Lambda_{min}, \quad f_\Lambda(\Lambda) = \frac{1}{\eta} e^{-\frac{1}{\eta}\Lambda}, \quad \text{for } \Lambda \geq 0.$$

Bid types

- One-time user bid
  - Exit the system once they fall below spot price.
- Persistent user bid
  - Resubmitted until job finishes or is manually terminated by the user.
  - Longer completion time.

Bid types

- One-time user bid

  How to finish the job before it exits?

  How to reduce cost?

- Persistent user bid

  How to reduce cost with acceptable completion time?

Bid types

- Job completion time

  = running time ($p \geq \pi$) + idle time

- One-time bid

  running time = execution time

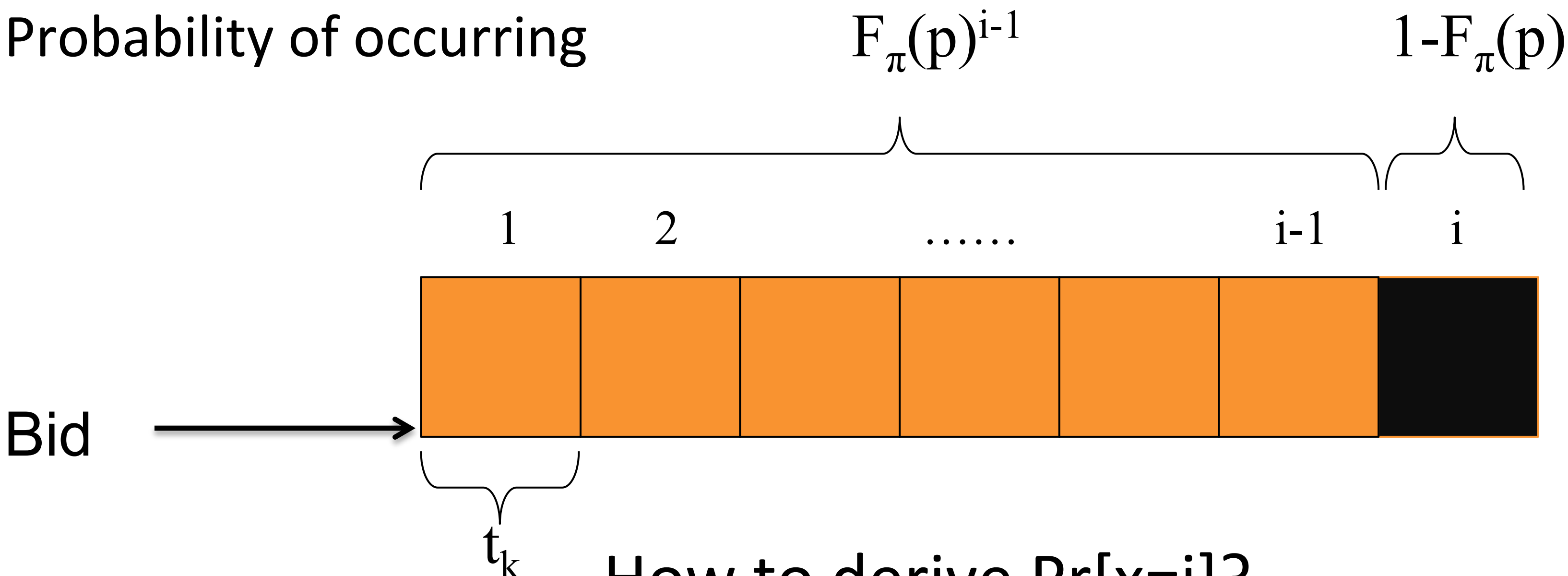
- Persistent bid

  running time = execution time + recovery time

Notations

- $f_\pi(\pi) \rightarrow f_\pi$
- $F_\pi(p) = \Pr[p \geq \pi(t)]$
- $\underline{\pi}$, $\bar{\pi}$

Placing one-time bids

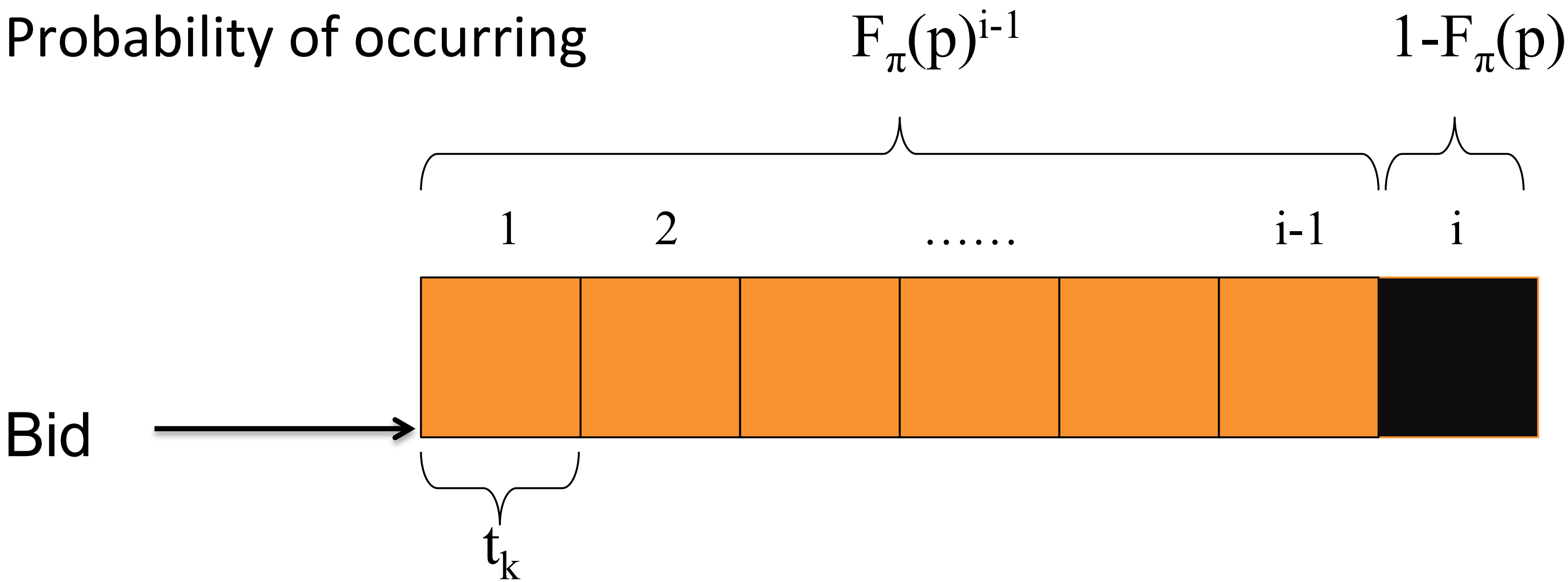


How to derive Pr[x=i]?

x is # of time slots without interruption

Expected length of time without interruption = $$t_k \sum_{i=1}^{\infty} i F_\pi(p)^{i-1}(1-F_\pi(p)) = \frac{t_k}{1-F_\pi(p)}.$$

Placing one-time bids



Execution time $t_s \leq \dfrac{t_k}{1 - F_\pi(p)}$

Expected length of time without interruption = $t_k \sum_{i=1}^{\infty} i F_\pi(p)^{i-1}(1 - F_\pi(p)) = \dfrac{t_k}{1 - F_\pi(p)}.$

Cost minimization for one-time jobs

execution time

$$\begin{aligned} \underset{p}{\text{minimize}} \quad & \Phi_{so}(p) = \boxed{t_s}\mathbb{E}(\pi \mid \pi \le p) = \frac{t_s \int_{\underline{\pi}}^{p} x f_\pi(x)\mathrm{d}x}{F_\pi(p)} \\ \text{subject to} \quad & \Phi_{so}(p) \le t_s \bar{\pi}, \ \boxed{t_s \le \frac{t_k}{(1-F_\pi(p))}}, \ \underline{\pi} \le p \le \bar{\pi}. \end{aligned}$$

execution time ≤ expected running time without interruption

The optimal bid price: $p^\star = \max\left\{\underline{\pi}, F_\pi^{-1}\left(1 - \frac{t_k}{t_s}\right)\right\}.$

Conclusion: $t_s/t_k \uparrow \longrightarrow p^\star \uparrow$

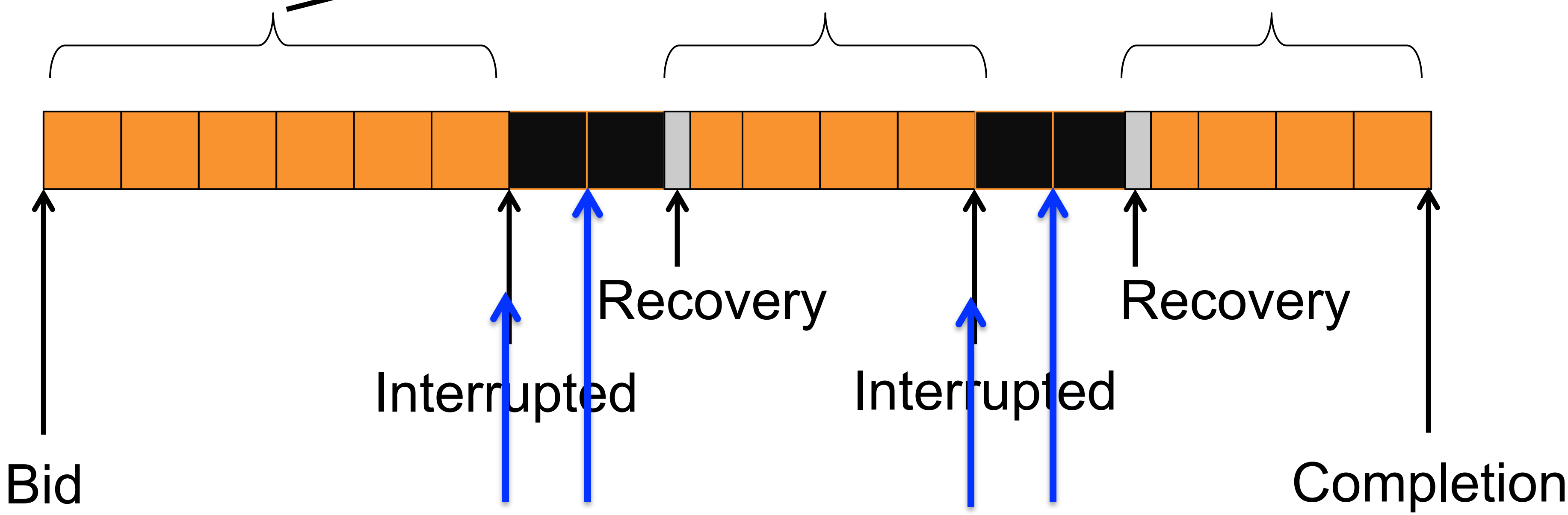
Placing persistent bids

completion time

Expected running time

$$\boxed{\boxed{T}F_\pi(p)} = \frac{t_s - \boxed{t_r}}{1 - \frac{t_r}{t_k}\left(1 - F_\pi(p)\right)}$$

recovery time per re-resuming



Placing persistent bids

The expected number of interruptions is:

$$
\begin{aligned}
&\mathbb{E}\left(\frac{1}{2}\sum_{k=0}^{T/t_k-1}\Big(\boxed{\mathbb{I}_\pi(\pi(t))}-\mathbb{I}_\pi(\pi(t+1))\Big)^2\right)\\
\overset{(a)}{=}\;&\frac{T}{t_k}\Big(\mathbb{E}\big(\mathbb{I}_\pi(\pi(t))\big)-\mathbb{E}\big(\mathbb{I}_\pi(\pi(t))\mathbb{I}_\pi(\pi(t+1))\big)\Big)\\
=\;&\frac{T}{t_k}F_\pi(p)\big(1-F_\pi(p)\big),
\end{aligned}
$$

$$
\begin{cases} =1, \text{ if } p \geq \pi(t) \\ =0, \text{ otherwise} \end{cases}
$$

Placing persistent bids

The expected # of interruptions $= \quad \dfrac{T}{t_k} F_\pi(p)\left(1 - F_\pi(p)\right)$

Expected running time $\quad TF_\pi(p) = \left(\frac{T}{t_k} F_\pi(p)\left(1 - F_\pi(p)\right) - 1\right) t_r + t_s$

constraint:

$$TF_\pi(p) = \frac{t_s - t_r}{\boxed{1 - \frac{t_r}{t_k}\left(1 - F_\pi(p)\right)}}, \rightarrow >0 \qquad t_r < \frac{t_k}{1 - F_\pi(p)}$$

Cost minimization (persistent bids)

Expected running time, $TF_\pi(p)$

$E[\pi \mid P \geq \pi]$

$$\underset{p}{\text{minimize}} \quad \Phi_{sp}(p) = \boxed{\frac{t_s - t_r}{1 - \frac{t_r}{t_k}\left(1 - F_\pi(p)\right)}} \boxed{\frac{\int_{\underline{\pi}}^{p} x f_\pi(x) \mathrm{d}x}{F_\pi(p)}}$$

$$\text{subject to} \quad \Phi_{sp}(p) \leq t_s \bar{\pi},\ \underline{t_r < \frac{t_k}{1 - F_\pi(p)}},\ \underline{\pi} \leq p \leq \bar{\pi},$$

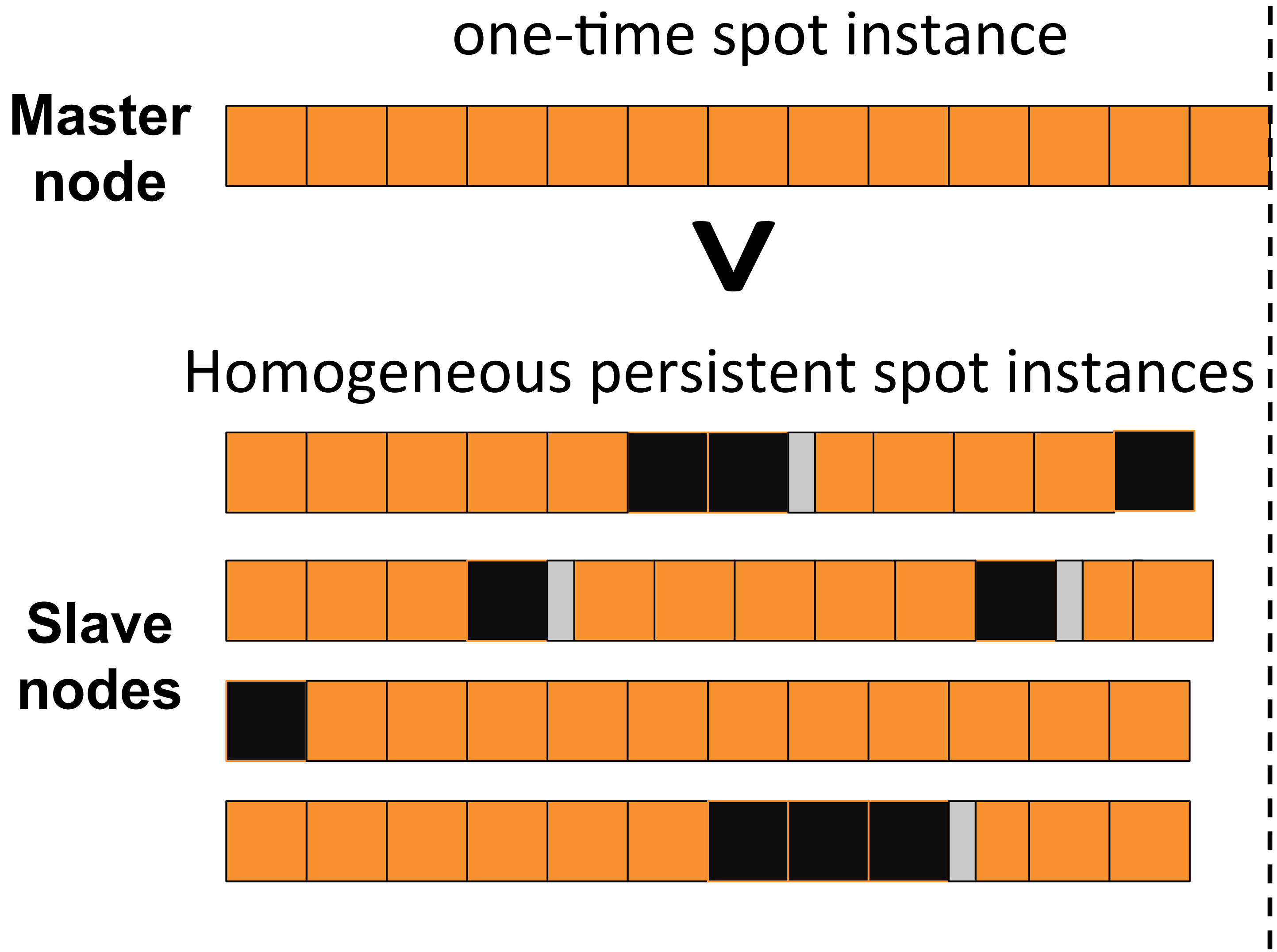
recovery time should be short

Optimal bid price: $$p^\star = \psi^{-1}\left(\frac{t_k}{t_r} - 1\right)$$

where $\psi^{-1}(\cdot)$ *is the inverse function of*

$$\psi(p) = F_\pi(p)\left(\frac{\int_{\underline{\pi}}^{p} x f(x) \mathrm{d}x}{\int_{\underline{\pi}}^{p} (p - x) f(x) \mathrm{d}x} - 1\right)$$

Bidding MapReduce jobs



Experiment setup (single-instance bids)

They simulate an one hour running time of a spot instance by creating Amazon Machine Image (AMI)
t_k= 5 min

Spot price history: 2 months

Job: t_s = 1 hour, t_r = 10 s/ t_r=30 s

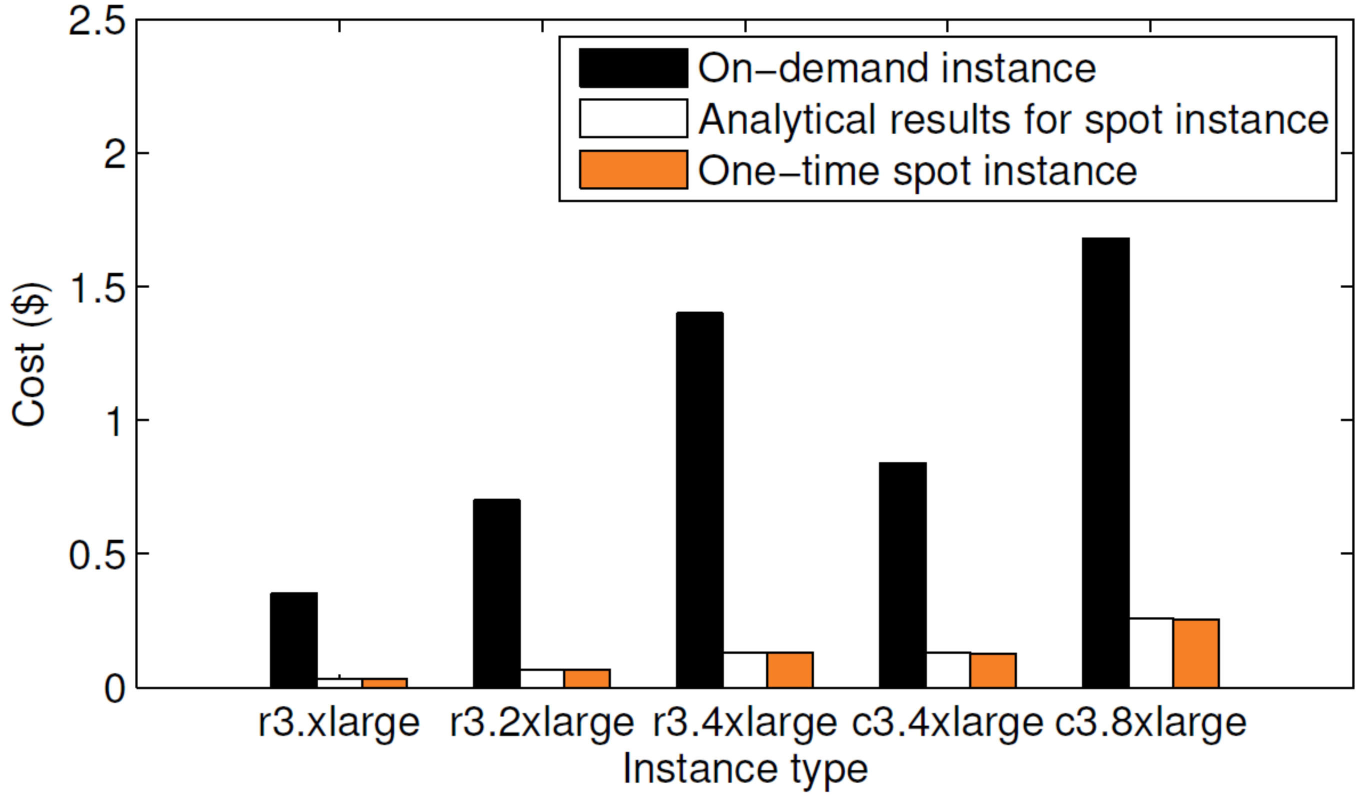
Compared heuristic: bid price is the minimum that consistently exceeds the spot prices for the past 1 hour

Single-instance one-time bids

Optimal bid prices for one-time bids that run for one hour.

Instance type	On-demand price	One-time bid		
		Optimal bid price p^*	Offline retrospective price	Actual price $E[\pi \mid \pi < p^*]$
r3.xlarge	\$0.35	\$0.0374	\$0.0324	\$0.033
r3.2xlarge	\$0.70	\$0.0795	\$0.0644	\$0.066
r3.4xlarge	\$1.40	\$0.1430	\$0.1304	\$0.130
c3.4xlarge	\$0.84	\$0.1669	\$0.1324	\$0.128
c3.8xlarge	\$1.68	\$0.2903	\$0.2640	\$0.256

One-time bids



User costs are reduced by up to 91%, without any interruptions.

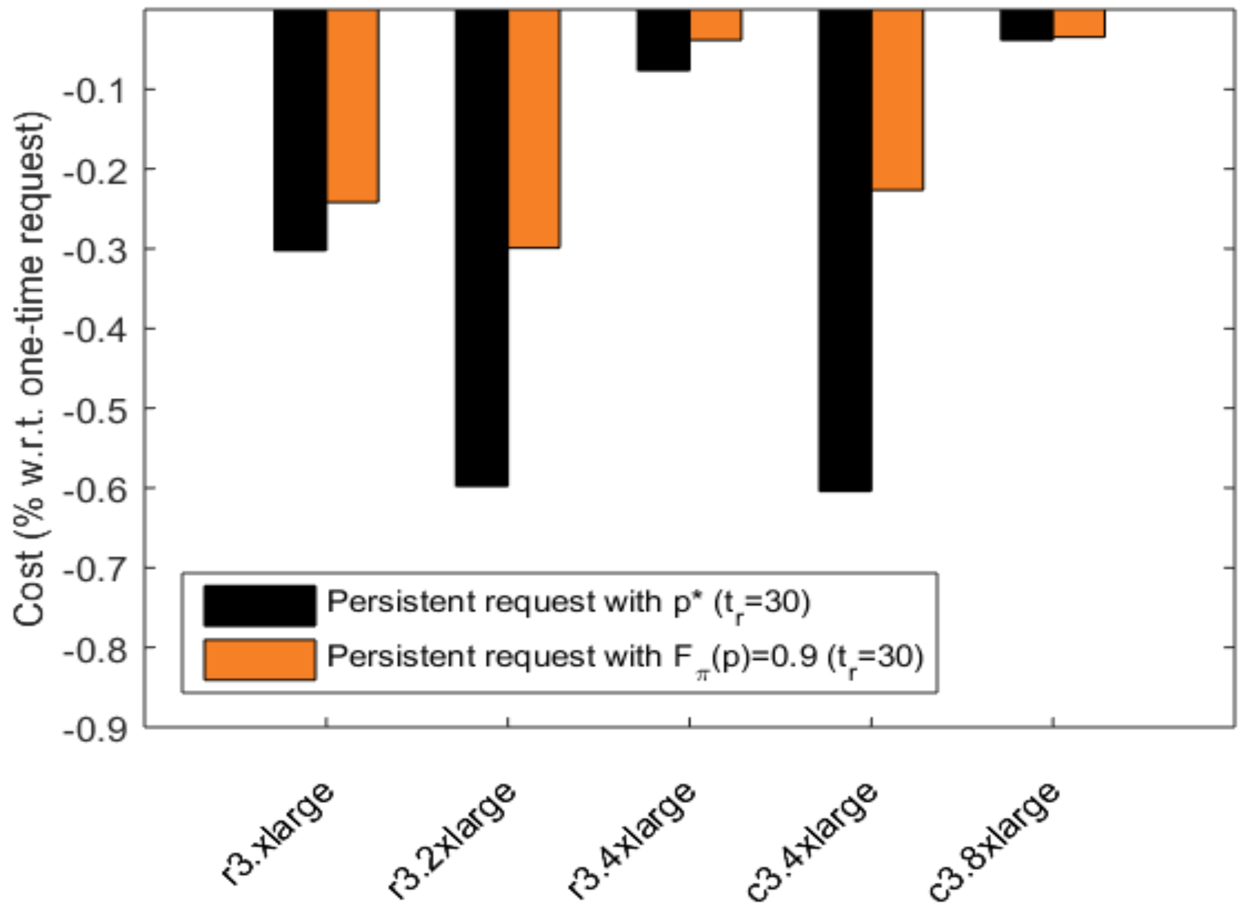
Single-instance persistent bids

Optimal bid prices with different recovery times.

Instance type	On-demand price	Persistent bid	
		Optimal price p^* (t_r=10s)	Optimal price p^* (t_r=30s)
r3.xlarge	\$0.35	\$0.0332	\$0.0355
r3.2xlarge	\$0.70	\$0.0661	\$0.0711
r3.4xlarge	\$1.40	\$0.1327	\$0.1422
c3.4xlarge	\$0.84	\$0.1322	\$0.1413
c3.8xlarge	\$1.68	\$0.2648	\$0.2831

Longer recovery times yield higher bid prices.

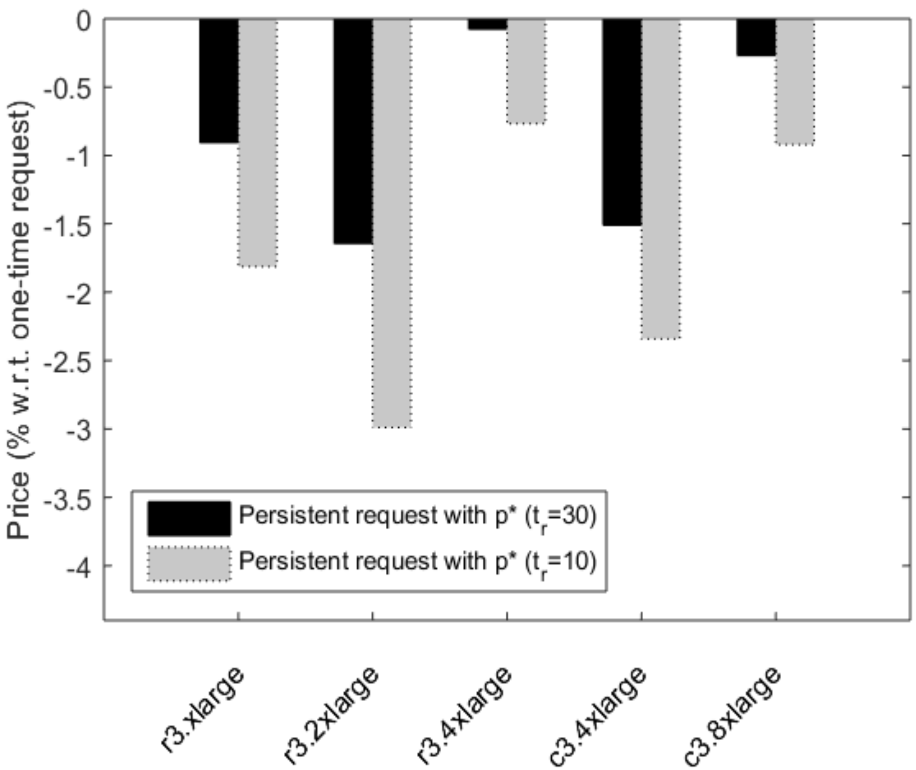
Single-instance persistent bids

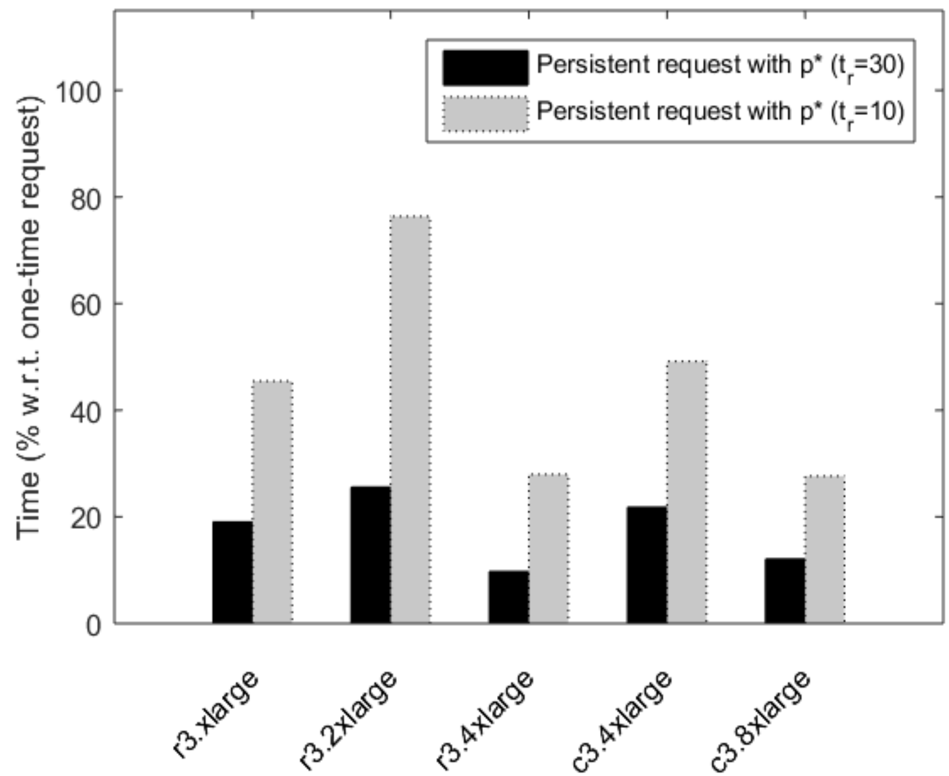


Our bid prices are optimal for minimizing users' costs.

Persistent bids

$$\frac{\text{bid price (time) of persistent bids} - \text{bid price (time) of one-time bids}}{\text{bid price (time) of one-time bids}}$$

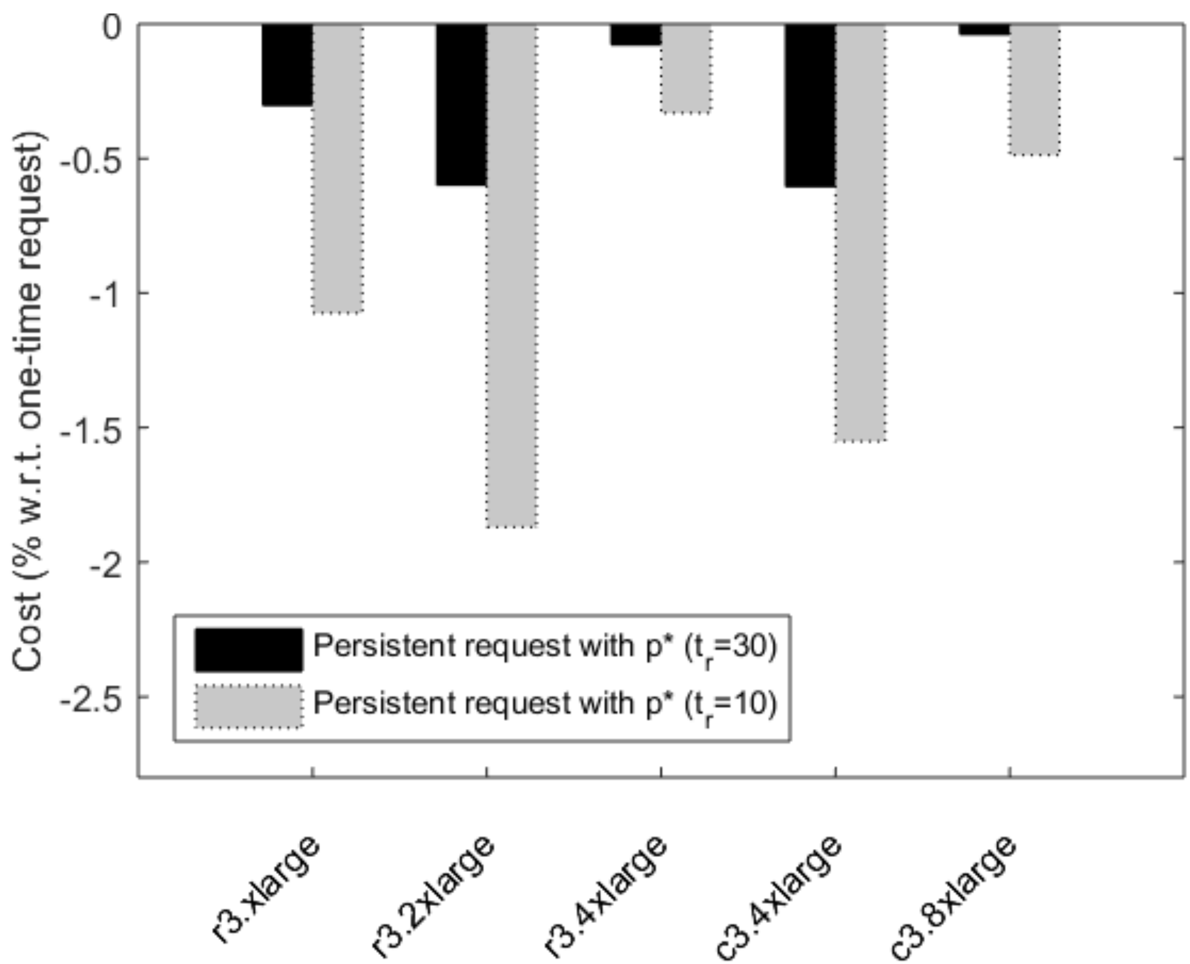




A lower optimal bid price.

A longer completion time.

Persistent bids



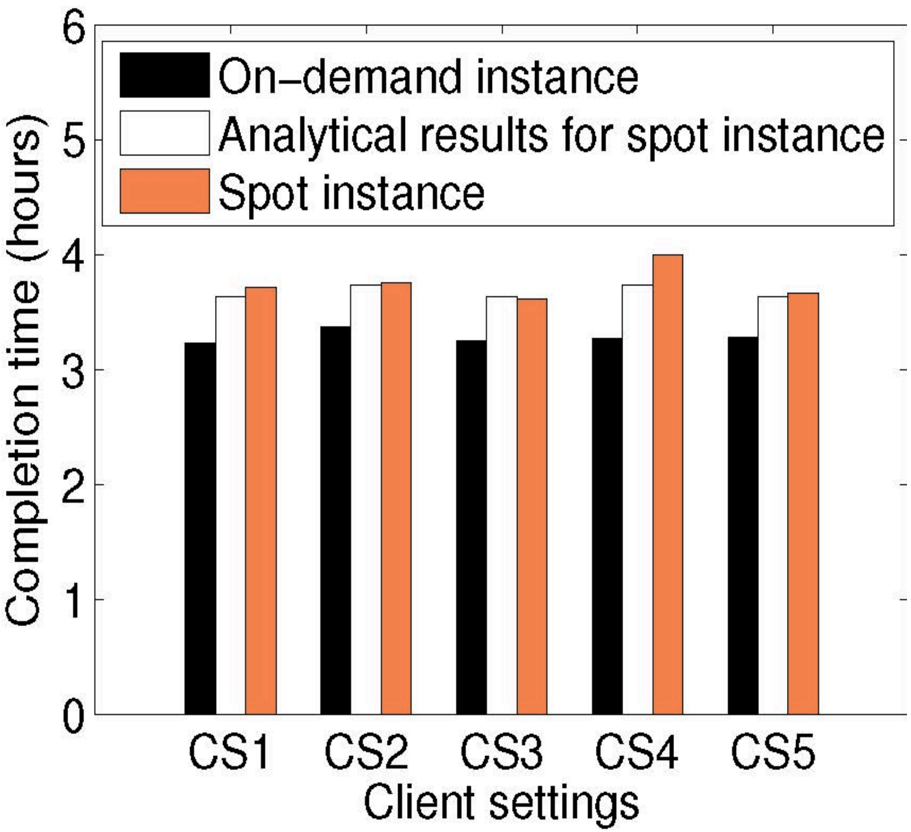
The overall costs are further reduced.

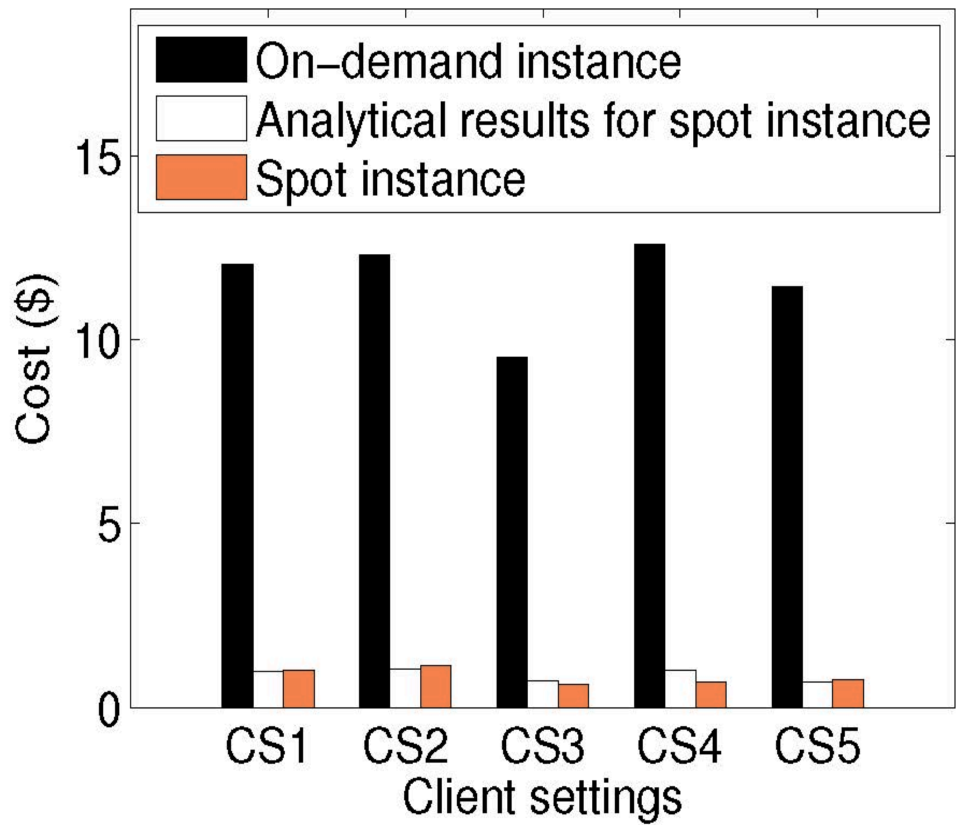
Experiment setup (MapReduce jobs)

Job: run Hadoop MapReduce jobs (count the frequency of words) on the Common Crawl Dataset using Amazon Elastic MapReduce (EMR)

$t_r = 10s$; $t_0 = 60s$

MapReduce jobs





The cost is reduced by up to 92.6% with just a 14.9% completion time increase.

Conclusion

- Model for cloud provider's setting of the spot prices.
- Bidding strategies: tradeoff between prices and runtimes
  - One-time bids: bidding higher prices to avoid interruptions .
  - Persistent bids: bidding lower prices to save money.
- Application to the MapReduce jobs.

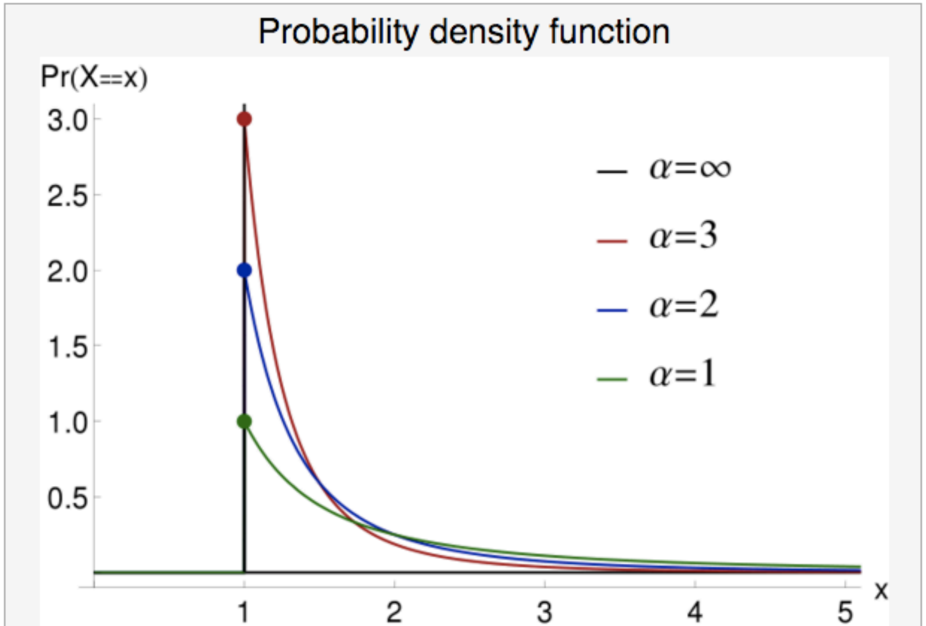
Discussion

- Risk-awareness of users.
- Social welfare maximization in predicting the spot price.
- Adaptation to an online algorithm with good competitive ratio if possible.

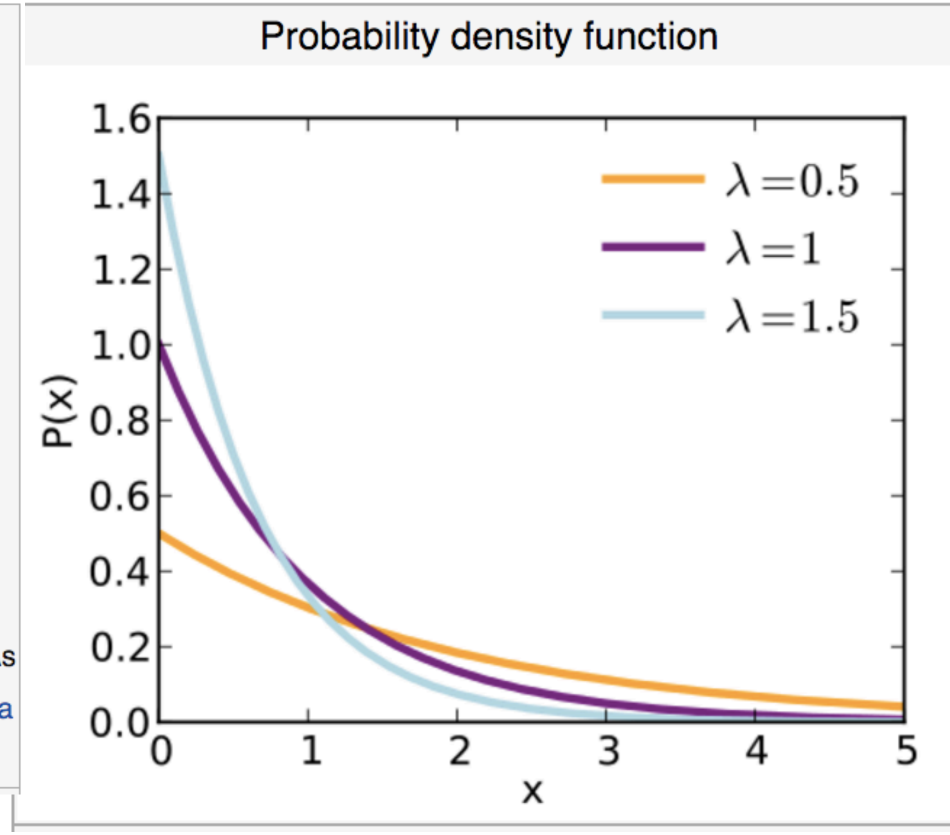
Thank you
Q&A

Jan. 21, 2016

Validation from historical spot prices



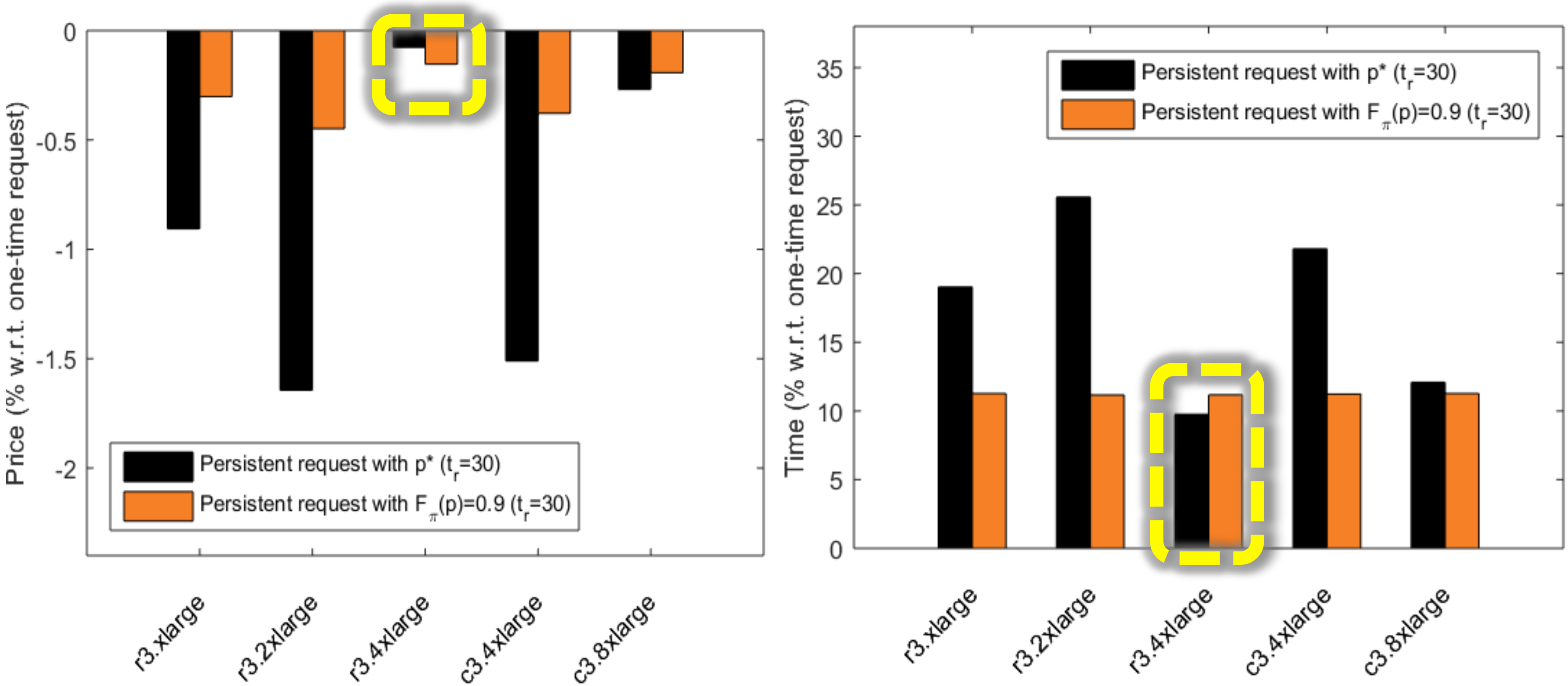
Pareto Type I probability density functions for various α with $x_m = 1$. As $\alpha \to \infty$ the distribution approaches $\delta(x - x_m)$ where δ is the Dirac delta function.



PDF of Pareto distribution

PDF of exponential distribution

Single-instance persistent bids



Bidding at the 90th percentile price yields either higher bid prices and lower completion times or lower bid prices and longer completion times.