Amazon Elastic Compute Cloud (EC2) vs. in-House HPC Platform

a Cost Analysis

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Summary

1. **Amazon Web Services for HPC**
2. **TCO Analysis for an in-house HPC Facility**
   UL HPC Platform
3. **Toward a novel EC2 Price Model**
4. **Application for a Cost Comparison against in-house HPC Facility**
   Hourly Price Model
   Yearly Price Evaluation from Real Usage
5. **Conclusion**

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Overview

- Plethora of Cloud Services
  - ↪ **Compute:** Elastic Compute Cloud (EC2) / Docker containers
  - ↪ **Storage:** Block Storage (EBS) / Simple Storage Service (S3) / Glacier (archiving)
  - ↪ **Networking:** Virtual Private Cloud (VPC) / Route 53 (DNS)
  - ↪ **Database:** Relational Database (RDS) / DynamoDB (NoSQL)
  - ↪ **Analytics:** Hadoop / Machine Learning...
  - ↪ etc.

⇒ Of main interest to mimic HPC facility: **EC2**, EBS, VPC

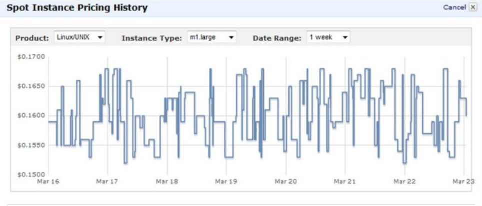
- Elastic Compute Cloud (EC2) Instances
  - ↪ Grouped by **Region** and **Availability Zone** (AZ)
  - ↪ VMs organized in *families*
  - ↪ Pay per VM according to time used

EC2 VMs Organization

Instance Family	Instance Type	Processor Microarchitecture	Introduction Date
General Purpose	m1 m3 t2 m4	Xeon Family Ivy Bridge-EP Xeon Family Haswell-EP	2006-08-23 2012-10-31 2014-07-01 2015-06-11
Memory Optimized	m2 cr1 r3	Xeon Family Sandy Bridge-EP Ivy Bridge-EP	2010-02-22 2013-01-21 2014-04-10
Compute Optimized	c1 cc1 cc2 c3 c4	Xeon Family Nehalem-EP Sandy Bridge-EP Ivy Bridge-EP Haswell-EP	2008-08-08 2010-07-13 2011-11-14 2013-11-14 2014-11-13
Storage Optimized	hi1 hs1 i2	Xeon Family Sandy Bridge-EP Ivy Bridge-EP	2012-07-18 2012-12-21 2013-12-20
Dense Storage	d2	Haswell-EP	2015-03-30
GPU	cg1 g2	Nehalem-EP Sandy Bridge-EP	2010-11-14 2013-11-05
Micro	t1	Xeon Family	2009-10-26

EC2 Pricing

- Depends on the region, instance type, options and pricing mode
- 3 payment modes:
  1. **On-Demand:** Fixed hourly rate. Most expensive / flexible
  2. **Reserved:** Fixed hourly rate with several upfront options. Contracts on 1 or 3 years term. Less expensive than OD / not flexible
     - ✓ no upfront
     - ✓ partial upfront
     - ✓ all upfront
  3. **Spot:** Price bidding / flexible. Fixed duration option (1 / 6 hours)


Spot Instance Pricing History

Product: Linux/UNIX

Instance Type: m1.large

Date Range: 1 week

EC2 for High Performance Computing

- **Useful Features**
  - ↪ Enhanced networking (SR-IOV)
  - ↪ Placement groups
  - ↪ EBS-optimized (increased throughput)
  - ↪ Dedic. instances (no multi-tenancy)
- **Possible Instance Families**
  - ↪ Compute: *c3, c4*
  - ↪ Memory: *r3*
  - ↪ Storage: *i2*
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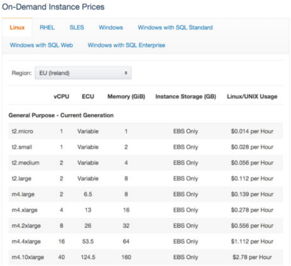
On-Demand Instance Prices

Region: EU (Ireland)

	vCPU	ECU	Memory (GiB)	Instance Storage (GB)	Linux/UNIX Usage
General Purpose - Current Generation					
t2.micro	1	Variable	1	EBS Only	$0.014 per Hour
t2.small	1	Variable	2	EBS Only	$0.028 per Hour
t2.medium	2	Variable	4	EBS Only	$0.056 per Hour
t2.large	2	Variable	8	EBS Only	$0.112 per Hour
m4.large	2	6.5	8	EBS Only	$0.139 per Hour
m4.xlarge	4	13	16	EBS Only	$0.278 per Hour
m4.2xlarge	8	26	32	EBS Only	$0.556 per Hour
m4.4xlarge	16	53.5	64	EBS Only	$1.112 per Hour
m4.10xlarge	40	124.5	160	EBS Only	$2.78 per Hour

Computing Performance

- Measured in **ECUs** (black-box)
  - ↪ EC2 Compute Unit
  - ↪ currently $\simeq$ 1 Xeon core @ 1GHz

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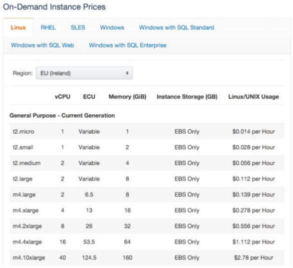
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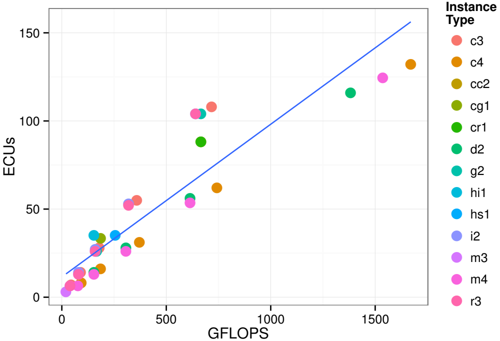
⇒ ECU vs *traditional* HPC metrics?

EC2 Computing Performances

- **Strong linear relationship between ECUs and GFLOPs**
  - ↪ **adj. R^2=0.9**
  - ↪ Other explanatory attributes (e.g. processor generation).



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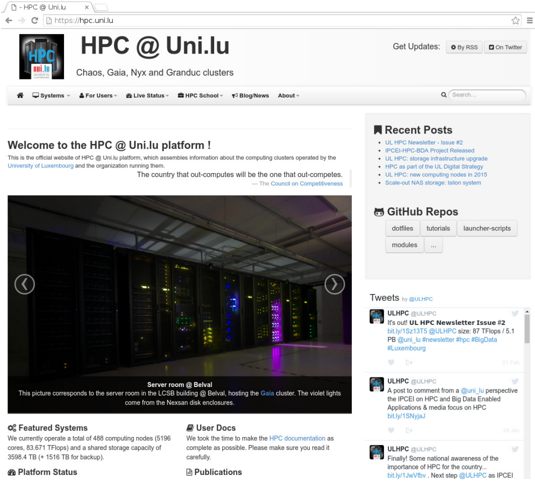
High Performance Computing @ UL



HPC @ Uni.lu

Chaos, Gaia, Nyx and Granduc clusters

Welcome to the HPC @ Uni.lu platform !

This is the official website of HPC @ Uni.lu platform, which assembles information about the computing clusters operated by the University of Luxembourg and the organization running them.

> The country that out-computes will be the one that out-competes.
> — The Council on Competitiveness

Server room @ Belval
This picture corresponds to the server room in the LCSB building @ Belval, hosting the Gaia cluster. The violet lights come from the Nexsan disk enclosures.

Featured Systems

We currently operate a total of 488 computing nodes (5196 cores, 83.671 TFlops) and a shared storage capacity of 3598.4 TB (+ 1516 TB for backup).

Platform Status

User Docs

We took the time to make the HPC documentation as complete as possible. Please make sure you read it carefully.

Publications

Recent Posts

- UL HPC Newsletter - Issue #2
- IPCEI-HPC-BDA Project Released
- UL HPC: storage infrastructure upgrade
- HPC as part of the UL Digital Strategy
- UL HPC: new computing nodes in 2015
- Scale-out NAS storage: Isilon system

GitHub Repos

Tweets by @ULHPC

ULHPC @ULHPC
It's out! **UL HPC Newsletter Issue #2** bit.ly/1Sz13T5 @ULHPC size: 87 TFlops / 5.1 PB @uni_lu #newsletter #hpc #BigData #Luxembourg
01 Feb

ULHPC @ULHPC
A post to comment from a @uni_lu perspective the IPCEI on HPC and Big Data Enabled Applications & media focus on HPC bit.ly/1SNyjaJ
29 Jan

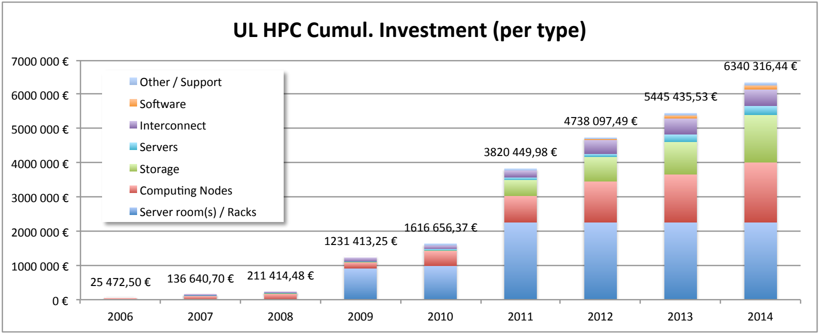
ULHPC @ULHPC
Finally! Some national awareness of the importance of HPC for the country... bit.ly/1JwVfbv . Next step @ULHPC as IPCEI

Key numbers

- 344 users
- 98 servers
- 492 nodes
  - ↪ 5300 cores
  - ↪ **85.543 TFlops**
- **5354.4 TB**
- 4 sysadmins
- 2 sites
  - ↪ Kirchberg
  - ↪ Belval

http://hpc.uni.lu

Local HPC Platform Investment



From Platform TCO to Hourly Cost (1)

- **CAPEX**
  - ↪ machines
  - ↪ servers
  - ↪ storage
  - ↪ interconnect
  - ↪ room equipment
  - ↪ lifetime licenses
  - ↪ building estimation
- **OPEX**
  - ↪ manpower
  - ↪ energy
  - ↪ support
  - ↪ yearly licenses

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Used Method

- Amortized CAPEX + OPEX → yearly TCO
- Permits to **compute node hourly cost**

From Platform TCO to Hourly Cost (2)

- **Obtained Results for the UL HPC platform**

	Node	CPUs	RAM GB	GPUs	#Nodes	CPU Family	GFLOPS	**Hourly Cost ($)**
Chaos	h-cluster1	12	24	0	32	westmere	108.48	0.428
	d-cluster1	12	24	0	16	westmere	108.48	0.439
	r-cluster1	32	1024	0	1	nehalem	289.28	1.814
	e-cluster1	16	32	0	16	sandybridge	281.60	0.433
	s-cluster1	16	32	0	16	sandybridge	81.60	0.433
Gaia	gaia-[1-60]	12	48	0	60	westmere	108.48	0.453
	gaia-[61-62]	12	24	1792	2	westmere	108.48	0.641
	gaia-[63-72]	12	24	10240	10	westmere	108.48	0.599
	gaia-73	160	1024	0	1	sandybridge	2560.00	2.649
	gaia-74	32	1024	0	1	sandybridge	614.40	1.516
	gaia-[75-79]	16	64	12480	5	sandybridge	281.60	0.577
	gaia-[83-122]	12	48	0	40	westmere	140.64	0.344
	gaia-[123-154]	12	48	0	32	westmere	147.36	0.344

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⇒ How to compare/match with Cloud offers ?

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Methods and Objectives

- **Goal:** Build a new model for *EC2 relative instance price*
  ↪ ... in function of *all* its HPC characteristics

- **Obj.**: fair comparison between EC2 & in-house HPC facility
  ↪ for each HPC node, compute its *EC2 relative price*
  ↪ compare EC2 versus HPC for same characteristics
  ↪ answer the question: **which one is the cheaper?**

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  - ↪ answer the question: **which one is the cheaper?**

- **Method used**: Multiple linear regression
  - ↪ Automated bidirectional stepwise selection
  - ↪ Selection on both criteria and instance types
  - ↪ Selection criterion: adjusted R^2 shrinkage

Proposed Price Model Details

Selected Criteria

- HPC characteristics:
  - ↪ GFLOPs: F
  - ↪ Memory (GB): M
  - ↪ Disk size (GB): D
  - ↪ Nb. GPUs: G

Equation [1]

$$Instance\_Price = \alpha.F + \beta.M + \gamma.D + \delta.G$$

With $\alpha, \beta, \gamma, \delta$ for a given model generation and pricing mode.

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With $\alpha, \beta, \gamma, \delta$ for a given model generation and pricing mode.

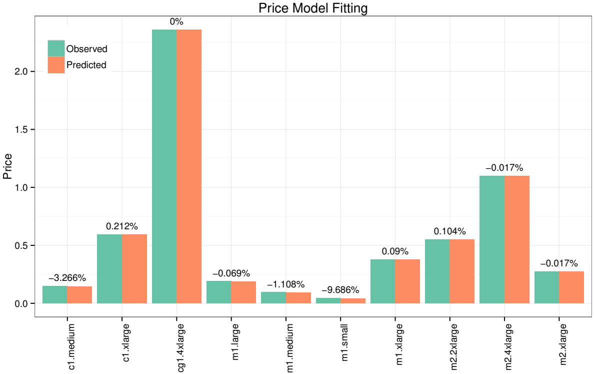
Model	Types	**GFLOPS** (α)	**MemGiB** (β)	**DiskGiB** (γ)	**GPUs** (δ)	Adj. R^2	P-Value
1st Gen.	m1, c1, m2, cg1	0.0039522	0.0061130	0.0000670	0.0015395	0.9999909	0e+00
2nd Gen.	cc2, m3, hi1	-0.0035266	0.0355353	0.0007284	0.0000000	0.9999785	1e-07
3rd Gen.	hs1, cr1, g2, c3	0.0017209	0.0106101	0.0000655	0.0001644	1.0000000	0e+00
4th Gen.	i2, r3, c4	0.0009952	0.0081883	0.0007605	0.0000000	0.9998832	0e+00
5th Gen.	m4, d2	0.0000000	0.0173750	0.0000342	0.0000000	1.0000000	0e+00

Note: The linearity of the model works for instances released at the same period and is broken for new instance releases. Leads to different model generations.

Model Evaluation – On Demand Pricing

- Evaluation of Proposed EC2 Price Models Fittings (with error rates)
  ↪ ... against actual On Demand instance prices.

1st Instance Generation



Model Evaluation – On Demand Pricing

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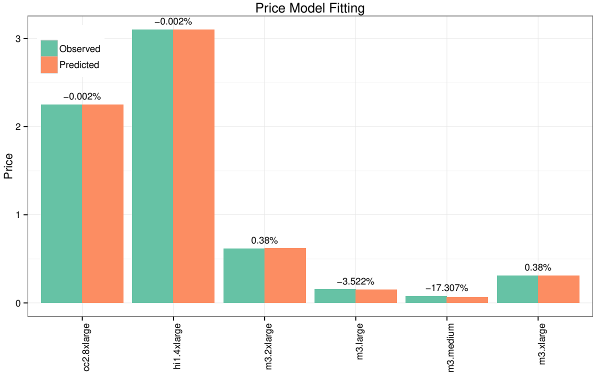
2nd Instance Generation



Model Evaluation – On Demand Pricing

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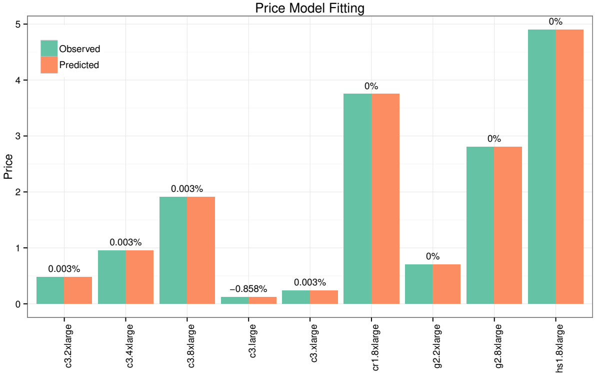
3rd Instance Generation



Model Evaluation – On Demand Pricing

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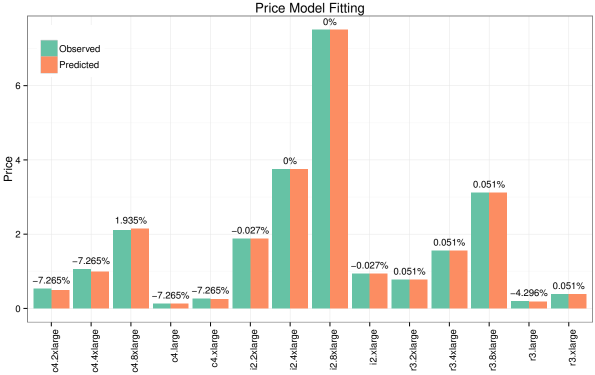
4th Instance Generation



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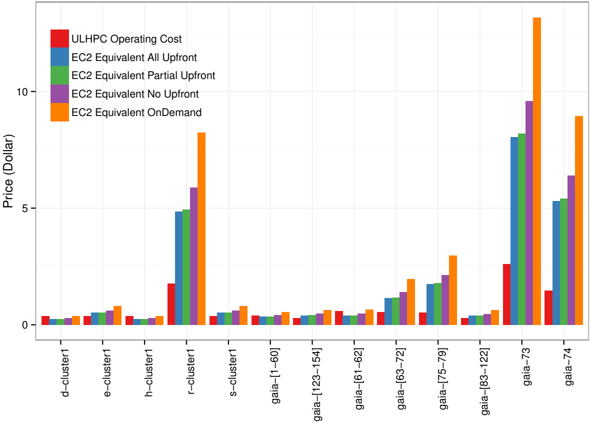
Hourly Price Comparison

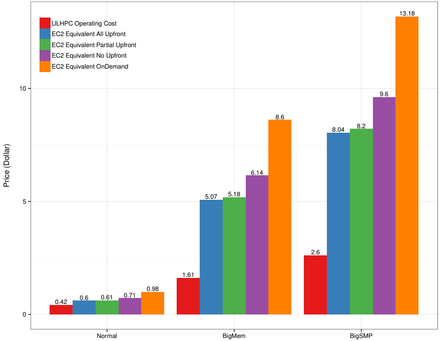
- New cost model permits to estimate *EC2 equivalent price*
  - ↪ ... for **any** computing node configuration



Hourly Price Comparison (by resource classes)

- Assuming definition of 3 HPC *resources classes*

Class	Description
`Normal`	Regular HPC resource
`BigMem`	Regular HPC resource with huge RAM ($\geq$ 1024 GB)
`BigSMP`	SMP node ($\geq$ 16 sockets) with a huge RAM ($\geq$ 1024 GB)



Perf. Comparison – HPC workload

Pure Computing Performance Comparison

- Based on HPCG benchmark http://www.hpcg-benchmark.org/
- compare in-house *gaia*'s cluster obtained performance with EC2
  - ↪ use instances that match the most *gaia* nodes characteristics
  - ↪ obtained score for **1024 cores**

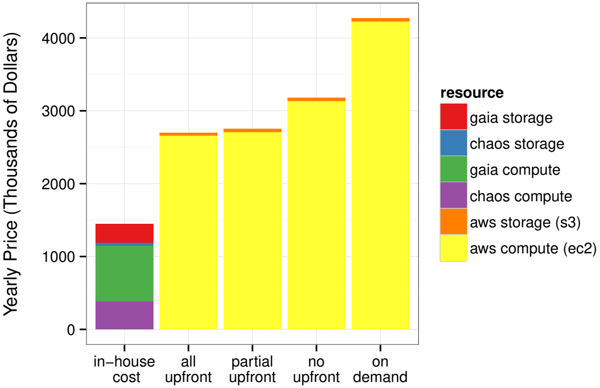
	c3.4xlarge	*r3.4xlarge*	*r3.8xlarge*	*g2.8xlarge*
in-house *gaia*'s efficiency **IMPROVEMENT factor**	2.5	2.4	2.3	3.2

Toward a Yearly Price Comparison

New Price Model Applied to Real Cluster Usage

- Real HPC job usage extracted from Batch Scheduler Logs
  - ↪ collect all jobs resource allocations
  - ↪ refine cost model with actual performance
  - ↪ apply refined cost model to each job
  - ↪ sum up for year 2014
- includes storage costs

Toward a Yearly Price Comparison



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Conclusion & Perspectives

- **In this talk...**
  - ↪ Cost-effectiveness of CC platforms vs. in-house HPC facility
  - ↪ TCO analysis of a medium-size academic HPC facility
    - ✓ $\simeq$ 350 active users, 5000 cores, 4 sysadmins
  - ↪ novel price model applied to the main Cloud IaaS provider
    - ✓ flexible model that relies on inherent HPC performance metrics
  - ↪ **accurate** cost analysis **based on real HPC usage**

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⇒ advocates in general in favor of the acquisition of an in-house HPC facility

Conclusion & Perspectives

Lessons Learned

- Deciding where to run your workload is complex
  - ↪ Depends on the performance needs and the workload itself
    - ✓ highly variable or more stable?
  - ↪ Depends on the users' *awareness* of system usage optimization.
- Despite what the Cloud providers advertises
  - ↪ Scale out is complicated...
    - ✓ And not necessarily because of your application scalability.
  - ↪ Do not neglect the cost of experimental setup time

- **Open Perspectives**
  - ↪ extend our analysis over Spot instance (Amazon) and Azure offer
  - ↪ integrate communication cost (to/from cloud storage)

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http://2016.cloudcom.org

Full Papers:	**July 15th, 2016**
Short Papers/Demos:	August 10th, 2016
Notification of acceptance:	August 31th, 2016
Conference Date:	Dec. 12th →15h, 2016

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Thank you for your attention...

Questions?

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