Testing Testbeds Towards Reproducibility

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Context: the Grid'5000 testbed

- **A large-scale distributed testbed for distributed computing**
  - 8 sites, 32 clusters, 894 nodes, 8490 cores
  - Dedicated 10-Gbps backbone network
  - 550 users and 100 publications per year

Context: the Grid'5000 testbed

- **A large-scale distributed testbed for distributed computing**
  - 8 sites, 32 clusters, 894 nodes, 8490 cores
  - Dedicated 10-Gbps backbone network
  - 550 users and 100 publications per year
- A meta-grid, meta-cloud, meta-cluster, meta-data-center:
  - Used by CS researchers in HPC, Clouds, Big Data, Networking
  - To experiment in a fully controllable and observable environment
  - **Design goals:**
    - ★ **Support high-quality, reproducible experiments**
    - ★ **On a large-scale, shared infrastructure**

This talk: the Grid'5000 testing framework

Goals:

- Systematically test the Grid'5000 infrastructure and its services
- Increase the reliability and the trustworthiness of the testbed
- Uncover problems that would harm the repeatability and the reproducibility of experiments

Outline:

- Motivations for this work
- Our solution
- Results
- Conclusions

Grid'5000: overview

- Fairly used testbed
- Many services that support good-quality experiments
- Still, sometimes (rarely), scary bugs were found
  - Showing that some serious problems were not detected
- Problem: very few bugs are reported
  - Reporting bugs or asking technical questions is a difficult process[1][2]
    - Typical users of testbeds (students, post-docs) rarely have that skill
    - Or lack the confidence to report bugs

[1] Simon Tatham. "How to Report Bugs Effectively". 1999. URL: http://www.chiark.greenend.org.uk/~sgtatham/bugs.html.

[2] Eric Steven Raymond and Rick Moen. "How To Ask Questions The Smart Way". URL: http://www.catb.org/esr/faqs/smart-questions.html.

But many bugs should be reported

Several factors for many different and interesting issues:

- Scale: 8 sites, 32 clusters, 894 nodes
  - Not really a problem on the software side (config mgmt tools)
  - Hardware of different age, from different vendors
  - Hardware requiring some manual configuration
  - Hardware with silent and subtle failure patterns[3]
- Software stack
  - Some core services – well tested
  - But also experimental ones
    - Testbeds are always trying to innovate
    - But adoption generally slow

[3] https://youtu.be/tDacjrSCeq4?t=47s

Bugs can have dramatic consequences

- Most experiments focus on measuring performance
  - So subtle performance bugs can have a huge impact
  - 5% decrease in performance
    $\rightsquigarrow$ wrong results
    $\rightsquigarrow$ wrong conclusions
    $\rightsquigarrow$ retracted paper?
- Example bugs (all real):
  - Different CPU settings (power mgmt, hyperthreading, turbo boost)
  - Different disk firmware version, disk cache settings
  - Cabling issue $\rightsquigarrow$ wrong measurements by testbed monitoring service
- Problems on the software side
  $\rightsquigarrow$ unreliable services
  $\rightsquigarrow$ harder to automate experiments

Our testbed testing framework

- Based on Jenkins
- With custom developments
  - For job scheduling
  - For analyzing and summarizing results

Jenkins automation server

- De facto standard tool for automating processes (CI, CD)
  - `cron` on steroids
  - Extensible through plugins
    - Matrix Project: jobs as matrices of several options
      test_environments: 14 images X 32 clusters = 448 configurations
    - Matrix Reloaded: retry subset of configurations in Matrix jobs
- However, Jenkins alone was not sufficient for our needs

Job scheduling

- Basic scheduling available in Jenkins (time-based)
  - Not sufficient for our needs
- Different kinds of tests:
  - Software-centric: one node per cluster
  - Hardware-centric: all nodes of a given cluster
- Resources are heavily used
  - Waiting for all nodes of a given cluster to be available can take weeks
- One cannot just submit a job and wait because:
  - It would use a Jenkins *worker* (slot)
  - It would compete with user requests

Job scheduling (2)

- Implemented in an external tool that triggers Jenkins builds
- Queries the job status and the testbed status, and decides to submit a job based on:
  - Resources availability
  - Retry policy (exponential backoff)
  - Additional policies (peak hours, avoid several jobs on same site)
- If the Jenkins build creates a testbed job, but that testbed job fails to be scheduled immediately, it is cancelled and the build is marked as *unstable* in Jenkins

Analyzing and summarizing results

- Requirements:
  - Per test status, or all sites/clusters $\rightsquigarrow$ OK
  - Per site or per cluster status, for all tests
  - Historical perspective
- Solution: external status page that uses Jenkins' REST API

Analyzing and summarizing results

Site	Average	cmdline	console	disk	environments	kavlan	mpigraph	multideploy	multireboot	oarproperties	oarstate	paralleldeploy	refapi	sidapi	stdenv
grenoble	77%	100%	33%	33%	87%	33%	100%	66%	100%	100%	100%	0%	0%	100%	66%
lille	85%	100%	60%	40%	98%	80%	100%	100%	80%	60%	0%	100%	0%	100%	80%
luxembourg	95%	100%	100%	100%	100%	50%	100%	100%	100%	100%	100%	0%	100%	100%	100%
lyon	78%	100%	25%	50%	100%	50%	75%	100%	25%	0%	0%	100%	0%	100%	100%
nancy	92%	100%	100%	55%	99%	66%	95%	88%	33%	100%	100%	100%	100%	100%	88%
nantes	88%	100%	100%	0%	100%	0%	100%	100%	0%	100%	100%	100%	100%	100%	100%
rennes	89%	100%	60%	40%	98%	60%	100%	100%	60%	100%	100%	100%	60%	100%	100%
sophia	80%	100%	75%	0%	100%	25%	100%	75%	50%	100%	0%	100%	0%	100%	25%
Average	86%	100%	69%	42%	98%	54%	96%	90%	54%	81%	62%	75%	45%	100%	81%

Showing 1 to 9 of 9 entries

hide bugs with comments | reset

Search:

Job	Configuration	Status	Last successful	Last failed	Streak	Last attempt	Next	Comment (from pad)
test_disk	site_cluster=nancy-graphene	Fail		2017-01-18 07:50:45	7	2017-01-24 15:18:39	2017-01-24 16:18:39	NORETRY graphene-[45,48] ont des disques différents
test_disk	site_cluster=grenoble-edel	Fail		2017-01-19 19:30:38	11	2017-01-24 15:18:39	2017-01-24 16:18:39	NORETRY Bug 7696 Les disques du cluster Edel ne sont pas homogènes
test_disk	site_cluster=nancy-griffon	Fail		2017-01-25 15:00:56	11	2017-01-25 15:00:56	No retry	NORETRY Bug 7675 griffon : disks are not homogeneous
test_console	site_cluster=rennes-paravance	Fail		2017-01-27 07:30:57	7	2017-01-27 07:30:57	2017-02-03 07:30:57	Bug 7770 - kaconsole failed on paravance-56
test_disk	site_cluster=rennes-paravance	Fail		2017-01-20 07:00:41	10	2017-01-27 07:31:10	2017-01-27 07:00:41	Bug 7737 test-disk on paravance
test_multireboot	environment=jessie-x64-min,site_cluster=sophia-uvb	Fail		2017-01-02 15:10:40	1	2017-01-02 15:10:40	2017-01-09 15:10:40	Bug 7686 - uvb - some nodes fail on reboot
test_kavlan	site_cluster=grenoble-genepi	Fail	2016-12-02 02:10:45	2017-01-24 20:30:57	12	2017-01-24 20:30:57	2017-01-31 20:30:57	Bug 7685 - kavlan fail to put node in VLAN 100: Configuration session timed out!
test_refapi	site_cluster=rennes-parapluie	Fail		2017-01-27 12:01:15	34	2017-01-27 12:01:15	2017-02-03 12:01:15	Bug 7585 Homogénéité des clusters de Rennes

Test scripts

- Goals: exhibit issues, but also provide sufficient information to testbed operators to understand and fix the issue
- Coverage (total of 751 test configurations):
  - Homogeneity and correctness of testbed description (*refapi*, *oarproperties*, *dellbios*)
  - Testbed status (*oarstate*)
  - Basic functionality of command-line tools, REST API (*cmdline*, *sidapi*)
  - Provided system images (*environments*, *stdenv*)
  - Reliability of key services (*paralleldeploy*, *multireboot*, *multideploy*)
  - Other important services (*console*, *kavlan*, *kwapi*)
  - Specific hardware: Infiniband, hard disk drives (*mpigraph*, *disk*)

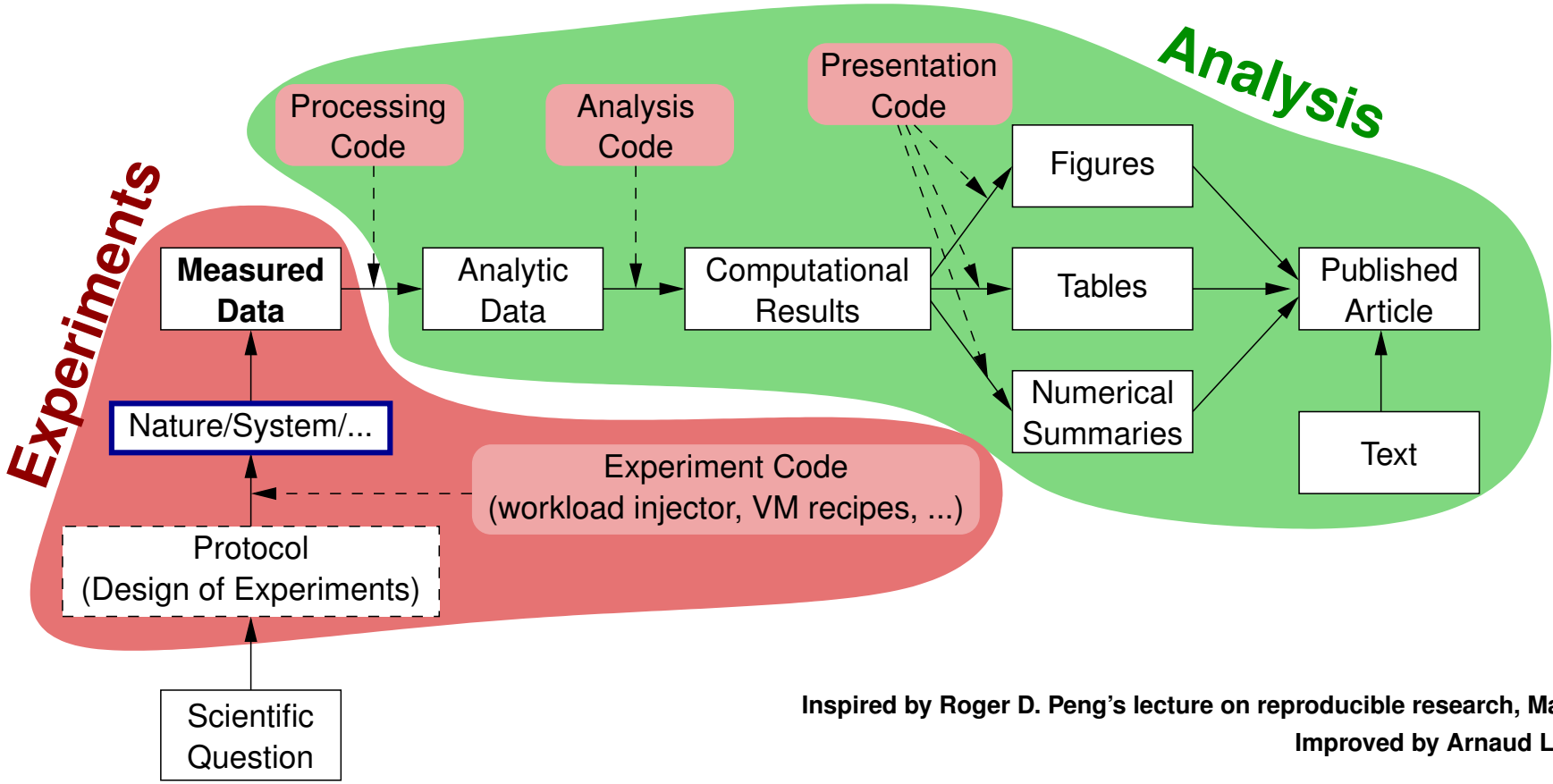
Results

- From October 2016 to April 2017: 118 bugs found
  - Disk drives configuration (R/W caching), CPU settings (C-states)
  - Different disk performance due to different disk firmware versions
  - Cabling issues
  - Various weak spots in the infrastructure, and configuration problems
  - A cluster was decommissioned after tests exhibited random reboots
  - Other random problems:
    - A race condition in the Linux kernel caused boot delays
    - A bug in the Infiniband stack caused random failures to start

Wrapping-up

- Testbed testing framework:
  - Systematically test the Grid'5000 infrastructure and its services
  - Increase the reliability and the trustworthiness of the testbed
  - Uncover problems that would harm the repeatability and the reproducibility of experiments
- Outcomes:
  - Many problems identified and fixed
  - Testbed reliability improving (85% of tests successful in February $\rightsquigarrow$ 93% today, despite the addition of new tests)
  - Impact on the way the testbed operators work $\rightsquigarrow$ *Test-driven operations*, more confidence that what should work actually works
  - Tests still being added
    - ★ Adding real user experiments as regression tests?
- Open questions:
  - Job scheduling: requiring the availability of all nodes of a cluster is not very realistic. Move to per-node scheduling? (and drop Jenkins?)
  - Respective roles of testbed operators and experimenters?

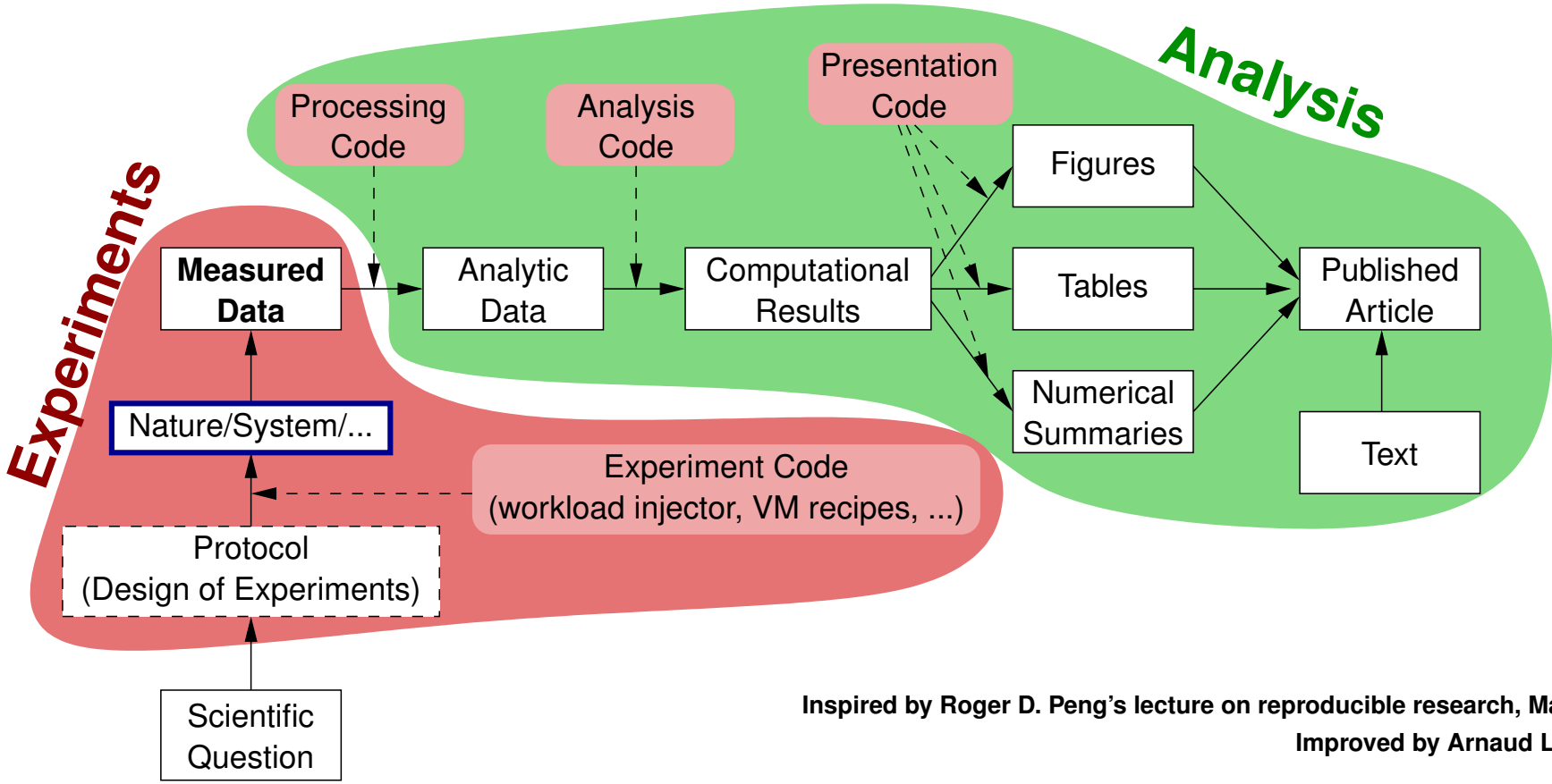
Reproducibility 101



Inspired by Roger D. Peng's lecture on reproducible research, May 2014

Improved by Arnaud Legrand

Reproducibility 101



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How much do you trust your experiments' results?

How much do you trust your simulator or testbed?

Calibration/qualification phase?

- Goal: Make sure that tools and hardware behave as expected
- Challenging task:
  - Many different tools (experiment orchestration solution, load injection, measurement tools, etc.)
  - Mixed with complex hardware, deployed at scale
- Result: very few experimenters do that in practice
  - Most experimenters trust what is provided
- Shouldn't this be the responsibility of the tools maintainers (simulators developers, testbeds maintainers)?

Related work

- Infrastructure monitoring
  - Nagios-like (basic checks to make sure that each service is available)
  - Move to more complex checks (functionality-based) and alerting based on time-series, e.g. with Prometheus (esp. useful on large-scale elastic infrastructures)
- Infrastructure testing
  - Netflix Chaos Monkey
- Testbed testing
  - Fed4FIRE monitoring: `https://fedmon.fed4fire.eu`
    - Check that login, API, very basic usage work
  - Grid'5000 g5k-checks (per-node checks)
    - Similar tool on Emulab (CheckNode)
  - Emulab's LinkTest
    - Network characteristics (latency, bandwidth, link loss, routing)

Resources discovery, verification, selection[4]

- Describing resources $\rightsquigarrow$ understand results
  - Covering nodes, network equipment, topology
  - Machine-parsable format (JSON) $\rightsquigarrow$ scripts
  - Archived (*State of testbed 6 months ago?*)


```
"processor": {
  "cache_l2": 8388608,
  "cache_l1": null,
  "model": "Intel Xeon",
  "instruction_set": "",
  "other_description": "",
  "version": "X3440",
  "vendor": "Intel",
  "cache_l1i": null,
  "cache_l1d": null,
  "clock_speed": 2530000000.0
},
"uid": "graphene-1",
"type": "node",
"architecture": {
  "platform_type": "x86_64",
  "smt_size": 4,
  "smp_size": 1
},
"main_memory": {
  "ram_size": 17179869184,
  "virtual_size": null
},
"storage_devices": [
  {
    "model": "Hitachi HDS72103",
    "size": 298023223876.953,
    "driver": "ahci",
    "interface": "SATA II",
    "rev": "JPFO",
    "device": "sda"
  }
],
```


[4] David Margery et al. “Resources Description, Selection, Reservation and Verification on a Large-scale Testbed”. In: *TRIDENTCOM*. 2014.

Resources discovery, verification, selection[4]

- Describing resources $\rightsquigarrow$ understand results
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  - Machine-parsable format (JSON) $\rightsquigarrow$ scripts
  - Archived (*State of testbed 6 months ago?*)
- Verifying the description
  - Avoid inaccuracies/errors $\rightsquigarrow$ wrong results
  - Could happen frequently: maintenance, broken hardware (e.g. RAM)
  - Our solution: g5k-checks
    - Runs at node boot (or manually by users)
    - Acquires info using OHAI, ethtool, etc.
    - Compares with Reference API


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"type": "node",
"architecture": {
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    - ★ Compares with Reference API
- Selecting resources
  - OAR database filled from Reference API


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    "rev": "JPFO",
    "device": "sda"
  }
],
```


```
oarsub -l "cluster='a' and gpu='YES'/nodes=1+cluster='b' and
      eth10g='Y'/nodes=2,walltime=2"
```

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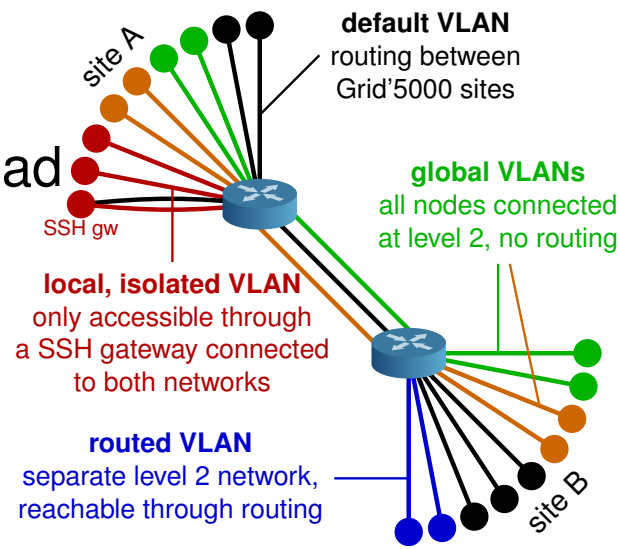
Reconfiguring the testbed

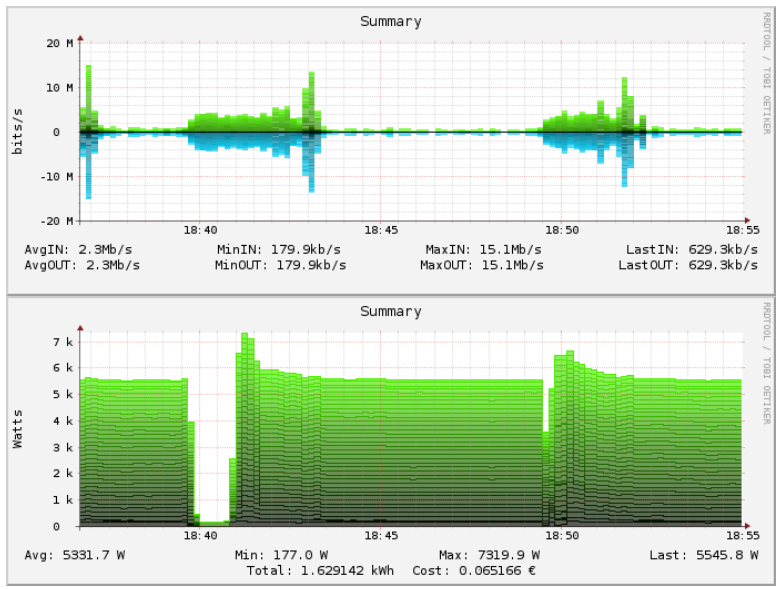
- Operating System reconfiguration with Kadeploy:
  - Provides a *Hardware-as-a-Service* cloud infrastructure
  - Enable users to deploy their own software stack & get *root* access
  - **Scalable, efficient, reliable and flexible**:
    200 nodes deployed in ~5 minutes
  - Images generated using Kameleon for traceability
- Customize networking environment with KaVLAN
  - Protect the testbed from experiments (Grid/Cloud middlewares)
  - Avoid network pollution
  - Create custom topologies
  - By reconfiguring VLANS $\rightsquigarrow$ almost no overhead



Experiment monitoring

Goal: enable users to understand what happens during their experiment

- System-level probes (usage of CPU, memory, disk, with Ganglia)
- Infrastructure-level probes
  - Network, power consumption
  - Captured at high frequency (≈1 Hz)
  - Live visualization
  - REST API
  - Long-term storage



Why Jenkins, after all?

- Several Jenkins limitations were worked-around
- Was using Jenkins really a good choice in the first place?
- Yes. Benefits:
  - Clean execution environment for scripts
  - Queue to control overloading
  - Access control for users to trigger jobs manually with a web interface
  - Long-term storage of results history and test logs
- (Also, our Jenkins instance is increasingly used for traditional CI/CD talks)