



Grid'5000 for high-quality reproducible research

Lucas Nussbaum

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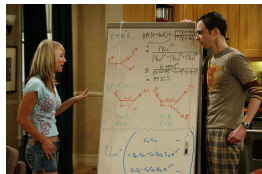
Grid'5000 for high-quality reproducible research

Lucas Nussbaum
lucas.nussbaum@loria.fr



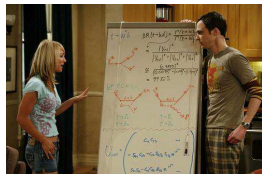
Validation in (Computer) Science

- ▶ Two classical approaches for validation:
 - ♦ **Formal**: equations, proofs, etc.
 - ♦ **Experimental**, on a scientific instrument
- ▶ Often a mix of both:
 - ♦ In Physics
 - ♦ In Computer Science



Validation in (Computer) Science

- ▶ Two classical approaches for validation:
 - ◆ **Formal**: equations, proofs, etc.
 - ◆ **Experimental**, on a scientific instrument
- ▶ Often a mix of both:
 - ◆ In Physics
 - ◆ In Computer Science
- ▶ Very little formal validation in distributed systems research
 - ◆ Counter-examples:
 - ★ Worst-case analysis of allocation/scheduling heuristics
 - ★ Properties of algorithms (e.g. deadlock-free)
 - ◆ Our scientific objects are often intractable theoretically:
too complex, dynamic, heterogeneous, large



(Poor) state of experimentation in CS

- ▶ 1994: survey of 400 papers¹
 - ◆ *among published CS articles in ACM journals, 40%-50% of those that require an experimental validation had none*
- ▶ 1998: survey of 612 papers²
 - ◆ *too many papers have no experimental validation at all*
 - ◆ *too many papers use an informal (assertion) form of validation*
- ▶ 2009 update: *situation is improving*³

¹Paul Lukowicz et al. “Experimental Evaluation in Computer Science: A Quantitative Study”. In: *Journal of Systems and Software* 28 (1994), pages 9–18.

²M.V. Zelkowitz and D.R. Wallace. “Experimental models for validating technology”. In: *Computer* 31.5 (1998), pages 23–31.

³Marvin V. Zelkowitz. “An update to experimental models for validating computer technology”. In: *J. Syst. Softw.* 82.3 (Mar. 2009), pages 373–376.

(Poor) state of experimentation in CS (2)

- ▶ Most papers do not use even basic statistical tools

Papers published at the Europar conference⁴

Year	Tot. papers	With error bars	Percentage
2007	89	5	5.6
2008	89	3	3.4
2009	86	2	2.4
2010	90	6	6.7
2011	81	7	8.6
2007-2011	435	23	5.3

- ▶ 2007: Survey of simulators used in P2P research⁵
 - ◆ Most papers use an unspecified or custom simulator

⁴Study carried out by E. Jeannot.

⁵S. Naicken et al. "The state of peer-to-peer simulators and simulations". In: *SIGCOMM Comput. Commun. Rev.* 37.2 (Mar. 2007), pages 95–98.

State of experimentation in other sciences

- ▶ 2008: Study shows lower fertility for mices exposed to transgenic maize
 - ◆ AFSSA report⁶:
 - ★ *Several calculation errors have been identified*
 - ★ *led to a false statistical analysis and interpretation*

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- ▶ 2011: CERN Neutrinos to Gran Sasso project: faster-than-light neutrinos
 - ◆ 2012: caused by timing system failure
- ▶ ☹ Not everything is perfect
- ▶ 😊 But some errors are properly identified

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Related to the Reproducible Research movement

- ▶ Mostly in computational sciences
- ▶ Explores tools and methods (provenance, executable papers, etc.)
- ▶ Different types of experimental reproducibility⁷:
 - ◆ *Replications that vary little or not at all with respect to the reference experiment*

same method, environment, parameters → same result
 - ◆ *Replications that do vary but still follow the same method as the reference experiment*

same method, but different {env., params} → same conclusion
 - ◆ *Replications that use different methods to verify the reference experiment results*

different method → same conclusion

⁷Omar S. Gómez et al. “Replications types in experimental disciplines”. In: *ESEM'10*. 2010.

Author

The diagram illustrates the scientific process. At the top, a horizontal arrow points from left to right, labeled 'Author' at its tail. At the bottom, a horizontal arrow points from right to left, labeled 'Reader' at its tail. On the left side, a vertical flow of boxes is connected by upward-pointing arrows: a box labeled 'Scientific Question' at the bottom, followed by a dashed box labeled 'Protocol (Design of Experiments)', and then a box labeled 'Nature/System/...' at the top. To the right of this flow, a box labeled 'Published Article' is positioned. The 'Published Article' box is aligned vertically with the 'Nature/System/...' box.

Published
Article

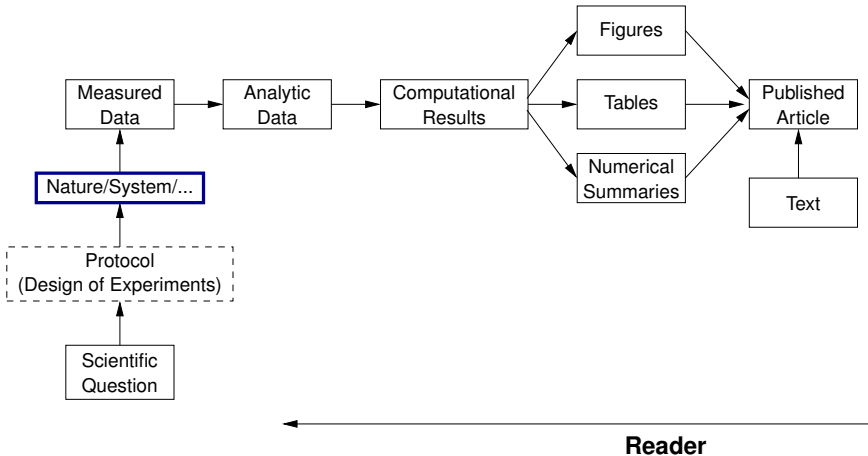
Nature/System/...

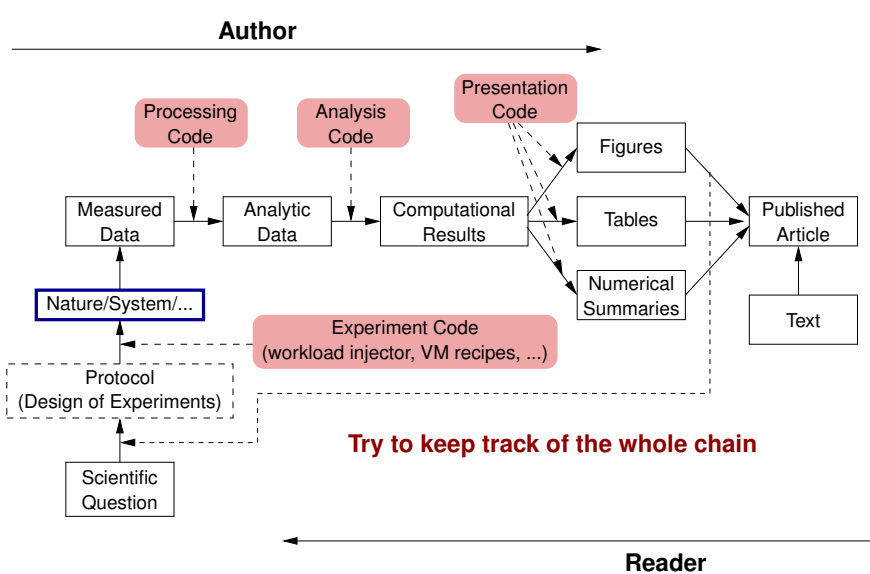
Protocol
(Design of Experiments)

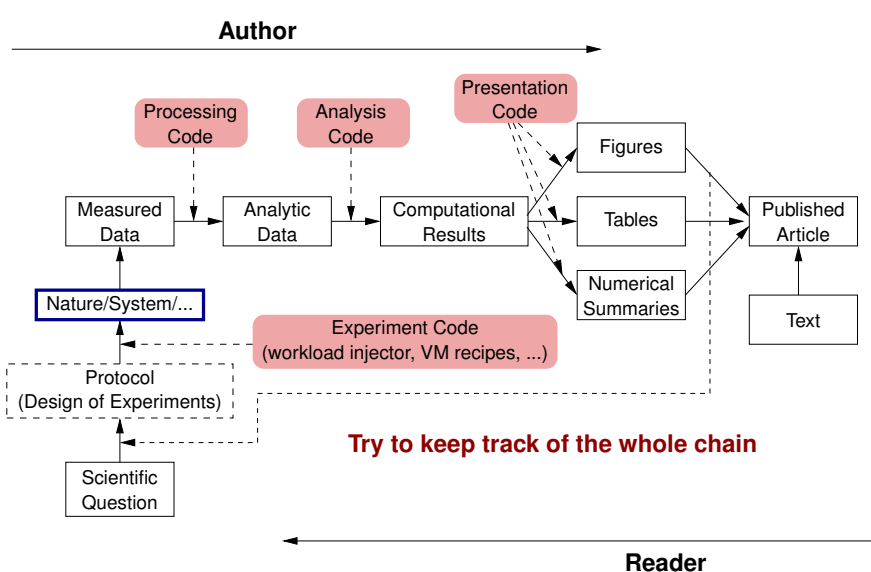
Scientific
Question

Reader

Author







- **Grid'5000 mission: support high-quality, reproducible experiments on a distributed systems testbed**

Two axes of work

► Improve trustworthiness

- ◆ Testbed description
- ◆ Experiment description
- ◆ Control of XP conditions
- ◆ Automate experiments
- ◆ Monitoring & measurement

► Improve scope & scale

- ◆ Handle large number of nodes
- ◆ Automate experiments
- ◆ Handle failures
- ◆ Monitoring & measurement

Both goals raise similar challenges

Outline

- 1 Introduction
- 2 Description and verification of the environment
- 3 Reconfiguring the testbed to meet experimental needs
- 4 Monitoring experiments, extracting and analyzing data
- 5 Improving control and description of experiments
- 6 Conclusions

Description and verification of the environment

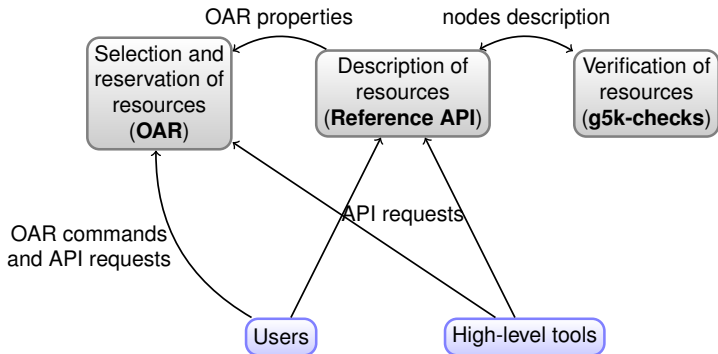
Typical needs:

- ▶ How can I find suitable resources for my experiment?
- ▶ How sure can I be that the actual resources will match their description?
- ▶ What was the hard drive on the nodes I used six months ago?

Description and verification of the environment

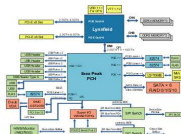
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Description and selection of resources

- Describing resources \leadsto understand results
 - ◆ Detailed description on the Grid'5000 wiki
 - ◆ Machine-parsable format (JSON)
 - ◆ Archived (*State of testbed 6 months ago?*)

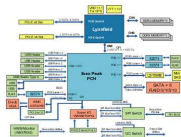


```
"processor": {
  "cache_l2": 8388608,
  "cache_l1": null,
  "model": "Intel Xeon",
  "instruction_set": "",
  "other_description": "",
  "version": "X3440",
  "vendor": "Intel",
  "cache_l1i": null,
  "cache_l1d": null,
  "clock_speed": 2530000000.0
},
"uid": "graphene-1",
"type": "node",
"architecture": {
  "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"
  }
],
```

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

► Selecting resources

- ◆ OAR database filled from JSON

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

Verification of resources

- ▶ Inaccuracies in resources descriptions \leadsto dramatic consequences:
 - ◆ Mislead researchers into making **false assumptions**
 - ◆ Generate **wrong results** \leadsto retracted publications!
- ▶ **Happen frequently**: maintenance, broken hardware (e.g. RAM)

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- ▶ Our solution: **g5k-checks**
 - ◆ Runs at node boot (can also be run manually by users)
 - ◆ Retrieves current description of node in Reference API
 - ◆ Acquire information on node using OHAI, ethtool, etc.
 - ◆ Compare with Reference API

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- ▶ **Future work** (maybe?)
 - ◆ Verification of **performance**, not just availability and configuration of hardware (hard drives, network, etc.)
 - ◆ Provide tools to capture the state of the testbed \leadsto archival with the rest of the experiment's data

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Reconfiguring the testbed

► Typical needs:

- ◆ How can I install \$SOFTWARE on my nodes?
- ◆ How can I add \$PATCH to the kernel running on my nodes?
- ◆ Can I run a custom MPI to test my fault tolerance work?
- ◆ How can I experiment with that Cloud/Grid middleware?

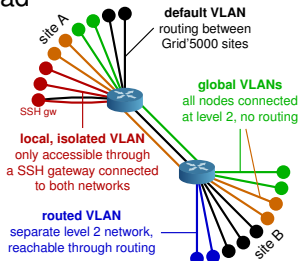
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 - ◆ How can I experiment with that Cloud/Grid middleware?
- ▶ Likely answer on any production facility: **you can't**
- ▶ Or: use virtual machines \leadsto experimental bias

Reconfiguring the testbed

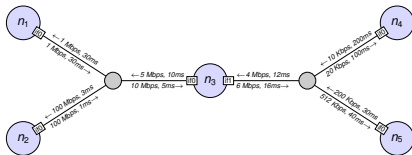
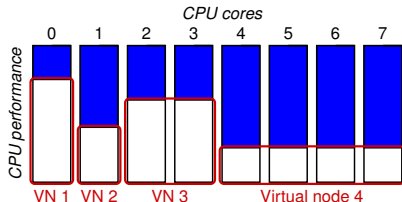
- ▶ Operating System reconfiguration with **Kadeploy**:
 - ◆ Provides a *Hardware-as-a-Service* Cloud infrastructure
 - ◆ Enable users to deploy their own software stack & get *root* access
 - ◆ **Scalable, efficient, reliable and flexible:**
200 nodes deployed in ~5 minutes (120s with Kexec)
- ▶ Customize **networking** environment with KaVLAN
 - ◆ Deploy intrusive middlewares (Grid, Cloud)
 - ◆ Protect the testbed from experiments
 - ◆ Avoid network pollution
 - ◆ By reconfiguring VLANS \leadsto almost no overhead
 - ◆ Recent work: support several interfaces

KADEPLOY



Changing experimental conditions

- Reconfigure experimental conditions with Distem
 - ◆ Introduce heterogeneity in an homogeneous cluster
 - ◆ Emulate complex network topologies



<http://distem.gforge.inria.fr/>



What else can we enable users to change?

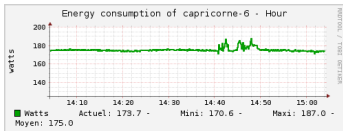
- ▶ BIOS settings
 - ◆ Power management settings
 - ◆ CPU features (Hyperthreading, Turbo mode, etc.)
- ▶ We need more crazy ideas:
 - ◆ Cooling system \leadsto temperature in the machine room?

Outline

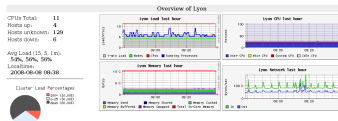
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Monitoring experiments

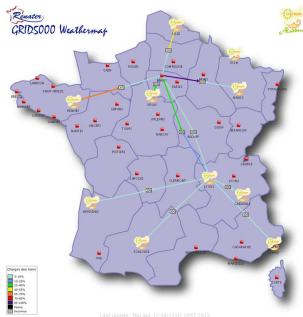
Goal: enable users to understand what happens during their experiment



Power consumption

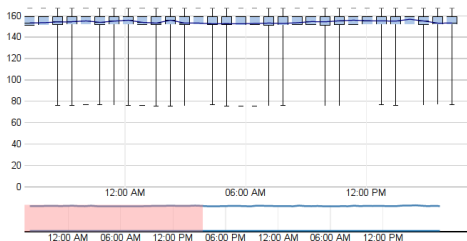


CPU – memory – disk



Exporting and analyzing data

- ▶ Unified access to monitoring tools through the Grid'5000 API
- ▶ Automatically export data during/after an experiment
- ▶ Current work: **high resolution monitoring for energy & network**



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Improving control and description of experiments

- ▶ Legacy way of performing experiments: shell commands
 - ☹ time-consuming
 - ☹ error-prone
 - ☹ details tend to be forgotten over time
- ▶ Promising solution: **automation of experiments**
 - ↪ Executable description of experiments
- ▶ Support from the testbed: Grid'5000 RESTful API
(*Resource selection, reservation, deployment*)



Tools for automation of experiments

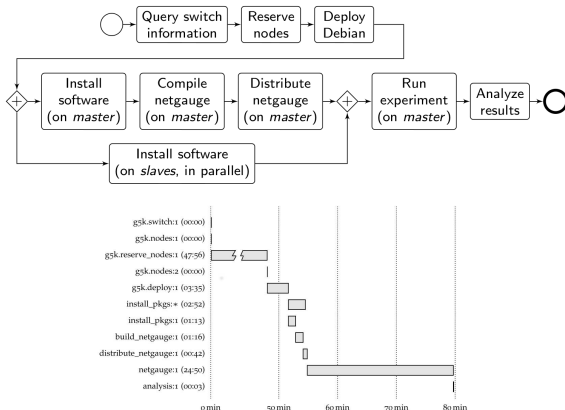
Several projects around Grid'5000 (but not specific to Grid'5000):

- ▶ **g5k-campaign** (G5K tech team)
- ▶ **Expo** (Cristian Ruiz)
- ▶ **Execo** (Mathieu Imbert)
- ▶ **XPFlow** (Tomasz Buchert)

Features:

- ▶ Facilitate scripting of experiments in high-level languages (Ruby, Python)
- ▶ Provide useful and efficient abstractions :
 - ◆ Testbed management
 - ◆ Local & remote execution of commands
 - ◆ Data management
- ▶ *Engines* for more complex processes

XPFlow



```
engine.process :exp do |site, switch|
  s = run g5k.switch, site, switch
  ns = run g5k.nodes, s
  r = run g5k.reserve_nodes,
    :nodes => ns, :time => '2h',
    :site => site, :type => :deploy
  master = (first of ns)
  rest = (tail of ns)
  run g5k.deploy,
    r, :env => 'squeeze-x64-nfs'
  checkpoint :deployed
  parallel :retry => true do
    forall rest do |slave|
      run :install_pkgs, slave
    end
  end
  sequence do
    run :install_pkgs, master
    run :build_netgauge, master
    run :dist_netgauge,
      master, rest
  end
  checkpoint :prepared
  output = run :netgauge, master, ns
  checkpoint :finished
  run :analysis, output, switch
end
```

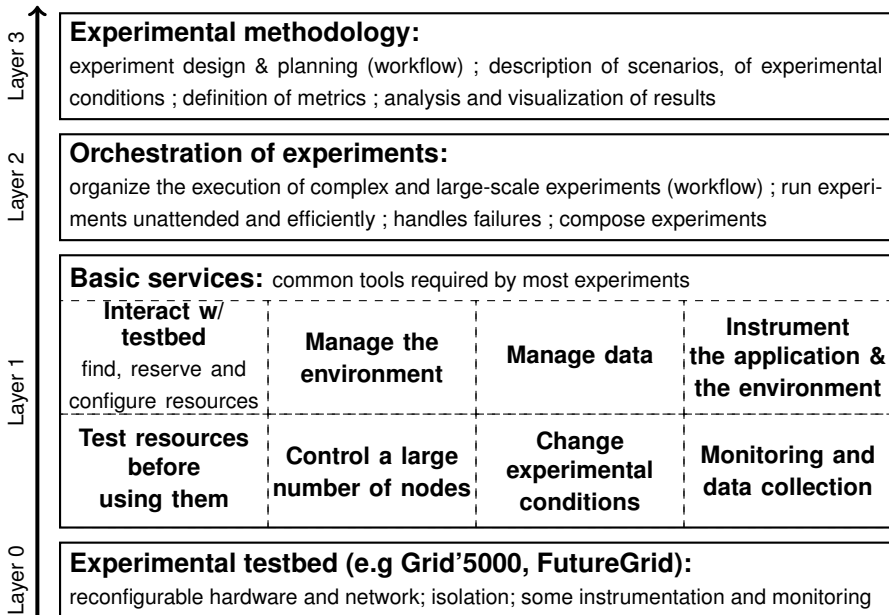
Experiment description and execution as a Business Process Workflow

Supports parallel execution of activities, error handling, snapshotting, built-in logging, etc.

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A multi-tier challenge



Conclusions

- ▶ Grid'5000: a **testbed** for high-quality, reproducible research on HPC, Clouds and Big Data
- ▶ With a **unique combination of features**
 - ◆ Description and verification of testbed
 - ◆ Reconfiguration (hardware, network)
 - ◆ Monitoring
 - ◆ Support for automation of experiments
- ▶ Paving the way to **Open Science of HPC and Cloud** – long term goals:
 - ◆ Fully automated execution of experiments
 - ◆ Automated tracking + archiving of experiments and associated data

*One could determine the age of a science by looking
at the state of its measurement tools.*

Gaston Bachelard – *La formation de l'esprit scientifique*, 1938

Bibliography

- ▶ **Resources management:**
 - ◆ Resources Description, Selection, Reservation and Verification on a Large-scale Testbed. <http://hal.inria.fr/hal-00965708>
- ▶ **Kadeploy:**
 - ◆ Kadeploy3: Efficient and Scalable Operating System Provisioning for Clusters. <http://hal.inria.fr/hal-00909111>
- ▶ **KaVLAN, Virtualization, Clouds deployment:**
 - ◆ Adding Virtualization Capabilities to the Grid'5000 testbed. <http://hal.inria.fr/hal-00946971>
 - ◆ Enabling Large-Scale Testing of IaaS Cloud Platforms on the Grid'5000 Testbed. <http://hal.inria.fr/hal-00907888>