Grid'5000 for high-quality reproducible research

Lucas Nussbaum

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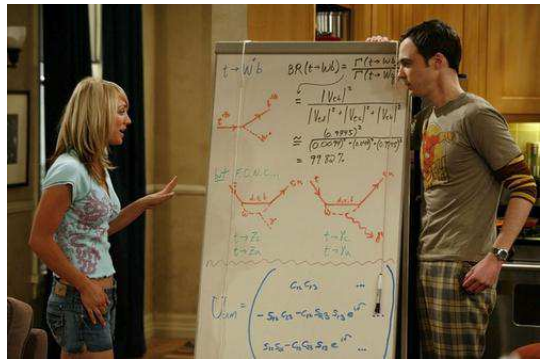
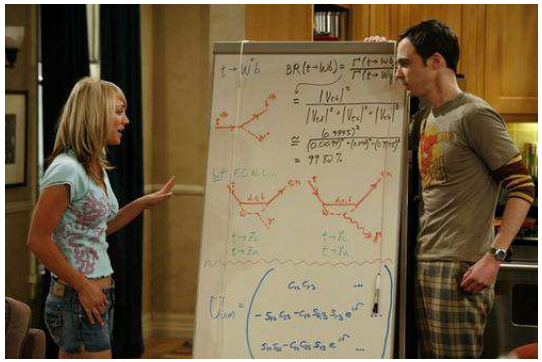
Validation in (Computer) Science

- 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 papers[1]
  - *among published CS articles in ACM journals, 40%-50% of those that require an experimental validation had none*
- 1998: survey of 612 papers[2]
  - *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]

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

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

[3] Marvin 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 conference[4]

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 research[5]
  - Most papers use an unspecified or custom simulator

[4] Study carried out by E. Jeannot.

[5] S. 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 report[6]:
    - *Several calculation errors have been identified*
    - *led to a false statistical analysis and interpretation*

[6] Opinion of the French Food Safety Agency (Afssa) on the study by Velimirov et al. entitled "*Biological effects of transgenic maize NK603xMON810 fed in long-term reproduction studies in mice*"

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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

[6] Opinion of the French Food Safety Agency (Afssa) on the study by Velimirov et al. entitled "*Biological effects of transgenic maize NK603xMON810 fed in long-term reproduction studies in mice*"

Related to the Reproducible Research movement

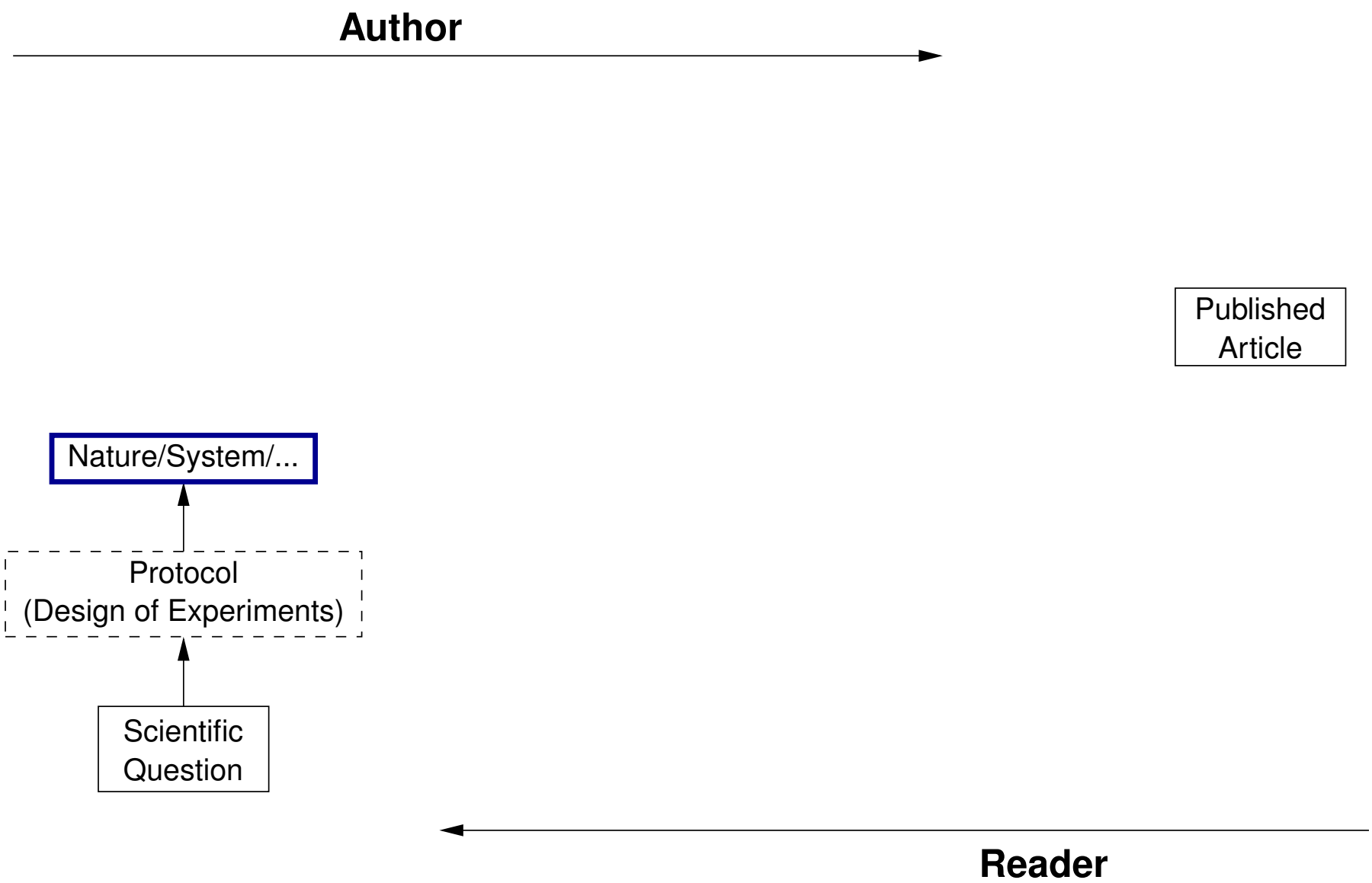
- Mostly in computational sciences
- Explores tools and methods (provenance, executable papers, etc.)
- Different types of experimental reproducibility[7]:
  - *Replications that vary little or not at all with respect to the reference experiment*

    same method, environment, parameters $\rightarrow$ same result
  - *Replications that do vary but still follow the same method as the reference experiment*

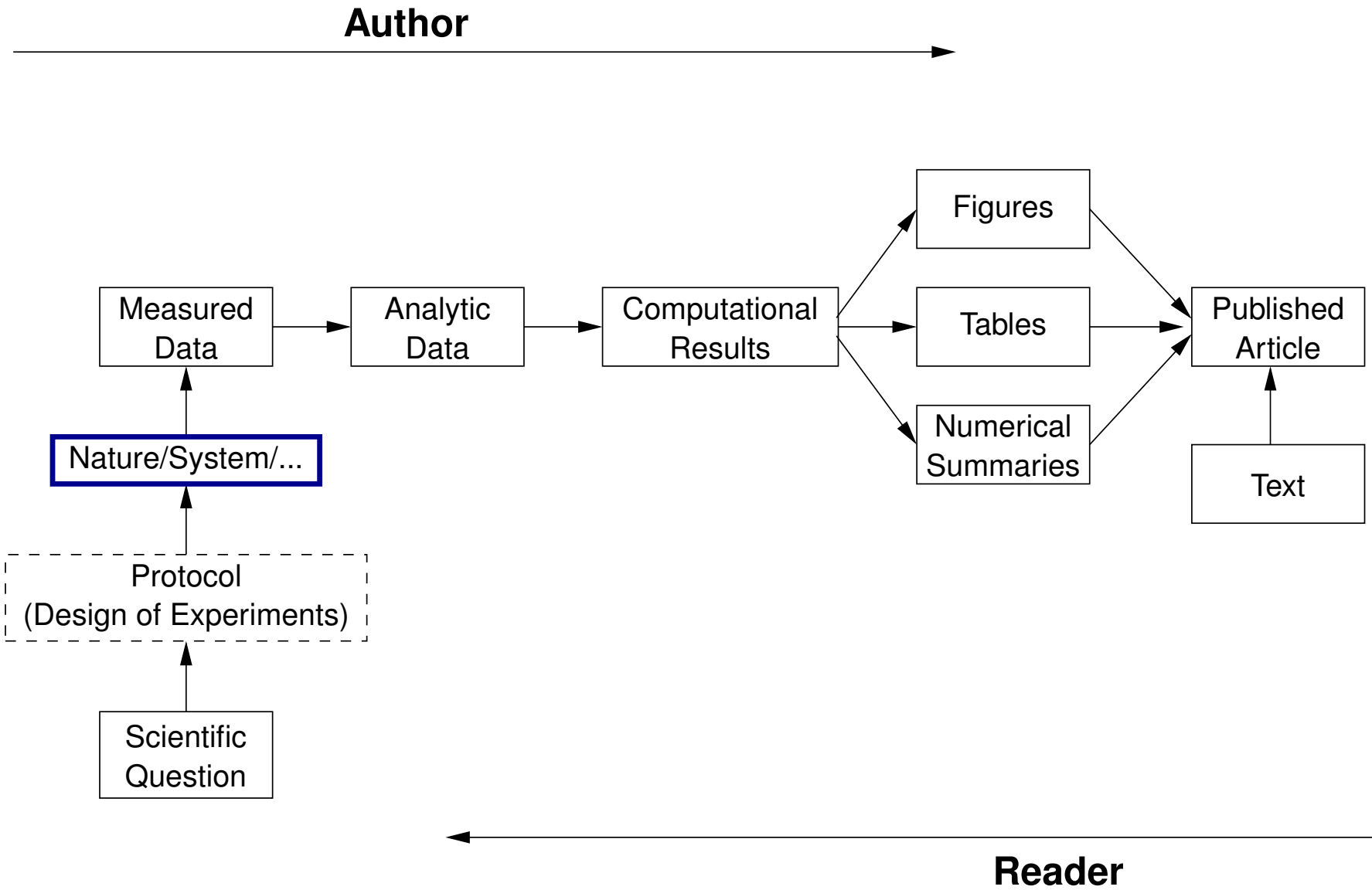
    same method, but different {env., params} $\rightarrow$ same conclusion
  - *Replications that use different methods to verify the reference experiment results*

    different method $\rightarrow$ same conclusion

[7] Omar S. Gómez et al. "Replications types in experimental disciplines". In: *ESEM'10*. 2010.



Courtesy of Roger D. Peng (Coursera lecture on reproducible research, May 2014)



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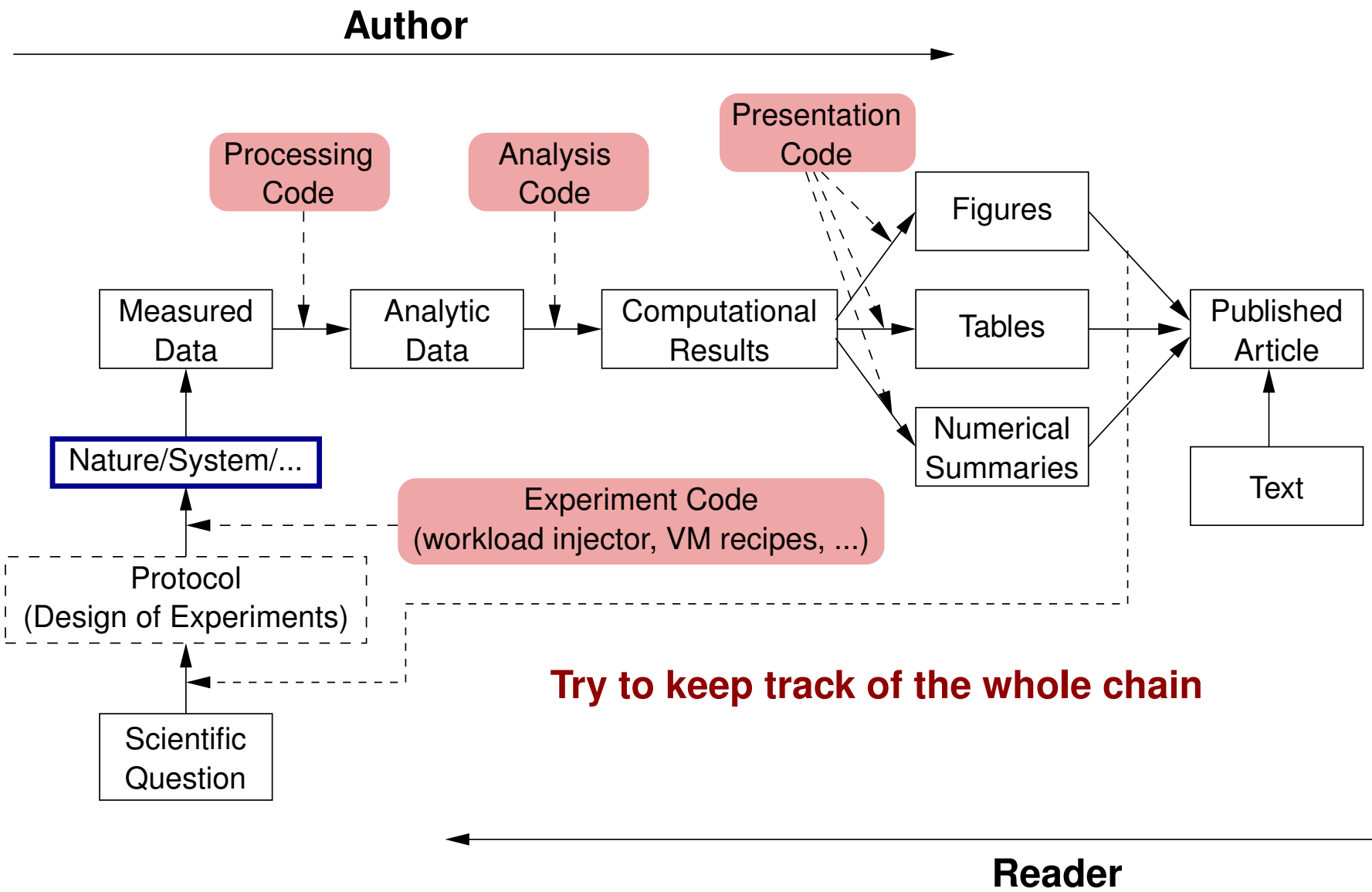

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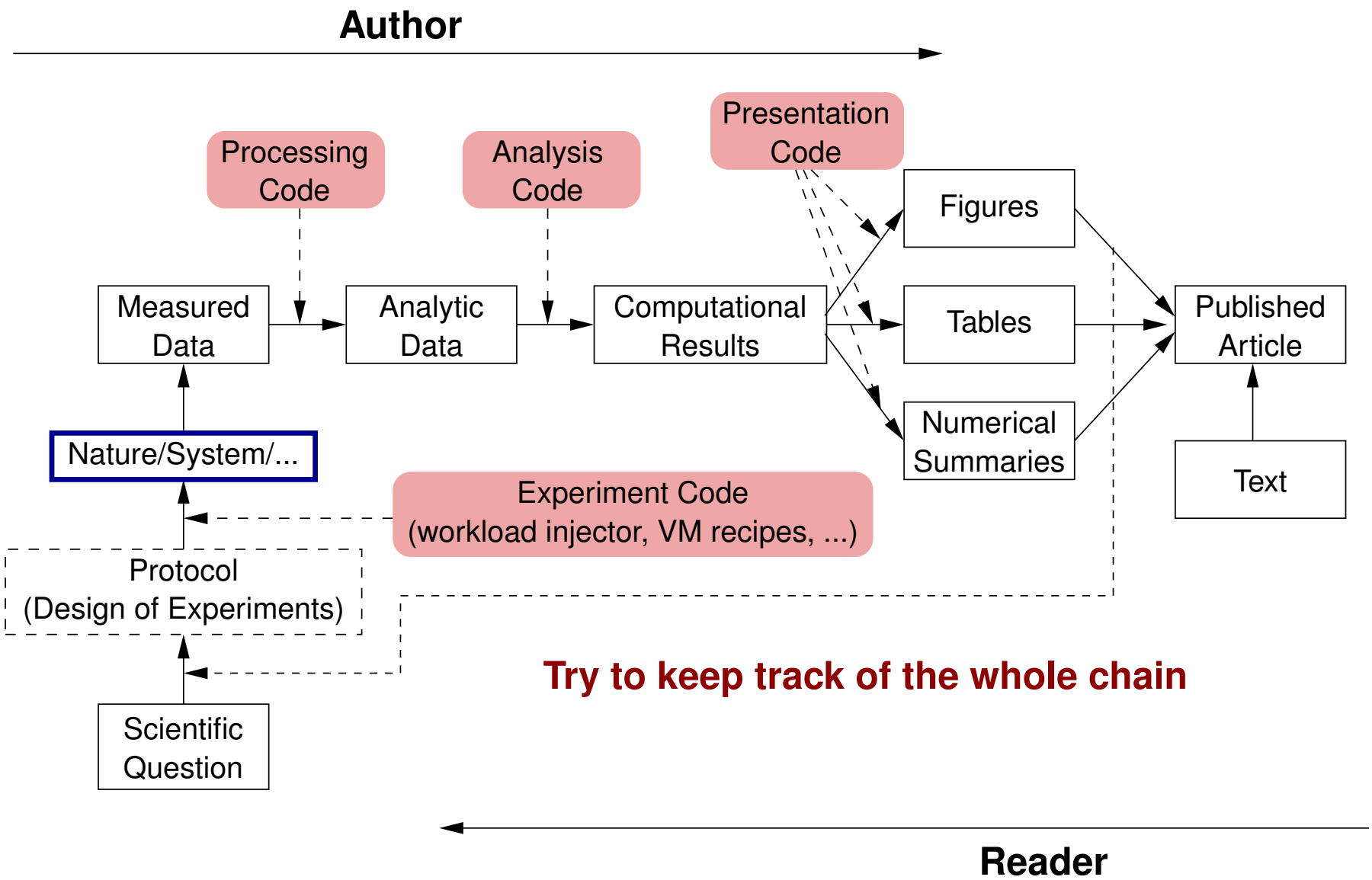

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- Grid'5000 mission: support high-quality, reproducible experiments on a distributed systems testbed

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

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?

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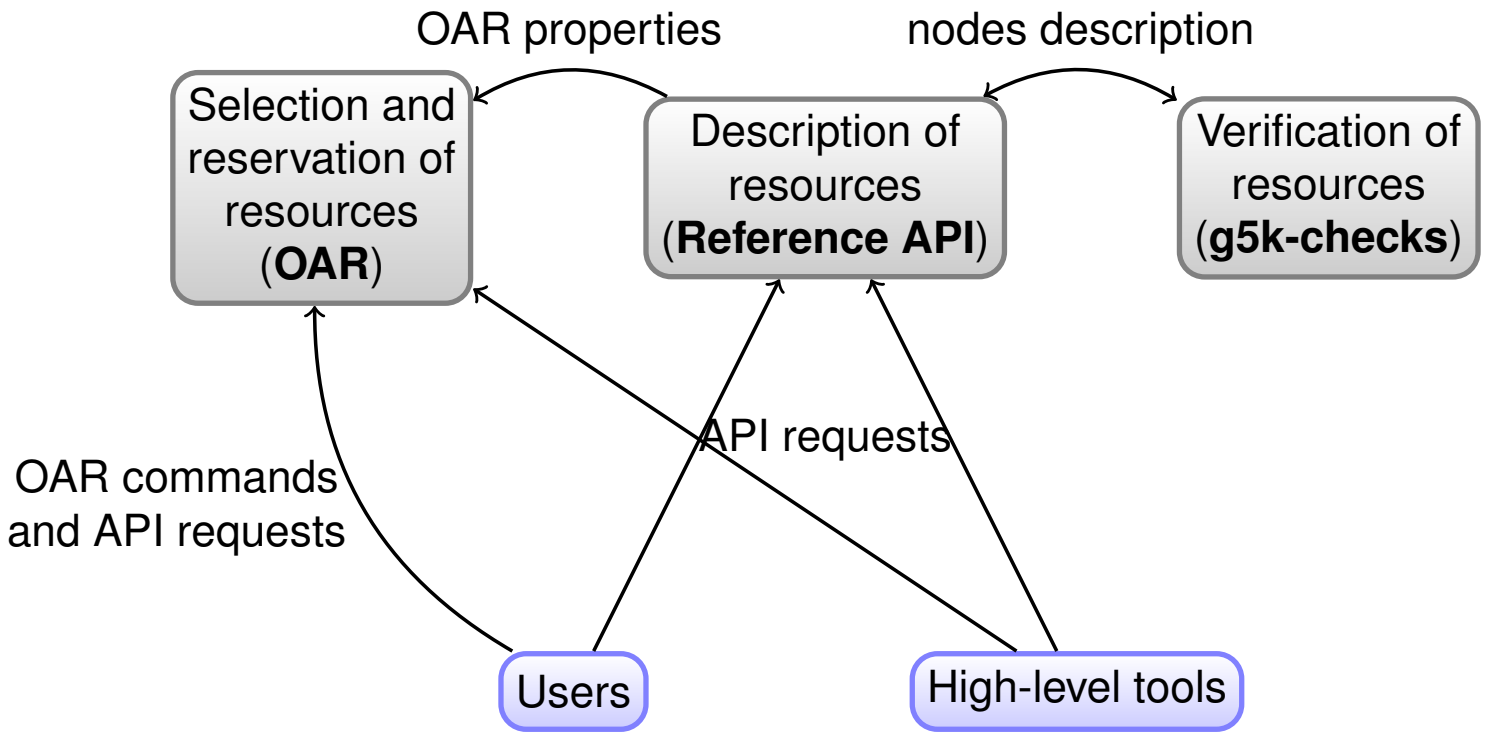
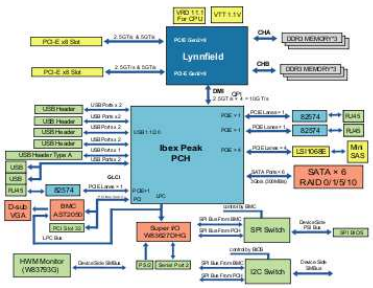
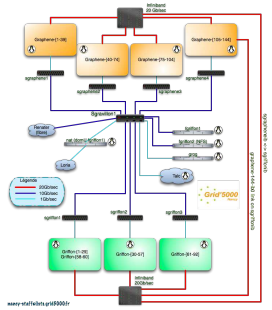


Description and selection of resources

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





```
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  "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",
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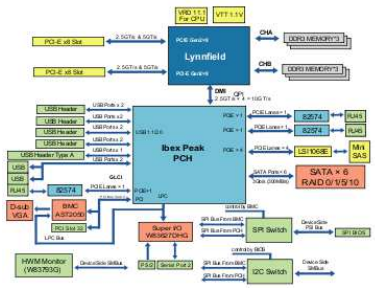

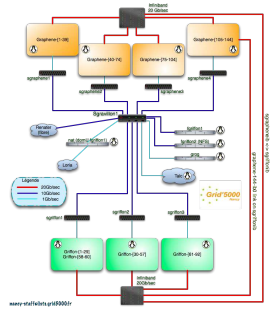


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```


- 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 $\rightsquigarrow$ dramatic consequences:
  - Mislead researchers into making false assumptions
  - Generate wrong results $\rightsquigarrow$ 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
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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 $\rightsquigarrow$ archival with the rest of the experiment's data

Outline

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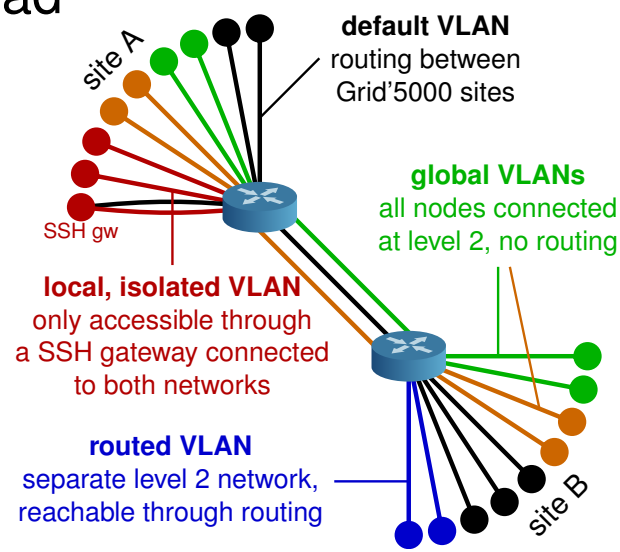
  - How can I experiment with that Cloud/Grid middleware?
- Likely answer on any production facility: **you can't**
- Or: use virtual machines $\leadsto$ experimental bias

Reconfiguring the testbed

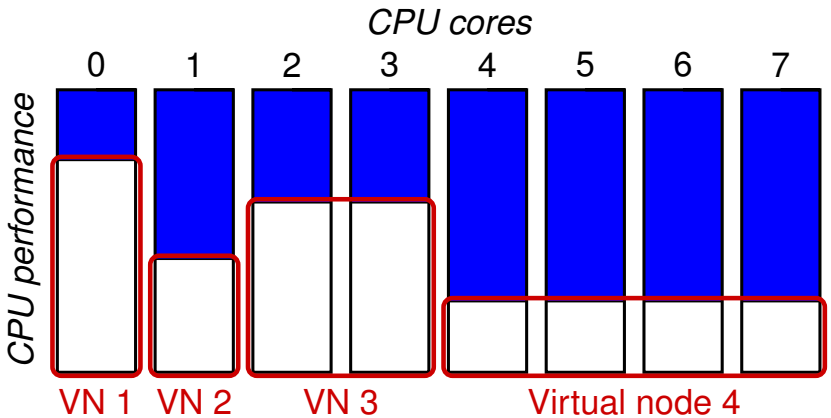
- Operating System reconfiguration with Kadeploy:
  - Provides a *Hardware-as-a-Service* Cloud infrastructure
  - Enable users to deploy their own software stack & get *root* access
  - **Scalable, efficient, reliable and flexible**:
    200 nodes deployed in ~5 minutes (120s with Kexec)
- Customize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

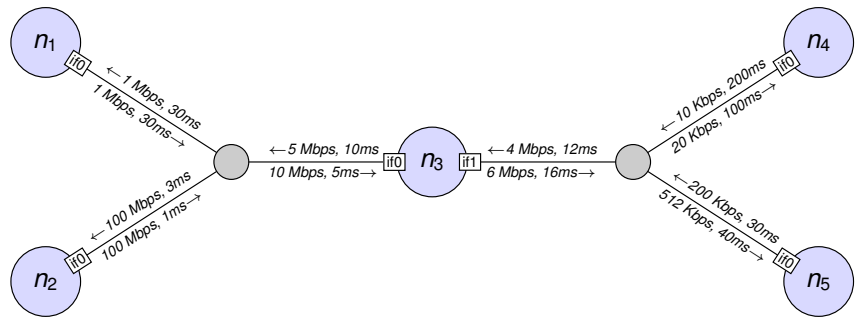
KADEPLOY



Changing experimental conditions

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





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

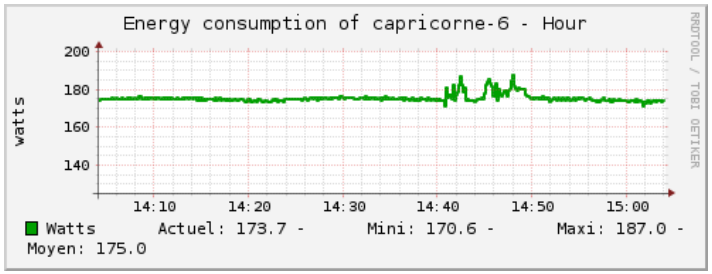
What else can we enable users to change?

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

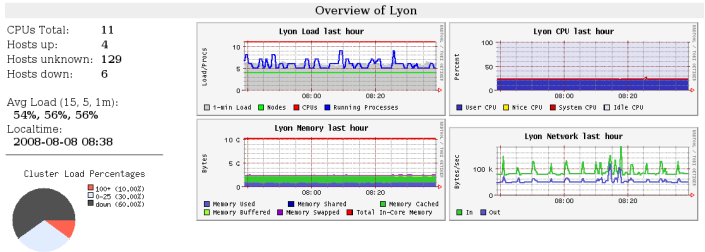
Outline

Monitoring experiments

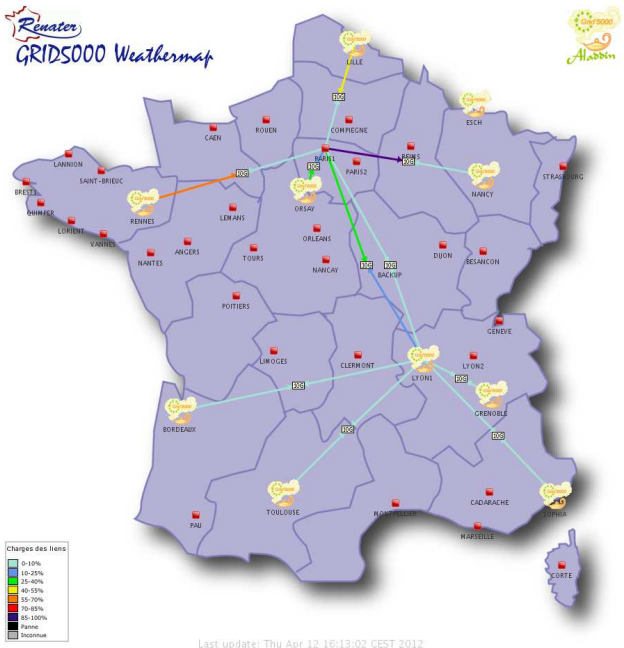
Goal: enable users to understand what happens during their experiment



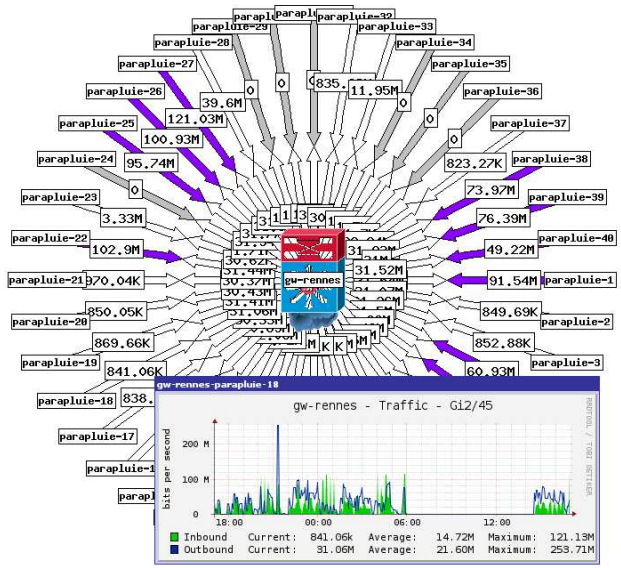
Power consumption



CPU – memory – disk



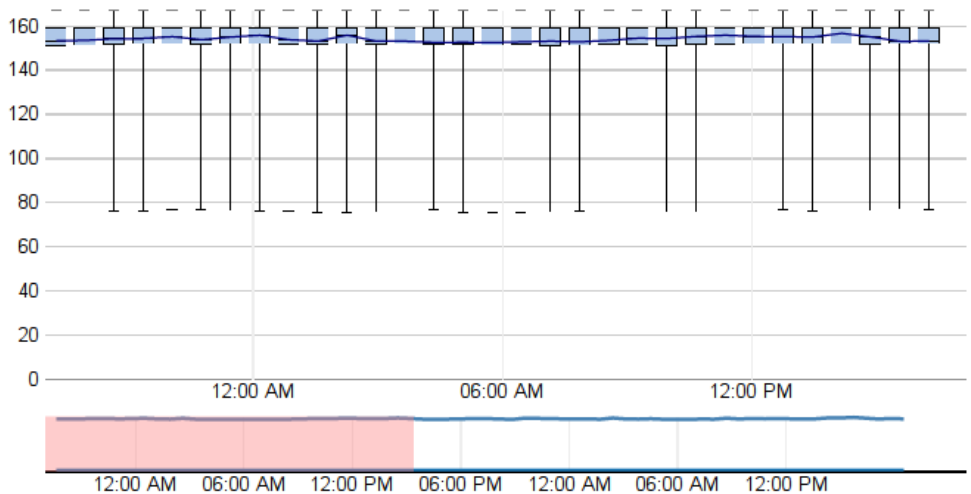
Network backbone



Internal networks

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



Outline

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
  $\rightsquigarrow$ Executable description of experiments
- Support from the testbed: Grid'5000 RESTful API
  (Resource selection, reservation, deployment)

Tools for automation of experiments

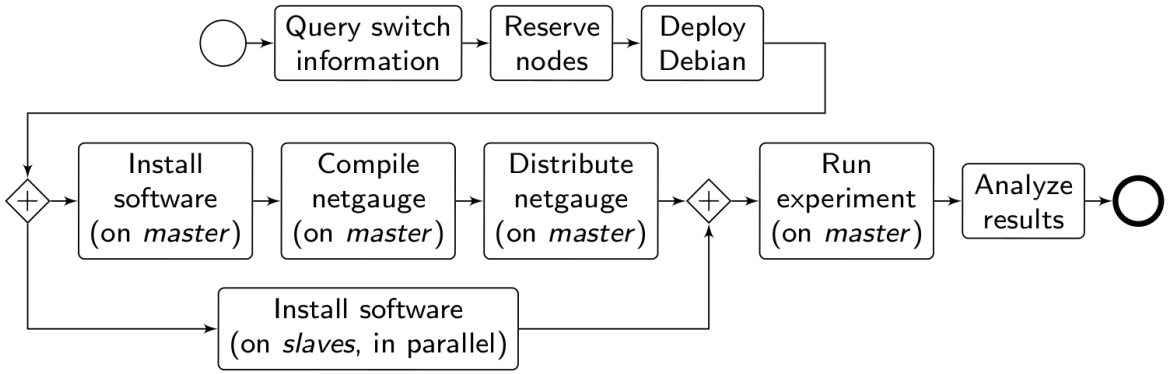
Several projects around Grid'5000 (but not specific to Grid'5000):

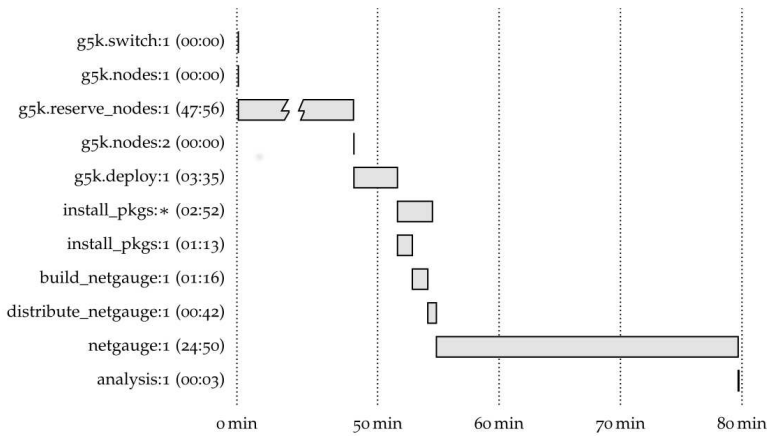
- g5k-campaign (G5K tech team)
- Expo (Cristian Ruiz)
- Execo (Mathieu Imbert)
- XPFlow (Tomasz Buchert)

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
        sequence do
            run :install_pkgs, master
            run :build_netgauge, master
            run :dist_netgauge,
                master, rest
        end
    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.

Outline

A multi-tier challenge

Layer 3

Experimental methodology:
experiment design & planning (workflow) ; description of scenarios, of experimental conditions ; definition of metrics ; analysis and visualization of results

Layer 2

Orchestration of experiments:
organize the execution of complex and large-scale experiments (workflow) ; run experiments unattended and efficiently ; handles failures ; compose experiments

Layer 1

Basic services: common tools required by most experiments

Interact w/ testbed find, reserve and configure resources	**Manage the environment**	**Manage data**	**Instrument the application & the environment**
Test resources before using them	**Control a large number of nodes**	**Change experimental conditions**	**Monitoring and data collection**

Layer 0

Experimental testbed (e.g Grid'5000, FutureGrid):
reconfigurable hardware and network; isolation; some instrumentation and monitoring

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

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- 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