Grid'5000

a testbed for reproducible research on HPC, Clouds, Big Data and Networking

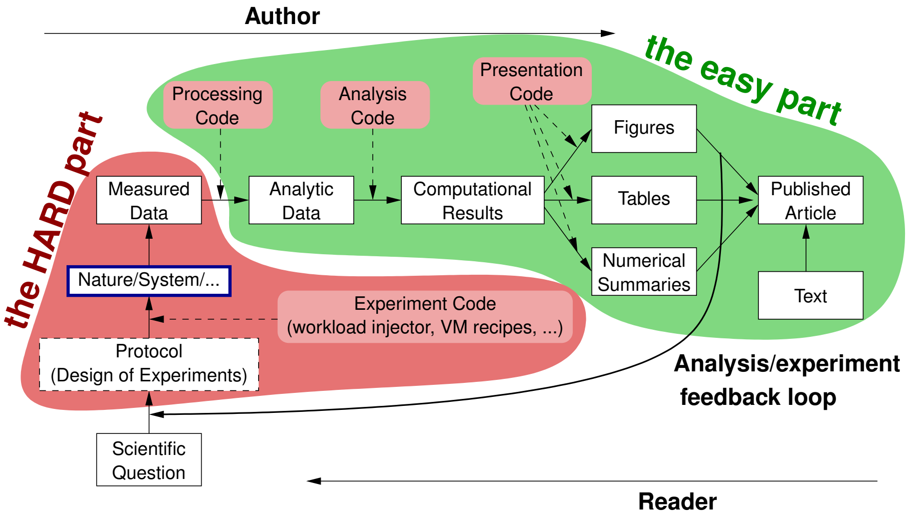
Lucas Nussbaum

With the Grid'5000 architects committee and the Grid'5000 technical team

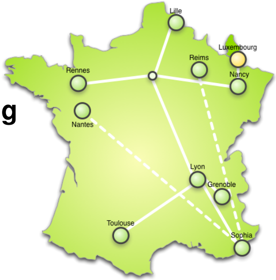
Distributed computing: a peculiar field in CS

- Most contributions are validated using experiments
  - Very little formal validation
  - Even for theoretical work $\rightsquigarrow$ simulation (SimGrid)
- Performance and scalability are central to results
  - But depend greatly on the environment (hardware, network, software stack, etc.)
  - Many contributions are about *fighting* the environment (load balancing, fault tolerance, middlewares, etc.)
- Experimenting is difficult and time-consuming
- Shifts the scope for reproducible research:
  - **How can one perform *reproducible* experiments?**
  - Very similar to (not computational) biology or physics

Research pipeline in experimental DC research



The Grid'5000 testbed



- **World-leading testbed for distributed computing**
  - 10 sites, 25 clusters, 1000 nodes, 8000 cores
  - Dedicated 10-Gbps backbone network
  - 550 users and 100 publications per year

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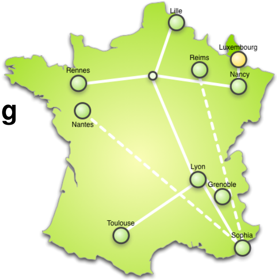

- **World-leading testbed for distributed computing**
  - 10 sites, 25 clusters, 1000 nodes, 8000 cores
  - Dedicated 10-Gbps backbone network
  - 550 users and 100 publications per year
- Not a typical grid / cluster / Cloud, more a meta-grid, meta-cloud:
  - Used by CS researchers in HPC / Clouds / Big Data / Networking to perform experiments
  - **Design goals:**
    - **Large-scale, shared infrastructure**
    - **Support high-quality, reproducible research**

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. Evaluating current experimental practices
7. 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?

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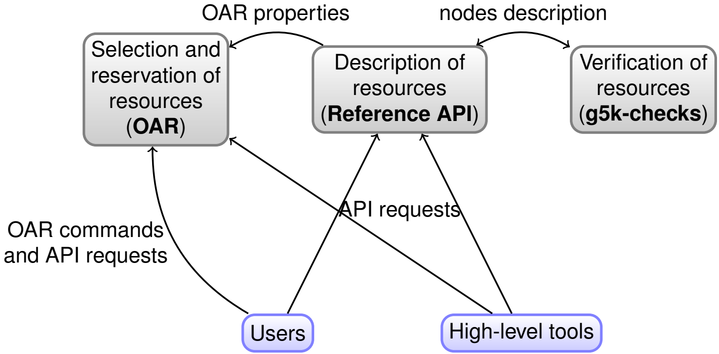
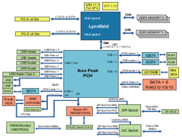
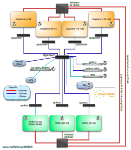

OAR properties
nodes description
Selection and reservation of resources (**OAR**)
Description of resources (**Reference API**)
Verification of resources (**g5k-checks**)
API requests
OAR commands and API requests
Users
High-level tools

Description and selection of resources

- Describing resources ⇝ 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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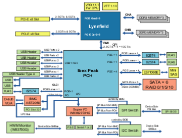
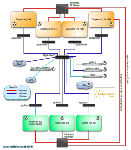
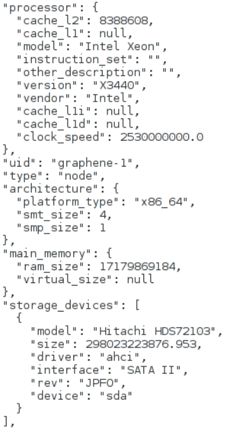




- Selecting resources
  - OAR database filled from JSON

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



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},
"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,
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    "interface": "SATA II",
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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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  - Compare with Reference API
- Future work
  - Verification of performance, not just availability and configuration of hardware (hard drives, network, etc.)
  - Provide tools to capture the state of the testbed ⇝ 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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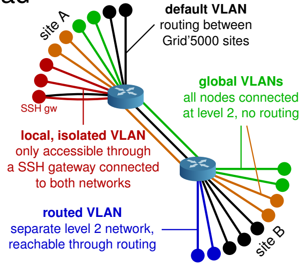
- Likely answer on any production facility: **you can't**
- Or: use virtual machines $\leadsto$ experimental bias (performance), limitations

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



default VLAN
routing between
Grid'5000 sites

global VLANs
all nodes connected
at level 2, no routing

local, isolated VLAN
only accessible through
a SSH gateway connected
to both networks

routed VLAN
separate level 2 network,
reachable through routing

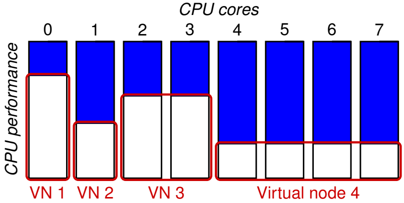
Creating and sharing Kadeploy images

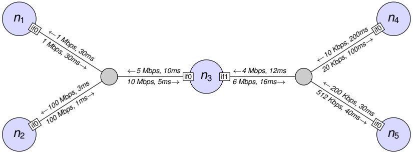
- Avoid manual customization:
  - Easy to forget some changes
  - Difficult to describe
  - The full image must be provided
  - Cannot really reserve as a basis for future experiments (similar to binary vs source code)
- Kameleon: Reproducible generation of software appliances
  - Using *recipes* (high-level description)
  - Persistent cache to allow re-generation without external resources (Linux distribution mirror) $\leadsto$ self-contained archive
  - Supports Kadeploy images, LXC, Docker, VirtualBox, qemu, etc.

http://kameleon.imag.fr/

Changing experimental conditions

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

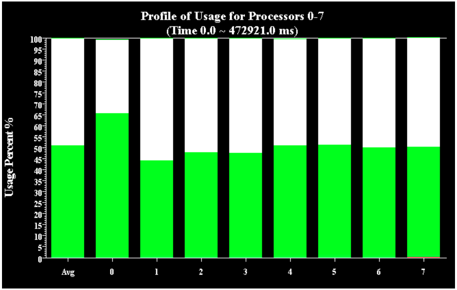




http://distem.gforge.inria.fr/

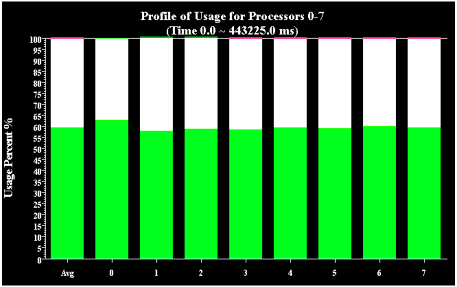
Testing Charm++ load balancing with Distem

No load balancing



total run time: 473s
Average CPU usage: 51%

RefineLB



total run time: 443s
Average CPU usage: 59%

- Every 2 minutes, 1/8 of the nodes are downclocked for 2 minutes
- On the figure, node 0 has been downclocked
- Visible improvement thanks to load balancing

What else can we enable users to change?

- BIOS settings
  - Power management settings
  - CPU features (Hyperthreading, Turbo mode, etc.)
- Cooling system $\rightsquigarrow$ temperature in the machine room?

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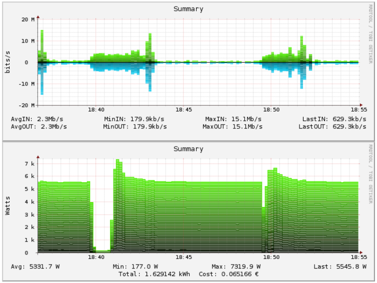
Monitoring experiments

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



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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
  $\leadsto$ Executable description of experiments

- Support from the testbed: Grid'5000 RESTful API
  (Resource selection, reservation, deployment, monitoring)

Tools for automation of experiments

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

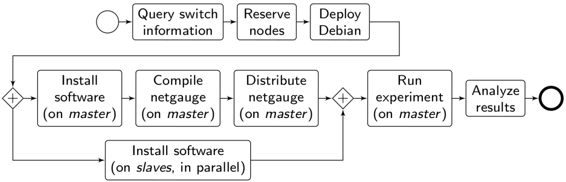
- g5k-campaign (Grid'5000 tech team)
- Expo (Cristian Ruiz)
- Execo (Mathieu Imbert)
- XPFlow (Tomasz Buchert)

Features:

- Facilitate scripting of experiments in high-level languages (Ruby, Python)
- Provide useful and efficient abstractions :[1]
  - Testbed management
  - Local & remote execution of commands
  - Data management
- *Engines* for more complex processes

[1] Tomasz Buchert et al. "A survey of general-purpose experiment management tools for distributed systems". In: *Future Generation Computer Systems* 45 (2015), pages 1–12. DOI: `10.1016/j.future.2014.10.007`. URL: `https://hal.inria.fr/hal-01087519`.

XPFlow



Query switch information

Reserve nodes

Deploy Debian

Install software (on *master*)

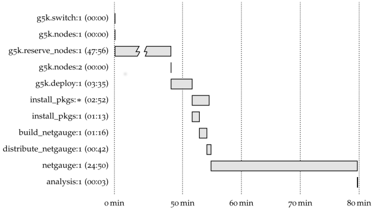
Compile netgauge (on *master*)

Distribute netgauge (on *master*)

Run experiment (on *master*)

Analyze results

Install software (on *slaves*, in parallel)



```
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 and provenance collection, etc.

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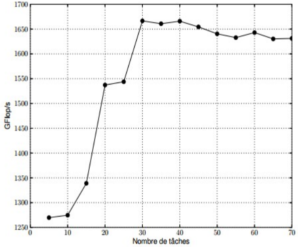
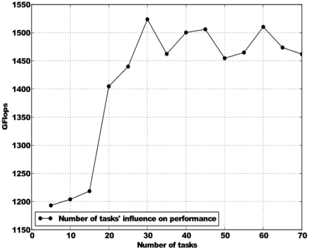
Realis: evaluating current experimental practices

- COMPAS: Conférence en Parallélisme, Architecture et Système
  - French-speaking, mostly for PhD students
- Realis: test reproducibility of papers submitted to COMPAS
  - Participating authors submit their experimentation description
  - Each author reproduces the experiments from another article
    - Try to get identical results, without contacting the authors
    - Evaluate the quality (flexibility, robustness) of the approach
- Most results can be reproduced (but none without contacting the authors)





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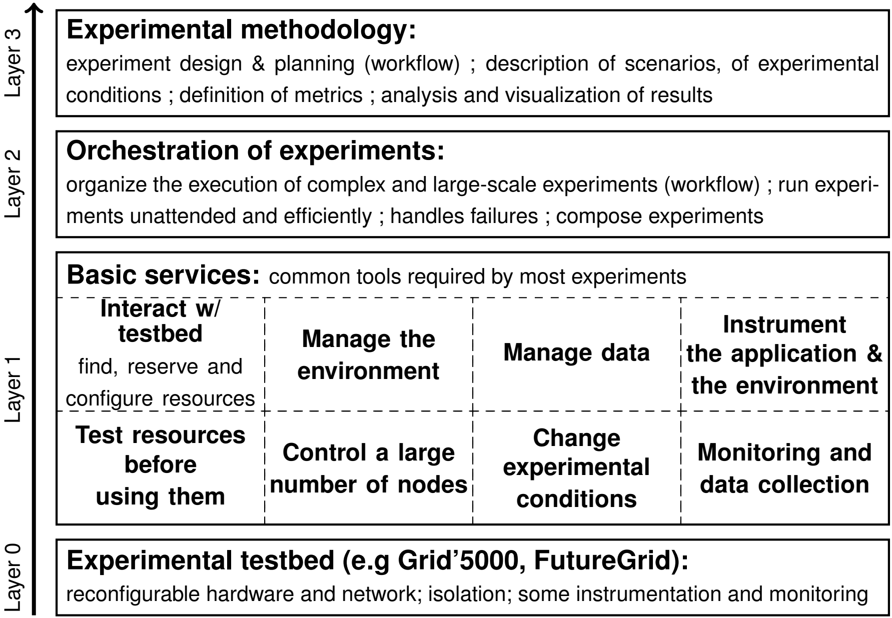
A multi-tier challenge



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

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

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**

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, Big Data and Networking
- 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 – mid term goals:
  - Fully automated execution of experiments ($\approx$ CI in SE)
  - Automated tracking + archiving of experiments and associated data
- Try it yourself! $\rightsquigarrow$ Open Access program

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`
- Kameleon: Reproducible Software Appliances for Experimentation. `https://hal.inria.fr/hal-01064825`
- Distem: Design and Evaluation of a Virtual Experimental Environment for Distributed Systems. `https://hal.inria.fr/hal-00724308`
- XP management tools:
  - A survey of general-purpose experiment management tools for distributed systems. `https://hal.inria.fr/hal-01087519`
  - XPFlow: A workflow-inspired, modular and robust approach to experiments in distributed systems. `https://hal.inria.fr/hal-00909347`
  - Using the EXECO toolbox to perform automatic and reproducible cloud experiments. `https://hal.inria.fr/hal-00861886`
  - Expo: Managing Large Scale Experiments in Distributed Testbeds. `https://hal.inria.fr/hal-00953123`
- Kwapi: A Unified Monitoring Framework for Energy Consumption and Network Traffic. `https://hal.inria.fr/hal-01167915`
- Realis'2014: Reproductibilité expérimentale pour l'informatique en parallélisme, architecture et système. `https://hal.inria.fr/hal-01011401`