GREEN ICT

Anne-Cécile Orgerie

Lecture, INSA Rennes
18th November 2019, Rennes

Who I am

- Full-time researcher at CNRS (about 33,000 people)
- Located in Rennes, France.
- IRISA laboratory (about 1000 people)
- Myriads team: INRIA, CNRS, University of Rennes, INSA, ENS Rennes (about 30 people)
- Energy efficiency in large-scale distributed systems

http://www.people.irisa.fr/Anne-Cecile.Orgerie

Green Computing?

"Designing, manufacturing, using, and disposing of computers, servers, and associated subsystems -- such as monitors, printers, storage devices, and networking and communications systems -- efficiently and effectively with minimal or no effect on the environment."

Sam Murugesan, "*Harnessing Green IT: Principles and Practices*" IEEE IT Professional, 2008.

- Green use: reduce usage of hazardous materials
- Green design: design compliant with the environment
- Green disposal: recycling e-waste with little impact
- Green manufacturing: new products without hazardous substances

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Outline

I. **Introduction to (not) green ICT**

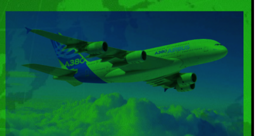
II. **Trails to green ICT from my research point of view**

A. Inside data centers
B. Powering data centers
C. Green computing history
D. Cooling data centers
E. Understanding energy consumption
F. Reducing energy consumption

III. **Concluding remarks**

ICT is not green

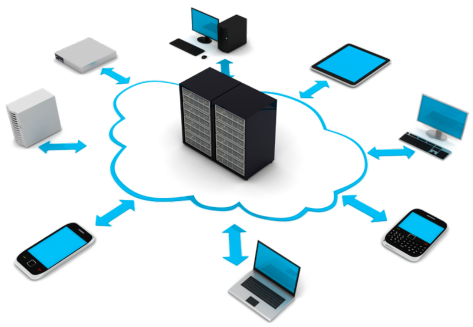
ICT is responsible for 2% to 10% of CO2 emissions



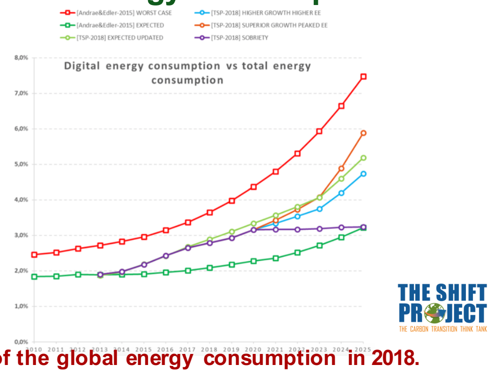
M. Mills. The Cloud Begins With Coal - Big Data, Big Networks, Big Infrastructure, and Big Power. Technical report, Digital Power Group, Aug 2013.

Computing in the 21st century?

The Cloud



ICT's energy consumption



3% of the global energy consumption in 2018.

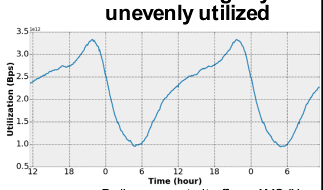
Resource waste

Servers are used 6% on average.

Source: *Revolutionizing Data Center Energy Efficiency*, McKinsey, Juillet 2008.

Virtualization to the rescue.

Networks are lightly of unevenly utilized



Daily aggregated traffic on AMS-IX (Amsterdam InterneteXchange Point), July 2015.

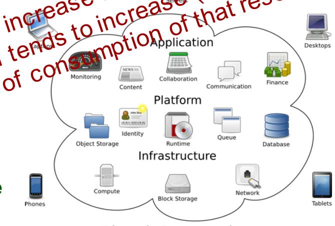
Cloud computing in 1 slide

Cloud computing: access through networks to on-demand self-service, configurable, shared computing resources.

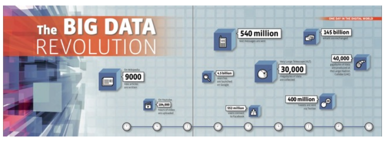
- Mutualization of services
- Elasticity of infrastructures
- Externalization of data

Jevons Paradox: *the increase in efficiency with which resource is used tends to increase (rather than decrease) the rate of consumption of that resource.*

↳ **Economies of scale**



Can we save ICT…



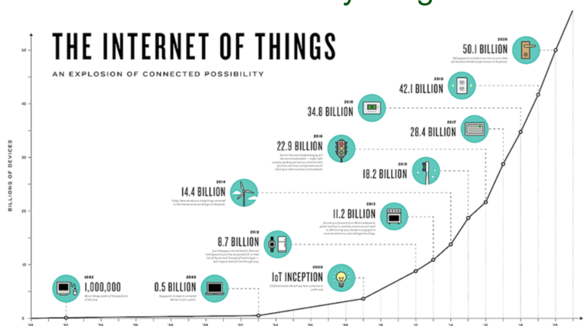
"The Big Data revolution", CNRS International Magazine, 2013.

For one day in 2013:
- 145 billion exchanged emails
- 4.5 billion searches on Google
- 104,000 hours of video uploaded on Youtube
- 9,000 new articles written on Wikipedia

- 30,000 MB of data collected by the Very Large Telescope (VLT)
- 40,000 GB of data produced by the Large Hadron Collider (LHC)

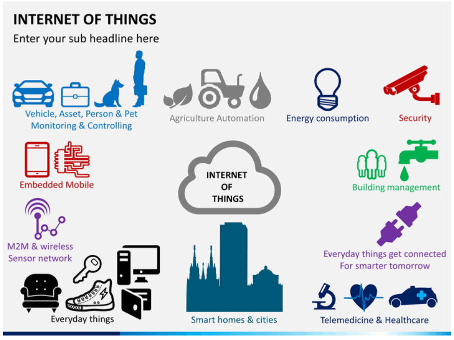
… without changing users' habits

Internet of many things



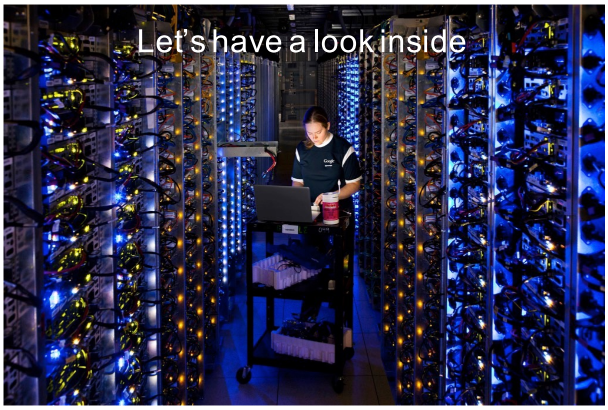
Source: Cisco

Practical Internet of Things



Anne-Cécile Orgerie http://www.supinfo.com/articles/single/4235-internet-of-things *13*

Let's have a look inside



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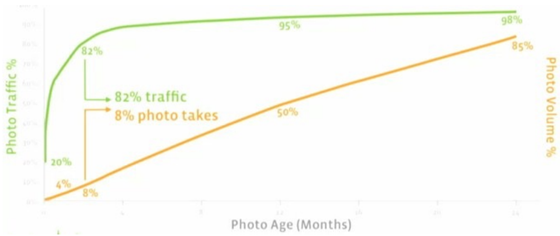
Access pattern of Facebook photos



Traffic vs. age of the photos
82% of traffic pulling photos out is only accessing 8% of the capacity
-> 92% can be stored on slower, lower-powered disk arrays

http://www.enterprisetech.com/2013/10/25/facebook-loads-innovative-cold-storage-datacenter/

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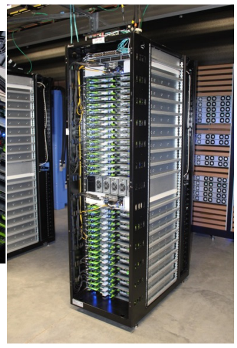
Cold storage @ Facebook



Source: http://www.enterprisetech.com/2013/10/25/
facebook-loads-innovative-cold-storage-datacenter/

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One Google Data Center (Dalles)

11,5 football fields
100,000 servers

100 MWatts

https://www.google.com/about/datacenters/inside/locations/the-dalles/

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UPS to the rescue

Uninterruptible power supply:

- Emergency power system
- Used to protect hardware from power disruption
- Supplies energy stored in batteries, supercapacitors of flywheels (converted into alternating current)

But only for few minutes!

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And then?

Engine-generator

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OVH example

Roubaix site: ~ 10,000 servers

8 MVA at max: 1,600L/h of oil

Tests: every 2-3 weeks

https://lafibre.info/ovh-datacenter/test-de-groupes/

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Other data centers

http://www.datacentermap.com/blog/datacenter-container-55.html

https://news.microsoft.com/features/microsoft-research-project-puts-cloud-in-ocean-for-the-first-time/#sm.0000q5ts4lqgfez110wem1gb0ig5o

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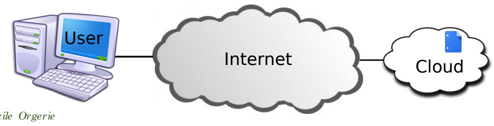
Inside the cloud



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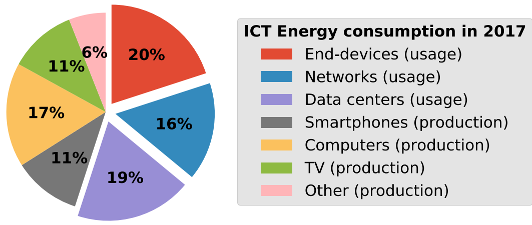
Distribution of ICT energy consumption



RapportLean ICT : Pour une sobriété Numérique, 2018
https://theshiftproject.org

THE SHIFT PROJECT
THE CARBON TRANSITION THINK TANK

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CO2 impact

LES ÉMISSIONS DE GAZ À EFFET DE SERRE GÉNÉRÉES PAR LE NUMÉRIQUE

25 % dues aux data centers

28 % dues aux infra-structures réseau

47 % dues aux équipements des consommateurs (ordinateurs, smartphones, tablettes, objets connectés, GPS…)

15 000 km

c'est la distance moyenne parcourue par une donnée numérique (mail, téléchargement, vidéo, requête web…)

INTERNET AU NIVEAU MONDIAL

- 9 milliards d'appareils
  - 2 milliards de smartphones
  - 1 milliard d'ordinateurs
  - 5 à 7 milliards d'objets connectés
- 45 millions de serveurs
- 800 millions d'équipements réseaux (routeurs, box ADSL…)

En 1 heure

- 8 à 10 milliards de mails échangés (hors spam)
- 180 millions de recherches Google

Prévision 2020

- 50 milliards d'objets connectés

Source: ADEME, Oct. 2019.

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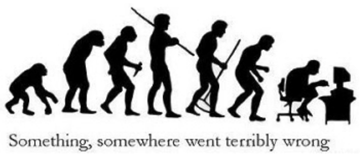
Green computing history



First eco-labels

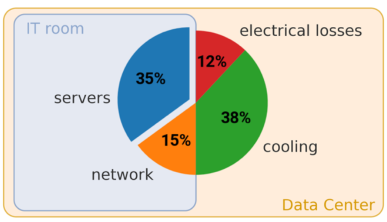
- Energy Star: international standard for energy efficient consumer products
  - 1992, USA
  - Voluntary labeling program
  - To promote energy-efficient monitors, climate control equipment and other technologies
  - Main result: sleep mode
- TCO certification
  - 1992, Sweden
  - To promote low magnetic and electrical emissions from CRT-based computer displays

Specific eco-labels

- 80 Plus: voluntary certification program to promote efficient energy use in computer power supply units (2004):
  - More than 80% energy efficiency at 20%, 50% and 100% of rated load
  - Power factor of 0.9 or greater at 100% load
  - 80 Plus Titanium : 90% energy efficient
- RoHS: Restriction of Hazardous Substances Directive (2003):
  - Adopted in 2003, effective in 2006 in EU
  - Restricted use of six materials

Data center level

Where is electricity consumed? Data center example



J. Ni and X. Bai, "A Review of Air Conditioning Energy Performance in Data Centers", 2017

Great part consumed by facilities

→ Cooling accounts for 30-50% of the total value

Let's reduce the heat

- Water-based cooling

https://www.datacenterknowledge.com/archives/2012/12/11/defense-department-cool-servers-with-hot-water

Let's reduce the heat

- Oil-based cooling

Green Revolution Cooling, https://www.grcooling.com

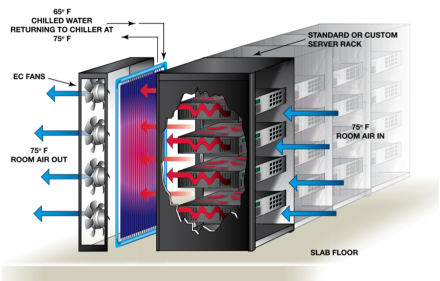
Let's reduce the heat

- Free cooling

https://www.google.com/about/datacenters/inside/locations/hamina/

Water-cooled doors

- Hybrid cooling



Exploded View of Chilled Door®

https://www.monman.com/motivair-chilled-door-rack-cooling-details

Water required!

Water tanks

Capacity:
900,000 liters

Google data center in South Carolina, US

https://www.google.com/about/datacenters/gallery/index.html#/tech/19

Water pipes

[Source : https://www.google.com/about/datacenters/gallery/index.html#/tech/19]

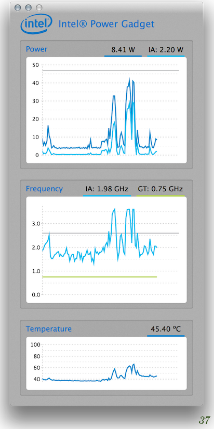
Understanding energy consumption

- Mandatory to optimize the energy consumption of a resource or an application
- Mandatory to simulate or emulate energy consumption
- Other usages:
  - monitoring,
  - forecasting,
  - accounting...

Grid'5000

Intel Power Gadget

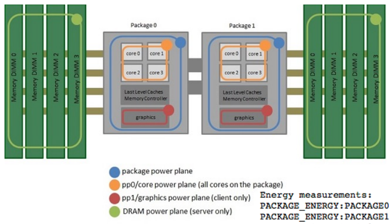
https://software.intel.com/en-us/articles/intel-power-gadget-20



Without wattmeters

PAPI (Performance Application Programming Interface) can read RAPL (Running Average Power Limit) values

- Uses software power model, hardware performance counters, temperature, leakage models and I/O models

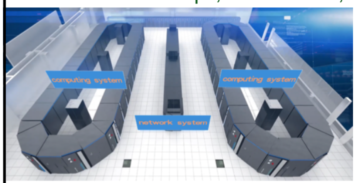


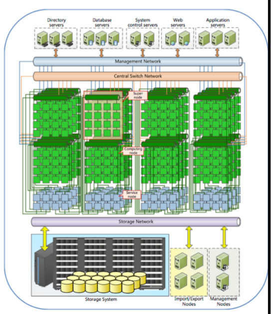

```
Energy measurements:
PACKAGE_ENERGY:PACKAGE0    176.450363J   (Average Power 42.9W)
PACKAGE_ENERGY:PACKAGE1     75.812454J   (Average Power 18.4W)
DRAM_ENERGY:PACKAGE0        11.899246J   (Average Power 2.9W)
DRAM_ENERGY:PACKAGE1         8.341141J   (Average Power 2.0W)
PP0_ENERGY:PACKAGE0        118.029236J   (Average Power 28.7W)
PP0_ENERGY:PACKAGE1         16.759064J   (Average Power 4.1W)
```


Supercomputers

N° 3: Sunway TaihuLight

94 Petaflops, 15.27 MW, **10,649,600 cores**





"Report on the Sunway TaihuLight System", J. Dongarra, Tech Report UT-EECS-16-742, 2016.

Typical applications:
- Atmospheric simulations
- Global surface wave simulations
- Phase-field simulations

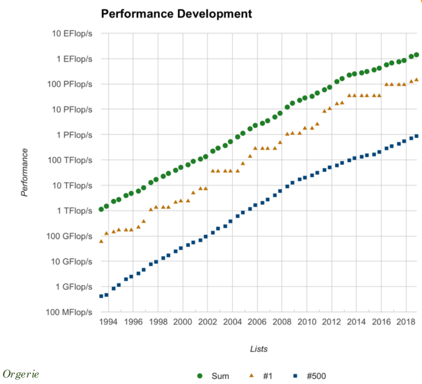
http://www.netlib.org/utk/people/JackDongarra/PAPERS/sunway-report-2016.pdf

Top500

Rank	System	Cores	Rmax (TFlop/s)	Rpeak (TFlop/s)	Power (kW)
1	**Summit** - IBM Power System AC922, IBM POWER9 22C 3.07GHz, NVIDIA Volta GV100, Dual-rail Mellanox EDR Infiniband , IBM DOE/SC/Oak Ridge National Laboratory United States	2,397,824	143,500.0	200,794.9	9,783
2	**Sierra** - IBM Power System S922LC, IBM POWER9 22C 3.1GHz, NVIDIA Volta GV100, Dual-rail Mellanox EDR Infiniband , IBM / NVIDIA / Mellanox DOE/NNSA/LLNL United States	1,572,480	94,640.0	125,712.0	7,438
3	**Sunway TaihuLight** - Sunway MPP, Sunway SW26010 260C 1.45GHz, Sunway , NRCPC National Supercomputing Center in Wuxi China	10,649,600	93,014.6	125,435.9	15,371
4	**Tianhe-2A** - TH-IVB-FEP Cluster, Intel Xeon E5-2692v2 12C 2.2GHz, TH Express-2, Matrix-2000 , NUDT National Super Computer Center in Guangzhou China	4,981,760	61,444.5	100,678.7	18,482
5	**Piz Daint** - Cray XC50, Xeon E5-2690v3 12C 2.6GHz, Aries interconnect , NVIDIA Tesla P100 , Cray Inc. Swiss National Supercomputing Centre (CSCS) Switzerland	387,872	21,230.0	27,154.3	2,384

http://www.top500.org, Top500 list, November 2018.

Performance development



The Green500

Rank	TOP500 Rank	System	Cores	Rmax (TFlop/s)	Power (kW)	Power Efficiency (GFlops/watts)
1	375	**Shoubu system B** - ZettaScaler-2.2, Xeon D-1571 16C 1.3GHz, Infiniband EDR, PEZY-SC2 , PEZY Computing / Exascaler Inc. Advanced Center for Computing and Communication, RIKEN Japan	953,280	1,063.3	60	17.604
2	374	**DGX SaturnV Volta** - NVIDIA DGX-1 Volta36, Xeon E5-2698v4 20C 2.2GHz, Infiniband EDR, NVIDIA Tesla V100 , Nvidia NVIDIA Corporation United States	22,440	1,070.0	97	15.113
3	1	**Summit** - IBM Power System AC922, IBM POWER9 22C 3.07GHz, NVIDIA Volta GV100, Dual-rail Mellanox EDR Infiniband , IBM DOE/SC/Oak Ridge National Laboratory United States	2,397,824	143,500.0	9,783	14.668
4	7	**AI Bridging Cloud Infrastructure (ABCI)** - PRIMERGY CX2570 M4, Xeon Gold 6148 20C 2.4GHz, NVIDIA Tesla V100 SXM2, Infiniband EDR , Fujitsu National Institute of Advanced Industrial Science and Technology (AIST) Japan	391,680	19,880.0	1,649	14.423
5	22	**TSUBAME3.0** - SGI ICE XA, IP139-SXM2, Xeon E5-2680v4 14C 2.4GHz, Intel Omni-Path, NVIDIA Tesla P100 SXM2 , HPE GSIC Center, Tokyo Institute of Technology Japan	135,828	8,125.0	792	13.704

https://www.top500.org/green500/, Green500 list, November 2018.

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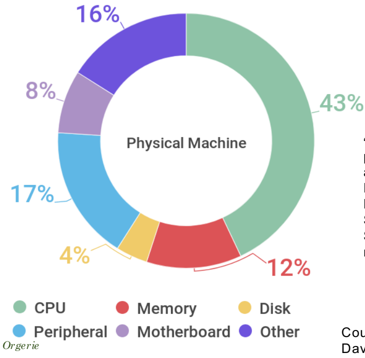
Energy spent in a server



"GreenCloud: A Packet-level Simulator of Energy-aware Cloud Computing Data Centers," D. Kliazovich, P. Bouvry, and S. U. Khan, The Journal of Supercomputing, vol. 62, no 3, pp 1263–1283, 2012.

Courtesy of David Guyon

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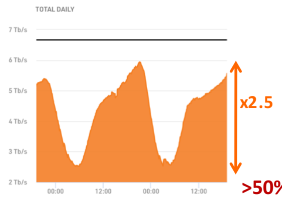
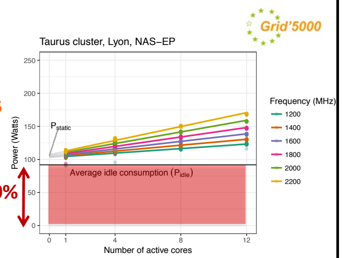
Variable workload & non-power proportionality



Aggregated traffic at Amsterdam Internet Exchange Point (AMS-IX).

[Source: https://www.ams-ix.net/ams, May 2019]



[Cluster 2017]

High idle power consumption.

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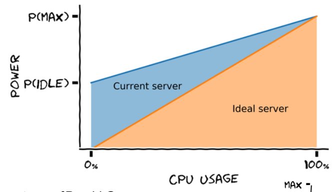
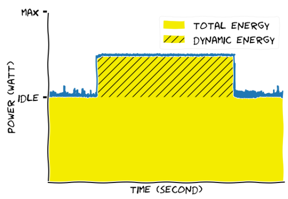
Ideal server vs. current server



Courtesy of David Guyon



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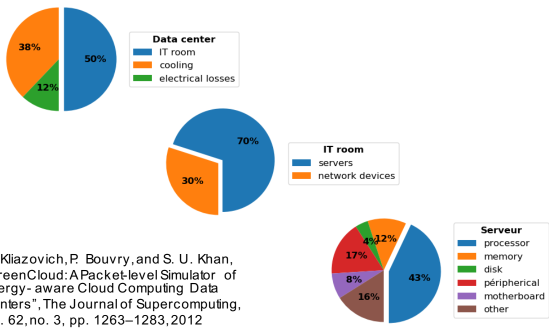
Wasted energy



D. Kliazovich, P. Bouvry, and S. U. Khan, "GreenCloud: A Packet-level Simulator of Energy-aware Cloud Computing Data Centers", The Journal of Supercomputing, vol. 62, no. 3, pp. 1263–1283, 2012

Courtesy of David Guyon

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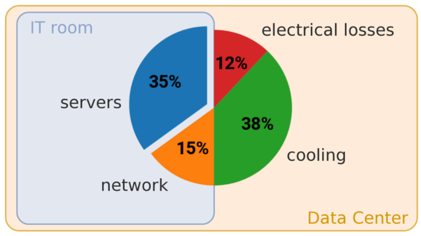
How to measure energy efficiency?



Courtesy of David Guyon

PUE: Power usage effectiveness

$$PUE = \frac{Total\ Facility\ Power}{IT\ Equipment\ Power}$$

"*Green Grid Data Center Power Efficiency Metrics: PUE and DCIE*", Green Grid White Paper, 2008.

the green grid

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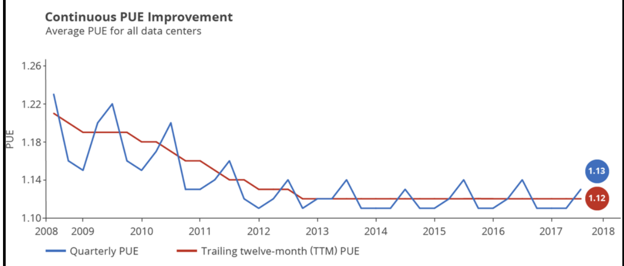
PUE as a selling point: Google case



https://www.google.fr/about/datacenters/

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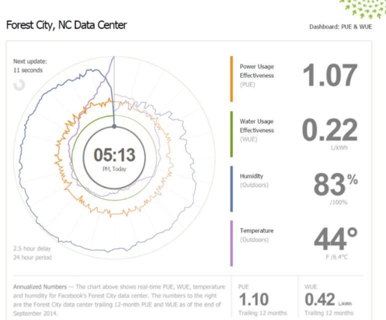
Facebook live dashboard



https://www.facebook.com/ForestCityDataCenter/app_288655784601722

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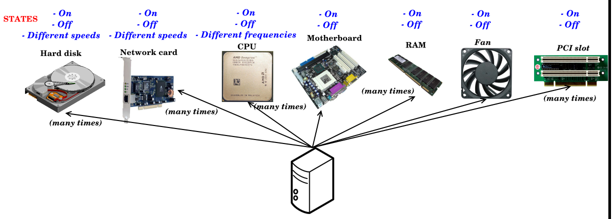
Power modes by component



Dynamic adaptation to the load:
- Hard disks: spin-down
- Processors: Dynamic Voltage Frequency Scaling (DVFS)
- Network cards: Adaptive Link Rate

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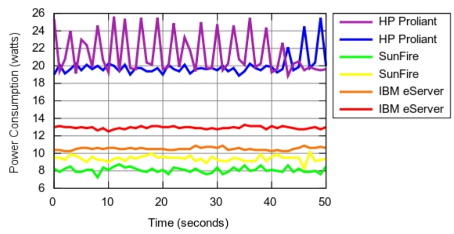
Does a switched off node consume energy?



"*Demystifying Energy Consumption in Grids and Clouds*", A.-C. Orgerie et al., WIPGC, 2010.

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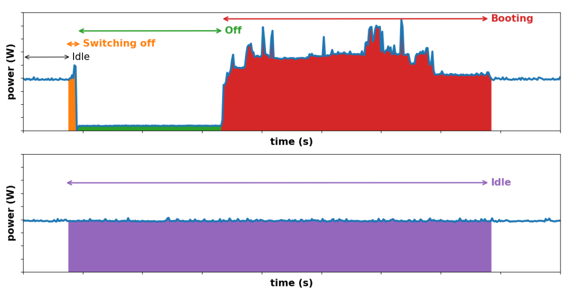
When can we switch off?



$$T_s = \frac{E_s - P_{OFF}(\delta_{ON \to OFF} + \delta_{OFF \to ON}) + E_{ON \to OFF} + E_{OFF \to ON}}{P_I - P_{OFF}}$$

"*Towards Energy Aware Reservation Infrastructure for Large-Scale Experimental Distributed Systems*", A.-C. Orgerie et al., Parallel Processing Letters, 2009.

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big.LITTLE architecture

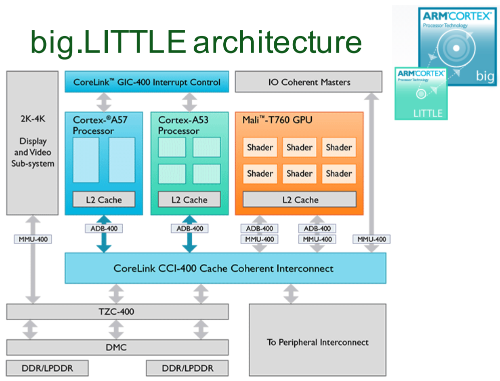

Fig. 3: Block diagram of a big.LITTLE System on Chip design representation

https://www.arm.com/products/processors/technologies/biglittleprocessing.php

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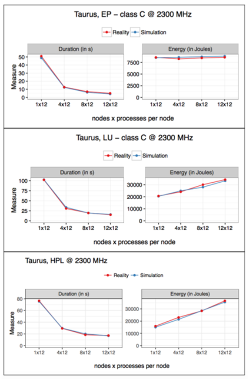
Simulating energy consumption of applications

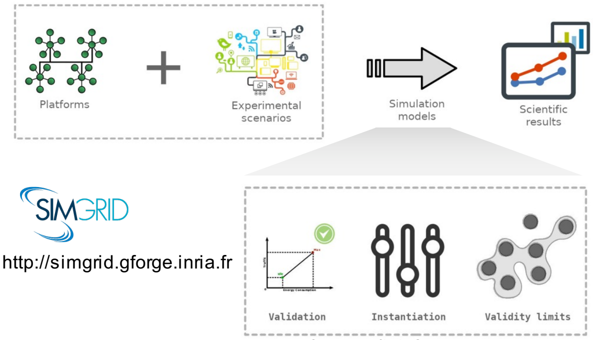
Simulation useful because:

- No need of big infrastructure
- Testing new approaches
- Fair comparison between two methods
- Reproducible

Reproducible results:
https://gitlab.inria.fr/fheinric/paper-simgrid-energy



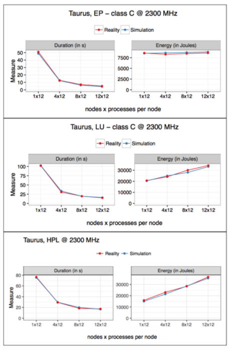
Simulating energy consumption



http://simgrid.gforge.inria.fr

Courtesy of Loic Guegan

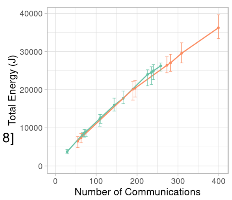
Simulating large-scale distributed infrastructures



HAC SPECIS

[Cluster 2017]

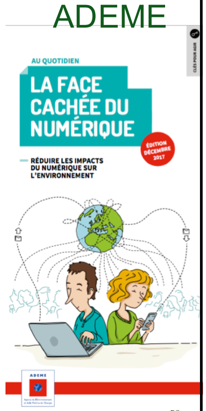
[AINA 2018]



Reproducible results:
https://gitlab.inria.fr/fheinric/paper-simgrid-energy
https://gitlab.inria.fr/lguegan/flowlvlwiredenergy

interstices.info

ADEME



http://ecoinfo.cnrs.fr

Thank you for your attention

http://people.irisa.fr/Anne-Cecile.Orgerie