Consommation énergétique des ordinateurs

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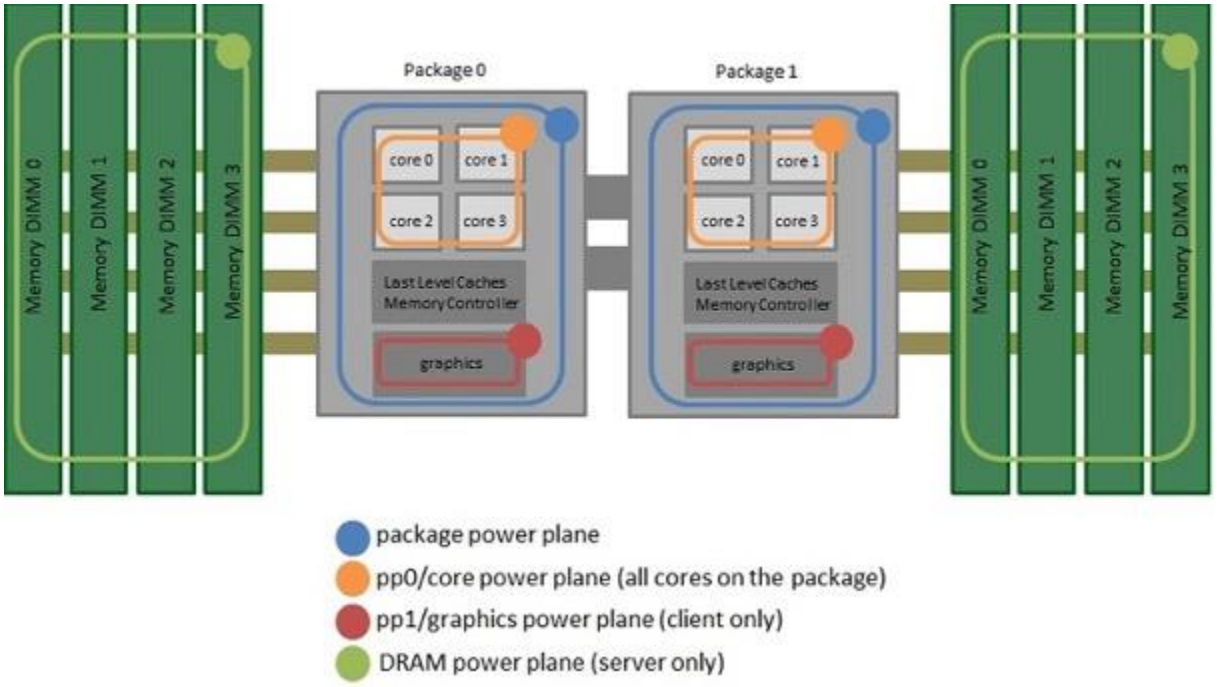
RAPL

Intel's RAPL (Running Average Power Limit) interface

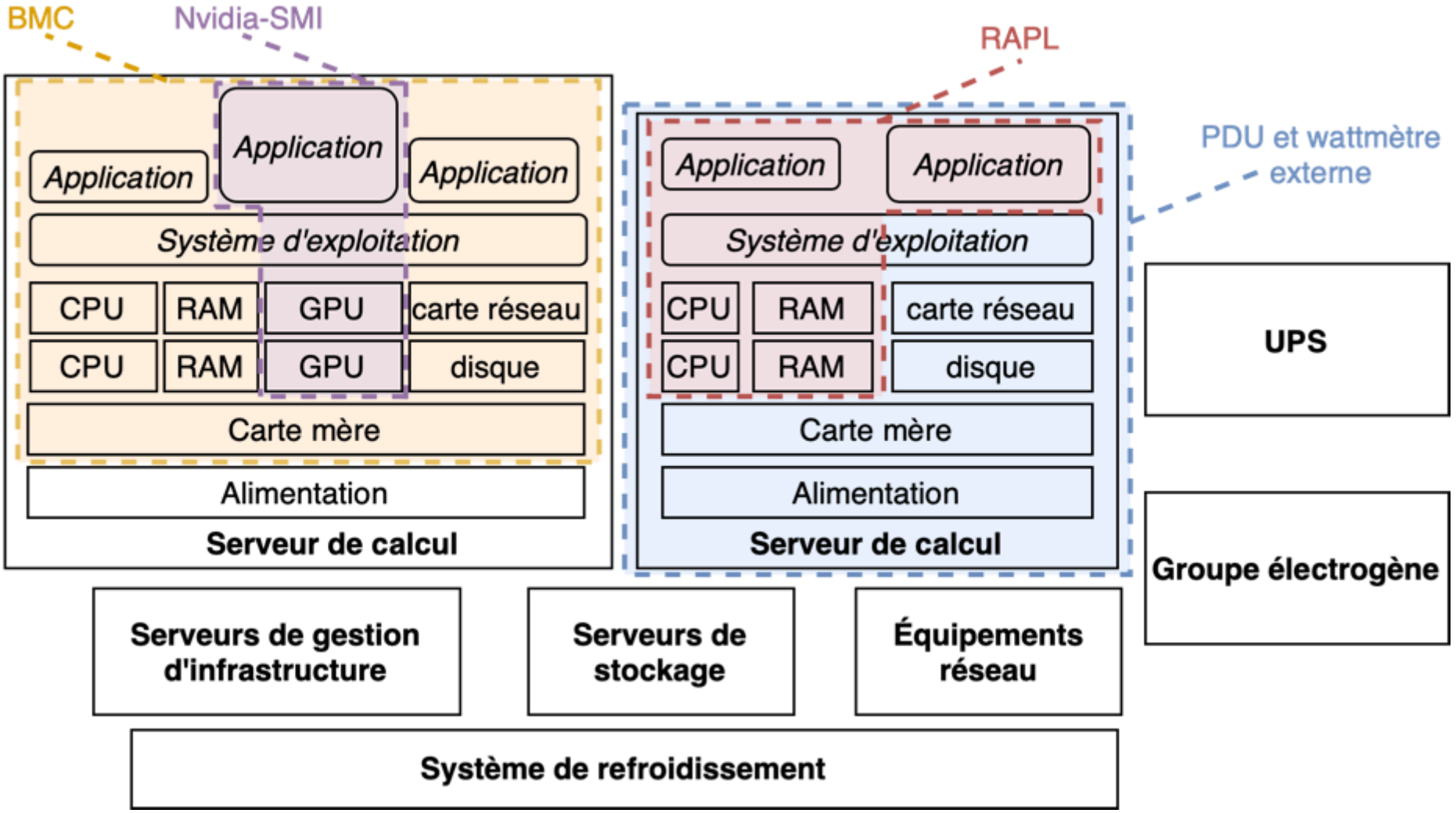



```
Energy measurements:
PACKAGE_ENERGY:PACKAGE0     176.450363J   (Average Power 42.9W)
PACKAGE_ENERGY:PACKAGE1      75.812454J   (Average Power 18.4W)
DRAM_ENERGY:PACKAGE0         11.899246J   (Average Power 2.9W)
DRAM_ENERGY:PACKAGE1          8.341141J   (Average Power 2.0W)
PP0_ENERGY:PACKAGE0  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


https://www.cl.cam.ac.uk/research/srg/han/ACS-P35/obj-4.2/zhpc52d06a1b.html

https://people.irisa.fr/Anne-Cecile.Orgerie/tp-rapl.pdf

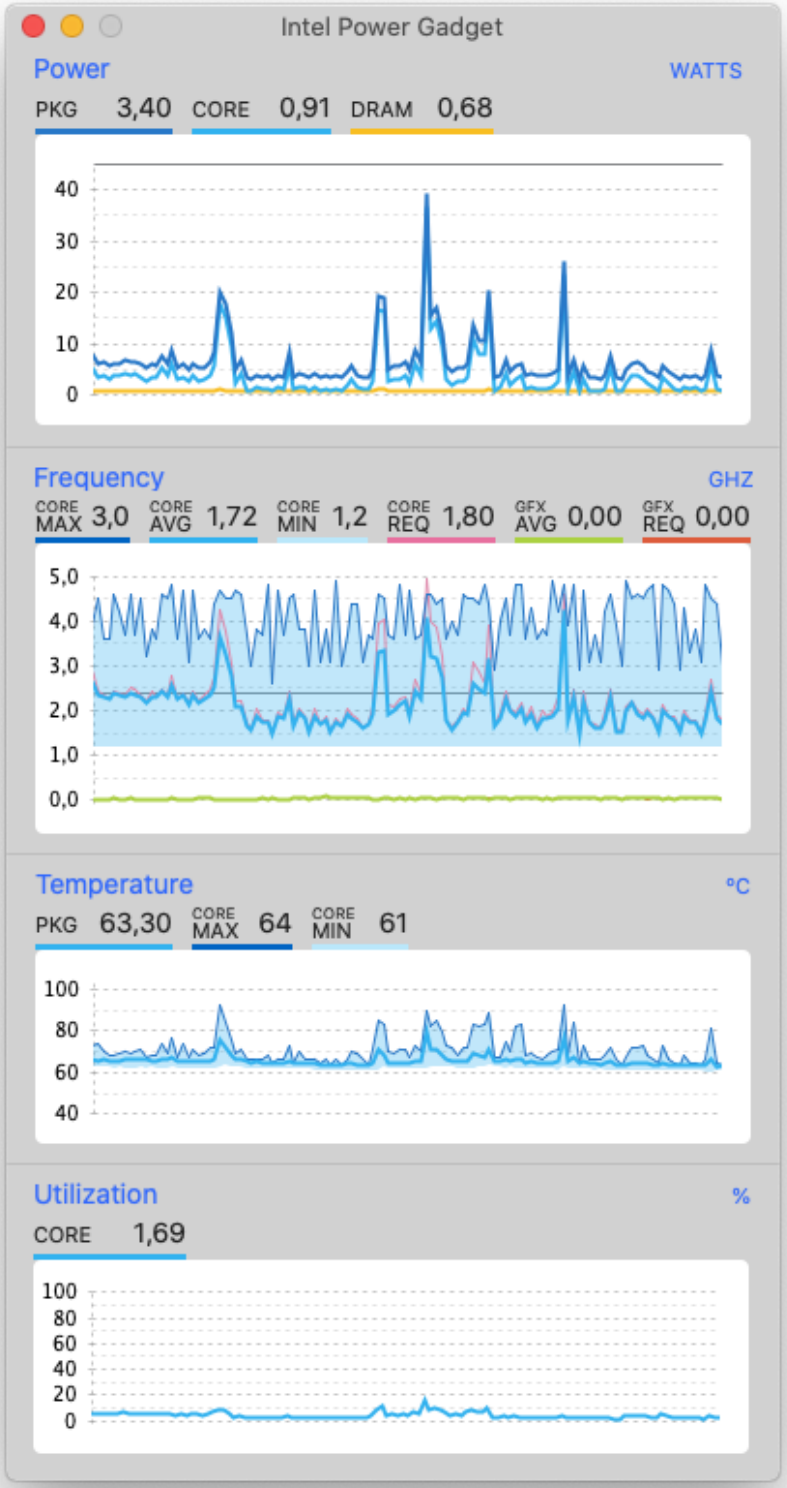
Périmètres de mesures



[Source: Matthieu Simonin, Anne-Cécile Orgerie. Méthodologies de calcul d'empreinte carbone sur une plateforme de calcul : exemple du site Grid'5000 de Rennes. *JRES*, 2024. ⟨hal-04893984⟩]

Intel Power Gadget

- Power: PKG, CORE, DRAM
- Frequency: MAX, AVG, MIN, REQ
- Temperature: PKG, MAX, MIN
- Utilization: CORE



https://www.intel.com/content/www/us/en/developer/articles/training/using-the-intel-power-gadget-30-api-on-windows.html

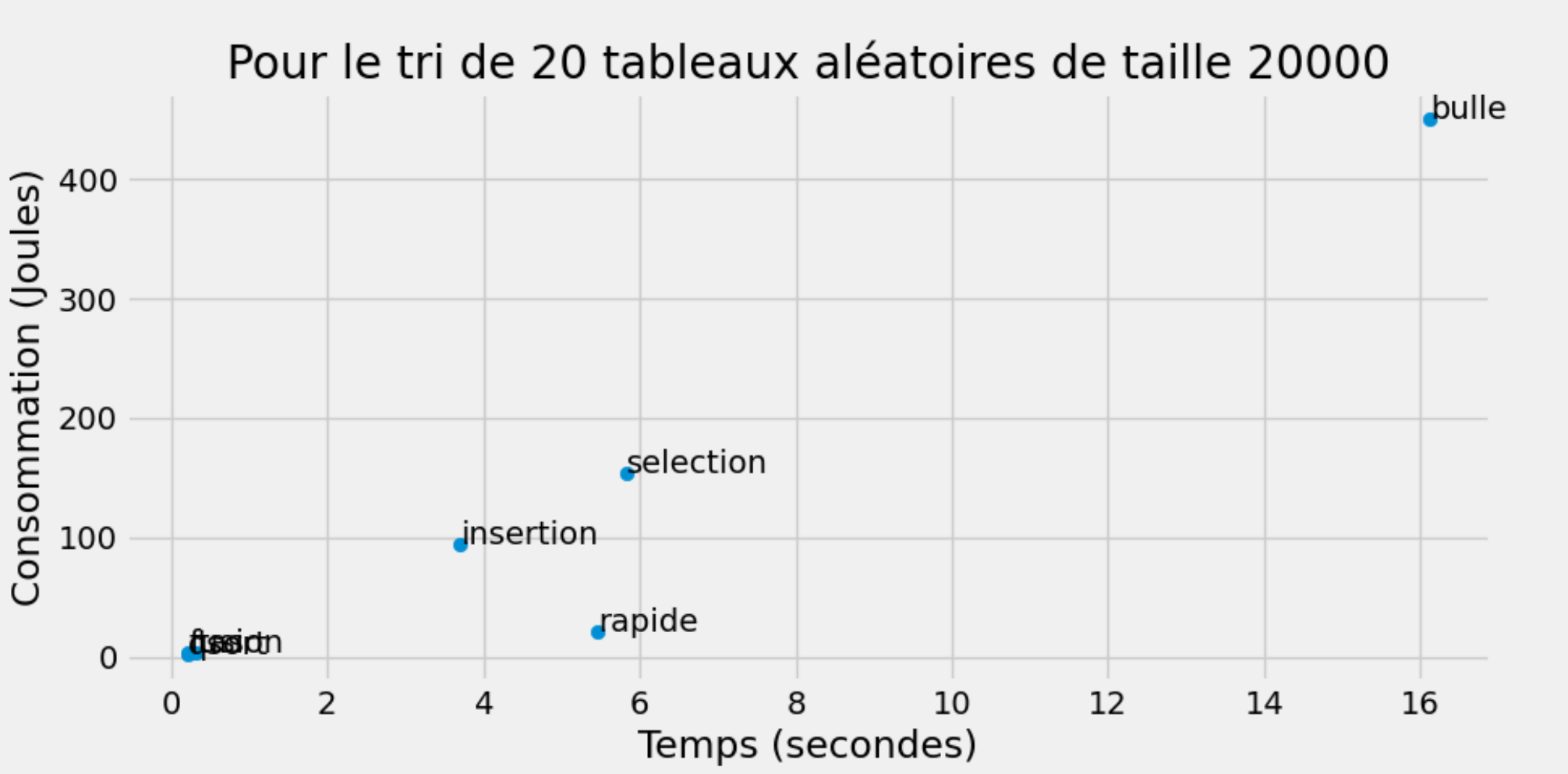
Intel Power Gadget – Powerlog

```
Done
annec@macao Intel Power Gadget % ./PowerLog -file /Users/annec/Desktop/TP/truc-rapide.csv -cmd /Users/annec/Desktop/TP/untri rapide
Num Packages: 1
Using Package: 0
Num Cores: 16
GT Available? 1
IA Energy Available? 1
DRAM Energy Available? 1
Max Temperature: 100 degrees Celcius
IA Base Frequency: 2400 MHz
IA Max Frequency: 5000 MHz
TDP: 45.00 W
package temperature: 43.00 degrees Celsius
Tri rapide de taille 20000
2349 2220 2221 2220 2207 2153 2153 2153 2154 2159 2421 2154 2154 2152 2150 2119 1995 1896 1830 1729
Moyenne : 2129
Temps total : 45102
Done
```

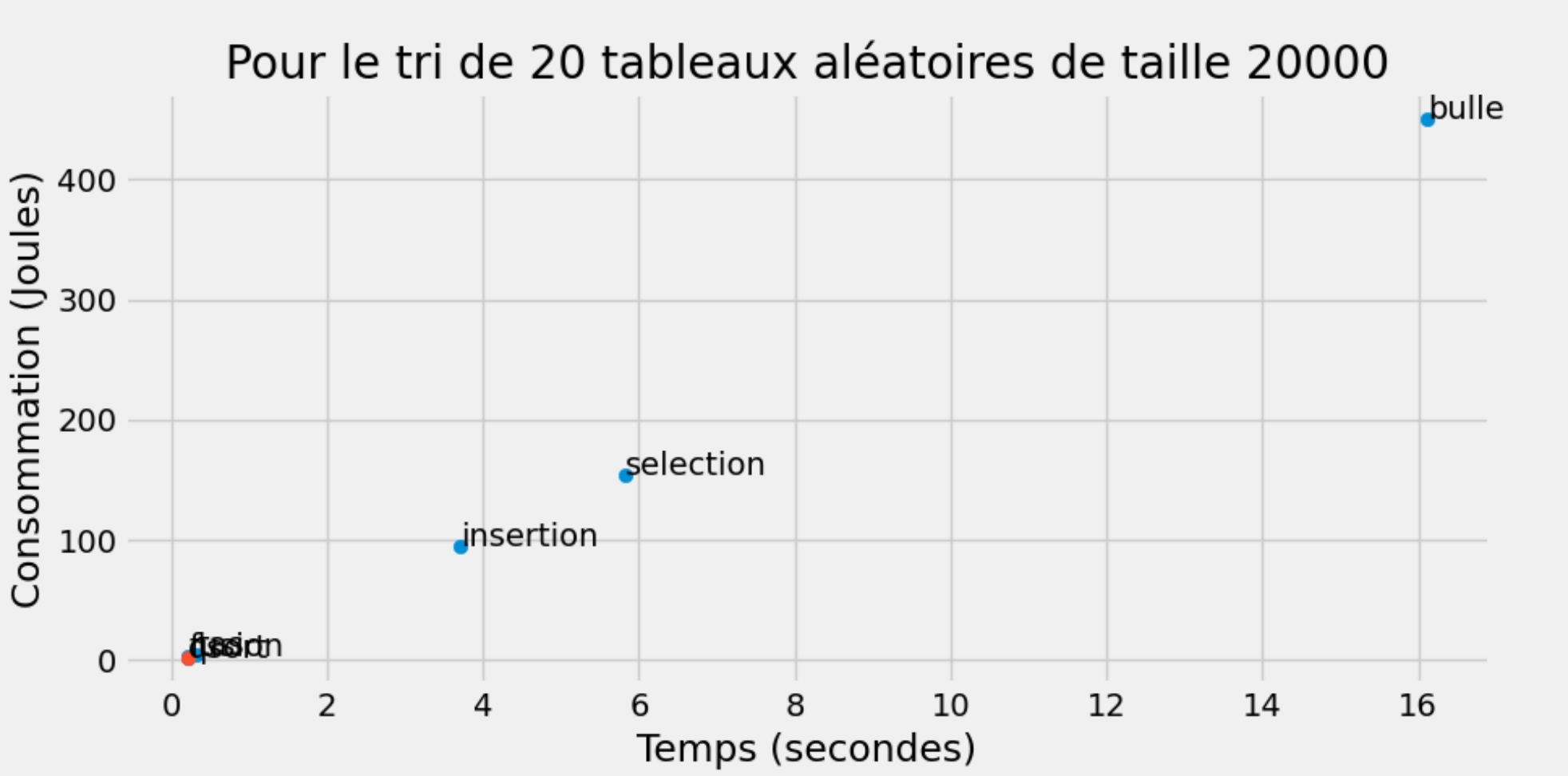
untri.c :

- Générer aléatoirement un tableau d'entiers de taille 20000
- Trier le tableau suivant le tri choisi
- 20 fois
- Tris : rapide, sélection, insertion, fusion, bulle, tas, qsort

Joules en fonction du temps



Joules en fonction du temps



Likwid

https://github.com/RRZE-HPC/likwid

```
git clone https://github.com/RRZE-HPC/likwid.git
cd likwid/
make
sudo make install
```

Si nécessaire : `sudo modprobe msr`

```
likwid-powermeter sleep 5
```

Likwid

```
acorgerie@gros-101:~$ likwid-powermeter ./untri insertion
--------------------------------------------------------------------------------
CPU name:       Intel(R) Xeon(R) Gold 5220 CPU @ 2.20GHz
CPU type:       Intel Cascadelake SP processor
CPU clock:      2.19 GHz
--------------------------------------------------------------------------------
Tri insertion de taille 20000
227896 244217 235935 227618 225131 225065 224385 224413 225731 225922 225986 227033 226835 227788 226959 226406 225897 225084 225060 225121
Moyenne : 227424
Temps total : 4551954
--------------------------------------------------------------------------------
Runtime: 5.61403 s
Measure for socket 0 on CPU 0
Domain PKG:
Energy consumed: 187.12 Joules
Power consumed: 33.3307 Watt
Domain PP0:
Energy consumed: 0 Joules
Power consumed: 0 Watt
Domain DRAM:
Energy consumed: 39.9822 Joules
Power consumed: 7.12184 Watt
Domain PLATFORM:
Energy consumed: 0 Joules
Power consumed: 0 Watt
--------------------------------------------------------------------------------
```

Powerstat

```
sudo apt install powerstat
sudo chmod -R a+r /sys/class/powercap/intel-rapl
powerstat -R -D
```

https://manpages.ubuntu.com/manpages/xenial/man8/powerstat.8.html

Powerstat

```
[acorgerie@gros-101:~$ powerstat -RDH
Running for 60.0 seconds (60 samples at 1.0 second intervals).
Power measurements will start in 0 seconds time.

  Time    User  Nice   Sys  Idle    IO  Run Ctxt/s  IRQ/s  Watts    pkg-0   dram
10:00:58   0.0   0.0   0.0 100.0   0.0    1     98     58   9.02     9.02   1.16
10:00:59   0.0   0.0   0.0 100.0   0.0    1    320    142   9.44     9.44   1.20
10:01:00   0.0   0.0   0.0 100.0   0.0    1    102     96   8.98     8.98   0.95
10:01:01   0.0   0.0   0.0 100.0   0.0    1     63     63   8.99     8.99   1.02
10:01:02   0.0   0.0   0.0 100.0   0.0    1    237     86   9.10     9.10   1.13
10:01:55   0.0   0.0   0.0 100.0   0.0    1    163     82   9.06     9.06   1.21
10:01:56   0.0   0.0   0.0 100.0   0.0    1    248    105   9.15     9.15   1.14
10:01:57   0.0   0.0   0.0 100.0   0.0    1     57     55   8.94     8.94   0.87
-------- ----- ----- ----- ----- ----- ---- ------ ------ ------  ------ ------
 Average   0.0   0.0   0.0  99.9   0.0  1.0 1019.0  973.3  10.28    10.28   1.55
 GeoMean   0.0   0.0   0.0  99.9   0.0  1.0  248.6  184.6   9.99     9.99   1.36
  StdDev   0.1   0.0   0.1   0.2   0.0  0.1 2339.0 2332.2   2.99     2.99   1.05
-------- ----- ----- ----- ----- ----- ---- ------ ------ ------  ------ ------
 Minimum   0.0   0.0   0.0  99.0   0.0  1.0   57.0   29.0   8.47     8.47   0.76
 Maximum   0.8   0.0   0.3 100.0   0.0  2.0 9266.0 11563.0  23.93    23.93   6.03
-------- ----- ----- ----- ----- ----- ---- ------ ------ ------  ------ ------
Summary:
CPU:  10.28 Watts on average with standard deviation 2.99
Note: power read from RAPL domains: package-0, dram.
These readings do not cover all the hardware in this device.
```

PyJoules

```
pip install pyJoules
sudo chmod -R a+r /sys/class/powercap/intel-rapl
```

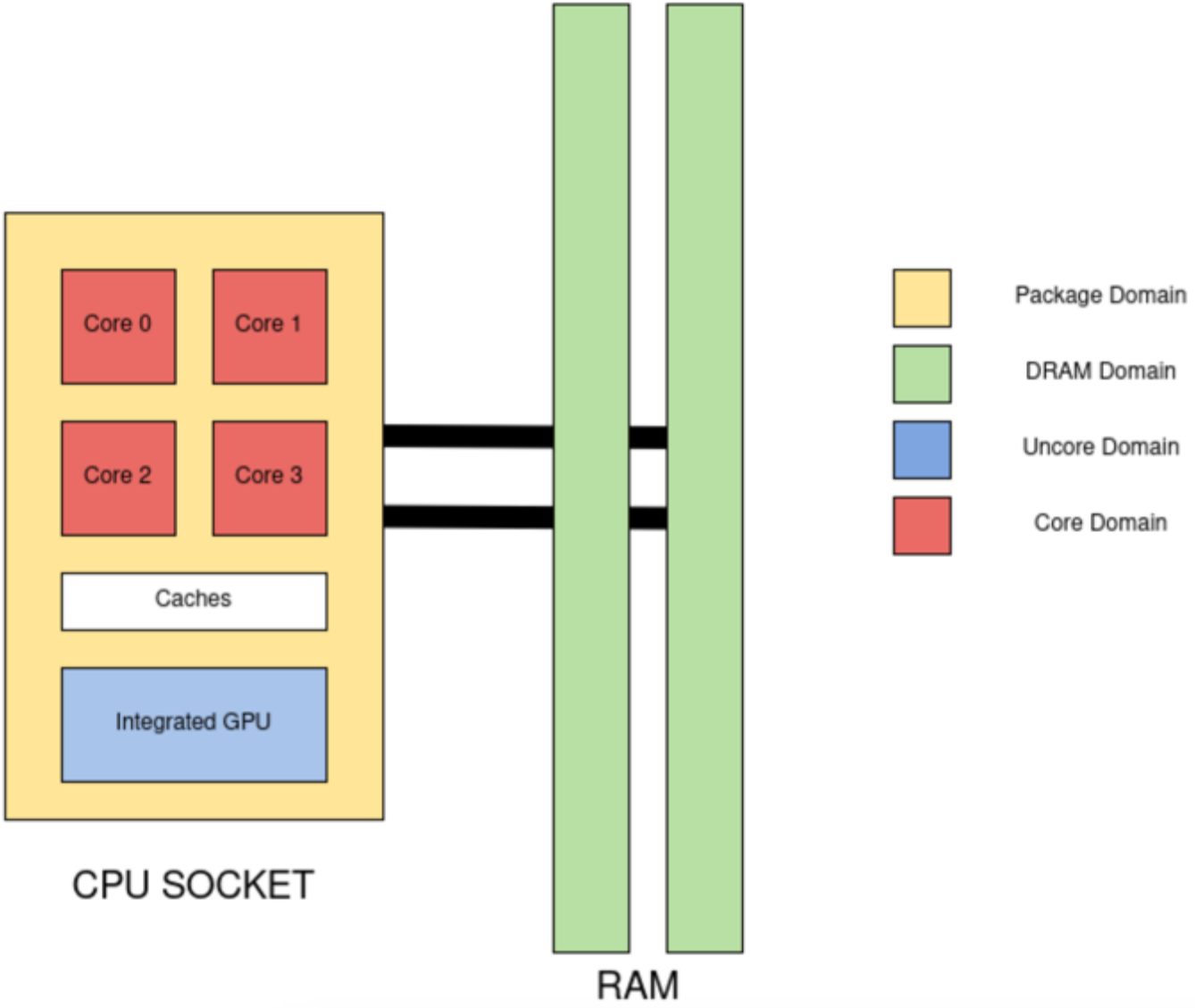
```python
from pyJoules.energy_meter import measure_energy

@measure_energy
def foo():
        # Instructions to be evaluated.

foo()
```

https://github.com/powerapi-ng/pyJoules

pyJoules



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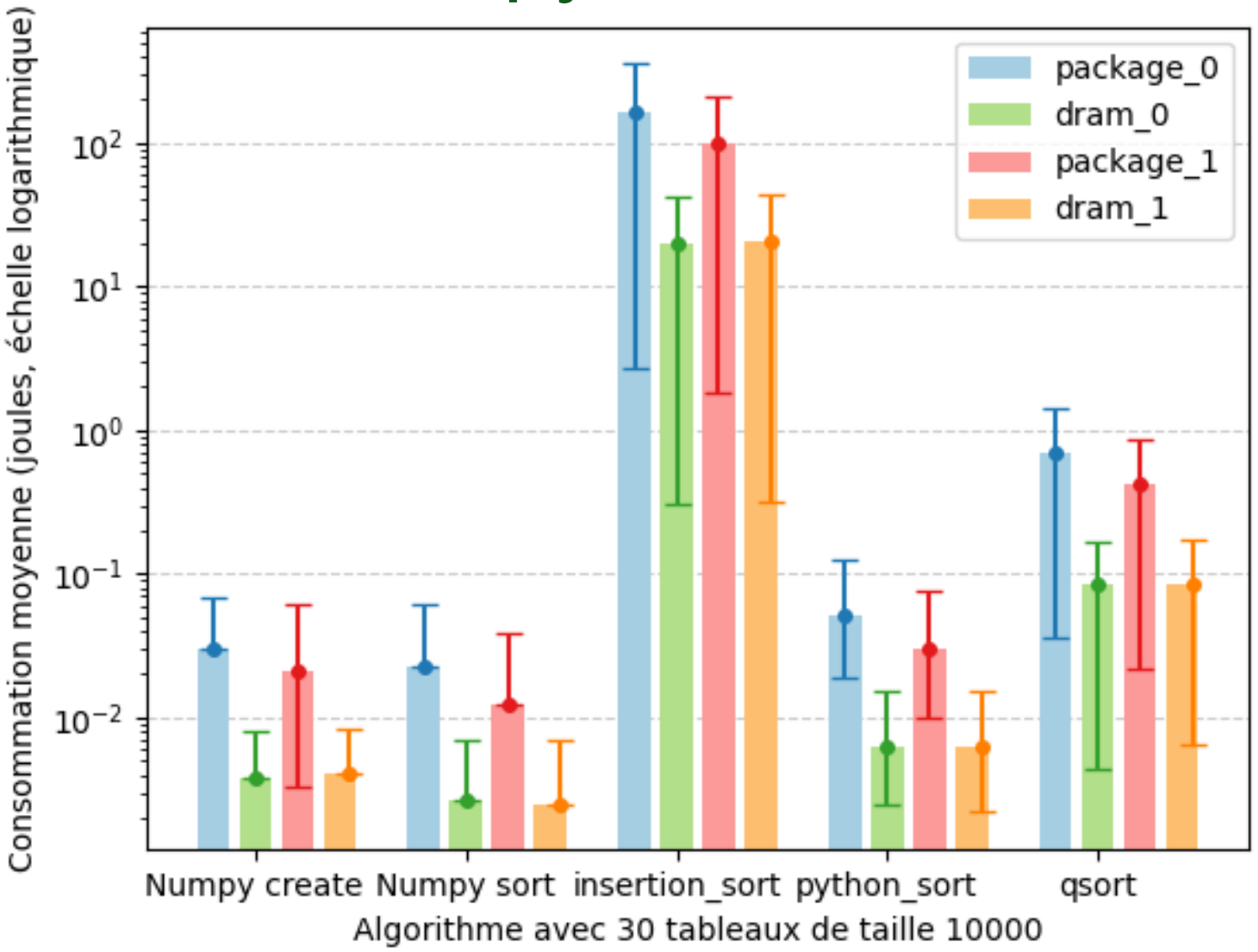
pyJoules



https://recherche.noiraudes.net/ecoinfo/numres/ressources/TP/04-mesure-conso.html

PCM

```
Time elapsed: 1000 ms
Called sleep function for 1000 ms
S0P0; QPI Clocks: 99175166; L0p Tx Cycles: 46.97 %; L1 Cycles: 3.11 %;
S0P1; QPI Clocks: 99182474; L0p Tx Cycles: 46.69 %; L1 Cycles: 3.46 %;
S0CH0; DRAMClocks: 45080387; Rank0 CKE Off Residency: 94.48 %; Rank0 CKE Off Average Cycles: 4504; Rank0 Cycles per transition: 4767;
S0CH0; DRAMClocks: 45080387; Rank1 CKE Off Residency: 95.40 %; Rank1 CKE Off Average Cycles: 6087; Rank1 Cycles per transition: 6380;
S0CH1; DRAMClocks: 45087526; Rank0 CKE Off Residency: 95.39 %; Rank0 CKE Off Average Cycles: 6053; Rank0 Cycles per transition: 6345;
S0CH1; DRAMClocks: 45087526; Rank1 CKE Off Residency: 95.43 %; Rank1 CKE Off Average Cycles: 6180; Rank1 Cycles per transition: 6476;
S0CH2; DRAMClocks: 45094724; Rank0 CKE Off Residency: 95.38 %; Rank0 CKE Off Average Cycles: 6001; Rank0 Cycles per transition: 6292;
S0CH2; DRAMClocks: 45094724; Rank1 CKE Off Residency: 95.39 %; Rank1 CKE Off Average Cycles: 6068; Rank1 Cycles per transition: 6361;
S0CH3; DRAMClocks: 45102076; Rank0 CKE Off Residency: 95.38 %; Rank0 CKE Off Average Cycles: 6026; Rank0 Cycles per transition: 6318;
S0CH3; DRAMClocks: 45102076; Rank1 CKE Off Residency: 95.43 %; Rank1 CKE Off Average Cycles: 6171; Rank1 Cycles per transition: 6467;
S0CH4; DRAMClocks: 0; Rank0 CKE Off Residency: -nan %; Rank0 CKE Off Average Cycles: -1; Rank0 Cycles per transition: -1;
S0CH4; DRAMClocks: 0; Rank1 CKE Off Residency: -nan %; Rank1 CKE Off Average Cycles: -1; Rank1 Cycles per transition: -1;
S0; Consumed energy units: 170876; Consumed Joules: 10.43; Watts: 10.43; Thermal headroom below TjMax: 39 °C;
S0; Consumed DRAM energy units: 68544; Consumed DRAM Joules: 1.05; DRAM Watts: 1.05;
S1P0; QPI Clocks: 99461582; L0p Tx Cycles: 79.31 %; L1 Cycles: 3.39 %;
S1P1; QPI Clocks: 99461918; L0p Tx Cycles: 79.60 %; L1 Cycles: 3.04 %;
S1CH0; DRAMClocks: 45952035; Rank0 CKE Off Residency: 95.29 %; Rank0 CKE Off Average Cycles: 5748; Rank0 Cycles per transition: 6032;
S1CH0; DRAMClocks: 45952035; Rank1 CKE Off Residency: 95.53 %; Rank1 CKE Off Average Cycles: 6369; Rank1 Cycles per transition: 6667;
S1CH1; DRAMClocks: 45951947; Rank0 CKE Off Residency: 95.49 %; Rank0 CKE Off Average Cycles: 6178; Rank0 Cycles per transition: 6470;
S1CH1; DRAMClocks: 45951947; Rank1 CKE Off Residency: 95.53 %; Rank1 CKE Off Average Cycles: 6390; Rank1 Cycles per transition: 6689;
S1CH2; DRAMClocks: 45951825; Rank0 CKE Off Residency: 95.48 %; Rank0 CKE Off Average Cycles: 6161; Rank0 Cycles per transition: 6453;
S1CH2; DRAMClocks: 45951825; Rank1 CKE Off Residency: 95.54 %; Rank1 CKE Off Average Cycles: 6406; Rank1 Cycles per transition: 6705;
S1CH3; DRAMClocks: 45951811; Rank0 CKE Off Residency: 95.47 %; Rank0 CKE Off Average Cycles: 6151; Rank0 Cycles per transition: 6443;
S1CH3; DRAMClocks: 45951811; Rank1 CKE Off Residency: 95.53 %; Rank1 CKE Off Average Cycles: 6369; Rank1 Cycles per transition: 6667;
S1CH4; DRAMClocks: 0; Rank0 CKE Off Residency: -nan %; Rank0 CKE Off Average Cycles: -1; Rank0 Cycles per transition: -1;
S1CH4; DRAMClocks: 0; Rank1 CKE Off Residency: -nan %; Rank1 CKE Off Average Cycles: -1; Rank1 Cycles per transition: -1;
S1; Consumed energy units: 114815; Consumed Joules: 7.01; Watts: 7.01; Thermal headroom below TjMax: 41 °C;
S1; Consumed DRAM energy units: 62625; Consumed DRAM Joules: 0.96; DRAM Watts: 0.96;
```

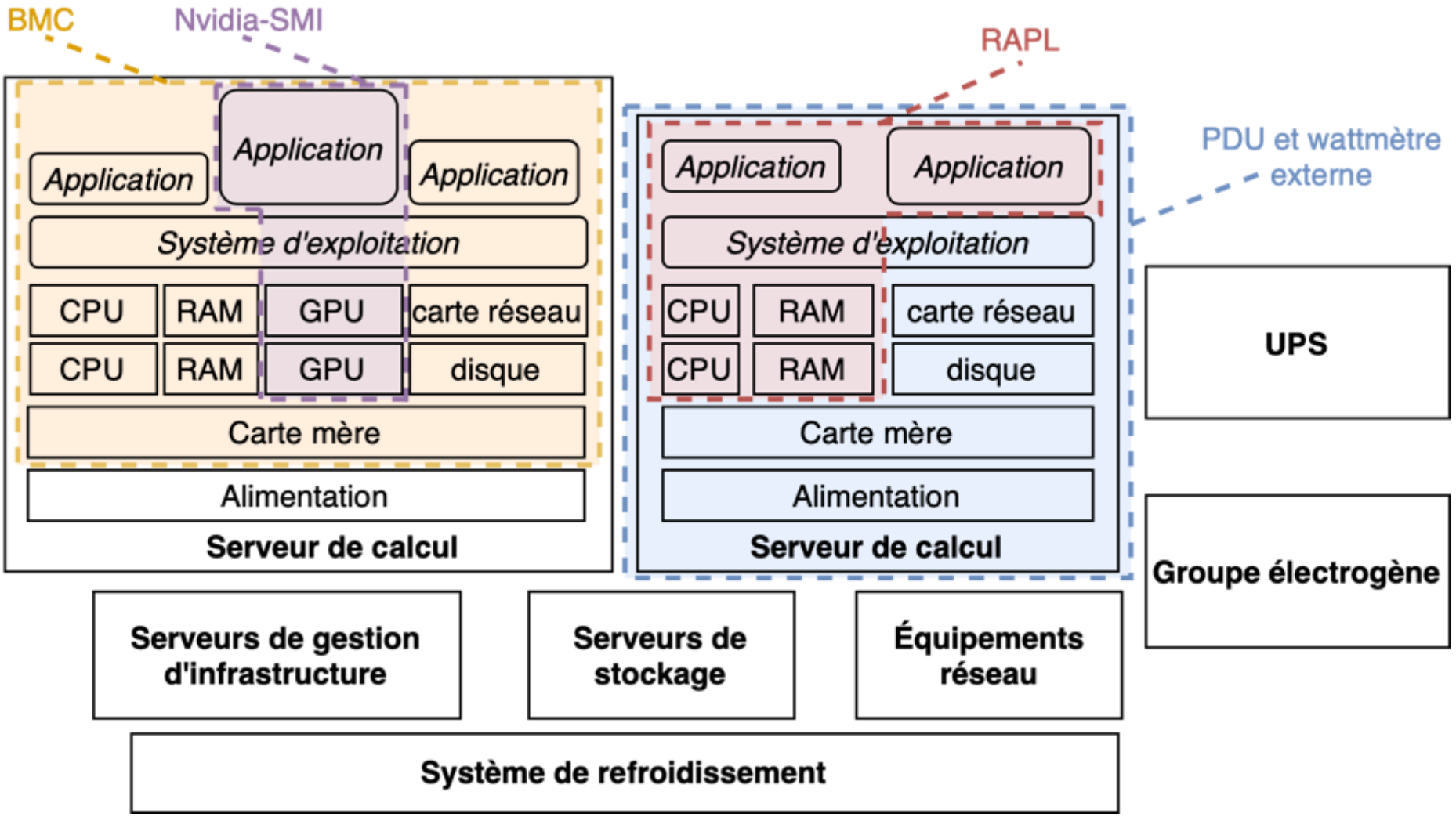
https://github.com/intel/pcm

librairies diverses et variées…

Nombreuses autre librairies disponibles qui utilisent :

Mesure RAPL $\times$ *PUE* = *chiffre magique*

Périmètres de mesures



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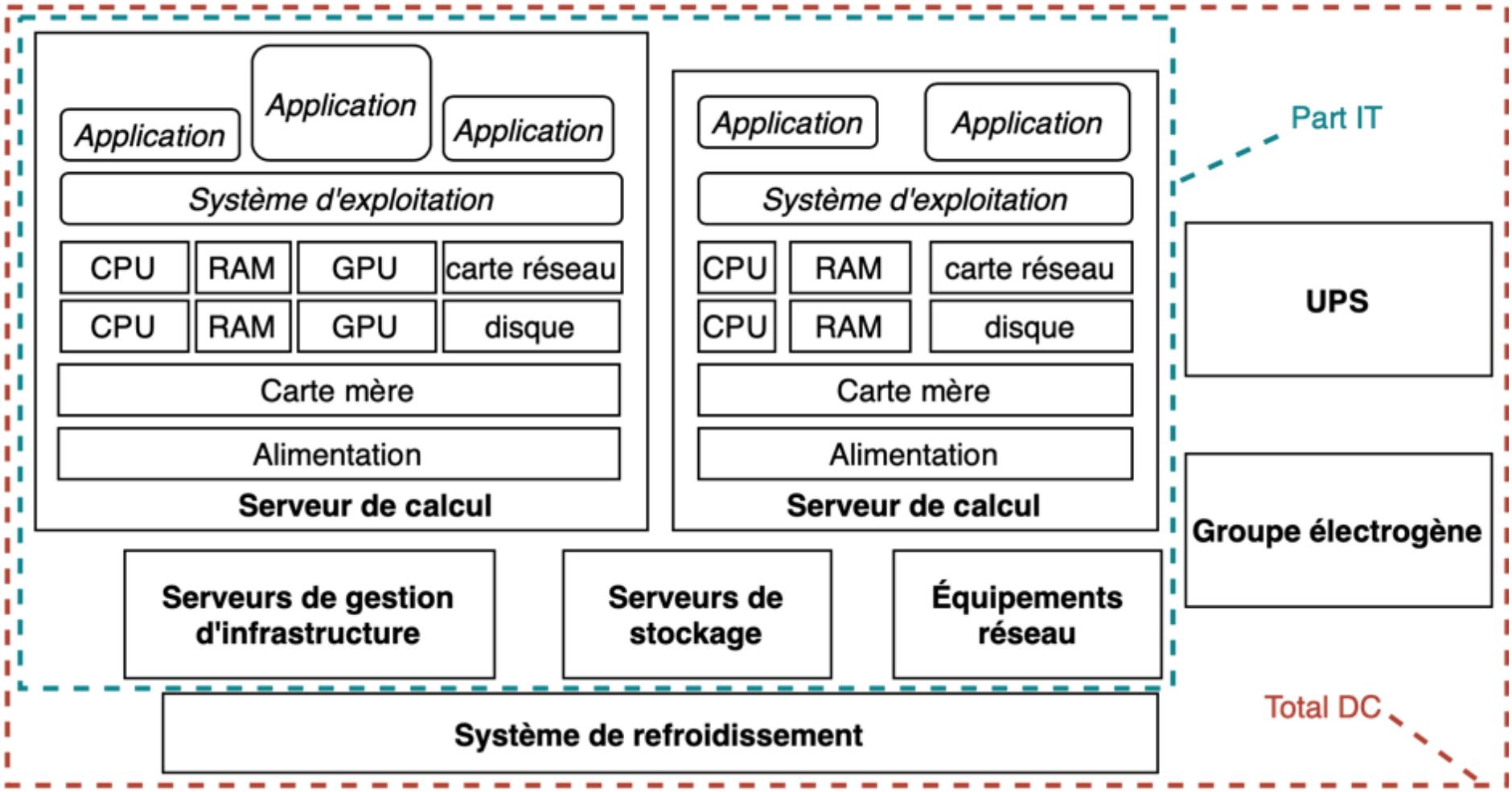
PUE

$$PUE = \frac{Total\ DC}{Part\ IT}$$



⚠ librairies diverses et variées…

Nombreuses autre librairies disponibles qui utilisent :

Mesure RAPL × *PUE* = *chiffre magique*

- RAPL = une partie de la consommation énergétique d'une machine (CPU, RAM)
- PUE = ratio entre consommation totale et consommation IT dans un centre de calcul
- Pas de prise en compte du reste de la machine (disque, carte mère etc.)
- ⚠ somme de tous les chiffres magiques ≠ consommation totale DC

Autre sujet de TP

(aucune installation requise)

Evaluation de performance des tris

Complexité en temps de calcul et en espace mémoire

Robustesse ?

Opération de comparaison : dans 10% des cas, résultat aléatoire (donc correct ou non)

Mesure d'erreur : distance $|j - i|$ si le *i*-ème élément aurait dû avoir la position *j*

Erreur : somme des distances pour le tableau final

Questions

- Quel algorithme de tri est le plus robuste ?
- Comment pourrait-on réduire l'erreur moyenne des algorithmes de tri ?
- Combien de comparaisons sont nécessaires pour obtenir une robustesse similaire pour les 3 algorithmes (rapide, fusion, bulles) ?
- Quelle est la performance des algorithmes si les erreurs ne sont pas indépendantes ?

https://people.irisa.fr/Anne-Cecile.Orgerie/tp-resilience.pdf

Article source

"Beyond Efficiency", David H. Ackley, *Communications of the ACM*, 2013.

Figure 2. Errors sorting a deck of cards with 10% failed comparisons.