Introduction to Green Software

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LOOKING FURTHER

SOURCE: https://youtu.be/UqJJktxCY9U?si=esVrqrMBJQCyNp6l

Computing as Ecocide

Ecocide: unlawful or wanton acts *committed with knowledge* that there is a substantial likelihood of severe and either widespread or long-term damage to the environment being caused by those acts.

- **Computation** as Ecocide
- Computing **Infrastructure** as Ecocide
- Computing as a **facilitator** of ecocide

		Wanton	Severe	Widespread	Long-term	Environment
Computation	Bitcoin	✓	✓	✓	?	CO_2e emissions
	LLMs	✓	✓	✓/ ?	?	CO_2e emissions
Infrastructure	Data centers	✓	✓	Localised	✓	Water and Land
	Lithium	✓	✓	Localised	✓	Water
Material	eWaste	✓	✓	✓	✓	Genotoxicity
Facilitator		?	✓	✓	✓	CO_2e emissions, biodiversity loss

Comber, R. and Eriksson, E., 2023. Computing as Ecocide. *Ninth Computing within Limits.*

Computing as Ecocide

Computation as Ecocide:

Training LLama produced nearly 1,1015 tons of carbon emission (tCO2eq)[1]

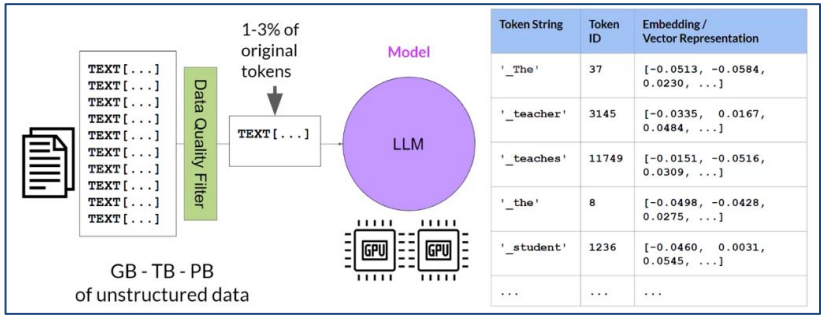
= annual emissions of approximately **197 average US households**.

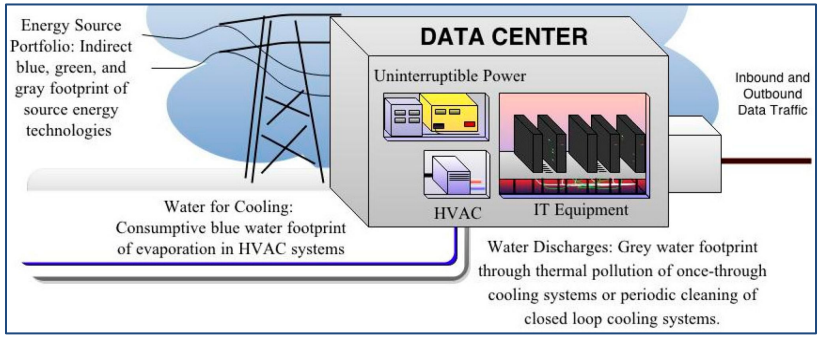
Computing **Infrastructure** as Ecocide:

In 2021, Google's data centers consumed approximately **4.3 billion gallons of water**. On average, a Google data center consumes 450,000 gallons of water a day. [2]

Computing as a **facilitator** of Ecocide:

Precision agricultural technology, incorporating computer vision and robotics, is apparently capable of killing up to 100,000 plants in a hour.[3]





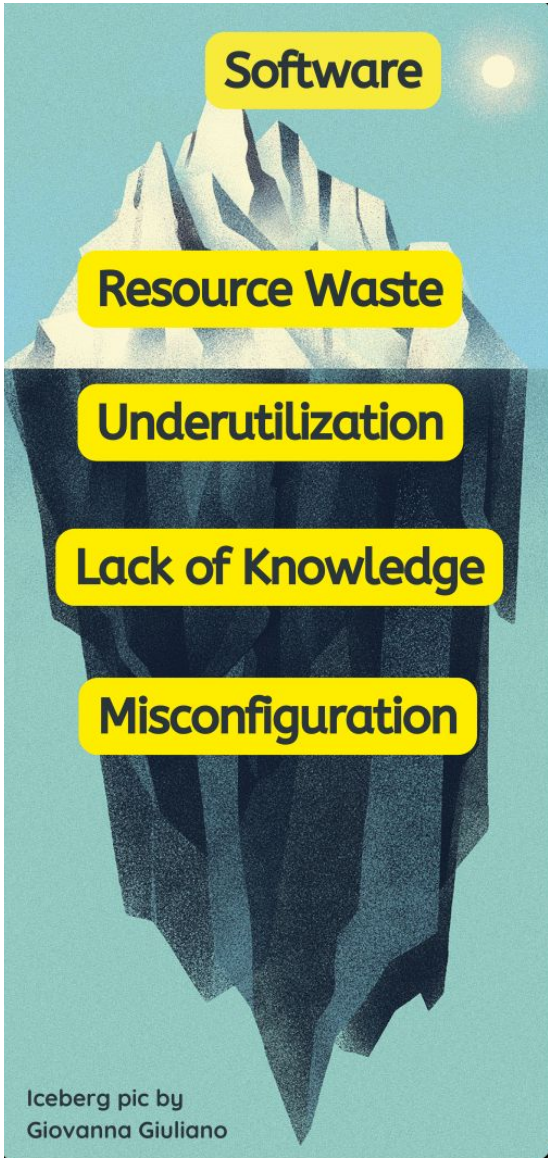
1. B. Rozière et al., Code llama: Open foundation models for code, 2023
2. Google, Our commitment to climate-conscious data center cooling, 2021
3. Comber, R. and Eriksson, E., 2023. Computing as Ecocide. *Ninth Computing within Limits.*

How can we use computing for good?

Green IT: designing, manufacturing, using, and disposing of computers, servers, and associated subsystems efficiently and effectively with minimal or no impact on the environment.

Examples of Green IT practices:

- Digital Sufficiency
- Circular Economy
- Reducing E-Waste (e.g., Repair Cafè)
- Remote Work
- Optimizing resource efficiency (e.g., on-demand provisioning)
- **Energy-efficient Computing!**

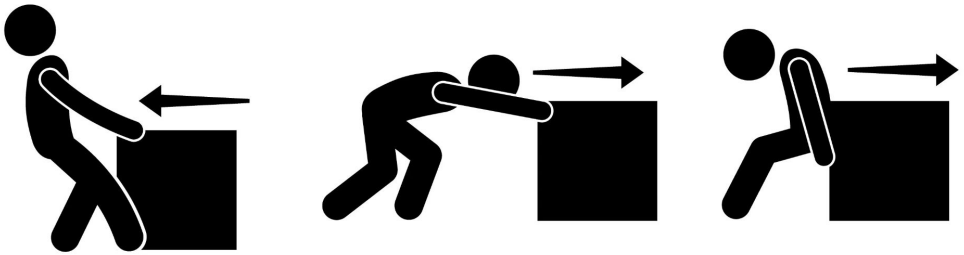


Green IT: https://www.techtarget.com/searchcio/definition/green-IT-green-information-technology

Power and Energy

Energy vs Power

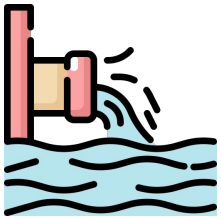
Energy: is defined as the capacity to do *work*. This means it is the ability to exert a force that causes the displacement of an object[1]



Power: amount of work done *W,* or energy transferred, divided by the time interval *t*—or *W*/*t*.[2]

Power represents the rate (W/t) at which water flows

Energy is the amount of water that flowed out of the pipe



[1] Energy: definition https://www.britannica.com/science/energy
[2] Power: definition https://www.britannica.com/science/power-physics

IMG: https://shorturl.at/lcZeO

Electric Power

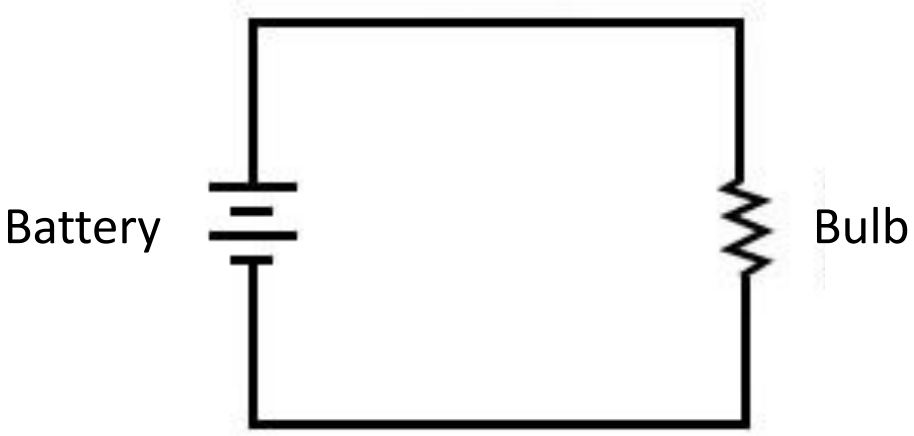
Electric Power: the rate at which electrical energy is transferred in a circuit

$$P(t) = V(t) \times I(t) \quad \text{Watts (W)} = \text{Volts (V)} \times \text{Amperes (A)}$$

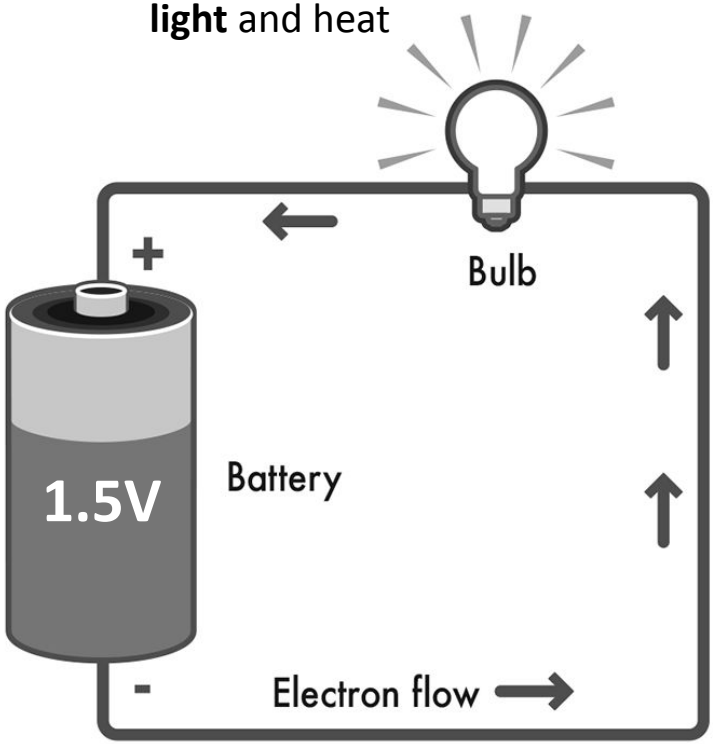
where V(t) is the *voltage* at **time t** and I(t) is the *current* at **time t**

$V(t)$ = potential energy needed to move the electrons through the circuit

$I(t)$= the quantity of electrons crossing a specified area per unit time



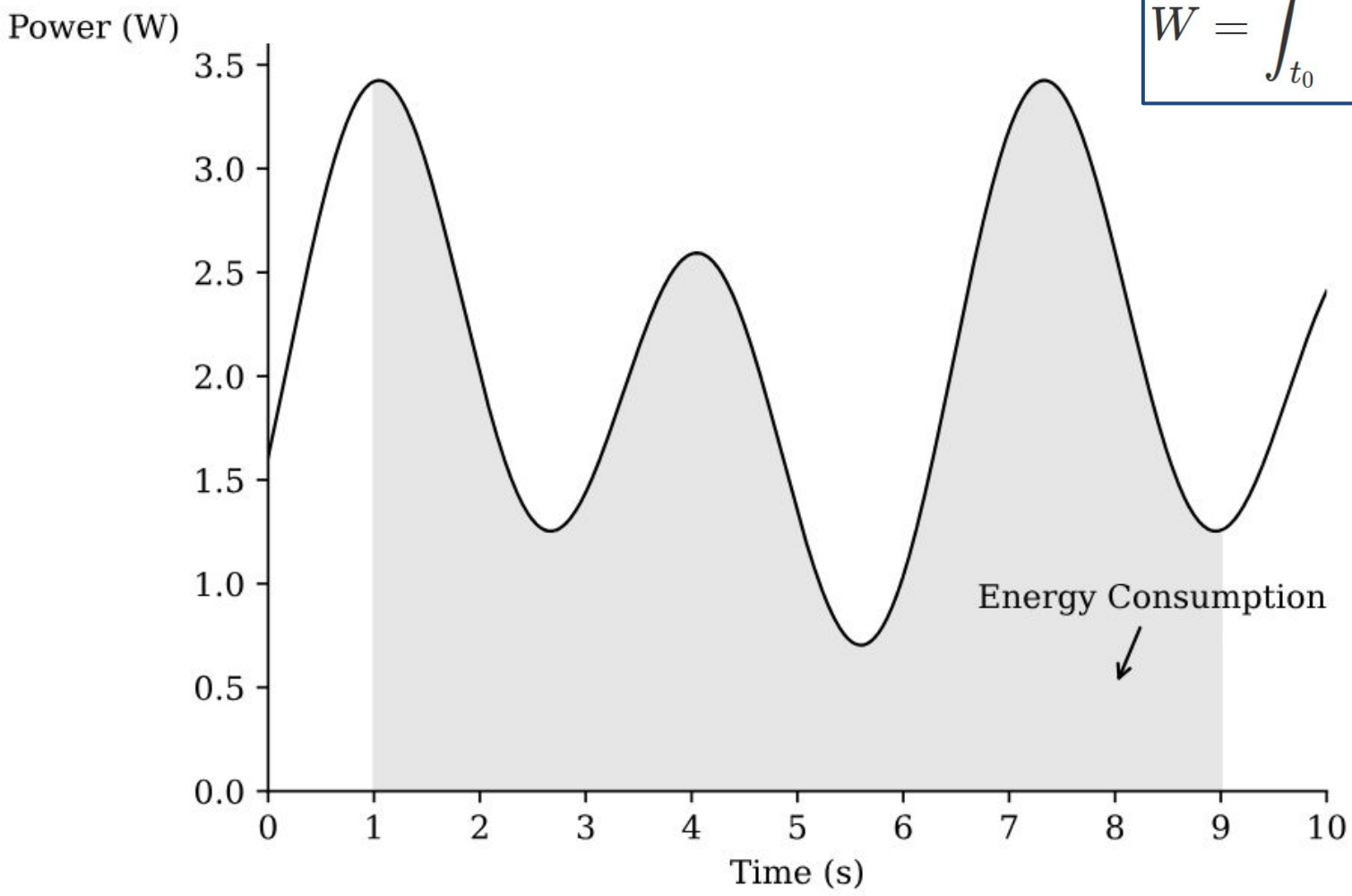
Electricity passes through the filament of an incandescent bulb, the **filament heats up due to resistance,** producing **light** and heat



IMG:https://energyknowledgebase.com/topics/electricity.asp

Electric Energy

$$W = \int_{t_0}^{t_n} P(t)dt$$

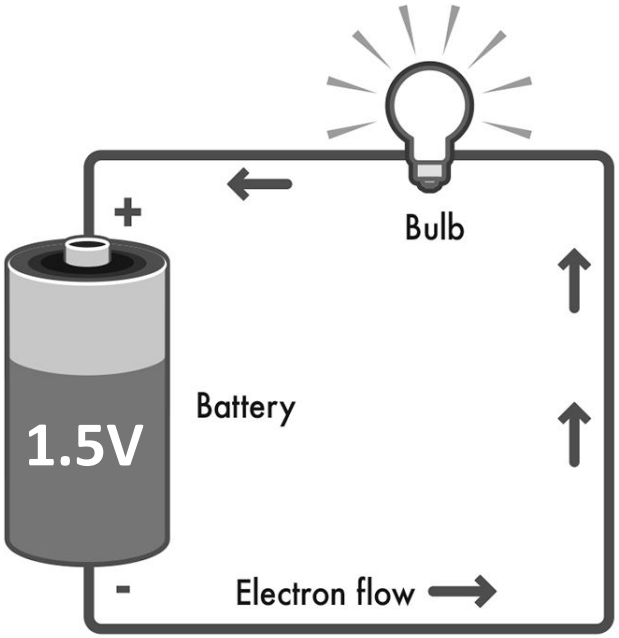


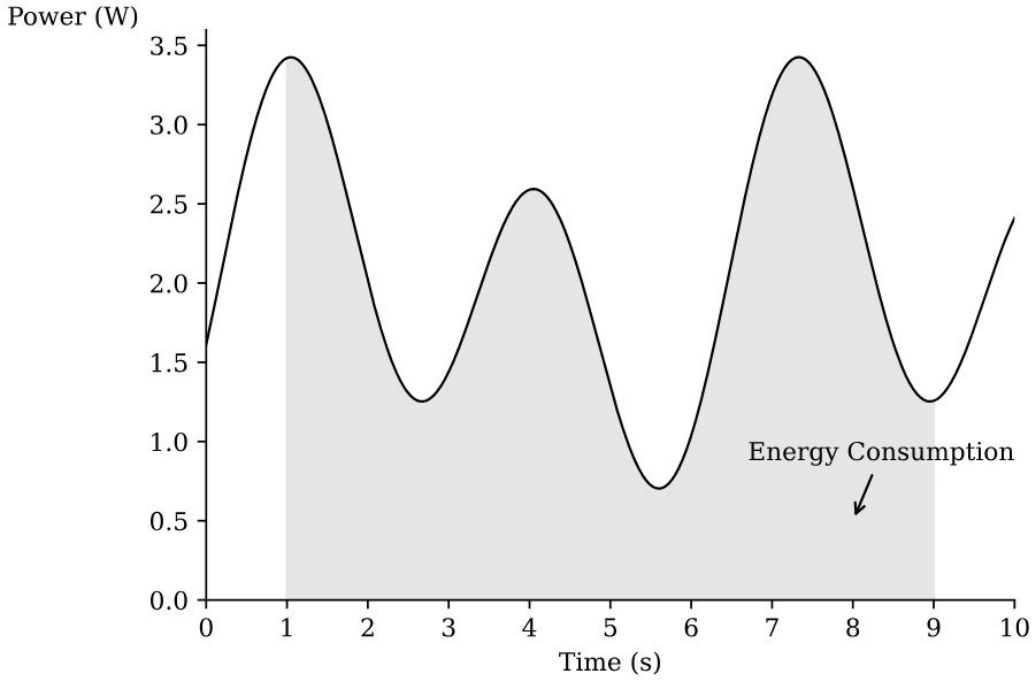
Source: https://luiscruz.github.io/2023/05/13/energy-units.html

Electric Energy

Electrical energy is defined as the energy associated with the movement of electrons.

Electrical energy is typically measured in **joules (J)** or **kilowatt-hours (kWh)**, where one kilowatt-hour equals **3.6 million** joules.





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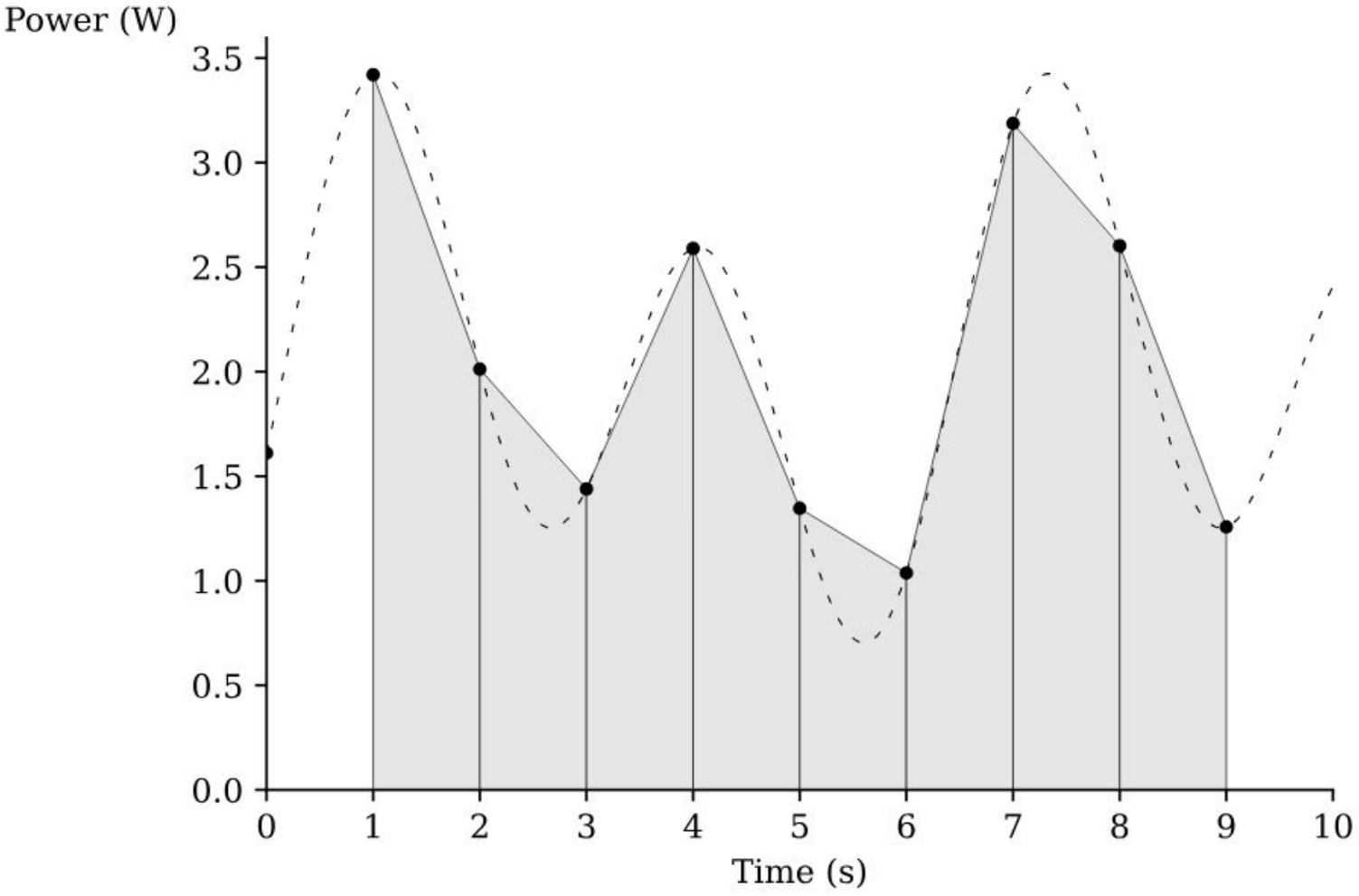
Electric Energy



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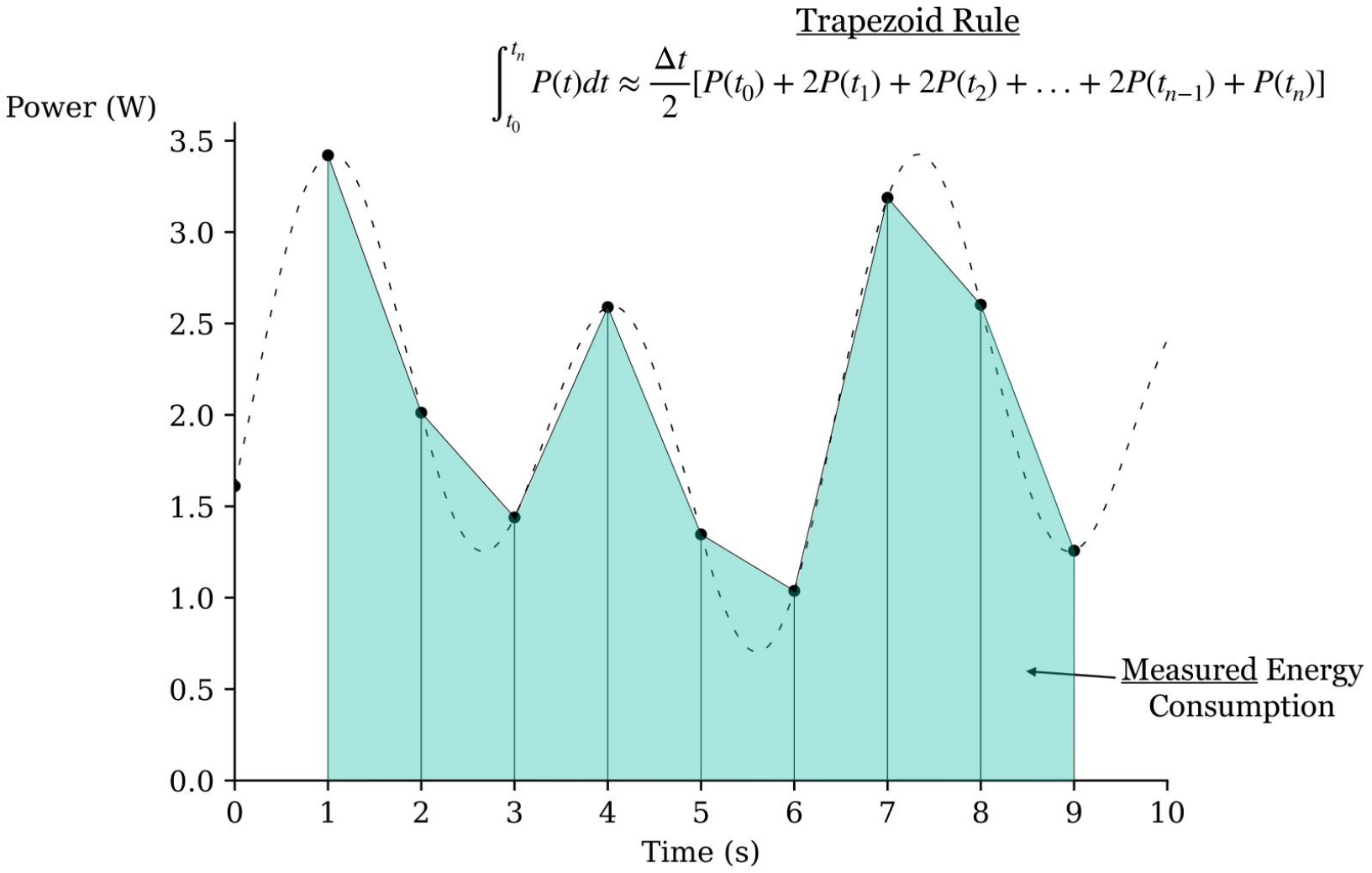
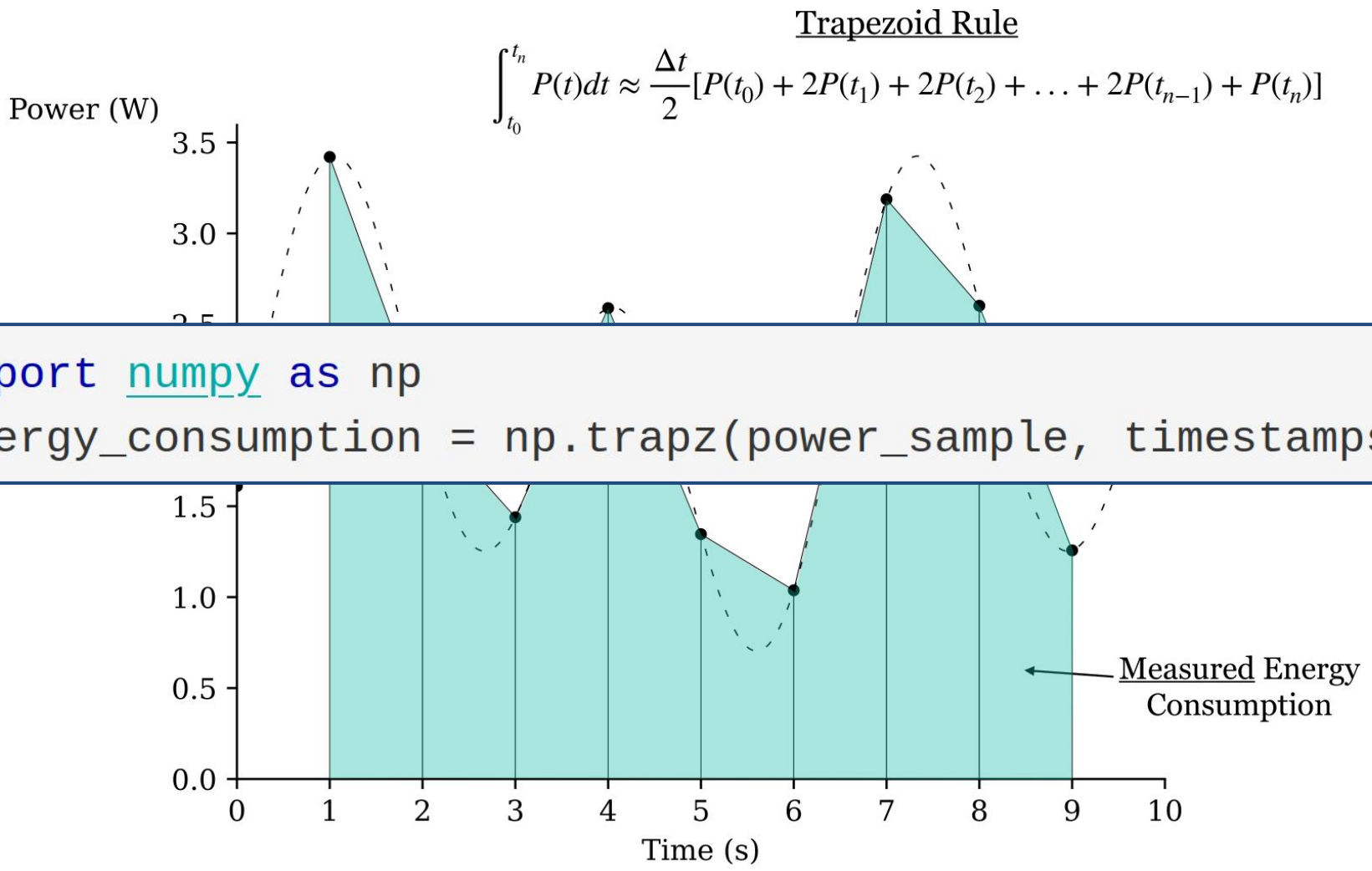
Electric Energy



Source: https://luiscruz.github.io/2023/05/13/energy-units.html

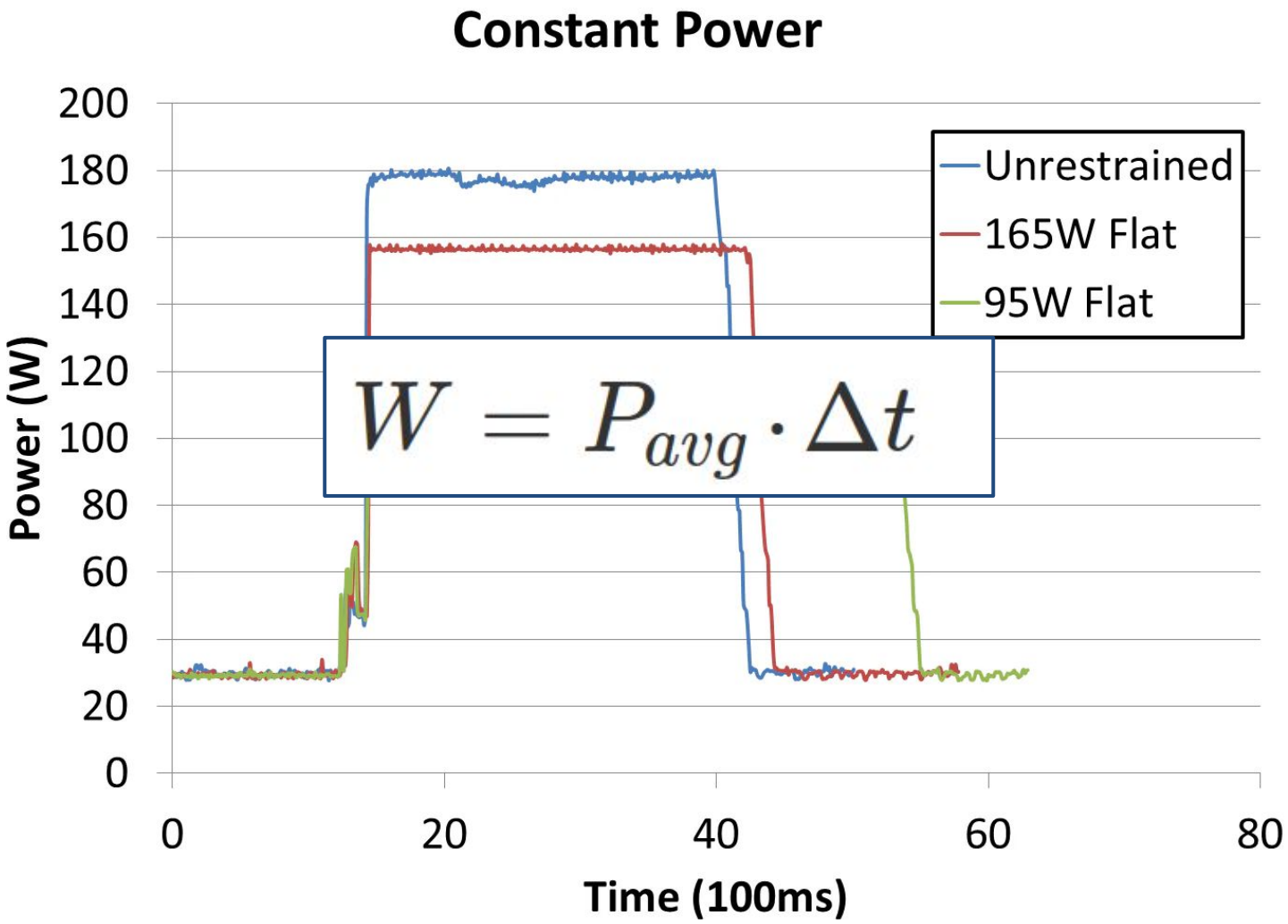
Electric Energy




```
import numpy as np
energy_consumption = np.trapz(power_sample, timestamps)
```

Source: https://luiscruz.github.io/2023/05/13/energy-units.html

Electric Energy



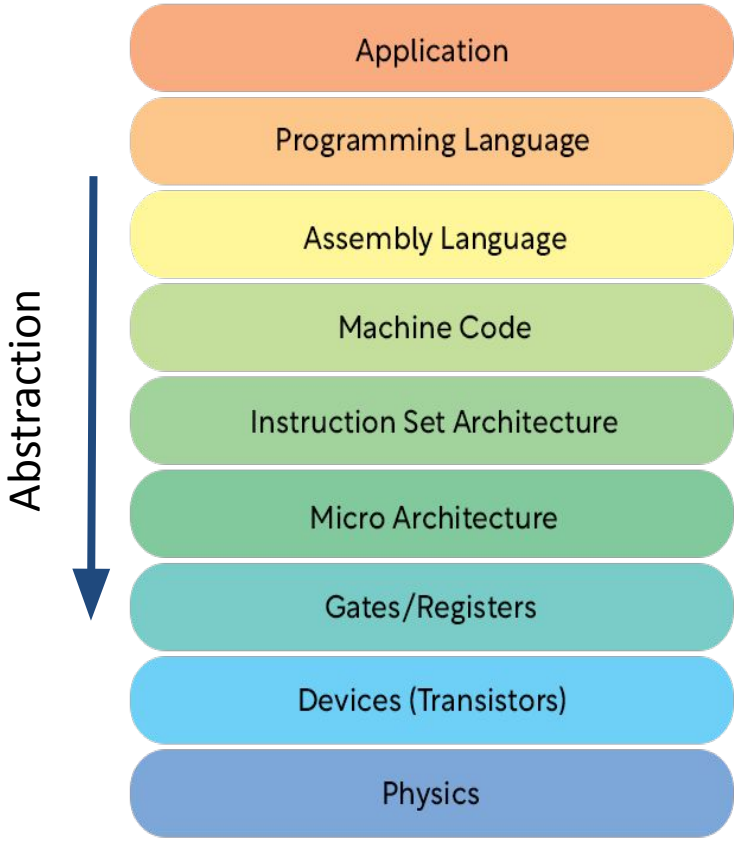
Source: https://softwareg.com.au/blogs/computer-hardware/cpu-tdp-vs-power-consumption

Software Energy Consumption

Software Energy Consumption: energy used by a computing device as a consequence of the instructions of a software system

Example: a CPU tasked with heavier calculations or more complex processes, engages more circuit components (transistors) and operates at higher clock frequencies.

We can **control** or **accurately** consider factors that might affect how much energy the device uses, in order **to focus on the impact of the software system.**



IMG: https://t.ly/HQ2q4
Fernando Castor, Estimating the Energy Footprint of Software Systems: a Primer, 2024

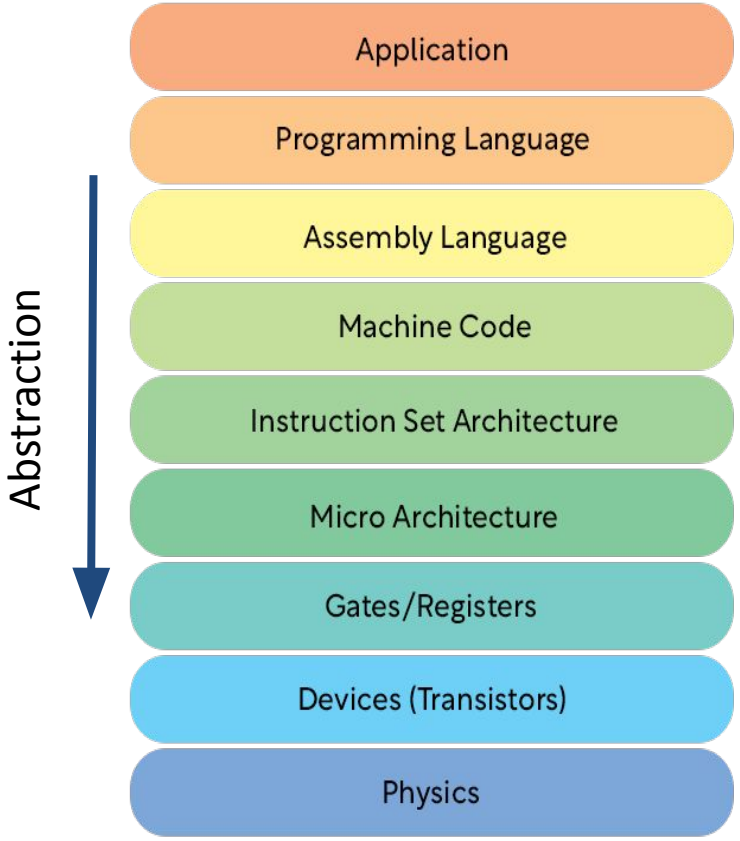
Software Energy Consumption

The **influence** of confounding factors of our measurements can be reduced by following a set of simple tips:

- **Control your testbed:** e.g., shut down unnecessary processes, plug off any hardware that is not required

Control the temperature of your testbed:

- **Warm Up:** carry out a series of tests to warm up the testbed
- **Cool Down:** include a break between runs to cool the testbed



Source: https://luiscruz.github.io/2021/10/10/scientific-guide.html

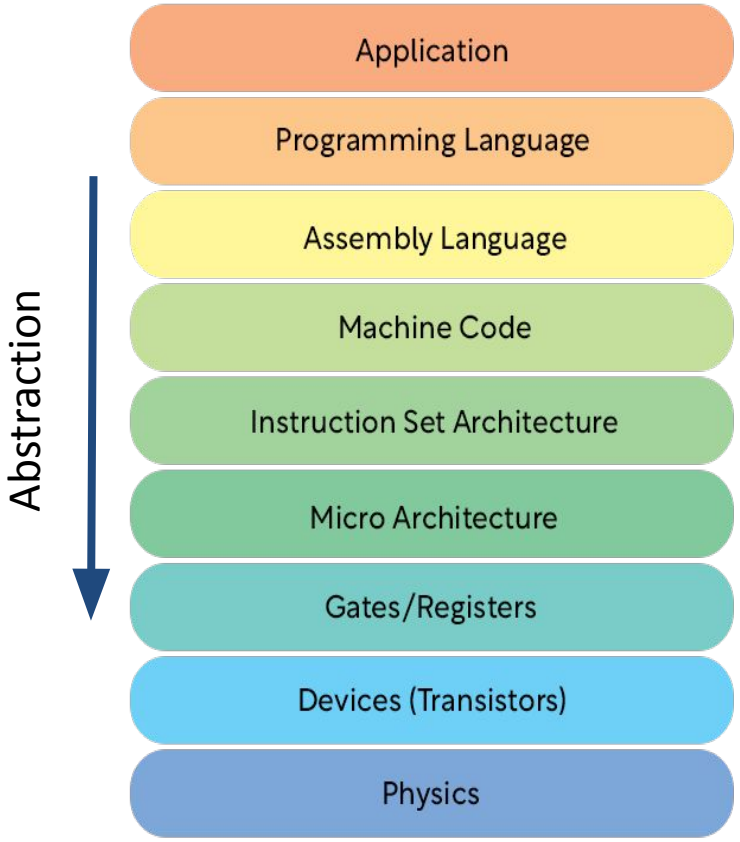
Software Energy Consumption

The **influence** of confounding factors of our measurements can be reduced by following a set of simple tips:

- **Randomize Runs:** subject characteristics could influence the measurements, if these characteristics are not a primary concern it is possible to randomize the runs to mitigate their impact

- **Automation:** reduce manual intervention during experiment orchestration

+ **Perform a dry run test and check the power distribution**



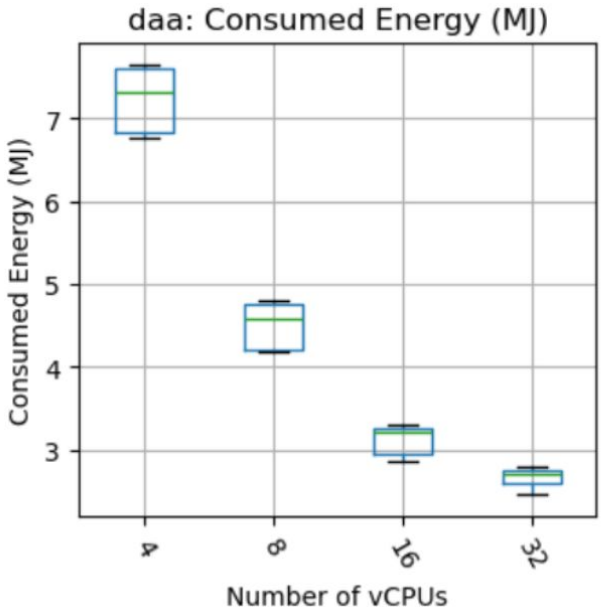
Source: https://luiscruz.github.io/2021/10/10/scientific-guide.html

Software Energy Consumption

Software is **intangible**; it cannot be touched, smelled, or seen. It consists of **pure logic** and automates the functions of hardware components.

Thus, comparing software energy consumption using **relative units** can help to better understand its impact.

I spent approximately 7 MJ running a software using 4 vCPUs for 18 hours



How many 10 W light bulbs did I spend during my experiment?

$$W = P_{avg} \cdot \Delta t$$

E = 10 W × 3600 s = 36,000 J

Number of Bulbs = 7000000 J / 36000 J =
I spent the equivalent of **194.4** light bulbs running for 1 hour

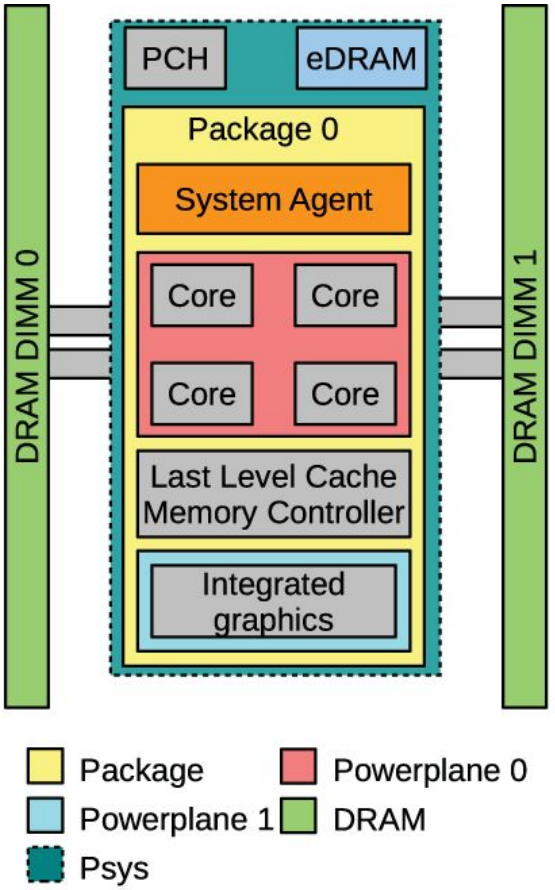
Measurement Techniques and Tools

Software Energy Profilers - Running Average Power Limit (RAPL)

Interface provided by Intel and implemented on **modern** Intel/AMD processors

- **PKG**: The entire package
  - PP0: The cores.
  - PP1: An uncore device, usually the GPU (not available on all processor models.)
- **DRAM**: main memory (not available on all processor models.)

The following relationship holds: PP0 + PP1 <= PKG. DRAM is independent of the other three domains.



https://firefox-source-docs.mozilla.org/performance/power_profiling_overview.html

VU

RAPL support

- Supported by Intel Processors since Intel **SandyBridge** Architecture **(2011)**
- Supported by AMD Processors since **AMD Family 17h** Processors **(2017)**
- NVIDIA has a similar interface called [NVML]

```
#define MSR_RAPL_POWER_UNIT     0x606

/*
 * Platform specific RAPL Domains.
 * Note that PP1 RAPL Domain is supported on 062A only
 * And DRAM RAPL Domain is supported on 062D only
 */
/* Package RAPL Domain */
#define MSR_PKG_RAPL_POWER_LIMIT    0x610
#define MSR_PKG_ENERGY_STATUS       0x611
#define MSR_PKG_PERF_STATUS     0x613
#define MSR_PKG_POWER_INFO      0x614
```

RAPL-based Tools: Intel Power Gadget (Windows/Mac), Powerstat/Powertop/perf (Linux), Powermetrics (Mac), SmartWatts (Linux), PyJoular (Linux)

You will see them in action during LAB1!!

VU

RAPL support

- install `msr-tools` and read registers can be read

Supported

```
vincenzo@GreenLab-STF:/sys/devices/platform$ sudo rdmsr 0x606
a0e03
```

Not Supported

```
(base) vincenzo@gl4:/sys/devices/platform$ sudo rdmsr 0x606
rdmsr: CPU 0 cannot read MSR 0x00000606
```

- check and read Linux kernel directories

```
ls /sys/class/powercap/

sudo cat /sys/class/powercap/intel-rapl/intel-rapl:0/energy_uj
```

- check if processes can read kernel files

```
sudo perf stat -a -e "power/energy-cores/" /bin/ls
```

VU

RAPL support

- ins

Suppo

Not S

- c

```
ls /sy
sudo c
```

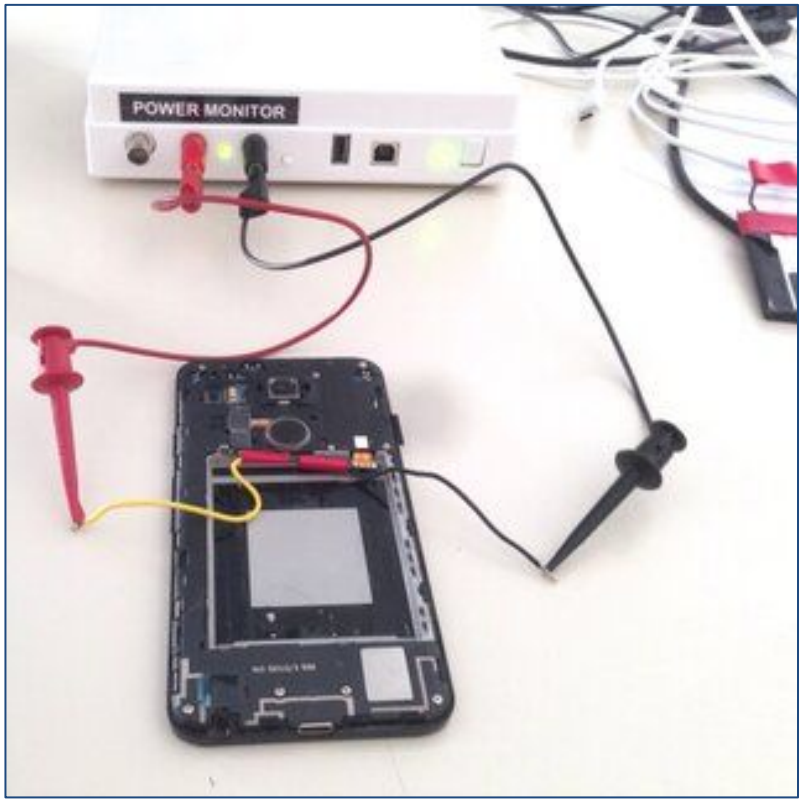
- c

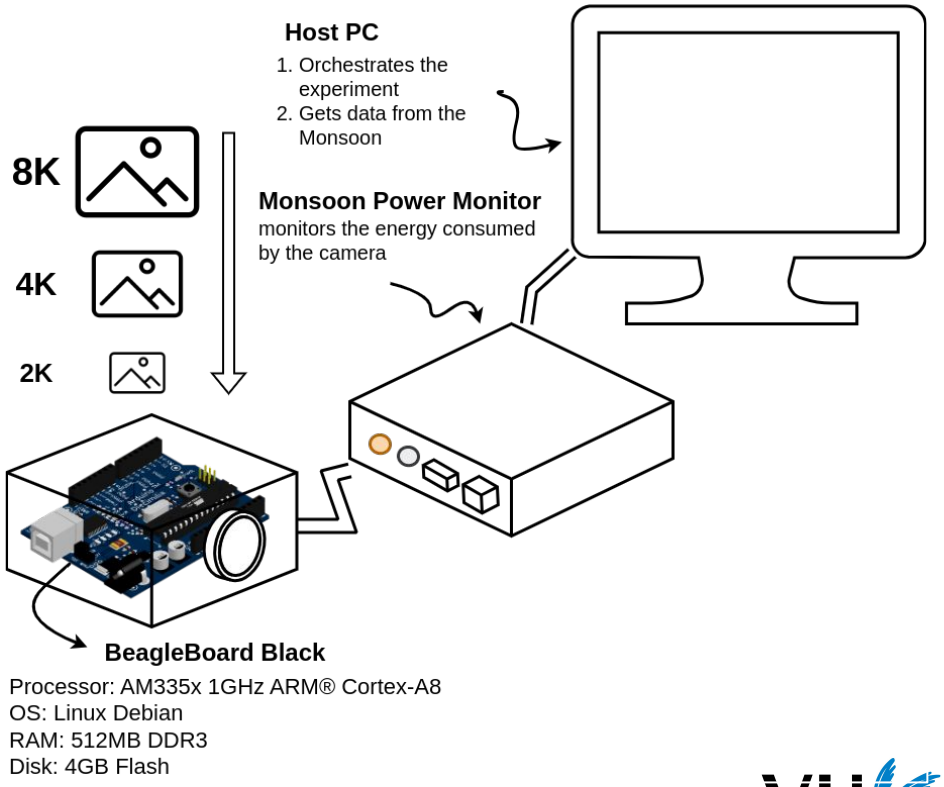
```
sudo p
```

```
→  intel-rapl cat enabled
1
→  intel-rapl ls -la intel-rapl:0
total 0
drwxr-xr-x 5 root root    0 23 jul 18:22 .
drwxr-xr-x 5 root root    0 23 jul 18:22 ..
-r--r--r-- 1 root root 4096 23 jul 18:22 constraint_0_max_power_uw
-r--r--r-- 1 root root 4096 23 jul 18:22 constraint_0_name
-rw-r--r-- 1 root root 4096 23 jul 18:22 constraint_0_power_limit_uw
-rw-r--r-- 1 root root 4096 23 jul 18:22 constraint_0_time_window_us
-r--r--r-- 1 root root 4096 23 jul 18:22 constraint_1_max_power_uw
-r--r--r-- 1 root root 4096 23 jul 18:22 constraint_1_name
-rw-r--r-- 1 root root 4096 23 jul 18:22 constraint_1_power_limit_uw
-rw-r--r-- 1 root root 4096 23 jul 18:22 constraint_1_time_window_us
-r--r--r-- 1 root root 4096 23 jul 18:22 constraint_2_max_power_uw
-r--r--r-- 1 root root 4096 23 jul 18:22 constraint_2_name
-rw-r--r-- 1 root root 4096 23 jul 18:22 constraint_2_power_limit_uw
-rw-r--r-- 1 root root 4096 23 jul 18:22 constraint_2_time_window_us
lrwxrwxrwx 1 root root    0 23 jul 18:22 device -> ../../intel-rapl
-rw-r--r-- 1 root root 4096 23 jul 18:22 enabled
-r-------- 1 root root 4096 23 jul 18:22 energy_uj
drwxr-xr-x 3 root root    0 23 jul 18:22 intel-rapl:0:0
drwxr-xr-x 3 root root    0 23 jul 18:22 intel-rapl:0:1
-r--r--r-- 1 root root 4096 23 jul 18:22 max_energy_range_uj
-r--r--r-- 1 root root 4096 23 jul 18:22 name
drwxr-xr-x 2 root root    0 23 jul 18:22 power
lrwxrwxrwx 1 root root    0 23 jul 18:22 subsystem -> ../../../../../class/powercap
-rw-r--r-- 1 root root 4096 23 jul 18:22 uevent
```

Hardware Power Monitors

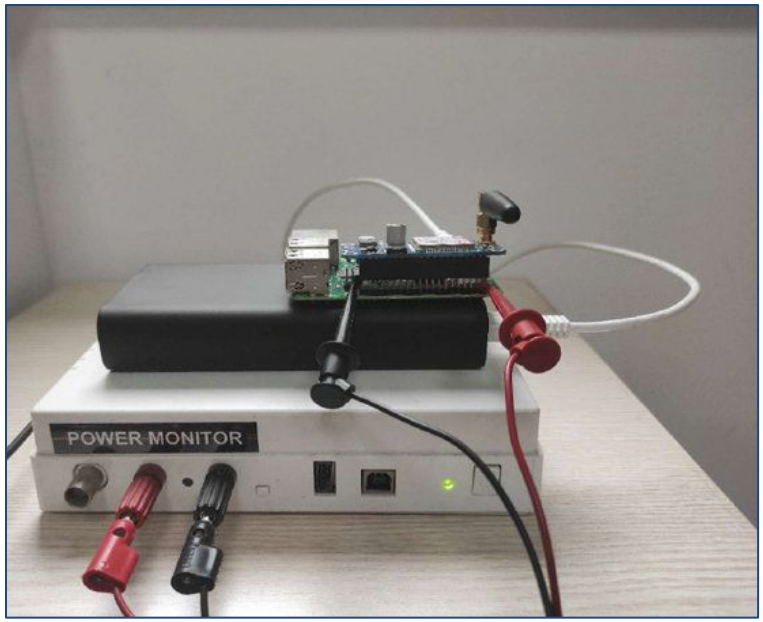
- The **Monsoon Power Monitor** is particularly valuable in environments where precise power measurement is critical.
- [PyMonsoon] is a python library to control and get measurements from the Monsoon

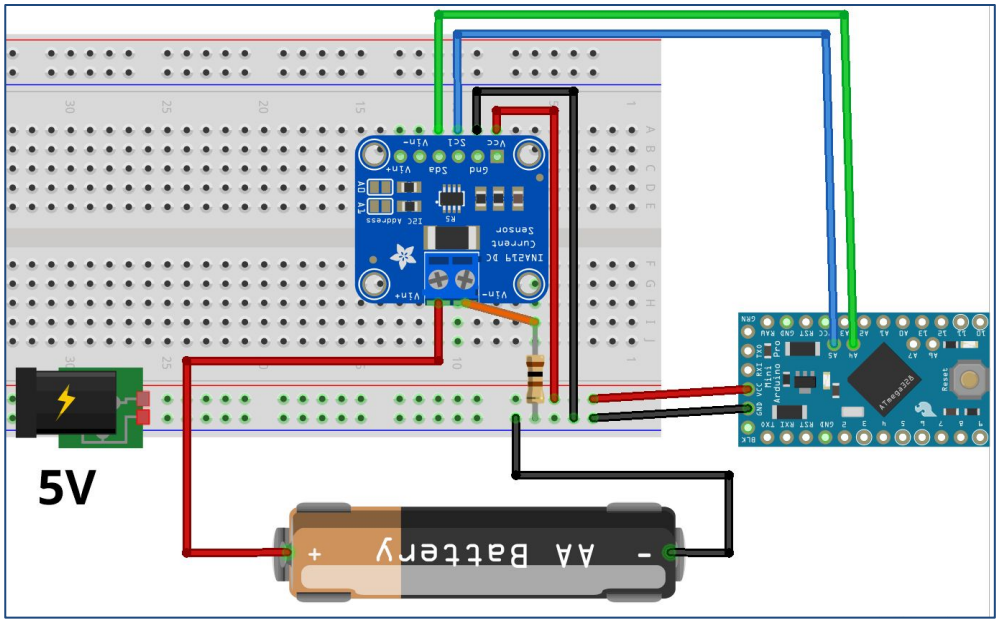




Hardware Power Monitors

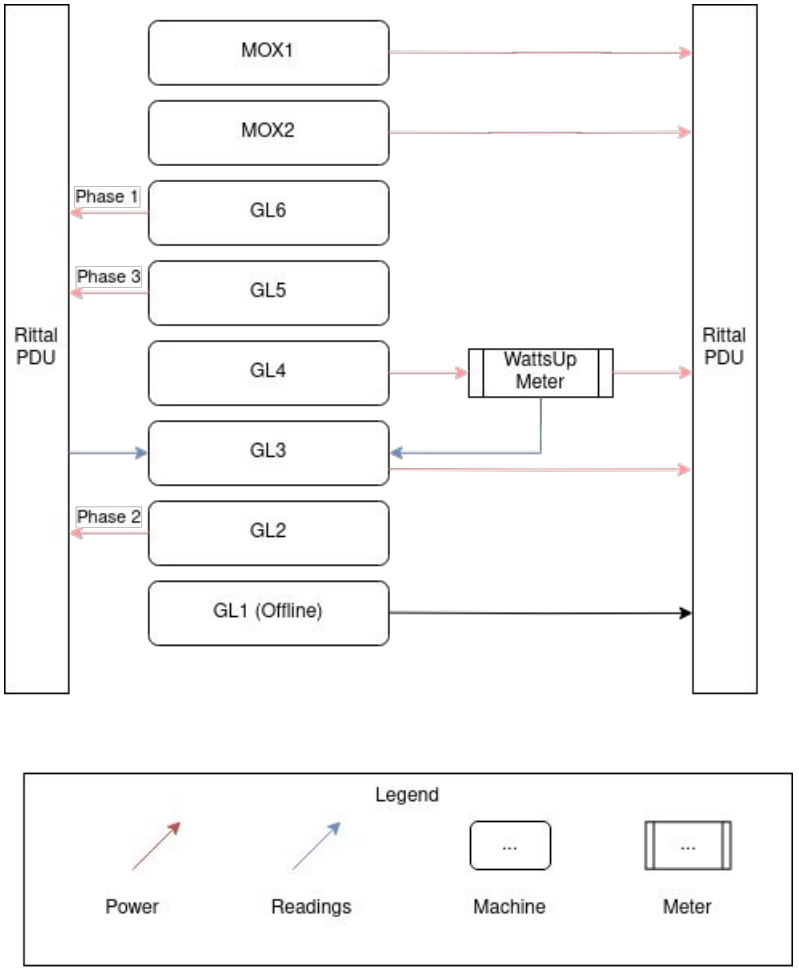
The **Monsoon Power Monitor** is not portable…. Sensors like **INA219** can be useful to track the energy consumption of embedded systems!





Hardware Power Monitors

To profile **servers** and **laptops**, you can connect a **profiler** between the **device** and the **power source**.



Hardware Power Monitors

To profile **servers** and **laptops**, you can connect a **profiler** between the **device** and the **power source**.

Any Questions?

v.stoico@vu.nl

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LOOKING FURTHER

SOURCE: https://youtu.be/UqJJktxCY9U?si=esVrqrMBJQCyNp6l