

The Hidden Cost of Computing

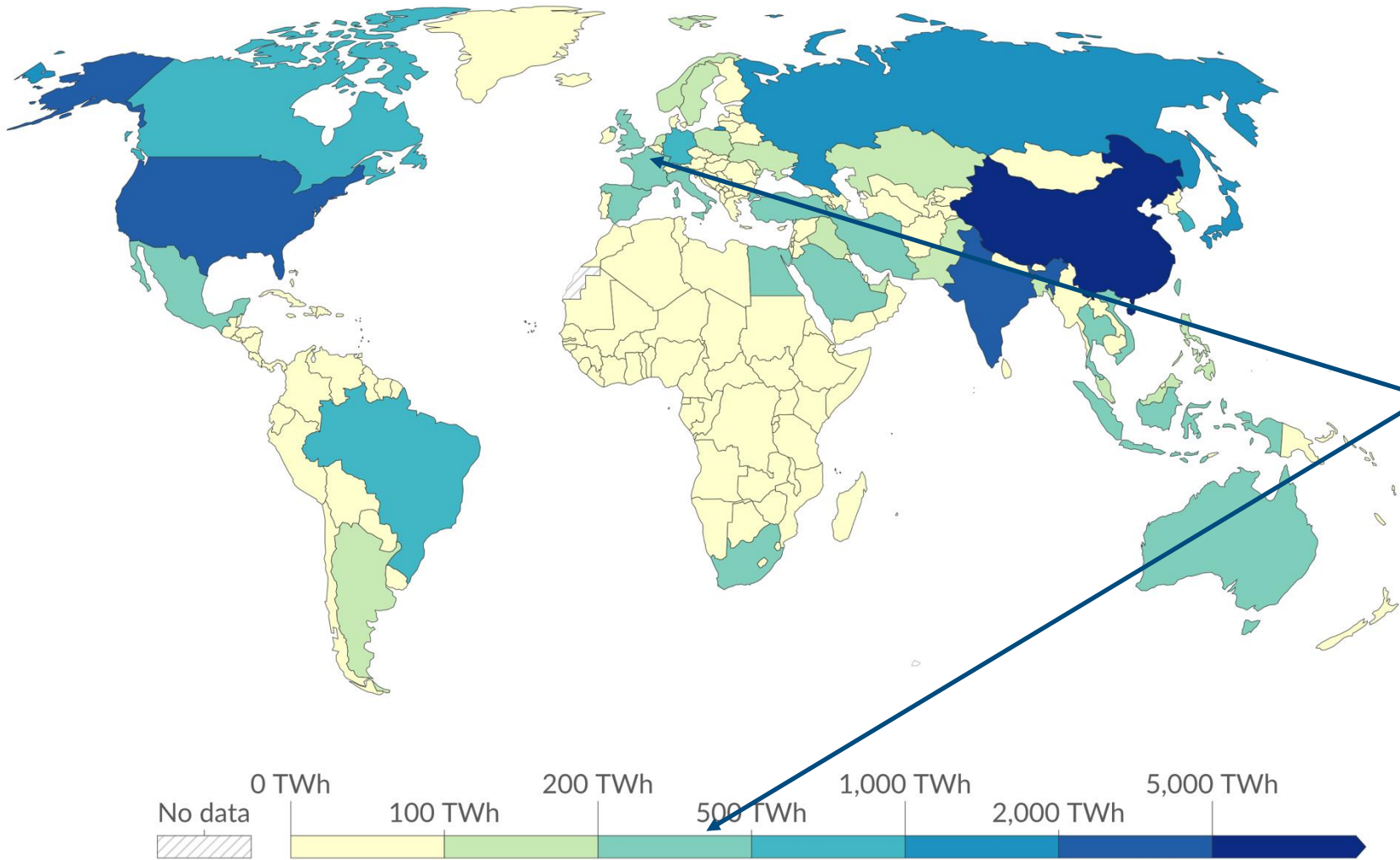
Energy from Data Centers to Algorithms

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PIER PhD reception
Hamburg 19.6.2026



Electricity demand, 2024

Electricity demand is measured in terawatt-hours¹, as total electricity generation, adjusted for electricity imports and exports.



**All data centers:
2024: 415 TWh**

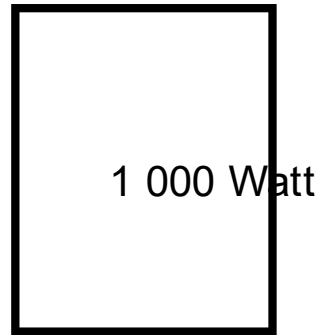
**Equivalent to
France (#10)**

Sources:
IEA (2024), Energy and AI

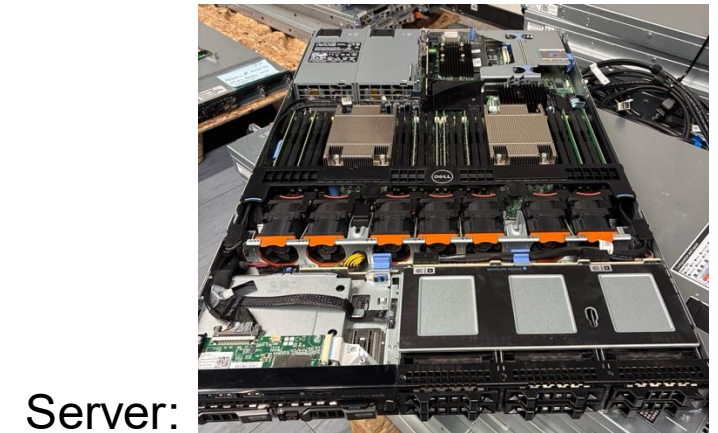
Our World in Data (2024),
based on Ember & Energy Institute
<https://ourworldindata.org/grapher/electricity-demand>

Wh : Watt Hour: quite an unhandy unit. What does it mean?

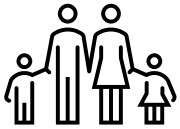
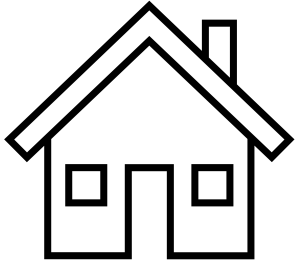
Disclaimer: Approximate numbers, order of magnitude only!



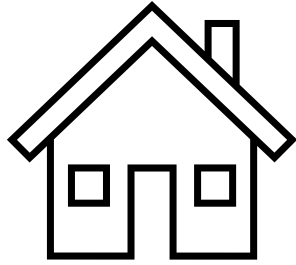
Data center (e.g. Amazon)
10-100 MW / DESY: 1.3 MW



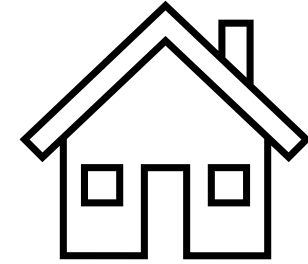
My house as a reference for energy consumption:



My house:
3 000 kWh/year



DESY datacenter
Equivalent to
4 000 houses



Datacenters worldwide
Equivalent to
140 million houses

```
1  #include <iostream>
2
3  int main() {
4      std::cout << "Hello, World!\n";
5      return 0;
6  }
```

Every line of code runs somewhere.
And this "somewhere" consumes real energy.

Data centers! Why do you consume so much energy?

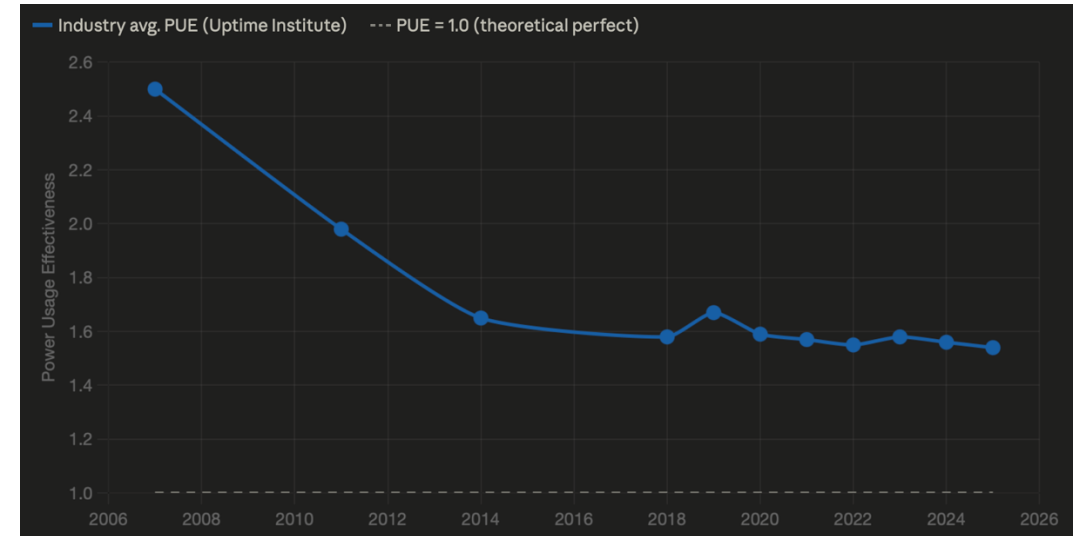


Well, we operate a lot of:

- Compute server
- Data server
- Network devices
- Cooling equipment (Chillers, ventilation, ...)
- Power systems (battery, conversion, ...)
- Lighting
- ...

$$\text{PUE} = \frac{\text{IT Equipment Energy} + \text{Facility Overhead}}{\text{IT Equipment Energy}}$$

(Power Usage Effectiveness)



With given Equipment:

- More efficient cooling
- More efficient battery backup (UPS) – or no backup at all (?)
- More efficient power distribution

→ **Reduces Overhead**

PUE = (Power Usage Effectiveness)

$$\text{PUE} = \frac{\text{IT Equipment Energy} + \text{Facility Overhead}}{\text{IT Equipment Energy}}$$

With given workload:

- More efficient CPU architectures
 - More efficient data storage
 - More efficient utilization
 - Faster renewal of hardware (?)
- Does not reduce PUE, but **saves Energy**

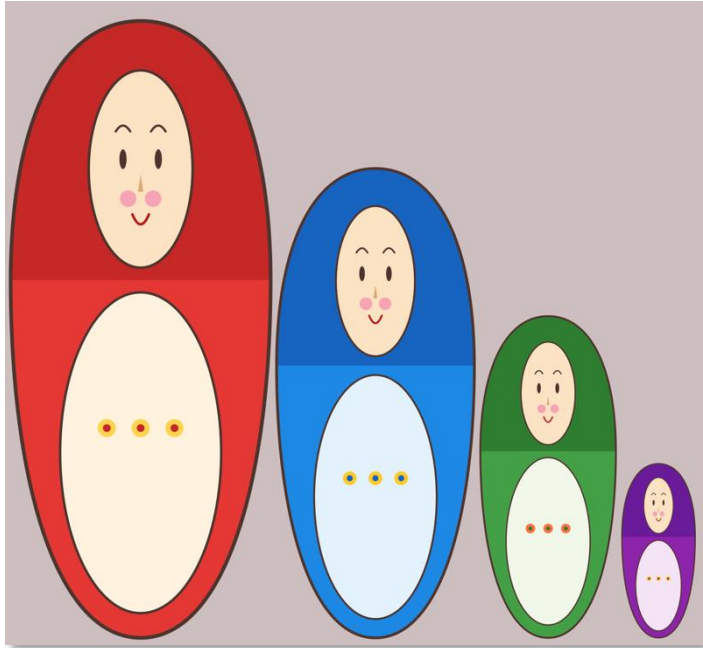
**All electricity goes to heat.
Can't you reuse the heat?**

Software:

**Every line of code that does
not get executed saves energy**

Software implements Algorithms

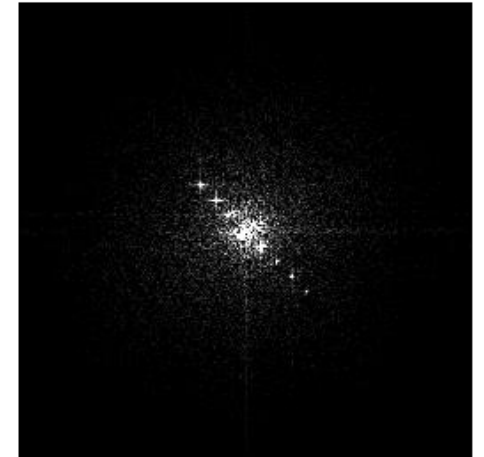
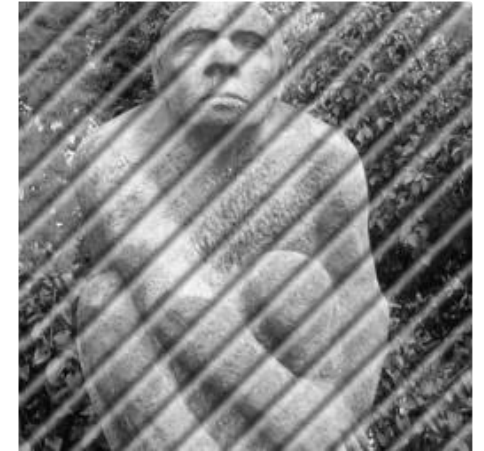
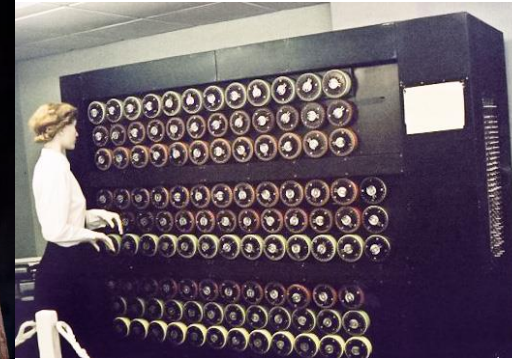
Some examples of ubiquitous algorithm families



Sorting Algorithms



Cryptographic Algorithms



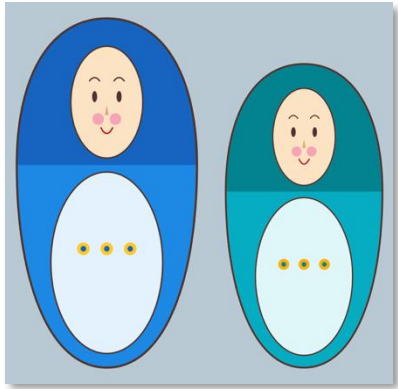
Fourier Transformation

Matryoshka, generated by claude.ai

William Warby, CC BY 2.0, via Wikimedia Commons

Messybeast, CC BY 2.5, via Wikimedia Commons

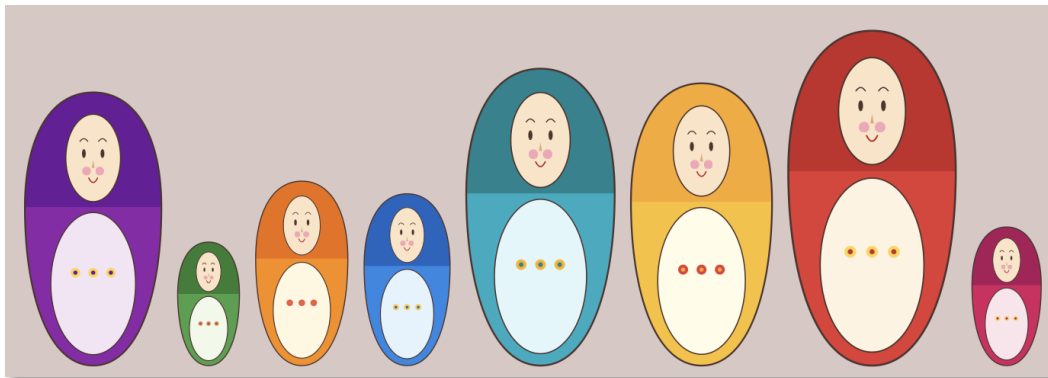
Scaling behavior of algorithms and implementations



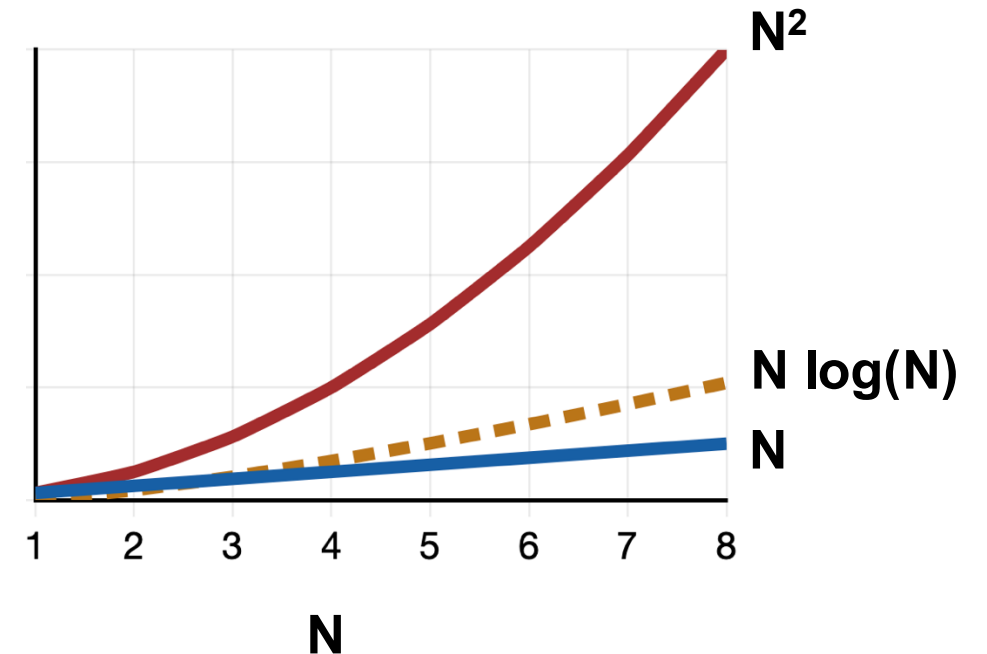
N = 2

N = 2 is easier (faster, less expensive) than N = 8

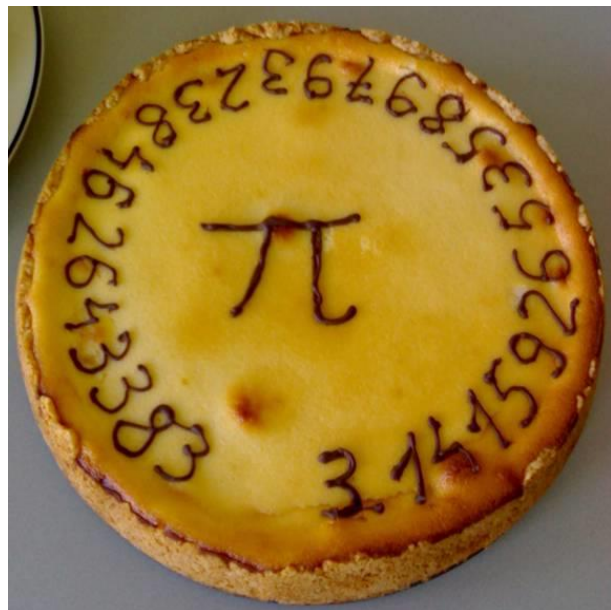
But how much?



N = 8

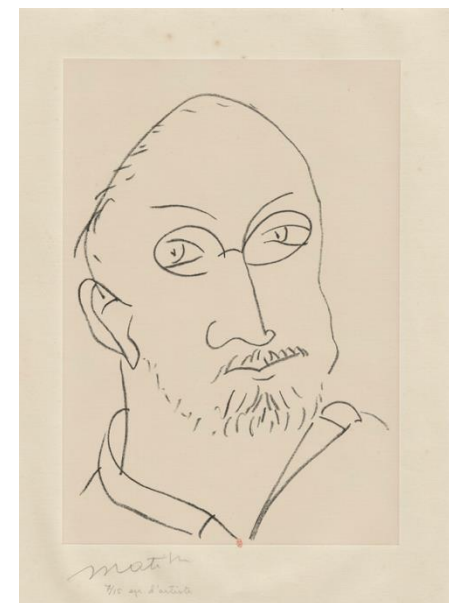
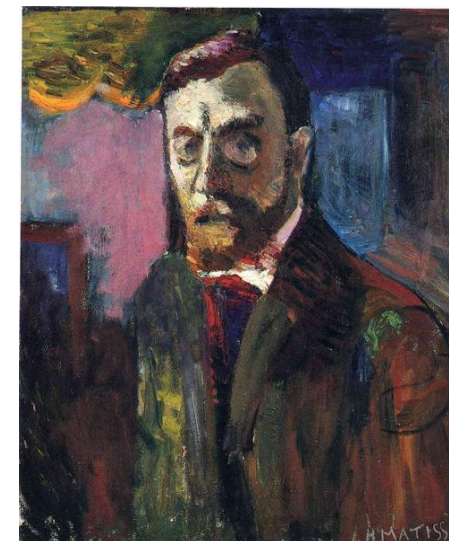


Runtime is not everything: RAM and storage usage



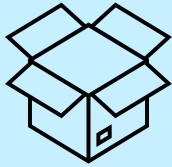
Which precision do you need?
Double precision float? 64 bit
Single precision float? 32 bit
Or even less?

Compress your data.
You save storage.
And you can analyze faster



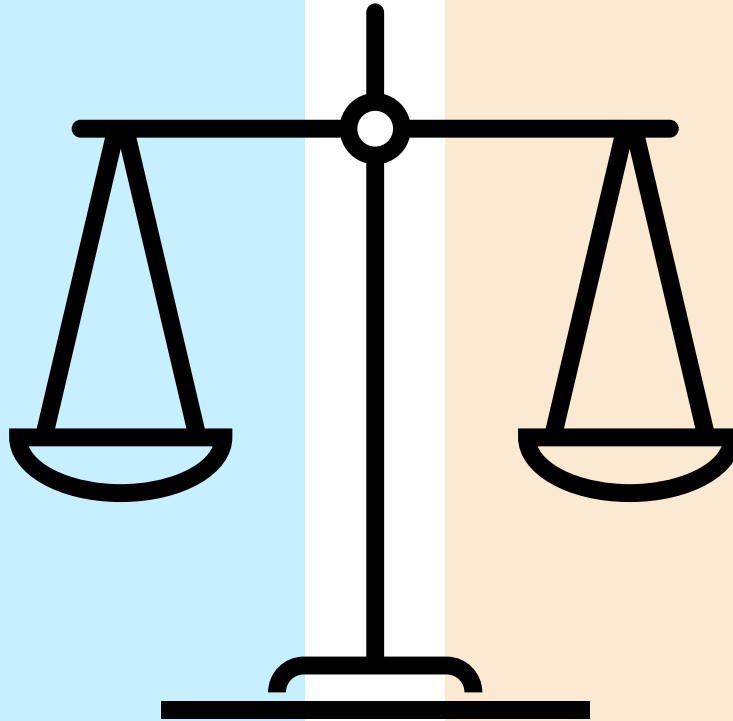
Henri Matisse:
- Self portrait
- Grand masque
(Source: Wikimedia)

Reuse or write yourself?

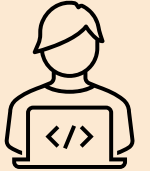


Use a Library

- + Tested, optimized, ready
- Generic, know limits

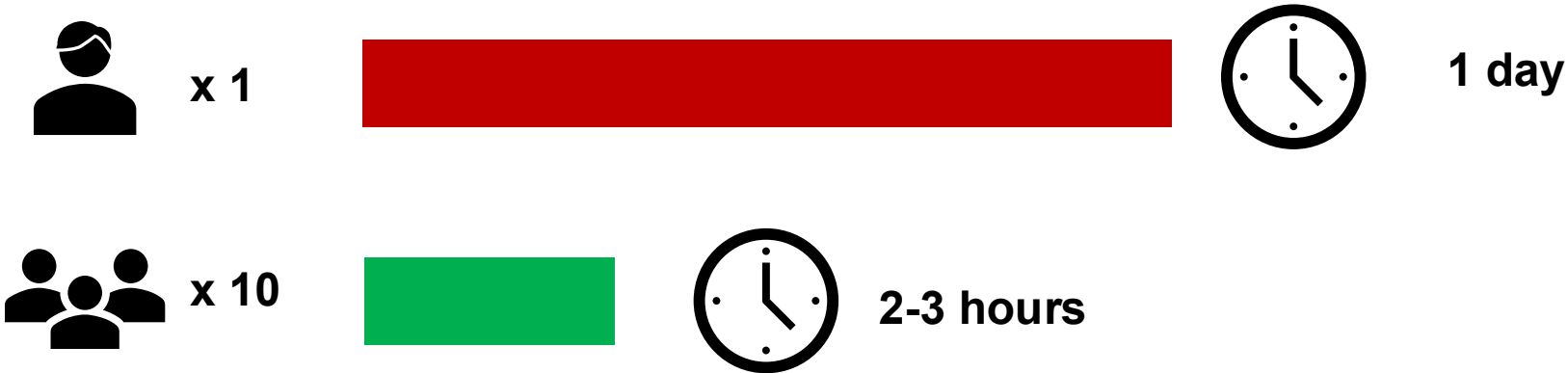


Write Your Own



- + Fits your problem
- You write and maintain

Many Hands Finish Faster: Parallelization



Time behavior:
Analyze several files in parallel.
Faster? Efficient?

A screenshot of a file explorer window showing a list of files in a directory named 'data > 2024 > experiments'. The table has columns for NAME, SIZE, DATE MODIFIED, and KIND. It lists eight TIFF image files with names like 'experiment-1592-image-0423.tif' and sizes ranging from 9.7 MB to 10.4 MB. At the bottom, it indicates '1,024 files · 10 GByte'.

NAME	SIZE	DATE MODIFIED	KIND
experiment-1592-image-0423.tif	9.8 MB	2024-03-14 09:21	TIFF image
experiment-1592-image-0424.tif	10.1 MB	2024-03-14 09:21	TIFF image
experiment-1592-image-0425.tif	9.9 MB	2024-03-14 09:22	TIFF image
experiment-1592-image-0426.tif	10.4 MB	2024-03-14 09:22	TIFF image
experiment-1592-image-0427.tif	9.7 MB	2024-03-14 09:23	TIFF image
experiment-1592-image-0428.tif	10.2 MB	2024-03-14 09:23	TIFF image
experiment-1592-image-0429.tif	9.9 MB	2024-03-14 09:24	TIFF image
experiment-1592-image-0430.tif	10.0 MB	2024-03-14 09:24	TIFF image

1,024 files · 10 GByte

Real-World Example of Code with a severe bug

Actually seen in published analysis framework

```
analysis.py
```

```
results = []
```

```
for event in events:    # N events
```

```
    open(file)           # opened EVERY time
```

```
    e = read(event)
```

```
    results += analyze(e)
```

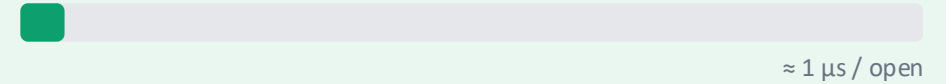
```
    close(file)          # ...and closed again
```



open() + close() repeat for all N events



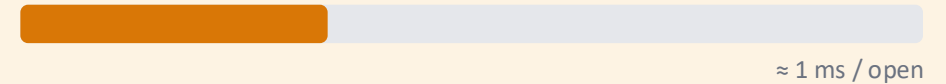
Laptop · local SSD



Basically no effect — the OS cache absorbs the repeated opens.



Cluster file system



Visible slowdown — plus extra load on the shared metadata server.



Object-store-like FS



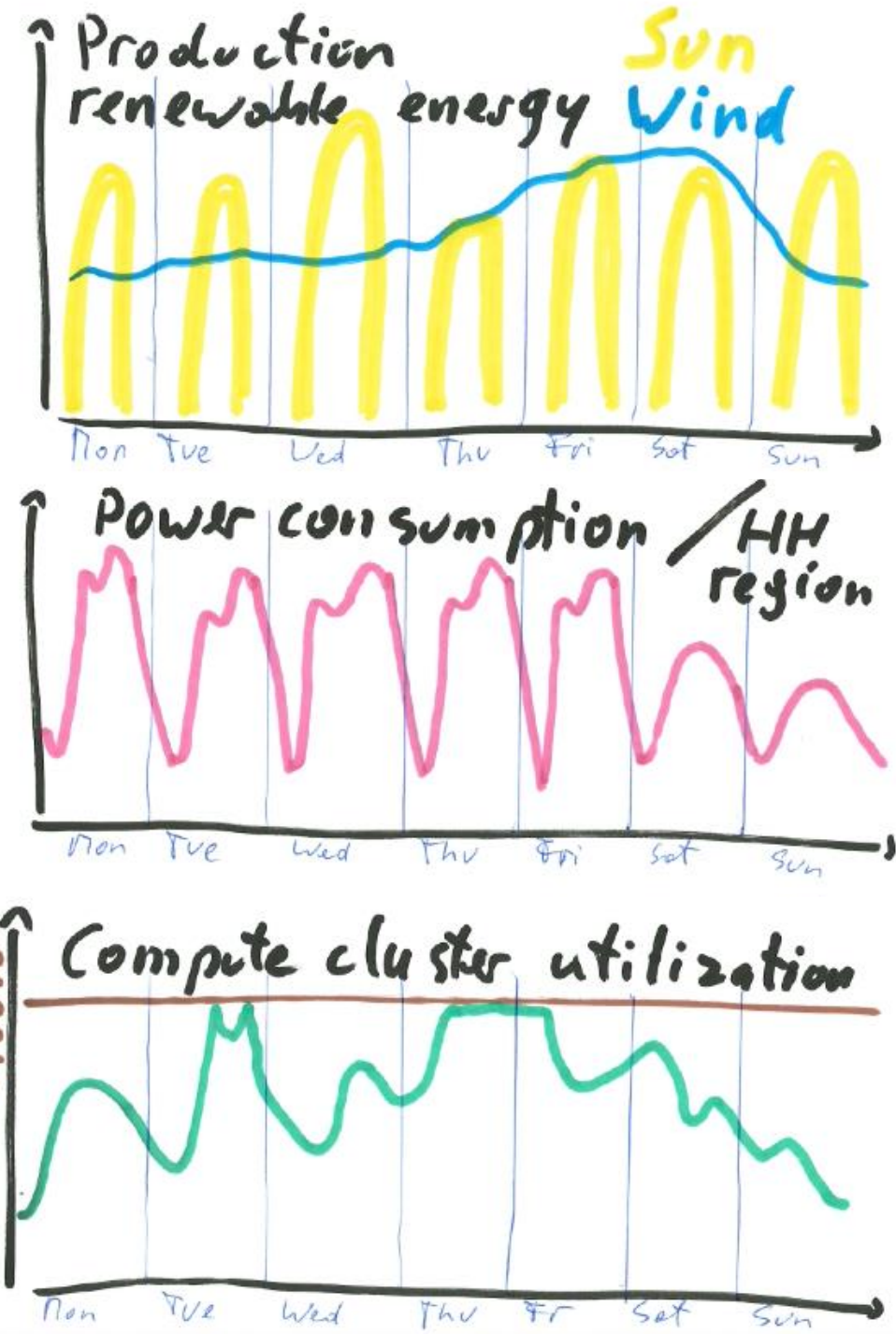
Run time is unbearable, totally dominated by bug.

The Sun does Not Always Shine!

[citation needed]

Research topic of my group:

- Make compute clusters “breathable”
- Interface with electricity providers and weather forecast
- Users will notice: Fast response will be more expensive than “can wait”
- Regulatory frameworks needs to change



OK,

**now, you made your code and
data center much more efficient.**

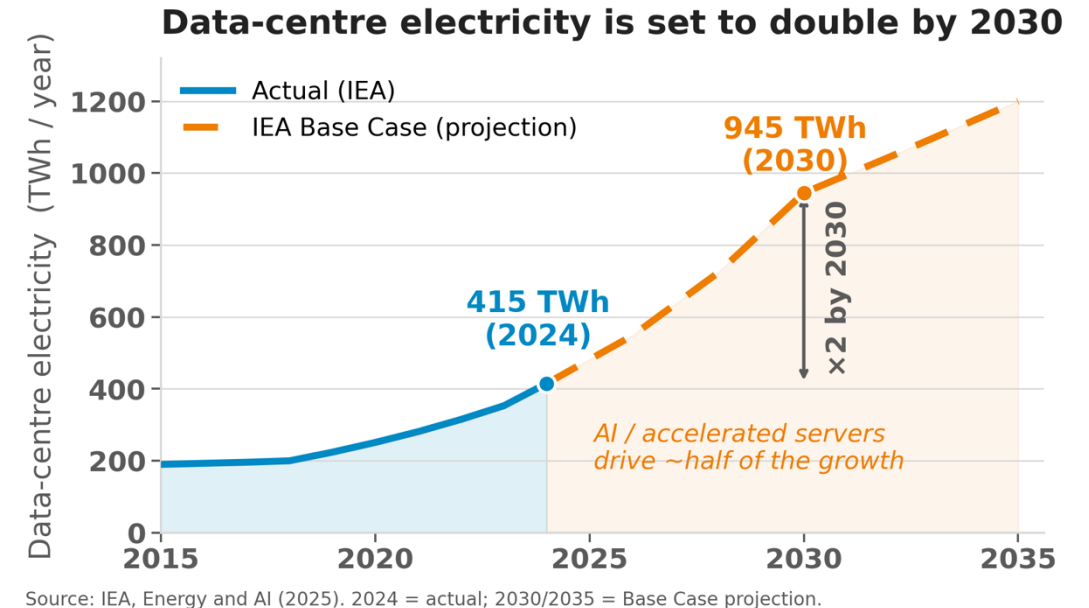
What next?

The Rebound Effect

Do the same with less energy

Use the same energy, but do more

Efficiency opens new doors:
Use more energy to do much more



Some AI numbers:

- Training: LLAMA3.1 405B (2024): 22–30 GWh
- Operating: 4x-5x training (per year)
- Single query/prompt: ~0.3 Wh ... ~ 30 Wh

Disclaimer: Order of magnitude, estimate only
Subject to change

Summary & Outlook



Many more aspects: E.g.:

Hardware $\leftrightarrow$ Environmental impact / Location of resources $\leftrightarrow$ Renewables / Sovereignty



Science and Society in general rely on Computing



Hidden costs do exist – Know them!



Efficiency is our common Scientific and Social Responsibility