Complexity and energy efficiency

Joris van der Hoeven

LIX, Palaiseau

December 7, 2023

Complexity and energy efficiency, among others

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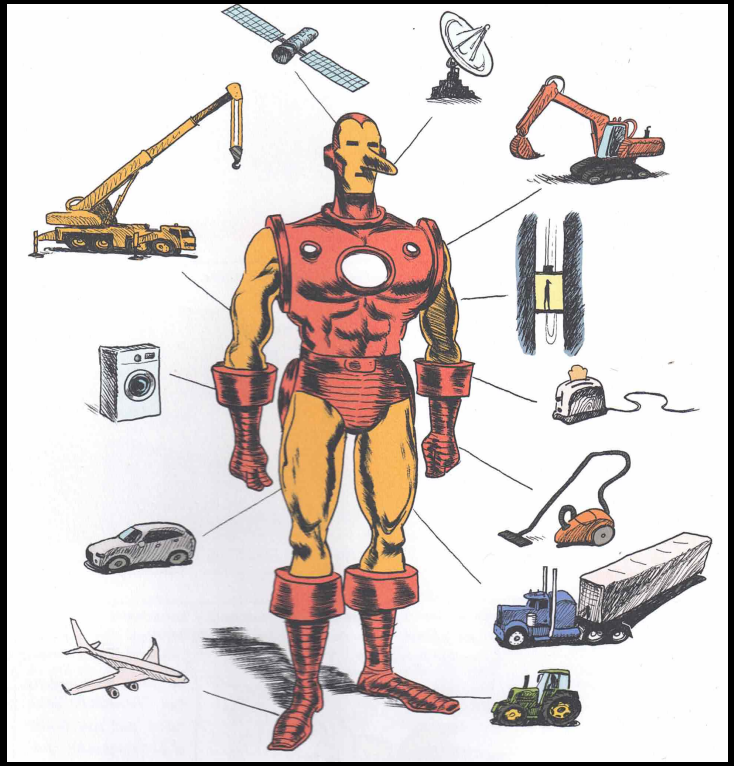
Part I

Energy efficiency — which solutions ?

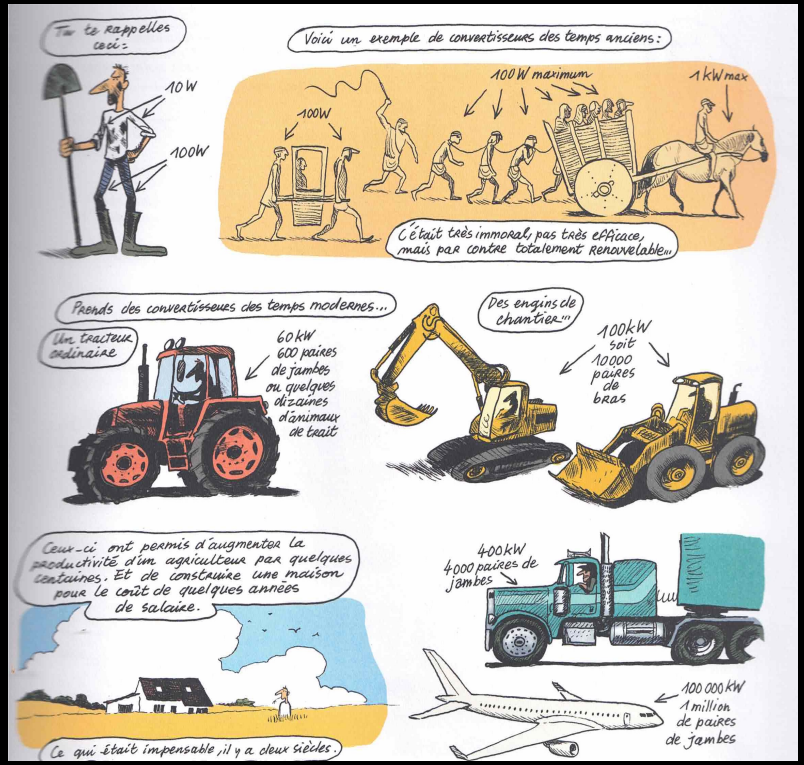
Digression — lessons from ecology

20th Century Man & favorite drink



Energy is RIDICULOUSLY cheap

600 legs



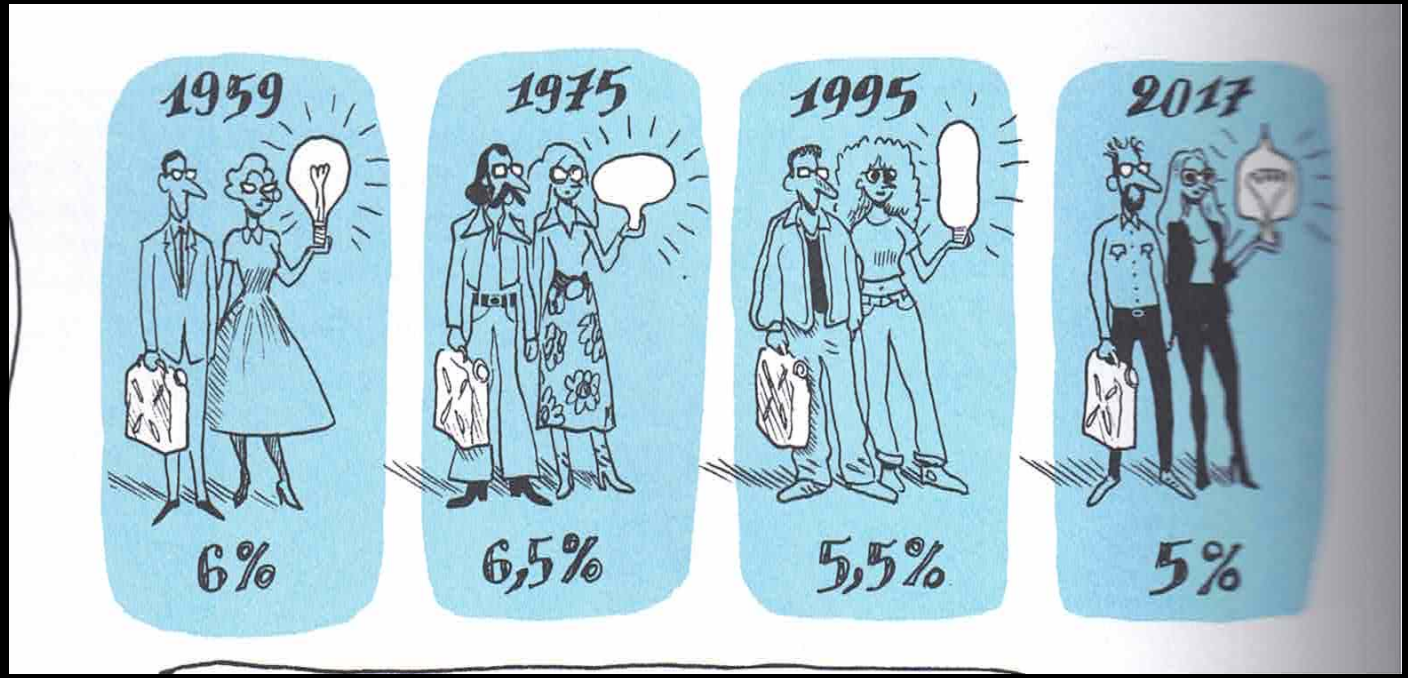
10 000 arms

4 000 legs

1 000 000 legs

Energy is RIDICULOUSLY cheap

Percentage of household money spent on energy



Kaya's equation

Goal: divide CO_2 by 3 before 2050 (to contain temperature growth to 2^{o} C)

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$$CO_2 = \frac{CO_2}{GEC} \times \frac{GEC}{GDP} \times \frac{GDP}{POP} \times POP$$

- CO_2: emission of CO_2
- GEC : global energy consumption
- GDP : global gross domestic product
- POP : world population

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POP $\rightarrow \times 1.3$ (unless objections by the audience)

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POP $\rightarrow$ $\times 1.3$ $\quad \frac{GDP}{POP} \rightarrow \times 2.2$ (or renounce retirement benefits)

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Hence?

Negative growth will be inevitable

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Three main ways to act:

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- Improve energy efficiency $\longrightarrow$ technological problem

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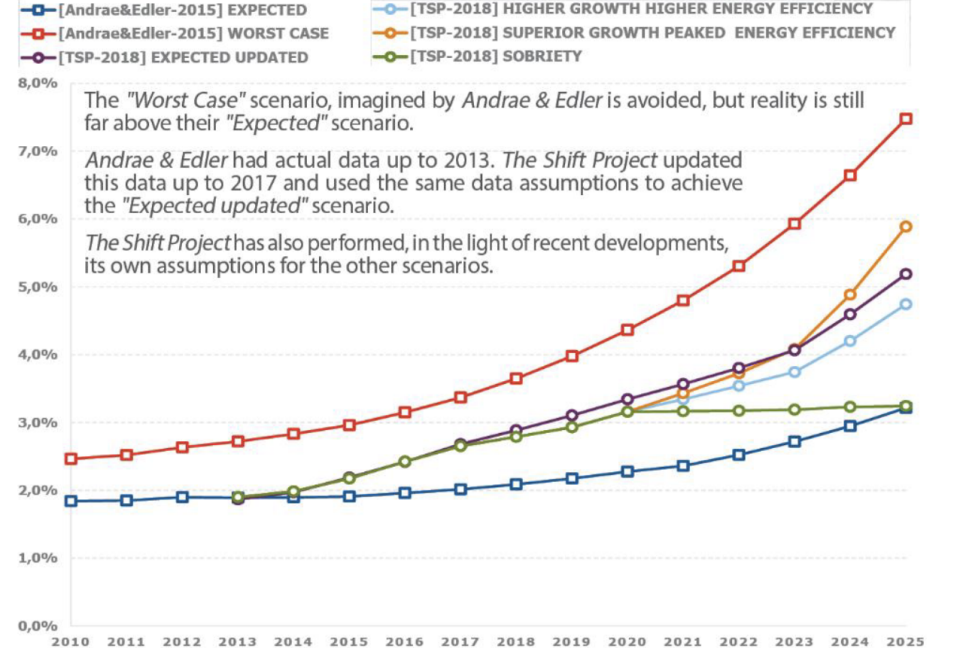
Negative growth will be inevitable

Three main ways to act:

- Improve energy efficiency $\longrightarrow$ technological problem
- Organize “energy sobriety” $\longrightarrow$ chosen reduction of consumption
- Make energy too expensive $\longrightarrow$ suffered reduction of consumption

21th Century Man

Energy footprint of the ICT sector

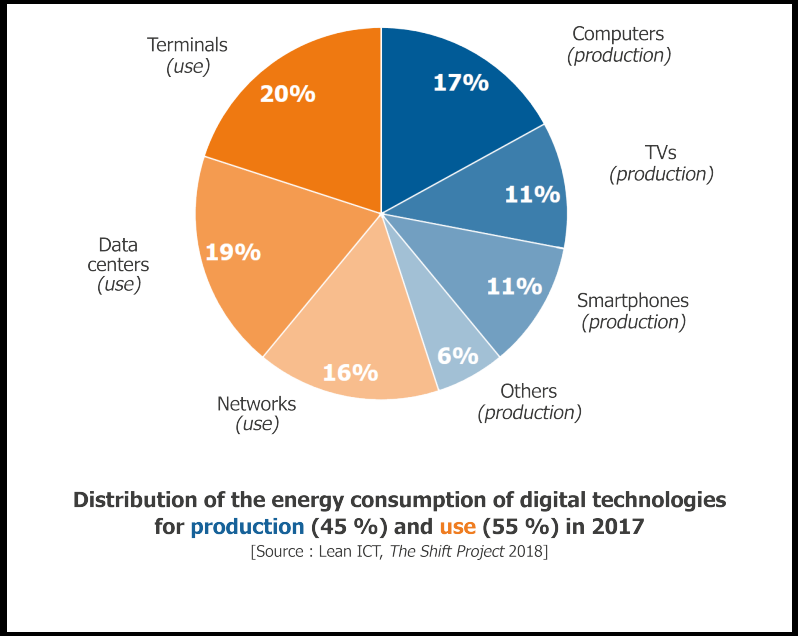


Evolution of global energy consumption of digital between 2010 and 2025, as a proportion of total world energy consumption

[Source: *The Shift Project 2018*, as of Andrae & Edler 2015]

Energy footprint ICT — total mix

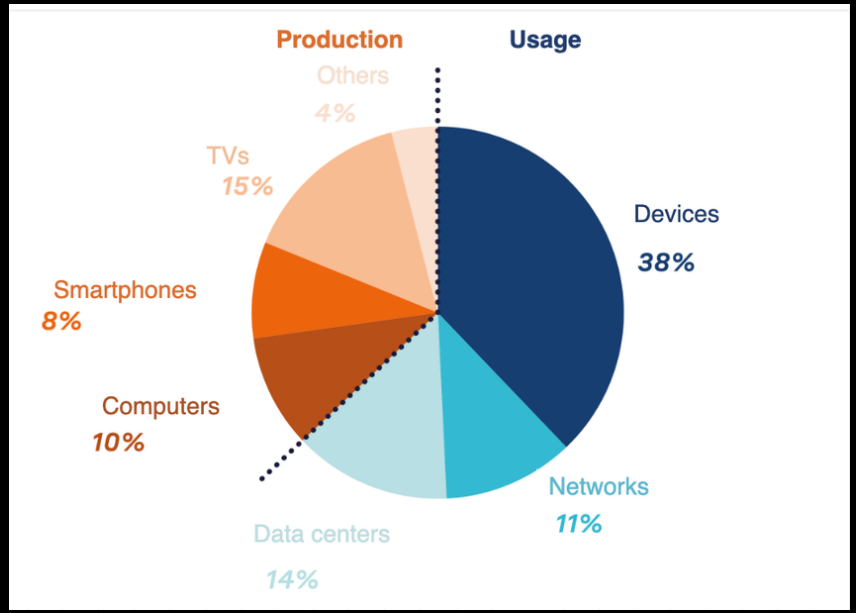
2017



Distribution of the energy consumption of digital technologies for production (45 %) and use (55 %) in 2017

[Source : Lean ICT, *The Shift Project* 2018]

2019



Energy footprint ICT — manufacturing

« The reality is that the energy requirements of semiconductor and nano-material manufacturing processes can be 5-6 orders of magnitude greater than the traditional manufacturing processes used to build, say, an automobile. To manufacture a kilogram of state-of-art integrated circuits requires tens of thousands of megajoules [49], in contrast with no more than 10 megajoules for conventional manufacturing [46]. The scope of manufacturing is here Raw Material Acquisition, Production of Parts, Assembly of the Devices and Distribution to Use. These life cycle phases are defined by the ETSI LCA standard for ICT [50]. »

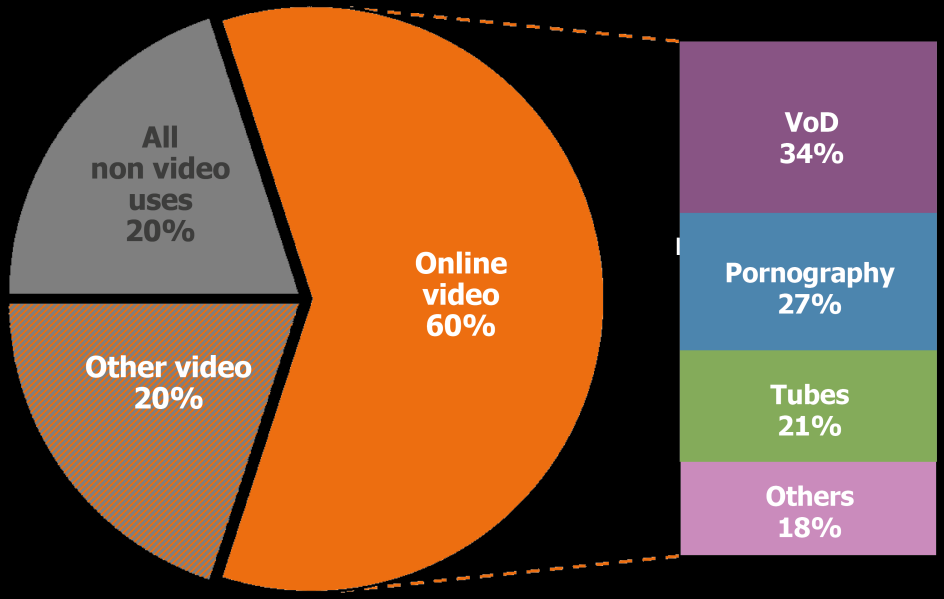
Corcoran–Andrae

Energy footprint of various devices in kg CO_2

	Smartphone	Tablet	Laptop
Manufacturing	50–85 kg	70–120 kg	135–300 kg
Typical use / year	5^{wifi}–50^{G4} kg	5–50 kg	10–30 kg

Airplane	0.115 kg / person km
Cheeseburger	4.35 kg

Energy footprint ICT — online video

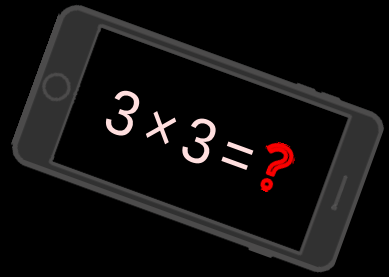


Distribution of online data flows between different uses of digital technologies and of online video in 2018 in the world

[Source : *The Shift Project 2019* - as of (Sandvine 2018), (Cisco 2018) and (SimilarWeb 2019)]

- **Video is a dense medium of information**: 10 hours of high definition video comprises more data than all the articles in English on Wikipedia in text format!
- **In 2018, online video viewing generated more than 300 $MtCO_2$**, i.e. as much greenhouse gas as Spain emits: 1% of global emissions.
- **Pornographic videos make up 27% of all online video traffic in the world.** Taken alone, in 2018 they generated more than 80 $MtCO_2$, i.e. as much as all France's households: close to 0.2% of global emissions.
- **The greenhouse gas emissions of VoD (video on demand) services (e.g. Netflix and Amazon Prime) are equivalent to those of a country like Chile** (more than 100 $MtCO_2eq$/year, i.e. close to 0.3% of global emissions), the country hosting the COP25 in 2019.

A typical computational task



Cost breakdown

Manufacturing	Usage
Phone	App + graphical interface
Network	G4 transmission
Data center	Virtual machine overhead
	Python interpreter
	Multiplication algorithm
	Hardware operations

Note: none of the documents I consulted mention the *conception costs*, e.g. of phones, network devices, CPUs, fast algorithms, education, etc.

Modeling the cost

$$C(N) = C_{\text{Phone}}(N) + C_{\text{Network}}(N) + C_{\text{DataCenter}}(N)$$

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$$P_{\text{Phone}} = P_{\text{Phone,Usage}} + \overbrace{\frac{E_{\text{Phone,Manufacture}}}{T_{\text{Phone,ServeTime}}} + \frac{E_{\text{Phone,Conception}}}{T_{\text{Phone,ServeTime}}\,\text{Nr}_{\text{Phones}}}}^{P_{\text{Phone,Virtual}}}$$

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$$\text{Ops}_{\text{Phone}}(N) = \text{Ops}_{\text{GUI,Idle}} + \text{Ops}_{\text{GUI,IO}} \times N$$

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$$c_1 N \log N \leqslant \text{Ops}(N) \leqslant c_2 N^2$$

Overhead of various layers

$$1 \leqslant \Omega_{VM} \leqslant 5$$

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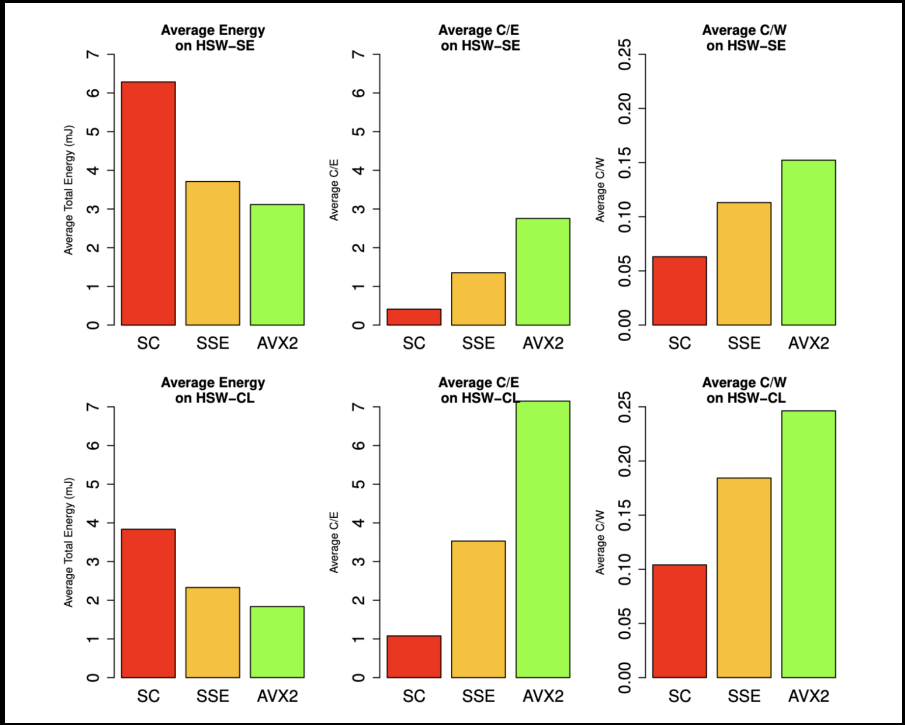
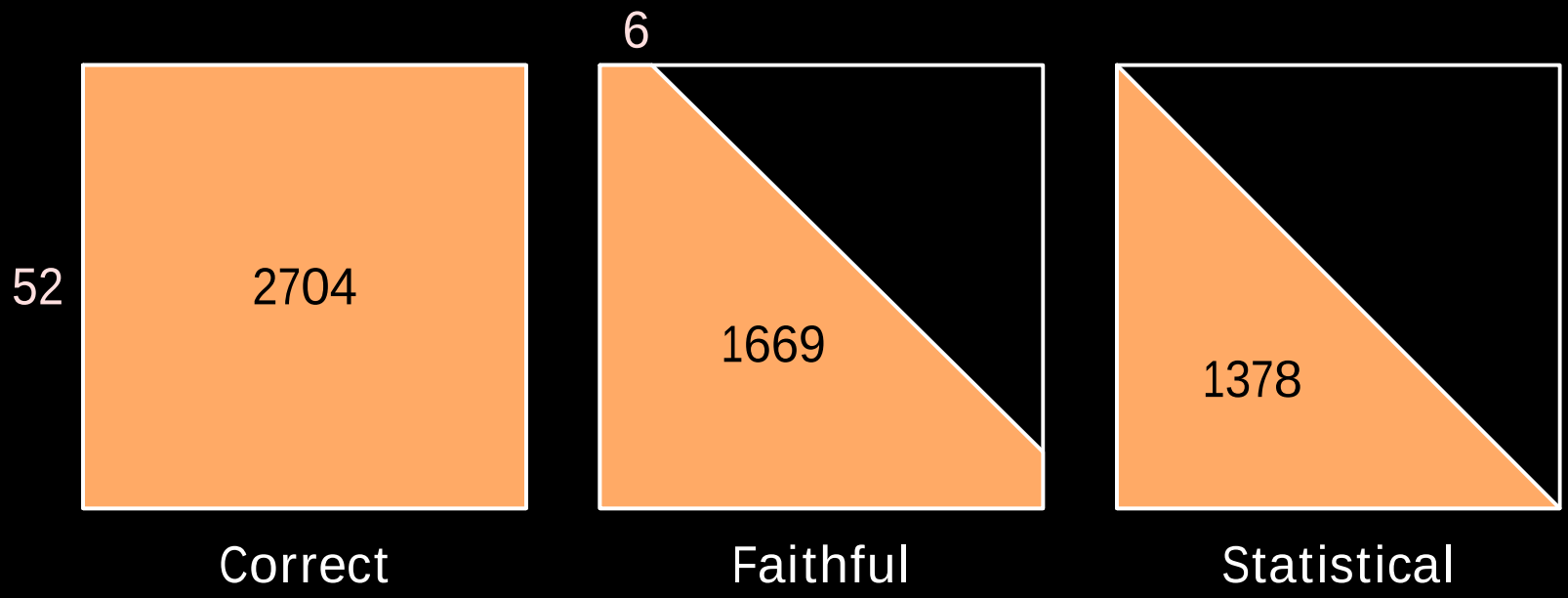
$\frac{\text{Secs}}{\text{Ops}}$: time for “typical” CPU instruction, full SIMD width

Ω_{CPU} : overhead with respect to using the “right” CPU instruction and/or with respect to correct hardware implementation

Example: energy efficiency of SIMD

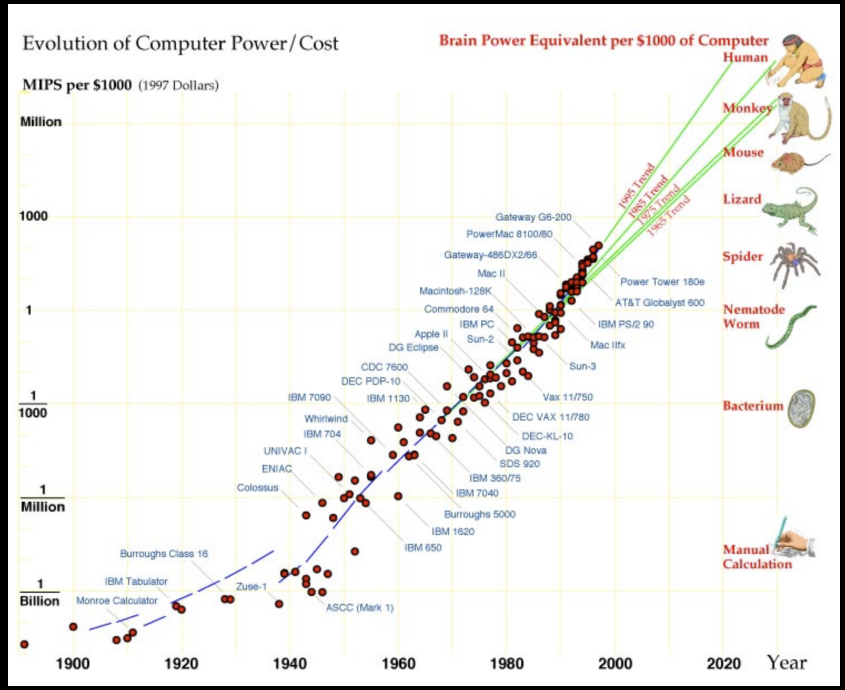


Example: rounding modes for multiply

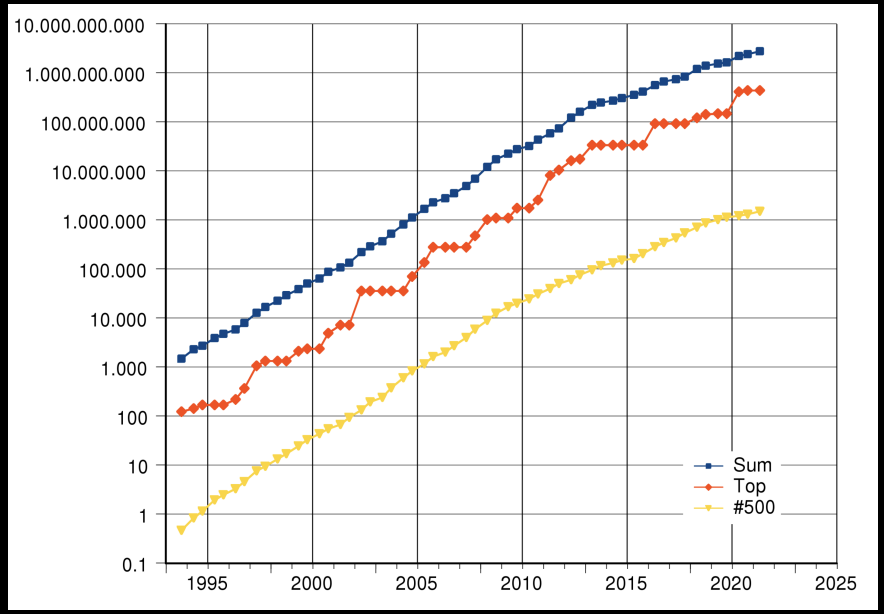


Performance over time

General computing



Supercomputing



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- Not enough students learn how computers work (SIMD, GPU, cache, …)

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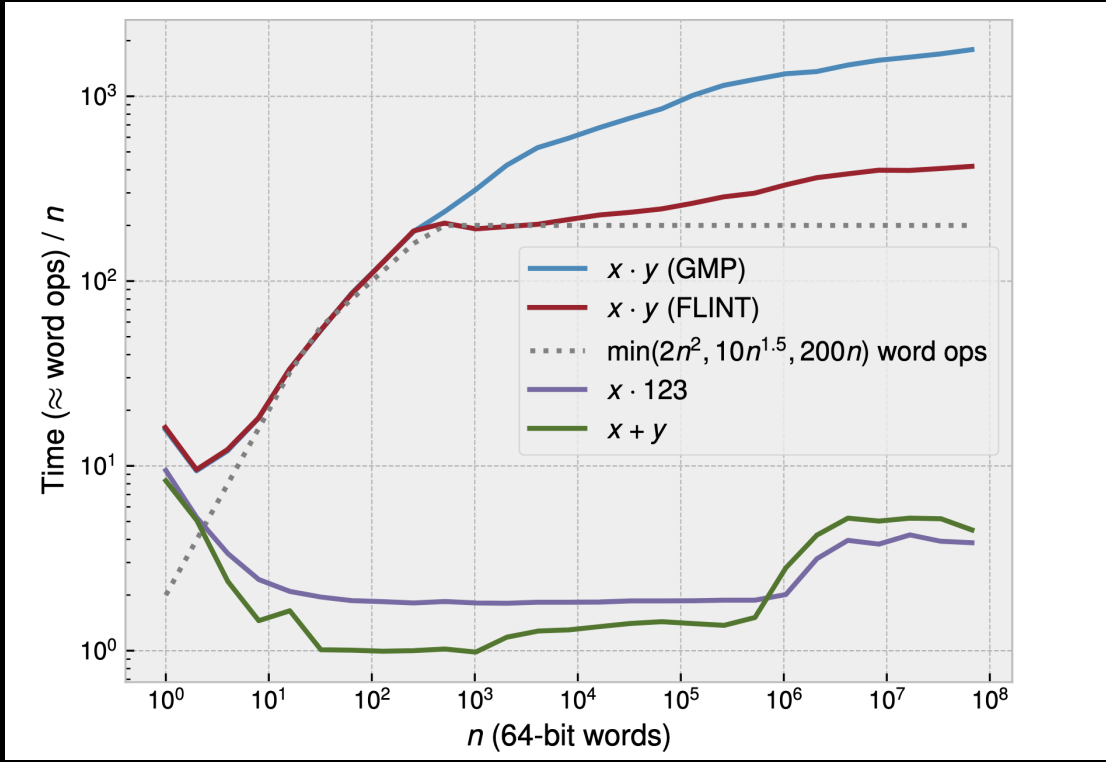
Science fiction has become real: why not quantum computing…?

Integer multiplication



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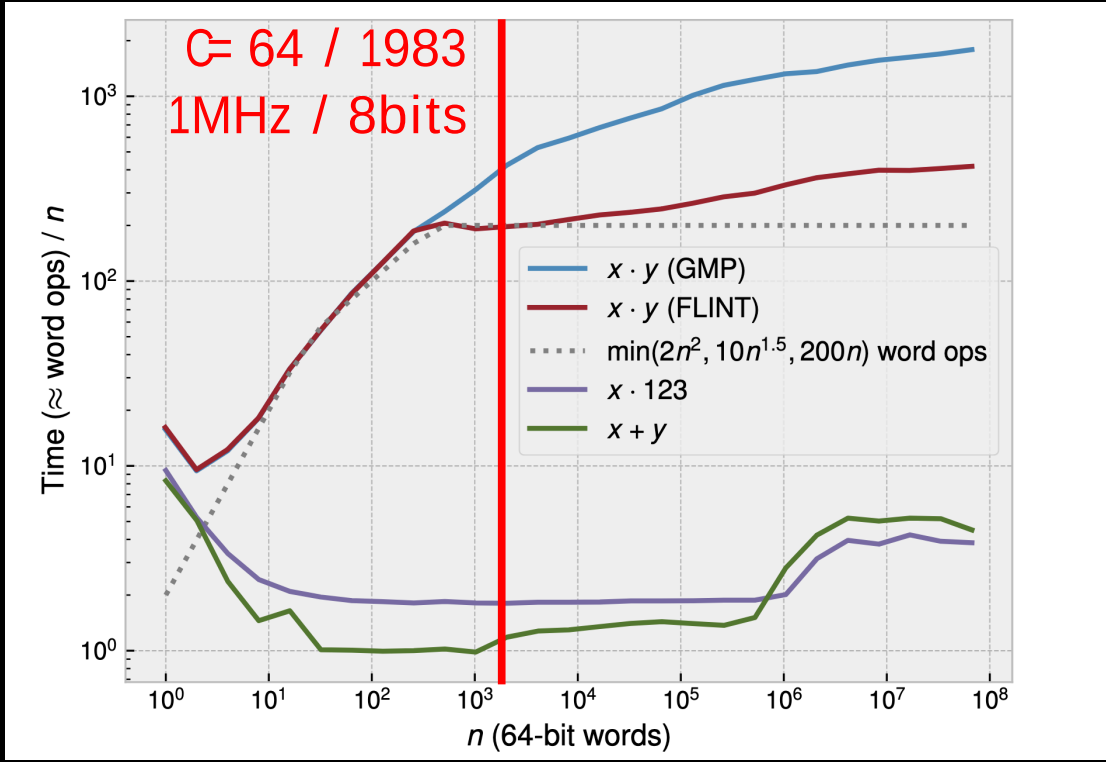

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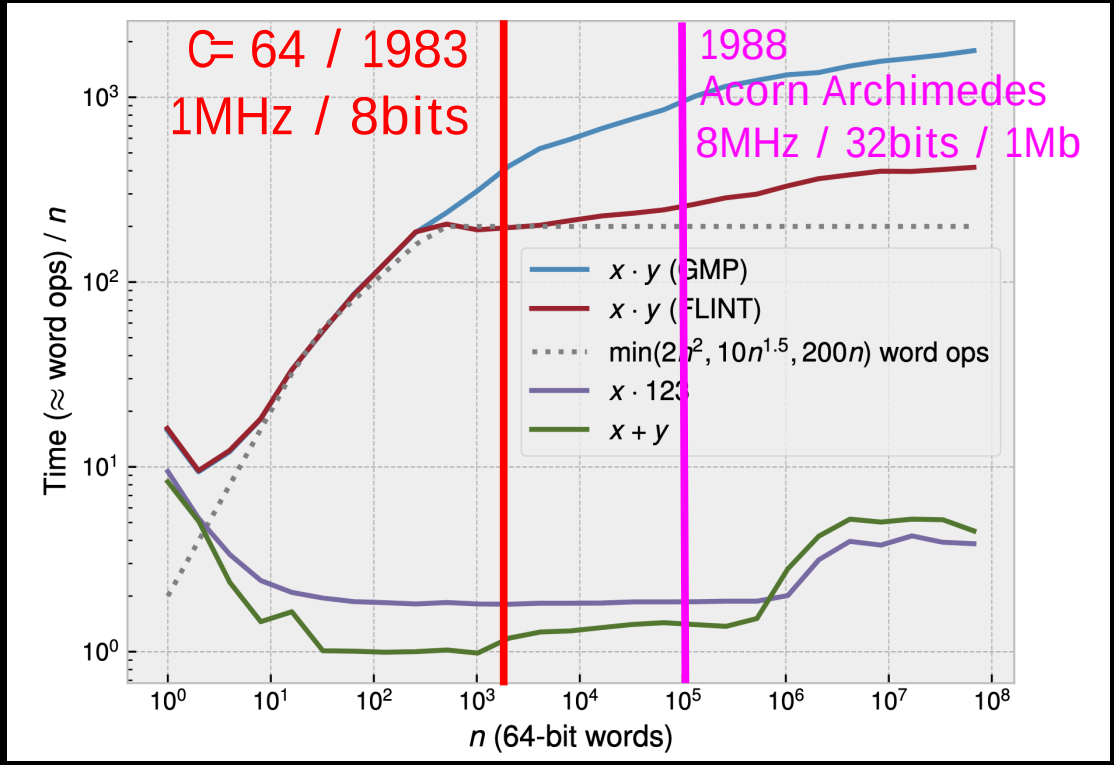

Faster algorithms

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- Asymptotically fast algorithms more and more interesting with time
- Important to value their design **and** implementation **and** teaching
- Privilege free implementations → transparent, reproducible, …
- Computer mathematics nice playground
  - Non-trivial theoretical & practical problems
  - Require special programming techniques (HPC, languages, …)

Energy efficiency

$$\text{Efficiency} = \frac{\text{Cost optimal solution}}{\text{Cost actual solution}}$$

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3×3 example.

Optimal solution: ≈1 nJ
Actual solution: ≈10 J
Efficiency: 10^{-10}

Energy efficiency

$$\text{Efficiency} = \frac{\text{Cost optimal solution}}{\text{Cost actual solution}}$$

3×3 example.

Optimal solution: $\approx 1\,\text{nJ}$
Actual solution: $\approx 10\,\text{J}$
Efficiency: 10^{-10}

10^9 digit numbers.

Fast solution: $\approx 1000 \times 10^8 \times 1\,\text{nJ}$
Naive solution: $\approx 2400 \times 10^{16} \times 1\,\text{nJ}$
Efficiency: $\approx 4.17 \times 10^{-9}$

Jevons paradox — rebound phenomenon

Computers have become 10^{15} times more efficient during last 80 years

Why does the ICT industry continue to require more power ?

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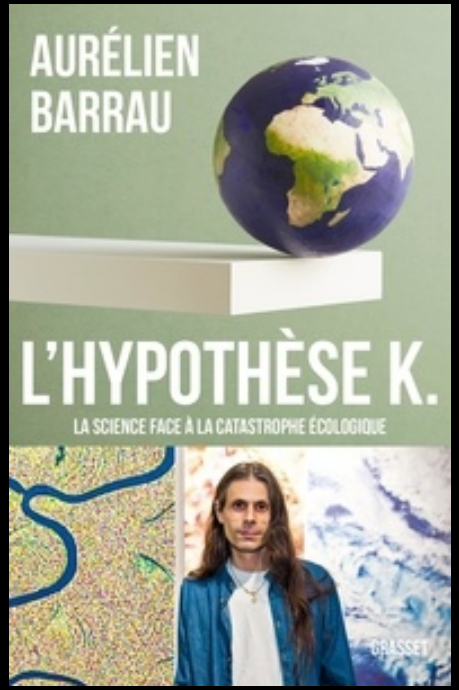
- 2× more efficient technology may attract 4× more users
- 2× more efficient algorithm may be run on 4× larger example (time)
- Easier web-based ticket purchasing $\longrightarrow$ more people fly

Part II

Energy efficiency — which problems ?

Digression — analogy with ecology



Some observations

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-

Quiz for deniers

We killed 70% of wildlife. Your opinion ?

- Cool, we are on a good track
- You are lying
- Maybe start doing something about it?

What do we WANT ?

A green fully recyclable bomb, is that a desirable thing ?

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… or truly disruptive and out of the box if needed, politically included ?

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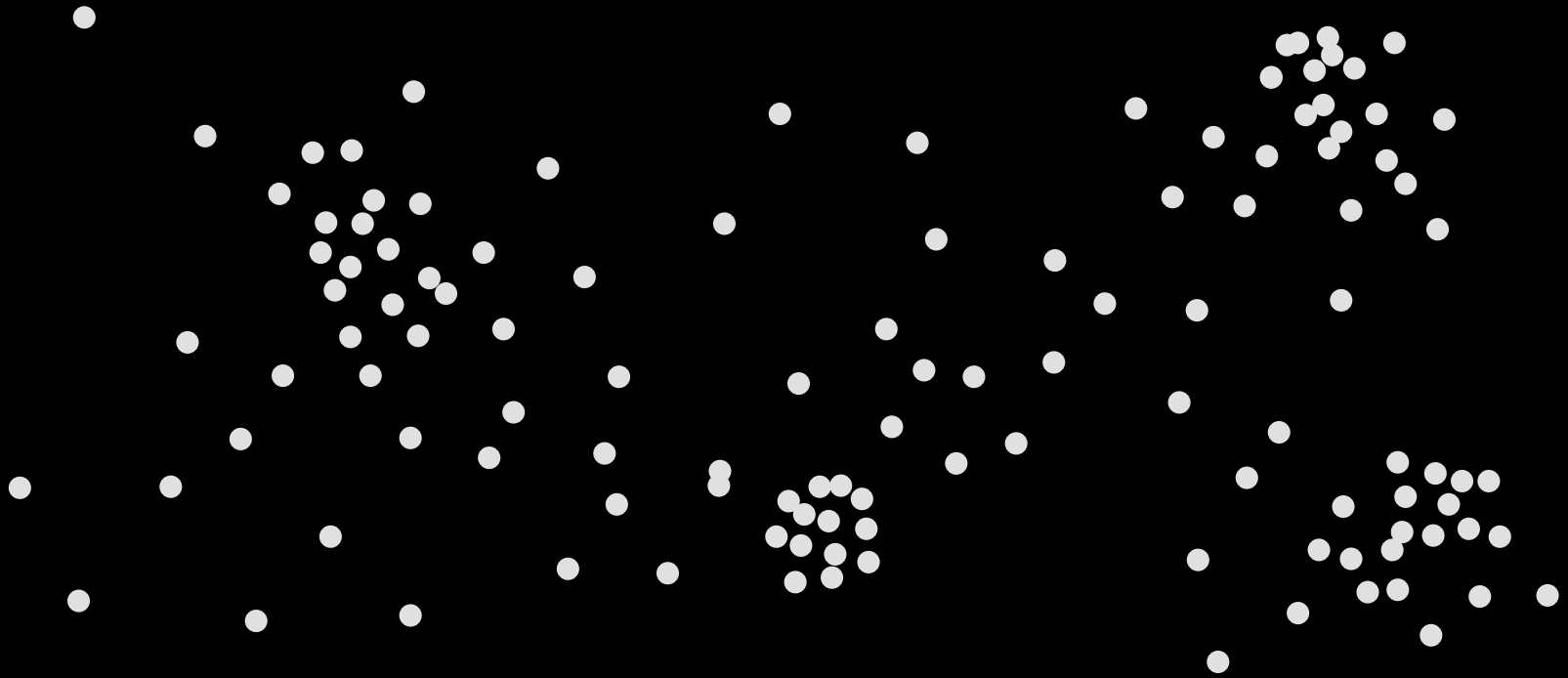
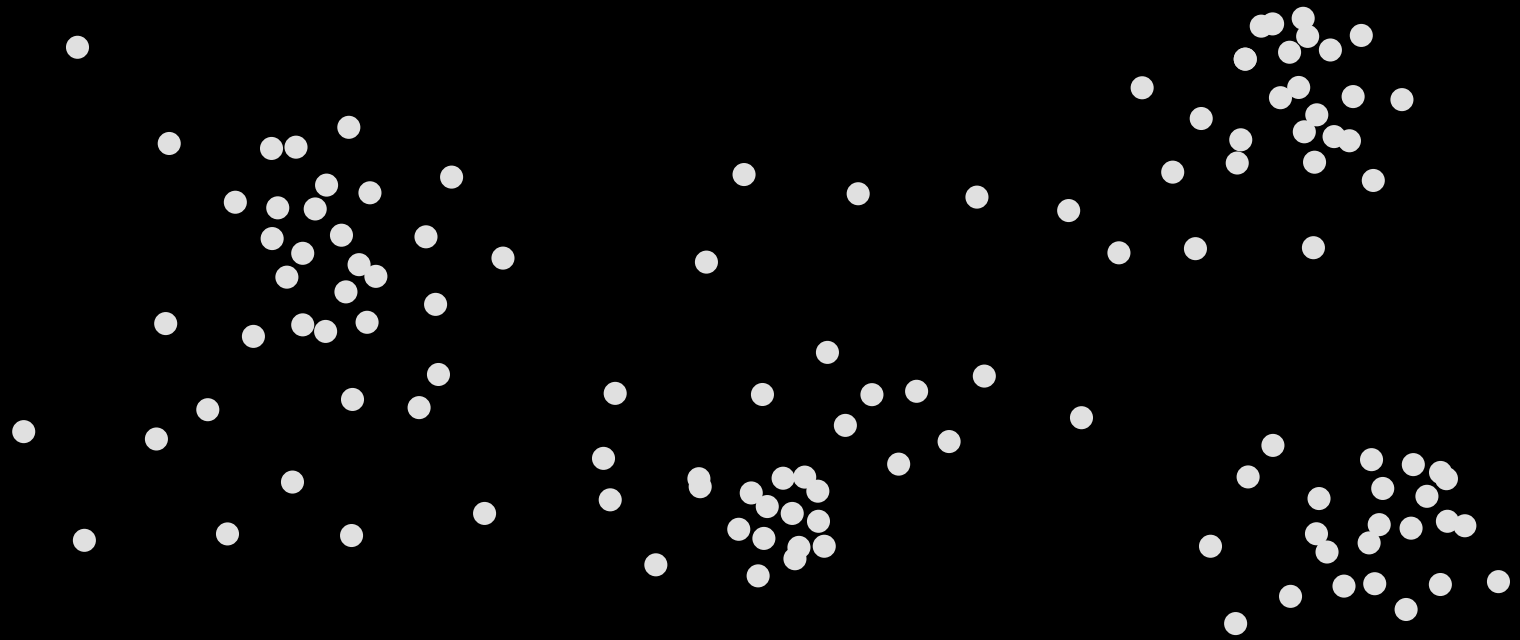
Reinject poetry into science?

Addicted or autistic ?

Intelligent map of Us All

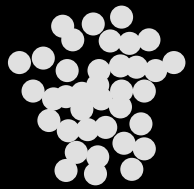


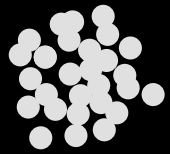
Social media and Us All



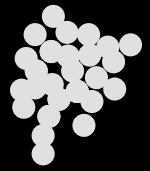
Logical truth

Earth is flat ⇒ drink bleach

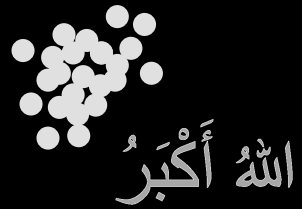




Chanel + Botox > Zara



∀x, x is poor ⇒ x cannot cross a street



How to take care of the elderly

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  But they don't allow you to do any money transfers anyhow

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  Mobile Apps bugged, especially when you need them

How to take care of the elderly

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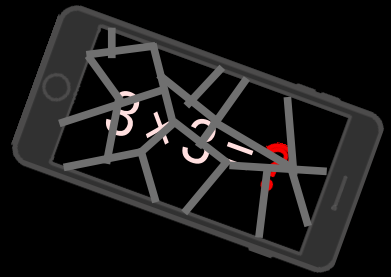
  AirBnB escalated me up to heaven after judging my passport too blurry

IA as a new business model

Let the computer think and humans do the physical work

Do we WANT this ???



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  Not blindly follow money, billionaires, fashion, ICT drugs
- Inversion of priorities
  Quantum computing or “no homeless”

Thank you !

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