TEDxMünster Talk VERSION 4 **von Sven Köppel**
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I. The Problem

Mankind has arrived at the dawn of the artificial intelligence revolution. Traditional computers allow us to explain, model, predict and control dynamical systems at ever increasing speeds and scales but they use vast energy ressources that are responsible for much of global energy consumption and pollution.

During the digital revolution, somehow we forgot that analog electronics can model dynamic systems using only a tiny fraction of the energy digital computers use for the same task. A massive paradigm shift of how information is processed is occuring. By migrating computing systems to the analog paradigm across the world, we can reduce our carbon footprint significantly.

We need a mental shift that takes us beyond the digital monoculture and opens the path to sustainable computing.

II. The History

I'm a theoretical physicist. I studied weird things such as evaporating quantum black holes. A few years ago, I stumbled up on a very interesting gedanken experiment called "analog gravity". Scientists discovered that waterfalls and black holes have something in common: Within a narrow range, they can be described with same mathematical equations. In the same way as light cannot escape a black hole, sound of marine life cannot climb a fast-flowing river or waterfall. This idea is valuable if you want to learn more about black holes, because while we cannot do experiments with black holes in the universe, we can do so with water flows on earth. The accessible water laboratory is an analogy to gravitational systems happening in the unreachable center of our galaxy.

I found out that analogies as this one are incredibly powerful, because nature incidentally solves mathematical equations of interest. In the 1960s, people engineered electrical analogies for all kind of system. Flight to the moon, wheather forecasts or car crashes: They were all built on so called analog computers, these bizarre and huge machines with lot's of cables which are used to quickly program a computational electrical circuit. Analog computing attempts to manipulate small electrical currents via common analog circuit building blocks, to do math.

So how does an analog computer work? It implements three principles:

First, an analog computer is a dataflow machine that exploits the principles of nature to compute, instead of relying on digit by digit processing. It is comparatively low precision computing, but very energy saving, compared to digital computing.

Second, they cannot do otherwise but computing perfectly in parallel. This makes them faster then digital computing which happens intrinsically serial, one digit after the other.

And third, being an electrical data flow circuit, with no algorithms, makes them less vulnerable to attackers and more secure then digital computers.

Almost 60 years later, when I wrote in my PhD thesis I stated that modern analog computing are still a very efficient alternative to simulate natural systems. My professor was not taking me very seriously. This is because analog computing is long forgotten since the digital revolution. The idea of expressing signals and data as a series of discrete states has turned out to be so much more powerful then the cumbersome and manual wiring of electronical circuits.

III. The Solution

Digital computers are well suited for algorithmic processing in discrete steps, something very relevant in every day life applications such as accounting, databases, word processing or your favourite social network in the internet. They are less suited to model continous relationships efficiently. This is however how the language of nature is written. Climate models, autonomous driving or Covid-19 drug discovery: Wherever you look around, all these sciences are primarily bound by the fastest computing facilities.

However, the development of smaller and better digital computers has come to a hard physical limit. You probably have made a similar experience as I did: After 10 years, I recently bought a new notebook. Sadly, the old and new ones are roughly the same speed. Some people call this »the end of Moore’s law«.

Moore’s law is that famous prediction from the 1960s that the number of little switches, called transistors, on a microchip doubles every two years.

In science, we call this an exponential law. In order to be fast, your computer nowadays does trillions of flips per second. But it turns out that flipping the switches comes at a cost, and that is lost heat. You easily reach the temperatures of the sun on an average chip. Digital computers have a fundamental problem with energy efficiency.

And this problem has reached a global scale: Computing and IT contributes already as much to global warming as the worldwide air traffic. The theoretical growth in digitalization will exhaust the global energy production already in 15 years. This is so much faster then most climate change impacts! And this is a major bottleneck for progress in scientific and industrial computing.

The answer is computing without flipping that many switches and exploiting the fundamental laws of nature instead. Let me give an example.

The digit by digit sum requires to flip many switches. You can imagine flipping at least one switch per digit. The analog sum does not require to flip that many switches. Imagine two water hoses plugged together. You open the taps, and the output current is just the sum of the inputs. In science, we call this conservation laws, and this is just how nature is summing on its own. This is the core idea of analog computing.

And this is how how the most efficient computer in the world is working. I'm talking about the human brain. While mankind has spent a century engineering smaller, faster and hotter digital computers, the biological evolution has spent millions of years to develop the human brain, a supercomputer with the power requirement of a light bulb. The brain consists of a plethora of highly interconnected and rather simple building blocks, the neurons. They process their inputs continously and fully parallel. Their interlinking corresponds to the information flow possible. This is fundamentally different to traditional digital computing, where a vast majority of time is spent on exchanging memory and realizing the communication. It is no wonder that it is widely beliefed that a breakthrought with artificial intelligence can only happen with analog computers!

←--- Okay, so computers are fast and this costs energy. But we get something for it, isn't it? Well, way too little. In artificial intelligence, when computing neural networks, the digital computer architecture is so unsuitable that two orders of magnitude in time and energy are lost at communication between memory and processor compared to the actual time and energy required for the neuronal computation. This is called »Von Neumann bottleneck«   --->

For those of you who followed recent tech news heard of quantum computing. This amazing prospective computer architecture exploits the tricky laws of quantum mechanics. Unfortunately, they require near vacuum and ultra low temperature cooling, which is very expensive. They are also hard to control and still fundamental research, probably ready to use only in a few decades. Once ready for use, quantum computing will be very powerful, but not necessarily energy saving. Also, despite being non-quantum, scientists assume classical analog computers can solve many problems similarly fast but at low-energy consumption and room-temperature.

IV. The Product

So here's my story how I got from black holes to building computers.

A few years ago, my father suddenly died. He left behind a one-of-a-kind computer collection which also included a few of these huge analog computer relics. My father ran a private computer museum which I honestly did not care about much in his lifetime. But this stroke of fate lead me to a recognized expert on analog computers. I realized that this exotic technology from the past could catch up with miniaturization and become an incredibly powerful platform for simulating phenomenae in nature.

Last year, together with experts in industry and microchip design, we founded a company for building the next generation analog computers.

But one of the first things our deep tech startup addressed is not the latest technological problem, but instead a big social problem.

Analog electronics is widely percieved as something from yesterday. The average age of analog engineers is far beyond 50. Many people in academia and industry have an affinity to digital and algorithmic approaches but refrain from electronics wherever possible, because it is percieved as expensive, unflexible and a thing from the past.

The mental shift of information processing begins with understanding the analog computing paradigm.

[Take T.H.A.T. in Hand]

To help you perform the mental shift, we present you today »The Analog Thing«, a high quality, low cost, cutting edge analog computer. The analog thing is designed carefully, to offer a limited number of easily understandable computing elements that support a broad range of interesting applications. With the analog thing, you can model dynamical systems, such as market economies, the spread of diseases, population dynamics, chemical reactions, mechanical systems, the firing of neurons and much much more. Not by writing code, but by wiring circuits that solve the mathematical equations without a single switch.

THAT offers an intuitive, hands on reduction to differential and integral calculus as well as analog signal processing, circuit technology, measurement and control engineering. Any number of THATs can be coupled together to run large, massively parallel analog programs, yielding endless possibilities.

It's hybrid port allows you to control The Analog Thing from digital devices, like low cost single board computers – think of Raspberry Pi or Arduino – enabling you to explore the future world of digital-analog hybrid computing.

The analog thing is not for profit. We developed this small modern educational analog computer in order to overcome stereotypes. It is portable, affordable and eye-opening. We want to bring it to universities and schools, to hobbyists, to boys and girls. It allows hand-on experience on analog computing circuits and invites to tinker with hardware, stimulating creative and mathematical programming.

The computer is completely open sourced. We have put all the schematics online and we will also mass-produce it in order to build and sell it as cheap as possible.

The Analog Thing is an educational analog computer, it has cables by purpose to be tangible and visual. But of course cables are not the future of computing! This computer is a spin-off within a much larger goal of our company.

[Put T.H.A.T. away]

V. The Future

In the end, let me come to our actual vision.

We will be one of the first which bring analog computing on a microchip. It will be software programmable with no more patch cables. Tomorrows analog computers are embedded in every smartphone and computer processor in the world. That means they become coprocessors and accelerators for compute intensive applications such as artificial intelligence. We call this a hybrid computer, combining the best of analog and digital. Less switches mean less energy demand with more computational power.

This technology is interesting both for high performance computing centers as well as ubiquitous and embedded computers, such as medical implants or the internet of things. Analog computing is an enabling platform for future products. Who knowns how your computer will look like in 10 years?

It is high time to care about sustainable and green IT. After the digital revolution, the analog revolution is next. Reapprising the past technologies without prejudices can help us to answer the important questions. Nature is analog, and so should be computers.

Thank you.

References

Ideas and formulations from the following talks influenced this talk. For the interested, they are also worth being listened as a follow-up:

- TED Daily Podcast Quantum Computing
- New Mind: The AI Hardware Problem https://www.youtube.com/watch?v=owe9cPEdm7k
- Texts by Thomas & Bernd