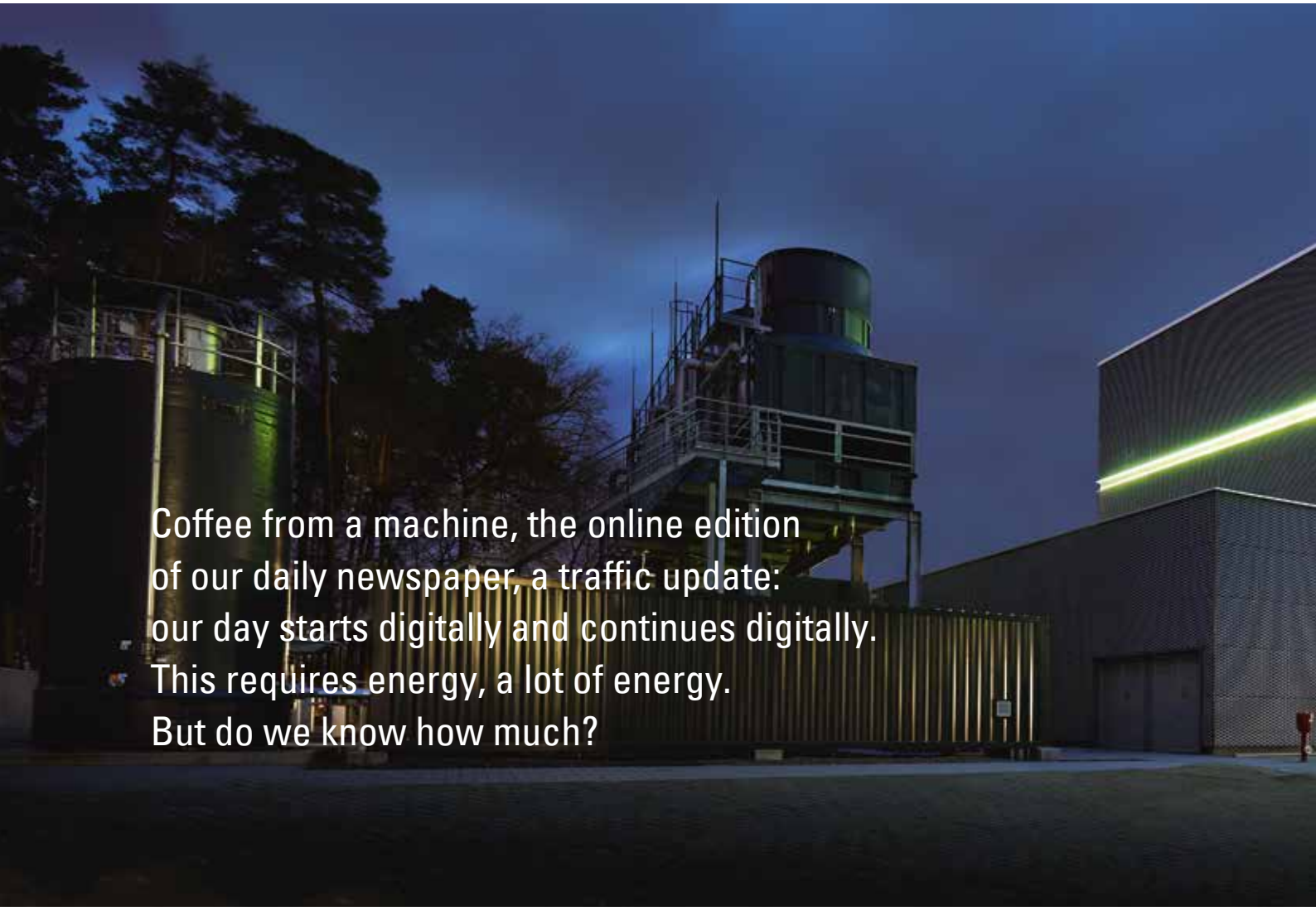
Digitalisation and sustainability – not a contradiction

Energy-efficient computers such as that of Volker Lindenstruth and his team provide an ecological cushion for growing data hunger

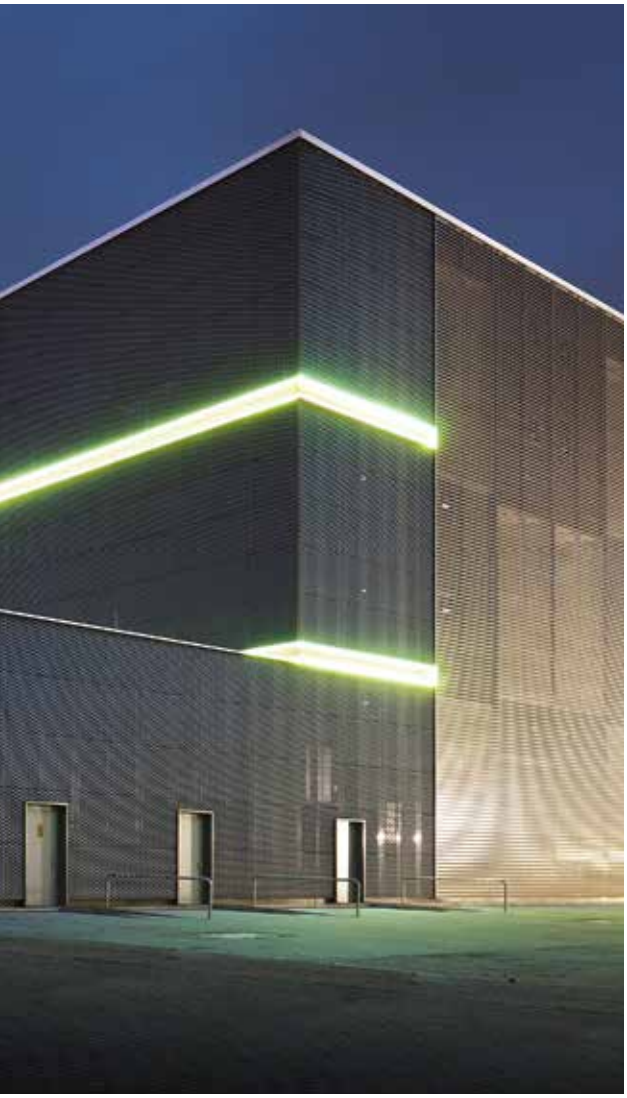
By Regina Kremer



Coffee from a machine, the online edition of our daily newspaper, a traffic update: our day starts digitally and continues digitally. This requires energy, a lot of energy. But do we know how much?

In Germany alone, the use of the internet releases as much CO_2 every year as total air traffic. But how can the possibilities of IT be exploited while saving environmental resources at the same time? The Frankfurt physicist, Professor Volker Lindenstruth has developed impressive and pioneering technologies toward this goal.

Lindenstruth has been working as professor for high performance computer architecture at Goethe University since 2009. Using unusual ideas, creativity and confidence, he mastered the challenge of building a high-performance computer for the university's research network that is fast and high performing, and both cost-saving and energy-efficient. In 2010 the supercomputer he developed, Loewe-CSC located at the Hoechst Industry Park, took up operation as the most energy efficient computer in Europe at that time. At the same time the corresponding data center is one of the most efficient ones world wide. It was followed by the Green IT Cube data center for the GSI in Darmstadt in 2016, and the GOETHE-HR – as successor to the Loewe-CSC – in 2017. An innovative construction principle that pairs high energy savings with high performance forms the basis. In February 2020, Lindenstruth and his team received a European patent for the overall concept of an energy-efficient cooling structure for data centers. Now this concept can be used economically worldwide.



Green IT Cube, computer centre of the GSI Helmholtz Centre for Heavy Ion Research in Darmstadt.

Enormous opportunities for the future with digitalisation

The developments of the past year have made it clear: digitalisation offers enormous opportunities for the future, both globally as well as for individuals. The economy, society and environmental protection all stand to benefit. High performance computers (supercomputers) provide calculations, security and predictions in a vast number of areas such as:

- the automobile industry for highly developed efficiency and security in driving,
- medicine for the prediction of diseases and calculation of their progression (see Forschung Frankfurt 2/2019 »Prevention is better than healing«),
- meteorology, with long-term prognoses for economic planning for the economy, medicine and politics – for farmers in the management of arable land, for insurance companies in adjusting premiums to probabilities of unusual weather situations, but also for hospitals for emergency planning in extreme weather conditions,
- for sustainability and climate protection with computer simulations on the future of electric cars and autonomous driving.

In the future, continually increasing amounts of data will be collected by ground stations, ships, airplanes and satellites with the help of computers, and more and more data will be stored, searched, distributed and visualised. The worldwide volume of data will continue to grow. With 40 zettabytes in 2020, it is already 50 times greater than in 2017. (For comparison: the maximum storage capacity of the human brain corresponds to about 2.5 petabytes in digital units, with a petabyte being a 1 followed by 15 zeroes.) The demands made on the performance of computers and processors, and on the speed with which data is accessed and processed are continually increasing. And there will also be ever larger amounts of data to manage on private computers, smartphones, tablets, external hard drives and in the cloud.

What is …?

Hardware
the »body« of the computer, can only be changed by reconstruction. Hardware includes:

Graphic card with ventilator for cooling.

- **processor or CPU (Central Processing Unit), centrepiece:** computing unit that carries out the assigned tasks/ computing operations, to date it consists of multiple CPU cores
- **CPU core Rechenkern:** smallest computing unit of a processor
- **graphic card,**
  typically serves two functions. It generates the signals for the display monitor and implements compute functionality to perform operations directly on the image data. In the computing context this computing capability is used for processing. The video functionality of a graphics card remains unused in this context.
  - CPU-dependent, converts data computed by the processor
  - GPU (Graphics Processing Unit)-dependent, computes data independent of CPU, works faster

Software – the »brain« of the computer
Programmes, responsible for system operations, information processing and all the data this produces. Can be changed by, for example, updates. Example: navigation system in a car

Server
A computer with typically several multi-core processors, large amounts of memory and a fast network. Servers are usually hosted in data centers.

Data centre
Centralised facility for hosting a typically large number of servers including mass storage servers. The storage, management and processing of data and information in servers is organised according to a certain area of knowledge or belonging to a specific company.

Supercomputer – the giants among the computers
Greatest possible computing power, difficult to imagine, »in its own league« Performance is measured in FLOP: floating point operations per second, Example: The fastest computer in the world, Fugaku in Japan has 415 petaFLOP. One petaFLOP means a quadrillion (1,000,000,000,000,000 / 10 to the 15th power!) floating point operations per second! 20,000 to 50,000 times faster than a »normal« computer

Internet nodes = Central train station/ Internet train station
Merger of various networks or servers at central hubs, data exchange between the different networks

Global internet nodes, centres for the organisation of data communication.

Toward this end, data centres are being developed and built all over the world, in which computes from one or more companies are located. Here, a server is a computer that sends, receives and stores data to and from other computers (clients) on request. The available IT resources are assigned according to an organised schedule and ideally work to capacity, allowing the simultaneous accessing of several data units in these servers. In terms of dimension: experts estimate that Facebook's data centres comprise 30,000 computers.

Corona crisis: heyday for digitalisation

The most recent example of network use is the corona crisis: networks were used here to follow the course of the infection worldwide. With the supercomputer of the GoetheUniversity, the evolution of the pandemic was predicted. This work was carried out by Dr. Maria Barbarossa (FIAS) and Prof. Dr. Thomas Lippert (Goethe-University/FIAS). As a consequence of the social distancing decreed by governments, digital forms of contact and leisure activities increased with a vengeance. The central German internet node DE-CIX in Frankfurt, the largest exchange point for internet data traffic worldwide, reported a 50 percent increase in the video conferencing rate and 25 percent increase in online and cloud gaming.

The TOP500 is a list of the highest performing computers in the world, compiled since 1993 by four experts at the universities of Tennessee and Mannheim. First place is taken by the high performance computer Fugaku at RIKEN in Japan with a performance of 416 petaflops. Its areas of application are various research fields such as nuclear physics and stem cell research. Its power consumption amounts to 28 334 megawatts. The computer SuperMUC-NG at the Leibniz Rechenzentrum in Munich is at 13th place. It carries out calculations for climate research, earthquake and seismology research.

Growing electricity consumption due to digitalisation

Scientists believe that that by the year 2030, 13 percent of worldwide electricity consumption will be caused by data centres. The city of Frankfurt, an extremely important exchange point (»network node«) for internet data traffic, already consumes 30 percent of total local electricity for data centres.

The Borderstep Institute in Berlin for innovation and sustainability in the future calculated the CO_2 emissions: a thousand tons of CO_2 are formed by the sending of a million emails per day in Germany, one gram per email. An hour of video streaming produces the same amount

View of some of the GSI's 768 computer cabinets, resting on green steel girders.

About Volker Lindenstruth

Volker Lindenstruth studied physics at the Technical University of Darmstadt. From 1989 to 1993 he did research at the Helmholtz Centre for Heavy Ion Research (GSI) in Darmstadt, and received his doctorate degree at the Goethe University Frankfurt. As part of a research fellowship, he went to the Ernest Orlando Lawrence Berkeley National Laboratory in Berkeley, USA, for two years as a postdoctoral fellow in computer science. From 1995 to 1997 he was a member of the UC Space Science Laboratory, USA, before founding iCore Technologies in 1997. Since 1998 Prof. Lindenstruth is back in Germany. Until 2009 he held the chair of Computer Engineering at the University of Heidelberg and director of the Kirchhoff Institute. Since 2009 he is professor for High Performance Computing Architecture at Goethe University. The chair focuses on the architecture, application and further development of high-performance computers in the natural and life sciences. At the European Research Centre CERN near Geneva he developed an intelligent readout technique for the data of the ALICE experiment. He is also a member of the board of the Frankfurt Institute for Advanced Studies (FIAS) at the Goethe University.

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of CO_2 as a kilometre of driving. The search machine Google handles about 5.6 billion search requests per day worldwide, with an electricity demand of 0.3 watthours per search request according to Google – to make it easier to imagine: with 200 search requests you could iron a shirt.

In Lindenstruth's view, this immense energy consumption, and the cost intensity of the machines cannot be attributed solely to use. Both aspects could already be positively influenced in the constructions of these machines according to Lindenstruth. His innovative concept for an effective computer architecture and architecture of data centres, combined with the development of a high-performing, energy efficient and cost-saving supercomputer is composed of different approaches:

- He takes a critical view of existing data centres with regard to energy efficiency, degree of use, architecture and arrangement of the many computers. The software-based servers must run day and night due to use, but often at a work capacity of only 25 percent. The data centres in Europe and the

One of Google's largest computer centres worldwide in Douglas County (Georgia, USA), not far from Atlanta.

What are the units a high performance computer works with?

Bit: a binary figure or unit for information content or data volume: alphanumeric symbols (0, 1 …, A,B …)

Byte (B): measuring unit for digital technology and information systems 1 byte = 8 bits

1 kilobyte (KB)	=	10^3 B (about a fourth of a printed page)
1 megabyte (MB)	=	1 000 000 bytes (500 pages of text, for comparison: long-term stored information units in the brain of a 60 year-old 150 to 225 MB
1 gigabyte (GB)	=	10^9 bytes (storage capacity of USB sticks up to 64 GB)
1 terabyte (TB)	=	10^{12} B(current maximum storage capacity of an external hard drive 16 TB)
1 petabyte (PB)	=	10^{15} B (memory content of all living 6 billion people today about 1350 petabytes as of the 1990's)
1 exabyte (EB)	=	10^{18} B (in 2019 customers of the mobile net O_2 caused more than an exabyte in traffic for the first time – this is more than 1 billion gigabytes)
1 zettabyte (ZB)	=	10^{21} B (presumably, the NSA stores data volumes of several zettabytes)

US alone have an energy use of 40 gigawatt. »Forty gigawatts are equal to about the half of total German electricity consumption, which is about 70 GW. Overall, 10 GW worldwide could be saved alone by optimizing the data centers,« says Lindenstruth.

- He furthermore explains that due to poorly written or outdated software, many computers work at lower levels of performance, with high energy consumption and low performance speed, comparing this to a car that only drives in one gear. The unused capacity of the computer is lost as heat. An increase in the performance of the software by the factor 100 to 1,000 could be achieved by a revision of the algorithms.

- Graphic cards are necessary computational tools for a computer to work. Today, all graphic cards have their own storage. The internal GPUs normally installed, however, are not super-fast. Moreover, the image resolution is not very high. Lindenstruth prefers GPU graphic cards developed for computer games that can operate independently of the computer's processor. The idea of integrating them in the computer as independently working graphic cards has proven to be pioneering and highly efficient. They are particularly high performing with fast computing power, because the individual computing power does not interact with others, and simultaneously-running algorithms accelerate the computing process. In addition, the computing power is produced in its own GPU processor. The cost of these graphic cards is manageable, as rising demand means they are manufactured at low cost in high number. Eight hundred of these graphic cards were built into the first supercomputer Loewe-CSC. At CERN, the European organisation for nuclear research, Lindenstruth tripled the computing power of the two-million euro computer by using graphic cards with a value of 500 euro per card.

- Lindenstruth sees one of the greatest need for action in the cooling of the computer.

Whether desktop or high performing computer, the processers emit heat while working. Until now, cooling has been carried out by the intake and release of air which is passed on to the exterior air by the computer's built-in fans. This leads to a rise in room temperature; in rooms containing supercomputers sometimes to more than 50 degrees Celsius. In addition, the fans themselves require about 4 percent of the energy required by the processor itself.

The cooling system developed by Lindenstruth and patented in February 2020 is based on a simple trick: a cold water cooling system is built into the back door of the rack containing the computer by means of a heat exchanger. The hot air of the system is transferred to the water and cooled. The heated water is cooled according to the principle of a refrigerator. »When you sweat in the summer and the water on your skin evaporates, you begin to shiver,« Lindenstruth says, describing his concept. The room temperature can be maintained at a constant using this cooling system. The server's waste heat can be used to heat other rooms or distributed beneficially through district heating systems.

»Green IT Cube« as a guide to more energy efficiency

With »Green IT Cube«, Lindenstruth was able to achieve the ambitious goal of building a large scale data center with these requirements. This data centre was completed in January 2016 in Darmstadt at the GSI Helmholtzzentrum für Schwerionenforschung. Stacked shelves stand in the »cube« which measures 27 m x 30 m x 22 m, in which 768 computer cabinets can be arranged on six levels. The three-dimensional structure – next to each other, on top of each other – is 10 times more compact than conventional building methods. The connections – i.e., the cable lengths between circuits are therefore shorter, signal transmission is faster, allowing experiments or simulations of extraordinary intensity and speed, and it is overall an environmentally friendly architecture. At least 300,000 computing engines Rechenkerne (1 processer contains several several computing units = computing engine Rechenkern) are planned, with storage space totalling up to 100 petabytes, which is equal to 100.000 conventional computer hard drives. The data transmission rate for experimental computing processes is one terabyte per second, which is equal to 500 000 private DSL connections. The cool water cooling system developed by Lindenstruth in the back doors of the computer cabinets cools 12 megawatts of the total computer performance and requires less than 7 percent of the total required energy of the data centre for cooling – compared to 30 percent for other cooling systems – making Green IT Cube an important step toward sustainable digitalisation.

Without doubt: our future is digital

It opens possibilities to make the rapid economic, social and – no contradiction – climatic changes easier to plan and shape successfully. The unavoidable increase in energy consumption does not have to be in conflict with sustaining the natural foundation of life. The research by Lindenstruth and his team, and of many other research groups in the field of green IT are promising. Sustainable technology contributes to the protection of climate and natural resources. Every individual can act in a »digitally sustainable« way. Digitalisation and sustainability do not have to be a contradiction. ●

The author

Regina Kremer, born in 1956, studied biology and chemistry for secondary teaching degree at the University of Gießen. She teaches at the Claus-von-Stauffenberg-Schule, a secondary school in Rodgau in the district of Offenbach. As senior teacher, having contact to the nearby universities is important to her. She regularly arranges for her students to participate in scientific projects at the universities in Frankfurt, Mainz and Darmstadt. She developed an affinity to IT through planning her classes and putting together the most up-to-date working materials.

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