Digital **Turning Point**

There have been enormous developments in our ability to store, transfer and analyze huge data volumes, commonly referred to as big data. Not only are these developments having a dramatic effect on our daily lives, but they are also creating a new dynamic in science, as research fields are redefined and traditional boundaries between established disciplines lose their relevance.

TEXT **MARTIN STRATMANN**

Googling the German phrase "*Chancen und Risiken der Digitalisierung*" ("opportunities and risks of digitization") together with the term "*Rede*" ("speech") returns thousands of hits, while entering the same search in English yields a very modest number of results. Evidently the digital society as a discussion topic is in far greater demand in Germany than elsewhere. The question is: Are we talking at the expense of doing? Not just in research, not just among ourselves … society as a whole in Germany must recognize the signs of the times and take action. Therefore: Yes, we need to talk! Not just about digitization, but also about the associated transformation that extends to every area of society.

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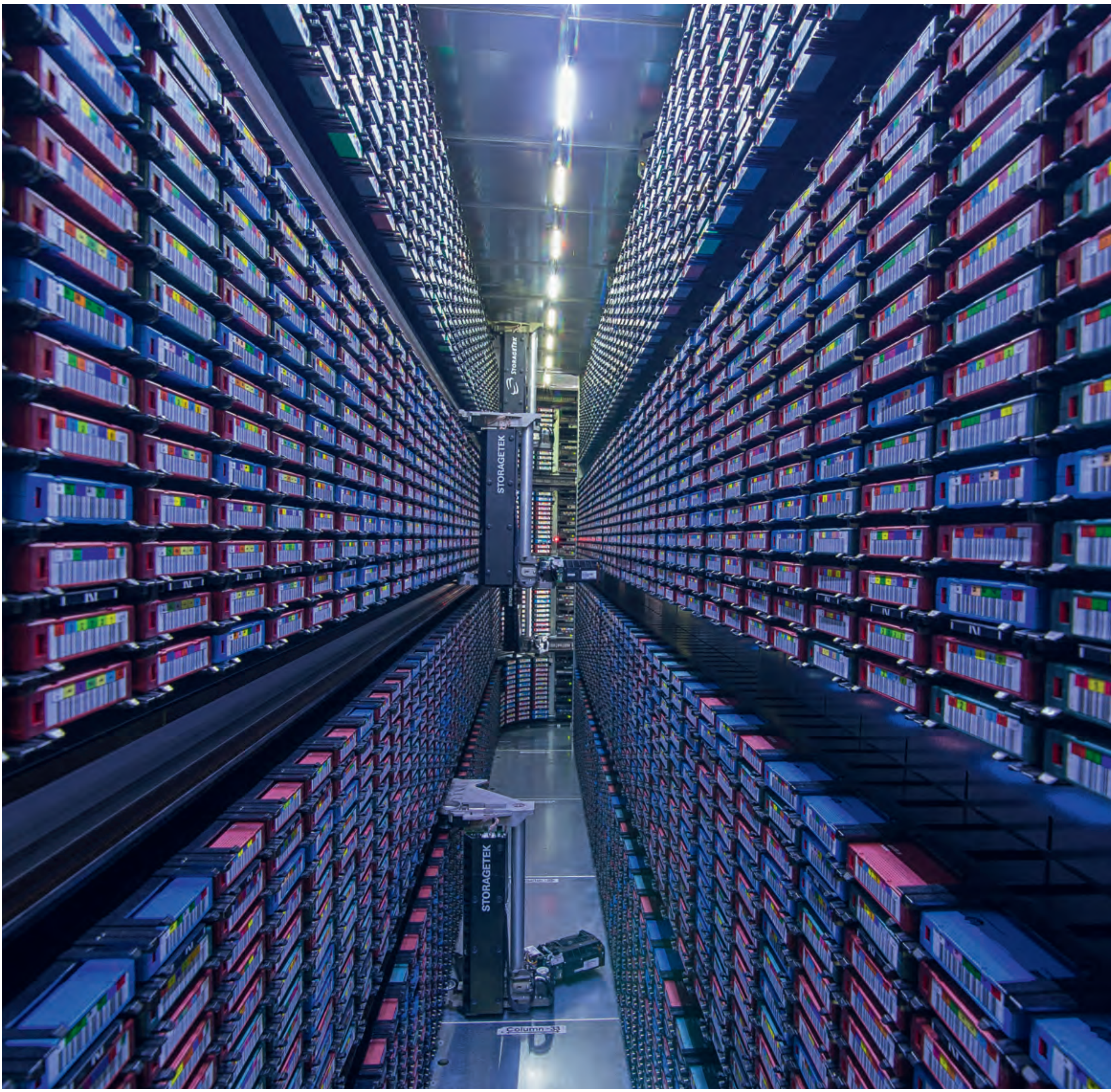
We have reached a turning point. Of course, the world has regularly experienced such turning points in the past, triggered by innovations and the resulting price decreases. The advent of printing in the 15th century and the Industrial Revolution in the 19th century are two examples of this. How much did it cost at the beginning of the 15th century for a monk to copy a book by hand? And what did it cost just a few decades later to disseminate Luther's Bible?

How dramatically did the price of high-quality materials decline in the 19th century as machines made them faster and easier to manufacture? And what a technological revolution this decline unleashed! And today? Hardly a week goes by without a significant drop in the price of computing power, data storage and data transfer.

This goes hand in hand with a significant increase in performance: experts expect that, in ten years' time, computers will be 60 times faster than they are today. The speed of processor chips is currently doubling every 18 months, while, thanks to developments in photonics, the transmission speed of fiber optic cable is doubling every nine months. As a result, we can now store, transfer and analyze vast quantities of data and build high-performance computer networks on a scale that until recently was unimaginable. >

In the heart of the virtual world: High-performance networks now exist on a scale that until recently was unimaginable. By the year 2025, the majority of the world population will have internet access.

Photo: Axel Griesch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Consequently, our daily lives are changing with amazing speed. For instance, the number of people connected to the Internet rose from 350 million to more than two billion in the first decade of the new millennium. The number of cell phones rose from 750 million to more than 6 billion. By the year 2025, the majority of the world's population will have internet access via mobile devices. And in a single year, the number of people registering for a massive open online course (MOOC) at Harvard exceeded the total number of students enrolled in the entire 380 years since the university's founding.

Knowledge and findings will be available with an ease and on a scale never experienced before

The availability of information in the sciences has changed meteorically: libraries, the cathedrals of knowledge, have moved into cyberspace and are now accessible to almost everyone. This means that information is now nearly as easy to obtain in Chile or India as it is in Munich or Boston. If open access becomes reality as the gold standard for future publications, it will open the door to what I would call the "Google of Science." Knowledge and findings will be available with an ease and on a scale never experienced before. And this much is obvious: the limiting factor will not be the ability to store knowledge, but the capacity to analyze it.

Scientists read on average around 250 articles per year – a tiny sample of the knowledge available. Imagine, then, the spectacular potential hinted at by pilot studies in which IBM's Watson – a computer – is tasked with automatically selecting, extracting facts and even generating hypotheses – all on the basis of published literature. However spectacular this future promise may be, it will not be able to replace the actual scientists. Nevertheless, in the learning process, data-driven generation of hypotheses may soon help computers more quickly ask the right questions.

These are pioneering, even revolutionary processes. I do not believe that there has ever before been such a momentous change in so short a time in the history of mankind. Like every previous turning point, this one, too, is technological in origin, but its consequences for society go far beyond technology. The exchange of information, the interaction between individuals, has never before been so easy or so affordable. This in turn raises the quality of the potential results of these interactions to an entirely new level.

The individual is no longer just a consumer, but is now a participant – and that with partly unforeseeable consequences. Examples? We are all familiar with them: revolutions are powered by Facebook and Twitter, opinions are no longer formed by editors and journalists, but by like-minded people inside closed opinion bubbles that are barely penetrable from outside. And of course the internet is not immune to crime. Consider how private computers are hijacked by botnets and manipulated for criminal purposes.

Many – even elementary – life experiences today are shaped by our digital environment. Clearly, where so much innovation emerges in so short a time, the supporting industry flourishes. So how is Germany positioned at this turning point? After the speculative new economy bubble burst, we in Germany apparently lost our enthusiasm for new start-ups. Maybe we failed to fully understand that a turning point is always accompanied by exaggerations and that setbacks must be accepted, but that the underlying trend continues.

There is more to the rise of Google and Facebook, Amazon and Apple, than a simple structural change. The ascent of the software industry is not a bubble, but a fundamental economic paradigm shift. In Germany it seems that we are only slowly becoming aware of this insight. Maybe the considerable economic success of our industrial sector has rendered us a little too self-confident. But we also know from

our own postwar history that major branches of industry can disappear and leave wastelands that are slow to recover.

For us, the decisive questions are: What is the significance of the digital turning point for science? How should the Max Planck Society deal with it? And what needs to happen in order for Germany to maintain its industrial leadership?

I can offer a short answer to the question regarding the significance of digitization for science: it is all-embracing. Whether in physics, astrophysics, materials research, bioinformatics or the digital humanities – the collection, storage and analysis of enormous volumes of data play an increasingly decisive role. This makes another question increasingly important: How can we penetrate, summarize and present this incredibly diverse information in an easily comprehensible form?

Identifying regular patterns and relationships, highlighting structure in the tangled mass of data – this is a core element of artificial intelligence, which reached a major breakthrough in recent years. Not because we developed some kind of super-algorithm – the concepts of machine learning are, in fact, several decades old. But it is only now that we are able to exploit what has long existed on paper, the functional logic of multi-layered neural networks, thanks, on the one hand, to huge increases in computing power, and on the other hand, to the increasing availability of networked data. There can be no machine learning without big data.

Allow me to draw a comparison: artificial intelligence is our new night-vision goggles. By providing us with an intelligent, automated analysis of big data, it offers us a view of the world that we would never see using our conventional, traditional methods. Machine learning is becoming the basis and the interface technology for dealing with huge data volumes – in science and elsewhere.

How is the Max Planck Society responding to this turning point? I can say that we are investing heavily in computer science as the new basic science. Now and in the future, in and across all Sections. And because this investment cannot be undertaken through growth alone, we are stepping back from established science fields – reluctantly, if I'm honest. However, we have to bear in mind that science is about expanding our existing knowledge, so good science is at home wherever the steepest learning curves are to be found. For us, this means not just addressing new areas of research, but also redefining them, irrespective of disciplines and specialist fields.

> Good science is at home wherever the steepest learning curves are to be found

In this process, basic principles and applications merge with one another and become indistinguishable; traditional boundaries lose their significance. Can the digital humanities really be separated from computer science or machine learning? And what about social computing: a domain of computer science with no knowledge of social sciences? Science is changing, and with it, the internal structures of the Max Planck Society – institutes that cross the lines between Sections are emerging, fields of work are converging.

Consider this example: At our new Institute for Intelligent Systems located at two sites – in Tübingen and Stuttgart – we cross the borders between engineering, computer science and neuroscience. The institute combines two elements with particularly steep learning curves: cognitive robotics and machine learning.

Previous pioneering achievements in artificial intelligence were developed for systems with a small number of variables and are not yet adequate to facilitate, for example, competent behavior in manipulation robots with high degrees of freedom. Genuinely autonomous behavior is still a long way from realization here. But in the future, the hardware – the

intelligent robotics – will be a fundamental part of the feedback loop consisting of perception, action and learning. This is why, at our institute, we aim to develop and combine hardware and software under the same roof.

This, by the way, is an approach that is extremely promising in Germany. We may not have developed any global internet platforms here, but when it comes to combining learning computer systems with hardware that possesses physical intelligence by design, we do have something to offer.

In locations where the Max Planck Society is restructuring, we also see ourselves as a driving force for supra-regional development. Here at the digital turning point, we are particularly aware of this responsibility. An exciting environment is developing around our Institute for Intelligent Systems in Stuttgart/Tübingen. We named it Cyber Valley. The hope is that it will one day link the Max Planck Institute with the neighboring universities, leading companies, a high density of junior scientist groups and a strong community of spin-offs. In other words, we aim to create a highly attractive cluster with international visibility – a home for scientists and nerds.

Many other projects are also under discussion within our Sections: from small-scale activities to potential new institutes. For example, we are deeply interested in the field of cryptography: How can we make communication today secure? The answer to this question could lie in a convergence of mathematics, quantum physics, optics and computer science.

Neuroprosthetics is quite clearly another field with the potential to be extremely fertile. The goal is to at least partially replace lost functions in the human nervous system with the aid of ultra-small technical systems. Is it possible to approach this goal without machine learning and intelligent robotics?

But also consider such topics as education, the right to be forgotten in the age of the internet, or privacy as a public commodity: all of these issues are of interest to our Human Sciences Section. And lastly, the digital humanities: What lies behind this label, and how do we put it into practice?

One task remains unchanged: the Max Planck Society will continue to build its institutes around outstanding scientists. We want to be a magnet for researchers from around the world in all of the research areas that are of interest to us. However, we must not concentrate solely on established fields in which this task is easily accomplished. We must also dare to venture into fields in which Germany and Europe have, as yet, no prominent visibility. Of the 64 winners of the Turing Award to date – the Nobel Prize of the computer science field – 47 came from the US, 6 from England and 11 from six other countries. Not a single one from Germany!

> We need to appoint outstanding scientists in such fields as computer science

This must not remain the case for the next 20 years. So what does Germany need to do? First of all, we must keep our eyes open: when a computer scientist in Germany scores an outstanding achievement, he or she is easily lured away – not just by Google, Apple and Facebook, but also by the small start-ups in Silicon Valley, who entice talent with their scope for creative development and flat hierarchies. The STEM gap in Germany is already far too wide.

We must increase our education and training capacities, create attractive research locations and, more than ever before, bring outstanding scientists to Germany – and at the same time stop the brain drain. In other words, we must invest significantly more, and we must do so quickly!

A glance at our history makes it clear that the Industrial Revolution was powered not just by coal and ore, but also by highly skilled labor. In the second half of the 19th century, Justus von Liebig fundamentally changed the study of chemistry. This change produced an entire generation of young

Photo: Axel Griesch

chemists who conducted research in the burgeoning dye factories. One of those was today's BASF, which remains a heavyweight in the chemical industry.

That was also a time of major investment. The universities were developed into international centers of excellence, while a new type of higher education emerged with the creation of technical universities. The Kaiser Wilhelm Society became the cradle of elite researchers in the sciences. Germany still profits from the dynamism of those days: our strong industry has survived catastrophic wars and continues to ensure our prosperity.

At present, the cards are being reshuffled, which is the hallmark of a turning point. Education and research are becoming more important than ever. We must make the same effort today that was made 100 years ago, and create the educational and research institutions that will ensure our prosperity in the decades to come. We must have the same courage.

Thanks to its reputation and its extremely flexible structure, the Max Planck Society can achieve a lot here. But it is also clear that there are limits to the restructuring of institutes. We are neither willing nor able to abandon established fields at the same speed at which computer science is developing, especially since these existing areas are also working very successfully at the forefront of scientific progress. We must therefore be willing to continue to increase our investment in science.

But maybe this also requires an initiative on the part of strong European countries. As the European Molecular Biology Laboratory (EMBL) has shown, a joint effort in the field of biomedicine has achieved a great deal in and for Europe. The EMBL is playing in the same league as Cold Spring Harbor, MIT and the Salk Institute in the US. We need the same commitment in the computer sciences! ◂

This article formed the basis for the address given by Martin Stratmann at the General Meeting of the Max Planck Society in Saarbrücken in June 2016.

Photo: Axel Griesch

THE AUTHOR

Martin Stratmann, born in 1954, studied chemistry at Ruhr University Bochum. He completed his doctorate at the Max-Planck-Institut für Eisenforschung (iron research) in 1982. Following a post-doctoral position in the US, he became a Research Group Leader at the Max-Planck-Institut für Eisenforschung. He earned his German postdoctoral lecturing qualification at the University of Düsseldorf and went on to teach at the University of Erlangen-Nuremberg from 1994 to 1999. In 2000, he accepted an appointment as Scientific Member and Director at the Max-Planck-Institut für Eisenforschung. He has received numerous awards, including the 2005 U. R. Evans Award presented by the British Institute of Corrosion. Martin Stratmann has been President of the Max Planck Society since June 2014.