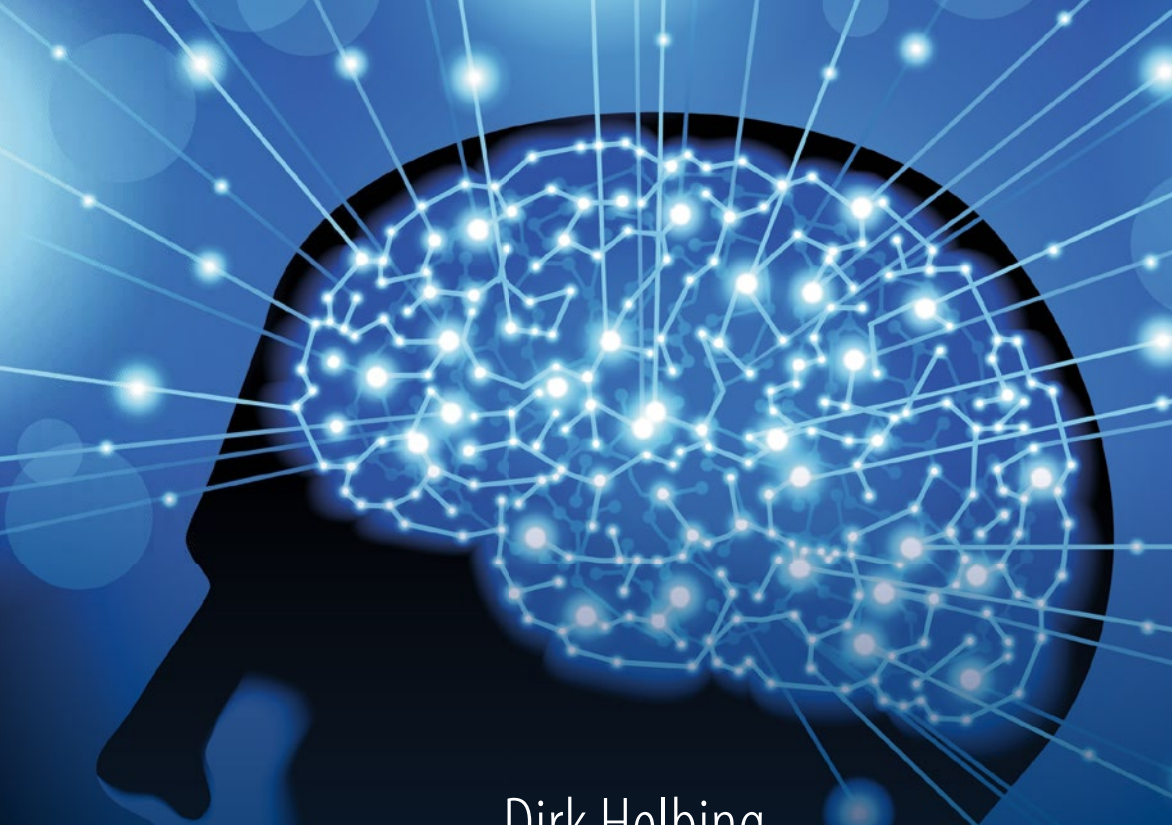

Dirk Helbing
Editor

Towards Digital Enlightenment

Essays on the Dark and Light Sides of the Digital Revolution

Springer

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Preface

When my book *Thinking Ahead* was published, our societies were on a path toward data dictatorship[1] or, as some people call it, technological totalitarianism.[2] Mass surveillance, as reported by Edward Snowden and others, was just the beginning. With the Digital Manifesto published in Spektrum der Wissenschaft,[3] it became increasingly clear that more and more areas of our lives were increasingly influenced by algorithms and often in such subtle ways that we had not even noticed this. Secretly, cookies used by our Internet browsers as well as our smartphones had delivered data to little known companies such as Axciom[4] or Axon Global,[5] which create detailed profiles about everyone living in the modern world—profiles that can predict our behavior better than our friends, family members, or even partners.[6] These profiles reveal more or less every relevant detail of our lives, including those that we consider highly private (such as the friends we have, our religious beliefs, sexual preferences, political inclination, and voting behavior). The company Crystal Knows[7] even runs a platform, which advertised for some time with the slogan "See anyone's

[1]Das DigitalManifest: Digitale Demokratie statt Datendiktatur, http://www.spektrum.de/pdf/digital-manifest/1376682; English translation: Will Democracy Survive Big Data and Artificial Intelligence? https://www.scientificamerican.com/article/will-democracy-survive-big-data-and-artificial-intelligence/

[2]F. Schirrmacher (ed.) Technologischer Totalitarismus: Eine Debatte (Suhrkamp, 2015) https://www.amazon.de/Technologischer-Totalitarismus-Eine-Debatte-suhrkamp/dp/3518074342;
M. Schulz, Technologischer Totalitarismus: Warum wir jetzt kämpfen müssen (FAZ, 6.2.2014) http://www.faz.net/aktuell/feuilleton/debatten/die-digital-debatte/politik-in-der-digitalen-welt/technologischer-totalitarismus-warum-wir-jetzt-kaempfen-muessen-12786805.html

[3]See footnote 1.

[4]https://www.acxiom.com

[5]https://axoncyber.com

[6]Diese Firma weiss, was Sie denken (Tagesanzeiger, 3.12.2016) https://www.tagesanzeiger.ch/ausland/amerika/diese-firma-weiss-was-sie-denken/story/25805157

[7]https://www.crystalknows.com

personality." In fact, it allowed everybody to study the personality traits of other people—neighbors, friends, colleagues, and even strangers, competitors, and enemies.

Google and Facebook are the best-known companies that realized early on how personalized information can be used to influence our attention and, with this, our opinions, emotions, decision-making, and behavior.[8] One might call this mass mind manipulation, and secret services can do this, too (see the JTRIG program).

But that's not all. Apple started to collect our activity data and set up a partnership with IBM to let their Cognitive Computer "Watson" determine our health status and diseases.[9] Microsoft's Windows 10 was spying on users.[10] Amazon's Echo is listening our conversations.[11] Game stations are spying on us.[12] And Cambridge Analytica produces psychological profiles of hundreds of millions of citizens to manipulate, for example, people's voting behaviors. The company claims that the Brexit and the outcome of the US election were largely their success.[13] "Has the "atomic bomb" of the digital age exploded?", people started to ask. Or was it rather a "digital Fukushima"?[14]

Was Elon Musk right that artificial intelligence (AI) was potentially more dangerous than nuclear bombs—considering the fact that it was used for cyberattacks on critical infrastructures such as hospitals, nuclear power stations, the electricity grid, and the Internet? Are we "summoning the demon"?[15]

At least, it eventually becomes clear that we were heading toward a cybernetic society, in which algorithms increasingly control society and individual behaviors. By revealing our personality traits, we have become vulnerable to manipulation. This has been used not only by the marketing industry, but also by politics, where one speaks of "social engineering" and "nudging" (and when combined with Big Data, of "big nudging").[16] Probably since the Arab Spring, or even before, social bots were used to influence social media and, by this, people's opinions and

[8]R. Epstein, R.E. Robertson: The search engine manipulation effect (SEME) and its possible impact on the outcome of elections, PNAS 112, E4512-E4521 (2015); R.M. Bond et al. A 61-million-person experiment in social influence and political mobilization, Nature 489, 295-298 (2012); A.D. I.Kramer, J.E.Guillori, J.T.Hancock, Experimental evidence of massive-scale emotional contagion through social networks, PNAS 111, 8788-8790 (2014).

[9]IBM forms new health data analytics unit, extends Apple partnership, http://www.zdnet.com/article/ibm-forms-new-health-data-analytics-unit-extends-apple-partnership/

[10]Microsoft was just ordered to stop Windows 10 from spying on users, http://bgr.com/2016/07/22/microsoft-windows-10-data-collection-france/

[11]Alexa and Google Home record what you say. But what happens to that data? https://www.wired.com/2016/12/alexa-and-google-record-your-voice/

[12]Our game consoles are likely spying on us, and this is business as usual, https://www.polygon.com/2014/2/28/5456940/our-game-consoles-are-likely-spying-on-us-and-this-is-business-as

[13]Ich habe nur gezeigt, dass es die Bombe gibt, https://www.dasmagazin.ch/2016/12/03/ich-habe-nur-gezeigt-dass-es-die-bombe-gibt/

[14]Carsten Könneker, Fukushima der Künstlichen Intelligenz, http://www.spektrum.de/news/interview-die-unterschaetzten-risiken-der-kuenstlichen-intelligenz/1377620

[15]https://www.youtube.com/watch?v=_rfHNvHu8OE

[16]See footnote 1.

decisions. As algorithms determine news feeds, i.e., the number and kinds of people who receive particular messages, social media have become a powerful tool for propaganda and censorship, instruments of disinformation, and hybrid warfare.[17]

In the end, president Obama himself warned the public in his last Correspondents' dinner speech:[18] "... this is also a time around the world when some of the fundamental ideals of liberal democracies are under attack and when notions of objectively and of a free press and of facts and of evidence are trying to be undermined or in some cases ignored entirely. And in such a climate it's not enough just to give people a megaphone. And that's why your power and your responsibility to dig and to question and to counter distortions and untruths is more important than ... ever."

With my books *Thinking Ahead*[19] and *The Automation of Society Is Next*[20] as well as the various FuturICT Blogs and the science fiction *iGod*[21] (jointly written with Willemijn Dicke), I have tried to follow this request to dig deeper. I believe that this—together with the many dozens of talks I have given on digital issues to more than 10,000 people and the weekly news articles in various countries—has eventually had some impact on the international debate about where we should be heading in the digital age ahead of us. I have fundamentally challenged the idea of a data-driven "benevolent dictatorship" with the *Nature* article "Build Digital Democracy,"[22] the Digital Manifesto,[23] and my article "Why we need democracy 2.0 and capitalism 2.0 to survive."[24] Now, a new game is about to begin.[25] To get there, it was important to not only criticize mass surveillance and manipulation, but to come up with an alternative, better model for our future—a world in which capitalism and democracy would not fight with each other, but where they would be married together to unleash the benefits of both. Such a new socioeconomic framework, which could dramatically improve our future prospects in a world of limited material resources, can now be built by combining Internet of Things with Blockchain Technology and Complexity Science.[26]

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[17]Notwehr against the Machine, http://www.zeit.de/digital/internet/2017-12/34c3-chaos-computer-club-kuenstliche-intelligenz

[18]The complete transcript of President Obama's 2016 White House correspondents' dinner speech, https://www.washingtonpost.com/news/reliable-source/wp/2016/05/01/the-complete-transcript-of-president-obamas-2016-white-house-correspondents-dinner-speech/

[19]https://www.amazon.com/Thinking-Ahead-Digital-Revolution-Participatory/dp/3319150774

[20]https://www.amazon.com/Automation-Society-Next-Survive-Revolution/dp/1518835414/

[21]https://www.amazon.com/iGod-Willemijn-Dicke/dp/1544271573/

[22]D. Helbing and E. Pournaras, Build Digital Democracy, Nature 527, 33-34 (2015) https://www.nature.com/news/society-build-digital-democracy-1.18690

[23]See footnote 1.

[24]D. Helbing, Why we need democracy 2.0 and capitalism 2.0 to survive, Jusletter IT (25 May 2016) https://www.researchgate.net/publication/301620104_Why_we_need_democracy_20_and_capitalism_20_to_survive

[25]D. Helbing, Digitization 2.0: A New Game Begins, https://www.researchgate.net/publication/317279118_Digitization_20_A_New_Game_Begins

[26]D. Helbing, An Urgent Appeal to Save the Planet, 7-part series in The Globalist, https://www.theglobalist.com/population-environment-technology-society-climate-change-disaster/

Particularly in its second part, this book offers an encouraging vision, how a better future could look like. In the past years, to those who were studying statistics and forecasts about our world, it appeared that we would eventually run into a situation of serious scarcity as well as economic and population collapse, as described by the Limits to Growth[27] and Global 2000[28] studies. Moreover, it seemed that we would lose our privacy, democracy, and human rights in an increasingly top-down controlled world trying to respond to these crises and disasters. But now there is a chance that we will take a different path into an alternative digital future characterized by peace and prosperity, which would be based on a digitally upgraded democracy supporting collective intelligence, jointly with a socio-ecological finance system ("finance 4.0") boosting the evolution of a circular and sharing economy or, in other words, a participatory information and innovation ecosystem.

Why am I getting more optimistic? Because an open letter has been calling for another kind of digital economy, recently.[29] Europe has come up with a Data Protection Directive. The highest European Court has forbidden today's kind of mass surveillance. Governments have started to worry about the dual use of artificially intelligent systems such as social bots. The White House has pushed for bottom-up approaches such as "Citizen Science" and "A Nation of Makers."[30] The IEEE has worked on guidelines for "Ethically Aligned Design,"[31] and leading IT companies have decided to collaborate in order to break the filter bubble[32] and develop accountable and moral AI systems, which "should be an extension of individual human wills and, in the spirit of liberty, as broadly and evenly distributed as possible."[33] An age of digital enlightenment, as it was called for by the Digital Manifesto,[34] seems to be on its way. It's now your turn to contribute this better future, which is just around the corner!

Zürich, Switzerland Dirk Helbing
February 14, 2018

[27]D.H. Meadows, Limits to Growth (Signet, 1972).

[28]The Global 2000 Report to the President, http://www.geraldbarney.com/G2000Page.html

[29]Open Letter on the Digital Economy, https://www.technologyreview.com/s/538091/open-letter-on-the-digital-economy/; http://openletteronthedigitaleconomy.org

[30]https://obamawhitehouse.archives.gov/blog/2016/04/14/collaboration-gives-federal-government-citizen-science-and-crowdsourcing-new-home; https://obamawhitehouse.archives.gov/node/316486

[31]Ethically Aligned Design, http://standards.ieee.org/develop/indconn/ec/ead_v1.pdf

[32]http://www.independent.co.uk/life-style/gadgets-and-tech/news/computer-simulation-world-matrix-scientists-elon-musk-artificial-intelligence-ai-a7347526.html; http://www.businessinsider.de/tech-billionaires-want-to-break-humans-out-of-a-computer-simulation-2016-10

[33]https://blog.openai.com/introducing-openai/

[34]See footnote 1.

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Contents

Chapter 1
The World Today: A Net Assessment

Dirk Helbing

Is it mere alarmism to talk about global emergency? Or do we really have reasons to be alarmed?

"Time to evacuation" is the time between the ringing of an alarm, say, in a cinema or theater, and the time when the first people begin to evacuate. This time span is decisive for the number of people who will survive a building fire.

When the alarm rings, many people will not flee right away. After all, it could be a false alarm. Is there any sign the situation is serious? Is there any smoke? Does it smell strange?

If not, what are the other people doing? Are they evacuating themselves? Then it might be better to join the flow of people trying to get out. And yet, often nobody wants to be first. It might be a false alarm, after all.

Also, what if it isn't any safer outside? In such a case, shouldn't we ignore the alarm altogether, for lack of reasonable alternatives?

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1.1 Planet Earth Is in Trouble

This is the kind of situation humanity currently finds itself in. Planet Earth is in trouble. I admit, we have heard that many times—and it often seemed to be a false alarm. So, we have to get a clearer sense of how serious the situation really is.

Today's economy is not sustainable, we hear. The world is overconsuming the Earth's renewable resources by 50%, Europe by 250% and the United States by 400%, we read.

In less abstract terms, that means nothing else than that "industrialized countries are living at the cost of developing countries" and that "today's generation is living at the cost of future generations."

It's not fair, but it's the way things have always been, one might say. The powerful exploit the weak—not nice, but a fact of life.

So far, we may have disliked such exploitation, but people in today's industrialized societies have implicitly consented to their political and economic system, which produces such drastic inequality in wealth and opportunities.

Most likely, their reason for acquiescence was that they did not have much to complain. Performance indicators have been growing for years: The world's gross domestic product (GDP) went up. The number of wars went down. Average standards of living increased. And so on.

1.2 Misleading Indicators

However, a closer look is revealing. The Millennium Goals were not met. Most of the progress that was made occurred mainly thanks to China's enormous development, while many world regions are still crumbling.

Moreover, indices measuring unemployment or GDP per capita have been conveniently—but usually silently—changed many times. What used to count as unemployed has, in part, been replaced by so-called one Euro jobs (or internships or other precarious kinds of employment).

Similarly, GDP per capita is manipulated by changing the composition of goods people are assumed to consume. For example, if a regular steak become too expensive for many to afford, it may be replaced by cheaper goods rather than counting as inflation. This artificially keeps inflation down and economic growth rates up.

In other words, "most jobs ever" and "lowest inflation ever" is often a result of manipulation—and that, in turn, is a sign of how serious the situation really is.

1.3 Fallout from the Financial Crisis

Of course, the fallout from the financial crisis still looms large—larger than most people realize. The relevant fact to keep in mind is that, so far, the upper classes of society did not suffer much from it. Central bankers came to their help.

However, public debt has increased dramatically, and this is basically everyone's debt. Thus, aside from the fact that we are already consuming more than we can presently pay, most people would not be able to ever pay for their share of the public debt, and those who could will make sure through the political process that they are protected.

As a result, there is no prospect that most governments will ever be able or willing to pay off their debts.

This debt is concentrated in industrialized countries, which reflects again that the industrialized nations' style of living is neither justified nor sustainable. It comes at the cost of our future, living on the backs of coming generations, and on the backs of other peoples.

Pay day is coming closer. Mass migration and terrorism are challenging the old powers. Forecasts by the Club of Rome and others imply that there are billions of people too much on this planet—commonly referred to as "over-population."

We cannot keep the problems caused by us at bay much longer—if we don't change the system.

1.4 Talk of World War III

Never before have people talked so much about a looming World War III. That is not really an option, however, as it would make the Northern hemisphere basically uninhabitable.

No wonder, though, that business for nuclear-proof bunkers for the elites and ranches in far-away places in the Southern hemisphere for the same elites are booming. They know things can't go on like this much longer.

One thing is clear: Continuing with today's economic system will surely end in disaster. In the past, we have perhaps not talked and read so much about this situation—better alternatives were lacking. The approach was to enjoy life as long as possible, if we could not do much about our existential threats.

1.5 Time to Start a New Chapter of Human History

Now, however, it's time to shout "the world is on fire." We can "evacuate ourselves" from a future that is doomed, because there are new concepts and technologies that allows us to build a different, better future.

Artificial Intelligence, the Internet of Things, and Blockchain Technology, 3D printers, and the sharing economy, for example, are potential game changers. They allow for a better organization of the world.

A new game begins. A better coordination of resources, empowered by digital technologies, will enable a better monetary, financial and economic system, and political systems can be upgraded as well, as Chap. 10 lays out.

In other words, if we act now, we aren't doomed, but major changes are needed. It's time to take our future in our hands and start a new chapter of human history, as it happened when the industrial revolution was on its way.

Metaphorically, we may imagine it like the transformation from a caterpillar to a butterfly. In other words, the outcome may be much nicer than the future we imagine today.

1.6 Takeaways

- When the alarm rings, many people will not flee right away. After all, it could be a false alarm.
- The world is overconsuming the Earth's renewable resources by 50%, Europe by 250% and the United States by 400%.
- The fallout from the financial crisis still looms large—larger than most people realize.
- We cannot keep the problems caused by us at bay much longer—if we don't change the system.
- One thing is clear: Continuing with today's economic system will surely end in disaster.

Chapter 2
Why Our Innovation System Is Failing and How to Change This

Dirk Helbing

Our innovation system has terribly failed. It is well designed to support gradual improvements of our knowledge and technologies. But it does not support disruptive innovations well, which would create new qualities and functionalities, or question the basis of our established knowledge and routines. Moreover, our knowledge does not keep up anymore with the pace at which our world changes, and solutions to new problems often come with serious delays. Therefore, we need to re-invent innovation. In particularly, we must learn to create systems embracing collective intelligence that surpasses the intelligence of even the brightest individual and of powerful supercomputing solutions. This cannot be based on top-down nor majority decisions. Diversity is absolutely crucial for collective intelligence to work. . .

2.1 The Innovation Crisis

In times of economic recessions and political crises, innovations and new ideas are bitterly needed. But great ideas are rare, and many ideas that appear to be new just reproduce or re-invent what somebody else has thought before. As I will show below, it is very difficult to have just one or two great ideas in a lifetime that will survive for more than 50 years, or even change the world. This is bad, given today's world is changing faster than ever due to climate change, environmental change,

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demographic change, conflict, war etc. Do we innovate quickly enough? Does our knowledge still keep up with this rapid pace of change? I don't think so.

I certainly don't deny that the digital revolution is brewing a perfect storm. Within just a few years, we have seen many new technologies such as social media, Big Data, cloud computing, Artificial Intelligence, cognitive computing, Internet of Things, Blockchain technology as well as virtual and augmented reality—and I love them. But which of these inventions will create anything that will remain for 5000 years, or just 50? "Creative destruction" is often cited as ideal, because a new and better world order would be born from the chaos created. However, if we look back at the events so far, chaos has mainly born more chaos, in a gigantic global cascading effect that poses existential threats. Think of the events after September 11, 2001, or the financial, economic and public spending crisis, which hit us pretty unprepared.

In 2013, The Economist started "The great innovation debate".[1] It raised the question, whether we will ever invent something as important as the toilet again. It is often said that Big Data is the "oil of the twenty first century", but people increasingly add that, apparently, we haven't invented the motor yet to use it. Or if we have invented it, we have failed to build it due to political or economic constraints. Let me stress that I love "moonshot projects", including many of Google's efforts in this direction. Some people believe that, thanks to superintelligent systems, we will have all problems of the world solved by 2036—apart from climate change.[2] However, this seriously underestimates the nature of complex systems such as our society and economy. For sure, we will be faced with new challenges such as cyber threats. And so far, none of our attempts have been able to restart the engine of the world economy, or create prosperity for all—a fact that has been criticized by an Open Letter on the Digital Economy, which obtained a broad support.[3] In the last decades, inequality has further increased. In times of stagnation, this means that the lower and middle class, in other words: the small and medium sized companies had to pay for this. The diverse "ecosystem of customers and firms" that makes up a thriving economy[4] has increasingly degraded. It trends towards the creation of monopolies, particularly in the IT industry. While these monopolies increasingly claim global leadership where our societies should head, I don't see that they would have the recipes to create global well-being.

According to mainstream economics, a lack of innovations should never occur. If a problem would just grow big enough, they argue, there would be an increasing willingness to pay a high price for a solution. Accordingly, scientists and engineers would be incentivized to work hard to find a solution. Therefore, any big enough problem would be fixed sooner or later. However, even though the fact of global

[1] http://www.economist.com/news/leaders/21569393-fears-innovation-slowing-are-exaggerated-governments-need-help-it-along-great

[2] and cybercrime, that's what I learned from Jim Spohrer of IBM.

[3] http://openletteronthedigitaleconomy.org/

[4] http://science.sciencemag.org/content/317/5837/482.short

warming due to our carbon-based economy has been known already in the 1960s,[5] 50 years later we are still lacking a solution to the problem. Climate change may erase as much as one sixth of all species, and it poses an existential threat to humanity. By signing the Paris Climate Agreements, it has finally been admitted that innovations did not manage to solve this problem, even though many billions have been invested.

I personally believe those innovations haven't gone deep enough. We need to think out of the box, but we have stayed within it. As Albert Einstein said, we can't solve problems with the same kind of thinking that created them. Let me illustrate this for the example of the future prospects of our world. Back in the 1970s, The Club of Rome published their Limits to Growth study. No matter how hard they tried, they could not find a sustainable development path for the Earth. We would, therefore, run into economic and population collapse. Even though the study was highly controversial, the Global 2000 report commissioned by president Bill Clinton came to very similar results. So, if we want to avoid economic and population collapse, we must change the system of equations underlying the simulation scenarios. This means nothing else than the need to change our socio-economic framework. That is exactly what "finance 4.0", a new socio-ecological financial system could do—by measuring, valuating, and trading externalities and creating a multi-dimensional incentive system that would boost a circular and sharing economy by unleashing powerful market forces.[6] It is time that responsible economic and political players take action on this (see Chap. 10 in this book).

And what about our health system? In fact, the pharmaceutical industry is in big trouble, too. Most of the relevant companies have a declining number of new drug registrations. Even though the large multi-national companies are buying lots of startups to stay on top of innovation, this hasn't changed their situation much. In the meantime, we are running out of antibiotics that are effective against multi-resistant strains of bacteria. This is a serious issue, indicating a failure of our current research and development approach.

Some people are even more pessimistic than that. They claim that there haven't been any great innovations since Darwin's theory of evolution and Einstein's theory of relativity. Unfortunately, this is probably true, and it has reasons. Science is increasingly run like a business, measured by performance indicators. But while we perform better and better according to these indicators and despite the highest number of publications and patents ever, many of the problems our society is facing haven't been fixed. We are far from having the answers that our quickly changing world demands from us. For example, many people think we are far behind the Millennium goals or the United Nation's 2050 development goals.

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[5] https://insideclimatenews.org/news/13042016/climate-change-global-warming-oil-industry-radar-1960s-exxon-api-co2-fossil-fuels

[6] D. Helbing, A Digital World to Thrive in: http://bit.ly/20T9BpX; Why We Need Democracy 2.0 and Capitalism 2.0 to Survive: http://bit.ly/1O5axWZ; Society 4.0: Upgrading society, but how? https://www.researchgate.net/publication/304352735

Unfortunately, the need to accelerate innovation will increase even more. According to Moore's law, computational power is doubling every 18 months. In 10–20 years, supercomputers are expected to exceed the processing capacity of a human brain. We will have computer programs capable of teaching themselves, robots producing other robots, and they will quickly improve over time. Hence, computer algorithms and robots will take over many of today's jobs. Anything that follows certain procedures, probably around 50% of all jobs in the industrial and services sector, could be performed by them cheaper and better. How can we cope with this challenge of having to reinvent half of our economy in just two decades? And how can we adapt our social, economic and legal system over such a short time? We need an Innovation Accelerator. But how would it work?

2.2 An Outdated Innovation System

Let us first analyze how we innovate today. While I will focus on the academic system, I expect that similar problems occur in industrial innovation systems as well. Currently, innovation is mainly happening in a competitive way. Each scientist, each company competes against all the others. Such innovation is expensive, slow, costly, and duplicates many results. This has led to an increasing percentage of programmatic research, which works roughly as follows: First, a ministry or agency determines research needs, emerging trends and knowledge gaps. It probably takes a few years until these become obvious, and it also takes some time to mobilize the budget (see, for example, the European Union's famous 7 year plans). But once a problem has been identified and the budget set aside, a call for proposals is launched.

These calls are usually oversubscribed, because there are never enough resources for everyone. This problem is "solved" by so-called "scientific beauty contests." Basically, one puts as many obstacles in the way as needed to retain the number of proposals that can be funded, i.e. one makes proposal-writing a complicated and time-consuming task. Selecting proposals is an equally complicated task. It is usually based on peer review—a process that consumes an increasing fraction of time as well. In the meantime, scientists probably spend about 40% of their time on proposal writing, reporting and reviews. Obviously, this time and money is lost for research, but the reason given for the inefficient administration is "having to justify how tax payers' money is spent".

2.3 Forget About Determining the Best Innovations Beforehand!

Can we at least be sure that the best contributions are selected? This is hard to say, as most non-funded projects are never carried out. However, the same peer review process is applied by scientific journals to select manuscripts for publication. Since

many manuscripts that are rejected in the originally chosen journal are eventually published in a lower-ranked journal, we know a bit more about the quality of rejected as compared to accepted manuscripts. Surprisingly it turns out that a significant percentage of rejected manuscripts performs better than the ones that were accepted in the journal of choice.[7] A further surprise is that the majority of accepted and published papers performs significantly below the average of the journal, because a few of its publications generate most of its impact. This basically shows that quality is very difficult to judge. Quality may become obvious only over a long time. In fact, the recommendations of referees are often extremely divergent, particularly for innovative contributions, for which established standards do not exist.

But let's assume the best proposals were selected after a typically half-year-long review process. Then, one must find suitable staff to work on the project. The working contracts will start about 6 months after the acceptance of the proposal. The project will typically take 3 or 4 years, basically until a PhD is obtained. Publication of the research results will require between 6 months and 3 years, depending on the research field and journal. In any case, it's safe to say that this is not a fast process, and that it may easily take 10 years between the emergence of a new problem and its solution. If such a solution finally enters the knowledge core of the field (i.e. when it enters educational books and programs, which is the exception rather than the rule), it will take another 10–30 years, until it becomes best practice in business and administration. In cases of commercial industrial bias, scientific progress is often delayed by at least another 20 years, as it happened in the tobacco and energy sectors.[8]

This situation is reinforced by making science increasingly dependent on industrial funding—typically in order to fix today's problems rather than thinking ahead to find new approaches for the future. The only exception are projects of strategic nature that are of national importance. Many of these are aimed at accumulating power. But power is not the solution to many of our problems in a highly networked world, where strong interference will have unexpected side effects, feedback effects and cascading effects and often destroy structures that are essential for our society and economy to function.

Therefore, my personal judgment is that, on the one hand, our research and development (R&D) system has become increasingly dysfunctional. On the other hand, I know that many of the most successful publications are produced under difficult circumstances—they result from spontaneous ideas that someone decides to follow in the spare time, even though there is basically no funding for this. I have often wondered, why this is the case. To get funding is not the biggest problem. The problem is that we are asked to plan innovations, while the best ideas just happen. Funding institutions love well-elaborated proposals, but once one can elaborate new ideas in detail, they are not anymore cutting edge.

[7] In fact, a number of Nobel-prize winning discoveries have been rejected by scientific journals, or published in low-level journals.

[8] https://www.smokeandfumes.org/documents/document16, https://insideclimatenews.org/news/13042016/climate-change-global-warming-oil-industry-radar-1960s-exxon-api-co2-fossil-fuels

Great ideas must be pursued immediately, without the delays imposed by conventional funding mechanisms. However, our current innovation system makes scientists spend their time on ideas they get money for, and usually there is no time left for others. This effectively undermines academic freedom, and in many cases, certain innovations will be delayed for years, or even buried forever. By the time money becomes available, there will be other exciting ideas.

Thus, the crucial question is how to produce results more or less in real-time? Given that, today, it takes about 30 years from an invention to the real-world application of ideas, and many good ideas will never make it—how can we shorten this process to 5 years, or even 5 months or 5 weeks? And how can we increase the success rate of inventions? If we understood this, we could produce a dramatic innovation boost. Given that we have already more than 20 million unemployed people in Europe alone, such an innovation boost would be bitterly needed.

2.4 Everyone Wants Innovations, but Opposes Them!

To improve the innovation mechanism, it is important to first understand the nature of innovation a bit better. It turns out that there are two different kinds of innovations: gradual and disruptive innovations. Gradual innovations can be measured according to established standards of a field. They may best be characterized as "improvements"—such as a motor that consumes less energy and produces less emissions. Here, it seems reasonable to expect consensus of the reviewers in a funding board.

Pioneering research, in contrast, produces disruptive innovations, exploring or creating entirely new quality dimensions. These are the "true" innovations, which decision-makers and business people are usually keen on. Thus, why don't they happen more often? Almost by definition, disruptive innovations can't be assessed with established standards. They transcend existing categories and require one to think "out of the box." Consequently, such innovations are often highly controversial, and majority decisions of the reviewers in a funding board will rarely support them.

History shows that basically every disruptive innovation has been opposed in the beginning. The following quotes are quite illustrative. Ten years after the first successful test of electric light bulbs on October 22, 1879, Thomas Edison said: "Fooling around with alternating current is just a waste of time. Nobody will use it, ever." But today, everyone is using this kind of electricity 24 hours, 7 days a week. Or take the US president Rutherford B. Hayes. After a demonstration of Alexander Bell's telephone in 1872, he concluded: "It's a great invention but who would want to use it anyway?" Later, the inventor Lee De Forest (1873–1961) stated: "While theoretically and technically television may be feasible, commercially and financially it is an impossibility." Similar opinions were voiced, when the radio, planes, drilling for oil, or nuclear energy production were proposed.

It's no wonder that Alexander von Humboldt (1769–1859), one of the great discoverers of the world (and inventor of our modern university system) came to conclude: First, people deny that the innovation is required. Then, people deny that the innovation is effective. Afterwards, people deny that the innovation is important, and it will justify the effort to adopt it. Finally, people accept and adopt the innovation, enjoy its benefits, attribute it to people other than the innovator, and deny the existence of the previous stages. In other words: most innovations won't make it.

The famous quantum physicist Max Planck (1858–1947) even claimed: "Science advances one funeral at a time." This is mainly a result of the "rich gets richer effect," as Robert Merton (1910–2003) called it: while new inventions are made all the time, highly referenced work tends to get an even increasing amount of attention. This creates a threshold effect: only ideas that manage to get above the attention threshold will have a chance to win through. Such ideas are called "revolutionary ideas" and cause sudden, fundamental changes of our understanding or even of our world, so-called paradigm shifts, as analyzed by science historian Thomas Kuhn (1922–1996).

Revolutionary breakthroughs trigger an avalanche of new ideas, change the perspective of our world, and have the potential to transform our reality. One spectacular example is the replacement of the human-centered ("geocentric") worldview assuming the Earth to be the center of the universe by our current view that our planets would circle around the sun ("heliocentric" view). This shift goes back to observations of Nicolaus Copernicus (1473–1543) and theoretical work of Galileo Galilei (1564–1642). Later, it allowed Isaac Newton (1642–1726) to come up with his equations for the dynamics of celestial bodies. Without these discoveries, we would not be able to send rockets to the moon or have satellites circle around the earth. What seems to be a natural point of view today questioned the Christian worldview so much that Galilei was sent to prison. Only 350 years later, the Catholic church apologized for this.

The discoveries of Charles Darwin (1809–1882) were not less shocking. His theory of evolution—implying that humans were descendants from apes—largely replaced the idea of divine creationism, and is still questioned by some people today. However, without this paradigm change, it would be hard to imagine genetic engineering today. Or think of the theory of relativity by Albert Einstein (1879–1955). Without it, we would not understand how to produce nuclear energy or how to operate the Global Positioning System (GPS) exactly. In 1931, a provocative book entitled "100 Authors Against Einstein" even tried to discredit his work. Nevertheless, after a couple of decades, Einstein's counterintuitive predictions were finally confirmed. Such revolutionary ideas are extreme events—one might even say: "black swans",[9] i.e. unexpected rare events that cause major shifts (often through a massive cascading effect). They occur only every fifty or hundred years or so.

[9]N.N. Taleb, The Black Swan (Random House, 2nd edition, 2010).

But if great ideas cannot be identified beforehand, why don't we engage in refunding excellent work that has already happened, rather than in funding people for impressive promises made in lengthy and complicated project proposals? In other words, why do we pay money for the best promises, and not the best results? Wouldn't it save billions of tax payers' money, if the relatively few brilliant minds that exist could concentrate on innovations rather than on proposal writing, evaluation, and reporting? The good point about the scarcity of ground-breaking ideas is that funding agencies would have more than enough money to (re-)fund them. The open problem though is how to identify them (which, as I said before, cannot be well done by consensus or majority decisions of funding boards, as long as the ideas are young and quality criteria and research communities are not yet established).

2.5 Detecting Game-Changing Ideas and the Innovators Behind Them

But there is, in fact, a way of detecting where new ideas are produced, and where they are consumed. I did such a study together with Amin Mazloumian, Katy Börner, and others.[10] Each scientific publication refers to others it has been inspired by. Therefore, one can identify the flow of ideas in the world, and what are the places that produce ideas that are over-proportionally successful (shown in green in Fig. 2.1).

It is even possible to reveal what are the main ideas discussed in these publications—by analyzing the spreading of "memes." Memes are single words or combinations of words that appear in texts such as scientific publications. In physics, "atom" or "quantum mechanics" or "high-temperature superconductivity" would be such examples. In fact, my postdoc Tobias Kuhn and I, together with Matjaz Perc, have scanned the abstracts of all publications of the American Physical Society for such memes. This allowed us to identify the first occurrences of any new word or combination of words (meme). Of course, scientists come up with new terms all the time, but only in a few cases is the usage frequency quickly growing significantly in time. If this is the case, a new trend is born. Moreover, there is another property that characterizes Earth-shaking ideas. Their memes are "inherited" through the citation graph, i.e. they spread through mentions in later publications of colleagues. This separates important scientific concepts from meaningless memes. In fact, the history of the most important fields in physics can be determined in a fully automated way[11] (see Fig. 2.2).

[10] A. Mazloumian, D. Helbing, S. Lozano, R. P. Light and K. Börner (2013) http://www.nature.com/srep/2013/130130/srep01167/full/srep01167.htmlGlobal multi-level analysis of the 'Scientific Food Web'. http://www.nature.com/srep/index.html Scientific Reports 3, 1167.

[11] T. Kuhn, M. Perc, and D. Helbing (2014) Inheritance patterns in citation networks reveal scientific memes. Physical Review X 4, 041036, https://journals.aps.org/prx/abstract/10.1103/PhysRevX.4.041036