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Towards a New Industrial Revolution? Entropy and its Challenges

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Translated by Joel White

Introduction

Below is a podcast and transcript of the interview concerning the 1st chapter of the book Bifurquer: Il n'y a pas d'alternative [Bifurcate: There is No Alternative] *on the scientific, technological, and political stakes of the notion of entropy. The discussion took place between Bernard Stiegler, Maël Montévil, Marie Chollat-Namy, and Victor Chaix, on the 1st of July 2020.*

More than four years ago, at the initiative of Bernard Stiegler and myself, Victor Chaix, the Association of the Friends of the Thunberg Generation (AAGT) held and recorded a discussion on the book *Bifurquer: Il n'y a pas d'alternative*, published a month earlier by Les Liens qui Libèrent.

This interview was intended to be the first of a long series on each chapter of the book. Between its main authors—members of the Internation scientific network—and young activists of the Association, in order to have an intergenerational dialogue and transmission, confrontation.

The book *Bifurquer* then served as a theoretical and scientific basis for the reflections and activities of the young Association, launched at the dawn of the year 2020. The aim of the interview was to highlight the political and economic issues at stake, in particular, through dialogue and collective reflection on the book's major theses. More broadly, we wanted to shed light on the key concepts of the book, using the format of an open discussion.

That's how Bernard Stiegler, Maël Montévil, Marie Chollat Namy, and I came together on the premises of the Institut de Recherche et d'Innovation and the Association, on this July afternoon, with the invaluable technical support of Riwad Salim and Giacomo Gilmozzi for the recording.

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Bernard Stiegler was president of both organisations at the time. He had edited the book *Bifurquer* alongside the Internation collective, which he had set up two years earlier. Maël Montévil, a researcher in theoretical biology, was a member of this interdisciplinary and international collective, as well as one of the main writers of the chapter we were going to cover in the book. He was also a PhD student under the supervision of Giuseppe Longo, who also contributed to the chapter and has taken the responsibility of president of the Association.

Marie Chollat-Namy and I were members of the Association, students of the life sciences and humanities respectively, and we were both activists in the ecologist civil disobedience movement, Extinction Rebellion.

It was our last meeting and discussion with Bernard Stiegler, before his death on 5 August 2020. We believe that his words are still relevant today, as is the philosophical, scientific, technological, and political project that he pursued during his final years.

After an overview of the current and historical epistemological framework of entropy by Maël Montévil, Bernard Stiegler continues the introduction by placing it in the context of the scientific and political project of the Internation collective. The discussion then continues with contributions and questions from Marie Chollat-Namy and myself. From Elon Musk to a sustainable and desirable political economy, from the imperative of efficiency to that of information theory, from the organisation of the living to the functioning of computers: the discussion was rich and sometimes difficult.

It comes at a time of intense reflection by Bernard Stiegler and the AAGT, around the Archipel Des Vivants project, which is intended to provide a concrete follow-up to the proposals in the book *Bifurquer* to set up "laboratory territories," as well as around the theme of theoretical computer science, on which the philosopher was working in spring 2020 and planning future events and publications.

Our approach to this dialogue is to not separate the scientific from the political, in the sense that one informs and orientates the other. Entropy, as much as it comes from thermodynamics, was a notion to investigate in its consequences for the living, as well as for our industrial economy and our relation to information technologies. For Bernard Stiegler, entropy was an understudied notion, as much by researchers of different disciplines and domains (beyond thermodynamics) as by the educational system. This discussion was as such a way to compensate for this "repression" of entropy, which he deplored to be mainly absent in spheres of knowledge and scientific circles, as much as in discourse by youth movements on climate and social justice.

Round Table

Maël Montévil: Today, we're going to give an overview of the first chapter of *Bifurcate: There is No Alternative*, which deals with science, anti-entropy, and exosomatisation.

Ever since Newton and the Industrial Revolution, science has played a central role in organising both society and production. The way in which it does this depends on the particular epistemology that constitutes it. The first epistemology that constitutes the relation between society and production is the classical epistemology that stems from Newton. This is a very specific epistemology in which equilibria are spontaneous and the world is fundamentally conservative. Nothing is lost, nothing is created, energy is conserved, and the laws remain the same as time advances. So, everything is very conservative. This epistemology was applied to economics, for example, with the idea that the balance of payments between states (Hume's idea) stabilizes spontaneously. And so, in this epistemological framework, there is no need for reflection: equilibrium is spontaneous and optimal.

With the industrial revolution, this type of conception was applied to the design of machines, machines that functioned spontaneously, spontaneously producing what had to be produced. In this situation, the worker becomes a proletarian in the sense that he loses his knowledge, because that knowledge is passed on to the machine, the knowledge that makes it possible to produce what we want to produce. However, with the industrial revolution came a scientific revolution: thermodynamics and the introduction of the concept of entropy. Thermodynamics was absolutely necessary to understand thermal machines, firstly steam engines, and involves entropy, which is a quantity that can only increase in an isolated system.

Increasing in an isolated system means that it defines a time arrow. There is a before and an after. And the laws are no longer the same if time is reversed. This scientific framework led to cosmological questions, i.e. the increase in entropy gave rise to the prospect of the thermal death of the universe. In other words, the idea that the universe is heading towards a gradual degradation until a situation where nothing can really happen. But the question of entropy has been very little integrated into economic concepts, which are still dominated by the concept of equilibrium and therefore a loosely Newtonian framework.

In mainstream biology, the question of entropy has not really been taken into account, although certain theorists, starting with Schrödinger, have considered it. The question that Schrödinger poses is how it is that living beings remain in a configuration of low entropy? If we look closely at the second law of thermodynamics, this is not a contradiction. Such a situation is possible because there are flows with the outside world. Entropy can only increase in an isolated system. In an open system, entropy can remain low or even decrease—if entropy is rejected on the surroundings.

However, the concept of entropy and low entropy is not sufficient to understand living organisms. Another industrial evolution has been initiated by the concept of information, which has two faces: on the one hand, computational information in the sense of calculation, as in mathematical logic, and information theory in the sense of Shannon, which describes the faithful transmission of the written message, for example. These frameworks radically changed the way society was organized, with the idea that intellectual activity would ultimately be information processing, by analogy with the computer and the transmission of information.

This has led to a second wave of proletarianisation, i.e. a loss of knowledge, in the sense that certain activities that used to be done by humans are now done by information processing systems, but also in the sense that the way in which humans now work tends to imitate these information processing systems. It's not the information processing systems or devices that replace humans because they would be equivalent, instead the two converge leading to the possibility of substitution. And this wave of proletarianisation is also taking place through the development of consumerism—consumer capitalism—where it's not just producers who are being proletarianised, who are losing their knowledge, but also consumers as such who undergo this process, whose activity is prescribed by marketing.

So, why is this informational framework inadequate for understanding living beings and then for understanding what we need to do in the face of the current crisis? In fact, this notion of information, which in a sense echoes Schrödinger's idea that living beings are characterised by a particularly low entropy (in the physical sense), is far too imprecise an idea. In other words, the entropy of living beings is certainly low, but living beings are also organised. In other words, the way in which they are configured enables them to survive; to reproduce and also to generate novelties that will become how their bodies then function.

So, by analogy with information theory, entropy alone does not describe the meaning of messages, it just describes the transmission of messages that have already been written. This means that a message that makes no sense can contain just as much information as a message that does make sense. As a result, a text written by a five-year-old, or even typed by a five-year-old, contains as much information as a play by Shakespeare.

Bernard Stiegler: According to this vision ...

M.M.: According to information theory. But with this idea, I think, that information theory is basically designed to transmit, for example, a written text. And therefore, to transmit it faithfully. That's its problem. Its problem is not knowing in what way this text contributes to the fact that society functions, for example.

B.S.: In very concrete terms, this leads to the compression of messages, whether text messages or sound messages, image messages. Hence, this image compression then can, by eliminating a great deal of redundancy, transmit complex images across twisted copper wires.

M.M.: The counterpart of information is noise. Shannon's original work was on noise: how to transmit a message faithfully across a noisy channel. So, noise makes absolutely no sense, it can't play a positive role. Whereas in Darwin's biology, random variation allows, or at least contributes to, the emergence of biological organisations. So, it's not an adequate framework, it's a framework that isn't sufficient, but which can sometimes be operational. In other words, it can be deployed, but that doesn't mean it contributes to understanding. It allows you to make calculations.

To go further, I'd like to talk a little about the concept of anti-entropy, which we introduced with Francis Bailly and Giuseppe Longo. The idea is not to stay with physics entropy and its derivates, but to add another distinct quantity, even if it is linked to entropy, which is used precisely to describe biological organisation as such. The counterpart of entropy is the production of anti-entropy, in other words the production of novelty. With the idea that in the Anthropocene, many processes destroy anti-entropy, or even prevent the production of anti-entropy, i.e. the production of functional novelty.

B.S.: So, this work, which we started exploring a few years ago, first with Giuseppe Longo, six or seven years ago—that's how it started—was very much linked to the problems of automation. They led us, along with Maël who has just spoken and a number of other people, whom I won't mention here but who are signatories to this book or who helped write it, to take up questions that were opened up by Alfred Lotka in 1945. Earlier, in fact: as early as the 1920s, after Lotka had begun to approach these questions, let's say, in particular this idea of the evolution of human beings that would be different from that of animals, and therefore not subject to Darwinian natural selection. Lotka summarised this in a very short text, 20 or 25 pages long, which was read and commented on by Nicolas Georgescu-Roegen. Both were mathematicians who had emigrated to the United States. Both were interested in biology, but Georgescu-Roegen was an economist and Lotka a biologist. Georgescu-Roegen popularised a concept called the bio-economy, which in my opinion is based on a misunderstanding.

I'd like to repeat, rephrase, and summarise what Maël has just said. We say ... when I say "we," in this book *Bifurquer*, it's also a project—it's a book, but this book is a weapon with which to carry out a project. Well, a weapon, that's perhaps a bit aggressive. A tool, let's say, to carry out a project. And this project is to launch what we call "laboratory territories," which will experiment with development that is, let's say, sustainable, if not sustainable and compatible with a multi-level distributed economy.

The nano-economy is the domestic economy—when I do my shopping, I'm in the nano-economy, I save as much as possible, I try to buy the best products as cheaply as possible. If I'm a member of the "Thunberg generation," I try to come on a scooter or by bike rather than by metro, or even by taxi, etc. [laughs]. It's local, and it meets Schrödinger, because Erwin Schrödinger posited that the negentropy that living organisms generate [is temporary and local].

That's not exactly what Maël thinks either, because we're not completely in sync on everything. There are things we haven't fully explored to the end. But I'm one of those who believes that applying the word negentropy to physics is not acceptable. That the word negentropy should be limited to living things. Because otherwise we confuse order and disorder on the one hand, and entropy and negentropy on the other. And if we do that, we give credence to a vision of the generation of order through noise that comes from physics, i.e. Ilya Prigogine's dissipative structures, and which in my opinion brings nothing at all to biology. That's not to say that it doesn't do anything for biology, but ... I think it can be misleading.

I say this for a very specific reason: it's because Schrödinger, on the other hand, coined the concept of negative entropy, which was later transformed into "negentropy" by Brillouin. Schrödinger states very precisely that this negative entropy can only occur on a local scale. So, it cannot be separated from an organisation's relationship with its environment. A gypsy tribe that was at the heart of Bohemia 50 years ago and is now in Seine-Saint-Denis must surely have changed a lot.

This locality is conditioned by the surrounding environment. This is extremely important. It's extremely important because we're starting to find issues linked to the Anthropocene, to global warming, to disturbances generated by what I call anthropy [pronounced as "entropy" in French], with an "a" and an "h". It takes up the concept of anthropogenic forcing of the G.I.E.C. (which, translated into French, is "forçage anthropique") and it also takes up a certain definition by geographers of what we call anthropised environments, i.e. environments inhabited by human beings, which impose models of the human, of the anthropos, and that's anthropic with an "a" and an "h." [pronounced as "entropic" in French].

So, where Lotka is very important is that he has shown that all human beings are equipped with artificial organs. Without artificial organs, they cannot live. He's not the first to say this, Rousseau and Herder were already saying it, so it's not new at all. What is completely new, however, is that he, as a biologist, says: firstly, biology is a question linked to entropy, it's inseparable, and secondly, in human beings, the fight against entropy, i.e. the reduction of entropy, is also an increase in entropy, which can become uncontrollable. Why does it get out of control? Well, because, to take an example, one can increase the speed at which people move around with planes or cars.

The entropic cost of these goods is becoming unsustainable on the scale of the biosphere, which is a locality where, at a given moment, all the effects of the biosphere's locality are consolidated.

There is a very, very big problem here, and this problem has been called the Anthropocene since 2000, but the first person to describe it, in my opinion, was Vernadsky in 1926. Because we always talk about the Anthropocene era, and Vernadsky described the Anthropocene era, although this is not what he called it: he called it the technosphere. Obviously, if we cross Vernadsky with Lotka (in fact, in 1926 Vernadsky wrote, "Just look at what Lotka is doing, because this guy is going to say some important things," I'd like to stress that he said the same thing about Alfred Whitehead too), then the question facing human beings is one where they need to optimise their potential for neguanthropy with an "a" and an "h" [pronounced as "negentropic" in French], in other words, to fight against anthropism in the sense of anthropisation [pronounced as "entropisation" in French]. In other words, to minimise its entropic effects.

Why is this so? Because these organs, as Socrates said, are pharmaka. In other words, they are multi-purpose. You can use a book, for example, as Socrates wrote in the 5th century BC, to demonstrate a mathematical theorem, and this is how book culture began, in fact, as early as the 7th century BC, but books can also be used to dogmatise young Athenians and get them to do stupid things, to cultivate their thirst for power. In the same way, you can use a computer to increase your profits in a totally disproportionate way—I would remind you that the sophists were also people who wanted to increase their profits. At least, that's what Plato says.

Of course, computers can do amazing things: they can fight entropy, even anthropy with an "a" and an "h". But on one condition: that we prescribe what Lotka calls knowledge. Because what Lotka is saying is that the function of knowledge in human beings is to reduce entropy and increase negentropy. And even to make possible what Bailly, Longo and Montévil have called anti-entropy, but here I say it with an "a" and an "h", that is anti-anthropy.

What is anti-anthropy with an "a" and an "h," as opposed to neguanthropy with an "a" and an "h"? Neguanthropy with an "a" and an "h" is the educational institution, the family institution—everything that constitutes frameworks that are maintained, conserved and reproduced. And that makes anti-anthropy possible: the adolescent's revolt against his father, the slightly insolent pupil who will perhaps become Arthur Rimbaud or Charles Baudelaire, or I don't know who, Albert Einstein (you should know that Einstein was considered not to be a very good pupil, and that he was rejected, and 15 years later it was said that he was the greatest genius in the history of humanity, which is quite an excessive claim by the way).

So, what we're saying today is that we need to try and develop an economy; an economy—and here I come back to what Maël was saying earlier—that revalues knowledge and fights against proletarianisation. Why does it enhance knowledge and combat proletarianisation? Because Lotka says that only knowledge can reduce entropy. From there, we say: we need to deproletarianise economic activities, the activities of what we call producers, but also consumers, because consumers, as [Maël] said, are also proletarianised. For example, through marketing and all sorts of things, we can lead them to behave in an entropic way against themselves, without them realising the impact on their health, on their own wallet economy, and so on. And so, for us, this means that we need to produce a kind of new industrial revolution.

Maël began by saying that the industrial revolution of the 19th century was based on Newton (in fact, it began at the end of the 18th century). Hume was a Newtonian. All these people thought that Newton was the culmination of science, at that time, that's what they thought. They thought that, at last, we have achieved physics. That's what Kant said. In our opinion, this led to a kind of repression of thermodynamic entropy in the nineteenth century. Knowing that, of course, what is quite delicious in a way, and somewhat paradoxical, is that it was industrial development that made thermodynamic theory possible. It was through the observation of artificial organs, which Lotka calls exosomatic, that we discovered that entropy could be increased enormously. So, it was by starting with human activity that we then returned to the laws of physics. It's not by starting from physics. This is extremely important.

Then, as you said, Maël, in the twentieth century—for reasons that are still open to discussion, and which Mathieu Triclot has clarified in a really important book—information theory developed in the wake of computer science, even if it wasn't initially designed to solve computer science problems, but telecommunication problems, and therefore problems of optimising signal communication ("signal processing," as it's called in engineering). This led to a notion of entropy and negentropy, which is not at all bounded, because if we compare the different protagonists of this notion who were in dialogue and worked together, they do not agree on what entropy and negentropy mean (Wiener and Shannon do not have the same vision of things).

This vision, which we will call computational—because Shannon's vision is that we can optimise, through calculation, the limitation of redundancy, the limitation of noise and be able, for example, to compress the signal—well, this is what will become theoretical computer science, combined also with the visions which posit that the computer is a Turing machine. In other words, a computational machine capable of any type of calculation. The combination of these two things will produce a theory of entropy in the twentieth century which seems to us to be highly problematic, and which will also generate a great deal of confusion. Because it all started in the '40s (late '40s early '50s), and it was linked to intelligence.

Today we are told that the "great singularity" will mean that in 10-, 15-, or 20-years' time, computers will tell us how to solve the new mathematical theorems. I find this totally fanciful.

Dan Ross's book analyses this model in some detail, drawing on the work of Mirowski, who has done a great deal of work on information in economic models, particularly the neo-liberal model (especially through Herbert Simon and Friedrich von Hayek). This model—that everything can be transformed into information, that all knowledge can be transformed into information, and that all information can be calculated—is going to be imposed on every activity today. Medicine, transport, cooking ... everything! Bringing up children ... Absolutely everything.

We maintain that this model is extremely dangerous. Because it assumes that everything is calculable, it overlooks incalculabilities that are in fact inevitable. Personally, I think that the pandemic we are currently experiencing is a typical case of this. When you think you can calculate everything, you think you can get rid of masks, you think you can cut hospital beds: there are a lot of things that you can do. Similarly, you can reduce the budget of the Ministry of Social Affairs, and then, why not, the Ministry of Education, etc., and the army too. And yes, this includes the army too because they want to replace soldiers with killer robots (in addition to all the enormous ethical and other problems, such as the preservation of justice, that may arise). This is totally false.

Decision cannot be reduced to calculation—Immanuel Kant explained why. This is what Whitehead later reiterated, based on mathematics and physics, and not just philosophy: decision is what always goes beyond calculation. And for a very precise reason: it's because human beings transform the world, not just interpret it, as Karl Marx said. When we transform it, we introduce an incalculable. This incalculable can be called Pablo Picasso, Albert Einstein, or Greta Thunberg. What we're arguing today is that all these issues require us to rethink the industrial economy.

What has just happened through the pandemic, the confinement and the economic catastrophe that all this engenders (which is colossal, and the extent of the catastrophe has not yet been gauged at all—no one has yet gauged it, because we don't really know how it's going to materialise, because it's global, so we can no longer separate China, Japan, North America, Europe, Africa, etc) this catastrophe is a catastrophe generated by proletarianisation. And we say that the theory of information and all those things have produced processes that should not be ignored, and which are sometimes extremely effective.

This technological efficiency means, for example, that a number of things can be robotised, tasks can be eliminated, or tertiary services can be replaced by consumer behaviour that is "cookised"—with cookies that ultimately trigger stock replenishment operations, or all sorts of things of that kind, all of which means that, for example, the OECD says that in the next 20 years, 16.6% of jobs in France will disappear. So there's a very, very significant reduction in employment.

That was before the COVID crisis. And we say that if you want to make people solvent, you have to redistribute productivity goods. And the question is: what criteria? We say that it's not enough to redistribute, for example, through a universal income, even if we're not against a universal income as long as it's not one that immiserates, as long as it's not lower than the minimum social benefits already offered, which is what, unfortunately, those who revendicate it are actually advocating... and above all we say that we need to pay for knowledge outside of the workplace. In other words, more and more people are going to produce knowledge outside their working hours, as the intermittent entertainers do.

Why do you want to do this? Because when you're not working, you're in anti-entropy. When you're employed, you're in neganthropy with an "a" and an "h". In other words, you're serving a system, you're maintaining the system, and that's fine. But what will produce knowledge is anti-anthropy with an "a" and an "h". This is the thesis that Marie will soon be defending, for example, introducing things that didn't exist before, in other words what we call novelty. From there, we need to try and rethink (this is what we develop in Chapter 3 of *Bifurquer*, in great depth) the accounting models, the qualification and quantification of value and wealth. To put in place a working method, which we call contributory research, so that all kinds of stakeholders—today we are starting to work with farmers, fishermen, and people involved in tourism too, in an island context that is across a group of islands—so that all these stakeholders can optimise their activities, for themselves, for their own interests. And not against the planet, and by integrating the whole question of entropy, which we call sustainability.

I'll finish by saying that we're all—well, more or less—very impressed by Google. Firstly, in the 20 years that Google has been around, I've been amazed by its advances. Even Amazon, which I detest. I hold Google in high esteem because I use it every day. Amazon is becoming more complicated. But in any case, I have great admiration for this structure. I have great contempt for Facebook because I think it's extremely trivial and beastly. But what I'm saying is that if it's growing, it's because it's efficient. And if we ever decide to ignore this effectiveness, the efficiency of these technologies, for example, by saying that we're going to defend French-style public services, and that we don't want this efficiency, then the French-style public service will collapse. We have to make this efficiency our own. And to make it your own, you have to criticise it. In other words, we have to point out its limits.

It's an efficiency that neglects what Aristotle, or even Immanuel Kant, called finalities. And that's not what we call finality today. That's the language of telos, with the Greeks, dating back to the fourth century, with Aristotle. We now call it sustainability. There is finality in living things. It was Kant who first understood this: in what is known as the Third Critique, the Critique of Judgement, Kant understood that living beings embody a finality. And that is very, very important.

A catastrophe occurred with what is known as neo-Darwinism, which led us to believe that we could eliminate the question of finality, that all these stochastic processes of natural selection could allow us to dispense with this question. But this is not true. What is true is that, like Jacques Monod, we have to try to do without finality, because at the beginning finality was God, in Aristotle as in Kant. So, let's try to do without God, without a transcendent finality such as that … and they try to find such a finality in probabilistic computational models. Monod said: let's look at the organism as a teleonomic system. But it's not just a teleonomic system. In other words, there is a consolidation at the level of the biosphere which means that, at a given moment, the human being is not simply an organism, but an exorganism. They have to engage in politics, they have to engage in economics, they have to produce works of art. They have to bring up their children in a way that no one else can. And that is absolutely singular and it's a singularity of purpose that can't be reduced to teleonomy. So we need to reinvest in this question of finalities, and finalities are what are produced in knowledge.

When I say "knowledge," let's be clear: for us, knowledge doesn't necessarily mean passing a thesis, a competitive examination, or an *agrégation*. Knowledge is knowing how to cook, how to cultivate a garden, how to bring up a child, how to take a car apart and put it back together again. It's all this very empirical knowledge. And it's also knowing how to live together. In other words, what we call cultures. Knowing how to be hospitable, all that ... And hospitality, I don't know, in Morocco is not at all the same as in China. But there is hospitality in all civilisations, just not in the same way. And we're not very hospitable.

If we're not very hospitable, it's not because we're bad people, it's because we've destroyed the knowledge that used to be passed on. Like knowledge of commensality, for example: we no longer know how to eat together. If you read Zola's *Germinal*, you'll see that they still know what hospitality is. This is also the theme of another novel that has been turned into a very famous film, called *Babette's Feast*. So that's what knowledge is, it's something fundamentally generous and in science it's the same, the great mathematicians are generous. They don't defend their little careers, ...

M.M.: Great chefs too, by the way...

B.S.: And great chefs too, of course, when they're not overly mediatised and proletarianised, like scientists, for that matter.

Victor Chaix: It seems obvious to me that we need to rethink the current economy, which is totally ill-adapted to the challenges of the Anthropocene. As is well described in chapter 1 of the book *Bifurquer*. Nevertheless, in relation to what [Bernard] just said, in relation to the fight against entropy, it seems to me that in its physical sense, there seems to be a limit. Given that entropy can only increase in an isolated system, in its purely thermodynamic and physical conception, what does it mean to fight entropy economically if it is bound to increase thermodynamically?

B.S.: It means making sure that the human species lasts as long as possible. It will disappear anyway. You need to know that. It will disappear like the sun disappears (the cooling of the sun: Hubert Reeves became very famous for this in *Patience dans l'azur*). So, your question is very important.

Elon Musk says: we have to leave. We have to get off the Earth. He doesn't say why, but it's because some people in Silicon Valley are building themselves floating islands 22 kilometres off the coast, because they're outside American law, they don't pay tax, etc. That's Peter Thiel. They say: we have to leave, we have to move to Oceania, and so on. In any case, people are all going to kill each other, they're all going to die of COVID, and so on. That's really what a number of people (not all) are saying, and it's been written down.

Musk is more likeable than that, I think. I like him because he's depressive! [laughs] So, like all depressives, he's cyclothymic. So, one minute he's saying we need to conquer Mars, and the next he's on TV saying: I'm getting high because ... well! And his shares plummet [laughs] and his shareholders say, "he's completely out of his depth." But he's brilliant. He says, we've got to get off the Earth. He says the same thing as Hubert Reeves. Hubert Reeves says: at some point we have to migrate. And to colonise the Moon (there's a project in China attempting to do this), and then Mars and much further afield too. And that will take thousands of years. But on our scale, on the scale of evolution, it's a very short time.

Why do I say this? It's because this question of non-sustainability, in the very long term—not only on Earth but in the solar system—is a scientific question. It's not at all a rant by a fortune-teller or whatever. It's not a doomsday prediction or anything. That wasn't the case until thermodynamics. I pointed out that this was the cause, in my opinion, of Friedrich Nietzsche's nervous breakdown. When he discovered Thompson's positions, he had a breakdown that lasted 2 or 3 years, and he cured himself by writing Thus Spoke Zarathustra.

What I'm saying is that we have to stop being in denial. We criticise Trump for being in denial, we criticise the boomers for being in denial. And we're right, but we shouldn't be in denial ourselves. Entropy is increasing, and at some point, we must also have the modesty to know that we can hardly anticipate more than a few decades. Anticipating in the sense of making decisions and trying to build things. That's what I mean by that. Not theoretical models, because theoretical models are always just theoretical models. They are never practical models. They can feed them but…

For me, the big political economy question is between those who say: "There are those who say, as we do, and I say this very specifically to Elon Musk: "you won't actually leave Earth because your rocket depends on the ground segment anyway." And before a rocket can do without a ground segment … The ground segment is the name given in the space industry to the Cape Canaveral base.

We worked with the C.E.A. [French Atomic Energy Commission] on the ground segment, and before we can do without a ground segment … [laughs] it's not going to happen any time soon! It might be possible once we've colonised the Moon or Mars. I'm not ruling those things out at all. I'm neither for nor against it, but I don't rule it out a priori. On the other hand, we do maintain that if we don't reinvent a sustainable economy … but sustainable means for a certain period of time. Not eternal. Eternal is … you have to go to the Pope for that. Or an Imam or whoever, but… [after all] why not, because having the ability to eternalise concepts can help people to do very good things. I've got nothing against it, at all, religious models, which help people to live. But scientifically, man will disappear from planet Earth and very probably from the universe as a whole.

If there is anything left to inherit from man—and from living beings, I would say, more generally—then I have no idea what it will be. There are, of course, then the transhumanists, who are trying to talk about hyper, hyper-acceleration—you could even call it archi-acceleration—in other words, much more than hyper-acceleration. What for? To take control of the exosomatisation on Earth, if need be, and not at all elsewhere, in fact. That's marketing. Very ambitious, a little delirious at times, in my opinion, but it's essentially marketing.

So, to come back to your question, which is a fundamental question, and a difficult one ... we have to mourn the loss of eternity. That's definitive. Arthur Rimbaud already said it, and it's nothing new. In any case, in physics. As for theology and all that, I leave that to people to sort out. But I have a lot of discussions with theologians. To make an economy, an economy that would be an economy of sustainability, and to ensure that there will still be human beings on Earth in 10,000 years' time and living beings, etc., well then, we need to build an economy of neguanthropy, but neguanthropy will never eliminate entropy.

Then there's a movement called the extropians, who claim that man can escape entropy. That, for me, is totally crazy. I don't know what you think [Maël]? It's a model that has developed in astrophysics: there have been astrophysicists who have fuelled this discourse to some extent. But for me it's completely fanciful.

M.M.: There's one thing I'd like to add—this is just one example of physical entropy, but it's related to another neguentropy, which is interesting because it's also relatively simple—and that's the question of minerals. This is dealt with a little in the book. Because, for example, we talk about peak production for minerals, but in fact minerals such as copper, phosphate, etc., are fundamentally conserved. So, they cannot be destroyed. They are destroyed, but in the very long term, with the increase in entropy, but that's hundreds of billions of years away. So, they are preserved.

What does it mean when production peaks? It means that there are pockets where they are concentrated. Therefore, it's feasible to extract them, but in fact these pockets don't appear spontaneously, because spontaneously it's the maximum of entropy and therefore the maximum of dispersion. They appear thanks to the movement of volcanoes, the Earth's geological movements. This is what will lead, quite accidentally, to concentrations of these minerals in certain places. Which we come to exploit, which we come to reconcentrate again, every time we produce entropy on Earth.

The Earth's movements also produce entropy. But it also produces concentrations like this. So we concentrate them even more, we use them to make things. And the question is: what happens next? If we disperse them completely in the environment, we increase entropy. Given the distribution of these elements on Earth, we'll very quickly find ourselves having to generate an enormous amount of entropy in order to have more of them, to extract areas where they're less concentrated, and so on. So the idea, as we all know, is to interpret these processes in terms of entropy so that they don't disperse. The aim of recycling is to prevent the dispersal of ores in particular. So this is a good example of how it works. Bearing in mind that the extent of the concentration of these ores, for example, the concentration of rare earth, etc., depends on a perspective that comes from the objects we are trying to produce, so it's relative. It's a question of perspective. The relevance of the low entropy of these minerals is entirely a question of perspective. So is the relevance of their dispersion.

Marie Chollat-Namy: You talked about the current framework, which is based on a Newtonian vision governed by calculation and at the same time poses a lot of danger, but on the other hand it also has a very effective function, which has succeeded in producing everything we know at the moment: the telephone, all that... Now, faced with the problem raised by the Anthropocene and the ecological crisis, wouldn't something effective, like this vision, be effective, precisely, in combating the ecological crisis, and in this case, would there be forms of calculation that could combat this crisis?

M.M.: So, this efficiency is analysed, albeit very schematically, in two dimensions. One dimension is that it is effective, but because it produces an enormous amount of entropy. So, its effectiveness comes from its destructive nature. Facebook, for example, falls into this category. And there's another dimension, where efficiency can be hijacked to be anti-entropic. So, the idea is to divert it, to mobilise it for this purpose.

B.S.: In other words, to criticise it. Immanuel Kant is considered to be the founder of modernity-modernity, if I can put it that way. Because we say that there is Descartes who founded modernity, who made Newton possible and all that. And then there's Kant, who built the epistemological framework of modernity, let's say industrial modernity, the modernity we're going to know, in which we're still more or less. And what does Immanuel Kant say? He says that criticising doesn't mean denouncing at all, it means stating the limits. There are limits, and Newtonian physics also has limits.

I often use an example when I talk to journalists about these issues. I often say: look, every aircraft has to be certified. It's important to know this, if you want to put all the scientific bodies in the air. As a result, there are no crashes—well, there are still some, but given the number of aircraft flying, it's absolutely incredible that there are so few accidents (although with drones, it's starting to get very complicated). But why is it like this? Firstly, because of certification, and secondly, international civil aviation legislation is extremely precise and extremely restrictive.

When you produce a new model of aircraft, it has to be certified. Boeing, you have heard, had a problematic certification. It's a bit like the Lancet affair … it's extremely serious because it discredits the certification bodies. And in principle these bodies are very serious, they are engineers and physicists (I'm talking about aircraft). For medicines, they are biologists, pharmacologists, or medical doctors. Today, if you submit the A380 for worldwide certification, it is certified. It has the right to fly. Because you take Newton's physics. But if you take thermodynamics, it shouldn't fly. Because it destroys its conditions of possibility. Why, you ask? Because it consumes so much fuel and causes so much pollution that it will exhaust all the conditions under which it can fly in the very short term. You could say that it's no big deal, that it will pay for itself in 30 years anyway, except that means that there are no more planes that can fly after that. So it's the death of aeronautics.

What I mean by this is that, of course, Newton is not dead. We are not at all saying that Newton is dead. Newton was a great scientist. Nobody has ever said that Newton was wrong. We're saying that he's no longer good enough. In other words, the principle of inertia and gravitation are two principles that are still used in aircraft certification, of course. They are Newtonian. Newton came up with them. After that, Newton didn't foresee the questions of thermodynamics, which he didn't ask himself. Now, what an aeroplane does is to articulate the laws of Newtonian physics with the laws of thermodynamics, except that it articulates them negatively with the laws of thermodynamics. And since we don't certify them, we can't see it.

What I mean by saying this is that we are not at all opposed to calculation. At all, at all. You have to calculate. Nothing can be done without calculation. Even playing football. Even a guy who plays football doesn't make rules of three, he doesn't do calculations, he doesn't have rules to calculate: by simply playing, his body calculates. In other words, his eye, with his muscle, his foot, etc. are making calculations that are encoded in his body, that are embodied. It calculates, it's always calculating. It's just that living beings cannot be reduced to calculations. Living things calculate all the time, and natural selection is a form of calculation. It is stochastic, and the neo-Darwinians are right on this point. But that's not enough to say what living things are.

So, if you want to fly an aeroplane, which is an exosomatic organ, you have to integrate calculation, Newtonian calculation, but also thermodynamic calculation, but also biological calculation. I say thermodynamic + biological + critical information theory. And these are all theories of calculability, so we're not at all saying that we should reject calculability or efficiency, quite the contrary. But efficiency must be subject to purpose. That's the big question. What are the libertarians in Silicon Valley saying today: we're much more efficient than Washington, so let's do away with the state. In fact, they are carrying out the neoconservatives' programme with extreme violence. And they are effectively ridiculing public power. But why is that? It's because public power hasn't got to grips with the issue itself.

Mr. Macron thinks we need to create a start-up nation. It's not certain that this will work very well. We don't believe that. We need what I call a new critique of political economy, which means building a new epistemology of industrial society, which for us is not post-industrial. It will remain industrial precisely because ... and what does industrial mean?

It's what formally inscribes the calculation. In other words, the person who transforms everything into an equation and so on. Before industry there were craftsmen, who did absolutely incredible things, often of a much higher quality than industry. They do things intuitively, empirically, not by calculation. There are exceptions, like Leonardo da Vinci or people like that ... But these people prefigured what would later become exosomatic production based on calculations. Which allows for economies of scale. Economies of scale are very, very important.

What do they achieve? Sometimes they enable us to optimise the food supply for human beings, thus combating hunger and so on. Not everything in this model should be condemned. I think that today it is condemned—it condemns itself. But it's a fact that rationalisations have been made. Even if I'm not necessarily a fan of pasteurisation. Pasteur made some very important contributions. All that was based on calculations, formalisations... we're not rejecting science at all, on the contrary, we're saying: we need to redo science. Because today, on the other hand, industry is no longer doing science. It uses scientific models to transform them into tools, without taking into account what every scientist does, which is theory: the theory of its own limits, otherwise it's not science. Today we practise pseudoscience, but it is not science, it is the use of scientific models.

M.M.: In fact, the limits of predictability and therefore of calculability were discussed and introduced by physicists and mathematicians quite early on. For example, at the end of the 19th century, Poincaré showed that we could not predict the stability of the solar system, because it is a chaotic dynamic. This is the butterfly effect before its time. A small disturbance can have huge effects.

And that's in a deterministic framework. We can't predict. In the same way, part of the birth of computing is Gödel's theorem, with a similar version by Turing, which shows that there are propositions that can be written but that cannot be demonstrated, in the sense of being demonstrated by a computer (which didn't exist at the time). In other words, the computer makes it possible to calculate the fact that there are things that it cannot calculate. And yet they are well formed. I don't know if that's very clear ... ?

M.C-N.: It's simply a question of uncertainty.

M.M.: It's the undecidability.

B.S.: It's not exactly uncertainty in the sense that Prigogine, in any case, talked about it.

M.M.: In fact, the computer is largely the result of questions that arose in mathematics. These questions arose because there were contradictions. In other words, people who thought they'd proved theorems, then went on to find counter-examples. All mathematics collapse if you find counter-examples. So, they tried to find new foundations for mathematical practice. And the foundation that was explored was potentially mechanisable logical reasoning. So mathematical proofs would have to be a logical sequence, that a machine could reproduce. This gave rise to Hilbert's programme, which aimed to transform geometry by reducing it to logic (Boolean logic, i.e., with zeros and ones).

What Gödel showed was that, in fact, when we do this, we can state propositions that are neither demonstrable, nor the opposite of which is demonstrable. You can't decide them. Nor can we demonstrate that there is no contradiction. In doing so, he invented coding, the idea of coding theorems with zeros and ones. That's how he proved it. Then we coded all sorts of things, we coded texts, we coded videos, we coded images, sounds and so on. It's all based on a negative result. And the current tendency is to forget that, including in the training of people who do theoretical computing and the idea that you can do anything by calculation. Without any limits.

B.S.: These are questions we'll be coming back to in Arles. In the seminar on theoretical computer science.

V.C.: With regard to your question, Marie, about efficiency, and to come back a little to what Bernard was saying about the question of purposes ... in fact, it seems to me that the question is: How can we divert efficiency, which is indeed very efficient and works well, so that it serves interests greater than just efficiency. So that it has some purpose other than itself. When Bernard said that the original purposes were mainly theological, that the purpose was once God, it seems to me that today, in the context of the Anthropocene, the primary purpose is to maintain life. Both human and non-human life. So, at this point, diverting efficiency so that it serves life...

B.S: I'd say adopt efficiency. Diverting it, yes, in other words, diverting the research that Amazon, or I don't know who, is doing—all these people are efficient for a reason, because they know how to manage their programmes in a pretty impressive way. Of course, you have to divert, but above all you have to adopt. In other words, you have to integrate.

V.C.: Practice?

B.S.: Not just practice … theorise. They don't theorise. They don't bother with theories, which is why Anderson says [that we've reached] the end of theory, that we don't need theory anymore—he doesn't bother with theory any more. He thinks it's a waste of time. And they're absolutely wrong. Because to stop theorising is to make a mockery of sustainability. It means what it means in concrete terms. But we need to go back to the adoption of efficiency. The current efficiency of what we call information technology, and digital technology in general, which is ultra-efficient, and which is in fact computing everywhere.

It's the programme of mathematical physics generalised to absolutely everything, and it dates back to the seventeenth century. So, it's not a new thing at all, but they've managed to do it. By throwing [religion] out the window, on the pretext that we need to get rid of God, and I think they're right. The greatest scientists of the 20th century were often believers, and they said the same thing: in science you don't need God, you do without. In church, yes, but not in science. But this efficiency is the efficiency of an exosomatic extension of understanding, in the sense of Immanuel Kant. In other words, the analytical faculty. In fact, calculation is analysis, it's a way of analysing. And in analysis, well, there are formal analyses, i.e. I'm going to put all this into an equation, or I'm going to make calculations, measurements … and then there are totally empirical analyses: a bricklayer, for example, he also calculates a bit, he has a square, and that is all he has...

M.M.: The Pythagorean theorem.

B.S.: He uses the Pythagorean theorem a lot. He doesn't know how to demonstrate it, but he uses it a lot. But then he's very fickle about a lot of things, you see. Nowadays, they calculate for a certain number of resistance problems and all that, because there are insurance obligations, ten-year guarantees … well they've learnt to integrate a certain number of things, they have software for that, too. But they don't calculate, they don't really analyse at a given moment, they decide on a whim. And that's what we'll call the art of the bricklayer, in other words his craft.

In industrial construction, we're working on it right now in Seine-Saint-Denis—it's completely different, everything is calculated in BIM [Building Information Modelling]—and this calculability today tends to replace any decision. So, what I believe is that we need to adopt efficiency, and that means re-politicising the economy, and saying that the economy cannot erase politics, and that politics is not Donald Trump, it is not Emmanuel Macron, it is not Putin. It has to be reinvented. In fact, it's the art of deciding collectively, by developing knowledge and integrating people who don't necessarily have mathematical knowledge, but who aren't idiots for all that.

V.C: So ... in order to re-politicise the economy and in a sense also save entropy, in relation to the aircraft you mentioned and the certifications, the legislation that governs aircraft today, which means that at least in the short term of an air journey, we are significantly protected from accidents and death ... I was wondering whether, in this desire to legislate on efficiency, to save entropy ... there should also be some legislation and criticism of air travel, for example in relation to domestic flights. For example, concerning the Extinction Rebellion movement (in which Marie and I are involved): last Thursday they blocked Orly airport with regard to domestic flights. Which doesn't mean banning planes, but criticising the absurdity [of domestic flights], in the sense that it increases entropy, or at least paraffin, when you could just as easily take the train for almost the same amount of time.

B.S: Of course. And you see, I totally agree with that, absolutely agree. What's really important now is that it's the local people who take the decisions. That's why I say repoliticise. And we say, we need a political economy based on contributory accounting. If, at some point, the people of Nantes, for example, had been led to adopt a contributory economy, Nantes airport would never have been built. So I'm not at all against the idea of limiting speed on the motorway to 110 kph. Not at all, not at all.

So, in any case, what's very important is that it's the residents who take these decisions and who take them consciously, as we say. In other words, with instruments that enable them to make decisions by really weighing up the consequences and making choices. Bear in mind that Maël said earlier that there is indecidability in mathematics, and every time we have to make a decision, it's because there is indecidability. In other words, at some point you have to make a decision. And we're not going to decide with maths. You have to decide, you have to make a decision. And so, I say this because political economy is what returns the question of decision-making to human beings, and not to calculus.

Who decides today? It's the financial markets, the stock exchange, and so on. And that's a disaster: they make all the decisions. So we think we're making decisions, but we're not making them anymore. Of course we do, in a certain sense, but the decisions taken in these contexts are infinitely more effective. So what we're trying to do—along with you, incidentally (we're in complete agreement on these things, for example stopping planes when they're not essential)—is to say: above all, we need to create the economic models that will enable people to decide. Including small businessmen, who say to themselves "oh, if there's an airport, I could do it," and these same people then realise, when they do their calculations properly—but taking entropy into account! [laughs]—that in the end it may not be as obvious as all that. In the end, he is much closer to the Gilets Jaunes than imagined. And the Gilets Jaunes themselves realised that they are closer to the ecologists than they first imagined. By discussing, deliberating ... it's the deliberation that does it.

M.M.: Perhaps one way of moving in that direction is that in physics, among the sciences of nature, I mean, the question is first and foremost always: what calculation should we make? What is the right calculation to understand a situation, to predict if we can. What can we predict? And so there are conceptual changes when we can't predict: for example, chaotic dynamics - we move from predicting the trajectory to predicting the attractor, in other words, what happens when we look at the trajectory over a very long time. What is the domain covered, etc. So the question of what calculation to make is not one that cannot be resolved by calculation.

B.S.: Of course, this decision cannot be calculated.

M.M.: And to come back to what is being done, for example, in the use of Big Data and what Chris Anderson is proposing. There is some bad theorising going on. But there is still this kind of work being done, bad theorising, in the sense that there are mathematicians, for example, or physicists doing statistical physics. But these scientists carry out their analyses within a very reductionist framework, i.e., one that posits hypotheses that are not criticised by them. And they don't engage in dialogue or deliberation around these hypotheses. This is reductionist in the sense that they just look at how to get things out of the data, and they don't look at all at the consequences this has for society. So they have a very partial vision, which is also political: in other words, they choose to make this calculation rather than another.

M.C-N.: And since you explained that entropy cannot be calculated, cannot in fact be measured, how can it be taken into account in calculation models?

M.M.: Well, entropy in the physical sense is not measurable in the sense that you can't use something like a thermometer to measure it. But it can be calculated. On the basis of other variables.

B.S.: Measurement and calculation are not quite the same thing.

M.M.: Measuring means putting in an instrument and getting a number. In fact, it involves commensurability between two objects. Calculating, on the other hand, means looking at several things and having to make a calculation too say: there's been this change in entropy. But for entropy, in physics for example, you need to know how much heat has passed from one object to another, and at what temperature. That's the basic trick in physics. Now, thanks to computers, there are other methods of calculation and another link with measurement. When I talk about temperature and heat, for example, from a distance it's very macroscopic. From a microscopic point of view, there are things moving all over the place, particles ... whereas in physics, if there are too many of them, it's not possible to measure. There's a thought experiment with ping-pong balls in space, for example. There, we can follow each particle, and so we can make a calculation about what these particles are doing, based on the observation of their individual trajectories.

B.S: There are many, many misunderstandings about these questions of entropy. There are also disciplinary presumptions of the word. For example, there are physicists who say, entropy is a physics problem, full stop. Leave us alone. Mind your own business. We don't think that's true. After that, we also think that the translation of Boltzmann's probabilistic models into other fields, such as biology and information, for example, is very problematic.

In other words, it's an open project. If I were in charge of, I don't know what, if I had the means, I'd say: I'll put a billion into this. That's the challenge of the century. Of the 21st century. And there are plenty of people who don't agree with each other at all. Physicists, biologists, mathematicians, computer scientists, economists, everyone is getting involved. But there's a reason for that. It's because some people are talking nonsense. One minute they were talking about order, the next about chaos, the next about organisation. I think that Edgar Morin has played a very, very harmful role in this area. He turned scientific questions into sometimes almost poetic essays and that was that. I say Morin because he's the best known, but there are many others. And that's very important to bear in mind.

What we are talking about is not a constituted field of knowledge. It's a field in the making. We're not saying: "We're going to explain..."—we don't know. There are lots of things we don't know. Or we don't even agree on: there are disagreements, and these are disagreements between very good people, very serious people, very rational people—these are legitimate disagreements. It's not like the Lancet and I don't know what. These are not polemics, they are controversies. But here, the question of vocabulary is extremely important. So we don't use the word chaos to describe this kind of thing. There are chaos theories, which we need, but that's not what we're talking about. That's why I say that.

And the word order, well, just to clarify, because Ilya Prigogine played a very important role, he's a great scientist Ilya Prigogine. He worked with a philosopher called Isabelle Stengers. They wrote a book which, at the time, was one of the books of the year. It was called *La Nouvelle Alliance* [*Order out of Chaos*]. The idea was that we were going to reunite knowledge from mathematical physics to philosophy, biology and all that, we were going to reunite everything through the concept of dissipative structure. And that was completely problematic. For the reasons Maël mentioned earlier.

M.M.: Just to emphasise a little because I haven't really described physical entropy itself, which is a starting point, but it's important to describe it well. The idea is that you have a system that is separated from its exterior, not necessarily physically separated but virtually, say, for example, this box here. This system is coupled to its exterior, macroscopically, on a large scale. And the idea is that for a given macro description, there are lots of microscopic possibilities that correspond to this macro description, and this is Boltzmann's entropy that I'm describing.

The idea is that a system will spontaneously move towards a situation that is compatible with its constraints and corresponds to as many possibilities as possible. Why is that? Because it's just a probability, in fact. That's all it is. So, for example, if you toss a coin lots of times, the most probable situation is the one that corresponds to the higher number of possible outcomes of the coin toss, and it's the one where, on average, you get about 50% heads. And the idea is that when there are lots of quantities like that, there's a really big difference in frequency between the most likely situation and the others. So, what the system will do spontaneously is move towards this state and then it will stay there because the probability of it getting out is less than 1 in the lifetime of the universe, for example. That's just it, the increase in entropy means moving towards the most probable.

M.C-N.: So, regarding the idea of a negentropic industrial revolution, how would it be sufficient to meet all the challenges of the Anthropocene, and, in particular, how could taking entropy and negentropy into account protect biodiversity?

B.S.: That's obviously a very good question, and it's at the heart of the problem of moving from a relatively small locality to a relatively large locality, i.e. one that is less local. This is what we call the "new industrial revolution," so that we understand each other. For us, industrial doesn't mean smoky, coal-fired or whatever, like the industrial society of the 19th century. Nor does it just mean the platforms that exploit the labour of Uber drivers. For us, industrial means knowing how to scale up, to change the scale from nano to micro, from micro to meso, and from meso to macro. I also say meta-economic, but that's for myself [laughs].

What do I mean by that? It's a very important political issue. I'm going to say again something that we haven't really talked about, but which is a subject that was discussed at length in the working groups that prepared it. At the time we started talking about these issues, the Front National was launching its localist programme. It was in 2019, on the first of May 2019 in Metz, Marine Le Pen was launching, based on an economist who was an adviser to Raymond Barre by the way, I can no longer find his name ...

V.C.: Hervé Juvin?

B.S.: Juvin, that's right. By relying on Juvin, who is an economist, published by Gallimard and all that—he's not just anyone. For a long time he was considered an authority. Since then, he's been a representative of the Rassemblement National, but he's not a member of the Rassemblement National, which is a strange position to be in, well ... he's a Member of the European Parliament. They have launched their localist programme. And we say, if you want to fight Lepenist localism, you have to go back to science. Because they never talk about it—I've read Juvin's books, he never talks about entropy, he never talks about the subjects we talk about. He never talks about questioning the accounting models of capitalism. As you well know, moreover, in general fascists, Nazis, and the far right are in fact people who are there to help capitalism maintain itself—a certain type of capitalism. Take Heinrich Böll, for example: you need to read some of the novels he wrote about the links between German capitalism and the Nazis. I'll stop there. They were novels.

What we are saying is that a new industrial revolution is first and foremost one that will exploit very high-speed networks. It's what's going to exploit all these new dimensions without necessarily completely abandoning transport and all that, because there's a need for transport and it's going to rethink exchanges. Today's scandal is green beans from Kenya, for example. If we counted the price of the green beans in question in CARE's accounts and using our accounting models, they would be €70 a kilo. Because it's the cargo planes that make the most money from this, and the supermarkets. Kenyan farmers are getting their backsides kicked, and French consumers could eat frozen French green beans, which would be a lot less catastrophic—it's not great, but it's still a lot. Because frozen green beans from Brittany are very good ...

The big question today, when we have 8 billion inhabitants (not quite), 4 billion of whom are connected, is: How do we ensure that this state of affairs, a connection of 4 billion inhabitants, becomes a producer of negentropy and not entropy. When I say neguentropy producer and not entropy producer, I'm lying, because as we said earlier, we only produce neguentropy when we produce entropy. Whether the balance sheet is better, that's the question. We need to improve the balance. If we want to produce biodiversity. Biodiversity doesn't just have to be protected; it has to be reactivated. We need to repollinate.

If we want to develop this, we need to reintroduce what we call noodiversity, i.e. highly differentiated knowledge. This knowledge needs to be combined with the means to achieve economies of scale, which are powerful tools. For example, a very high-speed line that uses fibre optics and is capable of transmitting information to 200,000,000 km/s. A third of the speed of light. These are industrial resources, and we need them, just as we need all kinds of things. But the problem is that today, the needs we used to have, which were really vital needs, have been transformed into needs for speculators … mass tourism, for example.

So the question is to make a new industrial revolution (I come back to what I said earlier about rethinking theoretical computing) by integrating everything we've just said. We're saying that Europe needs to launch a new industrial revolution, starting again with mathematics, the limitation of decidability and taking these things on board. What for? To work. At the moment, as you know because we talked about it last week, we're in the process of setting up a project with livestock farmers and fishermen—it hasn't even started yet, it's in limbo, but we're in the process of setting up the system. We intend to use the platforms and all those things, so it's hyper-industrial technology. But it's a technology that is being used to achieve a positive negative environmental balance.

So that means completely rethinking the platforms. At IRI [Institut de Recherche et d'Innovation] in particular, we've been saying this for a long time: we say that there must be incalculable fields of information. So it's no longer information, it's knowledge, and it mustn't be transformed into information. There are things that can be transformed into information, because sometimes there are fields where it's interesting to use algorithms to optimise statistics and so on. This is very, very important. There's no question of abandoning statistics, on the contrary. It's a question of criticising them and making them deliberative. So that's what we call contributory platforms. And it's linked to contributory accounting and so on.

Then, and I'll stop there, there are some changes of scale. In the next 10 years—the next 7 or 8 years, if we believe the G.I.E.C (if we follow what the G.I.E.C said in 2014, we have about 8 years still), to really make a change, these will be years of negotiating compromises. Because you can't do something like that if you can't mobilise forces, including people and capital, who have technologies. So we're going to have to negotiate compromises. First you have to convince the higher macroeconomic levels, which are collapsing. If the economic level collapses, it collapses. It's also a pyramid. And it's like biodiversity.

We're saying that it's not just a pyramid of biodiversity: it's a pyramid of noodiversity. We need to organise it, and we need to use the industrial resources available today to put them back at the service of that, and here I'm saying the same thing as Socrates said about writing. Socrates was a great critic of writing, but he never said you shouldn't write. He said that writing should be subjected to a real model, not that of the sophists. It's not about making money; the aim of writing is to produce knowledge. So, we're saying the same thing, in fact, but not just with writing but with all technologies.

V.C.: It also seems to me that in its statistical interpretation, entropy raises the question of homogenisation, so in relation to biodiversity, [anti-entropy] is what also fights against what is homogenous and unique, by diversifying. And so, it applies just as much to noodiversity, i.e., the diversity of knowledge and cultures, as it does to biodiversity. Both of which, it seems to me, can be seen in parallel in the question of resilience. In the sense that the resilience of ecosystems, as a result of biodiversity, is more or less equivalent to the resilience of societies and cultures, as a result of the diversity of knowledge?

B.S.: So on the subject of resilience ... but I think Maël will say something about that. It's one of the interesting aspects of what we want to launch with dairy farmers, milk and cheese producers. Here we can see how biodiversity and noodiversity are linked. Because—to pick up on what you've just said about resilience—there's a homogenisation today of digestive systems, for example, linked to diet. This leads to a loss of diversity (we all have internal biodiversity). And if we standardise it, well, we undermine the human species. So all these issues are very much integrated, in fact.

Then there's the fact that scientific specialisation has led to a disintegration, with people working on [isolated] things and never working together. What we're trying to do, with what we call laboratory territories, is to get biologists, mathematicians, and computer scientists to work together, alongside farmers, consumers, lovers of cheese, milk and whatever else. So that we can begin to reconstitute a biodiversity brought about by noodiversity—which is also the diversity of cultures.

M.M.: To go along the same lines, the current development model, whether in the agri-food or digital sectors, for example, is very much based on what physicists would call extensible variables, i.e. the more you sell, the better. The aim of development is to sell more, to have a bigger place in the market. And that, by its very nature, is extremely resource-intensive, whatever the resources. And it's also standardising because we're selling relatively standardised things, even if there is a little customisation through personalisation algorithms. It's standardised customisation.

Here, the opposite, anti-anthropy, consists of focusing on the production of novelties, but not novelties of any kind, not novelties for novelty's sake: the novelty that allows a locality to last. The locality that lasts can be a city, a field, or a fishing ground with its ecosystems. So by thinking in terms of locality of entropy and anti-entropy, we are focusing development on making the ecosystem last, from which we also draw resources.

And then from a more theoretical biology point of view, so just anti-entropy and its relationship to entropy, in fact there's a lot of work to be done to which I'm contributing on how to theorise what's happening at the level of living organisms. In other words, there's a loss of diversity, that's one thing, but it's not necessarily as easy as that to define precisely because we count species, but that's a crude way of getting an idea. But in fact, some of what happens is extensive, meaning that habitats are lost, for example, and so the living things that live there disappear, but some of it corresponds to disorganisation, which we can't really grasp in purely quantitative terms.

So, for example, global warming is disrupting the relationships between plants and pollinators. It's not that there's no more room for them. It's just that there's also this problem, and the two add up. And so, this is analysed in terms of anti-entropy, the fact of being organised, the fact of being able to reorganise as well, and in terms of entropy, i.e., the fact that we push living things towards something random, we simply disorganise them. And it's the same thing, for example, with endocrine disruptors, to take two very different examples. So the analysis we're developing of what's happening with living things needs to introduce these concepts, in my opinion.

B.S.: What we're saying is that we need to create local economies that are open and not at all closed. It's absolutely not a question of closing the local economy in on itself. It's about opening it up, deliberately opening it up, and ensuring that there are exchanges between localities. Then there are the possible scales of exchange. How far ore can be transported, I don't know, 20,000 km. These are very big questions, and there are trade-offs to be made. A carrier will always say that it's perfectly possible to transport ore 20,000 kilometres. So it's in his interest. But it's not at all clear that this is sustainable in terms of the biosphere. So what I'm trying to say is that the idea of creating a new industrial revolution is not about inventing new industrial technologies and so on. It's about producing a new industrial economy. One that takes advantage of existing technologies and creates strong relationships of exchange between localities. Because exchanges are extremely important.

For example, I don't agree at all, and I think it's extremely dangerous to say that the biosphere is Gaia, an entity—it's not true at all. But on the other hand, and this is why I say you have to read Vernadsky: [the biosphere] forms a whole. And that's extremely important to introduce today, as one of the dimensions. That's what I call meta-economics. It's a dimension: it's not just macroeconomics, how I consolidate exchanges with international or national chains. I call it meta-economics, because it's about the trade-offs involved in maintaining the biosphere as a whole. This is a question that has never been asked. The West has never asked itself how I can also look after Africa and the Middle East, and that's why we're facing a catastrophe in those countries today. Because it exploited all that. And in a totally irresponsible way. And we can't do that anymore.

Because now, all these countries have equipment, etc., and we absolutely have to maintain a dynamic with them. But what I wanted to say is that the industrial revolution here is not about geo-engineering or whatever. Of course, it can also involve research and technological development programmes. But it's a new industrial economy. It's a new way of counting in economics. And it means that localities should be recognised as producers of value as localities. But they have to be open. That's the only way they can produce value. If they are closed, they die.