Sample translation from

HANS GRASSMANN

AHNUNG VON DER MATERIE
PHYSIK FÜR ALLE

Prepared for the author by

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Introduction: Long live Boltzmann!

It was here, one hundred years ago, in 1906, that Boltzmann took his own life. Accordingly, the physicist Sreenivaan arranged a conference at Duino Castle to commemorate Ludwig Boltzmann. In the first place, invitations were sent to physicists at near-by universities. However, none of these physicists put in an appearance, apart from those who were due to lecture.

None the less, the castle was full, since young people from all over the World, from China, Africa and the European states, came with their teachers. They were students at the International School in Duino, where the World's best students, be they rich or poor, have been able to live and learn together for two years.

When so many young people go on a school journey, there is usually a great hubbub, but this did not seem to be a school journey, for they were all perfectly quiet, calm and collected, as though Boltzmann had only died yesterday, as though they had known him and as though he were their grandfather. And thus, he became that, in a way which is not easy to explain.

Therefore it is sensible to write physics books in such a way that they can also be understood by young people. That is the first reason for this book.

Then there is a second reason, which is another interesting story, which is also true. A couple of years ago, I wrote a physics book for young people (it was called 'Alles Quark?') which ended with the physics of Boltzmann and with the physics of information, to which Boltzmann's works led. Of course, in a physics book for young people one should not only speak about yesterday's physics for the 150th time, but also say a little about that of tomorrow, otherwise it becomes boring.

And so it was that that book led to developments which otherwise would not have occurred, which one might say, would not have arisen without young people. First, my friends in the publishing house were very taken by the physics of information and encouraged me to press on with my work.

This was very important, because when you do not have anyone to talk to about such things, you become gloomy and do not make any progress.

Then, old Valentin of Braitenberg took up the cause. Valentin was one of the 20th Century's greatest brain researchers. He is retired now and works in the ancient family castle above Merano. A castle like that is conducive to discussion and reflection, and Valentin's wife has her workshop in the castle chapel, where she paints her pictures in the meantime. This created a very good atmosphere and we made good progress with our work.

But to do new physics you at some stage need real money, otherwise, for example, you cannot pay the young people who are meant to program the first robot brains. Some people actually think that the young people should get on with the work anyway, and, in the framework of globalisation this use of a precariat labour force is somehow modern and in order. I do not see it that way. When someone works, he should also be paid, otherwise it is fraud. And if it is fraud, how should it become science?

It is strange but true, the book for young people also helped in this, for the book was also read by adults such as Gerhard Luhn, who was responsible for the robotisation of Infineon's chip factories. Dr. Luhn had already been thinking about 'information' for a long time. In the first place it was involved in his profession, and second Dr. Luhn is also a philosopher, and a major part of philosophy has to do with information problems in the broadest sense. He liked the idea of being able to apply physics in his work and has therefore given us a lot of support. Thus, the first practical work on information theory was financed by Infineon, thanks to the intervention of Dr. Luhn.

'Well good', one might say, 'young people have already played an indirect role, because without the book for young people Dr. Luhn would never have made your acquaintance, and so on. But this is all very indirect and, of course, young people can't contribute directly to physics because modern physics is so utterly complex that only technical specialists can find their way through it,and certainly not young people who nowadays can only look in amazement and can do nothing with the subject itself. . . '. There are a lot of people who actually speak and think like that. But it is not true.

Everyone can understand physics; that which people cannot understand is not physics. What is more, not only can everyone understand physics, everyone can do physics himself. If someone can write an essay or paint a picture, why should he not be able to do physics himself. Every contribution to physics is important, because each contribution adds to all the others and never fades away. Thus, schoolchildren and students can make important contributions to physics.

Three examples:

1. We have developed a very simple system of plane mirrors (I shall explain this in more detail later), which represents very good value.

This can be used to concentrate solar energy and thus also to build inexpensive solar power stations. Thermal energy at a price of 2 euros per 100 kWh (kilowatt hour) seems possible. The only things we needed for this were the law of reflection and the lever rule; this is schoolboy stuff. The system can be built in schools.

2. Similarly, we can double the performance of a wind turbine simply and inexpensively, based solely on a knowledge of the conservation of energy and momentum; this is again schoolboy stuff. Pupils at the Clavius-Gymnasium, together with their physics teacher Dr. Dietrich, have tested this: they placed a wind turbine next to an aircraft wing and then took measurements for this arrangement in a home-made wind tunnel. It worked really well.

3. The IBM CELL microprocessor has been around for about a year. This is not just yet another further development of conventional technology, but a completely new type of microprocessor which offers a completely new form of computation. CELL can be used to build the first robotic brains that can be taken seriously. This is only apparent when one studies CELL from the point of view of physics. But it is simple, the physics of information is not particularly difficult, set theory, schoolboy stuff. A school pupil can program the CELL, he only needs a little Linux. And where can you find such an ultra-futuristic high-tech computer? The answer is simple: it is built into the Sony Playstation.

There remain just two points to clarify, for the reader, and also for myself, because I need to have some idea of the type of book I should write. First, there is more than just physics in this World and should this book also be for people who are more interested in other things? Second, many people find physics boring; are they just stupid and can we have no hesitation in forgetting them, or are they in some way right, and should we take that into account, and thus write the book for them also?

As far as the first point is concerned, of course, not everyone will understand physics completely and want to carry out physics themselves, but this is also good, for there must be people to look after music, philosophy, law and politics. But when those who have a talent for physics pluck up courage to use their skills to improve the World a little, they thus empower others to follow their example in their own fields. But this was always true and not only today. Physics has never blossomed on its own, but always in conjunction with art, music, philosophy. democracy, commerce and law.

On the second point, we need to understand why some people find physics stupid, and whether they may be right to some extent. The physics that was done 100 or 300 years ago and was very exciting then, may now indeed actually appear boring at first glance. Here is an example. People used to believe, or fear, that if they sailed too far across the seas, they would fall off the Earth into where the sea monsters live. At the same time, there was an undercurrent of thought that the Earth was not a flat plate, from whose rim one could fall off, but a sphere. One can perhaps sense this when one stands on a beach and sees a slight curvature of the horizon, and how ships disappear completely, first their hulls and then their sails. But people were still unable to apprehend the notion of a sphere in all earnestness and continued to believe that one would fall off the sphere. And would not the sea run out? The problem was only resolved when Galileo reasoned rationally about such matters, and when Newton actually discovered the law of gravity. There is no absolute 'downwards', but 'downwards' is always the direction in which a stone falls when you drop it. It always falls towards the Earth's centre because of the force of gravity. Thus, one can understand why no one falls off the sphere, because those who to us live on the underside of the sphere live on top of it as far as they are concerned and not on its underside. Just as we do.

When this was first understood, it was of course of great interest. There was no need to be afraid of falling off the edge of the flat plate any more. But that which previously required the use of physics and made the latter important and interesting, is now available to us without physics: we see that the World is round every day on television, this can be clearly seen from space, we understand this intuitively even as small children, without really thinking about it, it does not require any physics. In the same way, no one is now amazed that we can see into the human body with x-rays and recognise every individual bone, or that we can switch the electric light on and off. No one is amazed by the television.

If it is not to be boring, we must also talk about the new physics, not only the old physics. This then starts to make the old physics interesting because it is needed to understand the new physics. We should also ask whether the old physics can help to solve new problems. Whether it is relevant for the future of our young people. Whether it can shape the future. For these questions relate directly to physics, even though many apparently clever people believe that physics has no part in these matters. I see things otherwise, as I shall explain.

Evolution without Physics

As far as evolution is concerned, any mention of 'open questions' remains an understatement. Here the pure chaos of thoughts and emotions reigns. On the one hand, some people reject the theory of evolution on supposedly religious grounds. They would even prefer to prohibit its teaching in schools because, in their view, the theory of evolution is incompatible with The Bible, while instead Genesis in particular describes the creation of the World as an evolutionary process, in a technically correct and detailed manner. In the beginning was chaos, and the World gradually emerged from this chaos. Neither stars nor Earth existed before this, they themselves had to emerge from a process of ordering. In the beginning the Earth did not look as it does today, even water and land had to be divided, or ordered, first. Only then did life emerge, first plants and then animals, first in the water and then on the land, first simple creatures and then higher ones and ultimately man. This is how it is written and it is unquestionably correct.

One can but ask how the author of Genesis knew all this so precisely. At that time, in the Bronze Age, there was no geology, no scientific astrology, no biology and no Darwin. There was only thought.

According to the devout, the intending meaning of what is said in Genesis was rather different. One can see this, since the narrative speaks of seven days, of seven times 24 hours, in which the World is supposed to have been created. This is clearly incompatible with science, and so the remainder of the text should not be compared with modern scientific results.

But this does not make sense. For, the seven days can in no way be taken to refer to seven times 24 hours, and this is also stated explicitly: the Sun and the Moon were created on the third 'day' to separate Day and Night. Consequently, it is clear that the term 'day' cannot be taken to refer to a period of 24 hours (since otherwise the Sun and the Moon would have to have been there right at the start), but only to an ordering which makes it possible to describe a time sequence of events, which could not have been described in any other way, if only because no one was able to count at the time.

It is therefore strange when people reject the theory of evolution on religious grounds. It is a puzzle in its own right and must have a solution. Perhaps we shall find that in modern biology, where else?

Evolution yes, development no?

In modern biology, evolution is understood as the interplay of two mechanisms. First, there are always changes in the genetic make up of living things and thus alterations of their characteristics. These alterations are random and they can increase or randomly decrease an individual's quality of life or chances of survival. Second, the environment in which an individual lives leads to a selection of these characteristics; living things which are better adapted to the environment as the result of a change are more likely to survive, those which are worse adapted are more likely to die.

Modern biology now sets great store on the conclusion that evolutionary processes in no way concern a 'higher evolution'; however, it does not justify this conclusion in any way. This is very nicely stated in Wikipedia: 'Evolution does not act in a linear direction towards a pre-defined goal, it only responds to various types of adaptionary changes. The belief in a teleological evolution of this sort . . . is not supported by the scientific understanding of evolution'. This means, for example, that when living things adapt to a change in the environmental temperature due to the ending of an Ice Age or after a meteorite strike, they are in no way more highly developed, since a higher temperature or a meteorite strike does not represent a higher state of development than a lower temperature or an absence of meteorite strike. The living things are simply better adapted and not better in any way.

Because this is so important for biology, to be on the safe side, the aforementioned article reiterates that: 'One of the most common misunderstandings of evolution is that one species can be more highly evolved than another. . . . The claim that evolution results in progress is not part of modern evolutionary theory; it derives from earlier belief systems which were held around the time Darwin developed his theory of evolution.'

However, nowhere can one find a justification for this statement that there is no such thing as a higher evolution, despite the fact that so much valued is placed upon the statement. Perhaps biologists feel that it is self evident and

that it is impossible for random processes to bring about target-oriented events. Perhaps it seems so clear to them that there is scarcely any need to question it or justify it.

In the chapter on thermodynamics, we also saw how pure chance determines the movement of atoms and how, at the same time, target-oriented events occur. Despite the fact that one cannot say, for example, what any atom will do in the future, one can still say that any two iron slabs (one hot and one cold) which are composed of these atoms, will become two equally warm iron slabs in the future. As we discussed, it is precisely because pure chance reigns in the microcosm, that order is generated in the macroscopic world. We should at least try to see what happens when we apply the Second Law of Thermodynamics to evolution.

But thermodynamics does not seem to exist at all for proponents of the theory of evolution. It does not occur anywhere in the theory of evolution. It is as though biology knows of something other than thermodynamics, other than the concept of entropy, with which it can explain and measure evolution; something that is perhaps better suited to the problems of biology, because biology has nothing to do with pieces of iron.

But that is not the case. Not only is biology not aware of thermodynamics, it also has no other measure, no definition for when something is more highly evolved. No matter whether or not evolution brings about a higher evolution, biology is unable to demonstrate either because it does not have the necessary tools.

The term evolution has a single meaning. It means 'development'. Development without 'further development' or 'higher development' is unimaginable. Development without further development is nothing. A random process is not development. No one would call the drawing of lottery numbers 'development'. However no word in whole human lexicon is more teleologically charged than 'evolution'.

If someone really believes that evolution does not involve any higher development, he should at least use another term. He should no longer talk about the theory of evolution. Just imagine an evolution biologist who is no longer allowed to talk about the theory of evolution.

What should he then talk about? And he would also no longer be able to refer to Darwin, which would not be so bad if there was something else he could refer to.

Finally, the statement that evolution does not involve any development directly contradicts experience. Clearly man is more highly developed than yeast. One can scarcely argue with this, just because biology cannot make this distinction with confidence or is unable to do so. But this inability is no argument against biology, and so against science; on the contrary, it is an incentive to make it better, to improve science further, in other words to do science.

The complexity complex

In the face of the objection that man is after all more highly developed than yeast, modern scientists reply as follows: That which we intuitively see as 'higher development' is the higher complexity of a living thing. In fact, there are highly complex creatures and very simple creatures with a low complexity, such as yeast. Logically, creatures with a low complexity should have been formed first when life began, and those with a higher complexity should only have emerged later. This would then be a bogus development, and not a real one.

This answer could only be scientific firstly if complexity were a scientific and measurable quantity, which is not yet the case (we shall come back to this), and secondly if a creature's complexity bore a direct relationship to that which we perceive as 'highly developed', which is not the case either.

On the contrary, one could propound the view that given two largely similar creatures, the one that is more highly developed is the one that is less complex. Let us suppose, for example, that a man had lost the genes for the appendix, the coccyx and genetically determined cancer. He would then have no appendix, no coccyx and could no longer suffer from certain cancers. Let us suppose that, due to a change in his genes, the same man also lost certain instincts, which in the greyer past were necessary for survival, but which are now counterproductive because of the changed living conditions and might even endanger the survival of humanity. Such a man would then have a simpler construction and would be less complex. But would he be less 'highly developed'?

It is rather like the case of the King's new clothes. Everyone can see that the claims of the evolution theorist do not hold true at all, but no one will admit it. Instead of this, they constantly invent new terms in order to hide their helplessness a little. There is then talk of chaos theories and self-organisation. The present chaos admits such spongy concepts, everything goes, everything is jolly.

Physics of information

We cannot say exactly what 1 is. Neither can we start with 1. We could perhaps multiply it by itself $1 \cdot 1 = 1$ which gives 1 again, so we might as well leave it as it is. It is not even possible to carry out addition with just 1, because what would $1 + 1$ equal? 1 perhaps? But then multiplication would be the same as addition, which would be nonsense.

If you were powerful enough to create a universe, and if you created your universe just with 1, then that would be a completely dreary universe, in which nothing can happen. There would be nothing to say about your universe. The best you could say would be that it is not good that 1 should be alone. If you only have 1, then it is not possible to say what it is.

So we throw 0 in too. Let us imagine a universe in which there is not only 1 but also 0. Then everything changes at a stroke, now everything is possible: the Mona Lisa, the Sistine Chapel, The Bible, you, everything.

In turn, as soon as 1 and 0 are available, we can perform arithmetic, since we can now add and multiply in a meaningful way. This leads to counting and thus to numbers. First the natural numbers and then all the others. As we saw in the chapter on numbers, as soon as you have 1 and 0 you have everything.

Mathematicians have a name for both of these: 1 and 0 together form a set, which they call the remainder class modulo 2. Now we know what a 1 is, it is an element of the remainder class modulo 2. Neither can this remainder class be derived from anything simpler, we cannot say why it is there or where it came from, it is what it is. Can addition and multiplication at least be derived from something?

An attempt to better understand, explain or derive addition in the remainder class modulo 2 might look as follows. We could be inspired by everyday life and summarise in words what we know from experience. In everyday life, we can add, for example, 2 apples and 3 apples, makes 5 apples, and we can multiply, for example, an hour has 60 minutes, a day has 24 hours, $24 \cdot 60 = 1440$ minutes. These rules of arithmetic, which experience says must be followed for addition and multiplication can be summarised as concisely and as clearly as possible, and the term 'addition' applied to everything that follows the arithmetic rules for addition. For example, we must have $a+(b+c)=(a+b)+c$ for it to be called addition. There must also be a neutral element, for it to be called addition, etc. When all this is the case, we call it addition.

In this way, we actually find addition and multiplication in the remainder class modulo 2. For example, we find (by trial) that for 1 and 0, we indeed have $a+(b+c)=(a+b)+c$. This derivation of arithmetic from everyday life is vivid, but it is not an explanation. We have only found something with which we are familiar from everyday life, even in the remainder class modulo 2; this is not a derivation from something simpler.

Another attempt to exhibit a derivation, a proof or an understanding of addition might involve giving a complete list of possibilities. Perhaps a full overview would lead to an understanding?

Thus, we ask ourselves which operations, which combinations of the elements 0 and 1 are possible. There are four questions to answer. What is 0 combined with 0? What is 0 combined with 1? What is 1 combined with 0? What is 1 combined with 1? There are only two possible answers to each of these questions, namely 1 or 0.

There are thus $2 \cdot 2 \cdot 2 \cdot 2$ different possible ways of defining combinations of the elements 1 and 0. We can give a name to each of these combinations, for example 'egon', 'triangle', ' cat', 'addition', 'multiplication', 'red', etc. Then, for each of these combinations, we can make a list which describes the combination. For multiplication, we shorten it by writing '$\cdot$' and the list is, for example as follows:

$$
\begin{aligned}
0 \cdot 0 &= 0\\
0 \cdot 1 &= 0\\
1 \cdot 0 &= 0\\
1 \cdot 1 &= 1
\end{aligned}
$$

Or, more briefly

·	0	1
0	0	0
1	0	1

There are 16 such tables, which are called 'combination tables' or 'look-up' tables; one of these is addition and another multiplication. If we call upon more fundamental justifications to explain why the above table must be the addition table, and no other, then we would have explained addition. As far as I know that is not possible, and we can only say that mathematics works well when we use these tables. Which brings us back to our earlier argument. We use the addition table instead of the egon table because it works. There is again no real explanation or derivation.

Perhaps we have reached the outermost frontiers of simplicity here. It is not possible to call upon anything simpler. There is no ‘why’ or ‘because’ here. Thus, we are at the frontiers of thought itself here. Yes, you too. Would you have thought so?

The small dog

You can book holidays to visit the foundations or high-points of human culture, in Greece, Rome or Berlin. There, you stand in amazement, for example, before Hammurabi. Often, seemingly unimportant small things, details, help us to overcome the imagined distance that has grown up between ourselves and these things. For example, in the Sistine Chapel, your guide will point out the small dog that appears in several different scenes. In one, a child has the dog under its arm, in another the dog is hiding in the bottom left-hand corner of the scene, and so on. The guide claims the dog actually existed. It is said to have been of good company to the artists while they were working and so they included the dog in their paintings.

Such a detail can also be found in our tables, at the bottom of the addition table. Can you see it?

+	0	1
0	0	1
1	1	0

It say $1 + 1 = 0$. This is true because it is in the table. But it is clearly not true for apples for one apple plus another apple does not make no apples. ‘There are more things in Heaven and Earth’, as Shakespeare might have said.

That concludes our tour of the remainder class modulo 2. Next we would like to turn our attention to the physical world. Although we find ourselves here in the deepest foundations of the human mind, we are at the same time already in the physical world, since everything is already contained in the remainder class.

There is a long and detailed route from the remainder class to the physical world, which passes from the remainder class to the natural numbers, to their addition, then to multiplication, thence to fractions, and ever onwards to the outermost number, the imaginary i. It is then possible to associate everything with the physical world.

However there is a short route, which is not actually a route at all, but shorter than that; we are already there. Since the elements of the remainder class can be added and multiplied and since addition and multiplication are connected by $(a\cdot(b+c)) = ((a\cdot b)+(a\cdot c))$, the remainder class automatically and immediately forms a mathematical field (the mathematicians call this F_2), which is of interest to us because over such a field there always exists an arithmetic vector space (in the terminology of mathematics) denoted by F_2^n. It elements are, for example, of the form (0,1,1,0) or (1,1,1,0,1,0,1,1,0). But we are already familiar with these, they are digital messages!

Thus, digital messages are vectors. They may not look like that, but they really are. They are subject to the laws of vector algebra, and we can also refer to the vector space F_2^n as the message space. Thus we have answered another question: 'what are messages?' They are vectors.

Messages and finiteness

In Shannon's theory the most important property of a message is its length (its entropy). Let us first consider the length of physical messages. Can we say anything relevant about the length of physical messages?

In conventional information theory, in principle, there also exist infinitely long messages. Indeed, these are dealt with by an important branch of information theory which asks whether one can determine in advance whether a program will produce an infinitely long message, whether its calculation can never be completed. This is the so-called stopping problem.

The messages which occur in the physical world, however, should always be of finite length, since the energy of the physical world is finite. The entropy S is also finite and because of Boltzmann's formula $S = k \log(W)$, the number of possible microstates W is also finite. Consequently, the whole of the universe can be fully described with a single message of finite length, since nothing more can be said once all its possible states are given. The same is also true for parts of the universe, for example messages. A message has a certain number of microstates and is in one or more of these; once that is described, nothing more can be said.

This means two things. First, all messages can be formulated as digital messages. Second, messages must be finite. This is also better, since the resources of the universe are finite, and infinitely long messages could not be represented within the universe, which does not have sufficient energy, matter or time to generate an infinitely long message.

This also corresponds to practical experience. We are always concerned everywhere simply with n-bit messages, where n is finite (although it may be very large, it is never infinite).

In a normal computer, n is very small. The input message for a computer is typically 16 or 32 bits long. The input message for the our brain's visual apparatus is substantially longer, but it is not infinite, rather it has a fixed length. The retina of the eye consists of 130 million visual cells, which produce the message that is forwarded to the brain. There are always 130 million cells, that never changes. Of course, a physicist can always write a program which continues to produce output and never terminates, but such a program is not necessary in order to do physics. Physics is always finite.

Digital sticks

If messages are vectors, then all vector processing can be expressed as vector transformation. An input message a is transformed to an output message $b = T(a)$. In other words, T turns the message a into the message b.

For example, T may be a computer which performs a computation. Then a is the input value and b is the result of the computation. T may also be a person performing the same calculation. Or T may be a person describing a picture. The picture is an input message a, the person's brain (with the visual apparatus) is T, the description of the picture, for example 'the picture shows a tree', is the output message b.

By writing $b = T(a)$ we have not made a discovery and not produced a sensation, but only tried to write this clearly and simply. $b = T(a)$ is intended to help us think more simply and speak more precisely. It is a stick.

When we first cut sticks, our question was: 'When are two lengths equal?' We now repeat that here: 'When do two messages say the same thing?'.

Such a question should be easy to answer in everyday life. When a contract is translated from English into Chinese, the Chinese version of the contract should say the same as the English. One can check whether that is the case by having the contract translated back from Chinese into English. If this results in the original English then the two versions of the contract say the same thing.

In mathematical terms, two messages a and b are identical (i.e. say the same thing) when b follows from a and conversely, in other words, $b = T(a)$ and $a = T^{-1}(b)$.

So, you see, we could not say why or how, but yet the strange thing called physics came about. We have not invented or discovered anything, we have said something simple and we find ourselves in a new world, which is different from the previous one. For what we have just said has simply taken out of the world of Shannon. We have just said that if messages are identical then they say the same thing. But that is not true for Shannon.

For Shannon, messages have no meaning or sense. The question as to whether two messages say the same thing is meaningless for Shannon. Moreover, even the underlying nature of the theory is now different. For

Shannon, a message is something absolute. For example, the amount of information in a digital message is the number of its bits. Consequently, it suffices to have the message, for then one already knows its amount of information. The amount of information in a message is a property of that message and does not depend on anything else. Viewed in this way, Shannon's theory is an absolute theory.

If we now say that 'two messages are identical when $b = T(a)$ and $a = T^{-1}(b)$' then we are making a statement which refers not only to message a and message b, but also to T. We cannot talk about a property of message a, or whether it is perhaps identical to message b, we can only talk about this with respect to T. a and b are identical for a specific T, they are not identical for a different T.

This difference from Shannon's theory is of great practical importance and helps us achieve a better correspondence with the real or 'physical' world. In fact, for a reader who speaks English and Chinese, a book and its Chinese translation are identical. For someone who does not speak Chinese, they are not identical. This is true in reality. It is not the case for Shannon. For Shannon it is not even different, it is simply not an issue about which one could talk. It is not conceivable there.

If it is possible, for the first time, to see if two messages say the same thing and are in that sense identical, in the next step one can postulate the following. Identical messages have the same amount of information. This is only natural. However, it broadens the difference from the notions of Shannon, for we now come up against not just a conceptual difference from Shannon, but one which can be measured, a numerical difference. For any (invertible) could, for example, form the output message $b = (1, 0, 0, 0, 1, 0, 1, 1)$ from the input message $a = (1, 0, 1)$. According to what we said previously, these messages say the same thing and have the same amount of information, although they have different lengths. However, for Shannon, they have different amounts of information.

Thus, in our scenario the length of a message can no longer be a measure for the amount of information. The only thing we could use in our scenario as a measure for the information content of a message would be the number of possible messages, or, to be more precise, the logarithm of the number of possible messages, or, in mathematical terms, the number of dimensions of the message space to which the message belongs. This definition would only give the same result as Shannon in the boundary case of optimally encrypted messages.

There is also another difference from Shannon. We previously postulated that if T transforms a invertibly to b, then the two messages are the same and have the same amount of information. However, this then means that T conserves information. Information is therefore that which is conserved by invertible T's. Thus we have in fact defined information. For Shannon this is not the case. (If, on the other hand, T converts English text to Chinese text and then the inverse of T, i.e. the reverse translation, does not lead to identical English text, T has not conserved the text's information, but altered it).

To summarise. If a transformation takes message a to message b , $b = T(a)$, and if by inverting T, one gets back to the message a, $a = T^{-1}(b)$, then the two messages a and b say the same thing (are identical), they contain the same amount of information and T conserves their information.

The phantom box

Shannon's information theory deals with messages. In the decades after Shannon, so-called algorithmic information theory, which deals more with information processing systems (i.e. programs and computers) was developed by information theorists such as Chaitin and Kolmogorov. The conceptual approaches to algorithmic information theory were based on Shannon's information theory. Just as the amount of information in a message is equal to the length of that message, the complexity of a program is equal to the length of the program (more precisely, to the length of the shortest program that a given message can produce).

As previously mentioned, the concepts of algorithmic information theory are of a non-physical nature. For example, the complexity of a program is not measurable (since it is only determined up to a constant, and so is not in fact determined). It is not malicious to say this, for I have discussed the matter myself with Gregory Chaitin, and he sees it the same way. I arranged a special meeting, in order to be able to discuss these things in peace.

From the conventional point of view, a computer program (which can always be thought of as a Turing machine) is something which processes the input character by character (which may be a letter or a bit) in a sequence of many operational steps and which completes the computation and the bit processing eventually after a long time, or perhaps even never.

We, on the other hand, write $b = T(a)$ and there is nothing to do with programs or sequences of operational steps here. This says: transform a vector. No one seems to have any objections if we wish to do this in a single operational step, possibly even at the speed of light. Neither does it seem important here whether T is very complicated or very simple.

There is also no indication that a certain amount of energy must be dissipated in order to execute T . This is already a bit thick if one thinks of the expositions of Szilard, Landauer and Bennet. Our T seems to be a real phantom T, which calculates, without actually doing anything, which therefore does nothing while it calculates, and which therefore reduces the calculation to nothing, so to speak.

On the one hand, it is very interesting for us physicists, for we like to reduce problems to nothing, just as in thermodynamics which can be reduced to the counting of numbers. Large numbers are larger than small ones, that is all, and that is enough to understand why there is a development in this world. We do the same in relativity theory which simply follows from the constancy of the speed of light. A physicist would be extremely delighted to reduce the immensely difficult information theory to almost nothing.

On the other hand, we must remain realistic and ask ourselves whether the thing about T is at worst cavilling and at best playing with mathematics, with no practical substance. This question can be resolved by constructing a T and checking whether it actually has phantom-like properties, whether it can calculate without expending energy, whether it can calculate at the speed of light, and whether it can really be reduced to nothing. This should at least be checked in the *Gedanken Experiment*.

Let us first think of a simple T. T should double numbers, i.e. multiply them by the factor 2. Let us suppose input is 6 bits long. (Then the output must have 7 bits, because when a number is multiplied by 2, it can become one bit longer). In a normal computer a 6-bit number is transmitted using 6 data lines. If only the first line carries a signal, this means '000001' (i.e. 1 in decimal notation), if only the second line carries a signal, this means '000010' (i.e. 2 in decimal notation), if the only the first and second lines carry a signal, this means '000011' (i.e. 3 in decimal notation), etc.

First, we make a box with 6 wire connections for the input and 7 lines for the results.

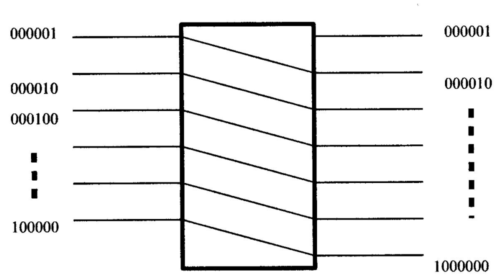

Figure 1.

Now we must put something in the box to perform the calculation. We connect input lines and output lines as shown in the next figure.

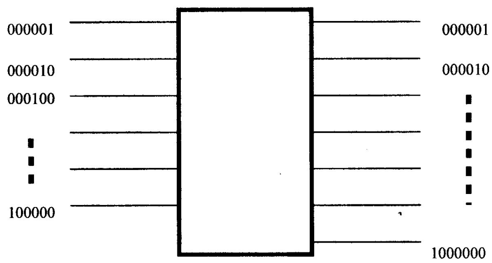

Figure 2.

You can follow this with your finger or with a pencil. If we input any number to the box twice that number is output. This box actually performs the calculation $b = 2 \cdot a$. But where is the program? And what is its complexity? The box dissipates no energy, and it also does nothing else. The signals travel at the speed of light through the box as though the box were not even there. The box really does nothing, or almost nothing, since it calculates. It is a true phantom T and yet it can calculate.

Admittedly, the calculation $b = 2 \cdot a$ is very simple. But one can also do the same thing for arbitrarily complicated calculations. It is only necessary to organise the wiring of the box in a different way.

Physical calculation

Normally, a computer computes with digital numbers. The numbers 1, 2, 3, 4 and so on are given in digital notation by 1, 10, 11, 100 and so on (or when expressed in terms of wires, 001, 010, 011, 100). However, one can also choose any other arbitrary notation, for example, the canonical notation. In the canonical notation, the numbers 1, 2, 3, 4 ... are written as 1, 10, 100, 1000.... Thus, every position denotes 'one more'. Canonical numbers are therefore very long. For example, to represent the number 64 as a digital number requires six positions (since $2^6 = 64$). Written as a canonical number, the number 64 has 64 positions.

Decimal notation	Digital notation	Canonical notation
1	1	1
2	10	10
3	11	100
4	100	1000
5	101	10000

If we wish to represent a 32-bit digital number as a canonical number, we need 2^{32} positions, i.e. four billion. This appears highly impractical, but it is nothing special, every personal computer (PC) does this incidentally. A random access memory (RAM) works in the last instance with canonical numbers. (It can only work with canonical numbers, a multiplexer is used to convert the digital numbers in the computer to canonical numbers, otherwise the RAM does not work at all).

If we wish to work with canonical numbers, can we perform arbitrarily complex calculations using our box? Here is a relatively simple example.

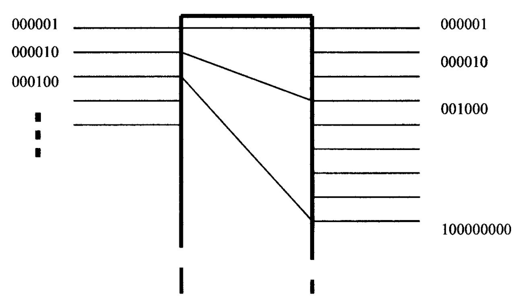

Figure 3. The figure shows a calculation box, which unlike the previous one uses canonical rather than digital numbers.

The example is still chosen to be relatively simple, so that the box can be easily understood; however, we see straightaway that it also works for arbitrarily complex functions, with no energy dissipation, without doing anything, and at the speed of light. As before, we have no way of saying where the program might be, although our calculation box calculates as well as any conventional computer, if not better, since it is faster. Moreover, it does not become hot.

We can also leave out the unused lines and instead write the corresponding number in the output line; then we have a look-up table. Again there is no energy dissipation.

Let us try to summarise. Any arbitrary function, however complicated, which has an n bit digital number as input, can

have only 2^n different input values and no more than 2^n different output values. The function can therefore be represented in full by a look-up table with 2^n values. This table can be read in the computer in a single step of work (as in a RAM). Thus, an arbitrarily complex function can always be performed in a single step of work.

In the days of Turing or Shannon there were only computer memories with a small number of bits, a memory with 2^{32} elements was inconceivable then. The approach to computation was thus quite different. In the Turing machine, one character is processed after another and the result is obtained after many small steps. The great advances in microelectronics in recent years have created a completely different situation. Today, it is not difficult to build very large memories, 2^{32} storage elements is not a problem, and they are not expensive either. In Germany, for example, the company Infineon builds such memories. However, there are problems with functions which have an input significantly longer than 32 bits. Such problems cannot be solved with a memory with 2^{32} elements and a memory with considerably more than 2^{32} elements (e.g. 2^{100} elements) cannot be built today.

Therefore three questions arise from the discussion in this chapter.

1. What is a program from the physical point of view?
2. What is complexity from the physical point of view?
3. Computation using only a look-up table would be ideal, and this can be realised provided the input is at most 32 bits long. Might it be possible to compose look-up tables from smaller ones so that problems with more than 32-bit input can be solved using look-up tables alone? Is it possible, for example, to replace a look-up table with $2^{1,000,000}$ elements by a system of smaller tables?

These questions are no longer easy, they are extremely difficult. It is like climbing on a steep mountain face, it is better to make oneself secure. We have stormed ahead very quickly in the preceding pages, and in view of that it is better to pause and form a better understanding of what we have achieved. We shall do this next. We should like to make our *Gedanken Experiment* with the calculation box theoretically secure, we should like to understand what we have already done from the mathematical point of view. Then we should like to make everything secure from the practical point of view. Can we create a connection with the computers of today, at least with the most modern ones? May there even be a connection between the *Gedanken Experiment* of the last pages and the computer on your desk?

As far as the theory is concerned, we have until now only used the fact that messages are vectors, so there should be more to say. There are many arithmetic rules for vectors, and vectors have precise mathematical properties which we have not used up to this point. Let us now do that, let us ask ourselves which mathematical properties our message vectors have, and how their properties depend on those of the transformation T. Who knows, perhaps at the end of all these considerations our phantom calculation box may pop out automatically?

Evolution with physics

What is life?

The better we understand what ‘life’ is, the better we can reflect on the evolution of life. It seems to me that many diverse books fail to answer this question clearly, and only give a description of ‘life’. For example, we can find lists with descriptions of things that are said to constitute life, such as ‘metabolism ’ or ‘reproduction’. But even if we would be happy with a pure description, that is to say prepared to make do without an understanding, these lists would still not be very helpful.

Reproduction, for example, is said to be a prerequisite for us to be able to talk about life. But what about when someone does not wish to or cannot reproduce himself? Is he not alive or only partially alive? In the case of bacteria, reproduction simply involves the splitting of a bacterium when it has eaten enough and has become sufficiently large. We may call this reproduction, but what does that mean?

Then there are worms, which continue to live and grow when they are cut in half. Is this also reproduction and are these worms possibly more alive than others which do not survive being cut in half?

It is also strange to want to define life by metabolism. When someone is badly constipated, is he already dead? Moreover, in the same way that people do not see a human being as the collection of living organisms (cells and single-celled organisms) from which he is formed, but as a single living thing, some people also see the Planet itself, its biosphere, as a single living thing, as ‘Mother Earth’. But this single living thing, Earth, does not have a metabolism, since in that case the milkman would have to fly in from Alpha Centauri by rocket every day. This is not the case, the Earth does not exchange any material with its environment.

What is an engine?

We can illustrate this more clearly with the simple example of the engine. In fact, a petrol engine actually drinks petrol and breathes air, before returning the combusted petrol to the air as exhaust gas. But the same cannot be said about a DC motor. The electric motor uses electric current as the petrol engine uses petrol. But this electric current (which consists of electrons, as we have seen) is in no way 'consumed' or 'combusted'. Moreover, in the case of an AC motor, there is not even a true flow of current, in that the electrons tremble hither and thither, and do not flow through the motor.

The steam engine is even more striking. When the steam used is allowed to condense to water and pumped back into the steam engine's kettle, the steam engine does not exchange any matter with its environment. It only takes in heat and gives it off again: no matter, no metabolism. The same is true for the Stirling engine which works only with gas, and not with steam. It has a hot end and a cold end, and as the heat flows from the hot end to the cold end, it converts part of this heat into work.

Indeed, the same is true for the Earth itself and its biosphere. It takes in heat in the day and emits heat at night: no metabolism.

From the physical point of view, a running engine is a spontaneous process. It runs without having to be wound up, the engine also runs when no one looks inside or looks after it, it runs more or less completely on its own (when there is petrol in the tank), that is to say, spontaneously. Now, we have already seen what keeps spontaneous processes running on their own and independently, and why they are spontaneous: they increase the entropy of the universe. Thus, they run spontaneously and cannot do anything else.

In the case of the petrol engine, this increase in entropy is effected by the combustion of petrol. Benzine and air molecules have a high entropy (they have a relatively high energy at a given temperature) and are ordered into states with lower energy (exhaust gases) by the combustion, and this local creation of order is accompanied by the emission of heat. This heat is ultimately emitted into the environment, thereby increasing the entropy of the universe. The heat emitted into the universe increases the overall disorder by more than the increase in local order due to the local ordering of the atoms.

This was the case for our example of hot and cold iron slabs. As the hot iron slab cools, its entropy decreases but it decreases by less than the entropy of the cold iron slab increases. Thus, the total entropy of the system of the hot and cold iron slabs increases.

In fact, it would actually be possible to drive an engine with only hot and cold iron slabs. It would only be necessary to place a steam- or Stirling engine between the (sufficiently large) hot and cold iron slabs to make the engine run. The combustion of petrol is therefore only a means to the end; in the petrol engine, the underlying process itself is simply just the increase in the entropy, which keeps it running.

However, it is difficult to visualise this clearly. One can picture how the bundles of energy in the hot iron slab wander around before they finally reach the cold iron slab. It is similar to a gas in a pressure vessel. It is easy to visualise how, when the vessel is opened, more and more gas atoms will make their way out of it as a result of their random motion.

It is much more difficult to visualise how the engine is moving because it generating entropy. Perhaps it is so difficult because this is scarcely gone into, if at all, at school and at most universities. Of course there is nothing to be found about this in the press. People are not used to thinking in this way. People are not used to thinking about these things. Hence the difficulty in visualising them.

But this is the interesting thing about physics: through its connections with mathematics it can always transcend our ability to visualise. As soon as one allows oneself the luxury to take a little time to think more precisely about these things, one actually begins to be able to visualise them, with the support of physics. But this takes time.

If thinking about a simple motor taxes our ability to visualise, matters are no easier when it comes to thinking about the much more complicated processes of life. Moreover, since we find ourselves here at the frontiers of what can be thought in our society today, we must also advance very cautiously.

We know that the laws of thermodynamics, and in particular the second law, must apply to the processes of life. The second law is utterly simple, nothing could conceivably be simpler, there is no room for anything that would permit restrictions on and exceptions to the second law. Thus, for living things, it must be the case that when the process of life is spontaneous (and it is), there can be only one explanation in the whole of physics, namely that life increases the entropy of the universe, otherwise it would not be spontaneous. Metabolism may play a role in this, but it need not do so. Mother Earth manages completely without it, the flow of heat from the Sun suffices.

An extremely complicated steam engine

Admittedly, a living thing has a more complicated structure than a steam engine. It is perhaps too difficult to visualise a fully functional living thing with a structure as simple as that of a steam engine. However, it is simple to do the opposite and imagine a steam engine with an arbitrary complexity.

We can incorporate a computer to monitor the steam engine and links with thousands of complicated sensors. We can add lubricants. We can include a library so that the operators do not become bored, or we can replace the operators by an army of complicated robots, and so on. In principle, all this will change nothing: the steam engine runs and it will run because it increases the entropy of the World, not because it is complex.

Thus, the difference between a steam engine and a living cell does not lie in the complexity, since we can at least conceive of the machine as an arbitrarily complicated *Gedanken Experiment*, even 1000 times more complicated than a cell. The difference lies elsewhere: a living thing is autonomous. It continues to function totally independently, totally spontaneously. In comparison, a machine has far less autonomy. It functions provided it has fuel and provided it does not break own. It cannot repair itself and cannot go in search of its own fuel.

The conclusion we wish to draw from the previous pages is the following: life is an autonomous cycle. It runs spontaneously (it lives) because it increases the overall entropy (the disorder) of the Universe, although it unavoidably generates a local order. The complexity of a living thing adds to its autonomy, but does not constitute life itself.

In the next section, we shall extend these considerations to the totality of living things, or in other words, to the Living Earth.

Life increases entropy

Let us briefly recall our *Gedanken Experiment* with hot and cold iron slabs. When we bring together hot and cold iron slabs, thermal energy flows from the hot iron slab to the cold iron slab. Thus, the entropy of the hot iron slab decreases, but that of the cold iron slab increases more and the total entropy of both iron slabs increases. The two iron slabs thus equalise their temperatures, since the state of 'two warm iron slabs' is much more likely than the state of 'hot and cold iron slabs'.

Let us imagine the Earth as a planet without life, possibly similar to the Moon. The side illuminated by the Sun becomes very warm, and the side in shadow is very cold. This is a situation similar to that with hot and cold iron slabs.

When we come to consider life on the otherwise identical planet, this life will result in a decrease in temperature differences. Plants will absorb the sunlight, but store it in chemical form. Thus, a plant illuminated by the Sun will not become as hot as, for example, a stone. The side of the Planet illuminated by the Sun will therefore heat up less. Moreover, if the Planet rotates, as the Earth does, the surface temperature during the night will not decrease as much, since living processes continue during the night and are always associated with the emission of thermal energy. A planet with life is more uniformly warm than a planet without life. A planet with life is therefore more likely than a planet without life.

Thus, life will form spontaneously on a lifeless planet. It will have to form, just as hot and cold iron slab have to become a uniformly warm iron slabs. Assuming of course that this is physically possible. If we place insulation between the hot and the cold iron slabs they cannot exchange heat. If a planet consists, for example, solely of iron, life cannot form. But our Earth does not consist of iron and insulating material.

Nor does the second law cease to apply once life has formed. Perhaps uniformly warm mammals increase the entropy of the planet more than lizards, whose temperature varies. Then mammals would become more likely in the long term. In that case, mammals would spontaneously edge out the dinosaurs. More precisely, they would replace the dinosaurs in special small biological niches, for example in the Galapagos Islands. Or the dinosaurs would mutate to birds, which have a constant high body temperature, precisely for that reason.

These arguments would in no way contradict the conventional view, according to which the dinosaurs were decimated by meteorite strikes and the like. It merely adds to that view, for we have to try to understand why the saurian species wiped out by meteorites was not replaced by better adapted saurians, but by mammals.

Of course, the same thing applies to mammals. The second law allows physically possible processes to run, but it does not allow physically impossible processes. Thus, mammals can only function above a certain body size, since for very small animals the ratio of the body volume to the body surface area is too small, the thermal energy within the animal is too small in comparison with the energy loss through the body surface, and the animal cannot live. The smallest mammal is approximately the size of a mouse. Mammals the size of ants are not possible and thus very small living things cannot be replaced by mammals.

Some evolution theorists point out that bacteria constitute a very large part of terrestrial life. Thus, they deduce that evolution is not higher development, for otherwise very simple bacteria would already have been replaced by more highly developed animals. This argument is inappropriate because the second law of thermodynamics makes physically possible processes spontaneous, it does not make the impossible possible. Bacteria cannot be replaced by mammals, since that would be physically impossible.

The conclusion here is then the following, in order to better understand the evolution of life, one must first understand life. Conversely, when one understands what life is, how it works and the laws which govern it, one also understands evolution better. Life lives quite spontaneously, because it increases the entropy of the universe. Life propagates on this planet because it increases its entropy. Life continues to develop, insofar as it increases the entropy even more.

Such arguments do not arise in the conventional theory of evolution. The present theory of evolution has no knowledge of how large the entropy of this Planet is and how large it would be if there were only dinosaurs, or there were no life at all. The current theory of evolution does not know that the unrestricted reign of randomness in the kingdom of the atom results in a target-directed development.

Meaningless evolution – meaningless life

Taking into account these considerations, evolution is therefore associated with the second law of thermodynamics, which gives and determines the direction in which life develops. Out of two possible states, evolution chooses that which leads to a greater increase in entropy.

But is it meaningful to describe this development as 'higher development'. To what extent should a system with higher entropy be seen as more highly developed? Two lukewarm iron slabs are no more highly developed than a hot iron slab and a cold iron slab separately. It does not make a great difference whether evolution has no overall objective or whether its objective is to increase entropy. The former would be as sterile as the latter.

Up to this point, we have only made use of the first half of the second law of thermodynamics. It is unquestionable true that entropy increases globally, and it is the case that all processes which increase entropy occur spontaneously. But this global increase in entropy is not possible without a local reduction in entropy.

The hot and cold iron slabs increase their total entropy, in that they become uniformly warm. At the same time, the entropy of the hot iron slab is reduced. It decreases by less than the overall entropy of the system increases, but it decreases. Disorder cannot be created globally without creating local order. (The mathematical reason is that in $\Delta S = \Delta E/T$, the transferred energy ΔE must always be conserved. When one inserts energy into a body of low temperature, this increases its temperature, but the same energy must be taken from a body with a higher temperature whose entropy thus decreases.)

In the first place, this order is created by the chemical processes of life. For example, oxygen and carbon atoms are ordered. In that case, the order involves these atoms being arranged in a particular formation relative to each other, corresponding to their electron shells.

But in addition to this ordering of atoms, there is also another ordering process. A bacterium must be adapted to its environment, so that it can order atoms. A bacterium which lives in an environment of 20° and 50% humidity and digests carbon, must have a totally different form to a bacterium that occurs in a geyser at 200° and eats sulphur. Thus, the bacterium has information about its environment. Formulated from our point of view, it ultimately amounts to the same thing, whether an individual oxygen atom arranges itself with respect to a carbon atom, i.e. takes up a certain position relative to the carbon atom, or whether the set of many atoms, which we call the bacterium takes up a specific position with respect to the set of many atoms which we call the environment.

Up to this point, our arguments have run parallel to the conventional theory of evolution, we have just used other terminology. Instead of saying that a living thing is adapted to the environment, we say that it contains information since, of course, the information which a living thing contains can only be information about the environment.

In the next step, the following difference arises. It is certainly meaningful to say that a living thing is adapted to its environment, but that cannot be quantified. We cannot measure the extent to which a dinosaur is better or worse adapted to its environment than a lion.

However, the information which a living thing contains can in principle be measured, even when in practice such measurement is still very remote.

Thus we can postulate the following. A living thing is more highly developed when it contains more information. (But this does not mean that it must have a longer DNA, since the length of a message says nothing about its information content, as we saw in the chapter on the physics of information.) This defines more highly developed living things. Moreover, this increasing adaptation, the increasing amount of information held in a living thing, can be comprehensively explained through the usual well known processes of mutation and selection.

According to the works of Szilard, there is another conceivable mechanism which is not provided for in the theory of evolution up to now. According to Szilard the transport of information in an information processing system necessarily dissipates energy. However, energy dissipating processes are spontaneous (insofar as they are physically possible). Consequently, the diffusion of information in a living thing must be a spontaneous process. It is thought to be target-directed in the same sense that the heat exchange between hot and cold iron slabs is target directed. It is thought to be an additional evolutionary mechanism to those already know, namely gene mutation and selection.

There are no scientific studies or even measurements related to this. But note: the prediction that information dissipates spontaneously in a living thing is an hypothesis which should be scientifically testable.

This process of spontaneous diffusion of information at first sight does not seem to have an effect on genes, i.e. on the 'hardware' of an individual living thing. For, the genes a living thing acquires are specified in the brief moment at which the organism is created, and cannot be altered during its lifetime. However, if one considers all living things, there might well be a related effect, since innumerable such brief moments occur on a daily basis. The spontaneous diffusion of information in the organism might therefore contribute to the information contained in the genes; this would be something to clarify in the future.

Intellectual life

The following is not true for bacteria but is true for people. Part of the information a person contains is not stored in the genes. The amount and the importance of the part of the information which is not contained in the genes can be visualised if in a *Gedanken Experiment* we separate twin siblings shortly after birth and let one grow up with wolves and the other in a normal human family with schooling and love.

Someone who groups up with wolves or apes will not be very different from a wolf or an ape, he will neither read nor write and will not be able to speak. He will differ from the apes only to the extent that his genes are different from those of apes. Thus the difference will be very small.

Thus, the main difference between someone who grows up with wolves and someone who grows up in a human family has nothing to do with the information in the genes. Hence it cannot be explained by random gene mutations and a subsequent selection process. The information that the former does not possess, but the latter does should be sought in the nervous system, and principally in the brain. There is a commonality between the information stored in the brain and that stored in the genes, and there are two important differences.

The information in both forms of information storage should diffuse there quite spontaneously, as previously discussed. Just as atoms take up an order relative to each other and thereby emit energy, quite spontaneously, so the brain will organise itself relative to the environment and thereby emit energy for the same reasons, equally spontaneously. The increase in the information in the brain would therefore be an expression of life, it would be a process of life subject to the same laws as physical life, and of equal spontaneity.

The first difference between the information in the genes and that in the brain is that the incorporation of information in the brain as a matter of fact does constitute a form of life, albeit not a form of organic life. We can see this by comparing the child brought up with wolves with the sibling brought up in the human family: the two are physically identical. The difference between them has nothing to do with the physical life. The incorporation of information in the brain is thought to be assigned to another life form, the intellectual life. Intellectual life would not be a metaphor, but literally a life form in its own right.

The second difference is that the diffusion of information in the brain of a living thing should unimaginably stronger than the diffusion of information in the organism's genetic make up. The inherited information can only be changed, improved or extended once in an organism's lifetime, namely when the organism is created. For the rest of its life the genes remain unchanged. The information in the brain, however, can be constantly altered, extended or improved, at any second. Even the extent of possible changes is very much greater. The brain is able to think new thoughts, to learn a new language, everything. The alteration of genetic information takes place more gradually. The teeth may become slightly longer or the ears shorter than those of Mum or Dad, but, for example, it is scarcely imaginable that the offspring of two elephants will be able to fly as the result of the alteration of genetic information. In man, on the other hand, it is conceivable, the brain has only to think of 'wings', and man will already fly.

Moreover, the incorporation of information in the brain can be performed incomparably more easily and more rapidly than the incorporation of information in the genes. This information can also be disseminated much more easily. A flying elephant could at best pass on its ability to fly to its offspring. A Pythagoras can explain the idea of the triangle to his aunt or his pupils or indeed to everyone.

Poor computers

Computers are not alive. Therefore they should not incorporate information from their environment spontaneously. Experience shows that they do not do so. No one has ever seen a computer incorporate information about the outside world spontaneously. The technical background to this fact is easy to understand if one casts one mind back to Szilard and takes into account the vectorial nature of the information.

The switching states of a computer are freely programmable like the switching states of the brain; however, the computer cannot alter these states spontaneously. One can also visualise a computer as a mechanical model with levers and cog-wheel transmission; such computers have already been built. There is nothing spontaneous about a lever or a cog-wheel, since there is no freedom and everything is predetermined.

The computer is specially constructed, in such a way that it cannot spontaneously alter its switching states, so that it cannot make computational errors. Given a specific input value, it should always produce the same result; it should deliberately not have the freedom to change it. If it could alter its bits spontaneously, each calculation would have a different result.

Computer calculations always output the same result because the microscopic switches (transistors) in a computer are very

rigid. It takes an extreme amount of work, in comparison with the unit of atomic thermal energy $1/2kT$, to switch one bit of a computer. Thus, the thermal movement cannot affect the bits of the computer, and so the computer is deterministic. The computer should not have its own mind, but should execute precisely what it has been told.

Our nervous system is unimaginably more sensitive in comparison. If, for example, the ear were slightly more sensitive than it us, it would always hear the noise of the thermal movement of air molecules. The eye's sight cells also perceive individual photons. Moreover, since the technology of the ear cells, the eye cells and the nerve cells in the brain is thought to be very similar, the brain should be able to change its switching states very easily.

The thermal movements of particles may then be sufficient to change the switching states of the brain now and again (but only now and again). For example, the sensitivity of the ear is precisely such that it does not hear the chaotic movement of air molecules, since the thermal movement of air molecules does not contain any information). If such a change does not increase the correlation with the outside world (i.e does not lead to an isomorphic relationship) it is thermodynamically irrelevant. However, if it leads to a higher correlation with the outside world, i.e. if it transports information to the brain, according to Szilard it must also dissipate energy. According to Szilard, only the incorporation of information is necessarily an energy dissipating process. The arbitrary switching about is not.

This again corresponds well with our everyday experience. When one learns to read or write, for example, this amounts to an incorporation of new information. It makes work and thus dissipates energy. If you undertake hard mental work for a day, you will be just as hungry as if you had been digging in the garden. But if you can already read and write, it is painless, automatic, and you scarcely notice that you are doing it: the incorporation of messages containing information which is already known (this is an A, this is an E) does not involve energy dissipation. Only the incorporation of new information requires an effort.

It is conjectured that the nerve cells in the brain are very sensitive, they are conjectured to switch with a lower expenditure of energy and are conjectured to be able to order themselves spontaneously. Conjectures. Although this is an open question, which concerns everyone, there seem to be no studies of the subject and no concrete knowledge about it, no research. I have asked a biologist or a neuroscientist once or twice, but they knew nothing. In my last book, I asked my readers whether anyone knows or knows someone who knows something. However, although my readers often tell me about very important and clever things, no one has yet been able to help me further on this topic. It actually seems that we do not know how much energy the brain dissipates in the switching process. (We know exactly how much energy the brain dissipates overall, in terms of Watts, but this is probably maintenance work which keeps the brain alive, and is not directly devoted to the thought process.)

Computers as they are now constructed will never play a part in intellectual life. This does not mean that they must always be as stupid and helpless as they are today. It is true that the poor things cannot learn spontaneously, but it is also true that the World contains a limited amount of information. Once the computer is taught, in the same way that illiterate people are taught to read and write, then the computer can become a very useful conversation partner, or a very useful bank director.

In addition, we had mentioned, that it would in the future be quite conceivable to build a living computer. This living thing would have exactly the same thoughts as we do. Our assertion that information must diffuse spontaneously within a

living organism is a theoretical prediction, which, if we have forgotten to think of something, might also be false. However, that the brain must be isomorphically related to the information it processes is already now a fact, since it follows from general mathematical considerations. A brain can, if nothing else, be a mirror of the outside world. In the next chapter we shall see the consequences of this. More precisely, we shall see the consequences it should naturally have, and why it sometimes does not have these consequences.

In this chapter we have shown how pure understanding of evolution changes, from the scientific point of view, when we consider the laws of physics, and in particular, the physics of information. There now arises the question as to whether these changes bear a relation to the moral and rational reservations of many people concerning the theory of evolution. Does the theory of evolution become more reasonable when one takes into account the physics, or does it not? Does it increase people's marginalisation when one takes into account the physics, or does it decrease it?

Finally the future

In the chapter on 'Evolution without Physics', we were obliged to note that in recent centuries the natural sciences appear to have really marginalised man. Until the time of Galileo man was the crown of creation, standing at the centre of the World which had been built about him, then, he suddenly found himself on an x-arbitrary planet, flying aimless through space. Subsequently, Darwin demonstrated that we are closely related to apes, and Freud showed how man is governed by his unconscious, his animal instincts.

Unfortunately, it is also true that if man really is an animal he can also be treated as an animal. He can be dealt with in the same way as other animals, for example in the slaughterhouse. The marginalisation of man is probably partially responsible for the atrocities of Stalin, Mao and Hitler.

There is worse. Every atrocity of the 20th Century is viewed as criminal and wrong, and the lessons are heeded by a majority of people. But the thoughts which were responsible for these events live on inside us and are cultivated.

The next blows against humanity are now being dealt out by computer experts and molecular biologists. The DNA of man is almost completely identical with that of apes, and hardly any different from that of mice. Man is not only no better than an animal, he is now no better than a computer. The brain is considered a poor computer. Proper computers will soon be deemed to be better than us. Machines will be deemed to be better than us, and we will be seen not only as nothing more than animals, but also as less than machines. Thus, as an aside, man will naturally have no freedom and no responsibility. When someone commits a crime, he cannot therefore be guilty! (Poor Hitler and Stalin had a tough childhood and could do little else.)

At that point, it will actually be laughable to get excited about small things such as the fact that more and more people are spending their lives in meaningless jobs and live from hand to mouth simply to make the unemployment statistics look good. It is then of marginal importance if people are not even able to support a family or have to look on helplessly as their patchwork children turn into zombies or become impoverished. Animals live in the present. If man is an animal then he has no future, for what could it possibly consist of?

Men do not really need democracy if they are nothing but animals. One can understand how it came about that Der Spiegel wrote (19/2008): 'The turnout in elections to the state parliament has been in decline for many years, at the local level there are nowhere near enough good candidates to turn every mayoral election into a democratic event, and the popular parties are experiencing a real exodus of members. Moreover, there is a dramatic decrease in the readiness of younger people to keep themselves regularly informed about politics. If this continues, Germany will one day become a democracy without people'. If man is an animal, this is only logical. For the same reasons, a decline in physics will also be logical, for animals do not have any physics and they do not need any.

Mirror to the World

How different the World looks if we now only take into account what we could actually have know already (many people have known only too well that one cannot live from bread alone, but they have not been able to explain this), and what the physics of information allows us put into words more precisely and more forcefully, if we take into account that man is involved in two forms of life, organic life and spiritual life, and if we take into account that in the past science has only dealt with organic life (which man has in common with apes and cauliflowers). As far as organic life is concerned, man is indeed marginal, he is an ape and a cauliflower. But what distinguishes man is his involvement in intellectual life, and this has never been a subject for the sciences until now. If the physics of information is right, intellectual life is more than the metaphor it has been until now. Then, the marginalisation falls away, without even the slightest need to contradict Darwin or Freud. Darwin and Freud were right, but they never talked about man as an intellectual life form, but always about things organic. In their day, intellectual life was not a part of science.

But intellectual life, and even organic life, is not a result of some self-organisation. There is no self-organisation, because there is no order which relates to itself. Order is relative, it exists only with respect to something else.

The formation of man is therefore necessarily an ordering process which is reshaping that what is the case (this is a quotation from Wittgenstein, we have to translate this maybe better). Man becomes a mirror of reality. In the language of mathematics: man is increasingly entering into an isomorphic relationship with the World. 'image' or 'likeness' people once used to say, and also today we cannot phrase it much better.