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Foundations of Quantum Mechanics

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1 Introduction[1]

The beginning of what is called *quantum mechanics* can be associated with Max Planck who around 1900 made the discovery that light visualized in terms of a wave-like structure is actually composed of small, but well-determined packets of energy called *quanta*. According to Planck, the energy of light E is proportional to the light's frequency ν such that $E = h \nu$, where h is a proportionality constant referred to as *Planck's constant*. In other words, what has been discussed in terms of a wave is in fact a *particle* after all. Soon afterwards, Louis de Broglie showed the converse: Matter behaves like a wave from time to time.

Following Einstein, the energy of a particle would be $E = mc^2$. (We stay with this somewhat approximate rather than exact result for a while serving our purposes in this present paper.) Then we have: $E = (mc)\, c = p\, c$, where p is the momentum. While for a wave in general, we have also $c = \lambda \nu$ with λ being the wave-length. Hence, from the above: $\lambda = h/p$. It is this particle-wave duality of the entities by which the Universe is actually composed that is in the centre of the early development of quantum mechanics. In fact, it has been Erwin Schrödinger who in 1926 proposed one way towards resolving quantum problems.

Let us now determine the position of such a particle. Among others, this is actually a problem of optics, because in order to measure a position, we have to (optically) *see* the object in question. Hence, there must be some light of a given wavelength which is shining onto this object. But due to the resolving power of the light utilized, there is a necessary uncertainty about the position such that

$$\Delta x \approx \lambda.$$

While the light particle (photon) hits the particle under observation, it alters the latter's momentum:

$$\Delta p \approx h/\lambda.$$

Hence, from these two equations, we have then: $\Delta x\, \Delta p \approx h$. This is what we call *Heisenberg's uncertainty principle*. Essentially, this principle tells us that the more accurately we determine the one (position, say), the less accurately we know the other (momentum). If in particular, one of the two is determined quite precisely, then the uncertainty in the other will spread out to infinity. So, if we have a light wave of a given colour (wavelength), we cannot say where the corresponding particle actually is. And the same is true the other way round: If we know the particle position precisely, we do not have any idea about the corresponding colour of a light wave.

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[1] The skeleton of the following text is composed with a number of slight modifications from the very illustrative and vivid web page provided by www.ipod.org.uk/reality/ (owner: Andrew Thomas). This is mainly done because of three reasons: (1) Quantum mechanics is presented in a large variety of standardized text books and articles by now such that it is not useful to invent different terminologies and new conventions. (2) The English is best on an *English* web page. (3) The series of papers provided by the afore-mentioned web page is sufficiently redundant so that it is easy to add one or the other amendment.

2 Computing Particle Properties

So after all, quantum mechanics is not so different from classical mechanics: The idea is to compute (or measure) the properties of particles such as position and momentum. In the case of classical physics, dealing with everyday objects (which are sufficiently large and not too fast), many properties can be concretely determined in terms of elementary measurements (taking e.g. clocks and rulers). Hence, we have two consequences then: On the one hand, particles in quantum mechanics cannot follow the same rules as particles in classical mechanics. (Because it is rather alien to classical physics, if an uncertainty is introduced into the measurement results, *independent of the measurement's accuracy*.) On the other hand, it is apparent that all what there is in everyday life (and what is thus subject to classical physics) is made of quantum objects of one kind or another. Hence, what in classical terms is well-determined (and observable in fact) must be *a kind of average* over all elementary parts that constitute a (macroscopic) whole.

The strange point is that we can clearly see that if the observation of quantum phenomena is measurement-dependent, then *before* measurement we can actually not know anything about a particle. But once it has been measured (its properties have been observed and determined), then this is a *creative* rather than objective result, because it is the measurement itself that strongly influences what can be observed by performing it. All what can be said is that the outcome will be a random selection of a set of given possibilities. And this is very strange indeed, if we think of the usual results as they are achieved in classical (school) physics.

In other words: The world is fundamentally uncertain (i.e. random), and not certain (determined) at all! Even worse: The reason for this randomness (its *cause* so to speak) cannot be determined either due to the restrictions following from the Heisenberg principle. And it would be quite precise (although difficult to understand) that before we perform a measurement, the property of a particle (object) can take all possible values at the same time!

In order to dissolve this somewhat disturbing situation, it is necessary to clarify what a wave actually is.

Essentially, a travelling wave in a one-dimensional space can be expressed as a function of position x and time t such that

$$\Psi(x, t) = A \cos (2\pi x/\lambda - \omega t).$$

In this expression for the wave function, the A means the amplitude of the wave, and ω the angular frequency which is the same as $2\pi\nu$.[2]

From de Broglie then, we take $\lambda = h/p = 2\pi\hbar/p$ ($\hbar = h/2\pi$), and thus $2\pi/\lambda = p/\hbar$. From Planck, we take $E = h\,\nu = \hbar\,\omega$, and so $\omega = E/\hbar$. If inserting this into the above wave ansatz, we end up with

[2] To be more precise, we deal here with a plane wave of the more general type $\Psi(\underline{r}, t) = A \cos (\omega\, t - \underline{k}\, \underline{r})$, where the underlined quantities are vectors now, and the amplitude is complex. The amount of $\underline{k}$ is ω/c.

$$\Psi(x, t) = A \cos (p\, x/\hbar - E\, t/\hbar).$$

But remember that sine and cosine functions have always to do with exponentials. So according to Euler we can write in a complex notation the above result as

$$\Psi(x, t) = A \exp i/\hbar\, (p\, x - E\, t).$$

Let us now take the partial derivatives with respect to position and time, then (thanks to the simple structure of exponentials)

$$\partial\Psi/\partial x = (i\, p/\hbar)\, \Psi \Rightarrow - i\, \hbar\, \partial\Psi/\partial x = p\Psi.$$

And similarly,

$$\partial\Psi/\partial t = (- i\, E/\hbar)\, \Psi \Rightarrow i\, \hbar\, \partial\Psi/\partial t = E\Psi.$$

Hence, we end up with two different wave functions, according to whether we are interested in determining a particle's momentum or energy. These two we call *observables*. The second equation is one form of the celebrated *Schrödinger equation*. (Usually, the energy E is replaced by what is called the Hamiltonian H in many cases. Essentially, these terms consist of the sum of kinetic and potential energies, respectively.)
The pair of observables mentioned above falls under the Heisenberg law. There are mainly two such relevant pairs: position/time, momentum/energy. We call these pairs of observables *conjugate* in the sense that they are complimentary to each other. Every type of observable has a corresponding conjugate observable.
With each type of observable we also associate an *operator*. Usually, the latter will be a differential operator acting on the wave function. For the momentum case above e.g. we have

$$p_{op} = i\, \hbar\, \partial/\partial x.$$

So we can write the wave function equation as

$$p_{op}\, \Psi = p\, \Psi.$$

Having an operator acting upon a wave function on the left-hand side, and a scalar being multiplied with the wave function on the right-hand side, what we have here is actually the expression for an *eigenfunction* and its *eigenvalue*. For the momentum observable measured along the x-axis, the wave function then takes the form of a plane wave, i.e.

$$\Psi(x) = \exp (- i\, p\, x/\hbar).$$

Note that we can verify this by simply inserting the expression into the left-hand side of the above eigenvalue equation. Hence, this wave function is a solution of that eigenvalue equation. Obviously, this wave function is representing a wave *in complex space* which is not the usual space we know in everyday life. So it is not advisable to think of this wave as one which looks like the wave of an ocean in Euclidean space. While classical mechanics is dealing with the usual (three-dimensional) space of everyday life, quantum mechanics deals with abstract spaces we cannot actually observe directly. Complex numbers are the central instrument of quantum mechanics. Consequently, the wave function is different from any classical objects we know from phenomena discussed at school: The wave function can be thought of as describing the value of any observable of a particle *before* observation. Hence, it is the *quantum state* of a system. Therefore, it is quite straightforward to place it in an appropriate *state space*.

The state represented by the wave function can be visualized as a point in state space. The respective eigenstates take the form of orthogonal vectors called *eigenvectors*. This is mainly because we deal here with what is called a *Hilbert space*. This is a complex vector space (i.e. the values multiplying the orthogonal basis vectors can be complex numbers). So the eigenvectors form an orthogonal basis themselves that can be used to span the entire vector space. This means that whatever state the system is in, we can represent it as being a sum (superposition) of varying amounts of the eigenstates. The amount that each eigenstate contributes to the overall sum is called a *component*.

Say, we have a state Ψ_s, and three eigenstates Ψ_1, Ψ_2, and Ψ_3, respectively. We can construct then a superposition of the form $\Psi_s = 0.5\ \Psi_1 + 0.83\ \Psi_2 + 0.25\ \Psi_3$. Note that the result is normalized, because $0.5^2 + 0.83^2 + 0.25^2 = 1$. Hence, any wave function of the system can be generated from linear combinations of the eigenstates. This is what we call *quantum superposition*. It is quite remarkable that before a measurement is taken, a quantum system can exist in a mix of all of its allowed states simultaneously.

The most famous experiment that illustrates the consequences of this most clearly is what we call the *double-slit experiment*: The idea is that an electron gun pointing to a screen with two slits. We record then the positions of the electrons once they have passed the screen by observing tiny dots on another screen. The result is that an interference pattern is produced similar to the cases of light or water. This illustrates the wave character of particles. But, if we restrict the emission to one electron at a time, things become weird somehow, because the interference pattern remains! In other words: Apparently, the single electron interferes with itself: It passes both slits at the same time!

As it turns out, a direct observation will reveal one electron passing through one of the slits only. Obviously, there is no splitting up of the electron into two halves or something like that. The electron behaves as if it passes through two different slits at the same time, but once it is being recorded, it behaves as if it is one single electron passing through one of the two slits only. This is very difficult to understand: But if we remember what we said above, then this becomes clearer at once. Because it is all of the possible position states of the electron that combine to produce the interference pattern. But an observation (i. e. the application of a given operator associated with a particular observable) lets the system appear to jump into a particular eigenstate associated with a particular eigenvalue. Operators of the appropriate type are *Hermitian operators*[3] and thus self-adjoint. Traditionally, physical observables in quantum mechanics are represented as self-adjoint operators on Hilbert spaces. For such operators, the eigenvalues are always real. This "jumping" to a corresponding eigenstate is also called *collapse of the wave function*. The probability of a state vector jumping to a particular eigenstate is related to the dot product of that vector and the particular eigenvector. The "nearer" the current state is to a particular eigenstate, the more likely it is to jump to it. In this sense, quantum mechanics can only give probabilities for a measurement outcome, it cannot make a precise prediction.

Paul Dirac is the inventor of what we call *bra(c-)ket notation*. A state vector is described here as a column $|\Psi>$ called *ket*. For each such vector there is a row $<\Psi|$ which is called *bra*. In fact, the bra is the adjoint of the ket. The inner product (or dot product) of the bra $<\Phi|$ with the ket $|\Psi>$ is denoted by $<\Phi|\Psi>$. The probability of a state vector jumping to a particular eigenstate is given by the square of the magnitude of this inner product. Hence, this probability can be written as $|<\Phi|\Psi>|^2$.

On the other hand, there is also an exterior (outer) product of a ket with a bra (also called *tensor product*) denoted by $|\Psi><\Phi|$. Hence, while the first product gives a single scalar value, namely

$$(\Phi_1, \Phi_2, \Phi_3)\ [\Psi_1, \Psi_2, \Psi_3] = \Phi_1 \Psi_1 + \Phi_2 \Psi_2 + \Phi_3 \Psi_3,$$

the second gives a matrix (a tensor, in fact):

$$[\Psi_1, \Psi_2, \Psi_3]\ (\Phi_1, \Phi_2, \Phi_3) = \begin{pmatrix} \Psi_1 \Phi_1 & \Psi_1 \Phi_2 & \Psi_1 \Phi_3 \\ \Psi_2 \Phi_1 & \Psi_2 \Phi_2 & \Psi_2 \Phi_3 \\ \Psi_3 \Phi_1 & \Psi_3 \Phi_2 & \Psi_3 \Phi_3 \end{pmatrix}.$$

Note that we have written here as a row in square brackets what is actually a column. This is simply due to technical reasons, but a convention we keep in the following.

3 Entanglement

The Dirac notation introduced in the last section enables us to differ between single and joint states. Take e.g. the two states $|\Psi>$ and $|\Phi>$, respectively. Then the *joint state* of the two is the adequate tensor product of the type $|\Psi><\Phi|$. So let us consider a particle which can be in state $|0>$ or in state $|1>$. Such a particle is called a *qubit*. Before measurement, the actual state of the qubit could be any superposition of the two states. But after measurement, the state will always be one or the other. Superpositions vanish then. If we have two photons,

[3] On a finite-dimensional inner product space, a self-adjoint operator is one whose matrix is Hermitian, i. e. equal to its own conjugate-transpose: The element in the i-th row and j-th column is equal to the complex conjugate of the element in the j-th row and i-th column, for all i and j.

then it is the superposition of the possible states that is really counting in a somewhat modified sense: The joint state space of the above is given by

$$[\,|0\rangle, |1\rangle\,]\,(|0\rangle, |1\rangle) = \begin{pmatrix} |0\rangle|0\rangle & |0\rangle|1\rangle \\ |1\rangle|0\rangle & |1\rangle|1\rangle \end{pmatrix}$$

Hence, the originally two-dimensional state spaces combine to give a single four-dimensional state space: $H^2 \otimes H^2 = H^4$.

The phenomenon in question here is referred to as *entanglement*. It denotes the situation that the state of one particle determines the state of the other due to their joint state as derived according to the above. This is essentially a consequence of what earlier had been called *EPR paradox*. The idea goes back to Einstein who was always quite unhappy about the implications of a quantum theory. In 1935, together with Boris Podolsky and Nathan Rosen, he developed a thought experiment of the following type: His main objection dealt with the claim that there is no physical reality before measurement. ("I like to think the moon is there even if I am not looking at it.") So what he did was to give a first definition of physical reality. ("If, without in any way perturbing a system, we can predict with certainty the value of a physical quantity, then there exists an element of physical reality corresponding to this physical quantity.") In other words: If it is possible to have knowledge of an object's property *without* its being observed, then that property cannot have been created by observation. Einstein's idea was therefore, to generate a contradiction with quantum mechanics, if entanglement could be used to determine a physical reality before measurement.

We take two entangled photons. One is sent to the observer Alice, while the other is sent to the observer Bob. We assume that Alice and Bob are quite a distance apart. Now, the direction of light's electric field is said to be its direction of *polarization*. If a laser beam is being sent onto a crystal, we can generate a pair of entangled photons such that their respective polarizations are always orthogonal to each other. In our case: When Alice measures the polarization of her photon, the polarization of Bob's photon is instantly known – even though Bob has not yet measured it!

According to quantum theory, Bob's photon cannot have a defined value for its polarization, before Bob measures it. Instead, it should be in a state of superposition. How can this be? In fact, the theory itself solves this problem by stating that it is Alice's measurement that collapses the wave function of both photons. Einstein however thought that this form of communication (information transport) would actually contradict his own theory of special relativity according to which it is not possible to transport anything faster than light travels. Hence, he concluded that quantum mechanics must be incomplete. He argued that the correct way of dissolving the paradox was to admit *hidden variables* that avoid causal problems (but are not actually part of quantum theory in the first place).

It was not before 1964 that John Bell succeeded in developing a consistent test for the existence of hidden variables. He showed that for a group of objects with fixed properties A, B, and C, the number of objects which have property A but not property B plus the number of objects which have property B but not property C is greater than or equal to the number of objects which have property A but not property C:

$$n(A, \neg B) + n(B, \neg C) \geq n(A, \neg C).$$

For illustrating this result more easily, let us consider a group of people with fixed properties such that A: sex (male vs. Female), B: height (tall vs. short), C: eye colour (blue vs. green). Then, no matter which group of people we are dealing with, we can always say the following: "For any collection of people, the number of short males plus the number of tall people, male and female, with green eyes will always be greater than or equal to the number of males with green eyes." Check this at the next occasion. It is hard to believe. The proof goes as follows: Every person present can be classified according to eight groups which are (1) short men blue eyes, (2) short men green eyes, (3) tall men blue eyes, (4) tall men green eyes, (5) short women blue eyes, (6) short women green eyes, (7) tall women blue eyes, (8) tall women green eyes. Then Bell's inequality reads like:

$$(\text{group 1} + \text{group 2}) + (\text{group 4} + \text{group 8}) \geq (\text{group 2} + \text{group 4}).$$

Remember that with the above, the number of "short males" is given by the members in groups 1 and 2. The number of "tall people, male and female, with green eyes" is given then by the members in groups 4 and 8. Finally, the number of "males with green eyes" is given by the members in groups 2 and 4. Hence, the above inequality must always be true. Of course, the sets of short males with blue eyes as well as of tall females with green eyes must be non-empty. So we have here the implications of Bell's inequality for everyday classical situations.

Let us come back to the polarization of light which can be actually expressed in terms of the *spin* of a photon. Following Heisenberg's uncertainty principle, we have to admit that we cannot obtain the correct spin of a particle in two different directions at the same time. So how can we test Bell's inequality after all? Say that we have *spin up* (90 degrees) as property A and *spin 45 degrees* as property B, respectively. This is where entanglement comes in, because if we measure one particle (of two entangled particles) for property A, we would expect that we can test the other still-unmeasured particle for property B. (This would be actually a trick in order to overcome the restriction posed by Heisenberg's principle!)

We divide our particles into three groups called *ensembles*, and extract entangled pairs of particles from each group. (1: test one for A, test the other for B; 2: test one for B, test the other for C; 3: test one for A, test the other for C.) Unfortunately, we can only measure two properties each per particle (not A, B, C together) so that the result cannot be conclusive after all. But what we can do is to test ensembles of very many such particles and perform a statistics then. In 1969, Clauser, Horn, Shimony, and Holt used photon pairs with polarization angles of 0 degrees, 45 degrees, 22.5 degrees, and 67.5 degrees, and found that indeed, the inequality was violated. The point is that it is entanglement that changes the balance. In the classical case this would imply that the probability of a person to have green eyes would increase, if the other (entangled) person had been found to be a male. Obviously, what is true for particles, is not quite true for persons (very many particles in a co-operatively bound state so to speak). Consequently, we have not really overcome the Heisenberg principle.

However, there is an interesting twist to this: As already Einstein has said, human beings are parts of a whole which is the universe. They are parts in fact that are limited in space and time. Hence, in strictly physical terms, the impression that human beings are separate entities within the world is hardly more than an illusion. It is rather unlikely to expect that a person's thoughts and feelings would be separated from the rest. But the difference between microscopic and macroscopic systems is what we will discuss later in more detail.

4 Decoherence

Essentially, the results on the concept of entanglement show that it is not possible to separate an object being measured and thus observed from the measurement device which is applied in order to perform the measurement. It is this point which is crucial for the mechanism we call "collapse of the wave function". Quite generally, in nature, particles and their environment are bound together as one system. The result is that in the macroscopic world, we usually do not observe the numerable states that are part of the superposition. While in the microscopic world, e.g. in the case of the double-slit experiment, we *do* observe these states which are represented by the interference pattern. Why is it that these patterns vanish for macroscopic objects?

We remember the superposition example from section 2, when we expressed a quantum state as a linear combination of components which are different eigenstates: $\Psi_s = 0.5\ \Psi_1 + 0.83\ \Psi_2 + 0.25\ \Psi_3$. For this, we also had the normalization condition: $0.5^2 + 0.83^2 + 0.25^2 = 1$. Now there is an important point: Every component eigenstate possesses an associated *phase*.[4] In order for the components to combine together correctly to produce a superposition state, they must be in the same phase or *coherent*.

What happens to a quantum particle in the real world is that each of its component states gets entangled with different aspects of its environment. So each component of our particle forms separate entangled states. The phases of these states will thus be altered. This is the reason why coherent phase relationships are destroyed. We say then that the components *decohere*. This phenomenon is called *decoherence*. Let us take a particle that interacts with just a single photon. The two particles enter an entangled state and this is enough in order to trigger the onset of decoherence. But it is not before the particle has a macroscopic rather than microscopic effect that all interferences can disappear. Hence, if the components Ψ_2 and Ψ_3 are out of phase, then the particle appears to be in a single state, one of the component eigenstates: Ψ_1. However, the neglected components do not actually vanish. But on the macroscopic level, we cannot notice them, because they are out of phase. In fact, they are dissipated out into the wider environment. They are like small ripples in the ocean which get entangled with other small ripples until it is impossible to tell from which big wave each ripple came. Usually, we can only observe the big waves.

If we throw a rock into the sea off the coast of Ireland, the ripples caused by the initial splash dissipate after a while and apparently disappear then. But in fact, they do not actually

[4] The phase shows up as a parameter φ in the wave expressions of the type: $x(t) = A\cos(2\pi\nu t + \varphi)$ or $y(t) = A\sin(2\pi\nu t + \varphi) = A\cos(2\pi\nu t + \varphi - \pi/2)$.

disappear. What they do instead is to decrease in size and mix and interfere with other waves. Some time (possibly two weeks) later, on the shore of Tierra del Fuego off the Argentinian coast, one of the small waves washing to shore is maybe an imperceptible fraction of one micron higher because of that rock we have thrown in the first place. This process cannot be reversed, because in the meantime, there have been many interactions on the way that cannot be retraced. Hence, decoherence is irreversible.
But because decoherence happens so quickly, usually of the order of magnitude of 10^{-27} seconds, the observer gains the wrong impression of a sudden jump. However, some time ago, decoherence has been delayed by actually decoupling particles from their environment. And then the superposition states have become evident. The reason that interference patterns can be observed in the case of the double-slit experiment and do not decohere is that the experimental set-up is not a macroscopic system, but a microscopic one. For an electron, the decoherence time is only about 10^7 seconds (roughly a year) so that there is plenty of time for observing interference patterns.[5]
So decoherence is what solves the problem of the apparent collapse of the wave function and explains why we do not observe superposition states of macroscopic objects. It does not quite explain which particular eigenstate is selected in the end though. In order to discuss this problem in some detail, we have to introduce a quantity that is called *density matrix*. Let us then consider an ensemble of particles in a box. We visualize the whole box as one quantum system. When we extract a particle from the box and measure it, we find it having property A or B, say. Before measurement, this system can be found in one of two states: (1) *a pure state* – each of the particles is in the same state with the same state vector, e.g. in an equal superposition of properties A and B. (2) *a mixed state* – the particles are all in different states, and so the whole system cannot be described by a single state vector, e.g. the particles have either property A or property B.
The density matrix is defined now as the weighted sum of the tensor products over all the different states, of the form $p\,|\Psi\rangle\langle\Psi| + q\,|\Phi\rangle\langle\Phi| + \ldots$ Here, p and q refer to the relative probability of each state. For the example with the particles in a box, p would represent the number of particles in a state $|\Psi\rangle$, and q would represent the number of particles in state $|\Phi\rangle$. Take the case now that we have a number of qubits in a box. Let us say that they are in a superposition state of the form

$$0.6\,|0\rangle + 0.8\,i\,|1\rangle.$$

Hence, the ensemble system is in a pure state so that we have a single probability p which is equal to 1, while q is equal to zero. The density matrix simplifies to:

$$|\Psi\rangle\langle\Psi|\,.$$

[5] Although there is a parallel string of phenomena in thermodynamics, decoherence is nevertheless much more effective than thermodynamic dissipation. Usually, for the latter, we can visualize the environment as a heat bath into which the interference terms spread and become completely disordered. This causes the irreversibility known from thermodynamics and coded in its second law. Essentially, it is a system's *entropy* that measures the amount of disorder.

The left-hand term can be written as a column: [0.6, 0.8 i]. In order to generate the density matrix, we need the adjoint (Hermitian conjugate) of this column vector which is the transpose of the complex conjugate, in fact. The adjoint is here the row vector (0.6, – 0.8 i). Hence the tensor product:

$$|\Psi\rangle\langle\Psi| = \begin{pmatrix} 0.36 & -0.48\,i \\ 0.48\,i & 0.64 \end{pmatrix},$$

where the diagonal elements of the matrix tell us the probabilities of finding the particle in the $|0\rangle$ or $|1\rangle$ eigenstate. (Note that the diagonal elements are normalized to give 1 or 100% in that case.) While the diagonal elements can never have imaginary components, the off-diagonal elements can. These imaginary components have an associated phase (because essentially, complex numbers can be written in a polar form). It is the phase differences of these off-diagonal elements which produce the interference.

The off-diagonal terms have a completely unknown relative phase factor which must be averaged over during any calculation since it is different for each separate measurement (and each particle in the ensemble). As the phase of these terms is not correlated (i.e. not coherent), the sums cancel out to zero. The matrix becomes diagonalized, and interference effects vanish. The quantum state of the ensemble system is then apparently forced into one of the diagonal eigenstates with the probability of a particular eigenstate selection predicted by the value of the corresponding diagonal element of the density matrix.

In 1957, an alternative approach has been provided by Hugh Everett who proposed the *many-worlds interpretation* of quantum mechanics. He suggested that when we make a measurement, the universe itself splits into different parallel universes, each universe containing one possible outcome of the observation. As seen under the perspective of decoherence, this approach is rendered useless after all, and there is no need for parallel universes. Dieter Zeh says: "During the recent decades, more and more superpositions have been confirmed to exist by clever experimentalists. We have learned about SQUIDs, mesoscopic Schrödinger cats, Bose condensates, and even superpositions of a macroscopic current running in opposite directions (very different from two currents cancelling each other). Hence, their components exist simultaneously."[6]

5 Time

What we can realize after the first four sections is the interesting point that physics becomes more and more related to philosophy, while it is converging with neighbouring topics that went somewhat detached so far. On the one hand, we can clearly see that it is the concept of information that is closely related to the various aspects of quantum mechanics: Quantum systems function very much in the sense of a computer. But it is not a computer as we know it. Instead, these systems are *quantum computers* processing information that is measured in

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[6] See his paper: The Wave Function: It or Bit? To be found as an attachment to this present text. (file 0204088v2)

terms of qubits rather than classical bits (cbits). On the other hand, many arguments applied in the field are based on *logic* rather than on physics proper: Combinatorics and algorithmic deduction, if not *abduction*, are in the centre of discussion, not induction. Although, contrary to ongoing research in the foundations of physics, quantum mechanics offers a lot in terms of experiments and practical applications in technology.

Note however, that the underlying parameters of quantum mechanics are still the same as in classical physics. This is particularly true for the concept of time. The starting point for discussing time is Smolin's formulation of relativity following the principles laid down by Einstein: "There is nothing outside the universe."[7] What he means is that there cannot be an absolute coordinate system defined for space and time as valid parameters outside the universe. Hence, the position of every object in the universe must be defined exclusively in terms of the position of other objects in the same universe.[8]

Traditionally, time is visualized as a kind of permanent flow that is defined in terms of a present moment (now) such that all what is before is called the domain of the past, and all what is after is called the domain of the future, respectively. The problem is that within this picture, the present (now) has to move all the time, and the question arises how long a moment will actually last (how fast does time flow)? But because a motion implied by a flow can only be expressed in terms of an appropriate concept of time, this would mean that we need an external time which is used to measure internal time (which is not possible according to the above Einstein principle). Hence, in logical terms, time cannot actually flow at all. Consequently, the alternative is that time is always there, and that there is no real distinction between future and past. In order to understand the implications in more detail, we add a little excursion here into the field of relativity.

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[7] Recall that Lee Smolin is not a philosopher. Hence, the explicit wording of his formulations is often not very precise as to philosophical concepts. See my forthcoming Schelling book for a discussion of the difference between *nothing* and *nothingness*. (Cf. Rainer E. Zimmermann: Nothingness as Ground and Nothing but Ground. Northwestern University Press. To be published, 2014.) Note that in particular, nothingness *is not* nothing. In other words: Physical nothingness is actually quite a lot after all. Hence, the correct formulation: The universe has a boundary outside of which there is something completely different. (Space, time, and matter are categories which are constitutive for the physical universe, but non-existent beyond its boundary.)

[8] Essentially, this is an immediate consequence of what we can call „principle of diffeomorphism invariance" which is also called *relativity principle* in Einstein's terminology.

Excursion under the Relativistic Perspective[9]

Odin's knowledge was the knowledge of forces
that bound things together, and of the runes
that read and controlled those forces.
Antonia S. Byatt: Ragnarök[10]

While revolutionizing physics by introducing his theory of relativity, Einstein (A) struggles with an epistemological contradiction: Although his theory is firmly based on the principle of diffeomorphism invariance, which prohibits the existence of a distinguished spatial metric from which the properties of various space-time regions can be derived, in practise, the theory relies nevertheless on the selection of individual metrics in order to extract concrete physical results about the universe. The latter turns out to be grounded in a physical singularity which shows up as a kind of epistemic horizon for the theory in the first place. In physical terms, this singularity is nothing but an abysmal unground in its own right. Different from Einstein, in his more recent approach, Hawking (B) tries to establish a background space which is self-grounded and reminiscent of an eternal universe. On the other hand, Penrose (C) tries to derive the ground of the universe from a combinatorial structure which is of purely conceptual type organizing a set of cyclic universes. The former re-introduces connotations of Spinoza's philosophy while the latter introduces a model which strongly reminds us of Schelling's approach.

A Einstein: Cosmic Necessity

Recently, Jörg Villwock has discussed in some detail an interesting relationship between modern physics and existential philosophy.[11] He is starting from Heidegger's reception of modern physics at the time relating particularly to Einstein's theory.[12] He quotes from Heidegger's 1939 paper on "The Essence and Concept of Physis", namely that metaphysics would be physics as well as physics would be metaphysics. Hence, Villwock states: "[This means that] physics deals with being, is ontology. In a surprising manner here and there the prognosis of Schelling's is fulfilled that the future of science and thus of mankind should decide itself on the field of nature whose concept however would undergo an essential transformation."[13]

Referring then to the results on Brownian motion, the idea is that if there is something beneath the optical threshold, then there must also be a space. Villwock relates this result to

[9] The following section is taken from an earlier version of the afore-mentioned Schelling book of mine.

[10] Canongate, Edinburgh, 2011, 112.

[11] Jörg Villwock: Signaturen des erdkolonialen Zeitalters. Shaker, Aachen, 2008.

[12] It is not quite clear whether Villwock's formulation is actually correct when stating that Einstein would have shown that "atoms are, mass is energy, the radiation of light is distributed discontinuously." (Ibid., xii) More precisely, one should formulate instead that Einstein showed that "atoms can be visualized as an adequate model of matter in which mass and energy show up as equivalent quantities, where energy is quantized, with consequences for the radiation of light."

[13] Ibid., xii sq.

Schelling's critique of Kant.[14] Hence, he continues that "it is Einstein's lore of the being of the atom that disrobes physics of its hypothetical character, but contains at the same time those key concepts along which Heidegger's philosophy is actually unfolding itself, namely being, space, time, light, and world."[15] From here comes Heidegger's opinion that in the light of relativity theory, it is the objective to express the totality of nature by surpassing all possible relativities.[16]

Villwock calls this an odd and remarkable formulation which can be seen as a direct parallel to Schelling's derivation of positive philosophy out of negative philosophy (only that in the latter's case it is not the totality of nature then which is being expressed, but the totality of God himself). This idea he also recognizes in Ewertowski's work. He concludes that apparently, Einstein and Heidegger have a methodological idea in common: namely to gain and mediate stringent and perpetuating insight only by starting from propositions and assumptions which are taken for granted, but which turn out to be highly problematic, if investigated in more detail. This is nothing but a stroke against established ways of thinking by explicitly accepting that it is ignorance which is the ground of knowledge, thus generating a productive confusion that unveils the knowledge before knowledge. In this sense, Einstein would have been the first to synchronize the physics of light with the latter's ontology.[17]

In a sense, this topic relates to Spinoza's discussion of a possible (onto-epistemic) harmony of unity and multitude. Obviously, this type of harmony is strongly based on the type of philosophical thinking itself (leading forward to Schelling's first paper already mentioned). Villwock thus continues:

"As far as I can see, Schelling is the only one who has actually anticipated exactly this: that it is the final destiny of school philosophy – as a negative one which permanently loses its contents – to sublate itself in the sciences in order to eventually fulfil itself as a science of the sciences in the historical moment when another beginning of philosophy is attainable ... which as a positive one accomplishes the real knowledge of God. Into this direction I interpret the remarks of Einstein ... The new physics lives in the reversement from negative to positive philosophy."[18] And this has immediate consequences:

"Hence, gravitation is reduced in the end to the shape of the universe's spatiality which in turn shows up as a harmony of world-lines in optical terms. / This physical conception shows a conspicuous analogy with Schelling's viewpoint in so far as the latter also declares gravitation to a mere phenomenon behind which something completely different is being veiled."[19]

We recognize here two well-known aspects: on the one hand, the fact that the world *is not as we observe it* (essentially a starting point for any type of hermeneutically oriented philosophy), on the other hand that human-made theories about the world are such that harmony will be achieved in a pre-defined (onto-epistemic) sense – which we can equally

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[14] Ibid., xvii.

[15] Ibid., xviii.

[16] SZ 9.

[17] Ibid., xxv – xxix. (par.)

[18] Ibid., 32.

[19] Ibid., 47. (Cf. 49 sq.) Referring to Schelling's *System der gesammten Philosophie*, 206, passim.

well call *aesthetical*. It is here where recent insight into the nature of gauge theories in physics comes into play. We will return to this in due time.
Hence, with an explicit reference to Schelling: "According to space, things show up as existing for themselves within the All without unity, according to time as existing for themselves without totality. Space possesses the totality, time is lacking, while the latter possesses the unity which is absent from space."[20] So, time is the deficiency of totality, space is the deficiency of identity.[21] Or, in other words: "Space is the being of analogy and thus also the principle of all the forming of metaphors within language. Language, says Porzig, translates all undescriptive relationships into the spatial."[22]
Hence, when time is completely expired into space, the latter transforms itself into chaos, while on the other hand, time into which space expires, becomes eternity."[23] This is the important result of Schelling's geometry of fundamental physics.[24] In fact, all of this is not very far from what Einstein himself puts forward in the few monographs of his.
For Einstein, geometry does not actually deal with the relationship between its concepts and the objects of experience, but only with the logical connection among these concepts.[25] In so far, it is not quite something like a "truth" which is being checked against empirical experience. Instead, it is a lind of onto-epistemic consistency which is being checked. If so, then each general law of nature must be such that it can be transformed into a law of equal form, when replacing variables (x, …, t) of a system K by variables (x′, …, t′) of another system K′ which is moving with respect to the former one. And this transformation must be such that it reproduces the mathematical connection between K′ and K in terms of a standard form which is called *Lorentz transformation*. Hence, general laws of nature are *covariant* with respect to Lorentz transformations.[26]
In order to illustrate this in more detail, remember how Lorentz transformations actually arise when comparing variables of relative systems: The essential idea is to base the comparison on the motion of light. In other words, for a one-dimensional process (propagation with respect to the x-axis of cartesian co-ordinates), we have

$$x' - c\,t' = \lambda\,(x - c\,t)$$

for the positive x-axis, and

$$x' + c\,t' = \mu\,(x + c\,t)$$

for the negative x-axis. The addition of these two equations gives

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[20] Ibid., 57.
[21] Ibid., 58 sq. (par.) With reference to Schelling's Mythology, 355, 364 sq., 376 sq., 426 sq.
[22] Ibid., 85. Referring to Porzig: Das Wunder der Sprache, Munich, Bern, 1971.
[23] Ibid., 88.
[24] Ibid., 94 sq.
[25] Albert Einstein: Über die spezielle und die allgemeine Relativitätstheorie. Springer, Berlin, Heidelberg, 24th edition, 2009, 2.
[26] Ibid., 28. (par.)

$$x' = a\,x - b\,c\,t,$$

$$c\,t' = a\,c\,t - b\,x,$$

with $a = ½ (\lambda + \mu)$, and $b = ½ (\lambda - \mu)$. The relative velocity turns out to be $v = (b/a)\,c$. Hence:

$$a = (1 - v^2/c^2)^{-1/2} \Rightarrow b = (v/c)\,a.$$

For (x, t) we have then:

$$x' = (x - v\,t)\,(1 - v^2/c^2)^{-1/2},$$

$$t' = (t - (v/c^2)\,x)\,(1 - v^2/c^2)^{-1/2}.$$

Obviously, for our example, $y' = y$, and $z' = z$.[27]
In other words, this *universal* relationship between two such systems can be utilized in order to check the consistency of *newly* discovered laws of nature.[28] But note now the important consequence: "Physics becomes a *being* within the four-dimensional world, out of a chain of events (out of something that happens) within a three-dimensional space."[29]
The allusion here to a classical concept of substance is obvious[30]: For the simple case of a flat Minkowski space (relevant for the special theory of relativity), the metric components can be written as an invariant equation of the type:

$$ds^2 = c^2\,dt^2 - dx^2 - dy^2 - dz^2$$

which can be formally re-written as

$$ds^2 = dx_0^2 - dx_1^2 - dx_2^2 - dx_3^2 = g_{ab}\,dx^a\,dx^b.$$

Here, we have put a, b = 0, 1, 2, 3 for the respective co-ordinate entries, and we utilize Einstein's summation convention which means that we sum over each pair of equal indices. Clearly, the elements of what looks like a matrix of coefficients (but what is actually displaying the components of a *tensor*) are (1, -1, -1, -1) in the main diagonal, while all the other components vanish. In particular, we put $c = 1$.
We can say that therefore, time (change) is thus integrated into the state of the four-dimensional space (instead of visualizing motion as a chain of events taking place in the interior of a three-dimensional space acting as a kind of container). This point which characterizes the main difference between the Newtonian classical physics and Einsteinian modern physics, raises important questions as to the constitution of the dynamics with

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[27] Ibid., 21, 78-80.
[28] Ibid., 29.
[29] Ibid., 81.
[30] I have discussed this aspect in more detail in my 1984b. See also: 1984c.

respect to its cognitive relevance for physical observers. This topic is still under discussion and far from being cleared completely.[31]

Hence, while in classical physics space possesses an autonomous existence with respect to matter, this is no longer the case in relativity. This is particularly clear when admitting functions of the co-ordinates for the coefficients of the metric components rather than merely dealing with constants. (By doing so, space becomes curved then such that one is passing from special to general relativity.) Now, the g_{ab} do not only provide for the force field proper, but also for the topological and metric structure of the underlying differentiable manifold (which is the mathematical construction of the space in question). Einstein stressed the point that Descartes was not right therefore when claiming that empty space would not exist at all.[32]

So, essentially, what Einstein calls a *field* (not necessarily one of gravitation) is the dynamical property of a general space which itself is non-dynamical in the first place.[33] In other words: It is only the human beings that according to their cognitive mode of being *have the impression* that there be motion and acting forces, but this is simply a necessity for those who have to observe space-time under given conditions such that it appears to consist of two disjoint parts, namely space and time, respectively.

B Hawking: Space as Ground

More recently, the philosophical grounding of modern physics, notably as to the basic categories of space, time and matter, has become topical in the works of Stephen Hawking and Roger Penrose who were able to draw a lot of interest towards their theories by means of publishing popular books written in a somewhat non-technical style in order to secure their general understanding.

Unfortunately, as far as Hawking is being concerned, contrary to what he usually announces, in fact, his contribution is quite modest and sometimes not only controversial, but even displeasing and upsetting, to say the least. This is mainly so, because he tends to promise more than he is able to keep after all. In his most recent book[34] he audaciously announces that “philosophy is dead”[35] and should be reduced to the viewpoint of “model-dependent realism” that is directly derived from the results of physics proper.[36] In this book, he claims, would he thus “not only show *how* the universe behaves, but [also] *why*.”[37] However, when actually reading the book, we find that neither is this viewpoint demonstrated in some detail, nor comes he back to these promises in the rest of the book – not to speak of the fact that he does not give any answer of the promised type.

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[31] See e.g. Julian Barbour: The End of Time, Weidenfeld & Nicolson, London, 1999, for a detailed presentation of this. Cf. also my 2001b (part III) for a different viewpoint.

[32] Einstein, op. cit., 107.

[33] Ibid., 108.

[34] Stephen Hawking, Leonard Mlodinow: The Grand Design. Bentam, New York, 2010.

[35] Ibid., 5.

[36] Ibid., 7.

[37] Ibid., 9.

Moreover, as to the philosophical topics raised in this book, the conceptualization is far from precise[38]: So the explication on the concept of free will is quite unusual indeed.[39] It is also quite questionable whether a model-dependent realism can answer to the question: "If the world was created, what happened before?"[40] In fact, utilizing such a formulation is not very clarifying indeed, because we cannot know what the word "creation" is actually intended to mean here (do we talk about absolute creation, once and for all, or about permanent creation, of the world, of the ground, in the purely philosophical sense or in the theological sense, and so forth?). It is equally unclear what the formulation "what happened before" actually means. Does this refer to a process in space and time (is it pointing to the world therefore), or does it refer to a generalized motion with a view to the ground? And finally, is the word "before" referring to a point in time (an event) or what else could be meant? Hawking seems to become more and more the Žižek of physics.

We can continue the line of inconsistent formulations: So, the multiverse discussion is not quite to the point, if invoking another Elvis in a parallel world[41]. And the strong anthropic principle is certainly *not* equivalent to the weak one.[42]

Now, what Hawking originally intended to do (completely in terms of physics alone), can be found out with much more precision, if having a look at the considerably earlier publications on what he used to call *Euclidean Quantum Gravity*.[43] The technical point is that he introduces an imaginary time co-ordinate $t = i\tau$ such that the metrics of the type displayed above become positive-definite. (In other words: There is only one sign for the relevant coefficients.) Hawking speaks here of *Euclidean* metrics. Summing up over all of them[44] gives a kind of total solution for the universe such that the result can be paraphrased by the formulation: The boundary condition of the universe is that it has no boundary.[45]

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[38] Conceptual precision is usually a controversial topic in itself. The quality as such is usually claimed only for the critic's own discipline. Cf. a contribution of Abhay Ashtekar to this by occasion of the 13th icmp2000 at Imperial College London: http://gravity.phys.psu.edu/mog/mog16/node13.html. (2000) See my commentary to that in www.arxiv.org/pdf/physics/0107061. Also in http://philsci-arxive.pitt.edu/382/ .

[39] In fact, the actual relationship between free will and determinism is not discussed in conjunction with the important problem of emergence which is essentially dealing with the equally important relationship between micro-levels and macro-levels of systems. (Hawking, op.cit., 32) The solution to this is mainly that what we call free will in terms of individual decisions of persons is a phenomenon which can be observed on the worldly macro-level, but not derived from the appropriate micro-level such that it is an emergent phenomenon with respect to the underlying processes which produce the result in the first place. And also, to "ask whether a model is real" cannot actually be an adequate formulation of a question at all, as we can see from the terminology common to all efforts towards ontological problems. (Ibid., 46.)

[40] Hawking, op. cit., 49.

[41] Ibid., 136 sq.

[42] Ibid., 164 sq.

[43] Stephen W. Hawking: Euclidean Quantum Gravity (1978). In: G. W. Gibbons, S. W. Hawking (eds.), Euclidean Quantum Gravity, World Scientific, Singapore etc., 1993, 73-101.

[44] In fact, by means of utilizing an adequate path integral.

[45] For details see Hawking and Penrose, 1996, 45, 79. We cannot here discuss all the related topics which range from black hole dynamics to wormholes and superstrings. See e.g. Stephen W. Hawking:

This is actually a result which is controversial until now, because the imaginary time has been utilized in early relativity theory in order to take care of the sign difference among time and space entries. As it turned out, this was nothing but a formality without physical relevance, because the metric is a quadratic form anyway so that the imaginary unit does not actually show up explicitly. Hence, the conclusion summarized above is contested by those who stick with the traditional form of the metric. This has further consequences, because it is closely related to the intentions of those who develop what is called *superstring* theory. Without going into details, we can say the following: The result of Hawking's as it is quoted above means in onto-epistemic terms that the universe is infinite. Together with the ontological interpretation of Einstein's as to the four-dimensional metric, this actually means that the universe by itself gains more and more the connotation of a substance by being a structure which in its totality is not changing and not subject to any boundary condition which could be defined by the human observer. A special conclusion of this is that the universe itself is not subject to dynamical differences. In a sense, re-phrasing classical metaphysics, we can say that the universe shows up here as one which is infinite and eternal. For Hawking, "behind" space there is nothing at all. Hence, space is also the ground of itself.

However, this picture is not generally accepted – not only due to the technical aspect of imaginary time, but also, because it falls back onto the idea of visualizing space as a container within which processes happen. Very much in the ancient Newtonian sense, the universe as space is the stage on which events take place. But the tendency in modern physics is instead to assume that stage and events are integrated into one entity, and that one cannot be separated from the other.

C Penrose: Ground as Combinatorial Concept

These are the problems which are tackled in a much more efficient way by Roger Penrose. Different from Hawking, Penrose is more reliable as to what he can offer in terms of foundations. Not only is he more modest in his announcements, but he is also more consistent with respect to the conclusions he draws from the physical results. So, in the beginning of his most recent book[46] he states: "One of the deepest mysteries of our universe is the puzzle of whence it came."[47] This is quite true indeed, and Penrose is far from promising that he will completely solve this puzzle. What he does instead is to explicate certain basic results from thermodynamics dealing with what we call *phase space*. Essentially, this is nothing but the space of all possible states a physical system can attain. Concentrating on phase space is useful, because we arrive at an explicit history of the system in question by simply reading the system's trajectory in phase space. And we can immediately check that the processes involved obey the law of growing volume elements: I.e., the actualized states of the system occupy larger and larger volume elements of phase space, which means in

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Wormholes and Non-Simply Connected Manifolds. In: S. Coleman et al. (eds.), Quantum Cosmology and Baby Universes. World Scientific, Singapore etc., 1991, 245-267.

[46] Roger Penrose: Cycles of Time. The Bodley Head, London, 2010.

[47] Ibid., ix.

physical terms that the number of degrees of freedom over which the respective states of energy are being distributed is not only increasing but also approaching what we can call an equi-distribution in the long run. In other words: The phase space representation illustrates directly the second law of thermodynamics securing the increase of the total entropy of a system which means that the odering implicit to the system is actually decreasing.
The examples Penrose provides have a characteristic relevance for what he would like to achieve in the end.[48] The important point is here that he uses this beginning in order to demonstrate the chief property of the Einsteinian approach which is its exhibiting a state of being rather than a history of events. This becomes quite clear when referring to Einstein's shifting from a Euclidean 3-geometry to a 4-geometry: "… Minkowski's space-time has a different kind of geometric structure, giving a curious twist to Euclid's ancient idea of geometry. It provides an *overall* geometry to space-time, making it one indivisable whole, which completely encodes the structure of Einstein's special relativity. / Thus, in Minkowski's 4-geometry, we are *not* now to think of the space-time as being simply built out of a succession of 3-surfaces, each representing what we think of as 'space' at various different times. … Instead, 'simultaneity' would depend upon some arbitrarily chosen observer's velocity."[49] This somehow changes the quality of the geometry thus perceived: "What Minkowski's space-time achieves is to provide an *objective* geometry, that is not dependent on some arbitrary observer's view of the world, and which does not have to change when one observer is replaced by another."[50]
Note that this raises already the concept called *gauge invariance* which turns out to be very important. We will discuss it in more detail later on. In principle, gauge invariance is something which secures the above-mentioned observer-independence of physical phenomena. For Lee Smolin this is important enough for starting his own book with a discussion of gauge principles.[51] His essential starting point is the fact that it is two basic aspects: *gauge principle* and *spontaneous symmetry breaking* that secure a unified visualization of a multifarious variety of phenomena ranging from electromagnetic and gravitational fields up to particle fields. Smolin refers these aspects back to a philosophical starting point originating in the philosophy of Spinoza (but commonly attributed to Leibniz who took the idea from Spinoza without mentioning this). The question is whether entities in the world are determined by the set of the relationships they possess with respect to other entities, or whether they can be described as isolated entities possessing a kind of autonomous existence of their own right. For the former position Spinoza and Leibniz are the leading representatives, while for the latter position Newton is the relevant witness. Smolin, by quoting Hermann Weyl, explains the characteristics of gauge by discussing the question whether the name of a particle charge is meaningful or not, because it shows up as a mere convention in the first place. Smolin shows that by trying to clarify this Weyl refers to

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[48] In former books, Penrose has exploited the insight into the phase space representation earlier and explained its consequences such that also the laymen can straightforwardly understand its meaning. See e.g. Penrose 1989, 1994 and to a certain extent also Penrose 1997. More technical literature is offered in Penrose 1979, 2005.
[49] Ibid., 80 sq.
[50] Ibid., 82.
[51] Smolin 1997, 51 sqq.

"theorem of sufficient reason" given by Leibniz. Without restricting the freedom of choice for the naming of charges, we can recognize that it is the concept of *field* that helps out here: "Because all that matters is the relationship between each charge and the field around it, Weyl discovered that it is possible to arrange the law by which the fields and the particles interact so that we keep the freedom to choose as we like which charges are negative and which positive. The field carries information about the presence of a charge in a form that does not depend on our convention. As a result we can choose differently in different places … But we can only do so, if the field satisfies certain equations. … And the field whose existence is necessary to preserve our freedom to call charges positive or negative as we like is real: it is the electromagnetic field."[52]

This also works, if we go back to the classical description of Newtonian physics. The gauge quality of simple mechanical systems is not so spectacular as in the case of electromagnetism (because Maxwell theory is covariant in a relativistic sense from the beginning on), but the idea is clear enough: In fact, that the laws of nature (e.g. of free fall) are independent of the observer's perspective can be shown easily by means of the two constants of integration which show up when deriving the equations of motion from the law of force.[53] Generalizing these results shows us what we gain from gauge invariance: As it turns out, in physics, gauge theory altogether is a field theory itself which can be utilized for a large variety of approaches. The dynamics of a given physical system is usually represented in terms of its *Lagrangian* which is essentially the difference between kinetic and potential energies. The advantage of this more abstract mode of representation is that the equations become much more flexible, particularly with a view to the utilized co-ordinates. This is why electromagnetism (in the shape of Maxwell theory) and relativity (by means of Einstein's theory) are commonly represented in Lagrangian terms. *Within the framework of the appropriate terminology, the concept of gauge refers then to redundant degrees of freedom in the Lagrangian.* (This is what we meant by perspective-independence in the explictation above.) A change of perspective is given then by a transformation of the respective gauges describing these perspectives. The idea is that under such transformations, the physics remains the same. Usually, these transformations form a group called *Lie group* (alternatively called *symmetry*

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[52] Ibid., 52.

[53] Namely in the following sense: Essentially, Newton's law of force can be expressed in terms of a simple differential equation of second order. This is so because the acceleration a showing up in the celebrated form $F = m\, a$ is the same as the second time derivative of the position the object onto which the force is acting can be found in. Hence, $d^2/dt^2 x = a$, if the position is given by $x(t)$, which gives $v = a\, t$ (velocity) after the first, and $s = ½\, a\, t^2$ (distance/position) after the second integration, respectively, up to constants. (For free fall we have to put $a = g$, where g is the gravitational acceleration on the surface of the Earth.) The constant arising as a result of the first integration is commonly chosen to be the initial velocity such that completely, $v = v_0 + a\, t$, while the second constant is taken to be the initial position: $s = s_0 + v_0 t + ½\, a\, t^2$. (Note that the second term in this gives the distance covered by an inertial motion.) But the important point is here that s_0 as well as v_0 are arbitrary! In other words, the two equations of motion as consequences of the law of force are true *independent of* an infinity of possible initial conditions the observer may be subjected to. With respect to the concept of motion of bodies or particles, the set (s_0, v_0) is nothing but the relevant starting point in phase space. A huge variety of different perspectives entailing an explicit freedom of choice is thus guaranteed without leading into the chaos of arbitrary laws (because they are much more than mere conventions)!

group from time to time). We know from the underlying mathematics that each Lie group can be associated with a Lie algebra of group generators. And for each such generator there is a vector field called gauge field.[54] This is the technical and formally correct explanation of what happens in the physical situations described above. We will come back to this. But first of all, we return to the issue of Penrose's.

Bearing in mind what we have said so far, we can give now a new enriched meaning to Einstein's *covariance principle*: This can be best seen when remembering that the metric equation displayed earlier is the algebraic equivalent of a graph in terms of analytic geometry which is essentially a double cone called *light cone*. When performing the transition from special to general theory, this amounts mainly to admitting functions of the co-ordinates as coefficients in the expression for the metric. In other words, the resulting light cone under the presence of gravitation is not anymore a figure constructed from straight lines, but rather a deformed version of this graph: "The idea is that such deformations do not alter the physical situation at all. The principle of 'general covariance', which is a cornerstone of Einstein's general relativity, is that we formulate physical laws in such a way that such 'rubber-sheet deformations' (diffeomorphisms) do not alter the physically meaningful properties of the space and its contents."[55] Penrose can demonstrate the immediate consequences in a very illustrative manner drawing different cone structures. In fact, as far as graphical techniques are concerned, he is one of the inventors of graphicality altogether, and in particular his *Penrose diagrams* are very useful in displaying global properties of space-times collected in one appropriate graph.

This is also true for his representations of conformal geometries: "The kind [of geometry] that will be of most concern for us here is the geometry known as *conformal* geometry. This is the structure that provides a measure to the *angle* between two smooth curves, at any point where they meet, but a notion of 'distance' or 'length' is *not* specified."[56] Essentially, we deal with a re-scaling here expressed by some positive real number Ω such that the conformal metric is related to the standard metric by

$$\hat{g}_{ab} = \Omega^2 g_{ab}.$$

The idea is that this type of mapping is practically 'squashing' space-time such that infinity is brought into the immediate neighbourhood of the geometric discussion. That is, we replace the original space-time manifold without boundary (usually asymptotically flat) by another manifold with a boundary on which we can study infinity. This is the reason why the Penrose diagrams achieve a *global* picture of space-time and not only a local picture.[57]

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[54] A Lie group is a group and a manifold (a differentiable space) at the same time. The group operations are compatible with the underlying differentiable structure. In particular, two special groups, the Lorentz group and the Poincaré group of transformations are the groups of linear and affine isometries of Minkowski space.

[55] Penrose, op. cit., 86. (It is exactly here where superstring theory possesses its deficits.)

[56] Ibid., 88.

[57] A very good introduction into the various techniques which cannot be discussed here in detail is given in William J. Kaufmann: The Cosmic Frontiers of General Relativity. Penguin, Harmondsworth, 1977, ch.9 (127-150).

What we can note now is that time plays a rather particular role within this context: Remember that in a 4-space, the distance is always one between events rather than between positions: "This illustrates the key fact about the metric of space-time, namely that it is really something that has much more directly to do with the measurement of *time* rather than distance. Instead of providing a *length* measurement for curves, it directly provides us with a *time* measurement. Moreover, it is not *all* curves that are assigned a time measure: it is for the curves referred to as *causal*, that could be the world-lines of particles, these curves being everywhere either *timelike* (…) or *null* (…). What the space-time metric *g* does is to assign a time measure to any finite segment of a causal curve (…). In this sense, the 'geometry' that the / metric of space-time possesses should really be called 'chronometry' …"[58]
This has a physical consequence, because any stable, massive particle behaves like a precise quantum clock by means of Einstein's celebrated equation

$$\nu = (c^2/h)\, m$$

which is a direct result from combining the equations $E = mc^2$ and $E = h\nu$. But the key point here is that we always need mass in order to have clocks. If the particle is massless, this is not working, because then time goes asymptotically to infinity. Hence, if we have the special case of *null geodesics* (i.e. extremal curves of a massless particle under the action of gravity only), their 'length' is actually zero, "and the null-cone structure of the space-time alone is sufficient to determine them. This null-cone structure is actually equivalent to the space-time's *conformal* structure …"[59] We will not go into the details here of drawing the appropriate diagrams, but it is noteworthy that conformal geometry is strongly facilitating the description of black holes which turn out to be the most fundamental entities in the universe, of both mathematical as well as physical importance.[60] In particular, from black holes the connection can be established with thermodynamics again. This is the starting point for the most recent innovation Penrose introduces as a kind of bridge from one universe to another.
The central idea of this is to invoke what is known about the *Higgs mechanism* of particle physics: The Higgs particles are hypothetical particles which are responsible for the emergence of rest mass. Penrose argues that in the very early universe when the physical conditions are rather extreme, the Higgs mechanism has not been initialized yet. Hence, only massless particles are around, and consequently, it is the conformal geometry which is relevant then. Paul Tod has developed a picture of the early scenario in order to show that at the singularity itself, geometry can behave as providing a smooth boundary to space-time.

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[58] Penrose, op.cit., 92 sq.
[59] Ibid., 94 sq.
[60] Re-written for the purpose of philosophical discussion I have commented on black holes in various other places: Cf. my 1978, 1991, 1998a, 2004a. After all, the main focus was much more often on the initial singularity of cosmology rather than the local singularities of stellar origin: Cf. my 1974, 1982, 1984, 1993, 1998, 2001, 2007c. Presently, there is a project under way which deals explicitly with the classical universes contained in the interior of black holes: Black Holes as Cosmic Incubators: The Inside Story Revisited. Forthcoming (2012).

This is related to what Penrose calls *Weyl Curvature Hypothesis*[61] securing the low entropy of the universe at the initial singularity: "This is to say, more or less, that there is a Big Bang 3-surface B(-) which acts as a smooth past boundary to the space-time M, when M is considered as a conformal manifold, just as happens in the exactly symmetrical FLRW[62] models as exhibited [earlier], but where the FLRW symmetry of these particular models is now *not* assumed."[63] This also entails the discussion of a small neighbourhood of the initial singularity[64], which is also extending into the region which is logically *before* the Big Bang. Penrose now utilizes this approach in order to attach a physical meaning to this region.
This is what he calls *conformal cyclic cosmology (ccc)* and which refers to a region of crossover between universes characterized by a conformal geometry (i.e. concerned with massless particles only). What he visualizes then is the following: There are pieces of physical universes called *aeons* for which normal space-time theory is valid and the relevant cone structure of the metric describes all possible particles including massive particles. These pieces are interconnected by means of *collars* which are essentially regions of crossover. There may be an infinite succession of aeons. (Hence, this is not really a model of the well-known multiverse type, but instead a kind of unique universe which is in a permanent process of phase-shifting.)
Take the geometry in the neighbourhood of a crossover 3-surface H with a collar C of smooth conformal space-time containing H, which extends both to the latter's past and future, respectively. In the collar there are only massless fields prior to crossover B. Choose a metric g_{ab} in this collar, consistent with the given conformal structure. Let the physical metric in the 4-region C↑ just prior to H be g_{ab}, and in C↓ immediately following H, $\breve{g}_{ab}$ such that

$$\hat{g} = \Omega^2 g_{ab}, \ \breve{g} = \omega^2 g_{ab}.$$ [65]

In each of the two regions in question Einstein's equations remain valid (including a cosmological constant), and all the gravitational sources in the earlier region are taken to be massless. This means that the energy-momentum tensor in that region has a zero trace, while its counterpart in the later region has a small trace such that this can be interpreted as anticipating the emergence of a rest mass according to the Higgs mechanism. The crossover is explicitly governed by a smooth transition of the type $\Omega \to \Omega^{-1}$ secured by a characteristic 1-form which is $\Pi = d\Omega/(\Omega^2 - 1)$, smooth at crossover.

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[61] Cf. Penrose 1979.
[62] FLRW = Friedman-Lemaître-Robertson-Walker
[63] Penrose, op.cit., 134.
[64] Note that for the time being we are not concerned with recent results of the Pittsburgh school demonstrating that there is actually no initial singularity, but instead a kind of re-bouncing scenario such that the extremal physical conditions mentioned above characterize some sort of transition between levels of more ordinary conditions.
[65] Penrose, op. cit., 142, 230 sqq. (appendix B.2)

Let us come back now to the problem of time: We have seen in the preceding that the universe can be visualized as a *block universe* such that space-time is laid out from the beginning. We have also seen the various philosophical implications of this which have become a fixed part of the conceptual tradition, in fact, beginning in the time of Spinoza already.[66] Obviously, this viewpoint is in a serious conflict with our everyday experience, but nevertheless, strictly speaking, this experience must be visualized as an illusion that is caused by our (biologically caused) time asymmetry which is due to the fact that we can remember the past, but not the future. In principle, we have to conclude that if there is not something like a flowing time, then nothing actually happens. History is a human artefact, in the sense that human beings produce it by means of their biological constitution which is essentially digitally organized.

The picture we have developed of decoherence earlier is actually confirming this viewpoint. This is mainly because phenomena related to fundamental parameters such as space (spatial locations) and time (duration) are chiefly aspects of decoherence rather than properties of the world. If there is coherence in the strict sense, then it is impossible to differ consistently between locations and moments in time, because everything is entangled, and one cannot actually decide what (i.e. which states) is (are) belonging to what (object). In fact, the common everyday experience of distinguishing between different objects (which have each a well-defined location at a given time such that they so not overlap somehow or mix their states) is exclusively an aspect of decoherence. In other words: The world of quantum coherence is what comes close to the ancient concept of substance in philosophical terms.[67] (We will come back to this in the conclusion.)

A still unsolved problem is the reconciliation of Einstein's (essentially classical) theory of relativity with quantum mechanics. Obviously, both approaches claim to describe the one and only universe, but they unfold in quite different domains: Relativity is a theory that deals with four-dimensional space-time manifolds that possess a metric of Lorentz type with a given signature. Quantum mechanics is a theory that deals with high-dimensional Hilbert manifolds that possess metrics with a crucially different signature.

It is useful to come back to the Hamiltonian concept known from classical mechanics: Essentially, the *Hamiltonian* is the total energy of a given system – as mentioned earlier. In quantum mechanics, it is the sum of the operators that correspond to the potential and kinetic energies. Usually, the kinetic operator is given by $T_{op} = (p_{op})^2/2m = (- \hbar^2/2m) \nabla^2$, where ∇ is the gradient operator. Hence, the momentum operator $p_{op} = - i \hbar \nabla$. The Schrödinger equation then is $H_{op} = (- \hbar^2/2m) \nabla^2 + V(\underline{r}, t)$. This admits applications on systems which possess a wave function. Given a suitable initial state at time $t = 0$, for a time-independent Hamiltonian one can solve Schrödinger's equation by the expression $|\Psi(t)\rangle = \exp(- iHt/\hbar) |\Psi(0)\rangle$. The exponential is essentially a time evolution operator which is said to

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[66] See also my earlier essay: Loops and Knots as Topoi of Substance. Spinoza Revisited. Available as a preprint version at www.arxiv.org/pdf/gr-qc/0004077.

[67] As it turns out, the block universe viewpoint is thus able to dissolve a number of difficulties when applying the consequences of the model directly: such as discarding a *real* evolution of the universe (so that we have to differ between what there is according to *reality* and what happens according to (our) *modality*) which also implies conclusions on our own existence as to life and death, and the logic of causal and non-causal time loops.

be *unitary*. The set of unitary operators forms also a group. Collecting these results, we notice a difficulty when talking about the universe: Because there is no external reference outside the universe, it is not possible to define consistent energies (e.g. kinetic energy) for the universe as a whole. In other words, we cannot define energy properly then. In this sense, we usually put the total energy of the universe equal to zero, and thus H = 0.[68] This is what we call the *Hamiltonian constraint*. Commonly, the zero balance of the total energy is interpreted as a compensation taking place between the positive energy of matter available in the universe and the negative energy provided by attractive gravitation which is holding everything together.

Nevertheless, the Hamiltonian concept allows for visualizing the universe as a single quantum object and to talk of the wave function of the universe. (The argument is mainly that when the universe emerged it was of the order of magnitude of an elementary particle and could exist therefore in many states.) The *Wheeler-DeWitt equation* which is essentially a Schrödinger-type equation for the gravitational field is thus of the simple form $H_{op}\Psi = 0$. It can be shown that in particular, the rate of change of the state of the universe with respect to time is actually zero. And hence we are back to preceding arguments: It is *because* there is no external reference that the universe as a whole cannot be considered as a dynamical object. This sheds also some light by the way onto the problem of free will: We can clearly recognize that the block universe model does not violate the principle of free will, because the one has nothing to do with the other. This is mainly because free will is defined as the ability to make decisions. Usually this means that one has the choice among possible actions to be undertaken. Obviously, this choice is made according to our (personal) state of information which enables us to estimate the outcomes of our possible actions. And most of the time, we choose what seems optimal. But our personal state of information is just a tiny section of the actual information that is present in the universe. Hence, it is incomplete in the first place. And it is internal. Hence, essentially, free will means the ability to act according to incomplete information. And this is well in compliance with the (internal) thermodynamics of the universe.

6 The Anthropic Principle

It is obvious then that human beings tend to be influenced in their speculations about the world by the fact that they are referred back to a modality of their being that is restricted by means of a biological capacity for the cognitive grasping of the environment. Hence, the world is not as we observe it. And when we base our theories about the world on what we can observe (what should we do otherwise?), then this will cause a decisive discrepancy between the picture of the world we actually develop on the one hand, and the real being of

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[68] Note that strictly speaking, it is not necessary to put the total energy to zero, once we have recognized that the concept of total energy cannot be consistently defined for the universe as a whole. Because this could also imply that there is something which is quite alien with respect to the energy as we know it. But if we put H = 0, then this implies that outside the universe, the *concept of energy* is essentially the same as inside, but simply vanishes. (The zero-case is always nothing but a special case of a general non-zero situation.) Hence, there is a certain inaccuracy on this level of discussion.

the world as it simply is (but as we cannot observe it). Hence, there is a close relationship between physics and metaphysics. This however is often coupled to conceptual misunderstandings and logical errors which dominate the public discussion of scientific concepts. One of these concepts is what is generally called *the anthropic principle*: The point is that a close inspection of physical constants shows that if one of these constants would be only slightly different, then life in the universe would be impossible. From this John Wheeler concluded: "It is not only that man is adapted to the universe, the universe is adapted to man. Imagine a universe in which one or another of the fundamental dimensionless constants of physics is altered by a few percent one way or another. Man could never come into being in such a universe." This aspect of a global fine tuning is often running into difficulties: One problem concerns the cosmological constant. Essentially, this constant can be interpreted as the "pressure" of the physical vacuum, which controls the expansion of empty space. If this constant was much larger, then the universe would have expanded so fast that no galaxies could have formed in the first place. If, on the other hand, it was much smaller, then the universe would have collapsed too quickly for our life to form. Related to this is the problem of the dimensionality of space: Why are there three dimensions rather than two or eight? In fact, one can show that stable planetary orbits would be impossible to achieve in any different number of dimensions.[69]

The situation is similar for the standard model of particle physics. There we have not less than 19 undetermined parameters that ask for a lot of fine tuning in order to achieve a universe that is inhabitable. In the end, the interpretations of fine tuning range from a *designer universe* to a mere technical condition of self-consistency. The first visualizes *a strong version* of the anthropic principle which states that it is necessary for the universe to acquire properties that guarantee the existence of human beings. Because it is difficult to understand why there should be a fine tuning in the first place, it is a straightforward argument to postulate a designer of God-like nature. The second is a very *weak version* of the principle, simply saying that it is self-consistent to expect that the living conditions in the universe are favourable, given the fact that at least one type of human beings is obviously living there. In other words: Innovative theories that are introduced, but do not satisfy this weak condition, can be refuted at once.

Recently, a number of counter-arguments has been presented in order to show that the basic ideas underlying the anthropic concept are not as clear as we might expect. One point is that life is not necessarily a life as we know it. Ours is based on carbon and water and thus the result of a long-term development of physical, chemical, and biological details. Theoretically, one could think of life forms based on silicon (which is in fact rather improbable, because the reactions involved would be very slow) or even on non-organic matter (which is even more

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[69] However, this is only true for three-dimensional planets as we know them. Of course, one could imagine that in a, say, five-dimensional space, there are "hyper-planets" satisfying different conditions. Indeed, the five-dimensional geometry of the Kaluza-Klein type has become quite relevant for a discussion of superstring theory. But note that the problem of dimensionality is only an internal problem for the universe as we understand it, because decoherence tells us, among other things, that if there are no locations for objects (in terms of reality), then there is no spatial dimensionality anyway. This is actually the reason for being able to show that superstring theory cannot be correct, despite its elegant (if only few) results.

difficult to understand and support). Or one could simply argue that the universe does not actually care whether there are inhabitants or not. This would mean that an empty universe that emerges and disappears again would also be possible. In anyway, if there are no human beings around (of our kind or of any other kind), then of course, there would be nobody who is able to discuss this question. Nevertheless, the recent idea of Smolin's that there is a large distribution of universes of all types such that universes of our own (comfortable) type define the distribution's average, is quite interesting though difficult to access.[70]
The problem with these issues is that most of the underlying hypotheses are not well-tested, and partly, the theories are referring to the fashionable *inflationary universe* which is probably called so because of its tendency to generate many misunderstandings in a truly inflationary manner: Hence, Susskind suggests that what he calls Landscape could arise within an eternally inflating universe the structure of which was originally proposed by Andrei Linde.[71] Presently, the expansion of the universe is believed to be a consequence of a scalar field (called *inflaton*) which is determining the universe's first moments of existence. This is the essential basis for inflation. On the other hand, random quantum fluctuations in the scalar field can be explained in terms of the Heisenberg principle. If the fluctuations are large enough, then this can result in regions of secondary inflation, otherwise called *nucleation*. Hence, if the universe is eternally inflating (more precisely: permanently inflating), *bubble universes* can show up like bubbles in a bottle of champagne. Due to these fluctuations the values of physical constants can vary. So the bubbles can develop differently, some grow up, some disappear again very soon. Obviously, our own universe would be contained in one of the expanding bubbles. All these bubble universes can be visualized as points of the Landscape. (Note that it is advisable to call the set of all possible bubble universes a *multiverse*.)
The advantage of the multiverse viewpoint is clear: We do not need any explanation for the values of fundamental constants, because this is simply the result of coincidence. Our universe is one sample in a random process. This is what we can call *agnostic* approach. There is a number of people who criticize this type of approach, Lee Smolin and Paul Steinhardt being among them.[72]

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[70] More details about this topic can be found in an earlier paper of mine which is attached as an appendix under file number 0304053. Some time ago, there has been a lively debate between Smlin and Susskind as to the epistemological consistency of the anthropic principle and related questions. See the addresses http://www.edge.org/3rd_culture/smolin03/smolin03_index.html (Smolin on loop quantum gravity) and http://www.edge.org/3rd_culture/susskind03/susskind_index.html (Susskind on the Landscape) as well as http://www.edge.org/documents/archive/edge145.html (for the debate itself). I have discussed this topic earlier in a contribution to an Abisco conference of the Royal Swedish Academy of Science in 1989: The Anthropic Cosmological Principle: Philosophical Implications of Self-Reference, in: J. L. Casti, A. Karlquist (eds.), Beyond Belief: Randomness, Prediction, and Explanation in Science, Abisko Summer Workshop, CRC Press, Boca Raton, Ann Arbor, Boston, 1991, 14-54.
[71] See his paper www.arxiv.org/pdf/hep-th/0211048.
[72] However, this is a kind of contradiction: because on the one hand, those critics are not content with certifying that an answer to the question "How to explain that the universe appears as it does?" is not possible to achieve, while on the other hand, they insist on calling a theory *scientific* that can be

In principle, the cosmological selection approach of Smolin's has a similar problem, because its assumptions are likewise non-falsifiable. Note however that both approaches lead back somehow to what we called *substance metaphysics* earlier (in the sense of Spinoza, say). This is mainly because in the required distribution of universes there should be a (small) number of structural features that are invariant *for all possible* universes. And this implies the existence of an underlying substrate of the entire multiverse. This substrate is to its own ground what the Aristotelian subject (hypokeimenon) is to substance. Hence, it is a kind of *prima material* that satisfies its own laws. And this is the reason that Paul Davies calls this the "Goldilocks Enigma": "In the standard multiverse theory, the universe-generating laws are just accepted as given: they do not come out of the multiverse theory." The point is that all different universes are *universes* at least. Hence, there must be a prescription of how to produce universes in the first place.

Note that this problem is quite similar to the starting point of decoherence as we have discussed it earlier: Fundamentally, the universe shows up here as a coherent quantum soup without well-defined spatial and temporal locations. It is the agglomeration of matter then that lets these locations emerge for a human observer, once it has reached a certain order of magnitude. The remaining question is the one for the origin (initial onset) of this agglomeration. Philosophically spoken: Why is there something rather than nothing? (To be more precise: Why is there something rather than *nothingness which itself is not nothing* at all, as we can clearly recognize from the description of the coherent quantum soup, because this contains all possible states of the global system. And this is quite a lot indeed.)

Traditionally, substance has been the genuine concept for avoiding infinite regressions in philosophy. So if the multiverse is visualized as the universe of universes, then there may be an *ultiverse* which is the multiverse of multiverses. In that case, clearly, the ultiverse takes on the connotation of substance. This is quite independent of the question as to whether in science, everything that is not explicitly forbidden, is allowed (Murray Gell-Mann, Andrei Linde), or whether our world is a simulation that runs on computer hardware. But what we can see after all is that we have to deal with logic more than it was the former custom in both physics and mathematics for a long time. Hence, we have here another aspect of the close relationship to the philosophy of nature.

7 Philosophy of Mathematics

Obviously, mathematics plays an important role in physics (and elsewhere). Intuitively, it is quite straightforward therefore, to associate mathematics with its own ontological reality. As Roger Penrose says (in his "The Emperor's New Mind"): "The Mandelbrot set is not an invention of the human mind: it was a discovery. Like Mount Everest, the Mandelbrot set is just *there*!" However, Penrose has a strong attachment to the philosophy of Plato's. For him, mathematical entities are ontologically real entities rather than aspects of human modality. In fact, there is no sufficient reason to believe this: Instead, it is the most economical and also rational (at least: prosaic and sober) choice to visualize *mathematical structures as an*

falsified (which is not possible for the anthropic principle). But by replacing any other model whatsoever for the anthropic one, falsification is not at all secured!

instrument of human cognition: This is mainly because human reflexion is primarily based on language. In other words: What we call *theories* is a set of models that cover a number of situations human beings are interested in. But what is a model? A *model* is essentially a set of propositions which are related to each other according to given rules and conventions.[73] This is true for a fairly large class of theories, ranging from the sciences proper up to psychology and sociology, respectively. But in particular, it is true for physics, where the rules are comparatively severe. Hence, theories are based on language and thus on *communication* among human beings. But communication in turn is based on *cognition*. Hence, like any language, theories in particular, are instruments that serve the mapping and expressing of what one can cognitively perceive. Science is based therefore on what we perceive (which is a biological quality in fact that is based itself on physics which is modelled by such theories – welcome to self-reference!). Of course, scientists can develop other instruments which can help to perceive what we normally cannot. But the principle stays unaltered.

But independent of this difference in viewpoints, there is no doubt as to the importance of the Mandelbrot set: This is a very significant structure within the framework of chaos theory and can be represented by a geometrical figure that is essentially of *fractal* type. The crucial property of fractals is their *self-similarity* which opens a large variety of applications in the analysis of structures in a manifold of topics. Chaos and fractal geometry are not so much in the centre of the topic we discuss here. But for us important is nevertheless the role that can be associated with mathematical modelling at all: It is not so far-fetched to expect that our universe is also structured in a self-similar manner. Although this does not necessarily imply that the organization of the universe is chaotic. But it is probable at least.

On the other hand, it is unlikely that mathematical structures themselves actually create universal hardware, as Max Tegmark would like to argue. This is because he, similar to Penrose, thinks that these structures have a real ontology of existence. As mentioned above, claims like Tegmark's lack a certain amount of precision, because they deal with the underlying concepts in a very generous way. In the case of Tegmark's, this is especially true for his concept of reality. Brian Whitworth is another such candidate: "Reality is relative to the observer, so by analogy, a table is 'solid', because our hands are made of the same atoms as the table." (The Physical World as Virtual Reality) Well, this is not quite true, in fact: Not *reality* is relative to the observer, but *modality*. And within the framework of human modality, a table is said to be solid, not because our hands are made of the same atoms as the table, but *because our hands – in terms of their elementary particles – have macroscopic dimensions*. In other words: The table is solid, because its macroscopic shape (consisting of many elementary particles) fits nicely to the macroscopic shape of our hands. Hence, it is a point of

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[73] Indeed, practically, what we do here is to talk about language altogether: A *language* system (langue) – different from speech (parole) – is defined by its *lexicology*, *syntax*, and *semantics*, respectively. Elements of the first define the objects that are relevant for the theory in question, elements of the second provide the rules of how to connect these objects. The semantics tells us the meaning of the result. In fact, a language can be visualized as a *mathematical category*, the objects being the words (the essential signifiers), the morphisms being the rules of connection. It can happen that it is the syntax which creates the semantics. Note that a language is nothing but an instrument of mapping things which are called significates. The latter can only be expressed in terms of signifiers, i.e. by a *sign* that associates them with a syntactical and semantic order.

the order of magnitude rather than a point of the same matter. So after all, I think that it is comparatively easy to refute the afore-mentioned claims. It is interesting to notice that Andrew Thomas himself is dealing for several pages with these alternative viewpoints and stresses then the mapping character of mathematical models when he talks of mathematics as a model of physical reality. (Unfortunately, the "It's a Small World" page he mentions is difficult to access.) Related problems are also dealt with in a very concise paper by Paul Davies which is attached here as an appendix under file number 0408014.

8 The Universe as a Computer

Apparently, protagonists interested in Platonic realms (like Tegmark) or visualizing the universe (if only tentatively) as a computer simulation (John Barrow and others) do not actually favour the idea of treating mathematical models as instrument of mapping the world. The reason is probably that for them, the obvious difference between the picture of an object and the mapped object itself, is not quite acceptable and somewhat unsatisfactory. Whatever the motivation for this viewpoint, the crucial aspect of this is its epistemological implication: In fact, such a viewpoint clearly contradicts the falsification principle (if intended or not). This is because human beings are restricted to their cognitive powers which in turn are based on their biological capacities of perception. In other words: If we visualize a system which is to our observable universe what a master program is to a sub-routine, then it is quite straightforward to realize that it is rather unlikely for a sub-routine to gain global insight into the master program. Essentially, this is what in philosophy we call the "brain-in-a-vat" scenario: The idea is that a brain (detached from a human body) is floating in a life-sustaining fluid being connected to various machines that produce an appropriate sensory input such that the brain owner's consciousness cannot actually realize whether it is in virtuality or actuality. This is essentially what we find behind recent film projects like "Matrix".[74] But much more interesting than conspiracy theories (either with human or with alien (human) protagonists) is the cosmological model for a universe that is organized like a computer. Because human beings can be easily visualized as products of nature (of the physical universe), they can also be understood as beings with the role of a sub-routine within a master program. The question is how to visualize a universe which is organized like a computer.

David Deutsch has summarized related aspects in his 2002 paper "It from Qubit" (which is attached here as an appendix under file name reality_deutsch). Obviously, he dislikes strongly the idea of simulated worlds. But the point is that the agnostic argument works in two directions: Neither can a brain in vat prove where it actually is, nor can we prove that

[74] In fact, in the same year of publication, "The Thirteenth Floor" was also published which reproduced the original matrix idea in a much better way and with far less errors than "Matrix". The whole conception goes actually back to a Science Fiction novel published in the fifties by Philipp K. Dick: "The Time is out of Joint." (This is obviously a quotation from "Hamlet".) The virtual world is here a concretely built environment which has the purpose of making the protagonist think that he would be living in the past. At another occasion, this scenario was made topical in the film "The Truman Show".

the universe is not a simulation. (Remember the requirement of falsifiability mentioned earlier.) Hence, the only thing that is certain is our (onto-epistemological) uncertainty.
But note that nevertheless, there are at least some useful aspects of the general idea: One point is that sooner or later, human beings might be able to construct very complex simulations of the world. However, as we know from the Santa Fe people, "the best simulation of California is a rebuilt California", and so the question is whether the economic effort would actually be worthwhile. It is the chief objective of mathematical modelling that complexity can be reduced decisively by cutting down the number of variables and parameters involved. On the other hand, computer games clearly show the possible impact of simulations: Essentially, human beings who manipulate the "pawns" in a computer game, behave like a God with respect to these pawns. In fact, a player can decide about life and death of such a "pawn", and to a certain extent about the operations being performed by that "pawn". And the player can also choose a "pawn" which is representing himself or herself. In other words: The player can more directly become part of the game by showing up as an *avatar*. (This is the ancient Sanskrit expression for the shape the Gods are taking on when walking on Earth.) Such a computer game then – provided it has gained a certain amount of complexity and relevance – can well serve the purpose of studying scenarios of interest. In physics, this has become true by inventing a third branch of this field beside theoretical and experimental physics: namely *computational physics*, mainly introduced in order to save the costs of actual experiments. But also in other fields, this might be useful.[75]
Keeping the general viewpoint of the universe being a computer itself, we can quote Seth Lloyd who in his book "Programming the Universe" says: "What does the universe compute? It computes itself. ... The world is composed of elementary particles ... and each elementary piece of a physical system registers a chunk of information: one particle, one bit. When these pieces interact, they transform and process that information, bit by bit. Each collision between elementary particles act as a simple logical operation."[76] Obviously, Lloyd uses the classical information unit when talking about his idea. Hence, it is necessary to clear the issue of equating the physical universe with information in the first place. (Note that the precise definition of information is still under debate.[77]) Probably, the whole conception goes back to John Wheeler who coined the formulation: "It from Bit."[78] Because Wheeler refers

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[75] I have discussed this point at another occasion in more detail within the framework of the INTAS cooperation funded by the European Commission at the time (2000-2005). Cf.: Otherland Revisited. Philosophical Implications of Artificial Worlds. Part 1: City of Golden Shadow or the Ontology of Artificial Worlds. In: I. Dobronravova, W. Hofkirchner (eds.), Science of Self-Organization and Self-Organization of Science (INTAS Volume of Collected Essays 2), Abris, Kyiv, 2004, 86-116. Also: Otherland Revisited. Philosophical Implications of Artificial Worlds. Part 2: River of Blue Fire or the Epistemology of Artificial Worlds. In: R. E. Zimmermann, V. Budanov (eds.), Towards Otherland, Languages of Science and Languages Beyond. (INTAS Volume of Collected Essays 3), Kassel University Press, 2005, 29-44.
[76] Have a look and watch this nice seminar talk of Lloyd's: http://www.perimeterinstitute.ca/videos/programming-universe
[77] This is also topical in my lecture course on the theory of systems which runs parallel to this present course.
[78] For a sufficiently compact overview on information, see in particular Rainer E. Zimmermann, José M. Díaz Nafría: Emergence and Evolution of Meaning. The General Definition of Information (GDI) Revisiting Program – Part 1: The Progressive Perspective: Top-Down. Information 2012, 3 (3), 472-503. Also: José M. Díaz Nafría, Rainer E. Zimmermann: Emergence and Evolution of Meaning. The General

this problem back to the initial distinction between "yes" (1) and "no" (0) decisions, he is essentially defining it as a problem of logic rather than physics. Indeed, as can be shown within recent research work, logic and physics converge strongly in the fundamental domains.[79]

The main objection to visualizing the universe as information is the need for hardware: Essentially, the universe should be a quantum computer which is processing its software, but producing its own hardware at the same time. In a sense, it would be more of a *multi-duplicator* than of a mere computer. But it is highly questionable whether information suffices in order to generate hardware (matter). Hence, we would rather prefer a kind of dual approach to the fundamental attributes of the observable world which is the physical universe: In this picture, there is *energy* as building material and *information* as organizational know-how. The latter finds its basic entity in terms of *entropy*. Note that energy balance and entropy balance are fundamentally different. In order to make them equal (as we would expect from a proper double-entry bookkeeping in accountancy), we have to add an additional term to entropy. This can be done, if we differ between *potential* and *actual* energy and information, respectively. Matter shows up then as actualized energy. Structure shows up as actualized information. The material structures observable in the world form then a kind of memory of the processes that have been necessary in order to create them in the first place. When adding the structural terms, we can thus equalize the energy-entropy balance in the sense of a double-entry bookkeeping.

Finally, we are left with the problem of intelligence: Given the case that human beings might be in the position one day to actually develop their own (hardware) models of universes in a laboratory (which for some is already common consensus), then human beings would transform themselves from mere observers of the universe to active participators. Of course, somehow they have always been participators from the beginning on, because their intelligence enables them to intervene with nature. But they are not really participating in the sense that they can cause structural alterations in the fabric of the world. If this becomes possible, the question arises whether the *universe altogether* could be visualized as an intelligent structure.[80] This is actually an old idea of Schelling's who said that nature developed itself and eventually opened its eyes by creating human beings.

Definition of Information (GDI) Revisiting Program – Part 2: The Regressive Perspective – Bottom-Up. Information 2013, 4 (2), 240-261.

[79] See also a paper by Schmidhuber which is attached here as an appendix under file number 9904050.

[80] An amusing solution has been proposed very early by Isaac Asimov: http://www.multivax.com/last_question.html

9 Conclusions

When trying to collect the conclusions of the paper so far, we notice that the results are more on the side of philosophy rather than on the physical side. In other words: There is a (quite recent) close relationship between the latter and the former such that discussing the foundations actually means determining the heuristic value of philosophical speculation in order to eventually illuminate new aspects of theoretical physics. So what we do here for the purpose of concluding is to reproduce an earlier paper of mine on exactly this complex of topics.[81]

We enter thus a more philosophical domain that shall help to illuminate the underlying (quantum) physics. The point is that starting from the philosophical perspective will also help to understand the meaning of heuristic methods in the sciences. Following Hans Heinz Holz[82], we can visualize Bloch's approach as one that puts forward the essential idea of a human mode of being (and thus of *worldly* being in the sense of modality altogether) which is still unsufficiently determined, because " […] it is *in actu* not yet what falls to its share *in potentia*, such that it is not yet identical with the concept of itself, that the decisive dimension of being is future, the decisive category possibility, the driving factor the striving towards what is beyond itself – and what to this Not-yet in consciousness corresponds is [nothing but] hope."[83] Hence, it is in hoping, i.e. within the various modi of anticipation, that the not-yet-actual is being brought into sight, more or less adequately: "The contents of hoping is more or less ideologically veiled or deforms the contents of a future world[.] Utopia is the still imperfect anticipation of future, its deciphering gives us the schedule of a history that is to be recognized and steered by human beings."[84] And Holz continues: "The objective of history must then be the exteriorization (Herausbildung) of the generic essence of humanity […]."[85] Indeed, it is assumed that human beings have at least some rudimentary knowledge about this objective. Hence, the fundamental question as to how imaginations of *non-being* could be visualized as a mapping of *not-yet-being* by utilizing the objective moments of actuality can be answered in a twofold manner: On the one hand, by extracting all the anticipating aspects that are implicit in the results of the arts and sciences, on the other hand, by utilizing (exact) phantasy. Nevertheless, what is hoped for, " […] does not arrive by itself. Instead, it must be pushed through against the resistances of the world."[86] Visualized this way, the world itself is still incomplete and its own substratum of possibility. Hence, this process of permanent becoming is nothing but one of self-actualization.[87] In so far, hoping is active grasping of the world rather than mere dreaming. It is " […] actualization of human solidarity within the social organization of life style; as construction of the perfect living

[81] The following is a text that I have delivered at a talk given during the 2nd meeting of the International Schelling Group, Freiburg/Br., April 2013.

[82] Hans Heinz Holz: Logos spermatikos. Ernst Blochs Philosophie der unfertigen Welt. Luchterhand, Darmstadt und Neuwied, 1975. (Quotations from German here and elsewhere are in my own translation.)

[83] Ibid., 21.

[84] Ibid.

[85] Ibid., 67.

[86] Ibid., 88.

[87] Ibid., 91. (par.)

space, at the same time symbol of succeeded being within architecture, as a free unfolding of human possibilities within work and game."[88] It is interesting to note here that this comparatively recent approach re-conceptualizes nothing less than what Don Garrett once called " […] Spinoza's monistic and naturalistic system that speaks most cogently and persuasively to the twentieth century".[89] As I have discussed in more detail at another occasion[90], this system is essentially based on three central aspects which are still important for ongoing research: (1) on the visualizing of a transcendental materialism with physics at the bottom, (2) on a radical approach to interdisciplinarity, and (3) on the aiming at explicit mediations leading up to ethics and politics. We will see later that this points to a similar project that is in the centre of Schelling's philosophy.[91] In fact, it is the implication of this very "line of thought" – i.e. from Spinoza via Schelling to Bloch – that is the central topic of this present paper. And this topic is immediately reflected in the latter's organization: Hence, we will start (in section 2) with a short and compact review of what we call Bloch's theory of matter rather than its materialistic metaphysics, in order to clarify a number of aspects which have remained ill-understood and thus controversial until today.[92] For illustrating the general idea, we will then continue (in section 3) with an example from recent physics. It should be noted in particular, that the presently ongoing convergence of (the fundamentally underlying conceptions of) physics, biology, and computer science within the field of the sciences actually implies a parallel convergence of philosophy and physics such that a fruitful interaction of these fields becomes possible as to the conceptualization of their respective foundations. Finally (in section 4), we will draw conclusions about the present state of the art in discussing the relationship between *the world as it is* (reality) and *the world as we observe it* (modality), respectively, and try to correlate this with more practical questions of philosophy.

The explicit relationship between the world as it really is and the world as it is actually observed (and modeled) by human beings is the fundamental problem of classical metaphysics. The advent of materialistic approaches to philosophy in the 19th century has suffered somewhat (probably chiefly based on a mis-interpretation of earlier approaches by Cusanus and Bruno[93]) from a mixing up of the one with the other as to its basic concept of (active, structure-forming) matter. Even when assuming that this type of universal matter is not the same as the physical matter we can perceive, it carries at least the decisive connotation of being a *primordial entity* (Urstoff) out of which all other types of matter

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[88] Ibid., 102.

[89] Don Garrett: [Introduction to] The Cambridge Companion to Spinoza. Ed. Garrett. Cambridge University Press, 1996, 2.

[90] Rainer E. Zimmermann: New Ethics Proved in Geometrical Order. Spinozist Reflexions on Evolutionary Systems. Emergent Publications, Litchfield Park (Az.), 2010, 12.

[91] Cf. Rainer E. Zimmermann: Nothingness as Ground and Nothing but Ground. Northwestern University Press, Evanston (Ill.), in press (2013).

[92] These aspects have been summarized in more detail in Rainer E. Zimmermann: Räume sind Schäume. Über Substanz und Materie im richtigen Verhältnis. In: Doris Zeilinger (ed.), Fragen der Substanz heute, VorSchein 31 (Jahrbuch der Ernst-Bloch-Assoziation), Antogo, Nürnberg, 2011, 105-121.

[93] Cf. Rainer E. Zimmermann: [Catchword] Subject of Nature (Natursubjekt). In: Beat Dietschy, Doris Zeilinger, Rainer E. Zimmermann (eds.), Bloch-Wörterbuch, Leitbegriffe der Philosophie Ernst Blochs, de Gruyter, Berlin, Boston, 2012, 374-403. See in particular: 380.

including the observable types may eventually flow in the run of the permanent self-differentiation of nature. The latter is a consequence then of the evolutionary picture derived for nature in order to develop a parallel conception that (at least metaphorically) compares human history with the history of nature. Hence, matter (in a generalized, philosophical sense, not in the strict physical sense) shows up as the classical *hypokeimenon* (subject of the world that underlies all what can be observed). It is in fact, the somewhat unclear identification of substance and subject as introduced by Hegel that catalyzes the type of mixing up that is characteristic for the materialistic approach of the late 19th (and in fact, the early 20th) century(ies). In the end, there is no conceptual difference then, between substance on the one hand and matter on the other. Indeed, matter shows up as being already substance from the beginning on. When Bloch tries to establish this line of thought in historical terms, he visualizes substance as *open* substance such that it is " […] a real problem in its own terms" which can be logically formulated as "S is not yet P […], the essential is not yet predicated actuality."[94] The somewhat unprecise utilization of "actuality" (Wirklichkeit) here uncovers the underlying conceptual insecurity.[95] Now, obviously, it is practically impossible to grasp the concept of nature without grasping the concepts of substance and matter including their *specific difference* at the same time. When Blochs sets out to tackle the quality of this difference, he explicitly refers to a line of thought that he himself characterizes as "Aristotelian Left", and which is based upon the Arab reception of Aristotle's philosophy in medieval times. He thus visualizes matter – very much in the tradition of this Arab reception, especially in the sense of Averroes, but also found in Bruno and finally in Spinoza – in terms of the crucial concepts of *natura naturans* and *natura naturata*, respectively (the former describing a nature that actively creates all its forms out of its own potentiality, the latter describing a nature that is passively product of the former, but also able to create new forms in the run of evolution).

Although it is quite legitimate to start from Aristotle (because he is the inventor of scientific prose, different from Plato e.g.), the explosion of secondary literature (even of literature that discusses Aristotle in terms of analytic philosophy) has produced many misunderstandings and erroneous conceptions as to the meaning of the underlying fundamental categories. In particular, the definitions of "substance" and "subject" have created one or the other difficulty.[96] But if trying to reconstruct the original (though admittingly sufficiently complex)

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[94] See in detail Rainer E. Zimmermann: [Catchword] Substance, substantiality (Substanz, Substanzialität). In: Beat Dietschy, Doris Zeilinger, Rainer E. Zimmermann (eds.), op. cit., 541-555. Here: 546. (referring to Bloch's SO 363, 517)

[95] In principle, according to Spinoza's terminology which essentially derives from Aristotle, it is *actuality* (precisely: "Aktualität", in German often expressed as „Wirklichkeit") that signifies the world as it is being observed (by human beings according to their cognitive capacity which is itself a product of nature), while *reality* signifies the world as it really is. If we speak of a theory of predication, we clearly deal with empirical situations, hence with the world as it is being observed (and thus modeled in linguistic terms). In the case quoted here, Bloch can only mean *actuality*. But then, he is not dealing with a "Realproblem", i.e. problem of reality. And there is not something like a process-substance, because process (as defined in space and time) falls under the attributes of the actual, while the real is *beyond* these (epistemic and thus linguistic) categories. There is *either* substance *or* process.

[96] A review of the relevant secondary literature is given in the above-mentioned catchword article in the „Bloch-Wörterbuch", see Rainer E. Zimmermann: [Catchword] Subject of Nature (Natursubjekt). In: Beat Dietschy, Doris Zeilinger, Rainer E. Zimmermann (eds.), op. cit., 375-383.

intention of Aristotle's as to his concept of substance, we can essentially summarize the various aspects such that *ousía* (substance) carries the main connotation of "essence" (essentiality) while *hypokeímenon* (subject) carries the main connotations of "what-is-underlying" (as a foundation) and of "substratum" (material cause that is underlying the formal cause). And quite obvious then the formulation: "If there are causes and initial grounds of what there is according to nature of which as the first ones it actually is and has become, […] then everything emerges out of what is underlying and out of the shaping/designing of form (ek te tou hypokeímenou kaì tès morphés)."[97] In other words: Substratum and form are the principles of design for what there is according to nature. Hence, the subject is underlying the world as it is observed, and in so far it is material cause (or primordial matter), it belongs itself to this world. "Nature" is thus utilized as an equivalent expression for the world as it can be observed (modality). This is compatible with what Aristotle tells us in his "Metaphysics": "What becomes does so partly by means of nature or by means of art, partly spontaneously. […] But all what becomes, either by nature or by art, possesses material [= stuff] (hýle), because all of what becomes possesses either the possibility to be or [the possibility] not to be, and this is in all what becomes the material [stuff]."[98] Hence, the concept of matter (even as abstract primordial matter) is traditionally associated with the world as it is observed (modality). It is not before the advent of the Greek Stóa that the *concept of freedom* is discussed as consequence of the achievement of adequate knowledge about the world. The idea is to eventually reach a practical life that is *according to nature* (o katà phýsin bíos). This leads generically to the necessity of understanding the laws of nature (anánke phýseos). The concept of freedom then is settled immediately within nature itself: It is indeed the Arab reception of Aristotle (which often mixes Aristotelian concepts with Stoic and Neo-platonic aspects), that by concentrating on the processuality of the explicit transition from *hexis* (as the field of possibilities) to *praxis*, introduces for the first time the differentiation between the active nature that lets forms of matter actually emerge (natura naturans) and the passive nature that is a product of this activity (natura naturata), although it can also be capable of generating forms itself. This twofold character of nature mirrors the twofold logic of possibility and actuality on the one hand, and of emergence and evolution on the other. From then on however (as can be seen e.g. in Bruno), active matter is much more in the foreground of debate than substance. A famous quotation of Bruno's illustrates the confounding utilization of the concepts of substance, nature, principle, and matter.[99] In Spinoza then, the two types of nature are taken up again, and especially the part of *natura naturans* is made clear in E1p29s.[100] This however establishes clarity for the last

[97] Aristotle: Physics, 190b19 sq., according to the Zekl edition, Meiner, Hamburg, 1987, pp. 38, 39.
[98] Aristotle: Metaphysics, 1032a12 sqq., 20-24, according to the Seidl edition, Meiner, Hamburg, 1991, pp. 26, 27 sq.
[99] Giordano Bruno: De la causa, principio ed uno. In: id., Dialoghi Italiani, vol. 1, Sansoni ed., Firenze, [2]1985, 273 sq.: „Peró la materia la qual sempre rimane medesima e feconda, deve aver la principal prorogativa d'esser conosciuta sol principio substanziale, e quello che è, e che sempre rimane: […] la materia; che appresso quelli è un principio necessario, / eterno e divino, come a quel moro Avicebron, che la chiama *Dio che è in tutte le cose*."
[100] Baruch de Spinoza: Ethica ordine geometrico demonstrata …, ed. Bartuschat, Meiner, Hamburg, 1999, 62, 63 sq.: „ … quod per Naturam naturantem nobis intelligendum est id, quod in se est et per se concipitur, *sive talia substantiae attributa*, quae aeter/nam et infinitam essentiam exprimunt, …" (my italics) In fact, the whole scholium is far from clear altogether, due to a very cryptic formulation of

time: Until the advent of classical (mechanical) materialism, even the finest differentiation has been lost in the meantime such that in the Marxist reception of materialism, matter, in fact, shows up as being already substance. In other words: By (unnecessarily) combating metaphysics, the difference between reality and modality is practically lost.

In the case of Bloch, it is very unlikely that he would have neglected this characteristic difference between reality and modality. This is especially, because he bases a large part of his argument on a line of thought he himself baptizes "Aristotelian Left". (And it is quite certain that he would have read Aristotle in some detail!) Unfortunately, Bloch's terminology is not always consistent and clear with respect to concepts like "substance" and "subject", respectively. Probably, the Hegelian influence unfolds its actions here[101]. The inconsistencies in Bloch as to that point have been discussed elsewhere[102], and we will not dwell on this here in further detail. But the central argument should be straightforward: Bloch's theory of matter is essentially a theory of the substratum (subject), not of substance. The two types of nature refer to fundamental aspects of modality, not to reality. A multitude of apparent contradictions in Bloch can be removed, once this view is accepted. Then matter (both in philosophical and physical terms, respectively) can be visualized as primordial ground of modality and as primary material, at the same time. In a sense, interpreted as a true *hypokeímenon* (that underlies what there is), primordial matter can be visualized as the boundary of modality and thus as a bridge to reality. So after all, Bloch's theory of material nature (theory of matter) can be mainly positioned within the body of *sceptical* philosophy, and in his works are at best weak traces of speculative philosophy. In other words, the anticipation of the utopian project (in Bloch's terminology "concrete utopia") aims at something which is empirically observable in the end. *The "experimentum mundi" shows up then as a transformation project of modality.* It can thus unfold concrete, practical actions in the future and does in fact point to a region of what can become an actualized non-being in the long run rather than pointing to a region of mere nothingness as the name (utopia) would imply.[103] The consequences of this viewpoint become especially important with a view to recent developments in the sciences.

Unfortunately, very often the attitude of philosophers towards the sciences is rather abstract, to say the least. (As far as physicists are being concerned, the viceversa is true as to their attitude towards philosophy.) Hence, the communication between the fields of fundamental research in the sciences and modern metaphysics in philosophy is usually not very successful. However, contrary to what is the common point of view, it is important to notice the parallel and convergent aspects of both fields in order to gain a certain amount of heuristic insight that can be eventually explicated in more technical detail later.[104] With

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Spinoza's. But the important point is quite clear: Natura naturans is an attribute of substance, not substance itself. Hence, it belongs logically to the realm of modality, not to reality.

[101] However, we will not discuss here Hegel's attitude of actually identifying substance and subject.

[102] Cf. Rainer E. Zimmermann: [Catchword] Subject of Nature (Natursubjekt). In: Beat Dietschy, Doris Zeilinger, Rainer E. Zimmermann (eds.), op. cit., 383 sqq.

[103] Some time ago, this has been the reason for me to actually replace the name of „concrete utopia" by „metopia" which is more to the point of what is actually achieved.

[104] From the outset, it should be always clear that neither Spinoza, nor Schelling, nor Bloch in person have actually created any insight in physics. But the structural aspects of their systematic approach and their attitude have done so. Most prominent examples are the influences of Schelling on Oersted,

respect to questions of the difference between what there is and what there is observed, and with a view to other questions of founding and grounding the world, it is especially qantum physics that serves as an appropriate heuristic starting point.
The central aspect of quantum physics is the phenomenon of "quantum correlations" that create completely new properties of a composite physical system that are absent for the individual subsystems of the composition.[105] Hence, if two systems A and B are characterized by their respective state functions ψ_A and ψ_B, then their composition is expressed by their joint state function ψ_{AB}. In that case one speaks of "entanglement" whose main feature is that nature becomes fundamentally non-local, because the outcome of a local measurement (on system B say) is determined by quantum correlations that are encoded only in the global entangled quantum state of the composite system.[106] If we utilize the common Dirac notation of state vectors, then $|\Psi>$ gives the complete description of the physical state of an individual system (usually referred to as a *pure* state). The superposition principle tells us then that linear combinations of vectors give again a new quantum state such that $|\Psi> = \sum c_j |\psi_j>$, where the sum goes over all the j = 1 … n, and the c are complex numbers. In other words: All the various $|\psi_j>$ are simultaneously present in this global quantum state. This is what we call *quantum coherence*. The evolution of $|\Psi>$ is governed by Schrödinger's equation, of the form

$$i\, d/dt\, |\Psi(t)> = H\, |\Psi> .$$

Note the explicit time-dependence here. (The *i* is the imaginary unit.) We call H the Hamilton operator (which is essentially codifying the total energy of the system). Furthermore, when projecting onto a pure state, we can define the *density operator* $\rho := |\psi><\psi|$ whose matrix representation gives

$$\rho = \sum c_j\, c^*_k\, |\psi_j><\psi_k|,$$

such that all the terms with $j \neq k$ are *interference* terms. (In the matrix they are off-diagonal terms.) Obviously, the sum goes now over both j and k, respectively.
The "impurity" of a state can actually be quantified, namely by means of what is called *von Neumann entropy*, defined by $S(\rho) = - \mathrm{Tr}\,(\rho \log_2 \rho)$, i.e. by simply taking the trace over the logarithmic expression. Then in a pure state, S = 0. If the state is maximally mixed, we have alternatively, $S = \log_2 N$ (where N is the number of systems). Consequently, the expectation value of an observable O is given by $<O> = \mathrm{Tr}\,(\rho\, O) = \sum <\varphi_j|\, \rho\, O|\varphi_j>$, the sum again over the j. Note that the observer will normally have access to one system only, to A say. Then the information extracted of system A can be described by what is called *reduced density matrix* such that $\rho_A = \mathrm{Tr}_B\, \rho$. Tracing over B means essentially that we average over the degrees of freedom of the unobserved system B.

Faraday, and Maxwell as to the concept of force fields. Or the influence of Spinoza on Einstein's relativity theory.
[105] Essentially, we follow here the structure of the argument as given in Maximilian Schlosshauer: Decoherence (and the quantum-to-classical transition), Springer, Berlin, Heidelberg, 2007.
[106] Cf. Schlosshauer, op.cit., 32 (par.).

For illustrating the basic idea, take for example an environment of photons (system B) scattering off an object (system A). Obviously, for an observer it will be impossible to intercept all of these scattered photons. Hence, what he will actually observe are the observables pertaining to the system A plus a small number of environmental photons. But by tracing over the degrees of freedom of the environment of the (combined) system-environment density matrix, the observer can obtain a complete description of the measurement statistics. That is, the influences of the environment on local measurements performed on A will automatically be encapsulated in the reduced density matrix. Utilizing the above relationships, we get for this matrix in detail:

$$\rho_A = 1/N \sum_{j,k=1 \dots N} |a_j\rangle\langle a_k|\langle b_k|b_j\rangle,$$

when the a and b are normalized states of A and B, respectively. The entangled state of A and B is then expressed as

$$|\Psi\rangle = 1/\sqrt{2}\ (|a_1\rangle\ |b_1\rangle + |a_2\rangle\ |b_2\rangle,$$

provided the states are bipartite. In fact, it is the amount of overlap of the relative states of B that are correlated with the states of A that quantifies the degree of interference that can be measured on A.

The consequences of this are quite striking: So light scattering off an object carries away information about the position of the object, and it is in this sense that we thus may view these incident photons as a kind of "measuring device". Indeed, these measurement-like interactions lie at the root of the transition from quantum to classical physics. And they are actually independent of the presence of a human observer! The mechanism according to which human observers usually make classical (macroscopic) observations rather then quantum observations, can be easily understood now as a process of removing coherence (which is called *de-coherence*). By carrying away information, scattered particles carry away coherence from a given object.[107] At the same time, " […] since the interaction between the system and the environment constantly encodes information about the system in the environment, [the latter] constitutes a huge resource for the indirect acquisition of information about the system."[108] We can even say more: It is the environment that superselects states of the system that are classically observable. These are the states that are least perturbed by the ongoing interaction on the one hand, while their probing leaves the environment largely unperturbed on the other.[109] This is called *environment-induced superselection* (einselection). At the same time, this mechanism secures the validity of physical gauges: "Since the same information about the pointer observable is stored independently in many fragments of the environment, multiple observers can measure this observable on

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[107] For a system which is described by a coherent superposition of two quantum states representing localization around two different positions, the details are shown quite illustratively in Schlosshauer, op.cit., 67-69.

[108] Ibid., 85.

[109] Note that the system perturbs the environment rather than viceversa – contrary to the picture we generally have of what we call *noise*.

different fragments and will automatically agree on the findings."[110] As it turns out, this mechanism is being performed on a very short time scale so that practically, there are no difficulties with possible ambiguities of classical observations.[111]

What we have done here is to discuss an example taken from quantum physics, and, by definition, this is not subject to the rules of philosophical argumentation. Note however the consequences for an interpretation of the results in terms of everyday language: The results imply that the classical observer can differ between objects, given at different times and at different locations such that they are cognitively perceived as *isolated* objects of an *individual* kind. Hence, typically, the observer can clearly differ between two different objects X and Y, and it is unlikely that the one can be mixed up with the other. But we note that a classical observation is the result of decoherence which has to do with the length (and time) scale on that classical observations happen. In other words: Because human observers are objects of the classical type (due to their typical orders of magnitude), their characteristic *modality* gives them access to classical objects. But classical phenomena (such as determining a precise location, or a precise time, or a precise individual object as to that) *are not generic* features of the world *as it is*. They are such features only, if the observers are classical themselves. Hence, classicality is a feature of the world *as it is observed*. Different from this, the "true" property of the world *as it is*, is *coherence* instead. And this simply means that objects are *not* well-isolated, well-located, well-timed. Essentially, the world is a coherent "soup" of quantum states that cannot become easily dis-entangled. Hence, categories of time, space and (material) object are meaningless in the real world (within reality). Depending on the relevant orders of magnitude, the classical world (of physics) is thus *emergent* with respect to the underlying (real) quantum world.

In order to understand the relevance of the above-mentioned in terms of a philosophical rather than physical context, we refer back to the idealistic aprroaches of the 19th century which are struggling with the concepts of "subject" and "object", respectively, trying to eventually overcome the strict separation between the two, equally important for a re-conceptualization of ontology as well as of logic. The idea is to find an adequate concept for an identity of both such that the observable world could be understood as a progressive differentiation of forms out of a unified (pre-worldly) entity. One of the main protagonists in this field has been Schelling who in his earlier works introduces the notion of a "co-existence of indifference and identity" such that in structural terms, the *neither-nor* is unified with the *as-well-as*. He formulates in his "Further Presentations from the System of Philosophy"[112]: "The fact that this unity […] shows up or expresses itself in terms of certain relations rather than in terms of an in-itself, as a unity of thinking and being, does not imply that it would be a unity that is composed of thinking and being, very much like the fact that light is coloured under certain conditions does not imply that the colours would have been within itself beforehand […]. " What we can immediately recognize from this is that *indifference* would be

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[110] Schlosshauer, op. cit., 87.

[111] Ibid., 135 sqq.: For a dust grain e.g., decoherence takes place within the order of 10^{-31} seconds, for a large molecule within the order of 10^{-11} seconds, respectively.

[112] F. W. J. Schelling: Fernere Darstellungen aus dem System der Philosophie. (= SW 4, 378) Quoted here according to Bernhard Rang: Identität und Indifferenz. Klostermann, Frankfurt a.M., 2000, 62. (See also this latter book for a detailed exposition and discussion of the conceptual problems involved.)

an appropriate analogy here to *coherence*. Note that this does not entail a formal identification of these concepts: Instead, what in physical terms is discussed under the heading of coherence can be visualized in philosophical terms *as* indifference according to the Schellingian approach. Hence, philosophers working on the conceptualization of some absolute unity have not at all anticipated quantum physics, nor have quantum physicists dealt explicitly with the concepts of 19th century philosophy. But what all of these protagonists have actually done is *to structurally anticipate a convergent conceptualization* of the difference between the world as it is and the world as it is observed, each of them in their relevant fields of research. And this is what we can call *heuristic*. If we visualize as one task of philosophy to provide a *theory of totality* ("Wissenschaft vom Gesamtzusammenhang" in the sense of Hans Heinz Holz), then indeed, this is exactly what the mentioned kind of conceptual convergence can eventually achieve.

The immediate advantage of referring to the philosophy of Bloch rather than to the philosophies of the 19th century is that the relevant concepts are (more or less) free from a traditional terminology that entails religious or other ideologies. On the other hand, the conceptual consistence is (more or less) secured, because Bloch works on the same line of thought.[113] But the merit of the Marxist reception is especially that aspects of "mind" can be visualized as being imprinted into the structure of matter. Hence, human cognition, communication, and co-operation show up as concrete consequences of processes that are related to various forms of matter. And this kind of matter is to physical matter what the "primordial stuff" of Aristotle's is to the unfolded variety of (observable) objects. In principle, one could visualize a modernized metaphysics as one that is making the difference between substance and attributes topical such that we are left with one attribute only which is matter.[114] For the metaphysical interpretation of any foundation that is dealing with the difference between the world as it is and the world as it is observed within the framework of an ontology of immanence (in the tradition of Spinoza's) there are manifold starting points as to a conceptualization of the practical field, especially with a view to ethics. This is mainly, because the picture that is derived from the process of founding the world unfolds a variety of important influences on the positioning of human beings amidst this world. Because human beings are the agents who actually do the modeling, this positioning is essentially nothing but a self-positioning. If we visualize human beings as part of a total organism of nature (whose ontological state is defined in terms of its epistemological activity), then we can come back to Schelling's attitude of visualizing human beings as "knowledge-acquiring organs" of nature. Hence, while human beings model their world, nature is essentially

[113] Not that Bloch's approach would be entirely free from any ideological influences. Probably no philosophy ever is. But the concept of matter put forward in the more systematic works, especially in his "Experimentum Mundi" of 1975, is sufficiently sober so as to open up perspectives that are not burdened with a context which is overcome by now.

[114] In the meantime, it has become apparent that we are essentially back to two attributes, because we would now systematically differ between one attribute that is *energy* (and energy that possesses mass is called *matter*) and another one that is *information* (and information that is actualized is called *structure*). Cf. Rainer E. Zimmermann, José M. Díaz Nafría: Emergence and Evolution of Meaning: The General Definition of Information Revisiting Program – Part I: The Progressive Perspective. Top Down. Information 2012, 3 (3), 472-503. See also an extended version in: tripleC 11 (1), 13-35, 2013.

modelling itself. Obviously, the ethics flows out of the fact that human beings are related to nature then as part to the whole.

In this present paper, we would rather take the other side instead: We ask for the consequences of the above examples for the heuristic value, philosophy can have for explicitly ongoing research in physics. As far as the fundamental questions of physics are being concerned, what we said above on the topic of decoherence relates to the basic problem of quantum gravity.[115] As recent work on decoherence in quantum gravity clearly shows[116], this topic turns out to be crucial with respect to deciding about the conceptual state of what is classical or quantum in physics, and of what is macroscopic or microscopic, respectively. Note that our above discussion on decoherence clearly displays the fact that in principle, there is only quantum physics, whilst all classical phenomena are emergent with respect to the process of decoherence. In fact, this entails quantum phenomena which can be observed in the domain that is usually referred to as being "macroscopic". If on the other hand, we agree upon the fact that objects need a certain "size" (order of magnitude of their characteristic length scale) in order to undergo decoherence, then the question arises from where the first objects of criticial size emerged in the first place. (This is a question similar to the problem of *initial emergence* as it is often discussed in Schelling or Bloch.[117]) As Anastopoulos and Hu have shown in more detail, this problem raises other questions as to the relationship between decoherence and statistics (in the sense of the coarse graining model) on the one hand, and between decoherence and symmetries, on the other. And even more important (especially for the cosmological implications of these ideas) the question: What is the system in question? What is the relevant environment?[118]

Hence, if we visualize (the physical picture of) reality in terms of a primordial "coherence soup", then the division between system A (object) and system B (environment) must be available from the beginning, because otherwise there would be no reason for the onset of decoherence. Even worse: If we take the whole universe as a system A, then the necessity of a system B would imply that there is a natural environment of this universe in the first place. But then, this particular object (the universe as system A) would have emerged within its environment before, so it must be the result of some pre-geometrical decoherence. (And so on.) Different from what one would expect, these questions (raised within the field of theoretical physics!) are not at all far from ongoing practical research. Smolin's model of

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[115] See earlier work on problems of foundation, mainly discussing aspects of loop quantum gravity, in Rainer E. Zimmermann: Beyond the Physics of Logic: Aspects of Transcendental Materialism or URAM in a Modern View. www.arxiv.org/pdf/physics/0105094 , also id: Recent Conceptual Consequences of Loop Quantum Gravity. Three Parts. www.arxiv.org/pdf/physics/0107061 , www.arxiv.org/pdf/physics/0107081 , www.arxiv.org/pdf/physics/0108026 . For a special application see also id.: Cosmological Natural Selection Revisited. Some Remarks on the Conceptual Conundrum and Possible Alleys. www.arxiv.org/pdf/physics/0304053 . (included here as an appendix)

[116] Cf. C. Anastopoulos, B. L. Hu: Decoherence in Quantum Gravity: Issues and Critiques. www.arxiv.org/pdf/gr-qc/0703137 .

[117] See appropriate reviews for Schelling and Bloch, respectively, in Rainer E. Zimmermann: Aesthetics as a Semiology of Nature. On the Unity of Schelling's Substance Metaphysics. System & Struktur IV 2, 1996, 151-173. And id.: The Utopian Function of Art and Literature in the Philosophy of Ernst Bloch. A Topic Revisited. Bloch-Almanach 15, Ludwigshafen, 1996, 33-73.

[118] Anastopoulos, Hu, op. cit., 8. (par.)

cosmological selection is very much on the line of this type of conceptualization, as is more recently the new approach put forward by Roger Penrose.[119] As it turns out in the end, the problem of (initial) emergence is indeed the most puzzling conundrum at the time whose resolution could give plenty of new insight into a large class of problems in physics, chemistry, biology, and even computer science.[120] This is more than a heuristic approach can actually expect.

[119] Lee Smolin: The Life of the Cosmos. Oxford University Press, 1997. – Roger Penrose: Cycles of Time. The Bodley Head, London, 2010.

[120] Ontological questions have been prominent within the field of quantum physics from the beginning on. See e.g. Abner Shimony: Search for a Naturalistic World View. 2 vols., Cambridge University Press, 1993. For an alternative view also David Bohm, Basil J. Hiley: The Undivided Universe. Routledge, London, New York, 1993.