BERGSON'S DURATION AND QUANTAL SPACETIME NON-SEPARABILITY

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This essay consists of four parts: (1) Duration and Newtonian mechanics, (2) Probability, entropy and information, (3) The advent of the relativity theory and the "spatialization of time", and (4) Quantal non-separability, Lorentz and CPT invariance.

DURATION AND NEWTONIAN MECHANICS

At many points of his writings Bergson critizes the concept of time as used in the physics of his day, largely the one inherent in Newtonian mechanics, or "rational mechanics", as it was often called.

Let us recall that as a student Bergson had been exceptionally gifted in mathematics. In 1877, at the age of 18, he brilliantly solved a geometrical problem Pascal had enunciated, but not solved; this solution is published in a book devoted to Pascal by Desboves,[1] his mathematics teacher. Again in 1877 Bergson won the first mathematics prize at the "Concours General", a yearly contest in the national education system; this solution has also been published.[2] So when Bergson decided, at the end of this same year, to prepare his entrance at the "Ecole Normale Supérieure" in the humanities section, Desboves was extremely disappointed and said to him "You could have become a great mathematician, and you will only be a philosopher."[3]

After graduating as a philosopher from the Ecole Normale, Bergson found a teaching position at the University of Clermont-Ferrand, in 1883. There he devoted much thought to the use of "the calculus" (the differential and integral calculus) in Newtonian mechanics, rightly considering that this newer mathematics contained something entirely beyond the classical paradigms of geometry and arithemtic inherited from the Greeks. Of course, quite a bit of differential, integral, and even variational calculus had been performed before the days of Newton, Leibniz and Lagrange, by mathematicians cleverly bypassing as yet undefined general algorithms. But, of course, the advent of "the calculus" has been a major change of "paradigm". Bergson often discussed these matters with his mathematical colleagues at the University of Clermont-Ferrand.

What emerged from this thinking and these conversations can be found throughout Bergson's works, for example in his discussions of Zeno's paradoxes. Here I will content myself with what is found in his famous book *Creative Evolution*,[4] which I will quote, translating (and adapting) directly from the French.

In Chapter I, entitled "Evolution and Life, Mechanism and Finalism" one reads:

> "When we say that the state of an artificial system [a non-living system] depends upon what it was at the moment immediately before ... we mean ... at the [moment] related to the present one by the interval dt ... We mean that the present state ... is defined by equations containing ... *present* velocities and accelerations. Therefore the present only is considered, a present taken, it is true, together with its *tendency*. Therefore the systems upon which science operates are inside an instantaneous present constantly renewing itself, and never inside the real, concrete, duration where the past is adhering to the present. When the mathematician computes the future state of a system at some future time t, he could just as well assume that, in between, the material world vanishes, only to reappear all at once. ... Even if the mathematician says he 'places himself' inside that time interval, it is always to a certain ... moment, the extremity ... of a time interval, that he transports himself. ... Always it is a 'given moment', I mean a 'stopped moment' that is at stake, and never time as flowing. On the whole, *the world upon which the mathematician operates is a world that dies and is reborn at each instant, the very same one considered by Descartes speaking of a continued creation.*" (p. 512)

Well, for one thing, the idea of a world that "dies and is reborn at each instant" — at each instant t of Newton's universal time — is undoubtedly the one almost everybody naturally has in mind. Almost everybody would be ready to declare that "only the present exists, that the past exists no more, and the future not yet". Even many professional workers in the field of Newtonian mechanics practically had, or still have in mind, something of this sort.

It is only natural, then, to ask what was Newton's position on the subject. Well, it seems that Newton, although he was the first to precisely define the concepts of a universal time, and a universal time instant t, was in fact nurturing the idea that time does have some sort of extendedness, or duration, for this is what he writes: "Absolute, true, and mathematical time, of itself, and of its own nature, flows equably without relation to anything external, and by an other name is called duration".[5] *Duration* writes Newton; as far as I know, Bergson nowhere comments upon such an ominous coincidence!

Thus it seems that Newton's view of time is likened to that of a flowing river, extending from source to ocean, the passage of which we are witnessing as if from a bridge. In relativity theory also time will have thickness, or extendedness, but there we, spectators and actors, are rather thought of as swimming up the river.

Anyhow let us not try to make Newton say more than he actually said. Let us rather interrogate the very formalism of the calculus, and this (why not?) inside the very realm of Newtonian mechanics.

A well known theorem states that the knowledge of a continuous function and of all its derivatives for a given value of the arguments equals the complete knowledge of the function. Inside this sort of paradigm, knowing one (instantaneous) state of a system together with its complete (instantaneous) "tendency" is knowing the whole evolution of the system.[6] It seems, therefore, that in the passage quoted Bergson is unduly quarelling with "the mathematician" who, by virtue of his own system of concepts, is perfectly willing to view time as actually extended.

And this is far from a mere '*flatus vocis*', because there exists, inside the formalism of Newtonian mechanics itself, a powerful algorithm due to Euler, Manpertuis and Hamilton, termed the 'extremum action principle', by which the present equations of motion of a mechanical system are derived from an integral extended over time. Truly, this is time taken as a whole, together with all of its instants, in its thickness, by the mathematician working as a professional.

But then Bergson certainly would have objected that the remedy is worse than the illness, because such an algorithm makes no distinction between past and future. This is "strict causality and strict finality", as discussed by Bergson in this same Chapter of *Creative Evolution*, and rightly considered by him to be mutually equivalent, since according to each of them, "everything is given all at once".

Bergson was willing to confer some extendedness to time in the past, but not in the future, feeling that, then, "becoming" would be excluded.

Let it be said, right now, that today's relativistic and quantum physics does view time as actually extended, and as symmetrically extended towards both the past and the future; and that, nevertheless, *there is becoming*!

These are deep and intricate questions to be discussed in the following sections.

PROBABILITY, ENTROPY AND INFORMATION

So now we turn away from 'rational mechanics', and the determinism implied in its paradigm, towards the calculus of probabilities, implicitely considered by Bergson in Chapter III of *Creative Evolution*. We read there, under the subtitle "Sketch of a theory of knowledge based on an analysis of the concept of disorder" that, when thinking of the absence of order, "the realist speaks of the regulation enforced by 'objective' laws" and, a little later, that "reality is ordered to the exact extent to which we understand it" — two seemingly opposite statements, both often encountered in discussions pertaining to the calculus of probabilities, to which we will return.

Considering Carnot's irreversibility principle and Clausius's entropy concept, Bergson writes that the second law of thermodynamics is "the most metaphysical of the physical laws" and, a little later, that "All our analyses show that life strives to go up the slope matter is going down on. They therefore suggest the possibility, and even the necessity, of a process symmetrical to that of matter, and which created matter just by breaking off. Of course, life evolving on this planet is fastened to matter. If it were pure consciousness . . . it would be pure creative activity. In fact it is bound to an organism and thus is submitted to [the Second Law]. But, as it seems, it does its best to free herself from it." Well, we can say that this is the spiritualistic view of a process much discussed by the school of Prigogine, where it is viewed from the opposite side: the production of order as occurring within and based on the Niagara falls of the universal entropy increase.

Let me stop quoting here, and discuss the calculus of probabilities and information theory per se.

Is the probability concept objective or subjective? This has been much discussed. My contention here is that it is neither objective nor subjective, because *it is indissolubly both, being the hinge around which mind and matter interact*.

First let me make clear that there is no such thing as an 'objective probability', but at most an 'intersubjective probability' depending on rules one has agreed upon. Among various examples produced in this regard by the mathematician Joseph Bertrand[7] I choose this one: What is the probability that the length of a chord in a circle is greater than the length of the side of an inscribed equilateral triangle? Bertrand considers three natural procedures for drawing 'at random' a chord in a circle.

1° One extremity being fixed, the direction of the chord is chosen at random. The probability then is $60°/180° = 1/3$.

2° The direction of the chord being fixed, the position of its middle is chosen at random on the diameter perpendicular to that direction. Then the probability is 1/2.

3° The position of the middle of the chord is picked at random inside the circle. Then the probability is $(1/2)^2 = 1/4$.

Therefore it is clear that there is no such thing as an 'objective probability' that the length of a chord is greater than the side of the inscribed equilateral triangle. *This probability is data dependent*. It depends on the procedure you and I have agreed upon, and this brings in the information concept.

So let us consider the basic question of evaluating a priori probabilities by using the 'principle of insufficient reason'.[8]

There has been endless discussion, first, of the 'bootstrap' character of deciding that two probabilities are a priori equal if there is no sufficient reason to decide otherwise, and, second, the fact that the frequency does objectively conform to the probability. Both questions are connected, and things are straightened out by likening the estimation of the a priori probability to a physical hypothesis to be

proved or disproved. If it is vindicated, we were right in believing that all 'sufficient reasons' had been taken care of. If it is not, we have a good clue for finding what sort of sufficient reason has been overlooked.

And now I come to a very important point: *the intrinsic symmetry between prediction and retrodiction*. This I do by considering a deck of cards.

It is a natural assumption that, when shuffling a deck of cards, the probability p^{ij} that a card goes from the rank i to the rank j. We then say that the '*transition probability*' is symmetric, which is very usually the case in physics, either classical or quantum. Thus, the procedure of card shuffling is *intrinsically reversible*. How is it, then, that *in fact this is not so*? Starting with a deck in order (whatever is the definition of order, as a small sub-ensemble of the ensemble of permutations of the cards) we do rely on shuffling for destroying the order, but not for putting the deck in order if it is not.

So let us look at the matter more closely. It is 'almost certain', in terms of probability theory, that, by shuffling the deck again and again, each permutation of the cards (whether or not it is an 'improbable' one), will show up from time to time. But we can never know when (except of course by looking each time at the deck, which is rejected as unfair); nor can we do this at will, producing, at a prescribed time, a chosen permutation of the cards.

So, again, we are sent back to the information concept but (beware!) to *two possible aspects of the information concept: information as knowledge*, and *information as organizing power*. But before discussing this important issue I must mention one more point.

There is another sense in which the transition probability p^{ij} is self symmetric: it can be used either as the *predictive probability* that an issue j follows from a preparation i, or as the *retrodictive probability* that a preparation i has been the one leading to the issue j. Both of these probabilities are easily visualized as frequencies, by collecting, on the one hand, the issues j having followed the preparation i or, on the other hand, the preparations i having yielded the issue j. This displays the *intrinsic symmetry between prediction and retrodiction*. In contrast, the *factlike physical irreversibility*, as mentioned before, here consists in the fact that probability increasing evolutions do go on by themselves while probability decreasing ones do not. This is named the "paradox of factlike irreversibility versus lawlike, or intrinsic, reversibility". It has been encountered in the realm of statistical mechanics in the Loschmidt (1876) and in the Zermelo (1896) forms, both implicitly mentioned in the preceding example of card shuffling. This I explain by using still an other example.

The disingration probability of a radioactive nucleus obeys an exponential decay law of the form exp $(-at)$. However, the transition probability having intrinsic symmetry, the mathematics per se would allow just as well a build-up law of the form exp $(+at)$. So, when used in 'blind statistical retrodiction'[9] (that is, exactly in the same way as one does in prediction) the mathematics per se then state that an excited nucleus observed at time zero must have built up in the very last instants according to the law in exp $(+at)$. This is equivalent to the Loschmidt paradox of 1876.

As for the Zermelo paradox, imagine that a typical radionuclide is enclosed inside a large perfectly tight box. The probability then is that, most of the time, the atom is disintegrated, but, however, from time to time, as the decay products cannot escape at infinity, the atom will get reexcited. The point is, however, that one *cannot foretell* when this will happen, nor can one *catch it at will* in the excited state.

In other words, there is nothing in the mathematical formalism excluding blind statistical retrodiction. So the decision must be made from outside of mathematics. It is somewhat like a narrow highway which by itself does not exclude traffic one way in favor of the other: the decision must be made from outside, and expressed by the appropriate road signal.

The classical authors were aware of this. They called retrodictive problems 'problems in the probability of causes', thus expressing their belief in causality and their disbelief in finality. They decided that retrodictive problems should not be handled by 'blind statistical retrodiction', but rather by using Bayes's formula of conditional probabilities, that is, using a set of extrinsic probabilities, chosen for describing at best how the system had originated from the environment. The implication was that a physical interaction produces its effects after it has ceased and not before it has begun. It thus amounted to selecting retarded solutions and excluding advanced solutions of the evolution equation, the definition being that arbitrary configurations are allowed as initial, but prohibited as final conditions. And this is acceptance of causality and rejection of

finality. In 1911 Van der Waals[10] explained that Boltzmann's so-called 'deduction' of physical irreversibility did imply this use of Bayes's principle, showing that, strictly speaking, it was no deduction at all, because irreversibility had been assumed at the start.

Loschmidt's 1876 objection had already made Boltzmann recognize the point, and it is interesting to quote his own words:[11]

> "In the universe ... occur here and there relatively small regions ... which ... fluctuate noticeably ... and ... the ... probability in such cases will be equally likely to increase or decrease. For the universe the two directions of time are indistinguishable, just as in space there is no up or down. However, just as at a particular place on the earth's surface we call 'down' the direction toward [its] center, so will a living being ... distinguish the direction of time toward the less probable state ... This method seems to me the only way in which one can understand the second law..."
>
> Boltzmann then adds a comment: "No one would consider such speculations as important discoveries or even — as did the ancient philosophers — as the highest purpose of science. However it is doubtful that one should despise them as ... idle. Who knows whether they may not broaden the horizon of our ... ideas, and by stimulating thought, advance the understanding of the facts of experience?"

As defined by Shannon, the information concept is 'minus an entropy', that is, 'minus the logarithm of a probability'. Shannon's problem was one in telecommunications, where a signal runs along some channel with a structure expressed as a 'negentropy' N, is 'decoded' when received, thus yielding an 'information as knowledge' I_2, and has been 'coded' when emitted, thus encapsulating an 'information as organization' I_1. *De jure* the whole procedure $I_1 \rightarrow N \rightarrow I_2$ is reversible, but *de facto* it happens that $I_1 \nrightarrow N \nrightarrow I_2$: at emission the typist makes mistakes; along the line there is noise; and at reception the reader again makes mistakes. This Brillouin[12] calls the 'generalized Carnot principle'.

It remains, however, that there is in this the *de jure*, or intrinsic symmetry $N \rightleftharpoons I$, which definitely cannot be rejected on mathematical grounds, and thus must be adequately interpreted. This is the problem Bergson had touched upon when speaking of "symmetry", and of "life doing its best to go up' the entropy curve.

Shannon had rediscovered something philosophers already knew: that *information is a two faced concept*, with an obvious face, 'gain in knowledge', and a somewhat hidden face, 'organizing power'. Aristotle knew both of these aspects, but had not made their antiparallelism explicit. Thomas Aquinas did it. Also, Schopenhauer's famous title "The World as Will and as Representation" clearly has this same implication.

Why there is a 'visible' and a 'hidden' face to information is a consequence of the irreversibility law, stating that the transition from negentropy to information is easy, and the one from information to negentropy difficult. Our whole practical experience of life testifies to this: the man in the street buys a newspaper for a few cents, expecting to get 'information' from it; also, many advertisements go straight to the wastebasket. On the other hand, the cost of a manufactured object is mainly the cost of craftmanship — even when the matter used is costly, meaning that it is rare, or difficult to extract.

Let me now remind you that physicists measure a negentropy in 'thermodynamical units', finding these 'practical', while cybernetists measure an information in its natural unit, the 'bit'. Between these two evaluations there is a conversion coefficient, the so-called 'Boltzmann constant k', the exact formula being $N = k \, Ln\, 2\, I$. The fact is that $k \, Ln\, 2$ is exceedingly small. Of course, a universal constant is not intrinsically small or large. What is meant is that our existential situation is such that we find such an evaluation convenient — nothing more.

The smallness of $k \, Ln\, 2$ directly expresses the fact that the transition $N \rightarrow I$ is easy and the transition $I \rightarrow N$ difficult. Going to the limit $k \rightarrow O$ would render 'gain in knowledge' absolutely costless and 'organization at will' utterly impossible — a theory known in its days as 'epiphenomenal consciousness'.

So, cybernetics has made consciousness-the-spectator pay her ticket, a very low price, but this alone has allowed consciousness-the-actor to exist, then at ~~very high~~ wages, because the exchange rate goes the other way.

To Brillouin's insistence on an 'equivalence' between negentropy and information Denbigh[13] objects that he has not given one single example of a *direct* conversion of information into negentropy — which is true. But let me remind you that in his book *Symmetries and Reflections* Wigner[14] argues from technical reasons, and also from the general rule that to every 'action' there must correspond a 'reaction', that to a 'gain in knowledge' there must symmetrically correspond a 'direct action of mind upon matter' — the very sort of symmetry Bergson was speaking of. Wigner goes on saying, tongue

in cheek as it seems, that 'every phenomenon is unexpected and most unlikely until it has been discovered — and some of them remain unreasonable for a long time after they have been discovered'.

Then comes the question: What would the *de jure* allowed, but de facto much repressed, direct information-to-negentropy transition look like, and consist of? Well, such a phenomenon is no less than the one termed either 'precognition' or 'psychokinesis' in parapsychology. It would be utterly unscientific to reject it a priori as, quite to the contrary, mathematical symmetry does point to its existence.

Why, then, if such phenomena do exist, are they so alien to our Western culture while, as it seems, they are alien neither to the more 'primitive' cultures, nor to the elaborate cultures of the 'Far East'? I believe we can guess part of the answer.

Clearly, it is by virtue of their nature, or 'by definition', that causality is obvious to knowing awareness as finality is obvious to willing awareness. Therefore, insisting as it does on knowledge, and on praxis based on knowledge applied *via* causality, our whole Western culture is looking in the direction where it cannot see the 'other side' of things.

This of course is the very paradigm of our Baconian science. But let me tell you that Sir Fancis Bacon did not let himself get blinded, for in his books *The Advancement of Learning* and *Sylva Sylvarum* he does not exclude the paranormal from scientific study, and proposes "deliberate investigation of telepathic dreams . . . and the influence of imagination upon the casting of dice".[15] So perhaps, after all, we should try to learn something from the East.

ADVENT OF THE RELATIVITY THEORY AND 'SPATIALIZATION OF TIME'

It is a long story that leads to the theory of relativity. Till the eve of the 20th Century it was believed that we live inside Euclid's 3-dimensional space, all at the same instant t of Newton's 'absolute time'. Inside this paradigm the geometers had easily worked out a so-called *principle of relative motions*, according to which any two solid bodies, in relative motion with respect to each other, are equally acceptable as reference frames. For example, either the market place of a village or the merry-go-round rotating there would be, according to this principle, equally respectable reference frames. We know today that this principle is dynamically and optically wrong.

It is Galileo, anticipated to some extent by medieval thinkers, who promoted the science of dynamics and changed this picture. According to his principle of inertia, a massive point particle free from external forces remains at rest or in a state of 'uniform motion', both statements being mutually equivalent. A 'uniform motion' is by definition one whose velocity is constant in direction and magnitude.

This principle is clearly not compatible with the preceding one. If a motion is rectilinear with respect to the village place, it is not so with respect to the merry-go-round. Also, if the velocity is constant as measured with a universal time scale, it is not so as measured with an arbitrarily different one. Therefore Galileo's principle of inertia does *define* both appropriate *spatial reference frames* and an appropriate *time scale*.

Two Galilean time scales are related to each other by an arbitrary linear transformation, and two Galilean space frames by a uniform translation. This statement came to be named the *restricted relativity principle*.

It is found that the space reference frame centered at the Sun, with axes such that the celestial vault is seen at rest, is, to a good approximation, Galilean. Viewed in that light, the discussion between Galileo and the theologians was the first battle waged by the restricted principle of relativity against the principle of relative motions. In those days, however, the matter was not yet completely clear. It so happened that Bergson repeated the theologians' error when discussing, in 1922, the relativistic 'twins paradox'. I will come back to this.

Now, quite independently of these significant technicalities, there was an old faith lying deep in the hearts of men, and even, very surprisingly, in Newton's own heart, for this is what he wrote concerning space:[16] 'Absolute space, in its own nature, without relation to anything external, remains similar and unmovable. Relative space is some movable dimension or measure of absolute space'.

As neither classical kinematics nor dynamics were able to characterize that absolute reference frame people believed in, the idea grew that perhaps the science of optics could have the answer. And this makes another long story.

Kinematical optics starts with the easily married ideas of Fermat and of Huygens, those of 'light rays' and 'wave fronts' obeying a stationary phase principle. Huygens thought that his light waves were propagated in a medium, the 'ether', and it was only natural to consider that this should be the absolute rest frame, and that finding it amounted to detecting the 'ether wind', as felt when not at rest.

Assuming the existence of an ether wind amounted to accepting the classical additive composition law of velocities, that is, the concepts of a Euclidean space and a universal time. Also, relying on light for finding the absolute space frame amounted to making optics the supreme arbiter in kinematics. Of this the classics were not aware, and, still in 1922, Bergson could not reconcile himself to the idea, having not understood the physical reasons which legitimate it.

Then something completely unexpected occurred: experimental and theoretical work pursued throughout the 19th century proved that *the additive composition law for velocities is wrong*, which entails that a change of inertial frame neither maps Euclidean space into itself, neither changes Galilean time into itself. In other words, *the formalization of the restricted relativity principle had to be changed, so that an inertial frame becomes both a space and a time reference frame.*

The first suggestion of this occurred in 1818, when Arago measured the deviation by a prism of light emitted by a star, finding, to his surprise, a 'zero ether wind effect'. Fresnel immediately reacted by his universal formula for an 'ether drag effect'. Today we know that Fresnel's formula is precisely the differential form of the new velocity composition law, and we know how to derive Einstein's relativity theory directly from it.[17] But things did not happen that way.

In 1887 Michelson and Morley performed their famous 'ether wind' experiment, designed so as to go one step beyond Fresnel. Again a 'null effect' was found, to which Fitzgerald and Lorentz reacted by their universal formula for the contraction of solid bodies. But now things were quickly ripening. Lorentz, Poincaré and others understood that the 'dynamical restricted relativity principle' is a universal principle of physics. They produced new formulas for it, similar to the old ones only when velocities are small with respect to c, the velocity of light in a vacuum. These formulas are so concocted that c is made an absolute constant, an 'equivalence coefficient' between space and time, which are partly transformed into each other by a change of reference frame. And this defines a new kinematics which no longer accepts the old 'principle of relative motion'.

Then Einstein, in 1905, boldly declared that the x, y, z, t symbols present in the Lorentz-Poincaré formulas denote space and time not only as measured in physics, but also as experienced by any living being. And again, in 1922, this is what Bergson refused to believe.

In 1908 Minkowski, generalizing a suggestion by Poincaré in 1905, proposed the 4 dimensional spacetime concept, which from then on has been regarded as the appropriate paradigm for relativistic physics, the true heir of Euclid's 3-dimensional space. All fundamental physics is formalized today in terms of the Poincaré-Minkowski 4-dimensional geometry.

Matter, in this paradigm, is time extended just as much as it is space extended. This is because the old *dissection* of time into a *past* and a *future* separated by a thin *present instant* is replaced by a *trisection* of spacetime, by the 'light cone', into a *past*, a *future*, and an *elsewhere*, so that any universal or global separation of past and future is no longer conceivable.

In one sense this should have delighted Bergson, because, in such a scheme, time cannot but have thickness, or duration: the whole of a physical evolution is presented as a single spacetime thing, with its past and its future not detachable in any way from each other. And this time thickness is taken so seriously that, as multiplied by the universal constant c, it is 'equivalent' to a space dimension.

But this very thing was the one that most revolted Bergson, because it truly is the "spatialization of time", much more than it had been in classical dynamics, which Bergson had ceaselessly criticized. Still worse than the "spatialization of time" came the fact that Minkowski's time extendedness held for both the past and the future, while Bergson had constantly argued that there is a radical difference between past and future, the one being fixed and the other not.

So what happened was a violent clash between Einstein and Bergson, a personal one at the April 6, 1922 meeting at the 'Société Française de Philosophie', and one expressed in various papers by the pros and the cons, and, mainly, in Bergson's book *Durée et Simultanéité*, first published in 1922 and reprinted in 1968.[18]

Alas for Bergson, this book is full of technical errors. The most

obvious one pertains to the so-called 'twins paradox' problem. So let me recall what this 'paradox' consists of, and what has been its verification in 1972 by Hafele and Keating, flying atomic clocks around the Earth.

Suppose in Washington we are given two brand new identical cars, one heading straight to Denver, the other one also going to Denver, but via New Orleans and Dallas. When both cars get parked side by side in Denver, they are no more twins at all: their respective mileages are, say, 1000 and 2000. Also, apart from possible minor accidents, the 'older' car is also the more worn out.

The twins paradox receives a similar treatment. Until they were, say, 20, two true twins had lived side by side, then one decided to take a big trip in the Cosmos and the other one to stay on Earth. Thus the former's spacetime trajectory is an extremely curved one, while that of the other twin, staying at home, is much less curved. Now please believe me if I tell you that the wrist watch of each man acts as the 'spacetime odometer'.

When the travelling twin is back home, it is found that both wrist watches display different time lapses, 1 and 2. However, in spacetime it is the curved trajectory that is the shortest, because the spacetime metric is pseudo-Euclidean rather than Euclidean.

Therefore the sedentary ex-twin has become older than the travelling one. Has the latter 'gained time'? No more than the former wandering car has 'lost mileage': the wandering car has seen New Orleans, Dallas, and many other interesting places that the rushing car has not. The travelling twin has just managed to jump into the future of his native town, as he could have done also by being deep frozen in a refrigerator.

This Bergson was simply unwilling to believe, as he says in his book. Alas for Bergson, the phenomenon has been demonstrated in 1972 by Hafele and Keating,[19] using atomic clocks carried around the Earth on jet airliners, one flying westward and the other eastward, from Washington to Washington. It is well known that a westward supersonic flight 'stops the sun', so to speak, thus annihilating the Earth's rotation. So this is the 'non travelling twin'. As for the eastward flight, it follows a spacetime helix more twisted than that of Washington.

As measured, the time lag has been found equal to the calculated one. Let me draw your attention to the fact that if the two pilots had left Washington as two freshly shaved twins, by comparing after their return the lengths of the beards the same effect would in principle have been found. Also — and this is another story — the fuel consumption of an airplane provides another means for measuring the duration of the flight; it also provides a means for measuring the length of the flight, and so, strictly speaking, the two crews do not ascribe the same length to the Washington parallel — again a relativistic effect.

Let me now tell you the values of the difference in time lags and of the durations of the flights:

Time lag: some 315 billionths of a second.

Journey's duration: eastward trip: 41.2 hours of flight;
westward trip: 48.6 hours of flight.

Concluding this section, it is regretable that Bergson was, in 1922, no longer the able mathematician he had been in 1877, because it would have been quite interesting to read the thoughts concerning duration which the relativity theory would have inspired in him.

Anyhow the story does not end here, and the Bergsonian kind of thinking will have to show up in a discussion of relativistic quantum mechanics, as I will explain now.

QUANTAL NON-SEPARABILITY, LORENTZ AND CPT INVARIANCE

Of quantum mechanics *per se* I will only say this: Einstein in 1905 and 1912, Louis de Broglie in 1925, have defined a *universal wave particle dualism* expressed as a proportionality between two space-time vectors: the 4-frequency of the wave and the momentum-energy of the particle, the ratio being Planck's constant h. A synthesis of the extremum principles of Fermat and of Hamilton was proposed by de Broglie.

The wave concept has continuity and the particle concept discontinuity. As probability is a natural mediator in such matters, it is not surprising that, in 1926, Born used it there. He likened the intensity of the wave to the probability that the particle is manifested at some point-instant. *Ipso-facto* the basic rules of the probability game were thus drastically changed. This is because, if there is phase coherence, the amplitudes, not the intensities of waves, add to each other, as interference or rhythmic phenomena show. So, without

much fanfare, Born proposed a radically new *wavelike probability calculus*, where partial amplitudes rather than probabilities are added, and independent amplitudes rather than probabilities are multiplied. From this stem the thousand and one 'paradoxes' of quantum theory, the latter being the 'EPR paradox'.

Notwithstanding Einstein's and de Broglie's early accomplishments there has been some difficulty in synthetising relativity and quantum theories. This was done in the years 1946–1949, when Tomonaga, Schwinger, Feynman and Dyson produced different aspects of a 'manifestly covariant' quantum electrodynamics. To this a significant postscript was added in 1952–1955, when Schwinger, Luders and Pauli[20] showed that the invariance group of relativistic quantum mechanics is not the original Lorentz-Poincaré group, but this group completed by reversals of the space and time axes. Let me explain this.

Poincaré's 1906 interpretation of the Lorentz transformation was a rotation of the Cartesian tetrapod of spacetime axes. As the spacetime metric is pseudo-Euclidean, this is a hyperbolic rotation, which can neither reverse the time axis, neither perform a right-left exchange in space. Therefore the Lorentz-Poincaré group is called 'orthochronous' and 'orthochiral'. Relativistic invariance is the essential requirement that physical laws retain their expression in spite of changes of inertial frame. In macrophysics there is no objection against orthochronality, as the 'factlike irreversibility' in probability theory and in wave theory is thus preserved. As for chirality, there are situations where it does make sense — for example, the electrodynamics of magnets and currents. It was tacitly understood that the 'chirality reversal', named also 'parity reversal', could be performed at will.

But, as was made clear by Loschmidt in 1876 and by Zermelo in 1896, when viewed at the elementary level, a statistical theory displays an intrinsic time symmetry. Therefore it is in the very nature of things that, being a fundamental theory, relativistic quantum mechanics shows up as time reversible, or rather, in view of relativistic covariance, as spacetime reversible. But this is not the end of the story.

Figure 1 displays an example of a 'Feynman graph': annihilation of an electron-positron pair into a photon pair (1a and 1b), and annihilation of a photon pair into an electron-positron pair (1c). According to the clever Stueckelberg-Feynman interpretation, the antiparticles (the positron, or antielectron) are endowed with a momentum-energy pointing backwards in time. *Particle-antiparticle exchange*, denoted as C, is figured in 1a and 1b as a reversal of the arrows. *Covariant motion reversal*, denoted as PT, is figured in 1b and 1c, as exchange of the emission and absorption processes. The figures do show that C is a spacetime symmetry operating on the arrows, and PT a spacetime symmetry operating on the trajectories.

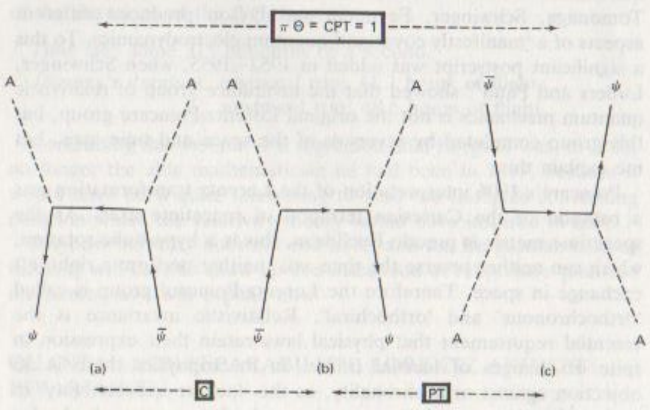

FIGURE 1.

The exchange of figures 1a and 1c represents the CPT-operation, which is seen to be total spacetime reversal, $\Pi\Theta^{21}$. Schwinger, Luders and Pauli[20] have demonstrated the CPT = 1 theorem, meaning *invariance of relativistic quantum mechanics under-the total spacetime reversal* $\Pi\Theta$ — a very natural statement in the spacetime geometrical paradigm.

Feynman's graphs, together with a clever system of computational rules, illustrate an algorithm known as the *S-matrix* — in fact the main algorithm of relativistic quantum mechanics, yielding almost anything that is needed - including the formulas of the EPR correlations. So *Born wavelike probability calculus, Lorentz invariance, CPT-invariance* are its essential ingredients.

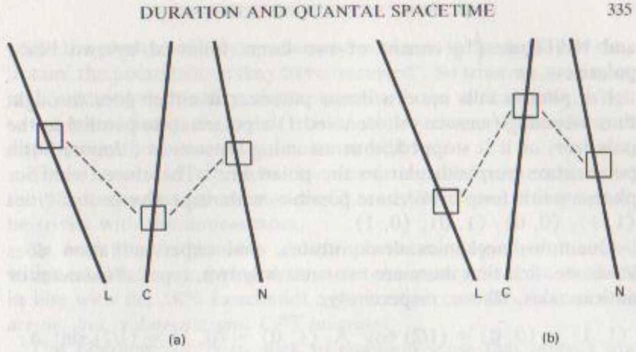

FIGURE 2.

Figure 2a is a Feynman graph showing a pair of photons emanating from an 'atomic cascade', the spacetime trajectory of the atom being denoted C, and later received in two detectors, the trajectories of which are denoted L and N. Figure 2b displays the CPT reversed procedure, where two photons are emitted by lasers L and N and absorbed in an 'anticascade' at C. Relativistic invariance of the whole procedure goes so far as to allow in principle (if not practically) arbitrary relative velocities of the three pieces of apparatus C, L, N. Figures 3a and 3b sketch the corresponding laboratory equipment.

The pair of photons emitted in a cascade, or absorbed in an anticascade, is said to be 'correlated', for a reason that will become clear. The two detectors L and N (Figure 2a) consist of two linear polarizers followed by two photon counters. The two emitters at L

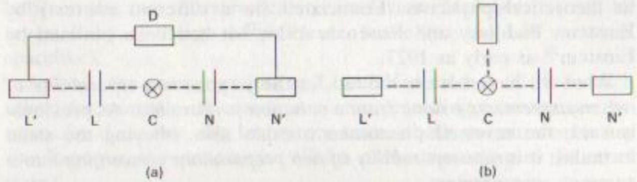

FIGURE 3.

and N (Figure 2b) consist of two lasers followed by two linear polarizers.

If a photon falls upon a linear polarizer it either goes through, thus assuming (answer *yes*, denoted 1) a polarization parallel to the polarizer; or it is stopped, thus assuming (answer *no*, denoted 0) a polarization perpendicular to the polarizer.[22] Therefore, with our photon pairs, four answers are possible, with respective probabilities $\langle 1, 1\rangle$, $\langle 0, 0\rangle$, $\langle 1, 0\rangle$, $\langle 0, 1\rangle$.

Quantum mechanics demonstrates, and experimentation does vindicate, first that there are two, and only two, types of cascades or anticascades, where, respectively,

$$\langle 1, 1\rangle = \langle 0, 0\rangle = (1/2)\cos^2 A,\ \langle 1, 0\rangle = \langle 0, 1\rangle = (1/2)\sin^2 A;$$
$$\langle 1, 1\rangle = \langle 0, 0\rangle = (1/2)\sin^2 A,\ \langle 1, 0\rangle = \langle 0, 1\rangle = (1/2)\cos^2 A.$$

Mathematically this is quite nice. But it is a terrible blow to common sense, as has been explained in many papers, of which I cite here two.[23]

Let us make this clear by setting $A = 90°$, that is, polarizers crossed, with the first type of cascade. Then all measured photon pairs do display parallel linear polarizations (all right; why not?) which are, moreover, parallel to either the one or the other of the crossed polarizers, the orientations of which are arbitrary, and could even be fixed after the photons have left the source! The latter sort of experiment has indeed been performed, vindicating quantum mechanics.[24] Let me put it this way: we are playing some sort of Alice-in-Wonderland game of dice, where the mathematics make clear that the chance event does not occur when both dice are shaken together in the cup. The chance event occurs when both dice stop rolling on the table (all right; why not?) but they are correlated! *That* is the EPR paradox, which causes so many headaches to theoretical physicists. Enunciated (in a different context) by Einstein, Podolsky and Rosen in 1935,[25] it had been outlined by Einstein[26] as early as 1927.

What we have here is termed, in the jargon, *non-separability of two measurements issuing from a common preparation*. As previously said, the reversed phenomenon exists also, obeying the same formulas; it is *non-separability of two preparations converging into a common measurement*.

Let it be remarked that, in the reversed procedure, there is no paradox at all in the fact that the polarizers can be turned at will

while the photons are flying, because common sense feels that they 'retain' the polarizations they have 'received'. So what we are saying is this: retarded causality, as displayed with the anticascades, is felt to be so ordinary as to be trivial, while advanced causality, as displayed with the cascades, looks incredible.

There is another aspect to this, consisting of the insensitivity of the phenomenon to the distances CL and CN. Again this is felt to be trivial with the anticascades.

So, both the mathematics and the phenomenology, in full accord with each other, are saying that, *at the elementary level*, — and well in line with the 1876 Loschmidt argument — *causality has no time arrow, but is Lorentz and CPT-invariant.*

This phenomenon is so alien to common sense that quite a few distinguished physicists have made, concerning it, demonstrably wrong statements, of which I select three.

The first wrong statement is that the EPR correlations are incompatible with relativity theory, as they seem to contradict the existence of an upper limit to the velocity of signals. The first to make such a statement was Einstein himself, in 1927.[26] Quite a few others have followed him in this.

What we have seen is that the EPR correlations are more relativistic than anything known before, as they are not only Lorentz, but also CPT-invariant. But the implication, as I have said, is that the very concept of causality must be made Lorentz and CPT-invariant at the microlevel.

The second mistaken assertion is that 'the first in time, say L, of the two distant measurements, instantaneously collapses at a distance the other subsystem, N, into the corresponding state'.

Two points show that this statement is definitely wrong. First, the correlation formula is L and N symmetric, so that the time ordering between the two measurements is irrelevant. Moreover, it can be reversed by a change of reference frame (as the LN vector is spacelike).

Second, the measurements at L and N need not at all fit each other; for example, the angle A in the preceding formulas is arbitrary. So if in, say, the laboratory frame, both measurements are simultaneous, the question is: 'Which of the two collapses the other state?'

The point is that the correlation formula essentially holds *if and only if such measurement (or preparation) is performed at L and if* *and only if such measurement (or preparation) is performed at N. It is a conditional probability.*[27] Also, this probability is invariant with respect to arbitrary displacements of the measuring (or preparing) devices along their respective beams — which has been experimentally verified. Therefore *the physical link connecting the pair of distant measurements (or preparations) L and N is the Feynman zigzag LCN connecting them via the common preparation (or measurement), in their past (or their future, respectively)*. This again shows that causality is arrowless at the microlevel.

The third wrong statement is a more technical one, pertaining to the so-called Feynman propagator used in the S-matrix algorithm. Misinterpreting Feynman,[28] some authors feel that there is a causal asymmetry built into the Feynman propagator. Inspection of the matter shows, however, that this is not so. The Feynman propagator has the symmetries P = CT = 1, and this entails no causal asymmetry. The S-matrix transition probabilities are symmetric with respect to 'blind' statistical prediction and retrodiction.

These points being settled, the following implications turn out to be of an extremely Bergsonian nature.

First, how is it possible, and even conceivable, that there is this marriage of water and fire consisting of a *relativistic quantum mechanics: water* is the Minkowski 'all written' space-time picture, *fire* is a probability calculus? There is, as it seems, no other conceivable answer than this one.

The spacetime background is not objective; it only looks so, just as does the frequency aspect of probability. Quantum physicists are of course aware of this, knowing well that the spacetime picture is 'complementary' to the 4-frequency picture; using the one precludes use of the other.

What can be said to be 'in fact' inside spacetime is the two pieces of the macroscopic apparatus: the preparing and measuring devices. They are 'inside spacetime' inasmuch as they are participating in the intersubjective day dream all of us are dreaming, relying, as we do, upon retarded causality and information-as-cognizance.

The quantum system, however, which is *transiting between preparation and measurement*, is *neither in the initially prepared, nor in the finally measured state*. Thus it is outside, or beyond, spacetime.

The S-matrix formalism does describe a 'universal spacetime telegraph' connecting, in a Lorentz and CPT invariant fashion, all those

observers-and-actors termed 'physicists', 'non phycisists', 'animals', 'plants', 'viruses', and what not. The signals of this common big cybernetical machine are expressed according to the Born wavelike probability calculus, as 'occupation numbers' of the waves.

Therefore, although all 'happenings' whatsoever are, in some sense, written inside spacetime, nothing 'occurs' without some knowledge flowing out of, and some organization flowing into, the cosmos. Negentropy, as it seems to me, is inside, and information outside, the cosmos.

Essential non-separability should of course not be forgotten. As the Vedas put it 'separability is an illusion created by a pragmatic approach', and as Bergson puts it,[29] we are much less a *homo sapiens* than a *homo faber*, and we use our intelligence by drawing artificial separations through a universal undivided flux, the continuity of which would be recovered if we could rather use intuition.

Finally I come back to CPT-invariance and factlike irreversibility. Born's wavelike probability calculus does bind together two earlier known aspects of macroscopic irreversibility: *probability increase* and *wave retardation*. This has been explained by Fock[30] and by Watanabe,[31] and is also more or less implicit in Planck's[32] and Einstein's[33] quantal thinking.

Let me remark also that there is another big 'lawlike-symmetry-and-fact-like-asymmetry': that of particles and antiparticles. The day dream all of us are dreaming together is made possible by both the tremendous preponderances of retarded over advanced actions, and of particles over antiparticles. They *define* the realm of macrophysics which, in their absence, would merely collapse.

The ultimate and most ominous aspect of intrinsic reversibility lies, as Wigner[14] also has pointed out, in that of the negentropy-information transition. So, now that the technical working of the spacetime telegraph is so well understood — thanks to relativistic quantum mechanics and the EPR correlations — the next thing to be explored is how this telegraph can be used, which is an interdisciplinary 'mind-and-matter' problem.

Easterners tell us that — even in such practical matters as archery or sabre fencing — the way out of 'maya' is meditation practice. This does sound Bergsonian. Of course, it also opens the Pandora box of parapsychology — in which Bergson was interested.[34]

As a final 'mandala' for your meditation I submit Figure 4.

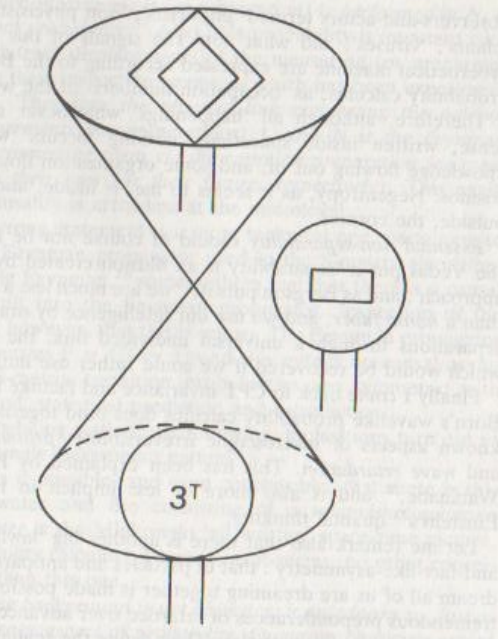

FIGURE 4.

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