On the Foundations of Physics.

Johan Noldus*

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Abstract

The road on the foundations of science in general consists in (a) making precise what the assumptions are one makes resulting from our measurements (b) holding a "good" balance between theoretical assumptions and genericity of predictions (c) saying as precisely as possible what you mean. Unfortunately, recent work where these three criteria are met is scarce and I often encounter situations where physicists talk about different things in the same words or the other way around, identify distinct concepts (even without being aware of it), or introduce unnecessary hypothesis based upon a too stringent mathematical interpretation of some observation. In this work, I will be as critical as possible and give away those objections against modern theories of physics which have become clear in my mind and therefore transcend mere intuition. All these objections result from the use of unclear language or too stringent assumptions on the nature of reality. Next, we weaken the assumptions and discuss what I call process physics; it will turn out that Bell's concerns do find a natural solution within this framework.

1 Introduction.

Unfortunate is the fate of those who try to improve upon things, reduce assumptions to their very substance and introduce new processes; there is no patience with them and in case they succeed, they are consumed by the community. All too human is the adversity against criticisms, thought experiments conflicting with formalism, metaphysical comments and so on; most easily, one eliminates the work by pointing out an error where there is none,making reference to some disjoint work using the same language, abusing terminology to make an outrageous claim or finally, the real kiss of death, dismissing it because it is not mainstream. Those who are lazy and of the latter character should stop reading here while those who genuinely have patience and good spirit might want to continue. This work is not intended for the mainstream physicist whose only occupation is to calculate numbers he or she does not really understand; indeed, I have given up on those people who tend to think that establishing a precise mathematical concept behind a metaphysical one, and deriving the consequences associated to this mathematical reduction is the highest possible achievement of humanity. How poor is ones life if one really believes such simple statement as

*email: johan.noldus@gmail.com, Relativity group, departement of mathematical analysis, University of Gent, Belgium.

if nothing would be lost by this very mathematical translation; now, one might suggest that in a sense this is an admirable attitude if those very same people were to be very careful and precise concerning the conclusions they may draw from this mathematical abstraction. Alas, as we will see in this paper, the "formula worshippers" are usually not that careful when it boils down to choosing the appropriate words or interpretation when dealing with the so called results of this elevated mathematical abstraction. As scientists, we must face the fact that spoken language is the best tool we have to speak about reality and that mathematics really comes second even if we don't like to hear that and think that mathematics is the more primary language. Well it is not and examples are provided by Russel's paradox or any statement about self reference one has to exclude in mathematical thought, but which are constantly used in everyday language. On the other hand, I do not enjoy endless metaphysical speculation either and recognize the virtue of making something as precise as reasonably possible but at least I do appreciate that metaphysical objections are real and should be taken seriously. If something makes no sense in words, then its value to society is very little indeed in the long run; it is true that some scientific concepts are only partially understood at the time they are launched and indeed, this very fact should not form any obstacle for people studying it for a while. But after some time, one has to elevate ones understanding and speak about it in natural terms, this very achievement announces usually the morning of a new revolution in ones thinking. So this paper is meant for those who share the concerns of a practicing physicist and a philosopher, not a very privileged position indeed. Obviously, in some part of this paper I have to use state of the art mathematical facts and concepts of topology, differential geometry, category theory, operator algebra's and so on but I will always remain focused on the very meaning of what one is calculating and the possibly circular character of the line of one's thought. It is this feature which is currently lacking in the physics literature and one meets a flood of distinct, unsubstantiated interpretations of some mathematical symbols and their logical connection.

I have tried for many years to find the real essence of physical principles using words I only understand; recently I told bluntly to my old PhD advisor that in the context of general relativity, I saw no place for concepts such as (the constancy) of the speed of light or a definition of the vacuum for that matter, insisting that units such as meter and second should have no fundamental status whatsoever (as is the case in the general theory, not in the special one however). He had to admit he could not define the speed of light neither, nor did he know what a vacuum was; this small anekdote reveals the spirit in which this paper will be written, I will use simple words and not shy away from specifying concepts to the fullest of my abilities. On the other hand, I will refrain from using words which have no unambiguous meaning such as clock, meter, (physical) speed and so on; therefore I must be harsh on the abuse of language in theoretical physics, something which occurs all too often. I have decided to write this paper for a large public, meaning I will explain every scientific word I use and introduce every concept in the historical way and in the one which is logical for me: my way will depend upon much weaker assumptions and surprisingly delivers the same qualitative results. There will be *new* qualitative results too and some old ones will get a new jacket which is more on par with others: for example I will *define* what a quantum measurement is and the dynamics for quantum measurement will be the same as the one replacing the Schrodinger equation. Also, I will point out that a single "new" principle of physics is a substitute for general covariance, quantum "causality" (a dirty word) and the existence of a probability "potential" (replacing the Hamiltonian and all constants of motion). There is an a priori distinction between an objection and an error and in giving arguments I will gather evidence from other sources in the literature working on similar problems trying to strengthen my case; the reader is advised to look at those treasures too. Finally, I will try to present at least one example where I believe quantum theory falls short so that we do not only have objections but also more solid evidence to pave the way for the "new" synthesis which consists out of two parts: (a) an extension of and reduction to well known principles (b) speculation about new principles further constraining the dynamics. As is well known, such principles are necessary given that gauge invariance as well as general covariance lead to an infinite number of action principles: at the real end, I discuss how these principles might connect to evolutionary biology and the second law of thermodynamics for simple, "closed" (whatever that means) systems.

There is another reason to write this work for a large audience, which is that some ideas are certainly not foreign to other branches of science such as biology and informatics theory. Indeed, in the grand sense of the word new, *very little* is really new in this paper, albeit many things might come as a surprise, apart from the synthesis I make and the coherence with which I try to argue the case - this is also not foreign to science as every new advance is just a tiny step resulting from coherently appreciating well known and not too well known facts. To pave the ground for the discussion, I will first introduce some terminology: (a) by an *operational* principle, I mean a principle which can be verified by means of a finite *process* which the experimenter can *fabricate* (I am not advocating here that the experimenter can achieve this outside the framework of physical laws such as is the case in quantum mechanics), operational principles are connected to the word operator and "acting upon" instead of "undergoing", (b) by a *meta* principle, I mean a principle which cannot be *directly* verified by experiment in the sense that it gives no unique predictions, but answers a question of the type: "what if this were true, then we conclude that...". Metaprinciples are there for the design of nature and do indeed constrain the world we live in but not in a decisive way. An example of a meta principle is general covariance, the corner stone of general relativity, which asserts that coordinates must be unphysical and laws of nature therefore must be invariant under coordinate transformations. Now, one may wonder if for example Newton's gravitation law is a prediction of Einstein's theory and I must confess this is not so by any margins. In order to arrive at Newton's law one must make additional assumptions, define unphysical measure sticks and units and ignore all types of backreaction and so on; indeed, the very probability that Newton's law emerges from general covariance must be close to zero if one examines the impact of the additional assumptions. Nevertheless, Einstein's derivation was accepted since those assumptions grounded into a scientific culture which found them to be plausible, in fact we know them to be plusminus true but we have no idea whatsoever as to why they are true. General covariance is therefore not a principle which can be directly verified experimentally but it is nevertheless one of the most important clues we have towards a formulation of a theory of nature because of its beauty and "evident" character. Actually, the most direct support for general covariance from experience comes from the geodesic equation which determines the motion of objects in a gravitational field while experiencing no other "force" fields; the geodesic equation simply says that free objects move on a straight line (autoparallel curve) which are nothing but the ellipses, circles and hyperbolea for objects moving in the solar system. So, where Newton would say that we experience a gravitational force, Einstein says there is nothing to be felt and indeed we humans do not "feel" the motion of the earth around the sun. An example of an operational law in physics is rotational invariance in *Newtonian* physics where we can, by means of a finite process (involving higher and higher speeds when one is further removed from the center of rotation) realize a finite rotation and come to the conclusion that our "rotated" experiments (ignoring the rest of the universe) have the same outcome as the unrotated ones. Operational principles are often connected to a symmetry of a deterministic theory whereas general covariance is no such symmetry at all since it renders *the formulation of* general relativity nondeterministic, gauge covariance likewise is a necessary meta principle for a consistent Lorentz covariant treatment of quantum fields making the formulation of Maxwell's theory nondeterministic.

As mentioned already, I will present concepts in a two fold way, historically and "logically" and due to the very broad audience I am to write for, the detailed line of this paper will look as follows : first we start by very general principles of physics and metaphysics and give some examples of how these have evolved in the history of science, these comments span the entire enterprise of physics and not just the modern era. What we will do in that section is to *gradually* build a language suited for speaking about nature; I have chosen to start from the language physicists hold today and develop upon that, clearly our framework needs to be broad enough so that the languages of classical, quantum and statistical mechanics are recognized to be special subcases. The very reason for doing so is that quantum mechanics might become a very *natural* way of speaking about the word instead of protesting against the rather weird and possibly incomplete interpretations which are used today. Second, we come to the modern theories of relativity and quantum mechanics: here, I will need to present many details and some abstract definitions, I intend to comment upon all of them and the reader will especially notice that I like to emphasize the distinction between being the same in the sense of equivalent and in the sense of identical. This discussion is almost identical to the one between Newtonian theories of spacetime and relativistic theories of spacetime. Now, not all of these comments ought to be taken as necessarily "bad" as I have stressed before, some of them arise from appearant inconsistencies in the theory which have not been resolved so far but which, on the other hand, enjoy more potential solutions than the one I choose here. I will explain patiently why I prefer to dismiss these other avenues, mainly because they introduce more problems than the one they "solve": as history has shown, good solutions usually involve bringing distinct things under the same umbrella as much as possible and not rely upon an entirely new thing such as "consciousness" altogether. What I will refrain from is attempting to give a detailed axiomatic framework of physics, that would be too cheap; certainly I will mention results from axiomatic approaches and use plain examples to confirm these or to reject them but the axiomatic approach is always useful to get a better understanding of what principles can or cannot hold in general.

It isn't very useful though in looking for new principles as such working style is equivalent to the one of indoctrination of people by means of religious and political authorities. Regarding quantum theory, I will follow two paths: (a) I will present the old Copenhagen doctrine and (b) comment upon the foundations of a *new* quantum theory in curved spacetime. Finally, we close our discussion by taking all of my comments together and present a new physical framework of "process" physics where I will show how fewer new principles reduce to the old ones and how new principles should be found to solve old paradoxes. This paper is written in such a way that it should be fully understood by someone with a level of knowledge in physics and mathematics comparable to that of a bachelor in physics, in section number two, especially when referring to the state of affairs in modern physics, I will use terminology such as spin, general covariance... without really explaining those but an intelligent but rather uneducated reader should easily find out what they mean by consulting Wikipedia. Also, the reader might just decide to absorb these statements for now and follow the general line of the discussion which should be understandable for anyone with a high school degree level of knowledge. In section three, I will discuss the state, limitation, shortcomings of modern physics and use some more technical terms which I cannot explain all but again may be found on Wikipedia or any decent book on the subject; if I will comment on limitations of them, this will be done with reference to the general framework build in section two. Section four then, is somewhere in between sections two and three as we form a synthesis between the general expose of section two with the worries and comments of section three.

2 General principles of physics.

Central to the entire enterprise of physics is the concept of spacetime and to really have an insight into the assumptions which creep in regarding the structure of spacetime, we must focus on our senses. Our mind tells us that each individual undergoes a *process* of renewal meaning we have a relationship of the form

$$A \to B$$

where we call A the initial state and B the final state, the arrow denotes the "process". One fundamental issue here is that if A and B determine the state of the entire "universe" then one has that B always has to be different from A otherwise we would not speak about a process, that is if there is no change in the state of the *total* system, there is nothing that happens (note that we do not speak about "time" here which I intend to *ban* from all discussions). This already delineates a very strong distinction between so called open and closed systems where I will call a system closed if observer and observed belong to it and open otherwise; this is a very rough definition indeed and one might opt for calling a system closed if and only if all physical questions asked come from within the system and not from outside. For example, a closed box (thermically isolated or not) can be seen as a closed system as long as one does not ask questions like "if I open the box, do I find a cat in it?". If the box is not isolated from the rest of the universe, a creature within the box will resort to a theory in which no conserved energy and momentum exist, probably he or she will expect there is something beyond the universe due to the different nature of the boundary region. However, when asked from the outside of the box, speaking as God, "where do you think this voice comes from?", the cat will probably answer that she came from the ferocious boundary region. When finally revealed the truth by opening the box, the cat will recognize God as another living creature and destroy all her boundary theories. The same trick can be played with other animals such as ants making them believe that the world is two dimensional instead of three dimensional, and who knows, perhaps we are fooled in the same way. This situation already appears for singularities in general relativity, where one can glue together different universes to form a larger inextendible universe. For an open system, it is possible for

$$A \to A$$

as long as it is understood that the process denoted by $\to$ comes with a change in the state of the observer but this is usually ignored in the description of the theory. Now, this begs the question already, what do we, as observers *and* observed percieve? The process or the initial and final states, both or something else? One should distinguish between the processes we observe and those which happen: indeed, as mentioned already, we can observe a static open system but that process is *not* the one which is happening since *nothing* is static for a closed system. This philosophical stance alone reveals that in the language of quantum mechanics one would have to say that the discrete spectrum of the Hamiltonian operator for a closed system cannot be observed, whatever time evolution would mean in such context. So, we have to rephrase our question as

$$A_o \to_o B_o$$

where the subscript stands for the *derived* notion of states and processes the observer holds. A quantum physicist would say that we measure *properties* of a state, but then, shouldn't properties not evolve too or is it something eternal? In the Schrodinger picture of quantum mechanics, one would indeed say that properties are eternal, but we will argue for a very different view on these matters later on. So, with my states A_o, B_o I really mean "state *and* operators" when referring to quantum mechanics; they are what evolves[1] according to $\to_o$ which is something entirely different from $\to$. It has been stressed several times by the founding fathers of quantum mechanics that the classical world is needed for the very existence of the quantum world and we shall argue that *therefore* the picture $A \to B$ is much richer than the picture $A_o \to_o B_o$ where the observer evolutions may be the set theoretical union of the observer's classical and quantum world. So a fundamental quantum universe does not exist and neither does an intrinsically classical one, as we shall posit in the last section of this work every object composed out of a sufficient number of elementary particles *is* classical as well as quantum. As a general comment, notice that the distinction between a state and process only arises when one writes down finite sequences, for infinite sequences the role of process and state might be interchanged and it is all a matter where one begins to write down the first entity. One notices that observation itself is a process, and one may ask oneself *what* one is observing : (a) what we observe are processes and we infer states

[1]So, in the traditional viewpoint, I would say that a state A_o equals $(\Psi_o, \mathcal{L}(\mathcal{H})_o)$ where $\mathcal{L}(\mathcal{H})_o$ is some star algebra of operators acting on Hilbert space $\mathcal{H}_o$.

from processes, this is identical to the idea that only work (the process) can be measured and that energy is the state which is arbitrary up to a constant (b) what we observe are (properties of) states now and we infer processes from measurements at different times (c) both. Note that all take (a personal) “now” as a fundamental notion and assume another process, the one the observer is consciously *undergoing*, as primordial although a theory from the observer’s perspective cannot qualify, but nevertheless quantify this process, it is just called the variable “time” in non general relativistic theories. In general relativity, Einstein extrapolated, as did all scientists which came before him, the personal notion of time as a quantifier to (mathematically) integrate the processes, to a meta time which exists and flows. Note that the notion of process is even more fundamental than the notion of time and that one can always rescale the time duration of a process. What the continuum hypothesis of Einstein’s meta time says is that no process is irreducible, meaning it can always be split up as the composition of two or more processes; the discreteness assumption on the other hand goes to the other extreme and says that, very much like the natural numbers, every process can be written as a finite composite of irreducible processes with that distinction that this decomposition does not need to be unique. There is of course the more generic attitude that irreducible processes do exist but not every process can be (finitely or infinitely) decomposed into them; nevertheless, as mentioned already, this situation does not need a quantifier for its description and therefore we think time is not a sane metaphysical concept to rely upon but process and state are. For sake of convention, nevertheless, I will continue to use the word spacetime but as the reader will discover it gets a somewhat different meaning than envisioned before. Before we proceed, we must make a perhaps unnecessary distinction between thought processes and actual processes in the sense that for the former, nothing is happening but for the latter something is; this evoques spiritual discussions such as, does there exist a mind irrespective of the body? These thought processes reveal a *reason* for a particular transition $A \to B$ to take place; one could argue that these thought processes do exist but from the point of view of our universe, they are pointless and we like to capture them into physical principles (note that there has to exist an infinite hiarchy of thought processes and universes in this line of thought). This is how one *has* to close that discussion if one wants to get anywhere in reasoning regarding nature. Other processes are *expected* processes, one might again put forward that these do not really exist but are a synthesis of real processes; expected processes are processes anticipated in the state of the universe which does not only reveal its being but also its potential becomings as well as their associated potentialities, prospects of the future if one likes. Mathematically, this would boil down to the fact that the *state* of the universe A contains symbols such as

$$B \to C, \ \lambda_{B \to C}$$

where in quantum mechanics $\lambda_{B \to C}$ is a complex number. There is something to say for this viewpoint if you want to make a distinction between *expected* potentialities and *realized* potentialities of *processes*. I believe, we humans do make that distinction in the way we move in a very simple way, we estimate the possible outcomes of a future process and their probabilities and make an actual move (with a certain probability) based upon this estimate and this move depends upon how far we can calculate ahead, such as is the case in a chess game.

Again, as said before, one might argue that these calculations are the result of more elementary processes in our brain and that it takes a while to make that specific move; physicists in any case do seem to prefer this explanation for the very elementary reason, I think, that it is the simplest one. This is a sane attitute as it would be hard, at this point, to falsify this simple premise; on the other hand physicists have also ignored the direct influence of processes which have happend in one's person's past, not just the remote past, as playing a role in his actions, this is so called physics where the dynamical law has no memory. As this does not imply at all that there does not exist such thing like memory, also this attitude is not stupid and motivated by the principle of simplicity.

This discussion already reveals that instances of perception of processes is not the same concept as instances between processes, nevertheless we *might* call such instances "now" and (eigen)time the lapse between succession of instances. Coming back to the question what we observe, I think it is pretty clear which philosophy is the correct one and that is (c), we observe both processes and properties of states: for example, one can observe oneself breathing but one never knows precisely how far ones chest is extended at that instant but nevertheless one measures that ones chest is extended. In physics so far, we speak about a *generator* of processes, something which has to do with determinism and the assumption of an a priori existence of spacetime and other eternal structures. Quantum physics is so far our only theory where the generator has a different mathematical prescription than the concept state which is good since both have philosophically nothing to do with one and another. So fine, we haven't said anything about space and time yet, nor about dynamics, neither did we clarify the word state and process, we just wrote down a diagram which clarifies the notion of a process related to the word state. Before we enter into the discussion of spacetime let us show by a very careful, but simple, reasoning how a generalization of the kinematics of classical and quantum mechanics comes around - this example is preliminary and ignores certain important points but it will do for now. Suppose that *space* (and not spacetime, we will explain later on why) is related to distinct generating properties (also called atoms in the lattice of propositions) $x, y, z \ldots$ all of which might have been created from nothing by a sequence of processes, then one can make (not logical, as we will see later on) *propositions* about these properties and the properties themselves have to be regarded as potentialities for making propositions. For example, the proposition $\star(x, \lambda)$, where $\star$ indicates the fact that we are making a proposition, would mean "the potentiality that a particle is found with property x is λ"; from now on, we will drop the star and λ and simply denote a one property proposition by the property x itself. This may be read as "a particle exists with property x" but one should always keep in mind that the potentiality matters too; we leave it completely open as how this potentiality is quantified. How space is related to atomistic properties depends upon one's point of view and we will come back to it later on but one may propose for now that space is "common" to all atomistic properties without really knowing what it means. Generating means that every property of a *single* particle is constructed from them by means of the operations $\wedge$ and $\vee$ *and* a quantifier potentiality λ associated to such word while distinct indicates that every combination (word, potentiality) is distinct (meaning there is no relationship between different words and potentialities). From the definition, it follows they are not mutually exclusive in having, meaning that one particle can have the property of two distinct atoms but in quantum mechanics some of them are mutually exclusive in the sense of measuring, meaning that one particle cannot be measured to have more of some specific properties (for example, a particle cannot be measured in two different positions). Before we proceed, we must decide wether the above sentence is a meaningful one; that is, wouldn't it be better to say *which* particle has property x? We do for sure theorize about one and the same particle having those and those properties and in particle experiments, it is *necessary* to assume that properties of a single particle propagate and under certain conditions, we pertain that "reason" obliges us to acknowledge that we observe the same particle once again. In the macroword, this happens all the time; for example if I were to commit a crime and later the police captures a person looking exactly like me using the record of the criminal act, he can sustain as much as he wants to that he did not do it but nevertheless he would get convicted. Supposing that we are identical in all other aspects too, that is our voice sounds the same, we both live on the streets and are beggars and so on, it would be impossible for the judge to separate us in case they would find me too; in a super advanced society, they might read your harddisk (memory stored in brain) and in this way they finally could judge me! This somewhat funny example reveals the following elementary facts: being identical of me and my twin drifter is in the eyes of a third party, I *know* I am me and not him and likewise does he, second the matter of being identical or not might be a matter of perception of the beholder and if he were to improve his or her perception he or she might disover the truth after all. We cannot ask to elementary particles or even cats where they come from, in the case of cats we have the possibility to trace back their steps based upon characteristics of their smell, skin and so on, but we have no such chance with elementary "particles". Nevertheless, *nature* might care which properties a particle had before it decides about its future properties; since *we* cannot decide about the "history" of a single particle, it is hard (but not impossible) for us to develop a dynamics where this should matter; in the theory of quantum mechanics, this limitation is elevated to a virtue since it is declared by fiat that nature just works like that - end of discussion. Heisenberg was a proponent of this principle which he revealed by the cryptic sentence that our theories of nature should not contain elements which *we* cannot measure, where the act of measurement refers to the object under study. Obviously, I cannot measure anybodies identity but I know I have one; in psychiatry one can even speak about appearant "multiple" identities when a person undergoing a psychosis hears voices in his head and wonders if they are really him or not. That is, there one could speak about the reflexive relationship that one hears oneself thinking and depending upon the sensation this comes with, one imagines that one hears oneself speaking or someone else. Of course, the predominant opinion is that these voices are just processes in the brain fooling us, but nevertheless it is necessary to speak about *at least* one I outside the brain, otherwise this sentence wouldn't make any sense. This I doesn't observe, but is the awareness of the observation; for example I could say "I observe the computer screen" and imagine what this sentence really means. Well, they would explain me that photons coming from the computer screen are hitting my eye, which translates this in an electric signal which is transmitted to my brain, there it is decoded into an image. This may all very well be so, but logically speaking I should still add that I see the image in my brain. This I cannot be a property one could measure but it is ultimately that what observes.

This is the *least* one could say, I have met religious types who would claim that our “intelligence” is not measurable either, by this of course they do not mean that one cannot perform IQ tests, for what that may serve, but that it does not correspond to any physical process. That is, the “I” should be supplemented with our thought process which are stored on a spiritual “harddisk”, in other words they are processes happing outside the framework of spacetime (note that an identity falls outside spacetime too); as I have said before, these are processes for which nothing happens, since happening is tied to spacetime and visa versa. Note that I don’t say what spacetime is, nor what a happening is, all I say is that one is tied to another; as I have mentioned before, science *has* to close that door and elevate it into physical principles. Coming back to our discussion, the I exists (even quantum physicists don’t deny that) but they claim it to be irrelevant for physical processes since we cannot measure it; what I will do, is to turn the role around and *define* measurement from certain changes concerning the properties of “I”. Indeed, quantum physicists are confronted with a supplementary definition of measurement process which they take for fundamental; the measurement process distinguishes itself from the “evolution” process in certain characteristics but in my opinion, they are just two extremes of something much more reasonable. Let me elaborate upon why this would be necessary in a closed system: in quantum mechanics of a single particle, the measurement apparatus is “symbolized” by an operator, so that what measures gets a fundamentally different status but also falls out of the quantum system. If one would take quantum physis of the universe seriously, then one arrives at the contradiction that the operator cannot be applied since the observer also belongs to the system. This has lead to speculations about a universal consciousness making the observation, but that doesn’t really make much sense and I believe most of the founding fathers of quantum mechanics would have repelled that attitude. What I will do instead, is to restore the identity matter, leaving it entirely open if “most of time” the dynamcis doesn’t care about this issue, but making it of primordial importance when it boils down to defining the measurement process.

Now, it happens all too often that one symbol gets different meanings and we shall disentangle those from the beginning by using another symbol: for example, the couple (a, b) can stand for the ordered pair (a, b) where a has meaning with respect to A and b with respect to B and as such a and b have nothing to do with one and another, or the sentence a is in relation to b which we shall denote by aRb. Likewise, we have the distinction of “union” and “joining” where the union of two identities just means that they happily live next to one and another (they still can send messages, but they need a third party for this) while two identities join if they *behave as one identity*, that is, their description is *generically* larger than the union of the individual descriptions. Let me say here that words are just words and one could say, as we will do in just a few moments, that a union is a trivial join is we decide that the dynamics should leave the properties of a single particle rather trivial. This relates to the eternal interplay between kinematics and dynamics where *both* decide what is possible: the kinematics paves the ground for what is *potentially* possible while it is the dynamics which is the ultimate arbiter of what possibilities *happen* and which don’t. Obviously, if a possibility does not happen, then one might wish to make ones structure thighter and eliminate the potentiality theirof. So when we say that two particles behave as a single particle, we intend to mean this in the *broadest* sense possibile (which is broader than quantum mechanics indeed), so from our viewpoint, the distinction between classical and quantum physics might *not* be one of kinematics *and* dynamics but one of dynamics only. Let me illustrate this point of view which I realized only when I wanted to say things very accurately: in a classical first order system (we will see how second order systems can be treated later on) for a particle given by an equation of the form

$$\dot{x} = f(x)$$

one could describe the kinematics by x and λ where λ indicates the potentiality for x to happen. In classical physics, this potentiality does not change over time and remains 1. That is why classical physicists do not even speak about it, because it is trivial; in quantum physics, we have a so called wavefunction

$$\Psi(x)$$

which is equivalent to writing

$$\wedge_{x \text{ realized in space}} x$$

and λ where λ attaches a potentiality (complex number) $\Psi(x) \neq 0$ to each property x in the conjunction of properties a single particle posesses. So, if we take the proposition of properties and their potentialities as fundamental: it is the dynamics that decides wether the proposition contains just one property and likewise wether λ remains trivial or not. Now comes the catch one must understand very carefully: *generically* the dynamics of quantum theory will prefer to include as many properties in the conjunction as possible while the classical theory remains at one single property. So the quantum theory is more "generic" from this point of view but it is not at all for sure that the quantum dynamics is more likely to happen as the classical dynamics; it might be something in between or even something far more general than quantum dynamics. What physicists unconsiously do when dealing with this matter is to call an electron a quantum particle and a closet a classical object so in our language one might interpret this as additional properties of an entity. Now, why would a fundamental particle be exclusively quantum and not classical also or something in between? In physics, David Bohm and Louis de Broglie forsaw this possibility and attributed as well classical as quantum properties to the electron: so this is a new idea, that an unmeasurable property of a single particle might limit the kinematics and dynamics, we will illustrate that point of view later on too. So the reader must appreciate that what I am going to say below can be said in many different ways, from different angles and one needs supplementary philosophical prejudices to elimate one way of speaking about something or to elevate one above another. Since this section was about general principles of physics, I will refrain so from doing that as much as possible but on the other hand I must give a balanced account of what possibilities have been entertained so far in physics when dealing with these issues. In other words, when we say that two quantum particles join in a quantum way, it might be that the dynamics can make them behave as if we would take the union of them, such dynamics would keep both particles effectively separated from one and another and might be called classical. Differently, we might take the classical join of two quantum particles and therefore pave the ground for a mixed classical quantum dynamics where the classical part relates to the dynamics between them and the quantum part refers to the individual dynamics. Such situation can, as said before, also be described by the union of two quantum particles. However, if we take the union, *then* we forbid the dynamics of a join unless the union becomes a join of course. I will come back to this point later on, it is largely a matter of language but it is far from trivial to even just imagine writing a classical dynamics in Hilbert space, altough this is very much possible as exemplified above, it is just so that Hilbert space is not the "natural" habitat for classical (first order) dynamics. So, all of what follows is largely a matter of language and one may shift between different points of view; the reader should realize this and keep in mind that one cannot speak about *the* kinematics and that the framework presented below is a fexible one.

As stated already, one could "join" in different ways, for example in a classical and quantum way (we will define precisely what it means later on); so far in physics, the joining is minimal: that is the properties of the join are composites of properties of the individuals[2], there is no room for fundamentally new elements to arise from the joining. In a subsequent section, we will argue against this idea by relying upon an old argument of Leinaas and Myrheim. So what mathematical operations could correspond to those ideas of union and (minimal) joining? The proposition of the union of particle one with property x and particle two with property y is denoted by $x_1 \cup y_2$ while the joining of particle one with property x and particle two with property y is denoted by $x_1 \otimes y_2$ (or we might equivalently have used the logical symbol $x_1 \wedge y_2$). Actually, we meet here already a very point of reflection; when we say that 1 and 2 have nothing with one and another to do, it is fine that we use $\cup$ as a symbol since it is symmetric, that is $x_1 \cup y_2 = y_2 \cup x_1$; we alternatively could also have written $\{x_1, y_2\}$ but when we "join" 1 and 2 it is maybe of importance in which order we join them (that would be new in physics) or the "join" depends upon the properties of the particles; indeed, so far we have not said that x would just correspond to a point in space, it might include other properties which do not "commute" meaning that one cannot just interchange them between particles (so it might matter for the "join" that particle one has property x and particle two has property y and not the other way around, depending upon the properties x and y). Therefore, we will use the symbol $x_1 \otimes_\alpha y_2$ where the α reminds us that the joining can happen in many different ways. This is an important fact as the questions we can ask about the "join" or "marriage" depend on the way it has been constructed. We are not there yet since so far, the only reason to make a distinction between a join and union was that the join might depend upon particle properties and the union not. Since our original definition was that a join behaves as a single element, we must first specify what operations can be done on single elements; since we identified $(\star)x_1$ with the proposition "particle one has property x" we simply have to take over all well known operations one can do with (logical?) propositions, that is $\wedge, \vee, \neg$. For example $x \wedge y$ means that a single particle has properties x and y - we will define a single particle to be classical if none of these operations apply, stochastic-classical if only $\vee$ applies, quantum if $\wedge$ applies and stochastic-quantum if both $\vee, \wedge$ apply.

[2]Mathematically, this expresses itself in quantum mechanics by the idea that the two particle Hilbert space is the tensor product of one particle Hilbert spaces.

For example, in classical mechanics, a single particle cannot have two positions which in quantum mechanics they can have; also, in quantum mechanics, a particle can have spin $\frac{1}{2}$ and spin 1, but these properties can only exclusively be measured which we said before. Let me stress so far that by distinct properties, I really mean properties which have nothing do with one and another - *appearantly*, this may differ from theory to theory, in classical mechanics the position and momentum of a particle are distinct properties while in quantum mechanics they are not; I do not need to comment so far on the specific mathematical implementation of this concept, sufficient to know is that these properties can be specified exactly (for example they can correspond to a real number or a word). I will argue against this viewpoint that the momentum is a property of a particle, something which is grounded in the philosophy of continuous time and "eternalism"[3], I will present a different interpretation later on. So, for a single particle, one could suggest that $(x \wedge y \wedge z) \vee (w \wedge v) \vee (\neg z)$ has to be interpreted in the usual way (and corresponds in quantum mechanics to a "union" of states, and can be interpreted in the same way as a density matrix, as we will see later on) albeit the $\neg$ operation is *never* used in classical nor quantum mechanics. There, one only states what *is*, or the property one posesses and not, what *not is* (or what one does not posess) since the absence of being (or posessing) of something automatically follows if it does not belong to the list of what is (or what one posesses); while, on the other hand, the above notation refers to what is true and what is not true and the absence of a statement about the truth of something does not reveal that it is false. So there is a *real* distinction in declaring that "an entity has those properties" or by "the sentence that "this entity has those properties" is true"; the former is just an object "sentence" while the latter corresponds to a process

$$\text{sentence} \overset{\text{logical}}{\to} 1$$

where 1 stands for "true". The reader must notice that I did not talk about the word "implies" symbolized by $\Rightarrow$ as a logical operation since there is no a priori *logic* in spacetime; it is pointless to say that one event "implies" the other event without saying something about the dynamics. So, the above operations are *not* the logical ones and the interpretation of the property $x \wedge y$ is that the single entity has both properties x and y and no other which is not the same as the proposition that particle one has properties x and y is true. Similarly, the property $w \wedge x \wedge y \ldots \wedge z$ means that a single entity has properties w, x, y, $\ldots$ and z. The $\vee$ operation used here, is the exclusive "or" where the property $x \vee y \ldots \vee z$ means that the entity has exactly one of the properties $x, y \ldots z$ and no other where the latter can be in general composed properties by $\wedge$. The de Morgan rules hold exactly in the same way as they do for the ordinary logical or/and operations.

Let us now come back to the definition of a join which was that two identities join if and only if they behave as one identity: this already means there exist at least (and indeed there exist more) four joins: a classical, stochastic-classical, quantum and stochastic-quantum one. According to the definition of

[3] By eternalism, I mean that space and time exist a priori, are uniform in (global and local) structure and are of vital importance in defining the dynamical laws.

a stochastic-quantum join, we can write down sentences like

$$((x_1 \otimes_\alpha x_2) \wedge (y_1 \otimes_\beta y_2) \wedge (p_1 \otimes_\gamma p_2)) \vee ((r_1 \otimes_\delta r_2) \wedge (s_1 \otimes_\kappa s_2)) \vee (t_1 \otimes_\lambda t_2)$$

where x_i stands for property x of particle i and these operations are already generalizations of what in quantum mechanics is called the two particle Schrodinger theory albeit the latter needs an extra, trivial ingredient. We are far from being done and as the reader will appreciate, the current status of theoretical physics is just at the second stage in a sequence of infinite stages one can write down in this way. Before we proceed, we will slightly change our notation for the better (as the reader will see):

$$(x_1, y_2)_{\otimes_\alpha} \equiv x_1 \otimes_\alpha y_2$$

this will allow us to speak about the "join" of n particles with properties x_i as

$$(x_{1\star}, x_{2\star}, \ldots, x_{n\star})_{\otimes_\alpha}$$

where $x_{j\star}$ stands for property x_j of particle j. In the physics literature, this tensor product is "deduced" from the lower tensor products by means of a strictly quantum mechanical argument (the cluster decomposition principle); as we will argue later on, the cluster decomposition principle is irrelevant in our more general setting and therefore such reduction should not take place. The catch is of course that one must be able to speak about the union of quantum mechanical systems, or in our language, the union of sentences in "joined" particles. This constitutes a part of the question of how our operations should be extended on composite objects. One usually regards it as a virtue of relativistic quantum field theory to recognize the following simple fact, which is here merely a question of completion of operators, which is that $\wedge, \vee$ extend between multiparticle joins; that is, one can write down things like

$$((x_{1\star}, x_{2\star}, \ldots, x_{n_1\star})_{\otimes_{\alpha_1}} \wedge (y_{1\star}, y_{2\star}, \ldots, y_{n_2\star})_{\otimes_{\alpha_2}}) \vee (z_{1\star}, z_{2\star}, \ldots, z_{n_3\star})_{\otimes_{\alpha_3}}$$

which prepares the setting for an extension of quantum field theory. Here, some caution is necessary, until so far we have *assumed* that if we write down things like

$$(x_{1\star}, x_{2\star}, \ldots, x_{n\star})_{\otimes_\alpha} \wedge (y_{1\star}, y_{2\star}, \ldots, y_{n\star})_{\otimes_\alpha}$$

that both indices $j : 1 \ldots n$ in the "superposition" referred to the *same* particle or entity, but how to interpret this more general situation? As a fact, for an infinite number of particles, how do we know that the indices j in the above refer to the same particles? The answer given in quantum field theory to this problem is that this matter of identity is *irrelevant* regarding proper physical questions one can ask; in other words, we do not need to answer this identification problem in order to extract physical predictions like I measure a particle with properties x or I measure two particles with property y and z. Hence, in this interpretation, one *excludes* observables which do not measure properties of a definite number of particles since it would be unclear how to interpret this. So, basically, one measures *properties*, the act of measurement can only be performed thanks to existence of particles or identities, but one declares oneself ignorant about which particle it is one measures a particular property of. The fact that in the macroworld, we can measure properties of specific identities (me or you) happens then because we are not in superposition and the problem is not asked.

The reason why one can do this is because one speaks about a one particle Hilbert space which is the same for all particles, the implication of this is well known and that is that every particle can have an infinite extend or has acess to the entire universe meaning one can form conjunctions and disjunctions of properties in an *unlimited* way; it is this principle which we will criticize later on. To jump a bit ahead, in quantum field theory, one speaks about creation and annihilation operators corresponding to a particle with specific properties, but one never mentions about which particle it goes; this gives a two particle state $x \otimes_f y$, where f stands for "fermionic", the meaning of the join of a particle with property x and a particle with property y, both properties which contain the word fermionic, and this "product" does depend upon the order in which one writes the *properties* x and y. That is,

$$x \otimes_f y = -y \otimes_f x$$

and since we *do* speak in terms of which particle has which property, we will refine the notation by stating that

$$x_1 \otimes_f y_2 = -y_1 \otimes_f x_2$$

where x_k has the usual interpretation. We will later explain the meaning of this minus sign in the context of quantum mechanics; So, I am going to properly restore the identity question and leave it as a matter of *dynamics* to determine whether one should make some identifications in a probability interpretation or not. So, from now on, we shall always denote

$$(x_{i_1 \star}, x_{i_2 \star}, \ldots, x_{i_n \star})_{\otimes_\alpha}$$

where $i_j \neq i_k$ for $j \neq k$ and $i_j \in \mathbb{N}$. There is no a priori philosophical, nor physical reason to be so easy going about the identity question in the micro domain. I admit it is a very strong principle to say that answers (probabilities) to dynamical questions do not depend upon it, but it is for sure no mandatory one since for example, there might be a principle concerning the number and size of joins a single particle might engage in, and we should be conscious about it when we decide to make either choice.

The reason why I have been so strict about the identity question is that one might in principle posit that for example 1 and 2 join and 2 and 3, but *not* 1 and 3, in quantum theory, this situation is impossible to describe as it does not matter (one would just say one has two particles) but it is clearly a very logical possibility and I shall develop it further now. As before, we cannot preclude that 1 is single also even if it joins with different parties so we make the liaison part of the dynamical content; moreover it should also be possible for 1 to remain separate from 2 and 3. How should we write such state down? We would write down for example

$$p_1 \cup (q_1 \otimes_\alpha r_2) \cup (t_2 \otimes_\beta u_3 \wedge v_2 \otimes_\gamma w_3)$$

where the correct interpretation is that one has a description separated from a description of the join of one and two and from the join of two and three. This does *not* reveal yet that one has *classical* properties and *quantum* properties from its joining with two for example; that is another question as we have adressed already. We have called a single particle state stochastic if and only if it is of form

$$x \vee y \vee z$$

that is $\wedge$ does not appear into it. Logically this reads, the single particle has property x *or* y *or* z. Now, one might be more liberal and assume the particle *must* always have a well defined event associated to it but it might posses the colours purple and green jointly. In that case x is a shorthand for (p, green) and we can write

$$((p, \text{green}) \wedge (p, \text{purple})) \vee (q, \text{red})$$

and so on, this state is neither classical nor quantum but stochastic-classical. However, it posses classical features in the sense that it cannot have two properties of event; as we will discuss later on, a classical dynamics maps classical states to classical states and likewise does a quantum dynamics but the most general dynamics can map classical to quantum states, change liaisons by creating new joins and destroying existing ones and likewise so for separated entities. So, in our general example

$$p_1 \cup (q_1 \otimes_\alpha r_2) \cup (t_2 \otimes_\beta u_3 \wedge v_2 \otimes_\gamma w_3)$$

we say that 1 has a classical property p_1 and a joint *pure* property with 2 and 2 has an *impure* property with 3. One might at this point agree that this situation prototypes the most general one in the sense that the correct order of operations is given by $\cup, \vee, \wedge, \otimes_\alpha$ and that would make a lot of sense. It is completely reasonable for a single particle to have two disjoint descriptions as a single entity, for example a "classical" and a quantum mechanical one such as is the case for the Bohm-de Broglie approach; also, it is a priori possible for a single particle to join twice with a second particle, as long as the "join" is different. The distinction between $p \vee q$ and $p \cup q$ is that in the first case only one conjunction is correct but nature has an *intrinsic* lack of knowledge about it (where usually this lack of knowledge is assigned to the limitation of a description by some observer), while in the second case both conjunctions are valid but *different* descriptions, meaning you cannot apply $\wedge$ nor $\vee$. Both arguments are familiar to people who know physics albeit they are more restricted there; for example, in quantum mechanics, we can have different descriptions of a single particle, but there those are assumed, by construction, to be equivalent (meaning the same up to a change of basis). Here, we extend this principle, by allowing them to be non-equivalent; in words we make a distinction between a conjunction of properties, which we might call a partial state and a conjunction of partial states. In the language of set theory, this is the distinction between $\{X, Y\}$ (the conjunction between partial states) and $\{X \cap Y\}$ (the conjunction of properties) where X, Y are subsets of some larger set; X or Y would then be given by $\{(X \cup Y) \setminus (X \cap Y)\}$ which is the disjoint union. One could try to imagine what something like

$$(1 \cup 2) \wedge (1 \otimes_\alpha 2)$$

would mean, literally one would say it has both descriptions as a system where 1 and 2 are disjoint and a description in which they are "joined". In my opinion, this would be equivalent to

$$1 \cup 2 \cup (1 \otimes_\alpha 2)$$

on the other hand

$$(1 \cup 2) \vee (1 \otimes_{\alpha} 2)$$

would mean that only one description is true but we don't know which one; it is here that I would launch a philosophical principle which is that of *definiteness of the description* which means that this "or" relation is forbidden. The reader must notice that so far, I have skipped sentences like

$$(p_1 \wedge q_1) \otimes_{\alpha} r_2$$

bringing the operations which are valid for a single particle under the multi-particle join; actually, we have declared (by our agreement upon the order of operations) that such sentences should not be written. Of course, we should comment upon this and we will postpone this discussion to the future, but suffice it to say that in quantum mechanics it has something to do with

$$(p_1 \otimes_{\alpha} r_2) \wedge (q_1 \otimes_{\alpha} r_2).$$

As mentioned in the very beginning, one attaches "potentialities" to these sentences; in standard quantum mechanics this means that to every particle property we attach an *amplitude*, which is a quantifier from which the probability for these exclusive properties to arise can be measured. Note, that this definition is far more general than the quantum mechanical one as we do not even demand this amplitude to belong to a division ring. Therefore, our setting is much more flexible than the one of Jauch, Piron and Aerts; indeed, we did not make any restriction on the lattice of propositions one can make, the only nontrivial input is that of a union and a join and the definition of operations on properties of a single entity. Moreover, one can further widen our scope in a categorical sense and we shall just do that later on, this section was just meant as an appetizer and there is much more to say about it than we did so far.

2.1 On the definition of spacetime and causality.

Now that we have defined the words classical and quantum given disjoint generating properties which we associated to space, let us now come to a further specification of what we mean by "spacetime", before we can proceed to the notion of universe. Spacetime furnishes, in the most abstract sense, the ground for properties of elementary particles just like Minkowski geometry does for point like particles. To start with, everyone's description, which is different from one's experience, of nature is that of a sequence of processes

$$A_o^1 \to_o A_o^2 \to_o \ldots \to_o A_o^n$$

and the question now is how to "glue" these experiences and descriptions of open systems together in a theory of a closed system, the universe. This is what the philosophy of spacetime is about and what causes all the heathed debates: experience has thought me that you need to weaken this gluing procedure as much as possible. Let me first give an idea of the scope of this question, its twists and turns as we know it in modern physics; as I have stated already, the theory of quantum mechanics is a theory of open systems meaning the observer does not belong to the system. Since in modern Quantum Field Theory particles are described *relative* to an observer, they have become an observer dependent concept, a philosophical stance which cannot be maintained for closed systems where the observer himself consists out of particles. So, the reader may guess that different observers might give different descriptions of what is going on: one observer might be an accelating one while the other freely falling (I will explain these concepts in far greater detail later on). What the theorists now do is to *compare* these descriptions of the universe of both observers by assuming three *objective* properties (that is spacetime, the so called field algebra[4] and the field equations); the very structure of quantum mechanics allows for such comparison to be made once these objective properties are taken for granted. Now, what one arrives at is that while the free falling observer may describe the universe as empty, the accelerating one will describe it as being full of particles (we will spawn more detail out later). From the viewpoint of a closed system, this would mean that the process of accelerating will necessarily create particles if the universe were empty so that the accelerated observer effectively sees them and a remote, free falling, observer at some distance of the accelerated one might observe something like particles surrounding the accelerated observer. Now, it appears rather obvious that the specific spectrum of particles which get born together with the act of acceleration will depend on something more than just the magnitude of it; for example it might depend upon the mass and charge of the observer. This is the nonsensical aspect of the usual quantum mechanical calculation which has been called the Unruh effect, the spectrum of particles seen only depends upon the magnitude of acceleration of the observer; this is in some way logical as the very scope of describing open systems is limited to the very primitive character of the observer. Indeed, for a perfectly massless and chargeless observer, such as is the case in quantum field theory, physical intuition would tell you that no particles are born whatsoever because of acceleration. This has often led me to say that there does not exist an Unruh effect while at the same time admitting that particles may be found whose spectral properties would *probably* depend upon a lot more than just the magnitude of acceleration of the observer. Of course, this is all just a theoretical exercise and an Unruh effect has never been detected, nevertheless most researchers would claim it *implies* an observer dependent nature of the particle concept and as I have just illustrated that is just plain nonsense (and also erupts the question what this metaphysical observer really is). Before I will enter in the rather difficult general discussion of gluing our experiences together, let me elaborate first on how science has dealt with this question for the last couple of centuries starting out with Newton, Galilei and friends: they assumed (a) there is a fixed number of material objects constituting the universe, the processes $\rightarrow_o$ every "conscious" material object observes also *happens* at the very moment the observation takes place (here again one abuses language -and identifies a process with a now- because they assume the process of observation to be infinitely fast). Therefore, they completely tie the concept of happening to observation by demanding that there is a universal "now" associated to an infinitely fast process (observation) such that in reality there is an *objective* process happening when we observe something like it happening. This is Newton's principle of simultaneity of happening and observation, by our senses, of this event; hence the deduction by Newton and consorts of the existence of signals which "travel" infinitely fast. These are of course not all the assumptions Newton made, but

[4] I will argue against an objective field algebra from the traditional viewpoint later on.

it is one of the most important and basic ones. Second, Newton assumed that this "now" had the structure of a three dimensional Euclidean space $(\mathbb{R}^3, ds^2)$ where

$$ds^2 = dx^2 + dy^2 + dz^2$$

so he did not only assume that material bodies made up the universe, but the universe was more than that, a fictitious space (which could contain no matter at all) equipped with a fixed Euclidean line element which he interpreted as a fixed physical measure stick which was outside the realm of dynamics. Third, he assumed that every past and future now had precisely the same structure and that time is a continuous parameter running infinitely far to the past and future. So, Newton went far beyond the more elementary process view explained in the beginning of this section and described everything with respect to a meta time.

Einstein, Minkowski, Lorentz, Poincaré and friends offered a less rigid but similar interpretation, very much like Newton, he presumed eternel material bodies making up the universe and likewise did he give the universe a fictitious structure beyond that but some interpretations of relativity deny the existence of an absolute now of *being*, meaning that the theory contais an element of where I am when you read this work. By this, I do not intend to say that the theory must give a unique answer to this question, but at least that it gives some answer; Einstein's theory of relativity leaves this completely blank and proposes that the issue is not a physical but a metaphysical one. I am not a historian of science and I usually do not really care who thought what, but let me present the minimal assumptions which go into the theory of relativity and then present possible "supplementary" interpretations. I think that Einstein was impressed by the fact that Minkowski's geometry turned up in the theory of light and he wanted a theory of gravitation which was compatible with it. If one takes this point of view, then the causal *interpretation* of the conformal structure of the metric follows from additional assumptions regarding classical (field) equations of motion. It is however so that classicaly, you can turn this relationship around, that is start from a notion of causality and a volume element and deduce gravitational phenomena from the geodesic equation of motion. The latter says, as explained before, that free particles move on a straight line which correspond to the ellipses and circles of flat Euclidean geometry when one makes a *three* (and not two) dimensional projection. We will come back to the causal interpretation in a while. As said, general relativity (and perhaps Einstein too) sees the question more broad, than Newton did. One recognises that the question of the happening of a process versus an image of it being "sensed" by an observer removed from it needs to be answered, but Einstein also thought that "signals" could travel at most at finite speed so that me measuring a signal coming from Venus means that Venus sent out this signal somewhere in *my past*; likewise he recognized that there were signals from places which had not received me yet so that they were "spacelike" to me. Moreover, in some bizarre twist, he designated the places in *spacetime* to which I can send (towards the future) a signal (in my personal) now. Einstein constructed his work furthermore on the insights of special relativity where it was the causal geometry of Minkowski which was being important, the latter being given by

$$(\mathbb{R}^4, c^2dt^2 - dx^2 - dy^2 - dz^2)$$

where c is the speed of light. To my mind, it is pretty clear that Einstein must have thought that the lightcone

$$c^2dt^2 - dx^2 - dy^2 - dz^2 = 0$$

delineated the propagation of physical processes, light is to travel on the lightcone and all material bodies are to travel within, that is

$$c^2dt^2 - dx^2 - dy^2 - dz^2 \geq 0.$$

This is one facet of the causal interpretation: all signals propagate within the lightcone. More precisely, one has the following initial value point of view: suppose that all initial conditions for the universe are given on a three dimensional hypersurface Σ, that is the initial conditions for the metric (gravitational field) and matter within the universe, then the evolution of this data has the following dynamical property: the state of matter or the gravitational field in an event is fully determined by the initial data in the past of this event. This implies that if you would change the initial data outside the past of this event, there would be no influence whatsoever on the state of matter and the gravitational field in that event. This is a result valid for fields, for point particles one can show that if they initially travel within the lightcone, they will continue to do so; but on the other hand it is possible for them to travel outside the lightcone (and continue to do so), such particles are called tachyons. For a philosopher, the very existence of a gravitational field is already an assumption he cannot a priori justify and it is natural to resort to a causal interpretation since this has something of a more substantial flavor. In other words, we need to find the *logical* origin of gravitation which is a question Einstein left far open. Now, there is a logical connection in theoretical physics between the concept of Minkowski geometry and some quantum mechanical assumptions on the one hand and the particle properties of mass and spin on the other. More specifically, the statement is the following: Minkowski spacetime has a symmetry group which we call the Poincaré group, quantum mechanics dictates that any symmetry should be elevated to an *operational* symmetry (so that invariance under it becomes an operational principle) and that one needs to study irreducible representations of the group. Those irreducible representations determine partially the distinct atomistic properties of a single particle; that is mass and spin are predicted but not say electric charge. Let me list the long chain of assumptions which goes in the deduction of these properties: (a) "eternalism" (b) continuum hypothesis (c) operational symmetry (I will spawn my comments on that later on) (d) irreducible linear representations determining distinct atomistic properties. There are other approaches towards this problem, one constructed several years ago by this author and another one relying on spinor bundles and the theory of fields. Both approaches elevate the above deduction to a more general setting and both have their problems. In classical general relativity, one could try to deduce the existence of a particle in terms of properties of the gravitational field, for example there exist solutions to the vacuum equation with so called singularities where the physical properties of the solution suggest that a particle should be present at the singularity or that the geometry represents a particle and its gravitational field even though we inserted no matter terms in the Einstein equations. This is for sure the case for the Schwarzschild and Kerr-Newman black hole solutions and such general programme might be called "matter from geometry" instead of "geometry equals matter" where the equality means that both influence one and another but are independently defined. It it unnecessary to say that here one still needs to define an identity from the gravitational field but the catch is that this identity is not going to influence the evolution of the gravitational field, the latter just evolves by itself (and the identity would need to be redefined during this evolution). It is just so that one can define an identity which one might reasonably suggest to be a source for the gravitational field but in reality it is not. This situation is less general of course than the one where one takes identities as fundamental as they are believed to have an influence on the notion of geometry. Let us now come back to the interpretation of causality in quantum mechanics, is it there also the case that particles propagate within the lightcone or that fields satisfy causal propagation properties? There, the answer is more subtle and is given by the statements that (a) the field operators for sure propagate in a causal way but (b) particles can "propagate" outside the lightcone and even into the *past* (another consequence of eternalism). More precisely, if I were to create a particle by acting on the vacuum here with the field operator, it *might* (with some probability) immediately be measured on Venus in some global reference frame. In that sense, signals do travel faster than light in quantum field theory, since I could replace the word particle by say Mozart's symphony. Nevertheless, the notion of causality presents a limitation on this kind of exotics by making the probability, for such detection to take place, exponentially small in terms of the spacelike separation; at least, this is so in Minkowski spacetime. Effectively, without reference to field operators at all, the notion of causality would mean *outcome independence*, a notion which is derived from a $3+1$ view on Einstein's four dimensional "block" spacetime and which will be explained in the next section. So, we are left with two distinct meanings on causality both of which may be right in their own domain of application; my suggestion is to dispell the notion of causality from foundational discussions and replace it by "evolution of an individual atomistic property" and maintain that it is the dynamics which decides what causality interpretation holds - that is outcome independence ought to be a constraint on the dynamics *resulting* from the notion of "evolution of an individual atomistic property".

Before we proceed with this more general discussion, let us further examine a bit the implications of Einstein's view on spacetime: for example, it implies that the future already exists (in a sense we will clarify in the next section), moreover, it obscures the experience of the process of measurement between two "nows" by an individual observer given that there is no such thing as "happening" in the theory. Nothing comes to creation in the theory and everything is eternal unless you run into a singularity (which should not be seen as an internal contradiction in the theory as some prominent physicists stress, it really depends upon one's interpretation); as it turns out, according to our definition of a process as a change of state, modern physics arrived in the murky situation that with a traditonal view on the notion of state within Einstein's theory, there is no process taking place whatsoever and therefore no observation. This is generally accepted to be a consequence of general covariance, a symmetry which is only possible because of the assumption of "eternalism" or in other words, due to the denial of some dynamical origin for this symmetry. It is a dead place for quantum mechanics and this is indeed the so called problem of time physics faces since 90 years. The intention of this section was to be general, so I am postponing more details on these problems of general relativity, instead I return to my original question and study if I can solve it into an even more general way than Einstein did and with a significantly different interpretation such as "evolution of individual properties" versus causality.

So, our discussion is still one of kinematics, meaning ways to phrase the basic ingredients to speak about a theory of nature, not about dynamics which dictates how these ingredients merge and evolve. To illustrate the great liberty at hand here, let me give a Newtonian way of describing Minkowski's geometry; suppose that *space* exists, which as we have said before is the collection of properies of elementary particles, and is given by $(\mathbb{R}^3, dx^2 + dy^2 + dz^2)$, a three dimensional metric space. Suppose that it just remains static during the process of evolution and introduce a time δt for a process of evolution to happen. Then, we would like to say which atom (point) evolved into which atoms (points) during this process of evolution; we declare by fiat that (x, y, z) evolves into all $(x + \delta x, y + \delta y, z + \delta z)$ for which

$$c^2(\delta t)^2 - (\delta x)^2 - (\delta y)^2 - (\delta z)^2 \geq 0.$$

Given that the geometry of space is fixed, one can now retrieve Minkowski's view by choosing an origin of time and taking $\delta t \to 0$. We are now confronted with the question, which point of view is the correct one? Minkowski's point of view which is "eternalist" and takes the Lorentz symmetry as fundamental, or this point of view with an absolute time and space but with emergent relations arising from reducible processes, with otherwise exactly the same physics? I think this question is again one of what one means by the observer: Minkowski would say the spacetime coordinate system is tied to a global observer while in my view one would need to add the observer as a physical entity to the system and then notice that its dynamical time (eigentime as measured by perfect clocks) does not need to coincide with the meta time t. Actually, I think that both interpretations are mistaken since in our view, why would the process of evolution of properties not depend upon previous established evolutions of properties and properties themselves ? On the other hand, one should just remark that the Lorentz symmetry is always a local symmetry and properties of particles should be determined by the local geometry and not the global one. For example, one might imagine that for some corner of the universe, the property spin is differently defined what would be the case if space were four dimensional instead of three dimensional over there or if the metric were four dimensional Euclidean instead of Lorentzian (such as is the case for the Hartle-Hawking wave function). Therefore, the virtues of Minkowski's viewpoint (the Lorentz symmetry) do not require his "eternalist" viewpoint. Hence, we arrive at the more general viewpoint that one needs to study processes from one universe, where one considers spacetime instead of space to a larger universe. Let us now try to make that precise, in our previous analysis which started out at page eight, we stressed that properties of elementary particles were related to space and preferred this over saying that they were related to spacetime, the reason why I made that choice is because I had not defined space nor spacetime yet and it was more correct, given that wecan only measure properties of space, to state space. So far, we have uttered the words properties which are necessary attributes for particles, evolution of properties, processes, space and spacetime:

let me now try to find a proper language for dealing with those concepts and point out its limitations. First of all, why would we like to speak about evolution of properties? As we will see later on this concept is one of pregeometry, that is under *additional* assumptions Lorentzian geometry follows from it. Strictly speaking, one can write out a process just as evolution of conjunctions and disjunctions of properties of particles; but such dynamics would not be based upon any *principles* if we did not specify any relations between properties. Newton already recognized that and unified these relationships by means of the concept distance (metric) so that he could speak about properties which are far apart and close by. Now, I believe it is a general principle that nothing must be static, meaning that those relationships had to evolve too which is part of Einstein's view; but there it are the spacetime relationships which count and not the space relationships. These relationships are what I call evolution of properties, wich are preserved and created by means of a process which is something even more radical in the sense that now, the properties get "reborn" also: it is the dynamics which must decide how far this birth process must go and their existence should not be a priori determined such as is the case in Einstein's theory. This paves the ground for *dynamical* laws (that is the potentialities we attach to processes) which evolve too: away with "eternalism"!

Now, we just spoke about the fact that a universe with laws needs relationships between its properties and that those relationships might change and new properties get born by means of a process. As far as I know, there is no real justification whatsoever to limit those relations to the concept of evolution of properties which I will explain now. In a sense, the latter constitutes a generalization of what Einstein did, but excludes such possibilities as a Riemannian (part of the) universe such as exists in the Hartle-Hawking wavefunctions. As the reader may guess, this concept relates to the dynamical notions of finite signal propagation, as laid out by Minkowski, and the notion of outcome independence, but I will present it in a somewhat more general way than usual. We will make the agreement here that all our spacetimes contain the relation "evolution of properties" although I warn the reader again that there is no good philosophical reason to do so - my attitude being grounded here in history. Now, in what language has been spoken *so far* about the evolution of properties? This has been done in the category of sets as we will work out now; when we say that a property x evolves *during a process*, it means we attach a set of properties to it $\{a, b, \ldots c\}$ some of which might not belong to the previous universe. That is, the new state of the universe contains all actual properties (including the new ones) as well as the information about the evolution $x \to \{a, b, \ldots c\}$. Unless we assume that evolution processes are irreducible, we must assume that we will allow for the birth of evolutions between *new* properties also. Now, and this is just a matter of convention; in order to "depict" the effect of a sequence of processes involving the birth of new evolutions of properties and properties themselves; it is convenient to assume that every property x is different from the properties $\{a, b, \ldots c\}$ it evolves in. Another option to reconstruct the process would be to enumerate the evolutions of properties so that we know which evolution came before another in the sequence of processes. Traditionally, one opts for the first viewpoint and this "picture" is what is called *spacetime*; in case for a finite number of properties in spacetime, one can depict this by means of a so called Hasse diagram. More in detail, we draw an arrow from x to a

if $a \in \{a, b, \ldots c\}$ where the latter should be read as x evolves into $\{a, b, \ldots c\}$ and *not* x has properties $a \wedge b \ldots \wedge c$ or x has properties $a \vee b \ldots \vee c$ or for that matter any proposition one can make from the properties $a, b, \ldots c$. How does this relate to set theory? Well, if the evolution of properties itself is *not* irreducible, then the reader must understand that for some of the properties in which x evolves into must evolve amongst themselves, that it is possible that $b \to \{c, d, \ldots e\}$. Consistency of what it means to evolve into, then should imply that

$$\{c, d, \ldots e\} \subset \{a, b, \ldots c\}$$

too. Now comes the fundamental assumption which is the following: our discussion suggests that we should expand the notion of evolution towards sets of properties. We assume that this evolution reduces to the individual one in the sense that $\{x, y, \ldots z\}$ evolves into the union of evolutions of $x, y, \ldots z$. Without this, it would be impossible to formulate initial value formulations for physics as x and y separately might not evolve into a but jointly they would. More abstract, consider the following category *prop* which consists of all subsets X, Y of properties as objects and with morphisms the inclusion $i : X \to Y$ if $X \subseteq Y$; then our evolution E is a functor $E : \mathit{prop} \to \mathit{prop}$ which maps every subset to the one it evolves into. E satisfies the four properties that

$$E(X \cap Y) \subseteq E(X) \cap E(Y),\ E(X \cup Y) = E(X) \cup E(Y),\ E(\{\emptyset\}) = \{\emptyset\},\ E^2(X) \subseteq E(X)$$

and moreover

$$E(\{x\}) \cap \{x\} = \{\emptyset\}$$

for any singleton $\{x\}$. All conditions, except the first one which follows from $E(X \cup Y) = E(X) \cup E(Y)$, are independent and one can wonder why we do not elevate E to a monodial category (containing *prop*) by allowing for a "join" $\otimes$ of properties just like we did for particles and properties theirof. The thing is that I would not know what it means. Spacetime, on the other hand is an identity and the description above, in terms of the category *prop* and functor E, which we will denote by the tuple (prop, E) constitute the properties of spacetime; hence, we can allow for looking at spacetime as a quantum, classical, stochastistic or classical-stochastic entity depending upon which operators $\wedge, \vee$ one allows for in the kinematical description. Also, here, one might go further and consider a single universe to consist out of multiple spacetimes and therefore allowing for a join $\otimes_\alpha$ applied to spacetimes; this would be considered as a second quantization of gravity. Even more exotic, one can quantize the universe, consider multiple universes and universes of universes, we will treat all this in greater detail later on. It is not as simple as it looks and one needs to be careful about it. So, what is now the definition of *actual* space given that we have a spacetime: it is the set of all properties $\{x\}$ such that $E(\{x\}) = \{\emptyset\}$. To relate to the literature here, the notion of evolution we have described here is equivalent to that of a partial order on the set of properties, and therefore our programme includes causal set theory. The virtue of my presentation is that one appreciates its limitations when speaking about nature while causal sets are usually percieved as a generalization of known physics. Moreover, in causal set theory, the partial order is suggested to determine a notion of causality, an interpretation which we rejected here; at best, it should have something to do with causality but the dynamics is the arbiter of that and not the kinematics. Indeed, causal set proponents regard this partial order to define the past and future of an event (which I call property), an interpretation which just does not make any sense and has lead them to consider the wrong notion of Bell causality.

2.2 The relations between the identity spacetime and the subordinate identities of matter.

For now, we have said that spacetime is constructed from properties of matter and evolutions thereof. These properties are assumed to be distinct but not necessarily atomistic in the sense that smaller properties of *particles* can be derived from relations between evolutions of these primary properties. For example, spacetime in general relativity is given by a four dimensional manifold equipped with a Lorentzian metric; the local Lorentz group is something which follows from the Lorentzian metric or one might also argue that it is encoded into it from the very start. As said before, the Lorentz symmetry, as part of the Poincaré symmetry, gives rise to the notion of spin while the translation part of the Poincaré algebra gives one a notion of mass (the arguments to get there do not need to be quantum mechanical in nature at all) and to my feeling there is a standard interplay between dynamics and kinematics here. That is, the concept of mass as well as its magnitude might follow from a mixture of kinematics and dynamical restrictions and not just from kinematics alone. We are still far removed from such an understanding in theoretical physics and certainly many theorists would dream to calculate the mass of an electron from first principles. Newton's concept of mass came from his intuition about the meaning of the concept "force" but nobody knows what that means either and certainly, as mentioned before, the units of meter and second cannot be fundamental either so that dimensional analysis really cannot be the main guide in one's thoughts albeit it is a very useful and a powerful way of thinking when dealing with theories for open systems which are written out with respect to an observer's reference frame. There appears to be no metaphysical argument beyond this which could settle further the kinematics of spacetime and therefore *deduce* the properties we are speaking of - here we must let ourselves be guided by our senses which may not be the best method after all. For example, our senses would say spacetime is four dimensional meaning that we have three dimensions of space and one dimension of time; it is very possible to construct theories with more dimensions of space and maybe of time which project down to our four dimensional experience which reminds me very much about the story of Plato's cave, that we observe a shadow world. Here, we *must* rely on our common sense and take Heisenberg's dogma that we only ought to speak about theories connecting direct relationships between our senses, and nothing more, into account. Modern physicists know that our senses aren't good enough and hope to find evidence for another structure beyond that, but then we enter into the realm of speculative theories while I would prefer a *dynamical* explanation for the emergence of our senses. That is, why to restrict kinematics beyond *reason* and refrain from finding a physical principle restricting the dynamics so that our four dimensional world rolls out on the scales we observe it? Some people try that, but not many, it is already a very hard problem to show how a smooth spacetime geometry emerges from something like a pregeometry, let alone that we can calculate an electron's mass from first principles. There will have to be done hard work indeed before we gain further insight into these matters - here I am not concerned as yet with how our properties of particles connect to our senses (which may be a complex business) and will continue to reason further on in terms of "fundamental properties" and emergent ones (deduced from relations between evolutions of fundamental properties). After all, I want to be general in this section and not be too much concerned about *our* universe; perhaps there does not exist a better exlanation for the existence of our universe and we are part of a *landscape* of universes - this would be very deprimating indeed.

What I want to speak about in this subsection is the tower of relationships one can and must develop between the identities of matter and the identity of spacetime and spacetime of identities of spacetime and so on. One notices that our language falls a bit short here and one can better speak about subordinate identities; in sociology, you can compare this to the identity "state" and "citizen" although you will never hear a state say that it is a state. Spacetime *may* be different since it is a fundamental substance to reason about particles, a state though isn't of much importance for reasoning about it's inhabitants. Let me warn the reader again that what follows is how far I can see and depends upon my personal interpretation of metaphysical concepts which I try to explain patiently; this necessarily implies that I will also make by definition idiosynchratic interpretations on the current state of physics, but I will at least warn the reader when they are not mainstream. Actually, I have already done that regarding the Unruh effect, let me elaborate upon that: (a) the mainstream interpretation is that the accelerated observer has a different vacuum state and particle notion and that one needs to calculate a Bogoliubov transformation between those, this makes sense from the viewpoint of quantum mechanics as a theory of open systems relative to an observer but not with regard to closed systems such as the universe and therefore we have to dismiss that viewpoint (b) Maldacena's viewpoint, which he and I discussed a few years ago, is that the vacuum state is for sure objective and tied to the Minkowskian geometry, it is just so that the accelerated observer measures different observables which are *not* diagonal in the particle base, this already makes more sense but we have excluded such observables in our interpretation of quantum field theory as we cannot speak about a definite particle number anymore which is necessary if one acknowledges that the observer too is made out of particles, something which is badly needed for closed systems, hence we have to dismiss that interpretation also (c) my interpretation which is that the Unruh effect, as it stands, is not a viable physical effect but that something like it must be true in a theory of a closed system if one takes more physical characteristics of the observer into account, such as his mass. Particles are defined objectively but are created, in a process, *because* of the acceleration of the observer. There is no ambiguity in the particle notion of one observer with respect to another one. Let me also mention how I interpret the Hawking effect, similar to the Unruh effect, there is *no* Hawking radiation whatsoever for an observer which remains far away from the event horizon of a black hole. That is, a black hole does not objectively radiate as many sources wrongly state today! Hawking computed, just like Unruh, a Bogoliubov tranformation between the viewpoint of an observer in the asymptotic past and one which remains close to the event horizon of a black hole. It is just so that for an observer close to the event horizon, who wants to stay out of the black hole, a rather permanent acceleration is required. It is this acceleration which causes particles to be born and a radiation spectrum to be observed, but again, this depends upon many more characteristics of the observer than just his acceleration. Therefore, it is just plain nonsense, as I have repeated over the years, that modern physics would not allow anymore for a realist worldview in which things objectively happen: it is rather the limited formulation of quantum theory which forbids this by the outset. In astrophysical observations, Hawking radiation could be seen by a distant observer if some matter is surrounding the black hole event horizon, but this has nothing to do with radiation being send out by a "naked" black hole.

Before we come back to our original project of speaking about the subordonation of the particle identity to the spacetime identity, let me first speak about how modern science has partially dealt with this question, where partially refers to the fact that not every scientist walks this road. In the so called perturbative approach towards quantum gravity or asymptotic safety for that matter, the insight relativists have gained in the sense that Einstein's theory should be regarded as one of dynamical spacetime is plain *rejected*. Indeed, those fellows restore the "eternalist" viewpoint of Minkowski and claim that gravity is just a force field like any other (which is against the philosophy behind the geodesic equation) and therefore is made up out of elementary interacting particles. Mind here that, so far, we have not identified gravity with the dynamics of spacetime nor did we say anything about the dynamics yet, but we have for sure stated that the dynamics of spacetime ought to be nontrivial and refuted the "eternalist" Minkowskian view! Our kinematics, as it stands now, is fully equipped to tackle this petty (and wrong!) worldview. Obviously, those people regard the universe as an open system and are not only confronted with the fact that different observers will give inequivalent accounts but moreover must face the fact that the predictions of their theory crucially depends upon the Minkowski spacetime they choose. That is, if they were to choose another spacetime, the predictions could not be mapped to one and another (are not equivalent), are not unique anymore (inequivalent choices of vacuum state) and moreover, they do not even know how to define non-perturbatively an interacting quantum field theory on a curved spacetime background. So even the very formulation of such theory is an open question! For those of us who recognize(d) that this programme is fundamentally flawed philosophically, it came as a relief that those Einstein bangers discovered an inconsistency in their own reasoning: that is the theory did turn out to be perturbatively non-renormalizable meaning one needs effectively an infinite number of coupling constants to make it consistent up to some energy level at which it goes completely havoc. Unfortunately, the tradition of quantum mechanical open systems remains to dominate the physics community until now as one has high hopes that these "technical" problems can be solved once one recognizes that particles cannot interact in points which they interpret as meaning that particles must be extended objects, like strings. I can safely make the bet upfront that this viewpoint will turn out to be fundamentally flawed too and that similar issues to non-renormalizability will show up at another level. So, the framework we are going to develop now for sure transcends strings and eventually also other approaches which do recognize that one needs a dynamical theory of spacetime *and* matter.

To be entirely fair, I have had objections in the past against what I am going to say now designating such programme as too liberal and containing too many degrees of freedom and I remember having made such comments to Renate Loll about causal dynamical triangulations. My viewpoint has evolved a little over the years in the sense that the kinematical possibility of it should be allowed for but that we need an entirely new principle beyond known physics to make sure that the dynamics only profits a bit from those exuberant liberties. It is *that* what I am still lacking in Loll's programme as one needs to go beyond a quantum dynamics to solve that matter; I am pretty sure that it needs to be solved as our spacetime is observed as a classical manifold with a Lorentzian metric on it and undergoes an entirely classical dynamics on scales where matter has quantum properties. This is not so because the gravitational force is weak (that is only part of it) but it should explain why we can speak about a four dimensional continuum with a Lorentzian metric to start with, so the issue is a much more primitive one: I will explain later in greater detail what I mean.

As for the moment, our only goal is to investigate what one can and cannot speak about in physics and as the issue of dynamics is only slightly tangential to this quest, we will proceed now with "deducing" the appropriate language. I have decided to talk about the issue of this subsection step by step allowing each time for greater liberties and will indicate which programme in physics applies to which level of this process of generalization: as the reader will notice, causal set theory and causal dynamical triangulations are at the highest stage of kinematical liberty in modern physics but our framework goes beyond these programs too. So far, we have spoken about spacetime, actual space and properties of elementary particles being linked to *actual* space (I did not say that yet); since I have elaborated already on how one could speak about emergent properties and properties one might perhaps not derive from spacetime at all, let me introduce the following notation

$$p = (x, F_x(spacetime), \zeta)$$

where x denotes an element of actual space, F_x a functional relationship depending upon spacetime and ζ other parameters not related to spacetime whatsoever. As said before F_x should depend in a local way of spacetime around x but since we haven't even introduced any notion of topology yet, the reader does not need to know what it means precisely. So, p is an atomistic property of a particle (we will extend this framework to "extended objects" such as strings in a canonical way later on) and everything we said from page eight onwards applies to p (so we will keep x, y, z for properties related to spacetime and in particular to actual space). We will use the canonical projection

$$\pi : p \to x$$

of properties on the respective property of actual space. At least, what I am developping now is the standard accepted view in physics and the reader *should* wonder why we take only the particle properties related to actual space into account and not the particle properties which are not actual? For example, they might matter too in a future process of the universe; this would immediately lead to, amongst others, a higher quantum theory where the evolution of the wavefunction depends upon its value at previous times too. There is no philosophical principle to exclude this and from now on we shall attach spacetime properties to particles so that we will speak about evolving "histories" instead of "actualities" - the rule that only actual properties can be *measured* remains of course which is the first and primary reason why we only assigned those properties to elementary particles albeit there is no logical need for it. Fine, so this is our *final* settlement of that issue, it is the most general thing one can conceive and I have repeatedly stated that our framework would be extended later on. For all clarity, let me formalize this as follows: "**the universe consists out of spacetime and particles, where particles have properties which project down to properties (or events) of spacetime. Actual measurements can only pertain to properties which project down to actual space**". In a sense, we assume that our spacetime is "future finite" and closed meaning that for every property x, $E(x)$ has a finite measure and contains the limit events towards the "future" (this is bad, but ingrained language). As this implies that we need a topology and its Borel sigma algebra, as well as an equivalence class of spacetime measures to make that precise, we will refrain from doing so temporarily. Note that we do not need the existence of a preferred measure but merely of an equivalence class which is defined by the fact that the property of finiteness and being distinct from zero coincide. This leaves open the door for so called conformally invariant theories of gravitation which have recently been investigated again.

Let us now formalize this in a categorical language: we have that the properties of the identity spacetime are given by $(events, E)$, moreover one has that there exists a projection map $\pi : prop \to events$ which projects a property of elementary particles on its underlying event, and finally we have the operations $\cup, \vee, \wedge, \otimes_\alpha$ with which we can write down propositions about particle identities. Since spacetime is also an identity, we must wonder how to generalize these operations to the identity of spacetime keeping in mind the dependency of *prop* on spacetime and $\pi : prop \to events$. This is what we mean when we say that particles are subordinate to spacetime; first of all, logic would oblige one to speak about "evolution of properties of spacetime" but this was the result of a process taking place, remember that the reason why we had to introduce the concept of evolution of properties in the first place was that we did not want a dynamics without law. Actually, we have been a bit sloppy so far since spacetime should be endowed with other attributes than $(events, E)$ as we have said already; for example with a Borel sigma algebra and an equivalence class of measures on it. Hence, our new objects to which the operations of $\cup, \vee, \wedge, \otimes_\alpha$ should be applied are

$$\{\text{spacetime}_a, \text{particles}_i, (events, E, \mathcal{B}, [\mu])_a, prop, \pi_a : prop \to events,$$

$$\text{words in}\, p_i \,\text{where}\, p \in prop \;\text{ constructed using}\, \cup, \vee, \wedge, \otimes_{\alpha,s}\}$$

where it is understood that $\otimes_{\alpha,s}$ also depends upon $(events, E, \mathcal{B}, [\mu])$. $\mathcal{B}$ denotes the Borel sigma algebra and $[\mu]$ an equivalence class of measures. We will use the latin letters a, b, c to denote spacetime identities and i, j, k to denote particle identities; the composite object of one spacetime with identity a and particles with identities labelled by i is called a universe with identity (a, i) where we mean one a and multiple i. One might opt for including all particle identities in one universe even if some identity does not appear in a word, we will do this from now on and call a particle identity active in some universe if it appears in some word. So far, the question which is adressed in a small part of the physics community is that of the extension of operators to the identies of spacetime alone, and only ocasionally matter is included in some sense, meaning one looks for an extension of the operation $\wedge$ on objects of the type $(events, E, \mathcal{B}, [\mu])_a$. These programs so far stay far removed from the issues which I will adress shortly; indeed, only global questions such as fluctuations on the total spacetime volume or the volume of actual space are adressed (as far as I know, one does not dispose of a well defined notion of curvature (operator) yet). The above notation for $universe_{(a,i)}$ implies that we have to talk about the *same* particles/spacetimes in distinct universes and the *same* events/properties in different universes (possibly with the same "universe" identity). It is this extraordinary luxury I was talking about before which needs to be kept under control by a new dynamical principle (see section four) since a naive dynamics won't reproduce any universe like we know it.

Now the reason why we don't have the logical need to separately specify relationships between different properties $(events, E, \mathcal{B}, [\mu])$ of spacetime is that there are plenty of natural relations between them! For example, what are the common events and common evolutions between common events? Is the measure space of events equivalent and if not quantify in some sense how they differ; how good can one "match" one spacetime to another using measurable functions (this question is meaningful if one chooses a measure and not just an equivalence class)? As said before, in principle, one has an infinite chain where one can specify additional relationships between universes and extend the dynamics to those relationships too, but why do it? We *can* close the discussion in a simpeler way by means of induced relationships due to the very definition of the properties of universes: so, it is reasonable to close the door at this level and we shall just do that for now. In principle, one can extend not only the operation $\wedge$ to universes, but also the operations $\vee$ and $\otimes_\alpha$ albeit it is unclear how the latter should depend upon the properties of the distinct universes; as we shall see,this is already no simple matter for properties of elementary particles! All one should keep in mind is that ultimately one only measures properties of particles by means of similar properties of other particles; in that sense, it is entirely plausible that a particle lives in multiple spacetimes and distinct universes (meaning having a different identity) without us fully realizing it. We only can be guided by the classical picture of the three dimensional universe in our mind and how it relates to the actual "multiverse" we live in where by multiverse I mean a superposition of universes or even more general any word one can write down in different universe identities.

2.3 Generalization of our language: extended objects.

So far, the identity of a subatomic particle was given by a single number such as $i \in \mathbb{N}$ and we now turn to the situation of what happens if the particle identity itself contains structure such as is the case for the identity "string". While some people would say that a closed string is something which is differentiably equivalent to the circle and that one needs to examine the processes this circle is undergoing (without relying entirely upon the metaphysical concept of time); string theorists have chosen to stick with some concept of time and to formulate dynamics in an "eternalist" fashion using the string wordsheet, a hypothetical surface to be swept out be a moving string. The very idea that a physical particle carries some internal structure is an old one as one hopes to "explain" constraints on the dynamics from structural properties of the particle *and* spacetime. Of course, such explanation only gives valuable clues about nature depending upon how well one can motivate the internal structure as well as its more primitive character. As I have explained already, the quantization of spacetime is definetly a higher project than making a consistent theory of gravitons where the latter is grounded in some "Newtonian" view on gravity, that it is a force carried by means of elementary particles while Einstein's wonderful insight was that gravity is not a force at all but the very structure of spacetime. That is, it makes it possible to speak about laws for force fields in the first place; without gravitation, no law for force fields could ever be formulated. Of course, we do realize the elementary fact that in contemporary formulations of physics, which all rely upon the eternal concept of time and space, that the "gravitational field" has a mathematical structure rather similar to that of "force fields" and "particle fields" but one should not deny its fundamentally distinct status. From the point of quantum field theory, one would say that it is a vital ingredient in defining particles, so how could it be made up out of them? I have once played with the logical possibility that one can have dynamical spacetime *and* gravitons, but the latter do not gravitate meaning they do not contribute to the energy momentum tensor defining spacetime. This already goes beyond the framework of quantum field theory and we will not further persue this option here.

Nevertheless, strings could turn out to be useful in finding out dynamical laws for elementary particles and it is from this point of view that we will adress extended objects. Another *type* (we will see how in a categorical sense, there is a duality between fields and strings) of extended objects are fields; those have a long history such as the gravitational field of Newton, the electromagnetic field of Maxwell, the (classical) Klein Gordon and Dirac fields and so on. The last two can be seen in two ways; either as a *classical* field or the wavefunction of a single quantum mechanical relativistic particle depending on wether one resorts to a $\{\,\}$ or $\wedge$ interpretation as I will explain later on. Finally, I will mention the "weak equivalence" between a quantized field and the particle language developped previously. So far, we have not emphasized one piece of notation too much albeit we have spilled it out in words: when denoting x_1 we meant "particle one has property x" and $x_{1\star}$ was a shorthand for "particle one has property x_1". Actually, this very notation reveals that we assume a particle identity to be structureless and a more civilized notation would have been

$$\{p\} \stackrel{f_1}{\to} prop$$

where f_1 is the property map f of identity 1 which we also could have denoted by

$$\{p\} \times \{1\} \stackrel{f}{\to} prop$$

by putting the identity in the domain of the mapping. This point of view can now easily be extended to a more general situation

$$A \stackrel{f_1}{\to} prop$$

or its dual

$$prop \stackrel{g_1}{\to} X$$

where in the second relationship *prop* is often relaced by spacetime and X may contain some structure over spacetime but can also be independent from it. Here, A is understood to be a space with sufficient structure on it; at least one would expect it to be a measure space equipped with a (measurable) relation such as is "evolution of properties" for spacetime. One can regard the f_i, g_j as functors between categories but this is not the place to fully develop that view since we did not specify the nature of the relations on A and X yet. One can decide to keep the strucures on A and X to be static or dynamical; for example, in string theory A is dynamical in some sense whereas *prop* is static but the mappings f_i, g_j are always part of the dynamical content.

The natural definition for a quantum field is then that of a field identity where one considers tuples $(\wedge_k g_1^k, \lambda)$ where λ attaches to each $g_1^k : prop \to \mathbb{C}$ a potentiality, this is the so called Schrodinger picture. Note that there is a trivial equivalence between the words, and the potentiality theirof, of a single quantum particle (so we use $\wedge$ only) and the object of a complex valued field, assuming that the potentialities are complex valued. We have already given this example at page eleven; so we need to qualify the space of "differentiable" complex valued functions $F(g)$ of complex valued (square) integrable functions $g : prop \to \mathbb{C}$. Standard results from functional analysis reveal that a dense subset is given by

$$\sum_{n \in \mathbb{N}; p_k \in prop,\, k:1\ldots n} \lambda(p_j : j = 1 \ldots n)(\chi_{p_1}, \chi_{p_2}, \ldots, \chi_{p_n})_{\otimes}$$

where

$$(\chi_{p_1}, \chi_{p_2}, \ldots, \chi_{p_n})_{\otimes}(g) = g(p_1)g(p_2)\ldots g(p_n)$$

giving the "equivalence" with our multiparticle theory: indeed, the reader may see that the above notation is equivalent to

$$(\wedge_{n;p_j}(p_1, \ldots, p_n)_{\otimes}, \lambda).$$

Obviously, one should interpret p_i as property p_i and not as property p of particle i or $p_{i\star}$ for that matter; new identities cannot arise out of first quantization and the only identity here is the identity "field (one)". That is why I have used "equivalence" since our original framework of distinguished particles is much richer. So far, the theoretical physics community has not bothered to extend the operations $\vee$ and $\otimes_\alpha$ to field identities or even string identities albeit there one hears sometimes dreams of a "string field theory". What we will see in the next section about modern theories of physics is that the quantized field suffers from (in my view) lethal problems which are inherent to the dynamical meaning of the word quantization. Since this section is only about kinematics, we postpone such discussion. When one interprets $g : prop \to \mathbb{C}$ as a classical field and not an "equivalent" description of a quantum particle, one allows for measurements of properties x and y whereas this is forbidden in the quantum mechanical interpretation.

2.4 Are macroscopic identities fundamental or emergent: weak reductionism.

So far, we have introduced from scratch a language which is intrinsically richer than the language used in physics up to this date; we will summarize and slightly extend our thoughts in the next subsection where we will adress for the first time the process of measurement. So far, three main themes where relevant to our discussion: (a) the notion of a single identity (b) operations which one can perform on properties of single identities (c) the structure of spacetime and how it has evolved into history. In this subsection, we will once more examine the matter of identity and its possible relevance to physics: more in detail, we shall ask ourselves the question wether macroscopic identities must be regarded as fundamental or emergent. This relates to the issue which we have discussed already, that the description of a system of identities is richer than merely the union or join of them; what we wonder now is whether new identities can be attached to groups of identities and if these new identities change the dynamics in a way which is "unforseen" by the dynamics for the constituting identities. Largely, this is of course a matter of the interplay between dynamics and kinematics where one has to resort to subjective notions such as unlikely or unplausible if one is going to judge whether something results from the interplay of molecules and atoms or whether something is inherent to the notion of what it means to be human. Let me give a programming example and one of a piece of art; when programming a game like Farm Frenzy or Plants versus Zombies which my kids like to play, you give every type of plant or zombie a name and likewise arise the names cow, gooze, sheep in Farm Frenzy. Using these variables, the programmer can define actions on them such as "zombie eats plant" or "cow produces milk"; usually these things are done in a very high level programming language which is far removed from the language of the machine which is one of bits and bytes. It is actually beneficial and more natural to write it down like that since it allows you to easily implement many more actions than those you could *reasonably* progam in a direct way; the same kind of reasoning holds for a work of art which is created out of a "dead" piece of material and which transcends its materialistic configuration. It gets an identity such as does the Eiffel tower or the Mona Lisa which attract every season millions of tourists to Paris: something new has been born out of something rather plain by an act of creation, very much comparable to the birth of a biological creature out of an egg.

So this is the question of this subsection: does nature also "reasons" in terms of John or Jack, arm or leg, statue or painting, or does it each time has to *explicitely* refer to the composition of these entities in terms of elementary identities of (structureless?) particles? Does she, just like the software on a computer, speak in several languages depending upon what has to be said? I for sure believe she does and I have in the past launched the principle of weak reduction meaning that on higher scales *new* variables matter whose kinematics nor dynamics can be *reasonably* reduced to the dynamics and kinematics of the constituting lower scale (microscopic) elements. This is a weaker version of the ordinary principle of reduction which is upheld by most scientists, I believe, and which states that such reduction should exactly take place. So, in our kinematics, I could introduce

$$John = \{1, 3, 5, 7\}$$

if I were to consist out of four elementary particles only and likewise could I use a property map to find out properties of John. In cosmology, we do this all the time giving identities to stars, planets, asteroids and several pieces of interstellar junk out there; it is important for us to set up the theory (and indeed, the theory of gravitation has been discovered in that way). On the other hand, in microscopic physics one relies on the notion of identical particles, a highly debatable concept we will discuss later on.

2.5 About a definition of measurement in the "multiverse".

We will close off this section by discussing an ansatz, a thought, for the definition of a process of measurement of an elementary particle. This thought is as far as I know new and I haven't seen it discussed anywhere else in the literature. We will first spell it out for elementary particles in one universe and later on in the multiverse since the latter requires some more sophistication; finally, we present our operational language in some more abstraction, now that one has gotten acquinted meantime with its ideas and motivation theirof. Let me also stress that this section is somewhat speculative in the sense that a choice of definition is always just that "a choice", which may or may not be a very meaningful one. We will meet definitions of this kind such as is the case for the concept of indistinguishable or identical particles, the latter has a long history and has changed over time. However, I feel somewhat inspired by the founding fathers who had the idea that a measurement involved measurement apparatus and the system under study; the problematic aspect of the concrete meaning they gave to this sentence was that, in their description, they made a fundamental distinction in language between the particle and the measurement apparatus. That is, the particle was represented by a wave and the measurement apparatus by an operator acting on that wave whereas the measurement apparatus itself consists out of particles! We will propose a more symmetric definition which speaks about a change in relationships and of which the standard operator description constitutes a *part* of what is really going on. There are two key ideas to measurement, one concerns the change of "join" (entanglement in quantum theory) and the other one accompanies this principle and that is that a change in join should come with a further localization in space - a principle I will make precise shortly. It is always best to explain the idea by giving a couple of examples illustrating what you want to say; consider two particles, one with the property electron and the other one with the property photon represented by wave functions (where we surpress spin indices) $\Phi_1(x)$, $\Psi_2(y)$ or better by words and their potentialities but for sake of making the connection with the standard quantum mechanical definition, I will speak in terms of wavefunctions. In our language, there are a few possibilities for describing this system, namely as a disjoint union $\Phi_1(x) \cup \Psi_2(y)$, a classical join $\Phi_1(x) \otimes_c \Psi_2(y)$, as a quantum join $\Phi_1(x) \otimes_q \Psi_2(y)$ and also as a "superposition" $\Phi_1(x) \wedge \Psi_2(x)$, a notation which is reserved in standard quantum field theory for a single particle having the properties electron and photon. There are still other possibilities but those involve composite operators; associated to those different ways of writing things down are of course different rules for interfering probabilities based upon the potentialities. The standard situation in quantum field theory is of course given by $\Phi_1(x) \otimes_q \Psi_2(y)$ where the tensor product also depends upon the nature of the properties of the particles, in this case "Bose" and "Fermi". We will launch the following idea here, in case a process introduces a novel type of join for a single particle 1 with other particles j it were not joined with before *and* in case the properties of 1 in every word are uniformly localized in some sufficienty small spatial region, then we say that 1 had been *strongly* measured by the particles j. This is a very broad definition and I refuse to say how accurate this localization should actually be and if the reader wants to, we can speak about strong ϵ-measurements to cover for that deficit. In our example above, we could say that the electron is strongly measured by the photon if for example $\Phi_1(x) \cup \Psi_2(y)$ evolves into

$$\Phi_1'(x) \otimes_q \Psi_2'(y) \wedge \Phi_1''(x) \otimes_q \Psi_2''(y)$$

where the joint support of Φ_1', Φ_1'' is contained within a spatial region of radius ϵ. So, what I want to convey here is that it is *not* sufficient for $\Phi_1(x) \cup \Psi_2(y)$ to evolve into $\Phi_1'(x) \cup \Psi_2'(y)$ for example, even if $\Psi_2'(y)$ is different from Ψ_2 and as such the photon's state has changed during the process and the electron's state has become localized. In such case we will speak about *weak* measurements or spontaneous localization; the very idea I want to launch now is that *all* our observations correspond to strong measurements. That is, a particle needs to get localized and entangled with some constituents (elementary particles) of the measurement apparatus before we can even speak about a measurement; this is the addition I wish to make to the standard measurement axiom in quantum mechanics. Remember here, that we introduced the novel idea before that a measurement apparatus has as well a classical as quantum description and what we posit here is that a change in its classical state necessarily is accompanied by a change in its very quantum structure, something which is impossible to describe in ordinary quantum mechanics. There is another issue, which I will highlight now and which has to do with the same fact I just mentioned, namely that the description of the world is not a pure quantum description. To illustrate what I want to say, consider a quantum-joined (Einstein Podolsky Rosen) pair of electrons, one moving left from the source towards Stern Gerlach apparatus A and the other towards B; suppose that the evolution of our universe is such that at A, the measurement occurs first. Then, after A made its measurement, what is the correct description of the relationship between the two particles? Is it a union, a classical join or still a trivial quantum join whose structure is equivalent at that moment to a classical join. Standard quantum mechanics would give answer three but here we see that this is not necessarily the case; it could be very well that the left mover joins with some particles in A and breaks its join with the right mover. This is not merely a matter of semantics but also reflects a dynamical issue; since I have no argument to prefer one over the other I will leave it at this. All I wanted to convey here is that measurement might involve a join between apparatus and particle, something which is impossible to describe in standard quantum theory. Note that I did not speak yet about the conditions a measurement takes place in, that is a matter of dynamics which we postpone to section four.

To define measurement of a particle by means of a bunch of particles (apparatus) when one allows for the $\wedge$ (and $\cup$) operation on universes, we need some more thought. First, let us note that the easiest thing to do would be to impose that the (geometry of the) boundary of our growing spacetime is classical when we make a particle measurement implying that the above definition can be straightforwardly generalized and obtain probabilities corrected by using amplitudes associated to distinct universes. This, however, does not need to be so and I could imagine dealing with "unsharp" boundaries of even different topology; we will work towards such definition in section four as it interconnects with how we are going to define the dynamics. So, let us finish this section by rehearsing and further clarifying the ontology developped in this section: we have defined spacetime by means of events or properties and the relation "evolution of properties", events were those elements which are common to all atomistic properties of elementary particles in the sense that every elementary property can be written as $(event, something\ else)$ where this "something else" could be derived from the spacetime structure, but this is not necessarily the case and distinct viewpoints exist. On properties of elementary particles, it possible to define the operations $\vee, \wedge$ to form words and determine their potentialities; note that the identity of a single particle exists out of spacetime and that the latter has to be seen as the stage in which those identities come to "live" and start to interact. Hence, it shouldn't come as a surprise that one single particle can have multiple properties at once; note that we defined four kinds of particles depending upon which of the operations are used. The next question we adressed, is how we should describe systems with multiple particles present: it is here that we introduced the join as having the same properties a single particle has and since a single particle came in four different types, likewise do joins. It is a this point that I will elaborate a bit further; for example, take the classical join of two quantum particles, then it is logical that only words of the type $word_1 \otimes_c word_2$ are allowed, such as

$$(x_1 \wedge y_1) \otimes_c z_2.$$

Here, one has to answer the question if there is any relationship between the latter word and

$$x_1 \otimes_c z_2 \wedge y_1 \otimes_c z_2$$

so that, in a sense, the wedge operation is still allowed but in a limited way. For example,

$$x_1 \otimes_c z_2 \wedge y_1 \otimes_c v_2$$

is forbidden since it is not of the right type. The same question concerning the quantum join leads in case of an affirmative answer to the linear structure of quantum mechanics. The main distinction between a union and a classical join is that the latter always involves distinct particles while the former can pertain to the same identities. The other rules regarding these operations, such as the order in which they come, were defined in a clear way and we finish this section at this point.

3 Critiques on modern physics.

This section is a mandatory one, not only from the point of view of the general kinematical framework in section two, but also regarding the principles to be discussed in section four. Indeed, a thorough understanding of the weaknesses in modern physics is mandatory prior to engaging in the project of finding out new principles behind the dynamical laws of the future. Some of the points raised in this section are as far as I know new whereas others probably appeared elsewhere but I am certainly not aware of those references and apologise upfront for my ignorance. As stated in the introduction, not every point I will highlight here, needs to be regarded as negative per se, some of the issues I raise point into the direction of an extension of the theory, others constitute in my view shortcomings which will be harder to overcome. One thing is for sure, we shall become more fundamentalist as this section carries on, meaning that as our views progress, we shall become critical of some very elementary things which every working physicist writes down and uses without too much thought. The "amusing" part, in which I will highlight several ideas of mine, which have become clear over the years, is in my view instructive for every student who has just encountered these concepts and is trying to eat them. Here, he or she can find the delight of wandering beyond the textbook boundaries which have been immortalized in print since they were constructed by the founding father(s). The line of my expose starts somewhere at the beginning of the twentieth century and progresses in time as the section carries on, so that we implicitely adress our comments in historical order. The mathematical background needed to understand all content is that of an elementary course in classical mechanics, quantum physics and general relativity; I decided not to rehearse these things as they would distract us too much from the main line. The interested reader, who is not familiar with some of the concepts, may acquire this knowledge by means of Wikipedia or standard textbooks on the matter.

3.1 Quantum physics.

Let us start at the foundations and contemplate if they are not too special, formulated too thightly with respect to several things ranging from algebraic input to geometrical specialization. I could start immediately by going straight against Hilbert space and comment on that; however several authors have done that before me and albeit I will make my own personal comments regarding that issue, let us not start from that. The first issue I will deal with is the quantization algorithm in its most primitive form.

3.1.1 Foundational issues of the old quantum theory.

In this section, we start with a rather personal account on the foundations of quantum mechanics which is written in a way inspired by the comments in the previous section; I do not claim that all details have been sufficiently covered, but there are for sure more "foundational comments" in here than in all textbooks I have encountered so far. Dirac was the first person to reconsile Heisenberg's and Schrodinger's quantum theory from the point of view of the Poisson bracket $\{f, g\}$ evaluated on functions f, g of the phase space coordinates q_α; a mathematical gadget used in classical physics to write down the so called Hamiltonian equations of motion. The Poisson bracket has the following properties:

$$\begin{aligned}
\{f,g\} &= -\{g,f\} \\
\{f,\{g,h\}\}+\{g,\{h,f\}\}+\{h,\{f,g\}\} &= 0 \\
\{q_\alpha,q_\beta\} &= \Omega_{\alpha\beta} \\
\{fg,h\} &= \{f,h\}g+f\{g,h\} \\
\{af+bg,h\} &= a\{f,h\}+b\{g,h\}
\end{aligned}$$

where $\Omega_{\alpha\beta}$ is the non-degenerate symplectic form and $a, b \in \mathbb{R}$. Now, Dirac was thinking about the procedure of quantization by replacing this "algebra" by means of a "quantum algebra" which is defined from the latter by replacing the third relation by

$$\{q_\alpha,q_\beta\} = i\hbar\Omega_{\alpha\beta}1$$

where the unit has to be interpreted as another generator of the algebra which commutes with everything

$$\{f,1\} = 0$$

which follows from the fourth condition. We will come back to this definition in while; at the time quantum mechanics was born, people were convinced that the essential part of the dynamics, one in which a single quantum particle was essentially free, must be linear in terms of the potentialities *and* that probabilities must be expressed in terms of the modulus squared of the potentialities. That is, the essential quantity, which is the wave function, which we associated to words and their potentialities before, was observed to undergo a quasi-linear dynamics, a most important feature indeed. Since it appeared natural to postulate a first order, time irreversible dynamics for the wave function, one needed an equation of the form

$$i\dot{\Psi} = H \triangleright \Psi$$

where Ψ is vector in a complex vector space V and H a linear operator (the i is chosen out of convention here since we did not impose any properties on H yet) and $\triangleright$ denotes the action of H on Ψ. The action of a linear operator on a state satisfies

$$H \triangleright (a\Psi + b\Phi) = a(H \triangleright \Psi) + b(H \triangleright \Phi)$$

and the trick now is that the action defines an operator multiplication "." by

$$(X.Y) \triangleright \Psi = X \triangleright (Y \triangleright \Psi)$$

which is associative by definition since there is only one way to read sucessive actions. With respect to this product and for time independent H, one can *formally* integrate this equation and obtain that

$$\Psi(t) = e^{-iHt} \triangleright \Psi(0)$$

where we have extended our definition of an action to

$$(aX + bY) \triangleright \Psi = a(X \triangleright \Psi) + b(Y \triangleright \Psi).$$

The evolution operator $U(t) = e^{-iHt}$ for time dependent $H(t)$ reads

$$U(t,s) = \lim_{n\to\infty} (1 - i\delta_n H(s+(n-1)\delta_n))\,(1 - i\delta_n H(s+(n-2)\delta_n))\ldots(1 - i\delta_n H(s+\delta_n))\,(1 - i\delta_n H(s))$$

where $\delta_n = \frac{t-s}{n}$ for $t > s$. Note that this is all formal in the sense that H can have a nontrivial domain $\mathcal{D}_H \subset V$ and it is by far not necessary that $H \triangleright \mathcal{D}_H \subset \mathcal{D}_H$ so that the composition is only well defined on $\mathcal{D}_{H^2} \subset \mathcal{D}_H$. For example, if H is a second order partial differential operator, then for the expansion to be well defined, it is necessary (but not sufficient) that Ψ can be differentiated an infinite number of times, while it is very well known that a unique strong solution exists for initial data which are twice differentiable. Indeed, it should be well known that the definition of e^{-iHt} is *not* given by

$$\sum_{n=0}^{\infty} \frac{(-itH)^n}{n!}$$

or by

$$\lim_{n\to\infty} \left(1 - \frac{iHt}{n}\right)^n$$

since these expressions produce infinities at every order, but one has that

$$U(t) = \int e^{i\lambda t} dP_\lambda$$

where

$$\int \lambda dP_\lambda = H$$

is the spectral decomposition of H and the equality is to be interpreted in a weak sense. A good definition, in case $H(t)$ is time dependent, is given by

$$U(t,s) = \lim_{n\to\infty} U_{s+(n-1)\delta_n}(\delta_n) U_{s+(n-2)\delta_n}(\delta_n) \ldots U_{s+\delta_n}(\delta_n) U_s(\delta_n)$$

where the limit is understood in the weak sense and $U(r)(\delta) = \int e^{i\delta\lambda} dP^r_\lambda$ where $H(r) = \int \lambda dP^r_\lambda$. Note that, at this point, $H(t)$ can be any operator whatsoever and does not need to be connected to the "quantization" of a classical Hamiltonian; a second ingredient is needed for the interpretation of Ψ. In fact, we did already encounter such ingredient, which was the existence of a spectral decomposition to *explicitely* integrate the flow, but why should we let ourselves be guided by such criterion to construct a physical theory. Most classical theories have no explicit formulae for the time flow, so why care? Moreover, why should it be that time dependent Hamiltonians are all self-adjoint on the *same* Hilbert space? In classical physics, one is not worried about fall-off criteria of the geometry towards spatial infinity, but in quantum physics one definitely is. To be more specific, the very definition of H is tied to the Hilbert space one chooses. Traditionally, to make sense out of the integration of the time flow in the way we did before, one posits the existence of a *time independent* scalar product $\langle | \rangle$ which defines a Hilbert space such that "time evolution" preserves this scalar product; that is

$$\langle U(t,s)\Psi | U(t,s)\Phi \rangle = \langle \Psi | \Phi \rangle$$

which is equivalent to

$$U(t,s)^\dagger U(t,s) = 1$$

where 1 is the identity operator on Hilbert space. Strictly speaking, this is the condition which needs to be satisfied for a partial isometry, but the founding fathers went beyond that and also required

$$U(t,s)U(t,s)^{\dagger} = 1$$

which is necessary to make $H(t)$ self adjoint and $U(t,s)$ well defined in the first place starting from our equation of motion[5]. Indeed, having a spectral decomposition with real eigenvalues is equivalent to the operator being self adjoint and one could contemplate so called normal operators with a complex spectrum but non-unitary evolution. These fine points concerning the very definition of a time evolution operator are constantly ignored when making perturbative calculations in Quantum Field Theory; indeed, there one assumes the formal definition of the exponential operator which is ill defined and it should not come as a surprise that infinities arise in the calculation.

It is often said that Schrodinger needed both the insight of the linearity of the time evolution in terms of the potentialities and the fact that $|\Psi(x)|^2 dx$ is proportional to the probability for an "event" $\left[x - \frac{1}{2}dx, x + \frac{1}{2}dx\right]$ to happen to arrive at quantum theory. Let us ask ourselves what rules one might posit based upon the demand of linearity only. For sure, we cannot derive the complex numbers out of this as we know quantum theory can be consistently defined for real numbers and quaternions as well. A rule related to a linear classical stochastic theory supplied by the demand of conservation of probability would result for example in the following mathematical framework: we demand that $\Psi(t,x) \geq 0$ and a linear functional ω_t to exist such that $\omega_t(\Psi(t,x)) = 1$. Differentiating this with respect to time results then in

$$\dot{\omega}_t(\Psi) + \omega_t(H'\Psi) = 0$$

where $H' = iH$ since we do not want to impose the complex numbers yet. In case ω is t independent, this results by continuity in the fact that H' must map V into the kernel of ω and therefore 0 is an eigenvalue (of the discrete or residual type). In a matrix language, such feature is for example realized if and only if $\sum_i H'^i_j = 0$ for all j and with $\omega(\Psi) = \sum_i \Psi^i$. Suppose we would make a change of basis $\Psi \to O\Psi$, then this operator needs to satisfy that $\sum_i O^i_j = 1$, a condition which is consistent with the matrix product OV since

$$\sum_{i,j} O^i_j V^j_k = 1$$

for all k. Moreover, the identity transformation 1 and the inverse of O also constitute valid transformations so that any such theory has an $n(n-1)$ dimensional transformation group if V is n dimensional. However, there is an additional condition here as the evolution H' and transformations O still need to preserve the condition that $\Psi^i \geq 0$; in general this will only hold if and only if all $O^i_j, H'^i_j \geq 0$, which makes the group rather small but it still contains the permutation group which should suffice to account for the Galilean transformations in Newtonian physics. One might be tempted to generalize this and drop

[5]One could could start from the weaker condition that $U(t,s)$ defines a map on rays satisfying $|\langle U(t,s)\Psi|U(t,s)\Phi\rangle|^2 = |\langle\Psi|\Phi\rangle|^2$ to deduce that $U(t,s)$ can be chosen to be linear and satisfy $U(t,s)^{\dagger}U(t,s) = 1$.

the condition that $\Psi(t,x) \geq 0$ which means they cannot represent probabilities anymore. Fine, so why not take, for example, $\frac{|\Psi^i|}{\sum_j |\Psi^j|}$ as a measure for the probability since that would settle the matter. Indeed, our transformation group would constitute the entire special linear group $SL_n(\mathbb{R})$ and the Hamiltonian H' is completely arbitrary in this framework. Therefore, having a large enough symmetry group cannot be a criterion for quantum mechanics to emerge.

Before we raise any further objections, let us come back to the Heisenberg picture and how Dirac reconsiled both formulations by quantization of a classical theory. The Heisenberg picture is usually presented for a time independent Hamiltonian generating a one parameter group of time translations $U(t)$; in the Schrodinger picture, a self adjoint operator O^S_t representing a physical observable (at time t) is kept fixed and the quantities corresponding to real measurements are of the form

$$\langle \Psi_t | O^S_t \Phi_t \rangle$$

which is the same as

$$\langle \Psi_s | U(t,s)^\dagger O^S_t U(t,s) \Phi_s \rangle = \langle \Psi_s | e^{iH(t-s)} O^S_t e^{-iH(t-s)} \Phi_s \rangle.$$

Hence, it is said that measurement of O^S_t on Ψ_t results in $P_\lambda e^{-iH(t-s)}\Psi_s$ at time t in the Schrodinger picture, while it results in $e^{iH(t-s)}P_\lambda e^{-iH(t-s)}\Psi_s$ at time s in the Heisenberg picture. This is a consistent view, since a second later measurement at r in the Schrodinger picture results in $Q_\mu e^{-iH(r-t)}P_\lambda e^{-iH(t-s)}\Psi_s$ while the Heisenberg view produces $e^{-iH(r-s)}Q_\mu e^{-iH(r-s)}e^{iH(t-s)}P_\lambda e^{-iH(t-s)}\Psi_s = e^{-iH(r-s)}Q_\mu e^{-iH(r-t)}P_\lambda e^{-iH(t-s)}\Psi_s$ all of which produce the same probabilities. Taking the differential of $O^H(s,t) \equiv e^{iH(t-s)}O^S_t e^{-iH(t-s)}$ with respect to t implies that

$$\dot{O}(s,t) = i\left[H, O^H(s,t)\right]$$

where the bracket is the commutator, that is $[A,B] = AB - BA$. This is all well known and accepted as standard material; but things become somewhat more complicated if we take the *Schrodinger* Hamiltonian H^S to be time dependent. Indeed, so far, we obtained the result that the Hamiltonian in the Schrodinger picture equals the Hamiltonian in the Heisenberg picture albeit the latter should depend upon two times and not just a single one as is the case for the Schrodinger Hamiltonian. Since by definition,

$$O^H(s,t) = U(t,s)^\dagger O^S_t U(t,s)$$

and its differential to time t equals, since $\dot{U}(t,s) = -iH^S(t)U(t,s)$,

$$\dot{O}(s,t) = i\left(U(t,s)^\dagger H^S(t) O^S_t U(t,s) - U(t,s)^\dagger O^S_t H^S(t) U(t,s)\right) \neq i\left[H^S(t), O^H(s,t)\right]$$

so that the famous Heisenberg equation appears not to be amenable to time dependent Hamiltonians. One may guess now that it is more natural to derive the Heisenberg operators with respect to the reference time s arriving at

$$\frac{d}{ds}O^H(s,t) = -i\left[H^S(s), O^H(s,t)\right]$$

where one should keep in mind that $t \geq s$ and the final condition $O^H(t,t) = O^S_t$ that is, if the actual and reference time coincide, the Schrodinger operator equals the Heisenberg operator. Note also the relative minus sign to our previous expression which of course came from switching actual with reference time. This is however not the correct way to go and one should define the Heisenberg Hamiltonian as

$$H^H(s,t) = U(t,s)^\dagger H^S(t) U(t,s)$$

and the latter satisfies

$$\dot{H}^H(s,t) = U(t,s)^\dagger \partial_t H^S(t) U(t,s)$$

and any general observable with explicit time dependence obeys likewise

$$\dot{O}^H(s,t) = i\left[H^H(s,t), O^H(s,t)\right] + U(t,s)^\dagger \partial_t O^S(t) U(t,s).$$

The crucial distinction between the Heisenberg and the Schrodinger Hamiltonian is that, albeit they constitute precisely the same expressions in terms of the canonical variables, the latter come in terms of the Heisenberg and Schrodinger operators respectively. For time independent Hamiltonians, this distinction does not matter and gives the same result, while for time dependent Hamiltonians it does. Note that therefore, the Schrodinger picture is the easiest to start with as it gives direct formulae for all observables, while the Heisenberg picture can be somewhat more complicated for time dependent systems due to its dependence on time dependent canonical variables.

So, Dirac recognized the formal equivalence of the structure of the Heisenberg equation and the Poisson bracket structure of classical mechanics even though at that point, nobody should ever have mentioned the word quantization. All we did so far is to deduce these structures from the Schrodinger equation which had a direct ground in experiment; nothing so far was said about some magical trick between the classical line of thought and quantum framework. Another issue shows up if we really take the Dirac programme seriously; that is, there is no a priori reason why the replacement of the Poisson bracket should have anything to do with the commutator defined by the product inherited from the action of operators on vectors $\triangleright$. Obviously, it should be like that if we want the Heisenberg and Schrodinger picture to be equivalent, but there is no a priori reason for it from the point of view of Dirac. Let me illustrate this by means of an example; as before, consider a Hilbert space $(\mathcal{H}, \langle | \rangle)$ with an action $\triangleright$ of operators on vectors and its associated product ".". Consider A to be a positive definite operator and define the product $\star$ by $X \star Y = X.A.Y$ where from now on, we will drop all the dots. This product is associative and has a unit element A^{-1} which we will interpret as the unit appearing in the Dirac Quantization programme. Consider now a time independent Hamiltonian H which will serve to build a Heisenberg dynamics

$$\frac{d}{dt}O(t) = i(H \star O(t) - O(t) \star H) = i\left[H, O(t)\right]_\star$$

where we have dropped the reference time s. If our Hamiltonian arises from the quantization of a classical Hamiltonian, we shall impose

$$\left[q_\alpha, q_\beta\right]_\star = i\hbar \Omega_{\alpha\beta} A^{-1}.$$

This gives

$$q_\alpha = A^{-\frac{1}{2}} \hat{q}_\alpha A^{-\frac{1}{2}}$$

where

$$[\hat{q}_\alpha, \hat{q}_\beta] = i\hbar\Omega_{\alpha\beta}1.$$

Hence, our Hamiltonian $H(q_\alpha, \star) = A^{-\frac{1}{2}} H(\hat{q}_\alpha, .)A^{-\frac{1}{2}}$ and therefore, the evolution operator $U(t)$, such that

$$q_\alpha(t) = U(t)^\dagger \star q_\alpha(0) \star U(t)$$

is given by $A^{-\frac{1}{2}} \hat{U}(t) A^{-\frac{1}{2}}$ where

$$\hat{U}(t) = e^{-iH(\hat{q}_\alpha)t}$$

is the evolution operator with respect to the standard product. In other words,

$$q_\alpha(t) = A^{-\frac{1}{2}} \hat{q}_\alpha(t) A^{-\frac{1}{2}}$$

and for the probability interpretation one just needs the spectral decomposition of this operator which is unrelated to the spectral decomposition of $\hat{q}_\alpha(t)$. For the Schrodinger picture, it would be mandatory to take the spectral decomposition of $q_\alpha(0)$ and apply it to $A^{\frac{1}{2}} \hat{U}(t) A^{-\frac{1}{2}} \Psi$ which gives a totally different result! This would immediately be repared if one adjusted the action $\triangleright$ to the new product $\star$ but the point of this argument was to show that they did not need to be equal to one and another. Therefore, Dirac, crucially, had to depend upon this piece of information to maintain equivalence between both pictures. Note that the new Schrodinger evolution operator $T_t = A^{\frac{1}{2}} \hat{U}(t) A^{-\frac{1}{2}}$ is unitary with respect to scalar product

$$\langle \Psi | A^{-1} \Phi \rangle$$

but the operators q_α nor $\hat{q}_\alpha$ are Hermitian with respect to this product. Note here that, in the derivation of our argument, we have disentangled the meaning of what it is to be an identity; for us, we just defined it as an operator which commutes with everything while in the standard interpretation it also means acting as the identity on vector states. We will continue to do this, even to a further extend, in our comments upon quantum field theory. As a final question, one may wonder what A should depend upon; a natural suggestion would be that it behaves invariantly under coordinate transformations so that it must be some invariant of the spatial metric. This is how geometry can creep into the foundations of quantum theory and destroy the equivalence between the Heisenberg and Schrodinger picture.

The reader might be astonished that we did not speak yet about the measurement axiom but we will do that in a better context later on, the issues I want to raise here are at least as foundational as the latter axiom. Let us list the points we mentioned before:

- Fine, so you have a quasi linear dynamics regarding the potentialities for isolated particles, but we don't observe anything like this in the macroworld. Effectively, for big objects, we can forget about potentialities all together. Is it possible at all for such limit to emerge from a fundamentally quantum system?

- Why a time independent Hilbert space? We agree one needs a measure on the space of all potentialities but the spacetime structure might dictate this measure to evolve and not remain static. Surely, it is tempting to let oneself be persuaded by a powerful tool such as a spectral decomposition but why should a time evolution operator posses such a thing? Why should we be able to write everything in terms of stationary states if the universe is evolving irreversibly?

- Why should we take Dirac's programme seriously? Quantum theory, as formulated above, is entirely motivated by the linearity of the time evolution and has no a priori grounding in a Poisson structure. Actually, if we were not able to integrate the time flow in the way we did (based on the demand that the Hamiltonian corresponds to a Hermitian operator), we might not have spoken about a Heisenberg picture in the first place since time evolution might not map self adjoint operators to self adjoint operators. In any case, our line of argumentation shows somehow that the Schrodinger picture allows one to ask more foundational questions about quantum mechanics than the Heisenberg picture does.

- This last conclusion is only enforced by looking again at the evidence; the main observation was that the dynamics for the potentialities of a single isolated particle was more or less linear, not that it was deterministic! In that sense, Schrodinger might have already overstretched himself by writing down the ordinary differential operator $\frac{d}{dt}$ and could have instead resorted to a stochastic operator (which, admittedly, did not exist yet at his time) in which the wave potentialities themselves become stochastic variables. In our language this would mean that he might import the $\vee$ operation in quantum mechanics! This would not sound very strange at all given that the measurement process is nonlinear and stochastic; but this would most likely completely destroy the Heisenberg picture and Dirac's programme.

Formal analogy may often be a good guideline but ultimately physical arguments carry more power; as I will argue later on, when we want to dismiss the notion of time, the Schrodinger equation needs some revision too in the lines argued above. Let me proceed by giving an example which has time and time again be discussed in history regarding the fundamentally linear character of quantum mechanics; it wasn't taken as an axiom before such as bachelor's are spooned today, but one wondered wheter it only pertained to single particle systems or also to systems of more particles. Let me provide an example where one did not take it for granted that linearity would just extend as usual (by effectively describing the classical join of two quantum particles or equivalently, the union of them). Let particle i be represented by a wavefunction Ψ_i which will conveniently depend upon the spatial coordinate $\vec{x}_i$ and no other properties of particles are assumed; then, one can write down

$$i\dot{\Psi}_i(\vec{x}_i) = H_i \Psi_i(\vec{x}_i) + \sum_j \left(\int d\vec{x}_j |\Psi_j(\vec{x}_j)|^2 A_{ji}(|\vec{x}_j - \vec{x}_i|) \right) \Psi_i(\vec{x}_i)$$

where H_i is the "single particle Hamiltonian" for particle i and A_{ji} is some real valued function depending upon the distance between particles i and j. Such models have been examined in the literature in the past as one did not immediately want to resort to a quantum join of quantum particles; that concept was radically new at the time and it still is in some sense. So far, only the suggestion of a time dependent scalar product is to my knowledge really new (and we will examine some of its consequences shortly); self adjoint observables have been given up before by some people (not by many) and modified Schrodinger equations with stochastic noise have been examined in the context of the measurement postulate.

Indeed, as the reader will notice, my opinions become only really deviating when we shall deal with quantum field theory albeit they stem from insistance on rigour, something which the largest part of the community has given up upon. However, there has been done some rigorous work on *free* quantum field theory but really nobody knows how to define a fully fledged non-linear theory in a non-perturbative fashion which does not suffer from perturbative infinities. We will describe this rigorous effort and some recent developments theirof in a later subsection, but the reader must keep in mind that most of our comments so far can be taken over to that programme too and I will have formulated additional worries by then. Let us now come to an exercise which if seldom, is almost never made and nevertheless we should make it if we are ever going to have some deeper insight into the theory; the issue of a time dependent scalar product will also be adressed there.

3.1.2 On covariance and quantum mechanics.

By covariance, I mean that the choice of coordinates should not matter in the definition of a physical law; this principle can pertain to the spatial coordinates only or to the spacetime coordinates all together. The question we shall adress here is if this simple principle does not already call for a revision of the Dirac programme; regarding the Schrodinger picture, there is nothing wrong a priori and one can just say by fiat that the Hamiltonian H enjoys this property. But perhaps, working through the Dirac programme might lead to additional insights which could reflect on the Schrodinger picture too *depending upon the questions you are going to ask*. Indeed, it is this very last sentence which is important and we shall see that the Schrodinger picture allows for more economic quantum theories if one does not ask about the momentum operator for example. Concerning momentum operators, it is well known one can define an inequivalent number of them; for example $i\partial_x$ and $i\partial_x + x^2$ the latter having different domain properties than $i\partial_x$ and therefore defining an inequivalent representation of the Heisenberg algebra. Indeed, it is well known that the Stone - Von Neumann theorem only applies to the exponentiated version of the Heisenberg position and momentum operators, the so called Weyl elements. From a modern point of view, one could say that the second operator should be excluded since it does not transform covariantly under $x \to y(x)$, but in the standard view on the Schrodinger picture, this transformation does not make any sense as the scalar product in three dimensions transforms as

$$\int d^3x \overline{\Psi(x)} \Phi(x) \Rightarrow \int d^3x' |\det\left(\frac{\partial x}{\partial x'}\right)| \overline{\Psi(x(x'))} \Phi(x(x'))$$

if $\Psi(x)$ transforms as $\Psi'(x') = \Psi(x(x'))$. One could cure this by letting $\Psi(x)$ be a density of factor $\frac{1}{2}$, meaning that

$$\Psi'(x') = |\det\left(\frac{\partial x'}{\partial x}\right)|^{-\frac{1}{2}}\Psi(x(x')).$$

In that case, the integral

$$\int d^3x\overline{\Psi(x)}\Phi(x)$$

would remain invariant but the expectation value of the momentum operator would transform as

$$\int d^3x'\overline{\Psi'(x')}i\partial'_j\Phi'(x') = \int d^3x|\det\left(\frac{\partial x'}{\partial x}\right)|^{\frac{1}{2}}\,\overline{\Psi(x(x'))}\,\frac{\partial x^k}{\partial x'^j}\partial_k\left(|\det\left(\frac{\partial x'}{\partial x}\right)|^{-\frac{1}{2}}\Phi(x(x'))\right)$$

which is fine in the sense that it is still a Hermitian operator. The problem however is that $i\partial_x\Phi(x)$ does not transform nicely under coordinate transformations anymore and it certainly does not transform as a $\frac{1}{2}$ density so that one has operators mapping densities of factor $\frac{1}{2}$ to something with no suitable covariance properties at all; this is the reason why the above formula does not make sense. Let us first deal with this fact and then point out a shortcoming in the Dirac programme; there are some real lessons to be learned here. Suppose $\Psi(t,x)$ is a spatial density of factor $\frac{1}{2}$, then the natural definition for a differential operator is given by

$$\partial^N_j\Psi(t,x) = h^{\frac{1}{4}}\partial_j\left(\frac{\Psi(t,x)}{h^{\frac{1}{4}}(t,x)}\right) = \partial_j\Psi(t,x) - \frac{1}{2}\frac{\partial_j h^{\frac{1}{2}}(t,x)}{h^{\frac{1}{2}}(t,x)}\Psi(t,x)$$

where $h(t,x)$ is the determinant of the spatial metric. Obviously, this definition can be extended to any density of factor r by simply replacing the factor $\frac{1}{2}$ in the last expression by r. Hence, one can generalize the usual covariant derivative ∇_j to ∇^N_j and interpret $-i\hbar\nabla^N_j$ as the natural momentum derivative; the latter however is *not* a symmetric operator since

$$\int dx\,\overline{i\partial^N_j\Psi(t,x)}\,\Phi(t,x) - \int dx\,\overline{\Psi(t,x)}\,i\partial^N_j\Phi(t,x) = \int dx\,\overline{\Psi(t,x)}\Phi(t,x)\,i\frac{\partial_j h^{\frac{1}{2}}(t,x)}{h^{\frac{1}{2}}(t,x)}.$$

Since a momentum operator applied to any tensorvalued density must transform as the same object with one covariant index more, this choice of momentum operator is unique up to first and second derivatives of the metric tensor. That is, any other vectorfield added, constructed from the geometry alone must contain at least third order derivatives of the metric such as $\partial_j R(t,x)$ where $R(t,x)$ is the Ricci scalar. This means that we are obliged to recognize that not all physical observables are Hermitian and in particular the momentum observables and Hamiltonian are not; a similar result follows from keeping Ψ as an amplitude (scalar under coordinate transformations) and choosing the usual $i\partial_j$ as momentum operator, but this time with time dependent scalar product

$$\int dx\,\overline{\Psi(t,x)}\Phi(t,x)h^{\frac{1}{2}}(t,x).$$

It is in this sense that gravity is very different from gauge theories since its coupling constant is imaginary whereas for gauge theories it is real; this mere fact has serious consequences for the foundations of quantum mechanics as we shall investigate further. Indeed, there are other consequences to be learned: *if* one takes it seriously that the momentum operator should be defined in the theory and that the Hamiltonian is constructed from the momentum operator, then one must conclude that the correct momentum operator is given by $i\hbar\nabla^N_j$ or $i\hbar\nabla_j$ depending upon whether we consider the wavefunction to be a density of factor $\frac{1}{2}$ or just a scalar. Let us first explain the latter case, since it is closer to what we know about quantum mechanics: suppose, for the contrarian viewpoint, that the classical Hamiltonian is given by

$$H = h^{jk} p_k p_j$$

then[6] substituting $p_j = -i\hbar\partial_j$ results in a quantum Hamiltonian of the kind

$$H = -\alpha h^{jk}\partial_j\partial_k - \beta\left(\partial_j h^{jk}\right)\partial_k - \gamma\partial^2_{jk}h^{jk}$$

which means it is *impossible* for the covariant expression

$$h^{jk}\nabla_j\partial_k$$

to be found since that one equals

$$-\hbar^2 h^{jk}\partial_j\partial_k + \frac{\hbar^2}{2}h^{jk}h^{lr}\left(\partial_j h_{rk} + \partial_k h_{jr} - \partial_r h_{jk}\right)\partial_l$$

which can be rewritten as

$$-\hbar^2 h^{jk}\partial_j\partial_k - \hbar^2\left(\partial_j h^{jk}\right)\partial_k - \frac{\hbar^2}{2}h^{lr}h^{jk}\partial_r h_{jk}\partial_l$$

and it is this last term which is missing in H. This means that we have to regard $-i\hbar\nabla_j\Psi$ as a one form and therefore Hilbert space itself should be extended to all covariant n tensors. That is, the underlying vector space is given by $T_\infty\mathcal{M} = \oplus^\infty_{n=0}T_{n,c}\mathcal{M}$ where $T_{n,c}\mathcal{M}$ stands for the vectorspace of complex tensors with n covariant indices. A scalar product can be defined by

$$\sum_{n,m\geq 0}\int dx\overline{\Psi}_{a_1\ldots a_n}T^{a_1\ldots a_n b_1\ldots b_m}\Phi_{b_1\ldots b_m}h^{\frac{1}{2}}$$

where $T^{a_1\ldots a_n b_1\ldots b_m}$ is a tensor constructed from the spatial metric h^{jk} alone such that the total expression is positive definite. Now, it is obvious that in case no coupling exists between the different n as well dynamically as kinematically that everything reduces to our previous setting with a time dependent scalar product and non-Hermitian momentum operators. Note that now, it becomes

[6]This Hamiltonian can be derived from the action principle

$$S = \int dt h_{\alpha\beta}(t, x(t))\frac{dx^\alpha(t)}{dt}\frac{dx^\beta(t)}{dt}$$

or in reparametrization invariant form

$$S = \int d\tau\frac{h_{\alpha\beta}(t,x)\dot{x}^\alpha\dot{x}^\beta}{\dot{t}}$$

where $\dot{t}$ denotes the derivative of t with respect to τ.

possible to define self adjoint momentum operators with respect to *physical* directions n in space; the relevant operators being given by

$$n.p = -i\hbar n^{\mu}\nabla_{\mu} - \frac{i\hbar}{2}\left(\nabla_{\mu}n^{\mu}\right).$$

The reader may check that those are indeed symmetric and densely defined with respect to the scalar product defined by $T^{a_1 \ldots a_n b_1 \ldots b_m} = \delta_{nm}\prod_j h^{a_j b_j}$. It is of crucial importance to notice that

$$\left[-i\hbar\nabla_{\mu}, -i\hbar\nabla_{\nu}\right]\Psi_{\kappa} = -\hbar^2 R_{\mu\nu\kappa}{}^{\alpha}\Psi_{\alpha}$$

and likewise so for higher order covariant tensors. This means that the Heisenberg relation is only *at best* valid on the scalar sector; indeed, nothing could have stopped us from defining the momentum operators as

$$-i\hbar e^{-\alpha R}\nabla_{\mu}$$

in the first place. All of this makes it much more difficult to integrate the time flow as no spectral theorem applies and very different techniques will have to be developped. Note that this entire setting has nothing to do with curved space (time) but follows from the mere demand of covariance and lifting the limitation of linear transformations between inertial systems. The Poisson bracket is generally covariant in the sense that coordinate transformations do constitute symplectic transformations as the reader may easily verify; bringing this covariance to the quantum sector requires one to reinterpret the meaning of the right hand side of the Poisson brackets as well as to consider quantum corrections on the classical dynamical laws concerning the so called observables of the theory. Indeed, for our above classical Hamiltonian, one obtains that the classical equations of motion are

$$\dot{x}^j = 2h^{jk}p_k, \; \dot{p}_j = -\partial_j h^{kl}p_k p_l$$

the second of which the left nor the right hand transform covariantly since the time derivative does not commute with $\frac{\partial y^k(t)}{\partial x^j(t)}$. However, both non-covariant terms are equal so that

$$\dot{p}_j = -\partial_j h^{kl}p_k p_l$$

is a basis independent statement. In our *covariant* quantum theory however, the second equation

$$\frac{Dp_j}{dt} = i\left[H, -i\nabla_j\right]$$

is manifestly covariant on both sides - at the reference time where the Schrodinger and Heisenberg picture coincide - and gives

$$\frac{Dp_j}{dt}\Psi = -\left[\hbar^2 h^{kl}\nabla_k\nabla_l, \nabla_j\right]\Psi = \hbar^2 h^{kl}R_{jkl}{}^{s}\partial_s\Psi$$

and more complicated expressions for higher order tensors. Hence, the new expression only depends upon the first order derivatives of Ψ whereas, in the old framework, this would have been the second order derivatives due to the noncovariant term $\partial_j h^{kl}$ which now vanishes identically. The first equation of motion,

$\dot{x}^j = 2h^{jk}p_k$ remains identical at the reference time as an easy computation reveals. This strongly suggests one to revisit the *classical* Hamiltonian theory and develop a *covariant* formalism by viewing p_j as a covariant one tensor from which one can build higher order tensors. An expression such as $x^j p_j$ must then be interpreted as a scalar by regarding the x^j as the coordinate expressions of a contravariant one tensor. Therefore, the correct derivative to apply to x^j is the covariant derivative defined by the spatial metric. This suggests one to define the covariant Poisson bracket

$$\{f, g\}_c = \sum_k \left(\nabla_j^k(f) \frac{\delta}{\delta p_j^k}(g) - \frac{\delta}{\delta p_j^k}(f) \nabla_j^k(g) \right)$$

where the index k sums over all different particles and f, g can be scalar functions of the type

$$\sum_n T^{a_1 \ldots a_n}(x_j^k) p_{a_1}^{k_1} \ldots p_{a_n}^{k_n}$$

or a general tensor in which we have surpressed the tensor indices. Since this Poisson braket maps tensors to tensors of the same type and the Hamiltonian is a scalar, the time derivative on the left hand side must be the covariant derivative

$$\frac{D}{dt} p_j = \dot{p}_j - \Gamma_{jk}^r \dot{x}^k p_r$$

with as result that we only have equations between manifestly covariant properties. Applied to our Hamiltonian above, this results in the system

$$\frac{dx^j}{dt} = \{x^j, H\}_c = 2h^{jk}p_k, \; \frac{D}{dt} p_j = \{p_j, H\}_c = 0$$

and we shall show now that this idea can be consistently applied to any Hamiltonian of second order in the momenta where the kinetic term is of the metric form. Given

$$H = h^{jk} p_j p_k + p_k A^k + B$$

the standard equations of motion are

$$\dot{x}^j = h^{jk} 2p_k + A^j, \; \dot{p}_j = -\partial_j h^{kl} p_k p_l - p_k \partial_j A^k - \partial_j B$$

and the last equation is equivalent to

$$\frac{D}{dt} p_j = -p_k \nabla_j A^k - \partial_j B = \{p_k, H\}_c$$

which we needed to show. What I propose now, is that it is the covariant bracket which needs to be quantized instead of the Poisson bracket; the former however does not satisfy the Jacobi identity anymore as

$$\{f, \{g, h\}_c\}_c + \{g, \{h, f\}_c\}_c + \{h, \{f, g\}_c\}_c = R_{jk}(h) \frac{\delta}{\delta p_k}(g) \frac{\delta}{\delta p_j}(f) +$$

$$R_{jk}(g) \frac{\delta}{\delta p_k}(f) \frac{\delta}{\delta p_j}(h) + R_{jk}(f) \frac{\delta}{\delta p_k}(h) \frac{\delta}{\delta p_j}(g)$$

which constitute the Riemann curvature tensor corrections. Hence, it seems that the Jacobi identity is something which pertains to flat space(time) which suggests that in a general curved space the commutator will have to be replaced by something else, at least if we take Dirac's suggestion seriously. Since this material is, as far as I know, a new addition to the literature we leave its full implications to be investigated in the future; also, we shall come back to this when dealing with quantum field theory.

In my opinion, we stress a very important point here which is that the formulation of physical laws should be such that, in principle, one could do without coordinates all together. General relativity is such theory as one formulates the basic functional, that is the action principle, in a way which does not depend upon coordinates; Regge calculus provides a generalization of this principle towards piecewise linear manifolds. Likewise did I want to convey the attitude in section two that potentialities do not really depend upon the coordinate system at hand and can be used in any framework of discrete spacetime too so that effectively they should transform as a scalar or a density like we suggested above. Nevertheless, there will be always those who would like to regard coordinates as fundamental in the description of the theory and for them alone can our potentialities be attached to a coordinate system, which would imply that one cannot speak in terms of "properties" anymore but one deals with "representations of properties". I deem this stance to be very unlikely but let us examine nevertheless its consequences; the constraints at hand are that the measure

$$|\Psi(x,t)|^2 dx$$

or

$$|\Psi(x,t)|^2 h^{\frac{1}{2}} dx$$

needs to be preserved. In the second case, one only can only make the transformation

$$\Psi'(t,x') = e^{i\theta(t;x;x')}\Psi(t,x(x'))$$

and we will show now that this is insufficient to compensate for the non-covariant terms in the Hamiltonian so that the entire enterprise is misguided. Note that we are extremely liberal here and allow for θ to explicitely depend upon t even if the latter has nothing to do with the coordinate transformation; applying two coordinate transformations in a row should imply that

$$\theta(t;x(x'');x'(x'')) + \theta(t;x';x'') = \theta(t;x;x'')$$

meaning one must have an additive group representation in the sense that

$$\theta(g) \circ h + \theta(h) = \theta(g \circ h)$$

where $x' = h(x'')$, $x = g(x')$ and θ sends a injective coordinate transformation to a function. We will argue now from different sides: suppose for a moment that the correct momentum operator is given by $-i\hbar\partial_j$ even if it is not Hermitian. The "canonical" Hermitian momentum operator is given by

$$-i\hbar\partial_j - \frac{i\hbar\partial_j h^{\frac{1}{2}}}{2h^{\frac{1}{2}}} = -i\hbar\partial_j - \frac{i\hbar h^{rs}\partial_j\left(h_{rs}\right)}{4}$$

and the latter contains the terms necessary for obtaining a covariant Hamiltonian. Closer inspection, however, shows that it produces also lots of higher order non-covariant terms which cannot be eliminated and moreover, it does not transform covariantly under spatial coordinate transformations. Therefore, we shall restrict to the usual momentum and posit the Hamiltonian to be

$$H = -\frac{\hbar^2}{2m} h^{jk} \partial_j \partial_k .$$

It is now a straightforward excercise to show that a transformation of the type $\Psi'(t, x') = e^{i\theta(t;x;x')}\Psi(t, x(x'))$ cannot compensate for the non-covariant terms in $H' = -\frac{\hbar^2}{2m} h'^{jk} \partial'_j \partial'_k$. Indeed, the noncovariant terms induce the following equation

$$i\hbar\partial_t \left(e^{i\theta(t;x;x')}\right) \Psi = -\frac{\hbar^2}{2m} h'^{jk} \partial'_j \partial'_k \left(e^{i\theta(t;x;x')}\right) \Psi -$$
$$\frac{\hbar^2}{m} h'^{jk} \partial'_j \left(e^{i\theta(t;x;x')}\right) \frac{\partial x^l}{\partial x'^k} \partial_l \Psi \; - \; \frac{\hbar^2}{2m} e^{i\theta(t;x;x')} h'^{jk} \frac{\partial^2 x^l}{\partial x'^j \partial x'^k} \partial_l \Psi$$

which can be split up in two equations, one for Ψ and another for $\partial_l \Psi$. The latter can be solved explicitely in terms of the derivatives of $\theta(t; x; x')$ and produces

$$i\partial'_j \theta(t; x; x') = -\frac{1}{2} h'^{lk} \frac{\partial^2 x^s}{\partial x'^l \partial x'^k} \frac{\partial x'^r}{\partial x^s} h'_{jr}$$

which is the necessary contradiction since $\theta(t; x; x')$ has to be real. This shows, in the context of this simple example, that one cannot eliminate the non-covariant terms by means of a measure preserving transformation. One might hope that adding a term

$$-\alpha \frac{\hbar^2}{2m} \partial_j \left(h^{jk}\right) \partial_k$$

would nevertheless allow for some representation of the group of coordinate transformations; a short computation, however, shows that the issue of a complex $\theta(t; x; x')$ remains unchanged proving, once again, that the non-covariant terms cannot be compensated by a measure preserving transformation. I think it is safe to say that such line of thought is dead and that this paragraph shows that Dirac quantization is in conflict with the principle of general covariance, at least this is so for point particles in a general background.

3.1.3 Against spacetime symmetries.

Here, the reader will meet further thoughts deviating from "accepted wisdom" in mainstream physics; actually, we will argue from different viewpoints that the point of view quantum mechanics takes on spacetime symmetries, such as is the case for quantum field theories, cannot be right but must be a low energy approximation. This, in my view, constitutes a most serious blow to the programme of quantum field theory which from the point of view of Minkowski spacetime was almost entirely motivated from the definition of particles by means of Poincaré invariance of the scattering matrix. Indeed, as Weinberg beautifully exposes, the field viewpoint comes secondary to this one and if one has to abandon the former, then most likely fields would be disposed of too. We shall come back to some problems of quantum field theory in the next section where our comments, most surprisingly, are almost entirely limited to the definition and properties of the *free* theory. So, we will barely touch issues having to do with renormalization as we believe that the free theory is already filled with conceptual and technical problems; this will take an entire subsection on its own.

It took me some time to transcend my intuition and to present "hard" evidence that something was seriously wrong with what is almost presented in an evident way in standard textbooks on the matter, especially the excellent account of Weinberg [13] which forced me to pinpoint which of his assumptions were overdone. There are several points I want to make here and I shall try to explain them all to the fullest of my abilities, being pretty sure that they interconnect in a deeper way as explained here. What I do *not* talk about here is wether quantization of a Poincaré covariant classical field theory provides one with a dynamical representation of the symmetry algebra in terms of self adjoint operators; that is almost self evident, albeit one needs to be careful and compute if any anomalies arise, and follows from the Dirac quantization progamme and Noether's theorem in terms of the symplectic structure. We, on the other hand, have become cautious about Dirac quantization and time independent Hilbert spaces and want to know from more primary grounds if the question at all is meaningful, but we will give classical arguments as well. First of all, one must recognize that the question itself is ill posed; if one wants to compare two different notes of the same bounded subsystem of the universe then one declares by fiat that the quantum system isn't the universe but some chunk out of it which is possibly bounded in space and in time and with classical boundary conditions on the spatial part. Different observers will have different notions about the size and shape of the (spatial) boundary so that albeit the local metric may look the same in the coordinate systems of both observers, the physical boundary conditions are different and may change over time in one coordinate system. Hence, both observers make different sets of observations and the descriptions are not connected by a *symmetry* transformation in the sense of Weinberg albeit they look at spacetime geometry in the same way. This constitutes our first objection against the standard viewpoint on symmetry transformations since all observed quantum systems are contained within a classical box. Weinberg starts by asserting that the same system under study S may be described by two different observers O and O' by means of two different rays $\mathcal{R}, \mathcal{R}'$ and we speak about a symmetry between both observers if and only if the transition probabilities satisfy

$$P(\mathcal{R} \to \mathcal{R}_1) = P'(\mathcal{R}' \to \mathcal{R}'_1)$$

and actually this P' is mine and not his. One could already argue that this definition is nonsensical from the viewpoint that quantum mechanics allows for just one observer and that both of them should be influencing the readings of one and another by making measurements; indeed, the state ought to be objective and the observers are just asking different questions, hereby questioning the standard wisdom that one observer can fully specify the state of a system by means of his questions, meaning that every state corresponds to a projection operator in the spectral decomposition of some observable of his. The objective state is the viewpoint taken in this whole paper and is mandatory from the perspective of a closed universe: this constitutes our second objection against the concept of a symmetry transformation. Now, let us forget about these comments for a while and return to the subsequent analysis; there follows immediately another (hidden) assumption which is that both observers are going to describe this system in the *same* Hilbert space. That is why I have set P' instead of P signifying that these probabilities might originate from a different scalar product; so, the result of Wigner's analysis should be that such transformation of rays can be defined by means of a *linear* operator $U : \mathcal{H} \to \mathcal{H}'$ satisfying

$$\langle U\Psi | U\Phi \rangle' = \langle \Psi | \Phi \rangle$$

where we have ignored the anti-linear solutions. It makes sense to request that U should be invertible because we would like to change viewpoint from O' to O too so that U must ultimately satisfy

$$U^\dagger U = 1_{\mathcal{H}}, \;\; UU^\dagger = 1_{\mathcal{H}'}$$

where $\dagger$ is defined with respect to the two Hilbert spaces, and the reader may at first sight object that surely two different Hilbert units is not going to cause a large disruption, is it? The fact is that it induces some subtle changes and we shall examine some of its consequences right now. Let me repeat again that I am of course aware of the standard treatment of Dirac who treats generators of symmetries as classical observables, which therefore need to live on the same Hilbert space, but Dirac quantization appears questionable by itself and we would like to have a more foundational treatment than just a trick of how to move beween classical and some quantum theories. Indeed, our problem becomes immediately appearant once we try to speak about generators for these symmetry transformations: for example, for small parameters ϵ_α in the group transformation, we would like to write down

$$U(O, \epsilon O) = 1_{\mathcal{H}} + i\epsilon_\alpha J^\alpha(O)$$

where $J^\alpha(O)$ cannot be a standard Hermitian operator on $\mathcal{H}$ since that would neglect variations in the scalar product; to give an example of this, assume that one would try to give meaning to this expansion by restricting to vectors $\Psi, \Phi \in \mathcal{H}$ which do not necessarily belong to $\mathcal{H}_\epsilon \equiv \mathcal{H}(\epsilon O)$ but for which the scalar product $\langle \Psi | \Phi \rangle_\epsilon$ has meaning and likewise for $J^\alpha(O)$, then one could tentatively write down something in first order like

$$\epsilon_\alpha \left(\langle \Psi | J^\alpha(O) \Phi \rangle - \langle J^\alpha(O) \Psi | \Phi \rangle \right) = i \left(\langle \Psi | \Phi \rangle_\epsilon - \langle \Psi | \Phi \rangle \right)$$

which shows that even if one might be able to speak about the generator of symmetries in some sense, the latter are not Hermitian operators in a standard way and therefore do not constitute ordinary Dirac observables. To get to the standard treatment from this more general viewpoint one must assume that all Hilbert spaces are equal and that $J^\alpha(O)$ is independent of O; how reasonable are those supplementary assumptions from the viewpoint of inertial observers in Minkowski spacetime? Both are reasonable in the sense that one can easily show that if one takes a positive frequency solution Φ of the free Klein Gordon equation (where the notion of positive frequency is observer independent for free falling observers) then $\int dx |\Phi(t,x)|^2$ is finite with respect to one inertial observer if and only if it is finite with respect to all others. This shows that the Hilbert spaces can be taken as identical and since the Poincaré transformation is independent of O, it is reasonable to assume that J^α does not depend upon O either. So, I would say that this point constitutes more a disgression which points in the direction of non-hermitian observables, rather than a criticism as does the following.

It is often said that the choice of observer is not just a matter of one observer but of a global congruence of observers filling up the entire universe. This remark, albeit nobody really likes it, is fundamentally correct; trying to imagine what a description of the universe would look like for a single inertial pointlike observer in Minkowski spacetime, one would resort to the advanced coordinates with regard to one's worldline. Here, the advanced coordinate of a point x with respect to the worldine of the observer $\gamma(v)$ written out in eigentime v is defined by means of the intersection point x' of the future lightcone at x with respect to $\gamma(v)$ and a Fermi transported tetrad basis e_a along γ, where e_0 equals $\frac{d}{dv}$. More precisely, the coordinates are given by $(v(x'), \hat{x}_j)$ where

$$\hat{x}_j = -e^{\alpha}_j(x')\sigma_{\alpha'}(x, x')$$

and $\sigma(x, x')$ is Synge's worldfunction. The problem with this viewpoint is not that it does not define an equivalence class of single observers since the Minkowski metric is canonically given by

$$g^{-1} = \begin{pmatrix} 0 & \frac{\hat{x}_j}{|\hat{x}|} \\ \frac{\hat{x}_i}{|\hat{x}|} & \delta^i_j \end{pmatrix}$$

but that the hypersurfaces of constant v are null so that the Legendre transformation is not invertible and the canonical quantization procedure cannot be set up. One could repair this and look for coordinates associated to

$$(t - v(x'))^2 - |\hat{x}|^2 = r$$

and in case $r > 0$ we have that the surface of constant v is spacelike, while for $r < 0$ it is timelike and the region $|\hat{x}|^2 < -r$ is not covered. So, in the former case, one might calculate that the inverse metric equals

$$g^{-1} = \begin{pmatrix} -\frac{r}{|\hat{x}|^2+r} & \frac{\hat{x}_j}{\sqrt{|\hat{x}|^2+r}} \\ \frac{\hat{x}_i}{\sqrt{|\hat{x}|^2+r}} & \delta^i_j \end{pmatrix}$$

and

$$g = \begin{pmatrix} -1 & \frac{\hat{x}_j}{\sqrt{|\hat{x}|^2+r}} \\ \frac{\hat{x}_i}{\sqrt{|\hat{x}|^2+r}} & \delta^i_j - \frac{\hat{x}^i\hat{x}_j}{|\hat{x}|^2+r} \end{pmatrix}$$

and one could quantize massive Klein-Gordon field theory in this way obtaining the same representation of the Poincaré symmetry group by means of an alternative expression in terms of the physical fields and coordinates. Due to the nature of the coordinate transformation, a solution to the Klein Gordon equation is of positive frequency with respect to t if and only if it is with respect to v (and with the same "energy"); therefore, the particle notions and vacua are identical to those for the entire congruence of inertial observers albeit the scalar product differs. The most important distinction is the fact that in such representation there is no natural momentum operator since the metric depends upon $\hat{x}^j$, this is due to the fact that a single inertial worldline breaks the four dimensional translation invariance to a one dimensional subgroup (the

v transformations) while this is not true for the entire congruence of course.

Let us give now a few other and more philosophical arguments as to why the question of a *kinematical* spacetime symmetry is ill posed. So far, I have focussed upon the case of the Poincaré symmetry for Minkowskian physics but the subsequent arguments also apply to the diffeomorphism symmetry in general relativity, albeit from a different angle. More specifically, spacetime symmetries are not operational symmetries and are grounded in an "eternalist" philosophy on spacetime; in the case of the diffeomorphism symmetry of general relativity both points are very clear. A diffeomorphism is a gauge transformation and does not correspond to any physical process; moreover, the very definition of a diffeomorphism requires the spacetime manifold to exist as a block, there is no evolution towards the future in this sense which is an eternalist viewpoint. Regarding the Poincaré symmetry in special relativistic theories, how could for example a time translation correspond to an operational act, you *undergo* time evolution but do not fabricate it. Also, a *global* Lorentz transformation cannot be accomplished, it would take an infinite amount of time in any reference system to go from one reference system to another. The problem here is not that the observers cannot accelerate for a brief moment and assume a different velocity but that the hypersurface of simultaneity has to be orthogonal to the flow lines too at the end of the process. These problems do not occur if one single observer changes reference system as presented in the previous paragraph, since there the variation of the spatial hypersurfaces is uniformly bounded. One may simply not like this line of argumentation and claim that the future already exists in some way and that it posesses all those symmetries; this is at odds with issues such as spatial topology change and the philosophical stance of genuine creation. For eternalists, it is justified to hang on to eternal structures but let me remind those people that the possible theories they can formulate constitute a set of "measure zero" within the entire theory landscape. Moreover, it just doesn't make any sense to stick to fixed spacetime structures and one could assume the weaker position that for any physical theory the set of future possibilities is constrained and not that our universe itself is limited in any way. Personally, I am someone who believes in genuine creation and therefore I am of the opinion that we will never be able to write down a *concrete* theory which holds for eternity; it is just so that genuine creation takes place on sufficiently long time scales and has a marginal impact on the laws of the very small and the very large. But not so for humans and living creatures.

3.2 Modern quantum field theory.

We now come to the way modern quantum theory treats multi-particle systems in a fashion which is consistent with a Lorentzian spacetime geometry; this enterprise originates from many different points of view and we have spread some comments already in sections two and three so far. The idea of this subsection is to deepen our understanding of those remarks and to elevate them to a technical level; I am afraid I have not much positive news about this theory in spite of the fact that many high energy physicists consider it our best attempt so far. Strictly speaking, there is no theory yet, there are just perturbative calculations which we do not really understand. The first issue I have been critical of concerns the fact that quantum field theory does not distinguish particle identities and the latter is indeed a foundational cornerstone if one wants to understand *why* people think fields are mandatory and not merely take the field viewpoint as an axiom. Therefore, let us comment first upon the history and evolution of that concept and give examples at each point of why this line of thought may be plain wrong. The metaphysical arguments have been provided in section two; here, we stick to criticisms on concrete definitions.

3.2.1 Indistiguishable particles and spacetime symmetry.

People have been trying for a long time to find an explanation as to why the statistics of two joined particles behaved differently than the product statistics; for example, for particles with the Bose property, they encountered the following phenomenon. Suppose each particle can take two states with equal probability, then they found that the probability for them to be in an unequal state was close to $\frac{1}{3}$ instead of the expected $\frac{1}{2}$. The explanation was that the allowed states the particles could take were

$$|0\rangle \otimes |0\rangle,\, |1\rangle \otimes |1\rangle,\, \frac{1}{\sqrt{2}}\left(|0\rangle \otimes |1\rangle + |1\rangle \otimes |0\rangle\right)$$

so that the two distinct possibilities

$$|0\rangle \otimes |1\rangle,\, |1\rangle \otimes |0\rangle$$

just constitute one option. A different rule emerged for particles with the so called Fermi property: here one only has one option, that is

$$\frac{1}{\sqrt{2}}\left(|0\rangle \otimes |1\rangle - |1\rangle \otimes |0\rangle\right).$$

For n-particles, the allowed states could now be written as

$$|\Psi_1, \ldots, \Psi_n\rangle = \frac{1}{\sqrt{n!}} \sum_{\sigma \in S_n} (\pm 1)^{p(\sigma)} \Psi_{\sigma(1)} \otimes \ldots \otimes \Psi_{\sigma(n)}$$

where $\pm$ distinguishes Bose from Fermi particles and $p(\sigma)$ is the parity of the permutation. At least, all particles in atomic and solid state physics in three dimensions were known to obey these rules. This obviously suggested that, in finding an argument for the emergence of these rules in these regimes, the permutation group S_n had to play an important rule. The concept theoretical physicists then thought of was that of indistinguishable particles, by which they really meant particles with the same properties; historically, the first argument was that $1 \ldots n$ are just labels of a particle and that physics should not depend upon the labelling. Now, as long as one particle can only have one property such as electron and not electron and neutron simultaneously, then I agree: but then, what does it mean precisely? Well, for me, it always meant that the Hamiltonian and observables of the theory have to be permutation invariant and that under a permutation σ, states $\Psi_1 \otimes \ldots \otimes \Psi_n$ are mapped to $\Psi_{\sigma(1)} \otimes \ldots \otimes \Psi_{\sigma(n)}$ so that all predictions of the theory remain effectively unchanged. This did *not* produce the Bose or Fermi statistics of course and many people wanted to take their wish for a reality and *defined* identical particles by the property that physical states had to be eigenstates of the permutation operators. This did not only produce Bose and Fermi statistics but also so called parastatistics, associated to nontrivial Young tableau labelling irreducible representations of the permutation group S_n. Amongst those, the Bose (one row) and Fermi (one column) rules are preferred since they treat all particle exchanges on the same level, but the argument was clearly unsatisfactory and did not explain at all why the n-particle Hilbert space equals the n fold tensor product of one particle Hilbert spaces.

Around the 1970 ties, Leinaas and Myrheim recognized the fact that such argument really did not *explain* anything and that the notion of indistinguishable particles merely was a replacement for the Bose and Fermi rules. They thought of an argument as to why one should take the tensor product in some cases and why the permutation group provided the correct point of view in more than two spatial dimensions; their argument has nothing to do with labelling invariance, as that really does not produce the correct rules, but corresponds to a *process* exchanging particle properties. They put forwards the argument that a slowely varying process exchanging particle properties, by which they meant position, was only affecting the wavefunction by means of its homotopy class. That is, any other process which can be continiously deformed into the former, produces exactly the same operator; physical states then transform in a particular, most likely abelian, representation of this homotopy group albeit the possibility of finite dimensional non-abelian representations is also examined. In plain language, in the abelian case, one obtains that the physical state remains the same under such exchange processes; however, it is by no means so that the multiparticle Hilbert space is constructed by means of a tensor product. Well, at least, this constitutes a physical argumentation and one can agree or disagree with its content; to my intuition, it must be "almost right" for spacetimes which remain flat on the scale of the exchange operation, but I see no reason for it to hold in widely fluctuating gravitational fields since there the exchange operation does not commute with the standard Hamiltonian for the subsystem under study. But even if one were to take it seriously, it leads to more interesting consequences than those anticipated by Leinaas and Myrheim; they considered the study of point particles in space $\mathbb{R}^d$ as well as the first homotopy group of the associated configuration space for n identical structureless point particles. The latter is formed by taking $\mathbb{R}^{nd}$, excluding n-tuples of d-vectors for which at least two coincide and identifying n-tuples differing by a permutation of the d-vectors. For, $d \geq 3$ the homotopy group is the permutation group, while for $d = 2$ it is the braid group B_n; in this way, they discovered anyonic statistics in two space dimensions and the usual parastatistics (for abelian representations) in more than two spatial dimensions. Anyons have been discovered as quasiparticles which shows that the argument of Leinaas and Myrheim is superior to the standard labelling invariance.

There is however an enormous richness in the construction of Leinaas and Myrheim; it must be immediately clear to the reader that spacetimes with a nontrivial topology or extended objects with a non-trivial topology can all produce a nontrivial statistics in $d = 3$ if one allows for the exchange operation to feel those degrees of freedom. Moreover, for particles with internal degrees of freedom, it is possible to find a topological argument behind the spin statistics theorem which shows under which conditions it holds and in what regimes one might expect it to fail. This is a valuable way of looking at things since it is a much more primitive argument than the one originating from field theory which is, moreover, mathematically ill conceived. There is another, rather interesting, philosophy behind the entire thought experiment which is that, for the exchange operation to be well defined, there must exist a classical world outside the quantum system under study and the latter must be bounded in space since otherwise it would take an unlimited time to exchange two particles. I cannot stress enough that the Pauli exclusion principle must only hold on atomic scales and that something like Bose condensation has only been observed in solid state physics. There is no need to extrapolate these findings to the very small and very large; moreover, as mentioned before, if a strong(ly fluctuating) gravitational field is turned on, nobody really knows how to make sense out of quantum mechanics as illustrated in the subsection on general covariance. Concluding, although these arguments for "exchangeable properties" instead of "indistinguishable particles" definetly have improved over the time, one can only feel that there exists a limitation to such construction and that exchange of properties always comes at price which appears to be small for our experiments so far on earth - but I would expect them to fail at very small distance scales as the pathological short scale structure of quantum field theory reveals.

Once you accept the stance that the operation "exchange of properties" is well defined *and* uniform on all scales, resulting in Bose and Fermi rules, and that our spacetime is Minkowski, the construction of field theory is rather immediate once you stick to the premise of local interactions and a Lorentz invariant scattering matrix. Strictly speaking, the entire enterprise is ill defined as local interactions give rise to infinities and therefore, the perturbation expansion of the scattering matrix in the interaction picture is full of meaningless expressions. The entire programme of renormalization has focussed upon trying to make sense out of the S-matrix elements as if no other physical quantities can be meaningfully computed from the theory, such as quantities which are finite in time as occuring in everyday life. This would let one focus on the position representation of the Feynman diagrams instead of the usual four momentum representation which is dual to the entire spacetime. Since we have criticised the use of spacetime symmetries regarding fundamental physics before and in that context repeatedly stressed that one needs to consider bounded quantum systems, one can only come to the conclusion that the whole enterprise of quantum field theory is misguided on long distance scales as well as on very small scales where the statistical properties may be very different if they even still exist. This, in my view, is the most serious physical objection against the whole enterprise of quantum field theory and all of what follows is a more detailed exposé of these facts.

3.2.2 The modern field viewpoint.

As stated in the previous section, the viewpoint of fields can be almost entirely derived from the Poincaré symmetry, a uniform Bose or Fermi statistics on all scales and locality of interaction. All three being principles which are not fundamental but emergent on appropriate scales: as we will see now, their naive marriage leads to all kinds of technical and interpretational inconsistencies. Let us first ask the question if a discrete formulation of physics might solve all these objections: the answer is negative, albeit it solves the symmetry objection and softens the locality issue, the problem of a uniform statistics remains resulting in finite structures carrying an arbitrary amount of Bosonic particles, something which is clearly unphysical.

We will now follow the more direct view on field theory which one obtains by writing down Lorentz covariant action principles, for a single scalar field one has

$$S = \frac{1}{2}\int d^4x \partial^{\mu}\phi(x)\partial_{\mu}\phi(x) - m^2\phi^2(x) - V(\phi(x))$$

where V is any function bounded from below, usually taken to be a polynomial of finite degree. Canonical quantization according to Dirac imposes a $3+1$ view and distinguishes the time variable so that one should regard $\phi(t, \vec{x})$ as a one parameter family of fields on space satisfying the following commutation relations

$$[\phi(t, \vec{x}), \phi(t, \vec{y})] = 0, \; [\phi(t, \vec{x}), \pi(t, \vec{y})] = i\hbar\delta(\vec{x} - \vec{y})$$

where

$$\pi(t, \vec{y}) = \dot{\phi}(t, \vec{y})$$

is the canonical momentum. It is of course the $\delta(\vec{x} - \vec{y})$ function which makes that at least one of the operators ϕ, π is a distribution so that taking products is troublesome; for example, the appearance of V strongly suggests one to work in the Schrodinger picture where, at $t = 0$, $\phi(\vec{x})$ is given by a multiplication operator and $\pi(\vec{x}) = -i\hbar\frac{\delta}{\delta\phi(\vec{x})}$ in either, the functional derivative. Since the Lagrangian does not explicitely depend upon time, the Hamiltonian is a constant of motion and the Heisenberg hamiltonian equals the Schrodinger hamiltonian given by

$$H = \frac{1}{2}\int d^3\vec{x} \, -\hbar^2\frac{\delta}{\delta\phi(\vec{x})}\frac{\delta}{\delta\phi(\vec{x})} + \partial_j\phi(\vec{x})\partial_j\phi(\vec{x}) + m^2\phi^2(\vec{x}) + V(\phi(\vec{x}))$$

and we meet several problems at this point. First of all, the Hilbert space one would like to talk about would be the space of "square integrable" functionals $F(\phi)$ on the space of square integrable real valued functions ϕ on space, in case we speak about real quantum fields. The simple fact is that the latter space is infinite dimensional and does not carry any translation invariant measure; to make sense out of such programme, one would need to resort to a finite lattice on space (and time) and later *try* to take the continuum and thermodynamic limit. Since the way of calculating the Schrodinger evolution occurs by means of the path integral, it is Feynman's formulation one studies on lattices and which is subject of "rigorous" analysis by which I mean that one resorts to perturbation theory, which one should not since the calculations involve unbounded operators, and that virtually nothing is known about the nonperturbative regime. One immediately notices that the problem of a double functional derivative in the kinetic term of the Hamiltonian vanishes on the lattice since the delta density becomes finite there. So, here one starts by giving up on the continuum and studies wether one can retrieve it in some limiting sense which is by no means garantueed; in case it is not, fundamental Poincaré invariance needs to be given up too. This is the kind of quantum field theory without an operational field, as is characteristic to Feynman's approach; one does not try to give rigorous meaning to the commutation relations, nor to operational products and the field equations. From the technical side, there is a lot to say for such line of thought; it is just not always clear what one is calculating, meaning what is the correct interpretation of the so called (time ordered) correlation functions

$$T\langle\phi(x_1)\ldots\phi(x_n)\rangle$$

in terms of particle measurements? I am of course aware that such correlation functions may be used, in the Feynman diagram language, to compute S-matrix elements but this is a rather feable connection as on a general curved spacetime the whole technique of Feynman diagrams dissapears as one does not dispose of a privileged particle notion nor about asymptotic vacua anymore. Therefore, a *direct* physical interpretation of these correlation functions in terms of local particle measurements would be desirable; Peskin and Schroeder[12] make an ansatz for the two particle correlation function (or Feynman propagator)

$$T\langle\phi(x_1)\phi(x_2)\rangle.$$

If the time ordering is given by x_1, x_2, then this formula is meant to represent the amplitude for a particle to be created at x_1 and annihilated at x_2 albeit this interpretation is *not* Lorentz covariant (due to the T-ordering symbol) and moreover, in case x_1, x_2 would have equal time, no interpretation of this kind can be put forwards. I am of course aware that the Feynman propagator is Lorentz covariant but we clearly cannot state that the creation of a particle at x_1 and the annihilation at x_2 is identical to the creation of a particle at x_2 and annihilation at x_1 if x_1 and x_2 are spatially separated. We shall come back to this line of thought later on; suffice it to say that in a general interacting theory it is not clear how the n-point correlation functions should be interpreted in this way as it is not reducible to a product of two point correlation functions as is the case in the free theory. In any case, I am not aware of any convincing, universal interpretation which does not rely upon the details of Minkowskian physics and does not immediately resort to an S-matrix picture.

Fine, our comments so far had to do with a Schrodinger like picture on quantum field theory, what about the Heisenberg or interaction picture I hear you say. Concerning the Heisenberg picture, in a general curved background, only the free theory has received a rigorous, non-perturbative treatment so far; people recognized that the commutation relations nor the Hamiltonian made any mathematical sense and enlarged the language of quantum mechanics to distribution valued fields. That is, $\phi(x)$ makes no mathematical sense, only the smeared quantity

$$\phi(f) = \int dx\,\phi(x)f(x)$$

for some Schwartz function has a rigorous mathematical meaning as an unbounded operator on Hilbert space. Also, from the point of view of spacetime covariance, the use of the momentum density

$$\pi = \sqrt{-g}g^{t\mu}\partial_\mu\phi$$

is rather unnatural as it transforms like

$$\pi' = \left|\frac{\partial x}{\partial x'}\right| \frac{\partial t'}{\partial x^\nu}\sqrt{-g}g^{\nu\mu}\partial_\mu\phi$$

and it can be verified that

$$[\phi(t', \vec{x}'), \pi'(t', \vec{y}')] = \left| \frac{\partial x^j}{\partial x'^k} \right| [\phi(x(x')), \pi(y(y'))] = \delta(\vec{x}' - \vec{y}')$$

at least for coordinate transformations such that surfaces of constant t' are spacelike. This is a weak covariance property of the hamiltonian formalism; weak since only spacelike foliations are allowed for. Therefore, it is much better to stick to objects which transform in a nice way and have strong covariance properties; this results in:

$$\begin{aligned} \phi(f)^\star &= \phi(\overline{f}) \\ \phi(\alpha f + \beta g) &= \alpha\phi(f) + \beta\phi(g) \\ \phi(\left(g^{\mu\nu}\nabla_\mu\partial_\nu + m^2\right) f) &= 0 \\ [\phi(f), \phi(g)] &= i\hbar(f, \Delta g)1 \end{aligned}$$

where $\Delta(x, y) = G_R(x, y) - G_R(y, x)$ is the so called Pauli-Jordan bi-function. This constitutes the starting point of a recent, much more abstract approach developped by Fredenhagen, Brunetti and Verch some parts of which will be discussed in more detail later on. There are a few things one should understand about this formulation of physics: (a) it *appears* to be manifestly covariant (b) it works in any globally hyperbolic spacetime, for extensions towards more general cases, see the work of Kay and Fewster (c) it is unclear what an accurate replacement for the measurement axiom is given that one works with "local states". Also, a bit of reflection shows that the commutator contains expressions such as $\phi(f)\phi(g)$ where the support of f is in the past of the support of g; such expressions are physically meaningless and it is somewhat unsatisfying that the basic formulation of the theory hinges upon such construction. One could weaken the fourth axiom to

$$[\phi(f), \phi(g)] = 0$$

for the support of f and g spacelike to one and another. Generically, this would not change the theory with the possible exception that "1" may be replaced by any constant hermitian operator and as such Planck's constant isn't fixed and also the classical theory can be found in this way, see Noldus and Fewster. Why did I say that this formalism "appears" to be covariant; well, in the section about general covariance and quantum physics, we also had covariant commutation relations and a covariant Heisenberg dynamics, but we noticed that the Hamiltonian was not covariant and that therefore, the measure derived from the Schrodinger wave became coordinate dependent. Also, we encountered time dependent Hilbert spaces in a natural way, from geometry, while nothing is said here about a geometrical construction of the Hilbert space at all. Indeed, all these remarks suggest that there remains something to be said about the covariance of quantum field theory albeit it may be a matter of interpretation.

Let me also repeat that nobody knows how to non-perturbatively define the interacting theory; constructions in a pertubative formulation can be worked out just as in the case of Minkowski spacetime. The reader also notices that particles have dissapeared from this formulation and albeit one can retrieve a particle formalism as well as a (non-unique) vacuum state, the latter are not seen as fundamental anymore and subordonate to the identity field. I have, far more than most authors, stressed the undesirable character of this situation and do not have to come back to it. What one does to measure "particles" is to introduce semi-classical particle detector models and show that for Minkowkian physics, a detector click most likely corresponds to the absorption of a particle: these constitute the real observables of the theory. So here we have some physically realistic observables for the free field in contrast to the Schrodinger approach; I am unaware of generalizations to the interacting case. We now come to the very important point of how causality is implemented in the theory.

3.2.3 Causality.

We now come to the meaning of the integrated causal structure regarding the interpretation of the theory; in this paper, we repeated the standard lore that particles can propagate faster than the speed of light in free quantum field theory. This, however, is not entirely accurate as single particle Schrodinger waves satisfy the Klein Gordon equation and it would be better to say that quantum field theory allows for no localized "initial data". By this, we mean that if

$$\psi(\vec{x}) = \int d^3\vec{k}e^{i\vec{k}.\vec{x}}f(\vec{k})$$

is of compact support, then the support of

$$\dot{\psi}(t,\vec{x})_{|t=0} = \frac{d}{dt}_{|t=0} \int d^3\vec{k}e^{i\vec{k}.\vec{x}}f(\vec{k})e^{-i\sqrt{\vec{k}^2+m^2}t}$$

has infinite extend due to the fact that one incorporates positive frequency solutions only. This gives the illusion that the waves are travelling faster than light while from a second order point of view, it are the first time derivatives which come to life outside the support of the zero'th order data. Indeed, this result is well known and can be found in any textbook on quantum field theory where it is interpreted as faster than light propagation while a classical physicist would say the wave is not localized at all since its "momenta" are everywhere activated. I believe this is a saner interpretation and restoring this strong form of localization in quantum field theory would impose one to consider the negative frequency solutions on the same footing as the positive frequency ones meaning one has to work in a Hilbert space of indefinite norm. The appearant propagation outside the lightcone is dominated by the Compton wavelength $\frac{\hbar}{mc}$ which equals 10^{-11} meters for electrons which is a very small number after all, so that these effects are neglegible; for massless particles such as light, the spread is infinite which is physically unacceptable. Obviously, the evolution of operators is causal, but the causality constraint (commutation relation) does constitute a non-local part of the theory. So, is the theory, apart from the measurement axiom, causal or not: I would say this depends upon one's point of view! The really important thing is that the measurement axiom is not, and perhaps reasonably cannot be, framed in a causal fashion inside spacetime: this is the big "discovery" of quantum mechanics. Since no process is strictly evolutionary nor linear, we must find an all embracing principle which captures the essence of measurement and evolution: we will come back to that later on in section four. Often, it is said that in quantum field theory one cannot send signals faster than with the speed of light; but if one sticks to the "propagation faster than light" interpretation instead of the "no localized wavepackets" how could one not receive a signal from a place which is spatially separated from the one of the creator? Coming back to the interpretation of the two point function

$$T\langle \phi(x)\phi(y)\rangle$$

in this regard, one can see that the amplitude to create a signal at y and to receive it at x, if x proceeds y in the time ordering, is a Poincaré invariant expression which is nonvanishing outside the lightcone.

So far, we have discussed the causality of evolution, let us now discuss the causality of measurement: for those amongst us who are still infuriated by the quantum revolution and want a classical deterministic theory to replace it, this is the real obstacle since the evolution could still be regarded as causal in some way. Now, I do have patience with those people who are not dirty of the word conspiracy, since quantum theory itself is like that; it is a first order theory which originates from a higher order one by means of the "position-momentum conspiracy" at least if we take Dirac seriously. This conspiracy just came to light in the sense that it was impossible for a particle to localize itself in a classical way; it is a very powerful principle which cannot be ignored. However, to explain away the measurement axiom from the point of view of spacetime will need an ingredient of a totally different order, such as is the case in spontaneous collapse theories. The way in which the causal structure reflects itself in quantum mechanical measurement is by means of the principle of outcome independence which states that the result of two measurements is independent of the order in which they have been executed; this is equivalent to saying that physical operators on spacelike separated regions commute, which on Hilbert space also implies that the probability of these measurements happening does not depend upon the order in which they were executed (on indefinite norm spaces, this could be different though). We will see later on how this crucial property connects with the dynamical property of "general covariance" in the context of process physics.

We will now come to those issues which are at the forefront of interpretational clashes which are foundational and reflect how one should deal with the theory; common to all those distinct attitudes is that one needs to supplement the theory with a classical observer in order for it to make predictions. This is the very least one could say and we had plenty of other objections too. But let us now deal with the question of how my previous comments regarding time dependent Hilbert spaces are dealt with in this framework: in the algebraic approach, one does not speak about Hamiltonian and unitary evolution operators so that the issues a time dependent inner product raise, do not arise here. The mainstream view held so far is that of an unsatisfactory S-matrix picture which makes one forget all physics inside the universe and makes one wonder why we went through the entire causality discussion in the first place; here, one chooses an IN and OUT representation of the field algebra and field equations and discusses a possible unitary transformation between them, called the S-matrix. In case the latter does not exist, one has a weaker form of equivalence in terms of finite measurements on a finite number of observables with finite precision. Happily, there exist deviating views which do lead to a time dependent Hilbert space and vacuum state by means of a spacetime instead of spatial construction; we will discuss this shortly in section four.

3.2.4 A recent categorical approach.

A crucial discussion in algebraic quantum field theory concerns the choice of a particle notion and vacuum state; the standard view is that this issue cannot be decided upon and depends upon the choice of observer. There will, of course, always be dissident voices claiming the existence of a preffered, objective vacuum in which observers distinguish themselves by the mere choice of observables. My views are, as explained before, even further removed from conventional wisdom than that. But sometimes, it is good to observe if the other camp has made any progress in longstanding issues or if it has retransformed itself in a novel language formulating things in a much more general way than before. After all, a change of language sometimes improves one's view upon the matter; let me stress from the very beginning that no fundamental issues regarding the physical input behind quantum field theory are touched in this programme, one merely seeks the most profound formulation of the theory within the usual "eternalist" spacetime philosophy and algebraic view on the free theory. Perhaps, such endeavour is going to provide the necessary clues towards a non-pertubative formulation of the interacting theory, something which remains to be seen. So, albeit to my taste, this programme does not deal with the physical assumptions behind field theory in any sufficient way, I do have some sympathy for what they are trying to achieve since one may find inspiration from their ideas. The framework I will briefly sketch was originally conceived by Fredenhagen, Brunetti and Verch and later on expanded by Verch and Fewster [14, 15, 16]. The central question those people ask themselves is how to regard the dynamics; they think of it as a functor $\mathcal{A}$ from the category **Loc** of globally hyperbolic spacetimes with as morphisms isometric, causally convex maps, to the category of $(C)^{\star}$-algebra's $^{\star} - \mathbf{Alg}$ with as morphisms injective, unital $\star$ homomorphisms. This is the so called covariance property, which is usually supplemented with the timeslice property which states that if $\psi : (\mathcal{M}, g) \to (\mathcal{M}', g')$ maps a Cauchy surface to a Cauchy surface, then $\mathcal{A}(\psi) : \mathcal{A}(\mathcal{M}, g) \to \mathcal{A}(\mathcal{M}', g')$ is a star isomorphism between algebra's. The timeslice property allows one to define a categorical substitute for the classical action which is the so called relative Cauchy evolution, for details see Verch. It turns out that these two axioms are extremely powerful and allow one to recover plenty of results from algebraic quantum field theory: novel ideas such as "the same physics in all spacetimes" and dynamical locality allow one to derive interesting results such as the nonexistence of a natural state under certain mild conditions. For people interested in a proper language to phrase known physics, I certainly recommend to study this work in more detail.

Concerning the larger goal of obtaining a fully fledged interacting quantum field theory, I am somewhat more pessimistic and rather sure that novel physical ideas will be required. I decided to keep this section very brief as all relevant criticisms had been given already and the reader can find the delight of learning about this approach in the cited papers.

3.3 General relativity.

As the reader may anticipate, our comments here stem mainly from the fact that the fabric of spacetime is given a priori, the future exists in a way isomorphic to the past and no questions are asked about it. This fact leads to the problem of diffeomorphism invariance in general relativity with as direct consequence that for fields, no general, local questions can be posed; for rigid objects and point like particles, this objection dissapears and one can obtain relations between the text on my computer and the clock on my cell phone. However, this relation may not be one to one if someone else in the universe would ever care about also writing this text on the same rather primitive type of laptop. The reader may somehow object that I am just more supportive of general relativity than I am about quantum physics since I gave away many more objections there: the fact is that the state of general relativity simply is much healthier than the one of quantum field theory. Indeed, the theory is well defined, has passed many mathematical criteria such as a well posed initial value formulation related to causal propagation of signals and moreover, the principle of general covariance is very stringent so that the number of action principles per order of differentiation blows up rather weakly.

It has been argued before in the past that infinitesimal diffeomorphism invariance, in the sense of a gauge symmetry, follows from the request of a well defined Poincaré covariant field theory for a spin two field. In that sense might one "derive" (the derivation is not mathematically clean at all) General relativity from quantum field theory for spin two fields on Minkowski; however, this dual point of view on the metric must be seriously contested and as mentioned before, looking at gravity in terms of a force field goes against Einstein's hard gained insights. We will not discuss this graviton picture here and as far as I am concerned, this is just an artifact of history, an old fashioned attempt to grasp with something radically new while not being ready at all to face its full consequences. Actually, the "desease" of the graviton picture and the promotion of it, as being the most fundamental one, is a something which is hard to get rid of: every "'half" decent relativist is aware of the fact that giving an intrinsic definition of a gravitational wave is no simple matter and recently one claims to have found one. Obviously, what one found is a travelling disruption in the fabric of spacetime but there is no need whatsoever to call this a wave with regard to some background metric as the flat physics people do; actually, it is pretty easy to derive such picture from the more fundamental, background independent, one while the other way around often turns out to be unsurmountable. I have heard plenty of stories of people who confidently speak about gravitational waves in a flat spacetime background while all they are discussing is a diffeomeorphism gauge transformation since the total Riemann curvature turns out to vanish. Pretty painful, I must admit.

3.3.1 Eternalism versus the "issue" of observables.

Imagine a universe only made up out of classical fields, what are its observables? How to define things like a particle or any extended object for that matter? In classical physics, one thinks of observables as being predictions of the theory and not as much stuff which one can measure with a measurement apparatus, in contrast to quantum physics. In classical field theory, the only thing one can predict are quasi-local field configurations which one measures with respect to one and another. This implies that one needs to find the correct field expressions behind a traveling particle, the collision of two particles, a bound state of several particles and so on. This is a notoriously difficult thing to do in which identities are emergent, they effectively interact according to which their constitution in terms of field configurations ("initial data") interact in the fundamental theory and they change over time in shape, mass, spin... even if you start out with a field of a given mass a priori. There has been performed little work in this direction of emergent identities due to the difficult nature of the subject; in quantum mechanics, one would not be able to speak about field configurations but about quasi-local operators applied to some state, and relations between the spectral decompositions of two such operators. However, more importantly, in quantum background independent field theory, one does not dispose of a physical clock so that it is effectively impossible to speak about evolution within such framework as explained in the following section on quantum gravity: a cure of this situation requires a modification of quantum theory. Related to this fact is that the usual, dynamical action of the diffeomorphism group, which is generated by means of the Poisson bracket (or commutator in the quantum theory), is given by

$$T \Rightarrow \phi_\star T$$

where T is any tensor field made up out of the dynamical variables. This action reads

$$(\phi_\star T)^{\alpha_1 \ldots \alpha_r}{}_{\beta_1 \ldots \beta_s}(y(p)) = \frac{\partial y^{\alpha_j}(p)}{\partial x^{\kappa_j}(\phi^{-1}(p))} \cdots \frac{\partial x^{\lambda_j}(\phi^{-1}(p))}{\partial y^{\beta_j}(p)} T^{\kappa_1 \ldots \kappa_r}{}_{\lambda_1 \ldots \lambda_s}(x(\phi^{-1}(p)))$$

and it is easy to see that $(\phi \circ \psi)_\star T = \phi_\star(\psi_\star T)$. Therefore, the only diffeomorphism invariant observables are given by spacetime integrals of densities and one should study so called diffeomorphism covariant observables which are nothing but the scalars satisfying

$$\phi_\star T(\phi(p)) = T(p).$$

In order to escape from this situation, one can put the field in a spacetime region and consider only diffeomorphisms which reduce to the unity on the boundary; in this way, one *can* recover local observables (classically and quantum mechanically) and define a generally covariant quantum dynamics. The important lesson to be learned here is that the very definition of local observables requires one to break the diffeomorphism symmetry which means one does not regard the manifold as being "eternally there" but as something which has to be build up in a process too. As mentioned in section number two, this implies the view of a growing spacetime and the boundary picture is just one specific *example* of realizing this: purely covariant field theory in an "eternalist" philosophy cannot give rise to local observables from this viewpoint. This example shows again that one's philosophy may be as important as the formalism to be employed; one has to go beyond Einstein's view in order to make sense out of a generally covariant field theory both classical and quantum mechanical. This problem does not arise if one considers classical relativity coupled to classical point particles however and here the "eternalist" viewpoint can be upheld since each observer does dispose of an idealized gravitational clock to measure his own evolution in the universe. One may object now that classical rigid objects are not good enough to describe nature and that here also, a more general process view is required to make the universe come to life and give meaning to quantum particles. We have discussed already on several occasions the quantum field picture as being a particular, rather exotic and ill defined multi-particle theory and I do not intend to come back anymore to the reasons given for preferring the, more broad, picture of particle identities over the field theoretical one. The boundary point of view regarding classical fields can easily be put under pressure in the sense that distinct boundaries may give rise to inequivalent pictures and that therefore, we do not obtain an "objective" view on what is happening in the universe since the latter concept is tied to the uniqueness of the processes happening. That is precisely the reason why we need fundamental identities, instead of subjective emerging identities, where the subjective character refers to the point of view taken by some unnatural superobserver. Indeed, to restore objectivity to physics, we need to endow everything with the characteristics of an observer: it is an identity and moves across an evolving spacetime; this reason has been stressed in section two to prefer the particle view of identities over the single identity "field".

I have argued carefully here about the mere logical possibility of some philosophical points of view regarding the four dimensional fabric of spacetime. I had to, since people are rather inventive when it comes down to defending a point of view which appears to be dead from the beginning; indeed, I have had plenty of conversations where my opponent would end up in branding certain basic experiences as an illusion of the mind. Hence, I would take a deep breath and ask if he still really believes in what he says as being true, or merely wants to point out the possibility of a different view which has trouble with many of our basic senses, while it is the very task of science to explain them. Such people are by no means "cranks", but rather well trained scientists who just don't know any better and hang on to some retarded philosophy: I remember, for example, having had a discussion with a rather good cosmologist who could not understand why I refused to speak in Newtonian terms about some cosmological solutions. I told him that such pictures are keeping us backwards and that there is no immediate benifit of using such language apart from being educated in the philosophy of conserved quantities in Lagrangian and Hamiltonian physics. He then looked at me as if I was saying something completely outrageous which had no immediate benefit to "his" physics. This is the reason why I finally cared about making my points very clear so that it becomes almost impossible for such people to shelter behind these impossible viewpoints which constitute an interesting playground for a well educated psychiatrist.

3.4 Modern theories of quantum gravity.

It is this field in which I have been an active researcher for a while and it is somehow a pleasure to come back to it; in my PhD years, I was encouraged to take a look at what then was called the canonical quantization programme which later evolved into loop quantum gravity. I had rediscovered a very simple argument in terms of the "straightforward" Feynman path integral which was that amplitudes between spatial geometries were not evolving since no time variable could be picked out. More formally, if $A(\Phi, \Psi)$ denotes the transition amplitude for a spatial geometry Φ to evolve into Ψ, then by means of the orthogonality properties one had that

$$A(\Phi, \Psi) = \sum_{\Theta} A(\Phi, \Theta) A(\Theta, \Psi)$$

meaning there simply was no evolution process at all since $A^2 = A$ so that A must determine a Hermitian projection operator since $\overline{A(\Phi, \Psi)} = A(\Psi, \Phi)$. This is the problem of time and I was curious to see how it emerged in the canonical formalism; at that point, I had never heard about constrained Hamiltonian systems or anything of that kind. So, it took me a while to fully appreciate the fact that classical "background independent" field theory was pure gauge, that is, the Hamiltonian consists out of four independent first class constraints which generate the diffeomorphism gauge group. As we have discussed already in the previous subsection about classical relativity, this makes in general an interpretation of the physical state of affairs impossible since fields would have to be interpreted in terms of the local geometry which, in general, does not separate the points. At that time, people thought about quantizing the Dirac algebra and a physical wavefunction was defined to satisfy the constraints, so that there was no time evolution at all. This is what most people called the problem of time in that context; obviously, I was quick to notice that there was a time evolution for states which did not satisfy the gauge constraints but such evolution would be gauge dependent. To make it gauge independent, I realized that if one were to be able to define something like a projection operator P on the physical states and construct a transition amplitude as

$$A(\Phi, \Psi) = \langle \Psi | P \Phi \rangle$$

then again $A^2 = A$ since $P^2 = P$, something which would only confirm my path integral argument. However, I did not see any benifit in such picture, resorting to non-physical states, since one could then equally do it with

$$A'(\Phi, \Psi) = \langle \Psi | \Phi \rangle$$

and likewise arrive at $A'^2 = A'$ while working with physical states only. The basic problem was that there was no physical time variable included in the state so that we could not retrieve a non trivial evolution; this has led me and other researchers to state that time is frozen in canonical (quantum) gravity. The intrinsic lack of a solution for this problem as well as a myriad of other issues concerning the definition of the Hamiltonian constraint, the quantization of the Dirac algebra and the way most researchers in this field separated the spatial constraints from the Hamiltonian constraint convinced me not to persue this programme. It was very clear to me that quantum mechanics needed to be formulated in a spacetime manner and that the path integral needed to be extended in some sense so that it could cope with generally covariant theories. Since I felt, in this paper, I should say something about some modern approaches towards these issues, since I plan to go beyond current theories, I took up some recent book by Rovelli and Vidotto on the matter and see if their views had evolved somewhat on these issues. Rovelli starts by rewriting all of known physics in a constrained way by making time into a dependent variable and thereby including it into configuration space; next, he notices that in this spacetime language the formula for the transition amplitude between unphysical states gives exactly the classical transition amplitudes of the standard quantum theory. That is nice albeit it constitutes a mere rewriting of known physics and does not change anything to the fact that the configuration space of a background independent field theory does not contain a physical clock. So, I thought, we are stuck again with the old problem; but now something curious happened, suddenly when talking about quantum gravity they spoke about states which partially correspond to a timelike geometry which has nothing to do anymore with the old canonical quantization method. Indeed, it seems Rovelli's views on the matter have progressed too from a quantum mechanics of space to one of spacetime; this can work out indeed. There are several things they write which I sharply disagree with however, such at the fact that they think one can measure spacetime geometry; as explained in the previous section, only characteristics having to do with particles can be measured while "geometry" is what is needed to make laws for particles in the first place. Therefore, we have dismissed the idea that one can have geometrical operators of area, volume and so on without ever having to use a physical (material) measure stick. Related to this is that they really do not deal properly with a closed system; their quantum mechanics of the universe appears to be one of a quantum system with a classical spacetime boundary and an observer outside it who can apply operators at free will. Obviously, such construction could at best be part of a theory of the universe as suggested in section two, where everything (including spacetime) has classical as well as quantum properties. As long as Rovelli and co apply this theory to investigations of parts of the universe of a magnitude well below 10^{-20} meters and a corresponding number for seconds, they are safe, but such line of reasoning cannot and will never apply to the whole universe.

To come back to my personal story, after I had dismissed the canonical programme as wrong, I was encouraged to take a look at causal set theory and causal dynamical triangulations both of which are theories of spacetime and not of space. In the former programme, one deals with an abstract generalization of quantum mechanics and a modification of the principle of general covariance; hence, it could solve the problem of time and we shall return in section four to the process physics defined in causal set theory so far. The programme of causal dynamical triangulations was somehow more modest and changed the path integral by computing transition amplitudes with respect to a *kinematically* preferred time. The modification is subtle since the Einstein-Hilbert action is preserved but crucial to get rid of the $A^2 = A$ conclusion; both programs however suffer from similar comments regarding the observer and observed as those applicable to the loop quantum gravity programme. Meanwhile, I got more interested in the foundations of quantum physics and relativity in order to understand the bigger picture prior to making any specific dynamical commitment; parts of this exploration are contained this paper.

A further comment on both theories, which is related to the fact that the quantum mechanical measurement is not taken under the same umbrella as the evolution of the wavefunction, is that nothing is happening in the theory. They do not have a theory of becoming but rather one in which they calculate transition amplitudes attached to classical boundary conditions and/or a kinematical time. The latter are not dynamical and the act of measurement has to be supplemented by some choice outside the system; we, on the other hand, have determined in section two a kinematical definition of measurement and have stressed that the measurement process is just a particular instance of far more general processes which do occur all the time and that the basic dynamics is probabilistic in nature with an evolutionary part having a probability close to one and a measurement part a probability greater than or equal to some $1 \gg \epsilon > 0$. Indeed, we do need a theory which tells us when a measurement takes place; in case spacetime is atomistic, such theory can be written down exactly in terms of irreducible processes and everything is directly defined. On the other hand, for a continuous spacetime, one has to write down that what is really happening as the limit of a sequence of reducible processes which is somewhat less easy to deal with.

3.5 Some philosophical musings on free will.

This section lies somewhat out of the main development of this paper but is included because of the sometimes quasi-religious debates which take on in some very small part of the community. The question is wether we have free will which most people intend to mean something like "a free spiritual choice to determine ones goals as well as the way to achieve them". In classical mechanics, everything is determined and there is no room for free will: free will is an illusion; in quantum mechanics on the other hand, the observer lies outside the theory and therefore has full liberty to decide what he or she wants. The last thing isn't very realistic however and once the observer is subjected to dynamical laws the only will which is left is in the principles behind those laws and it is free to the extend that the dynamics is probabilistic and not deterministic. But an identity can never ever make a decision outside the context of spacetime: this is something the enterprise of physics has to deny upfront as we stressed already in section two; in that sense, no free will can exist. In practice, when dealing with someone who has commited a crime, the judge has to make up "how much free will" the killer or thief posessed at the moment he or she commited the crime; by this, one means if there are any circumstances which one can think of which made him more likely to do what he did in comparison to a "normal" person. For example, if the thief was very hungry and without money, then the probability of the choice not to steal the apple was substantially lower than for a person with a standard income. In that sense could he not make use of his free will and this is taken into account into the penalty measure; but again there is no intrinsic will in the decision one makes, there are just principles and probabilities which explains why a perfectly sensible person can sometimes make stupid choices and then proclaims that he did not know why he did it. Now, we come to the conclusive section of this paper in which we put forwards some views on principles the dynamical laws have to satisfy.

4 Process physics.

There has been written very little about this in the literature and after a brief review of things I know about, we will find ourselves into the position of explorers trying to pave a way into this landscape of new possibilities. The search is obviously not unguided as we have to translate our very best insights into a novel language which allows for far greater extensions than previously envisioned: actually, this is in a sense what the very best of researchers are trying to do, to recognize old things from an entirely new perspective. We can repeat well known thought experiments regarding high energy deviations of the Heisenberg commutation relations at the Planck scale if we turn on gravity, that a particle would be hidden behind its own horizon and no further localization for an outside observer would be possible. Indeed, we have already encountered these aspects about Dirac quantization several times by now and have stressed that the right hand side of the Poisson bracket equations might very well become nontrivial in a non-flat context. Another question we raised was regarding the covariance of quantum mechanics: as we pointed out, standard quantum mechanics of point particles is not covariant and neither is the standard *formulation* of free quantum field theory by which I intend to say that there exists no single interpretation wich is *satisfying*. One could for instance simply say that the field equations and field algebra are covariant but that there exists no covariant criteria to single out a preferred vacuum state and particle notion; in that case, we end up with a very unpleasant theory in the sense that it does not allow us to make unique predictions anymore and we need another ingredient, beyond Quantum Field Theory to fill in that gap. This is not to say that in case we do find such preferred notions, we do not need to introduce extra structure related to the observer, we do but the procedures and ideas will sharply differ and I am rather unaware of the notion of a vacuum state attached to an arbitrary observer (for Killing observers it exists, but for arbitrary observers I don't know). This is an issue which is somewhat intermediate to process physics as process physics certainly needs to satisfy some form of covariance and we have to extract *conditional* probabilities such as an S-matrix relative to a (classical or quantum) background "field" which is described by the same dynamics. It are these conditional probabilities which constitute the replacement for the absolute probabilities calculated in standard Quantum Field Theory in a representation attached to an observer. We will look at this issue from different points of view which I have contemplated over the years; none of them are trouble free and none constitute a satisfying answer to the question. Moreover, they are still framed within an "eternalist" point of view on spacetime and we will point out immediate trouble when we go over to a process point of view on spacetime. But at least they are honest attempts in the sense that they do adress the question in an orginal but not completely satisfying way; it feels as if taking all these issues into account in one magistral coup is beyond the capacity of humanity at this point and certainly not in the reach of this author.

What I will describe now are a few attempts in the literature, most of which I have been directly involved in, to adress the issue of covariance of quantum field theory in the eternalist sense. The issue of covariance really is one of infinity, infinity in the very small and the very large: for systems with a finite number of degrees of freedom there is no covariance problem in a sense which we shall adress now. The model of spacetime these results have been framed into concerns the so called causal set theory, which suggests that spacetime is a locally finite poset C: this means that C is equipped with a partial order $\prec$ such that the so called Alexandrov sets

$$A(p,q) = \{z | p \prec z \prec q\}$$

are finite. Usually, one considers finite causal sets only; back in $2009-2010$ when I was visiting the Perimeter Institute, Rafael Sorkin introduced me to a student Steven Johnston who was working on this and in some afternoon, we were holding a brain storming session with around five people. In that discussion, I suggested two things to Johnston which should enable him to get rid of the equations of motion which on a causal set do not make much sense: (a) one had to recognize that the Pauli Jordan function was a bi-solution to the equations of motion and (b) that shifting the d'Alembertian operator through the commutation relations really meant that the center generated by the field operators was trivial so that the equations of motion, which are analytic, became a matter of algebra. Sorkin immediately recognized from this that the usual construction of the scalar field in terms of bosonic harmonic oscillators went trough and defined a unique vacuum state which is nowadays called the Sorkin-Johnston vacuum and is based upon the positive eigenspace of the Pauli-Jordan operator. So, the entire enterprise of free, scalar, quantum field theory on a causal set was reduced to finding a suitable substitute for the Pauli-Jordan function on the causal set which is given by a causal "path integral" as Johnston had already worked out [1, 2]. Now, I was not completely happy with this around that time since it really did not adress the issue that there should be a cutoff on the energy content of the bosonic field which is related to the size of the causal set and the Planck length; there are other problems associated with this construction which I will highlight later on. There has been done some subsequent work on this construction: (a) this author generalized the construction to Fermionic degrees of freedom which came with the unusual feature that negative norm and ghost particles had to be allowed for, it is still unclear what they mean or even if they should be eliminated or not (b) several people in the algebraic quantum field theory business studied the construction on a cosmological or static spacetime and concluded that the naive SJ state is well defined on a compact spacetime, but gives non-Hadamard vacuum states, in either vacuum states with a different short scaling or wavefront structure than the standard Minkowski vacuum state. This, however, can be easily repaired by "smoothening the boundaries" so that spacetime does not have a sharp cutoff: this appears to be physically sensible and personally I do not mind the introduction of a smooth cutoff function near the boundary which does not depend upon the geometry only in order to regain the Hadamard property. This shows that all problems with the energy momentum tensor are located at the nonsmooth boundary and therefore, the bulk physics is fine indeed, see Fredenhagen, Verch, Fewster [17]. So, for finite causal sets, we *do* have a fully covariant formalism which is on the other hand not very surprising since the latter define a preferred frame of reference as do compact spacetimes with a boundary. Obviously, issues as the Hawking and Unruh effect are framed here in a totally different way than they are in traditional Quantum Field Theory; the observer has to be introduced as a physical entity having impact on the physics of the quantum field under study rather directly instead of the usual disguise under a choice of a particular scalar product and vacuum state attached to some choice of coordinate system. As mentioned in section two before, this will lead to more physical and realistic versions of these phenomena involving the observers mass, charge, acceleration, rotation.... What we described above could be called a "minimal" covariantization of Quantum Field Theory, it is a generally covariant construction, albeit not a satisfying one, from the point of view of process physics, and it is minimal in the senae that it does not modify the field algebra as one would expect a full theory of quantum gravity to do. Indeed, one would expect the short scale structure of whatever replaces the vacuum state in quantum gravity *not* be given by something which has Hadamard form; neither would one suggest the Heisenberg commutation relations to survive at the Planck scale. The Planck scale should impose a physical cutoff beyond which it is meaningless (in the Copenhagen spirit) to ask any questions. We will now move to another, "less minimal" covariantisation of Quantum Field Theory which imposes dynamically modified commutation relations but which is as eternalist as the previous approach and, in contrast to the latter, has some problems at a nontrivial level.

The idea was launched in a research paper of this author [6]; we impose a few constraints on the theory: (a) the theory must be generally covariant and (quantum) locally Lorentz covariant in some sense (b) the definition of a particle must be quasi-local, that is tied to Minkowskian geometry on the tangent bundle of a manifold, in contrast to the global spacetime construction of Sorkin and Johnston (c) whatever replaces the field equations must be a first order partial differential equation which is locally Lorentz covariant and generally covariant (d) the main physical object is a unitary operator between two local frames of reference in different spacetime points relating one particle notion to another. One disposes of course of local vacua and these are the ordinary Lorentz covariant vacua; actually, *the* spacetime vacuum state is the canonical section in a Fock bundle. The problematic aspect of this line of reasoning is the following: while (a) is uncontroversial and Fock bundles, such as are necessary for (b), have been suggested before, it is (c) which contains the most radical element. Any first order, generally covariant and Lorentz covariant differential operator must be a combination of the left or right Dirac operators where the basis elements are multiplied from the left and right respectively. This implies that the complex number field has to be replaced by the complex Clifford algebra and we need to effectively study infinite dimensional Clifford inner product spaces, which are, in the case at hand, of indefinite signature. Hence, they constitute a generalization of Nevanlinna spaces and are not well known in the literature; more serious trouble arise when one tries to adress the issue of unitarity. There is no known solution for this problem albeit there are at least two suggestions which one might take seriously: the problems which arise when working them out concretely have stopped this author so far from working in that direction. Albeit this line of thought might be fruitful if one manages to solve the "unitarity problem" it is for sure the case that this novel line of thought requires more in depth and fundamental changes to quantum mechanics than the previous scheme where the compactness of the observed universe gave a preferred vacuum state. To my personal liking, the challenge of covariantizing quantum mechanics, meaning to have covariant Heisenberg equations and a coordinate *independent* interpretation of the state (or equivalently, a covariant Schrodinger equation) is a very challenging problem which is worthwhile studying in detail.

Perhaps the failure of these attempts indicate that we are framing our questions in the wrong language; maybe, we should not speak at all in the language of field operators, states and so on but crucially rely upon the language of the path integral. This reminds me of an old conversation I had as a PhD student with Rafael Sorkin back around 2002 or so at his home; we were talking about his quantal measure approach and how it relates to the decoherence functional framework and standard quantum mechanics. I was mumbling to him that the standard view on the propagator in the Feynman path integral formalism is not covariant, that it depends too much upon excess baggage attached to the observer such as the choice of an initial and final data hypersurface as well as the very definition of the quantal measure. I uttered that a natural step towards solving this problem constituted in summing over all future oriented causal paths only which would remove the rationale for quantum field theory since the causality problem would evaporate as well as the standard negative norm problem. I asked him what he thought we would get if we would sum over all future oriented causal paths between two spacetime points only attaching weights depending upon the number of traversed links. After a bit of reflection, we both uttered that it would need to be the advanced propagator or Green's function; I did not work this further out as I was busy with other problems at that time and meanwhile Johnston has rediscovered the same idea. However, his presentation of *why* this should be true leaves some specifications which I will add now and which may or may not be of importance in constructing such quantum theory. Basically, one can define the advanced Green's function

$$A(x,y) = \theta(y^0 - x^0)\Delta(x,y)$$

where θ is the usual step function and Δ is the Pauli-Jordan function, the difference of the advanced minus retarded propagator. A standard calculation, see Wald, yields that

$$\Omega(A(x,\cdot), A(\cdot,z)) = -\Omega(\Delta(\cdot,x),\Delta(\cdot,z)) = \Delta(x,z) = A(x,z)$$

where the Klein Gordon symplectic form Ω is evaluated on a spatial hypersurface between $x \prec z$. This formula may be explicitly calculated in case of the Minkowski scalar field where

$$\Delta(x,y) = i\int \frac{d^3p}{(2\pi)^3 2E_p}\left(e^{-ip.(y-x)} - e^{ip.(y-x)}\right)$$

and

$$\Omega(f,g) = \int d^3z\,(f(t,z)\partial_t g(t,z) - g(t,z)\partial_t f(t,z))$$

and the Minkowskian scalar product is given by $p.x = -p^0x^0 + \vec{p}.\vec{x}$. I have, however, never encountered the interpretation that this meant that the advanced Green's function is a propagator with respect to the Klein Gordon symplectic form and this is precisely the core of the formula for the advanced Green kernel in causal set theory. The fact that this does not appear to be well known is further exemplified by the fact that, for the Minkowski vacuum state, i times the two point function

$$W(x,y) = i\langle 0|\phi(y)\phi(x)|0\rangle$$

satisfies

$$\Omega(W(x,\cdot), W(\cdot,z)) = W(x,z)$$

as the reader may directly verify from

$$W(x,y) = i\int \frac{d^3p}{(2\pi)^3 2E_p} e^{-ip.(y-x)}.$$

Moreover, E and W are connected through

$$\Omega(W(x,\cdot),E(\cdot,z)) = W(x,z) = \Omega(E(x,\cdot),W(\cdot,z))$$

something which is true in general for any bi-solution W, and therefore does not add any information, determining a Poisson bracket algebra between the Pauli Jordan function and the two point function. It is our first equation,

$$\Omega(W(x,\cdot),W(\cdot,z)) = W(x,z)$$

which constitutes a strong characterization of the Minkowski vacuum and I intend, in a forthcoming publication, to investigate it as well as covariant "path integral like" formulations of relativistic physics[7]. So, maybe do generalizations of the path integral constitute a proper step forwards in getting a proper formulation of process physics; it might just be that the language of differential operators is too limited for obtaining the formulation of a covariant quantum theory. This would constitute a very strong indication that we have to dispose of eternalism indeed!

Let us now describe a real piece of process physics which has, not incidentally, been developed in the framework of the causal set approach towards quantum gravity: this is indeed no accident as the natural language for causal sets is the one of process dynamics in contrast to continuum physics. The idea here is that the causal set grows towards the future by adding one element as well as the appropriate causal relations at every stage of the growth process [10, 11]. Rideout and Sorkin developed four physical principles to delineate a very specific form of the dynamics leaving only one free parameter per growth stage: they are "internal temporality" which concerns a label attached to the stage of a particular process, "general covariance", "Bell causality" and the Markov

[7] In a well defined sense, the Pauli Jordan kernel is the identity operation with respect to a product defined by the symplectic form. That is, define the action $\triangleright$ of a bisolution $G(x,y)$ on a solution $f(y)$ to be

$$G \triangleright f(x) = \Omega(G(x,\cdot),f(\cdot))$$

and define the product

$$(G\circ H)\triangleright f(x) = G \triangleright (H \triangleright f)(x).$$

Then

$$G\circ H(x,y) = \Omega(G(x,\cdot),H(\cdot,y))$$

and the Pauli Jordan operator clearly constitutes the identity element. The correct scalar product is given by

$$\langle f|g\rangle = i\Omega(\overline{f},g)$$

and the kernel

$$\Delta(x,y) = i\int \frac{d^3p}{(2\pi)^3 2E_p}\left(e^{-ip.(y-x)} - e^{ip.(y-x)}\right)$$

can be interpreted as a spectral decomposition of the identity operator with respect to this scalar product. Such spectral decomposition is however far from unique and does not canonically define a positive norm subspace; in case of the SJ state we needed another, positive definite, scalar product to achieve unicity. There exist other *partial* characterisations, such as W is Hadamard, an orthogonal projection $W\circ W = W$ and $W^\dagger = W$ on a maximal positive norm subspace satisfying $\overline{W}(x,y) = -W(y,x) = \Delta(x,y) - W(x,y)$ which garantuees it is a quasi-free state and we shall come back to this in a forthcoming publication. Notice that just as for a generally covariant theory, the "propagator" or transition amplitude is given by a projection operator (this time from an indefinite inner product space to a standard Hilbert space) on the constraint space (solutions to the Klein Gordon equation) which strongly suggests that the above reasoning is correct.

property. General covariance demands the existence of a "probability potential" in the same sense that Newtonian physics demands that forces can be derived from a potential energy: that is, the product of a sequence of transition probabilities defines a potential function between the endpoints so that one has a path independence property of the growth process. This is at least one interpretation, another given by Sorkin and Rideout is that this path independence reflects a natural labelling invariance which is a dynamical version of Einstein's general covariance. Finally, as this author has stressed several times before, the very same principle reflects the quantum mechanical principle of outcome independence which says that it does not matter which happening occured first in some specific sequence of irreducible process as long as both happenings are "causally" disconnected. This is a very nontrivial finding and it indicates that, even if we need another principle, we have to be very careful in stating what it is and certainly Bell causality is totally wrong if we were to include matter; on the other hand, it is very constraining in the sense that it allows one to explicitely work out the general form of the transition probabilities depending upon the first n parameters at growth stage n. The question, however, is if it will produce realistic universes with a sufficiently high probability and I have serious doubts about that; it seems rather clear that as long as one keeps spacetime classical, the principle of general covariance is a correct one. How this principle should be extended towards quantal spacetime is an open question and in my mind requires a more covariant viewpoint upon quantum mechanics to start with. As stressed before, this viewpoint may require only some minimal effort or it may involve something more radical but it for sure requires *some* novel input; when I was discussing these matters in 2005 with another bright postdoc, he told me he was of the opinion we were not ready yet to adress these questions as our view on flat spacetime Quantum Field Theory was still too immature. I do for sure agree with that but I guess I am just a bit more adventurous than he is.

Finally, one may wonder if our heroic attempts to make sense out of a multiparticle quantum theory from the eternalist point of view are not going to clash with our growth process so that all our efforts are futile. I have done some work on that and the answer is the same as the previous one regarding the covariance of Quantum Field Theory: since the notions of general covariance according to Sorkin-Rideout and Einstein differ, it is for sure the case that novel ingredients are needed but again those may or may not be that radical. For a detailed discussion, see Noldus [8]. This is all I know about process physics: as the reader may sense, our situation is not an easy one. One may be tempted to further comprehend our existing theories from an eternalist point of view before moving forwards but on the other hand, there may just be a deep reason why that is impossible. It may be like trying to better understand the elephant by keeping on staring at his dangerous teeth; personally, I prefer to do both kinds of activity, to be conservative and avant garde at the same time. It must be clear that we are still far removed from a deep understanding of nature and especially from the project of process physics in general. There are so many technical and conceptual questions I could give away, but so few answers I know of. The very idea of this paper was to make clear to the reader what kind of difficulties we are still facing in our contemporary approaches and how physics in general may be understood from a broad way to speak about nature. Once one understands the language, quantum mechanical ideas become almost self evident and it is this what I wanted to convey to the reader.

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