Constructing Spacetime in Matter

Mikalai Birukou*

Friday, December 31, 2010.

Abstract

This article discusses concepts about time and space. It finds that spacetime better be defined as relations of matter states. And it shows how one may construct such spacetime(s).

1 About Time

Time is an obvious, common and intuitive concept to every person. It always goes on. We use watches and clocks to measure elapsed time. And the best instruments are atomic clocks that use quantum mechanical events as "ticks of time". But what is time?

Let's follow for a moment an evolution of concept of time.

Before clocks, human species perceived successive events, noticing that some actions are longer or shorter. Concepts of longer or shorter spans of time are relative concepts, cause one always compares quickness of one thing relative to quickness of some other thing be it explicitly present or implicitly assumed. Naturally, it is difficult to precisely convey a message that uses relative meaning while relying on implicit things which may not be assumed by the recipient of thy message. Thus, a need arises to have explicit and commonly excepted measures of time span[1], and clocks get inevitably invented.

Then Descartes came and coined in cartesian geometry among his vast input to our collective understanding of nature.

So, people go on to drawing different coordinate axis, like length vs. width, or distance vs. time. Time? Hmm. Now, thanks to eyes, i.e. thanks to processing in visual cortex of the brain, new concepts start to appear.

*E-mail: mikalai@birukou.net

[1]Similarly to a need to have common measures of length, mass, volume, et cetera.

Imagine, you are drawing a length vs. width coordinate grid with a purpose to solve some geometrical problem. You put two lines, one for x, and one for y. A “little box” is drawn and is ready for putting in some geometrical structures. And a brain naturally takes concepts related to boxes and transfers them onto space, depicted on paper by x-and-y axis. When a philosopher shapes these box-inheritted concepts into zer truth about space, he inevitably arrives to an *Absolute Space* view. If a said philosopher happened to be drawing x vs. t coordinate axis, like those in classical mechanics, an *Absolute Time* view would also be very natural to him.

An absolute time and space is like a big box. One can imagine an empty box. One can imagine to move stuff inside of this box in novel directions, like opposite to experienced direction of time flow. These are but two obvious sins of a space-like-a-box vision.

Empty box is a sin by virtue of contradicting with observations of Casimir Effect [Lamoreaux1997] and Unruh Effect [UnruhEff2007]. These effects are results of a pervasive presence of quantum fields anywhere in space. Id est, if we are to use box-like space, we have to additionally always require that there are no corners empty of quantum fields.

Wouldn't it be nice to have a vision of space that cannot be empty by its very nature. Then the use of box-like mathematical structures will be constrained to never be empty of quantum fields, with the constrain coming as a requirement of space's nature, and not as mere fitting to experiments.

The second sin, a travel back in time is, well, how can we put it softly. Travel back in time is just not healthy for physics as science. Yeah[2].

Wouldn't it be nice to have a vision of space where travel back in time is not allowed by the nature of space itself.

Next revolution of view of space and time comes with Eisntein's Special and later General Theories of Relativity (SR and GR, for short).

With SR time and space are squashed into one Minkowski spacetime. Things like rate of time flow, duration and simultaneity stop being absolute notions. Despite having a new structure, Minkowski spacetime is still a box-like construction. If it were not box-like, Casimir effect would be a part of the lecture that introduces Minkowski spacetime to students. Well, its not the case. And possibility of travel back in time is not ruled out in SR.

GR upgrades spacetime from being a simple example of a pseudo-Riemannian

[2] While we are on a historical retrospection, let's note that traveling *backwards* in time did not appear neither in folklore nor in art literature until after invention of a cartesian system of coordinates. Drawing space vs. time coordinates on paper allows visual cortex to create otherwise absent parallels between natural concepts of space with those of time. Without this cognitive trick, ancient greeks, for example, were not able to imagine travel in time, which could've helped handsomely their gods' magic activities.

box, to being less simple pseudo-Riemannian box. Yes, in GR curvature of space is dictated by matter distribution. But, there are quite celebrated solutions of GR equation with energy-momentum tensor being zero everywhere, so called vacuum solutions, exempli gratia, Schwarzschild black hole solution[3].

If you are into time travel thing, you have luck. There is a recipe for a practical time travel given by GR. All you need is a closed timelike curve. Finding a solution with one soon will become a usual problem given in a graduate course.

If you are not into time travel, you shouldn't despare as the Chronology Protection Conjecture has already been proposed.

2 Clocks

The above elucidation of thoughts about time is not particularly encouraging. Let's do something about it, starting from an obvious and probably simple task of measuring time.

We measure a span of time with clocks. Clocks use some processes as "ticks" of time that are simply counted. The International System of Units defines one second of time as some particular process, a particular "tick".

It is apparent that in order to have any practical measure of time, we have to use some processes that occur in matter. Let's then drop an idea that time somehow exists and matter happens *in* time, and see how far we can get away with it.

How do we lay out a time measure on matter?

We need a time measure to label all motions and all jiggling that matter can possibly do. And if some motions of matter happen between two elementary ticks of a clock, they all will be labeled as occuring at the same "tick"-count, or at the same time, which is not good, cause we loose time resolution.

Let's set an operator L to represent all of matter jiggling within some time interval dt. For a more precise time measure we need matter states labeled with t so that there is as less matter jiggle as possible in any given infinitesimal period of time, over any extended period of time. So we look for matter states odering or tragectories that minimize the following integral quantity:

$$S = \int L dt \tag{1}$$

[3]Radius of a black hole is connected to a mass of a black hole, but solution starts with $T_{\mu\nu} = 0$ everywhere, id est no energy or mass to begin with. Yes, it sounds paradoxical.

From quantum mechanics (QM for short) we know that an operator of infinitesimal change in time is an energy operator. Therefore, L shall have units of energy.

S is an integration of total matter jiggle, so, we'll call it an *action* with physical units energy$\times$time.

Let us summarize: in order to get a good time ordering of matter states we need to minimize action (1).

This same principle happens to be used in finding laws of motion. Thus, we can proclaim:
"Observed laws of motions are just time measures".

Starting from an assumption that time is relations between matter states we got a principle of least action as a way to find well formed time sequences. But this same principle is used to formulate fundamental theories like QED, which, in particular, is exceptionally good when it comes to match between theory prediction and experimental evidence. And because the principle produces such nice theories, an original assumption must be true, id est
Time is relations between matter states.

In this light, I have a humble suggestion that described here reasons for principle of least action should be used in QFT texts as current reasons are not as good. Let me explain.

In a second year or so of studying physics, in a classical mechanics class you are told that it is a good idea to use this nice principle of least action, motivated by some talk about *light paths* and/or *virtual work*. Later on, when in quantum mechanics class, together with a prof you *derive* classical mechanics principle of least action by means of path integration. At the same time you are told that really fundamental theories are QFT's. Then QFT class starts with an explosion of a logical bomb consisting of the following: take a *classical* action, do n-th quantization, and it gives you the dream[4].

3 Time Flow

It is morning of the 30-th of December 2010. I wake up thinking about this very article. New ideas popup. I put water in the kettle, go to check email, come back. The water is cold!

A thought flashes through my mind: *the Second Law of Thermodynamics*. Water does not get hot in time by itself. And when someone asks why time flows *forward only*, we mumble something about this kettle-related law.

[4]In fact, this has been killing me to the point that I had to write this very work to explain it to myself.

What if I want to have a clock that is ticking forward for sure, and never backwards. Will my gradfather's clock do? Its inner working is governed by classical mechanics. But the classical law of motion is not particularly convincing when it comes to why time flows *only forward*.

The Second Law of Thermodynamics tells that time should go forward. Use a kettle for a clock? The ticks of such a thing won't be small. We need a more precise clock, besides being sure that it goes in a right direction.

Sometime between an invention of a steam engine and today, people have discovered radioactivity. Upon close observation, atomic nuclei decay and do not seem to spontaneously recombine. And this stuff is now used to make nuclear kettles (no use to us here), and in radioactive dating on historical scale[5].

Radioactive decay is a process in which a system with a bunch of atoms goes through states were it first has no atom decayed $|0\rangle$, then a state with some atoms decayed $|n\rangle_{n>0}$, and with some more $|m\rangle_{m>n}$, till all N atoms of the system decay:

$$|0\rangle \to |n_1\rangle_{n_1>0} \to |n_2\rangle_{n_2>n_1} \to \ldots \to |N\rangle \tag{2}$$

Each of these consequent processes reminds a quantum mechanical measurement process, where a laboratory assistant $|L\rangle$ performs a measurement on some system $|\psi\rangle$, with some possible outcomes:

$$|L\rangle |\psi\rangle \to a_1 |L_{\psi_1 1}\rangle |\psi_1\rangle + \ldots + a_n |L_{\psi_n}\rangle |\psi_n\rangle + \ldots \tag{3}$$

where $P_{\psi_n} = \|a_n\|^2$ is a probability of each of the outcomes. Which is to say that (3) is what theoretician on the seveth floor has on the paper, but a laboratory assistant in the basement will have processes like

$$|L\rangle |\psi\rangle \to |L_{\psi_n}\rangle |\psi_n\rangle \tag{4}$$

occuring with a probabilities P_{ψ_n}.

I have wisely chosen the following phrase to describe (4): our laboratory assistant gets *entangled* with $|\psi_n\rangle$ state of the system, therefore is able to record in the lab journal n-th result, id est $|L_{\psi_n}\rangle$.

Let's ask our lab assistant to make a measurement on another system $|\phi\rangle$ after making a first measurement on $|\psi\rangle$, getting in the lab

$$|L\rangle |\psi\rangle |\phi\rangle \to |L_{\psi_n}\rangle |\psi_n\rangle |\phi\rangle \to |L_{\psi_n \phi_m}\rangle |\psi_n\rangle |\phi_m\rangle \tag{5}$$

Lab assistant gets entangled more and more with every consequent measurement. The lab journal gets more and more information written in it.

[5]History was moving forward which is reassuring.

Let's give a novel name to the lab journal. Information about new measurements or entanglements are written into it, so, the name should at least start with "i". The journal can be used to trace history of event, so, "trace" is an appropriate part of a new name. Short names are generally better, so, let's call our lab journal an *itrace*[6].

We are ready to make statement about time[7]:

A flow of time is a process of adding new entanglements to an itrace.

And I am not going to jump any further into QM interpretation business at this point. And let me tell you why doing so will be like shooting oneself in a foot.

Notice how general QM mathematics is. It allows one to switch from one view to another, create compound systems, talk about parallel possibilities and assemble events as a sequence of other events, et cetera. And when putting forward some QM interpretation, one uses examples with some quantum systems. These systems are assumed to persist in time with changing states as things go along. And we may have systems that span in space as well [EPR1935].

Sometime between formulation of QM in 1920-30th and today, Quantum Field Theories have been developed, and it has been experimentally shown that these theories explain observed phenomena exceptionally well. At the same time these theories *underly* [Feynman1948] QM. Sure, it is also a theory that uses these bizarre mathematics. But, and it is a huge but, there is only a handful fundamental things on this level, and operator fields tell something only about events that occurs at some *points* of spacetime.

Consider Stern-Gerlach experiment. You take electron, measure its spin relative to z-axis. A consequent measurement of "z spin" of initial z up electron, gives z up again, which is very *intuitive*. Then when between two z measures we do one x spin measurement, the last z spin measurement may produce both z up and z down results. And this starts a rave about how it is a single electron changes its characteristics depending on whether or how it has been looked at. And so on, ad infinitum.

Enter QED. An electron, that went trough Stern-Gerlach torture, is an *effective* object maid of many QED events summed up in a path integration. Electron changes its characteristics? No! One electron disappears, another appears with new characteristics!

So, we can do fundamental interpretations only when we are at the fundamental level, that of QFT's. Else we can easily get bogged down by ex-

[6]Given a non-zero expectation value of iMacs and iPhones numbers in the supposedly BlackBerry-infested Perimeter Institute, itrace seems to be a good name.

[7]In section 2 we came to a conclusion that time is relations of states of matter, and here we say what *sort* of relations it is.

traodinary aspects that start to appear in effective objects. While the extraordinarity comes from simple mismatch between QM's prediction and our *intuitive*, useful in every day, notions about stuff in our human environments.

4 Spacetime construction

We have been very critical of a box-like view of spacetime. In this view spacetime exists as fundamental container for all other stuff, which is matter. We do not like it, so the onus is on us to suggest another fundamental view.

Assertion 1: There is no fundamental spacetime.

Assertion 2: There is matter.

Matter is not a one blob, but has many parts. Let's label different parts with unique labels x.

We define some operator $\hat{O}(x)$ for every x. $\hat{O}(x)$ tells the state of matter at x.

Assertion 3: States of matter are allowed to get entangled.

Let's take some state at x_1 and let it entangle with some state at x_2. This entanglement will be a "tick" of time in this itrace. And we can say that x_1 and x_2 are separated by one "tick" of time.

In section 3 we showed that we may get some problems when we have quantum system extended in time. So, x label will signify some specific single event in itrace's time.

Assertion 4: For any given event x there are many events y that have the same separation in time from x.

Therefore, x shall be a vector $(t, \vec{r})$ with t as a time label, and $\vec{r}$ as a *space* label. Let's have t a real number. And since we may have many events for the same t, $\vec{r}$ shall also be a vector, with dimensionality $d > 1$.

Let the last time tick of some itrace correspond to event $(t_0, \vec{r_0})$. Then any next time tick will correspond to events $(t_0 + dt, \vec{r_0} + d\vec{r_0})$. Let's set a ratio of labels for this case to be $c = \frac{\|d\vec{r}\|}{dt} = 1$.

We will say that any two events $(t_1, \vec{r_1})$ and $(t_2, \vec{r_2})$ have time-like separation, if $c > \frac{\|\vec{r_2} - \vec{r_1}\|}{\|t_2 - t_1\|}$, and space-like separation, if $c < \frac{\|\vec{r_2} - \vec{r_1}\|}{\|t_2 - t_1\|}$.

c can be called entanglement speed, and with arguments analogous to those in SR, we will arrive at having built Minkowski spacetime.

We can continue onto constructing QED, by adding necessary assertions about matter in a form of relations placed on field operators and using principle of least action, outlined in section 2.

So, this is a way to construct spacetime in matter, and to view a spacetime as relations in matter.

Although I have been sloppy in details, I do not think that any important message is lost.

Entanglement is probably the best way to define time, as it will give nice historical order, and c is really a property of the spacetime construction, while zero-mass particle just happen to travel at this speed.

The resultant formalism of spacetime, although being a box-like mathematical construction, is bound by definition of time flow from section 3, making it impossible to even entertain an idea of traveling backwards in time. At the same time it is matter events that *define* spacetime points[8], so spacetime is not empty by construction.

5 Remarks

5.1 Space dimension

I have not set dimension of space, cause it seems that later introduction of spin degrees of freedom and a need to relate them at different points may fix space dimensionality as a function of spin properties. Doing this will involve use of connections and application of diffeomorphisms cause arguments about relation of different points sort of integrate all points into one entity.

This rigorous mathematical procedure must be done. It may uncover a need to introduce additional assertions.

At the same time a more rigorous process may produce not just the flat space, which we got in section 4.

5.2 Graviton

All arguments here push towards not having any *fundamental* gravitational degrees of freedom. Yet, later it may be possible to have quantum gravitons as an *effective* degree of freedom, in way like phonons in crystals are.

On a classical level, motion in curved space will look as if there is a force of gravity.

Speaking about GR, we should distinguish its very useful and powerful idea of equivalence principle from an actual mathematical equation. Physical sense of this principle is going to stay, but the math may go. And here is why.

An actual mathematical equation is good for Mercury, gravitational redshift, gravitational lensing, time dilation in gravitational field.

[8] GPS gizmos use physical events to identify points in spacetime. And they work!

Although, if one faithfully applies GR equation to galaxies, then a need arises to introduce dark matter to fit theoretical predictions with observed galaxy rotation curves.

If you allow yourself to be unfaithful to GR equations in certain regime, there exists a purely mathematical fix, called MOND [Milgrom1983]. It is a purely mathematical fix, as physical reasons that may stay behind it are missing. And without physical reasons mathematical scribbles are not physics. Yet, simplicity of the fix may be a hint that GR's mathematical part might be improved.

Amount of dark matter should be almost five times that of a regular matter. It is a fairly big dark problem, but you can get yourself a gigantic one simply by again being faithful to GR mathematical equation this time on a cosmological scale.

If we want to explain observed rate of expansion of the universe with a use of GR math, we need to introduce dark energy. And together with dark matter, accounting tells that there is only about 4.6% of non-dark stuff in the spacetime box.

Upon hearing about this state of affairs, a smart tax paying person may suggest introduction of 95.4% dark salaries for cosmologists and theoretical physicists. Cause it sounds like we are sticking too faithfully with some mathematical elements, almost religiously applying them in all regimes, instead of may be looking for good physical reasons to suggest modified mathematical expressions that will give results comparable to observation[9].

5.3 Entanglement and meaning of itrace

I said that I chose word entanglement very carefully. This choice says that whatever happens in the process in EPR experiment pair production (this is where we commonly use word "entanglement" today), is equivalent to process in the lab. This has been said in [Everett1957]. After all, equivalence of laws must be a good thing.

In EPR experiment this little entanglement happens in itrace of two particles and this itrace has no relation to an itrace of an observer before she later checks particles' states. And if we have a fundamental spacetime box, then it becomes troublesome to explain observed results together with observed innability to send information (that is create entanglements) faster than speed of light (that is entanglement speed), giving reason for current rave about entanglement.

[9]If it were in 1920-th, many would probably bug Albert into looking for better math. But it is a beginning of the 21-st century, and dark places seem perfect for superpartner particles and the likes. Should a current mood of time influence scientific enquiry?

Now, if our itrace at some point has no connection to some other itrace, does that itrace exist before or after entanglement with our itrace? Probably, otherwise quantum computers would not be able to work as they do, cause their designers arrange for some computation to be performed in those other itraces.

Can there be itraces that are totaly disconnected from ours, and will never be connected to us? There may be such things, but talking about them is not a part of a scientific discourse, cause it will make no dent to our life, assuming you believe that science is a practical endeavour.

5.4 Cyclic time

Imagine you have a few qubits. You entangle them together with usual operations, on and on. And before doing a measurement, or entangling yourself into those little itraces, you perform operation to return qubits to their original state.

From a qubit point of view there is cyclic order of states and therefore time. Is there then a possibility of time travel? No, cause when you travel in time, your *proper* time goes always forward, but in case of a qubit its own proper time returns to initial position. More so, in returning qubits back, we disentangle them.

Ok. These qubits are effective objects, but they demonstrate a point. Firstly, this cyclic time will not permit a time travel in a full sense of it. Secondly, this effect is possible only if disentanglement can be done.

References

[Lamoreaux1997] S. K. Lamoreaux, "Demonstration of the Casimir Force in the 0.6 to $6\mu m$ Range", Physical Review Letters, vol 78, 5 (1997).

[UnruhEff2007] Emil T. Akhmedov, Douglas Singleton, "On the physical meaning of the Unruh effect", arXiv:0705.2525v3 (2007).

[Milgrom1983] M. Milgrom, "A modification of the Newtonian dynamics as a possible alternative to the hidden mass hypothesis", Astrophysical Journal, Part 1, vol. 270, 365 (1983).

[Feynman1948] R. P. Feynman, "Space-Time Approach to Non-Relativistic Quantum Mechanics", Reviews of Modern Physics, vol 20, num 2, 367 (1948).

[EPR1935] A. Einstein, B. Podolsky and N. Rosen, "Can Quantum-Mechanical Description of Physical Reality Be Considered Complete?", Physical Review, vol 47, page 777 (1935).

[Everett1957] Hugh Everett, "Relative State formulation of Quantum Mechanics", Reviews of Modern Physics, vol 29, num 3, page 454 (1957).