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Non-triviality of time

This essay was written as part of an application for a Master's degree in Logic and Philosophy of Science at the Ludwig Maximilian University of Munich in Germany. The subject of this essay – Time – is at the heart of our understanding of reality, and its nature is still in a constant debate, therefore, due to vastness of the subject, the rigour behind some of the arguments may seem lost. The objective however, was only to point out some unavoidable physical observations, making our conception of time non-trivial. This text should be treated just as an overview of some notions in philosophy of time, and as a critique of some intuitions for time, strongly influenced by my own interpretations of current physical theories.

Intuition of time

When discussing reality, one cannot seem to escape the concept of time in any way. The most basic physical observations a human can make is observing change. Observing change seems to be somewhat at the origin of the concept of time itself. But as we shall see these observations infer a lot of characteristics of time – that is how we develop certain intuitions about time, that might not be well-founded. This understanding is, of course, commenced by the most basic questions. Let's imagine someone ruminating on the nature of time. There are three most fundamental immediate questions one can pose: What is time? How time works? and why time flows? Which sense seems difficult to grasp, and also we might have some other more specific questions like: Does time has a direction? is it local or global? is it essential to existence of our universe? Is time fundamental or constituted from something else?

Let us walk through a hypothetical conversation about those broad points of inquiry. It usually begins somewhat the same, person A might ask:

A: What is time?

B: Time is the measure for change that we observe.

A: You are saying that, we observe a uniformly moving car and to make sense of it you create a notion of intervals between the same distances.

B: I don't create those intervals. When looking at a moving car what we observe no change in its motion but a change in the position, therefore we know that this car is changing its location with respect to the equal spacing of distances. The unchanging acceleration infers that it is flowing through time uniformly.

A: So if the time is what the change is in respect to, then is your concept just not substitute for change? In other words how would you know time existed in a void?

B: In the void there would be no observation. Time exists because we suppose that we exist and we observe change. Time is what measures the difference between two different states, in the now and then.

Here, person A is trying to make sense of the abstract concept of time, but person B is only trying to make sense of what it is in front of him. This conversation left both of them unsatisfied, person A does not have his satisfying definition, and person B's concept is only as true as the moving of the car is. It also shows the first intuition that both of them held, that we could summarise in a sentence like "World changes uniformly with respect to ever-changing time". Even poetry invites us to think about the inevitability of the flow of time and to reflect on how we are prisoners of time. This intuition is deeply scientific, it is about creating a trust-worthy concept which works in accordance with reality – "We don't see the change going away, therefore the rate of change has to be unchanging and external". Unfortunately, both parties have not really questioned the observation itself. The doubt here is put on person B, because he is making at least one supposition worth discussing.

A: Suppose this change exists. Your concept still struggles here, as to understand change you brought the notion of then and now. How do you know that that then is at all relevant to now? Is then not outside of your observation? You have created a notion of past not out of the observation, you have just supposed it.

B: We are having this conversation in the now. After it is finished we will have said those words in the past. But because this conversation is happening I can suppose that it will have happened in the future, in the same way that the observation of the car at the beginning and at the end of its journey does not depend whether it will be conducted, is conducted or was conducted. Difference between was or is or will be does not influence the exact state of the car. We know past exists because we see change.

A: Unfortunately the difference of which you speak is merely an abstract belief, because I do not see the past. That may be that the observation happened but what is possible to observe, is only what is happening now. We are therefore not observing differences between states but differences in the now.

Here, we see a clash of two ideas with respect to a simple question: "Does past exist?". The person A is clearly speaking from our the very personal experience that the past seems to be untouchable and that the future is undetermined. Some may call it an illusion of free will or of the indeterminism. Therefore, it is very reasonable to assume that the time is just the description of the change, and that the future simply is "not real" it sense of "not observed". On the other hand person B is arguing for the opposite, change and reality is not dependent on the now. That is to say, time possesses a structure of order, the only temporal distinction between the given states is the relationship before-after, and because the flow remains then the future will arrive, so it "exists" and so does the past. This is also reasonable to assume. If one doesn't suppose the existence of the past, every observation of the change does not have an anchor to stand on - there is no 'now' to relate to when making deduction from the observations.

Those two approaches are well-known as the A-Series and B-Series of time, or respectively the tensed and the tenseless view of time. They were created by John McTaggart in 1908 in order to make some rather convincing points for the unreality of time, through drawing contradictions form the understanding of the temporal placements of events. Interesting idea to point out should be his regress or his “vicious circle” which states that in order to account for the incompatibility of being in the now, the future and the past, one have to always assume the existence of time, because every event can be relativised to any of those three: if X is now, it will have been in the future etc. In other words time has to be presupposed and therefore “unreal” in his sense. He also rejects the B series because he argues that the mere ordering of events can not create the effect of change in the now so it is an incomplete and therefore unreal picture. He concludes by creating a third coherent, non-temporal ordering of events – the C series. Note worthy is that this paper, having been written before Einstein’s complete notion of time-space, of course does not include any relativistic effects, which seems to be crucial in his concept of simultaneity of events. It is however critiquing both of the perspectives in a very formal philosophical manner, showing the inconsistencies of the intuitions we might have.

> *B: This difference in the now you speak of is very much a subjective experience form your perspective. When examining the movement of the car, it is almost as if, the car is uniformly moving through time more so than space. This is how you make the notion of the same intervals of time. In this sense you are only describing the effect of time and not the time itself, so there must be a constant motion, that only passes through now.*
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> *A: I am only stating that the now is the only place where the observation is made. It would be impossible to detect the illusion of passage of time from the subjective observation of time. I observe only the flow that, according to every observation, is uniform - movement of the car, fixed speed of light, movements of a pendulum clock. I would not be able to notice anything outside of this perspective.*
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> *B: But in order to account for this perspective you suppose time that flows.*

This to me shows that another intuition we have. When stating that we observe a “flow” of events, an immediate question should be - Flow of what?. So the intuition we might have for the “flow” through our static point in space, clearly demands those “tracks of time” for the train that is “now”, creating a contradiction - a similar vicious circle. This contradiction of those static - “we are trapped in the now “- and active - “the change we observe” - characteristics of time, gives rise to the convoluted understanding we might have.

But is also draws on a very important conclusion - whatever the nature of time, one has to assume time in order to understand it. For example when looking at matter, we can cut it up into small pieces - particles - in order to understand it better and those particles have a known property $E = mc^2$ stating that somehow, particles are equivalent to energy, so the statement “Matter is explained by energy” is not non-sensical. However, the statement “Flow of time is explained by…time?” is non-sensical, because of the lack of reference. In that sense time is fundamental - there is no cutting up of time. On a personal note, I once provoked a friend with a question “Does time have a direction?” and he replied “Define time.”. It seems that there is no reference to answer this question, nor by slicing into into smaller pieces, nor by creating a notion that encapsulates time and space (let us refrain from commenting on any God-like creationist positions). Search for a satisfying definition is futile, as the time is not abstract, but rather is a name we have for this "flow". To me, the lack of definition, or the lack of a good theoretical framework, does not seem to hint at *the unreality of time* as McTaggart states, but rather at the fundamentality of it (this is not exactly what the paper states).

> *A: Your understanding also has a lot of suppositions. There is no distinction between the car moving through time from the beginning to the end of its route and the car moving backwards in time from the end to the beginning, so you have to assume the ordering of all of the events. Whereas me I only assume local ordering in the now, form past to the future, nowhere have I said that I create the rules for this flow.*

Now, the mother of all problems dividing modern philosophy of time - the asymmetry and the direction of time. It is an intuition so fundamental that any breakage of this law can create an endless stream of science-fiction. There is no observation supporting possible time travel - except maybe for potential singularities in white and black holes, yet still the debate is open. Most basic physical theories actually do not contradict with any strict time reversal, for example Newtonian mechanics, Einstein's General Relativity or Schrödinger equation, but there are other phenomenas which create this asymmetry unavoidable - for example the entropy, both of those sides shall be explored in the next part of this essay.

For now, let us state the intuitions we might have after our initial examination of time, that have been mentioned, and let us reexamine them in the final section:

1. *Time is fundamental.*
2. *Time flows uniformly through now, from past to the future.*
3. *Every two events have a "before-after" relationship.*
4. *Now is "real", Past "exists", Future is "undetermined".*

Relativity

In the discussion above we have skimmed by a very axiomatical notion of time as a Cartesian dimension. Time was presumed to be this line-like element of this universe, simply because it is the easiest frame of mind on this, and creating a more complicated structure seems superfluous. Moreover, in our day to day life, there is no contradiction to be found, when talking about the car going from point A to B we can imagine a nice looking, simple two-dimensional graph with the position as the first coordinate and time as the second. Problems however arise when taking this approach to the extreme. For example in the astronomical study of macro-universe or the mappings of the fastest moving particles. Those problems have been answered in the beginning of the 20th century, giving us a completely new perception on nature of time.

Theory of special relativity was created by Einstein in his paper "On the Electrodynamics of Moving Bodies" in 1905. It is mathematical description of the relationship of space and time based only on two principles: principle of relativity and principle of light constancy. Physicists have noticed that there seemed to be this limit to the velocity of light, that being in the vacuum and more over that this speed does not depend on the frame of the reference's trajectory - the Michelson-Morley experiment, thus there was a need for a new theoretical framework in which to treat displacement of light. If the time was this external coordinate independent of space than with every change of velocity of any observer, light would new how to adapt its speed near the observer so that it could be observed as constant - nonsense. The second principle in the context of the special, and not general, theory of relativity, simply states the equivalence in the laws of physics for all frames of reference with no acceleration. Very intuitive axioms, that bring forth a lot of outstanding consequences.

The insight of the mathematics used by Einstein's is rather difficult to summarise, but it creates a nice mental picture of spacetime, so called flat Minkowski spacetime. This construction basically is a nice cartesian, euclidian space with one dimension of time T and three dimensions of space X,Y,Z but with a different way of understanding simultaneity - measurement of the spacetime intervals. Let us say we have a starting point P (the frame of reference) with the coordinates (0,0,0,0) and a second point Q in the (t, x, y, z) then the spacetime interval s^2 between them is equal to $(ct)^2 - x^2 - y^2 - z^2$, which can be both positive and negative (we note by c the speed of light). This value can be interpreted as an indicator whether it is possible to reach Q with the speed under the speed of light form P, it is only possible when $s^2 \geq 0$.

Let us simplify this to the utmost, in the "here and now" - P - we observe other events in the spacetime, that can only be observed if the light travelled to P with the speed of light, that is to say everything we observe has the property that the difference in distance is exactly equal to the difference in time times c, that is to say $s^2 = 0$. However solution to this equation is a 4-dimensional cone, called the light cone. Everything inside this cone is reachable from P - what we call a timelike intervals; everything outside is not reachable - what we call spacelike intervals; and the cone itself is made out of lightlike intervals. In this sense the simultaneous events are the ones in a lightlike interval form the point of reference.

Second insight is the calculus of Lorenz transformations. That gives us explicit formulas for calculating the differences between moving frames of reference. All of the specifics of the mathematics can be easily found elsewhere and are not needed for the arguments in the conclusion of this essay. The philosophical point behind it is this one: if a point is moving, than so does its light cone relative to original frame of reference. The faster it moves the squishier the light cone, in reference to the original frame of reference, because the light velocity has to be compensated by the velocity of the moving point. The extreme case is light, because it is a point traveling with the speed of light so its light cone is squished enough to the form of a line instead of a cone, therefore it has no "now". The squishiness also indicates that time is running more slowly for those point travelling closer to the speed of light relative to the point P. The difference in the flow of time is proportional to the constant $\frac{1}{\sqrt{1 - v^2/c^2}}$ - the Lorenz factor.

Over the next ten years after the publishing of the paper formulating special theory of relativity, Einstein formulated one of the most influential theoretical frameworks of our time - The General Theory of Relativity - GR for short. Which not only encompasses the latter but is also the best explanation of gravity. The main point of this theory is the substitution of the flat Minkowski spacetime for a pseudo-Riemannian manifold that is locally flat Minkowskian. What does it mean? It means that the space time is this collection of events glued together continuously (in a differentiable manner), in such a way that in the neighbourhood of every point it seems we are in a flat Minkowski space, but in not uniform way. That is to say there is curvature between points. In the same sense that if you zoom in every point on a sphere it looks like a flat plane. "pseudo-Reimannian" part simply means that there is a rigorous way of describing distances between events - a metric tensor. The main point of the theory is that this curvature is the cause of the force of gravity and is caused by matter/energy.

GR has been shown to be one of the most validated physical theories by evidence with great precision. Its predictions are very much real, but more importantly every experiment supporting GR is also an evidence against the independence of time from space and matter. GR tells us that not only the concept of simultaneity make sense only locally relative to some chosen frame of reference, but also that is not "linear" in the same sense as a line cone or in the sense of having the same time coordinate, this generalisation of a light cone is called a null hyperspace or even more broadly a Penrose diagram.

Theoretical consequence of GR is that it an extremely simply set of rules - the Einstein field equations - governing a very complex structure - a pseudo-Riemannian manifold. Of course it is possible to create specific manifolds that satisfy GR but which posses bizarre properties. One of those can be the existence of closed timelike curves - a trajectory of an object through spacetime that does not break the barrier of the speed of light but which traces back to its origin (in all 4 coordinates including time!). First CTCs were created by Gödel by curving and stretching spacetime(which is allowed), until he had this "spiral-like" universe (mathematical rigour was always on the side of Gödel, this sentence however is just to have a mental picture). This of course seems absurd - one cannot travel forward in time to past. Maybe yes, maybe not. There is a number of great arguments against the existence of CTCs but no conclusive arguments.

Quantum effects

Quantum mechanics is the most well-founded modern theory of physics. By and large, the attempts to merge it with relativity have been futile (string theory), and is still an ongoing, ultimate pursuit of physics. Therefore, it does not have any strong spacetime concept in its axiomatic basis, nevertheless some of the observed effects that influence our understanding of time. Let us discuss some of those:

1.The collapse of the wave function. It is the key quantum event. A quantum particle at rest is in a superposition of states, that is to say there some (maybe infinite) options of the current state of this particle - the wave function. One can think of it as a sort of "probability cloud" describing where and how the particle can be. Collapse happens the moment that an observation is made. For example, the measurement of position or velocity. Then knowing the position of a particle cancels all of the other states in its superposition, and the particle behaves very Newtonian-esque. - has a predictable evolution obeying the Schrödinger equation. This frame of mind for a particle has a very radical consequence - strong time asymmetry. From the wave function we can collapse it to a concrete state going from past to the future, but knowing the concrete state we can always reverse it using the Schrödinger equation (the complex conjugate of the wave function) indefinitely. This a clear one-way change, proving the asymmetry of time.This would be perfectly reasonable if the collapse of the wave function was a physical process. Wave function as an object is not physical, it describes where the physical particle might be but there is no way to measure it experimentally - there is a way of constructing the mapping of it thought, through a repeated collapse of the same particle. Consider this analogy:

A person sits in the middle of a circle of 1 light year diameter, he takes out a fine laser and points it to the edge of this circle. He makes one spin with his laser in one second. Thus the point of contact of the light from the laser with the circle has just traveled a whopping 2π *light years in one second, thus breaking the speed of light.*

How is that possible? Simply because, the point of contact in any moment is not a physical object, so it does not matter how it behaves. The point of the principle of light constance is that only photons travelled from the centre to the edge with the speed of light. When talking about superposition, we do not state that the existence of the particle is physically chopped up into different possible states with exact probabilities attached. We only say that we have a powerful prediction map. The collapse of the wave function does not say anything conclusive about the directionality of time but rather about the nature of determinism at small scale.

2. The quantum entanglement and Einstein-Podolsky-Rosen paradox. In short, there have been a lot of successful observations of entangled particles - those are bundled particles with quantum states that are "fused". For example, when measuring the spin of one of them, the spin of another is predetermined, because they are entangled. This observation gave rise to the famous EPR paper that tried to create a paradox that proved global breakage of locality and that there was a way to send information and influence some disconnected, distant part of the universe faster that the speed of light. The construction of this paradox was completely in the frame of quantum mechanics, and did not violate any underlying rules. Einstein himself was not convinced by it and only made him argue for the incompleteness of quantum mechanics, in his later life.

How does it influence our understanding of time? The paradox argues for the ultimate instantaneity that is non-relativistic. Then we could pass information through the barrier of null hypersurfaces. It is believed however, that this paradox falls flat to a similar objection as the one mentioned above. The relationship between entangled quantum states is that of a statistical correlation, not an actual physical information. It is impossible to extract the probability differences from an entangled pair of particles. It once again bring us not to reflect on time but rather determinism/causality at a grand scale.

3. The uncertainty principle. This principle comes about from the purely mathematical relationship between operator mapping the position and the momentum of the wave function. They are not commutative, which causes, through very basic calculus, this

extraordinary lower bound on the product of the standard deviation of those two measurements $\sigma_x\sigma_p \geq \frac{\hbar}{2}$, what's known as the uncertainty principle. This property is actually shared between all of the pairs of operators that are not commutative. However the extremely controversial time-energy uncertainty principle - $\Delta t \Delta E \geq \frac{\hbar}{2}$, was developed in a completely different manner. Within the confines of quantum mechanics, time is not treated as an actual physical quantity but rather as a coordinate of change, therefore there is no time-measuring operator. Why? It is a consequence of the Pauli theorem, which states that if such an operator existed then the Energy operator would have to be unbounded - particularly allowing for arbitrary negative energies. A physical impossibility.

So then what does Δt mean? It is actually not the temporal uncertainty, but rather the uncertainty time of the measurement of a given Hamiltonian with respect to the energy change, in a given quantum state. Formally we have $\Delta t = \frac{\Delta E}{|\frac{d\langle E\rangle}{dt}|}$. From this we see that it is treated only as a local phenomenon with respect to a given operator.

This result begs us to think of time as some sort of a discrete parameter (the smallest quantity being maybe the Planck time), unfortunately one cannot get rid of the relativism with respect to a given observation and given quantum state. This effect is real, but not global. To simplify it to the utmost: This quantum universe is not a grid of discretised events, but rather the observations are forced to be discretised because of quantum effects. It seems that claiming this global discretisation would equate observations with reality, in some profound sense.

I, personally, believe that within quantum mechanics we have almost the same axiomatic reference to time in the definition of time, as we have mentioned in the first section, when discussing fundamentality of time. For the following reason: *Wave function is a sort of probability cloud, a change in probability clouds is undetectable (it is the main critique of the EPR paradox) because, in short, any detection collapses the wave function. So in order to measure this change in probabilities one has to assume the notion of time in order to see an experimental change. Change explains time, and time explains change.* This assumption happens right in the moment of defining a quantum particle and prescribing in to a physical particle. Time is not treated as an actual physical property of a quantum particle, but rather as a guideline for the evolution governed by the Schrödinger equation etc.

The beginning

When trying to answer the ultimate question of whether time has a direction, one could easily answer it if there was an ultimate beginning of the universe. In this sense spacetime would be a "stick" with at least one end, making it the ultimate reference point. Also it would sync-up all of the events in the null-hyper-surface of the "now" to some point in the beginning, and our sense of the "now" would have become universalised. Science behind the beginning - the Big Bang - is not at all trivial, and a current subject of research, called cosmogony. In this section I would just like make a point that would undermine this sense of beginning as a point of reference.

Firstly, singularities. GR makes a precise calculation of the spacetime curvature. caused by matter. Thus making it the first prediction of black holes, that arise from the gathering of so much matter that causes the spacetime to curve so massively that it is impossible to escape, crushing the matter into oblivion - a singularity. Vaguely speaking, singularity is a "point" "where" spacetime breaks, "where" all of the field equations brake creating a lot of divergence in curvature, energy, density etc. I called it a "point" because it cannot have any reference to spacetime itself. This is a point of the unknown, but still they do exist as proven by the Nobel-prize winning theorems by Penrose and Hawking. Furthermore, the discovery of the Hawking radiation even showed that those singularities - black holes - are somehow a sink annihilating information that falls inside, another apparent impossibility.

Relating to Big Bang, my point here is that that there are still cosmologies that do not suppose any singularity at the beginning of the universe. The example being the Big Bounce theory by Ashtekar, Pawlowski and Singhor or the No-Boundary Proposal by Hawking and Hartle. Philosophically, those theories propose legitimate views of the universe that do not have a begging like a cone expanding from a single point, but start more like a sphere with the north pole as the point, that gives a direction to time but which is not the origin of time - "sphere does not have an end like stick". These concepts rely on the heavy use of the quantum effects that are omnipresent in the early universe. The spacetime for them sort of loops/connects back to everything in the beginning, making spacetime a coherent connected manifold rather than a forever extending euclidian space that demands an origin.

Entropy

Entropy is one of the central concepts in statistical physics. This concept originated from thermodynamics in order to understand propagating heat, and it was first used to properly state the second law of thermodynamics. Entropy is also one of the most convincing pieces of evidence for the directionality of time as we shall see. Intuitively low entropy state is something very "orderly" while high entropy state is more "uniform", the mentioned second law states that the entropy cannot decrease, it can only remain stable or increase. Defining entropy for global states is difficult, but we can start with a simpler example: Consider 100 numbered particles in the universe of 10 numbered cups; a state W such that all of the 100 particles are in the first cup; and a second state P with ten particles in each cup. Intuitively W seems much more orderly than P. In what sense? In that every particle seems to be somehow forced to be in the first cup in the state W, and in the state P it seems that every particle has more options to chose from. In W there is only one possible arrangement of the numbered particles - each one is in the first cup - so the number of possible arrangements is 1 with probability 1. In the second we have $\frac{100!}{(10!)^{10}}$ possible arrangements and each is uniformly probable. This discrete entropy is just a some over the probabilities of all the possible arrangements (micro-states) weighted with the natural logarithm, (this weight for smaller probabilities explodes drastically, increasing rapidly the entropy with the vastness and improbability of the options), giving us the Boltzmann's formula: $S_P = -k_B \sum p_i \ln p_i = -k_B \frac{(10!)^{10}}{100!} \cdot \frac{100!}{(10!)^{10}} \ln \frac{(10!)^{10}}{100!} \approx 230 k_B$ and $S_W = -k_B 1 \cdot \ln 1 = 0$, where k_B is some constant, implying $S_P > S_W$. This calculation creates the simplest way of conceptualising difference between systems with either a lot of structure, or a lot of uniformity. Let us now imagine this cup universe having a tornado inside; turbulences throwing particles in every direction. In that scenario it is intuitive that the state W would lose its structure with great probability converting to something of nature of P and the state P would only suffer minor changes. This is the second law of thermodynamics - entropy never decreases. Making those turbulences a statistically irreversible process.

An explicit experiment would be to imagine putting a hot glass of water inside a pot with cold water, this law states that after some time the temperature would be uniform in the glass and the pot. Any one putting a warm glass of water inside a warm pot, in order to heat it up and to cool the pot, would probably only disappoint himself. If this is not ultimate proof of the asymmetry of time, I do not know what is.

Unfortunately, entropy is only a statistical measure, hence the use of the word "probably". If this propriety was uniform, why would this universe after fourteen billion years not resemble a uniform mess of unmoving particles and would allow complex structures like life. There is still ongoing research into explanation of this phenomenon, however I enjoy the most how the issue is addressed by *the hypothesis of the branch structure* made by Hans Reichenbach. Author proposed, under five assumptions, a lattice structure of isolated systems (like galaxies, planets or even atoms etc.) that have their own behaviour and entropy curves(not necessarily increasing), such that vast majority follow the global increasing entropy curve. In this explanation the behaviour of the entropy has this unexplained global direction, but locally it does not necessarily prove the asymmetry of time, making it a compromise between the obvious increases in the entropy - like our glass and pot example - and the time-symmetrical behaviour on the micro scale - like particle physics.

On a side note, Roger Penrose in his book *The Emperor's New Mind* (and *the Road to Reality*) argued that the probability of finding an initial, low entropy state that would later develop into life according to the second law of thermodynamics is of the order of 1 in $10^{10^{123}}$, making the standard Big Bang a non-complete explanation of the universe. This also hints at how powerful of an observation entropy really is, when assert time asymmetry, and how irreversible it seems.

Death to intuition

We have finished our first section by listing some intuitions that feel "right" about time, unfortunately the devil lies in the details. Subsequently we have listed off some of the relevant theories in modern physics, and their implications for the notion of time. Let us re-reflect on those original points and give new insight to these concepts:

1. *Time is fundamental.* - meaning that time has to be assumed.

I do not believe it is a fair observation after the success of Einstein's Theory of General Relativity. The construction of spacetime as a manifold shows this profound merger of time with the rest of the universe, moreover the matter also is merged with the passage of time. One seems to be forced to make a mental picture of time as a part of a larger structure. Here the key difference is that GR starts with the assumption of the existence of the universe and then forces a structure with time as a coordinate that follows.

2. *Time flows uniformly through now, from past to the future.*

Here, once again, we reference GR. The uniform flow of time is only a local perception, that changes with the curvature of time and the relative velocity. The "now" is also difficult to understand: is it the null hyper surface discussed before or is it the hyper surface of "the same time coordinate" created in the analogous way? Which "now"?! Relativity states only that time flows through "now" for the observer, and not through the "global now". "From past to the future" can also be called into question through the construction of CTCs, discussed before.

Furthermore, this statement does not hold for light, at all. Light does not experience the passage of time - it has the "past"(moment of creation) and the future (moment of annihilation) all happening at the same moment. There is no "flow" and there is no "from past to the future". Making this intuition not a general truth.

3. *Every two events have a "before-after" relationship.*

Three objections would be the construction of the spacetime in GR, the possible existence of the CTCs and the uncertainty principle.

Consider an event outside of your light cone. Is it before or after you? It did not affect you and you cannot affect it at the present moment, you cannot even get to it in the future and past. So this relationship is purely mathematical - it is the difference in one coordinate, that does not hold any temporal connection behind it. (Of course observing such an event is by definition not possible within confines of spacetime, which is not held inside black holes)

Being in the CTC would be an immediate contradiction to this intuition. Before would be after and after would be before.

Supposing that the energy of the universe is finite, it provides us, by the uncertainty principle, the lower limit for the certainty of time of any measurement. What is then "before and after" of two events within the minimal lifespan of any measurement? Are they in the same moment? By the uncertainty principle, we do not know and we cannot know.

4. *Now is "real", Past "exists", Future is "undetermined".*

Understanding the uncertainty principle clearly makes one think, that "now" is a very foggy state, that always relates to future and past in a continuous way. The realness of it is contingent on the temporal surrounding, producing this loose sense of now on the micro scale.

Furthermore, I believe that the theories of cosmogony I have mentioned before, with this characteristic "wrapping around" of the spacetime, makes every single part of spacetime contingent on any other part, in that sense past exists in the same sense as does future and present. This pulverises the concept of "realness" of the now, and substitutes it with a global contingence of existence.

And finally the concept of "undetermined" is only as true as the global quantum independency. If everything is entangled(which is probable) in its entirety then the future is strictly contingent on the past, bringing some sort of global connection through spacetime.

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I would like to finish this essay by quoting Aristotle from *Physics*, Book IV, chapter 10, which is the main insight that summarises most of the issues mentioned here:

"Time […] is not held to be made up of 'nows.'"

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