On the Reality of Time

By Gillian Drake

“For a good part of his [Kafka's] work consists of tentative steps toward perpetually changing possibilities of future. He does not acknowledge a single future, there are many; this multiplicity of futures paralyzes him and burdens his step.”
— **Elias Canetti, Kafka's Other Trial: The Letters to Felice**

“And I asked myself about the present: how wide it was, how deep it was, how much was mine to keep." – Kurt Vonnegut, Slaughterhouse-Five

"All time is all time. It does not change. It does not lend itself to warnings or explanations. It simply is. Take it moment by moment, and you will find that we are all, as I've said before, bugs in amber.” – Kurt Vonnegut, Slaughterhouse-Five

“Old Time, the greatest and longest established spinner of all! … his factory is a secret place, his work is noiseless and his hands are mutes” – Charles Dickens

Entropy

“End of the film, the man behind me goes, ’Ugh! that’s two hours of life I’m not getting back.’ I thought, ‘oh I have got some bad news for this guy: Every hour of your life is an hour you’re never getting back. They’re gone forever. Time is *not* refundable. Death is the end.’” – James Acaster, Mock The Week

Supervisor: Jens Hjorth
Niels Bohr Institute and DARK

Quantum Physics: Theoretical High Energy Physics and Cosmology

Table of Contents

Abstract

What is time? A seemingly outlandish question. Time is so fundamental to our thoughts, to our lives, to our functioning, it feels odd to ask such an obvious question. But time is anything but a definition or a physical parameter that is agreed up widely in physics. This paper goes through the different fields of physics and looks at the way in which time is treated. The paper then goes into looking into the ways in professors of physics look time and in there is a overall agreement on the view of time in the professional world, and if that matches up with the literature on the history of time in physics. The paper was to look into the questions of fundamental or emergent time and the probabilistic nature of the universe versus the determinism of the universe. Knowing we look at space and not as much at time, even though time is considered to be a fundamental aspect of space. This paper seeks out to look at not just a broad overview of the view of time, but also at the anthropological and philosophical view of time in consideration of how physics are looking at time and therefore at how they can ask the correct questions to discover more. The paper comes to the conclusion that there is less agreement in physics and that the overall view is that physics have an agreement on the nature of time.

Chapter 1: Introduction

What is time? A seemingly outlandish question. Augustine wrote in Confessions, “What is time? If no one asks me, I know; if I wish to explain, I do not know” (Muller, 2016). The word time is used more frequently than any other word in the English language. Time is so fundamental to our thoughts, to our lives, to our functioning, it feels odd to ask such an obvious question. And yet, we do not know. It hovers around all of science, it is imprinted in our language, our awareness, how we move and think, and governs our thoughts and morals on the impetus of society and mortality. Not even space seems as fundamental to every aspect of consciousness, and maybe that is why we cannot say what it is. I will propose to look into the concept in so much as I am able in a mere masters thesis. We will begin by looking at time (through a physics lens) and we will begin with the broad arena of pre-scientific revolution (or more specifically pre-Newton, also Leibnitz will be discussed and we were famously Newton’s contemporary and nemesis).

We live and govern ourselves via our mind, which is governed by whatever concept we hold with the moniker: time. We’ll delve into the theories, that of change, of fundamentals, etc. We’ll look at the ontological and epistemological differences in concepts and if that makes a difference in physics at the end of the day.

But we’ll go back to how we arrived where we are. We have two large bodies of physics and two bodies therefore of time: theoretical and experimental. Is time more than a ticking of a clock? How did we even get to the concept of a ticking clock?

The road towards Newton is often forgotten but very important. Before the 20th century, and some could classify before the scientific revolution (but the scientific revolution wasn't exempt), our learning was derived and helped by religion. Especially in the west, knowledge was saved and institutionalized through religious organizations. So we'll dive back into religion and philosophy to begin (where else can we begin).

Chapter 2: Literature Review

<u>Methodology:</u> A historical (western look) into changing opinions of time from a historical perspective from physicists – first looking at relational time to Newtonian time, to general relativity, to quantum, to theories of everything

This section will look at an overview of how physics has looked at time. Time is such a broad and reaching topic, this section will take primarily a chronological review of how psychists reviewed time. Sections 2.1 and 2.2 cover classical physics, while 2.3- 2.7 will cover modern physics, nuclear physics, and a blending of all three.

2.1 Rationalism

"Time is one of the great archetypal experiences of man, and has eluded all our attempts towards a completely rational explanation" (Von Franz)

As Ernst Mach said (1883) "It is utterly beyond our power to measure the changes of things by time ... time is an abstraction at which we arrive by means of the changes of things; made because we are not restricted to any one definite measure, all being interconnected."

Outside Western views:

Prior to the mathematical parameterization, which appears to come from Western philosophy and physics, the contemplation of time is seen often as relational. It is not something mathematically in and of itself, but a concept that relates events. This is seen similarly with the understanding of space. You can ask where something is, (your headphones are on your desk in the living room),you can similarly ask when something is (it's in an hour). (Rovelli, Von Franz Etc).Time is a relational concept, something that relates events. It is not a solitary concept. Within this relationalism we can look at the physical aspect of time in three main theoretical ways: linear and circular. Linearly, it is related to when it happens or when something happened. There is a past, a present, and a future – linearly a flow that can be seen in discrete events like the frames of a film. This linearity is tied heavily to mortality - the linear birth and eventual death. Then there was also the concept of circular time. Circular time was seen in part as our main form of measurement and how we developed clocks - the earth revolving and circling the sun giving your days and your years (from the sundial). Linearity was often related to an infinite or eternal nature of time, like the Egyptian god, Heh, who was always shown with the symbol for life, not to be confused with the sun god, Ra who ruled 'time'. Not every civilization had a linear concept in the way the West has viewed time. The Hindu religion has many gods symbolizing different forms of time: Shiva as 'All Devouring Time' and Kali as time and death. Hinduism gives little credence to irreversible time, as it is conjoined with man but a cyclical and eternal time (which is reinforced with the idea of reincarnation). The qualitative way we center our ideas was different in different cultures, like Hopi Indians not having past, present, and future in their language, but concepts around something that is manifest and something that is beginning to manifest (Von Franz). Interestingly (especially when ignoring non western ideas), the concept of a type of spacetime (expounded in section 2.3) was seen in China and the Aztecs. The Chinese separate duration and becoming. Duration comes with linking the concepts of yin and yang (where yin is time and yang is space- and thus Time and space, says Garnet, "were considered an ensemble [grouping, cluster] of occasions and places" (Von Franz). And the Aztecs had the god, Omotéotl, who created time and space simultaneously.

Relationist

"In man's original point of view time was life itself and its divine mystery" (Von Franz). So the to pivot to the relative beginning of modern science's view, we will look at the Hellenistic culture of Aristotle, Zeno, and Theophrastus views of a relationist view of time. A relationist view of time is one of a relation between components (White 1989). Aristotle viewed time as "a number of motion with respect to the prior and the posterior" (Aristotle, Physics IV, 11). Here is where time is viewed in a more physical way and into the idea of time and the 'flow' of it as a number and eventually a parameter. Aristotle's components are mainly of two parts, the 'topogological' which is continuous and linear and as to do with change, whereas the other component is the "number of motion" (Annas 1975). This number is more to do with "what is counted or countable, not in the sense of what we count with" (Annas 1975). This could be thought of the breaking down of time into a type of discrete quantities. Aristotle further posits in Physics if time is a measurement of change, and therefore if nothing changes, there is no measure of time, and therefore no time. This relationist view is similar to Leibniz's view of time as "an order of successions" (Leinitz in Ballard). Leibniz was a rival of Isaac Newton, and wrote a series of letters to Samuel Clarke, which illuminated his views on time and space as relationist and not absolutist. To note, both were arguing about this in terms of a Judeo-Christian God. This view is the precursor of the relationist view of time "that something happens when something else happens" (Rovelli,LGG). As Bunge writes, this is not a "theory (=hypothetico-deductive system) of time" and the major difference in relational and relativistic time is that "they did not make duration relative to a reference frame" (1968). This idea of relational time started with Aristotle, continued with Leibniz, and was furthered by the philosopher Ernst Mach. Relational time is then deemed to be related to events. Leibniz's view of a "an order of successions" is seen as a type of "primary timelessness and Mach that 'time is to be abstracted from change" (Anderson 2014). Time is only seen relating events, and this view led towards the view held in General Relativity leading to a background independence, as spacetime is not flat and universal.

Absolute Time

The relationist view of time came into question against the absolutist view of time. This absolutist view of time, time that is "self-existent" (Bunge 1968). This view comes mainly from Judeo-Christian thought of "God as purely outside time, as having created time together with the universe." (Von Franz). Saint Augustine showed this view that God is therefore timeless and that it is something outside of the self (Muller). This ontological view of time is seen in the works of Kant "Time is" and most notably, Isaac Newton. This idea of time helped with the cartesian development of time as a parameter and a measure of "successive duration" (Gorham 2017).

For Modern Physics

These views of time shed light onto the ontological and epistemological views of time. As Bunge there are four main views of time, "ontologically, time may be regarded either as absolute ("Time is self-existent") or as relative ("Time is the pace of change"). Epistemologically, time may be viewed as subjective ("Time pertains to the cognitive subject") or as objective ("Time is a feature of the world"). Consequently, from a philosophical point of view, four kinds of consistent theories of time are possible:

AS: Time is absolute and subjective (Kant).

AO: Time is absolute and objective (Newton).

RS: Time is relative and subjective (Berkeley).

RO: Time is relative and objective (Lucretius)" (1968)

These views still pertain to way modern physicists view time. To look further into theories of everything, grappling with the marrying of gravity and quantum, physicists like Carlo Rovelli and Lee Smolin are viewing time in a way of looking at whether it can be seen as fundamental or emergent, and the fundamental and emergent views can look at the these ideas on time.

2.2 Newtonian

There was a shift during Isaac Newton, the 'father of modern science.' Before Newton (and synonymously, see Leibniz), there was the idea of relative time. Newton believed in two types of time: true and relative. We can find relative time (which is how time was perceived previously), but there is a true time (religious) that we cannot calculate but is intrinsic to nature. Newtonian (true) time is assumed to flow uniformly even when nothing happens, with no influence from events, and to have a metric structure, we can say that when two time intervals have equal duration. He believed absolute time was imperceptible and could only be understood mathematically, "Absolute, true and mathematical time, of itself, and from its own nature flows equably without regard to anything external, and by another name is called duration: relative, apparent, and common time, is some sensible and external (whether accurate or unequable) measure of duration by means of motion, which is commonly used instead of true time ..." (Newton, Principia).

Much like Newton's belief in absolute time, he similarly believed in absolute space, ("Absolute space, in its own nature, without regard to anything external, remains always similar and immovable" (Newton, Principia)). These ideas were put forward in Newton's seminal work, ‘Pilosophiæ Naturalis Principia Mathematica’, Newton ostensibly birthed modern science, and with this he ushered in our generalized heaviest influence on people’s general thoughts on time. His ideas overall not only influenced (and bounded), our way of doing science, he married his Christian religious ideas with his studied mathematical theories, for his ideas of absolute space and time “were both emanations from God” (Von Franz 69). There was now a separation of times, and a way in which you could ask scientific questions, without confronting your beliefs. He separated “divine time” and “common time”, where our common time was made into a linear parameter. This linear parameter is used for not only earth but also the heavens. He radically changed our processing of time from relational, separate ideas, into a uniform geometric (linear) parameter. This parameter could and should be compared regardless of space (earth vs the universe). However, it would be easy to then forget ‘common time’, wherein he believed humans are only capable of perceiving relative time, which is a measurement of perceivable objects in motion (like the moon or sun). This has in part fragmented the word time in our scientific endeavors, making the question, “what is time?” harder to answer when people in essence will use homonyms.

To put into context, “Ontologically, time may be regarded either as absolute ("Time is self-existent") or as relative ("Time is the pace of change"). Epistemologically, time may be viewed as subjective ("Time pertains to the cognitive subject") or as objective ("Time is a feature of the world")” (Bunge) and Newton’s concept of time is absolute and objective. This idea of absolute and objective time meant that you could scientifically (with mathematics) compare different things in different places.

Newton’s creation of dynamics, he made five absolutes: “time, its direction, position and direction in space, and scale” (Entropy and Arrow Barbour).

This is the view of classical physics (pre-relativity and quantum). This absolute and objective time is seen in the variable t, which is viewed as a real quantity (the measurement or duration from a clock). Time in this sense, 'flows', and is "a special physical quantity, whose value is measured by physical clocks, that plays the role of the independent variable of physical evolution" (Rovelli 2008). This can be seen easily in the Euler-Lagrange equations or the Hamilton equations of motions.

The Euler-Lagrange equation, for generalized coordinates, q_j, and velocity, $\dot{q}_j$, where L is the difference between the kinetic and potential energies of a system.

$$\frac{\partial L}{\partial q_j} - \frac{d}{dt}\frac{\partial L}{\partial \dot{q}_j} = o$$

The Hamiltonian equations (used often in quantum mechanics) are

$$\frac{dq_i}{dt} = \frac{\partial H}{\partial p^i}$$

$$\frac{dp^i}{dt} = -\frac{\partial H}{\partial q_i}$$

Where p_i is the generalized momentum and H(q_j, p^i) is a function on the phase. (Morin, 2008; Rovelli 2008).

This absolute and objective time also helped make possible our shift into global time and clocks, for "this incipient separation of "divine time" from measurable time is not unrelated to the development of the clock" (Von Franz 69), which develops into the uniformity of time on earth – places used to have their own times, but with extended travel (trains and planes) there became a need for everything to be on the same time duration. Clocks before the industrial revolution were mainly sun dials, or other measurement devices made using the sun, the moon, or other measurement from the celestial bodies. ‘Clock time’ was in tune we relational, common time, as it was measured directed from objects in motion. The time the sun is highest in the sky in Copenhagen is not the same time the sun is highest in Paris, and people were aware of this. This was their relative time. But with the development into industrial era, there was a need for a more uniform time which relates to the general principal of ‘true time’. Trains, which tied mainly. To business, to money, needed to make sure the there was a uniform time. Just because the sun is a slightly different place in the sky, doesn’t mean the times across Germany couldn’t be uniform, and with that synchronicity, we pushed into global uniformity. Oddly with globalization, ‘uniform’ time has become necessary, but is only possible with atomic clocks – a principle from General Relativity, which amusingly also principally refutes the idea of absolute time and simultaneity.

2.3. General Relativity

Dovetailing from the Newtonian classical physics, we are now in the place of Einstein. In 1905, he transformed the structure of classical physics with the theory of special relativity, which took into account Maxwell’s theory of electromagnetism. This concept of time takes an ontological difference to Newton’s. Newton’s view of absolute time is now replaced with a relative concept of time – many epistemological similarities may unfold, but within the reign of classical physics, a new ontology of time is now true.

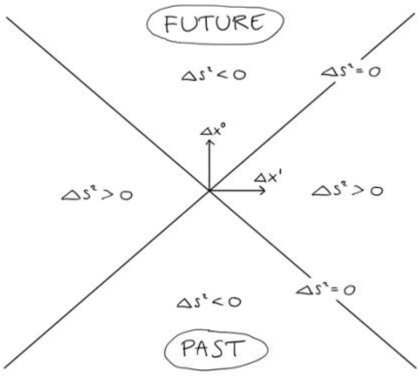
What is the new ontology of time? That time is relative. In Newtonian mechanics, Newton’s concept of space and time were inherently different. Time was absolute and the idea of simultaneity was true and justified. Two people can throw a ball simultaneously in different directions at different velocities. Each ball (which we can minimize to a particle) has its own dynamical set – a 3-dimentional space coordinate and its own time coordinate – "in Newtonian spacetime there is an absolute slicing into distinct copies of space at different moments in time" (Carroll Spacetime Geometry p4). The distinct different when Einstein came up with the theory of Special Relativity is that "there is no well-defined notion of two separated events occurring "at the same time"" (Carroll 2014). If we once had slices of space separated by time (or "unique slices of space parameterized by time"), we now have spacetime that is defined by events where particles cannot move faster than light (photons). Therefore we now have lightcones, and with this we can use Euclidean geometry and rotate our coordinates, where our separation of time and concurrence no longer adhere.

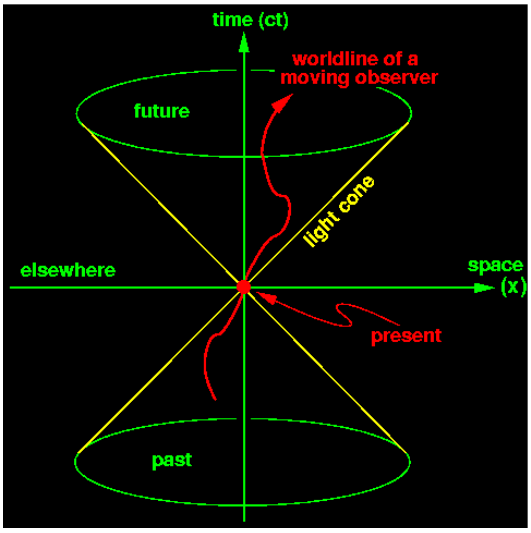
Via special relativity, and into general relativity, no longer have simultaneity, and in a larger sense, time is now a coordinate linked to space (for example (t, x, y, z) vs (x,y,z) at time t), and this linking forms a geometry. We can look at a spacetime interval as between two events as:

$$(\Delta s)^2 = -(c\Delta t)^2 + (\Delta x)^2 + (\Delta y)^2 + (\Delta z)^2$$

Where c is a constant (the speed of light), that allows for t

Considering we are now looking at spacetime and no longer at space and time – and thus an inherent ontological difference in the physical notion of time. And we can see a definition of a single event through a *light cone*. Spacetime can now be seen as a manifold, and spacetimes can interact with each other. To look at the new concept, a useful tool is a spacetime diagram, and see how events are related. The points in the event can therefore be either *timelike* separated, *spacelik*e separated, or *null* separated.





Figs 1 and Fig2 from Carroll's Spacetime

We need to look at the paths of the particles in this new geometry of spacetime, and looking at the line element and what that infers about the path.

A line element is defined by:

$ds^2 = g_{\mu\nu} dx^\mu dx^\nu$, where $g_{\mu\nu}$ is our 4x4 spacetime metric.

$ds^2 > 0$ defines space-like separated events,

$ds^2 < 0$, are time-like separated events, and

$ds^2 = 0$, are null separated events.

For timelike paths, we are now looking at the proper time (which will be found with the integral):

$$\Delta\tau = \int \sqrt{-g_{\mu\nu} \frac{dx^\mu}{d\lambda} \frac{dx^\nu}{d\lambda}} d\lambda,$$

This proper time ($\Delta\tau$) is time measured by an observer moving along the trajectory, and the spacetime path is via a parameterized curve $x_\mu(\lambda)$, and this parameter, λ, is not necessarily identified with the time coordinate unlike in Newtonian Mechanics (Carroll 2014).
Paths are made of discrete events (each lightcone), a physical particle can have a path be time-like in some places or space-like in other places. However, “physical particles never change their character (massive particles move on timelike paths, massless par- ticles move on null paths”(Carroll)

For this section, I am using the signature of the metric as (-, +, +, +), with the spactime indices, (μ , ν)=0,1,2,3 =0,1,2,3 and the spacial indices (i, j) = 1,2, 3, as well as setting c = $\hbar$ = 1.

With this progression of the understanding of Newtonian physics, there has been a splintering of the definition of the word time. Time now can have different definitions and the certain qualities are tied to the word. Time now has three main concepts: “relative order of events, Newtonian non-dynamical time, [and] the gravitational field” (Rovelli, LQG).

In Special Relativity, we can see the qualitative effects of this new perception as time dilation. (section B). And in General Relativity, we see that the spacetime geometry depicts gravity (which is therefore no longer thought of as a force). The curvature of spacetime is depicted by the Riemann tensor:

$$R^{\rho}_{\lambda\mu\nu} = \partial_\mu \Gamma^{\rho}_{\lambda\nu} - \partial_\lambda \Gamma^{\rho}_{\mu\nu} + \Gamma^{\sigma}_{\lambda\nu}\Gamma^{\rho}_{\lambda\nu} - \Gamma^{\sigma}_{\mu\nu}\Gamma^{\rho}_{\sigma\lambda}$$

The spacetime geometry is related to the energy momentum tensor (ie the matter of the universe) through the Einstein’s equations:

$$R_{\mu\nu} - \frac{1}{2}Rg_{\mu\nu} = 8\pi G T_{\mu\nu}$$

These depictions of spacetime dovetail into the paradoxes surrounding time travel.

Time Dilation: Twin Paradox and Schwartzchild Blackholes

The twin paradox comes from looking at spacetime in relation to inertial frames, and not as time and space.

The twin paradox can be shown through calculations using the time dilation equation. In using this equation, I will go back to using the speed of light and not having c=1.

$$\Delta t' = \gamma \Delta t = \frac{\Delta t}{\sqrt{1 - \frac{v^2}{c^2}}}$$

In this time dilation equation, γ is the Lorentz factor. If one twin (Twin A) stays on the earth (which we will take as an inertial reference frame, then Twin A's reference frame is at (t, 0, 0, 0) (as we are using Minkowski metric). Twin B's (who will be traveling) frame will be (t, f(t), g(t), h(t)). Twin B's spatial coordinates will be in reference to movement, and therefore will be a function of time. You would then need to look at the proper time ($d\tau$), which can be found from finding the proper time difference,

$$d\tau^2 = dt^2 - dx^2 - dy^2 - dz^2$$

Succinctly, the time dilation equation will display that the looking at the two twins, the twin that does not leave (is not moving) will age quicker than the twin that is moving. In other words,

If we look at the time dilation equation and the proper time (looking at clocks where one stays and one leaves), you can first tell that the closer to the speed of light one travels, the less time passes, ie $\gamma = 1$ when not moving and $\gamma > 1$ when moving.

For example, If twin A (Ashley) stays on earth, and twin B (Mary-Kate) leaves on a rocket. Ashley views the duration of time in which Mary-Kate left as 10years. Mary-Kate travels at the speed of 0.6c, the using $t_B = \frac{t_A}{\gamma}$,

$$\text{then } t_B = \frac{10years}{\frac{1}{\sqrt{1 - {(0.6c)^2}/{c^2}}}} = \frac{10years}{1.25} = 8years$$

And therefore Mary-Kate (twin B) viewed the time traveled as 8years, whereas Ashley aged 10years before Mary-Kate came back.

Time for both move relative to themselves, such that they cannot perceive a mitigation of 2 years- only when they see each other again do they see a difference. The paradox aspet comes into play when you would consider if twin B (Mary-Kate) was the inertial frame and not Ashley. You would consider that then Mary-Kate would view Ashley moving more slowly in time. However, because in this rocket ship scenario, Mary-Kate first has to travel away and then return, the journey going away would seen shorter and then journey back would seem longer. This paradox then isnt a paradox, but you would need to use the relativity of simultaneity in the Lorenz calculations:

$$x_B = \gamma(x_A + vt_B)$$

$$t_B = \gamma(t_A + \frac{v}{c^2}x_B),$$

to see that regardless, Ashley spent 10years waiting for Mary-Kate to return, while Mary-Kate only traveled for 8years.

When looking at this twin paradox, we can see how distinctly time differs from Newtonian time. It is an aspect of a 'dynamical field, the gravitational field" (Covelli, LQG). The twin paradox and basic time dilations are a part of special relativity, while the "General Theory of

Relativity (GTR) provides a deep analysis to effects of time flow in the presence of strong and weak gravitational fields" (Lobo 2003), as seen above with Einstein's Equations.

Another form of time dilation in General Relativity is in Black Holes. Looking at a basic Schwartzschild Black Hole (a stationary uncharged one - like from the collapse of star), the time it would take for something to fall in would be calculated radically differently based on the frame of reference. The Schwartzchild metric is found from solving the line element with $R_{\mu\nu} = 0$.

$$ds^2 = -\left(1 - \frac{2GM}{r}\right) dt^2 + \frac{1}{11 - \frac{2GM}{r} -} dr^2 + r^2 d\Omega^2$$

With $d\Omega^2 = d\theta^2 + sin^2\theta d\phi^2$

The event horizon of the static and symmetric black hole is called the Schwarzschild radius at $r_0 = 2GM$. Black holes not only have a singularity, but they also as seen shows the time component of the metric to go to zero when then radial component goes to infinity. If one was observing a spaceship from far away ($r \gg r_0$) it will appear an infinite amount of time has gone by before it reaches the Schwarzschild radius. Simplistically this can be seen when the spaceship follows a time-like radial geodesic, with fixed angles and because the space is from far away it will become a Minkowski flat spacetime. Solving you would find that

$$\frac{d\tau}{dt} \longrightarrow 0 \text{ when } r \longrightarrow r_0.$$

Whereas if you are close and watching the spaceship go towards r_0 it will take a finite amount of time.

<u>Time Travel</u>

General Relativity's introduction of spacetime and its spacetime geometry has introduced not only the theory of time dilation, but also the possibility of time travel, and by this I mean closed time-like curves (CTC). These particles travel along their time-like world line (using the line element equation) and return to their start. These closed time-like curves were confirmed by Kurt Gödel (ie the Gödel metric). Because the particle would travel back to its start along the closed curve, they imply time travel to the past. This mathematical solution in General Relativity leads to the grandfather paradox and its further implication in time and its link to causality. This CTC bends two of the definitions of time (the relative order of events and the gravitational field).

General Relativity as seen by Einstein equations and a small handful of examples, is a theory based on the relational view of time. In Relativity we see the Leibniz definition of relational time, "an order of successions", as pertaining to an order of events. General Relativity has done away with the notion of simultaneity and with that absolute time. The proper time and the coordinate time are no longer the same, and therefore there is no longer a preferred independent time variable, but multiple variables (ie multiple clocks). In a sense, we still have flow of time (some continuous variable), but now as a succession of related events. This does imply and order and therefore can imply causation (Lobo, 2003), but as seen by Gödel's CTC, the sequence of events can have little bearing theoretically.

2.4 Cosmology

Block universe and fatalism

If there is a block universe then do we have free will?

When we look at time in Cosmology, we see two main theories: the Block Universe theory and the growing block universe theory (also known at the evolving block universe). Ellis also expands on the evolving block universe, deeming a crystalizing block universe. The major difference between the two metaphysically is whether or not the future exists yet. The block theory interpretation of General Relativity implies “timeless naturalism”. “Timeless naturalism holds that laws are immutable and the present moment and its passage are illusions” (Smolin, Temporal Naturalism). The block universe theory naturally evolves out of general relativity and it displays a deterministic view of worldlines. Whatever unfolds on the worldline (past, present, or future) are all as equally valid. This pictures of the universe is “the result of deterministic and immutable laws acting on initial conditions” The block universe is under ‘externalism’ in philosophy (the future already exists just as the past exists), but also can imply fatalism – for if the future exists already then is there free will? But the question of free will is only in the realm of philosophy. However, as a thought experiment, it should be seen as an inditement of the block theory, and a question on how we can ontologically look at these physical concepts, but “in the absence of a decisive experimental test, both views remain in the realm of philosophy.” (Elitzur 2002)

The cosmological principle, which is an expansion of the Copernican principle, is that the universe as an approximation, is isotropic and homogeneous on a large enough scale. This so far has been confirmed by observations. This hypothesis leads to metrics with high levels of symmetries, and the metrics that works in the system are the Friedmann Lemaitre Walker Robertson metric. The curvature parameter is κ= -1, 0, 1. This is for a perfect fluid.

When we look at an expanding universe, with the line element of the metric in cartesian coordinates: $ds^2 = -dt^2 + a^2(t)[dx^2 + dy^2 + dz^2]$ or $s^2 = -dt^2 + e^{2Ht}[dx^2 + dy^2 + dz^2]$

And more generally: $ds^2 = -dt^2 + a^2(t)\delta_{ij}dx^i dx^j$.

The expanding universe metric is a 4 dimensional hypersurface manifold embedded in 5 dimensions. De Sitter space is maximally symmetric with as many killing vectors as there are in Minkowski space (10 killing vectors).This implies that the distance between different points in space is growing exponentially via the scale factor, a, which is a function of time. De sitter space is maximally symmetric spacetime with a positive curvature (κ>0), anti de Sitter space is a maximally symmetric spacetime with a negative curvature (κ<0), and Minowski space is the maximally symmetric spacetime with no curvature (κ=0), or flat space. De Sitter space is a solution to the Einstein's equations (which is 4 dimensional, and the cosmological constant is in 5 dimensions : $R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R + \Lambda g_{\mu\nu} = 0$

In an expanding universe, you will derive the Friedmann equation, $H^2 = \frac{8\pi G}{3}\rho - \frac{kc^2}{a^2} + \frac{\Lambda}{3}$.

And therefore find the equation of state,

$$w = \frac{p}{\rho} = \frac{\frac{1}{2}\dot{\varphi} - V(\varphi)}{\frac{1}{2}\dot{\varphi} + V(\varphi)}$$

If we put the FLRW metric into Einstein's equations above, you will produce the Friedmann-Lamaitre equations, where H is the Hubble constant. The Hubble constant, as seen, is not a constant, but is defined by the scale factor in time.

This led to the steady state version of the universe and the Hot Big Bang model – we correct to the theory of inflation – which then goes into the Hot Big Bang model of the universe.

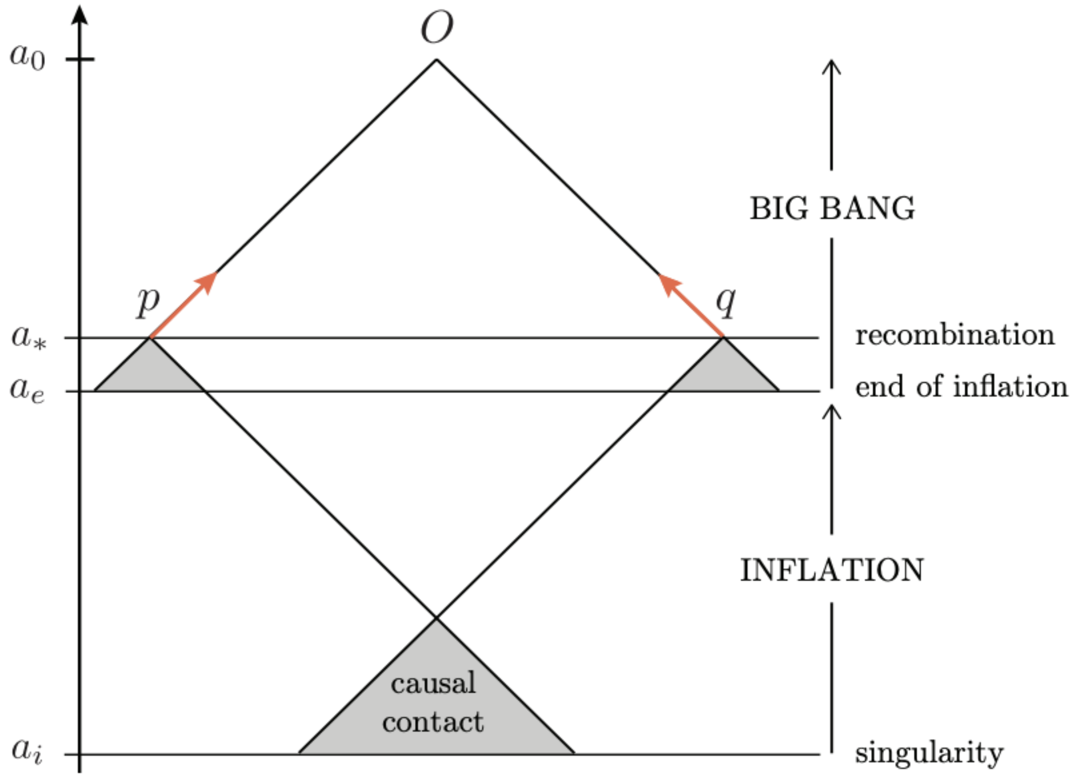


Fig 3 from Bauman– a conformal time diagram looking at the redefinition of the 'big bang'

In an expanding universe, there is no time like killing vector, the energy momentum tensor is defined on a background that is changing with time. Looking at this Minkowski 4-D spacetime, "all events – past, present and future – coexist along time just as all milestones coexist along a road. Only a few heretic theories sought to incorporate time's transitory aspect within a new theory. Frustratingly, however, the debate never became genuinely scientific. All physical observations are equally consistent with a Block Universe ("all events coexist along time") and with the hypothesis of Becoming ("events are created anew one after another"). In the absence of a decisive experimental test, both views remain in the realm of philosophy." (Elitzur 2002)

Explaining the different notions of time in cosmology:

Presentism	Growing Past	Eternalism	Block Unverse
-Only present objects exist -Past & future are not real and thus must be tied to what is in the present -The present is ontologically different than the past/ future	Past is real and growing larger all the time	No objective ontological difference among the past, present, and future Just like how there is no ontological difference between here and there	The future is part of the block is a region of actual events (not possible events) Future is ontologically real despite epistomological limitiations Block theory has been accused of spaciality time and geometrizing time Block describes change but does not change so 'static' is a questionable definition

<u>Block Universe</u>

To Smolin, the past hypothesis feels more like an admission of failure than a useful step forward. As he puts it in *The Singular Universe*: "The fact to be explained is why the universe, even 13.8 billion years after the Big Bang, has not reached equilibrium, which is by definition the most probable state, and it hardly suffices to explain this by asserting that the universe started in an even less probable state than the present one." (2015). The Block Universe is based on determinism from initial data. (Looking at Gisin, is this possible to even have this much information at the beginning of the universe?). The block universe both forces at inherent determinism (which doesn't coincide with the nature of quantum), but also forces the early universe into an inherently low entropy system and the universe must also increase in entropy. Looking at quantum fluctuations during inflation, then how could there be a deterministic view of the unfolding universe. Quantum is inherently unpredictable, and from a purely philosophical view, the block universe in many ways clashes with the idea of free will. However, if we look further into the Block Universe theory, then we are looking at moments along world lines, much like in General Relativity. If the world lines are looking at the flow of time (a continuous sequence) and although everything flows along its world line, the idea that everything is determined, then time in the present, the past and the future are all relative concepts. There is no real difference between the past present and future and therefore making time an illusion.

This block universe can be progressed to be seen in either a growing block universe concept or in the crystalized block universe concept. These haven't caught in the physics community though, but are seen as a way differentiating past and future and the chosen paths they go on (Ellis 2008).

Past Hypothesis:

The past hypothesis is a theory that the universe started in low entropy state – as we know from the second law of thermodynamics, that the entropy of a closed system can only increase and this gives an arrow of time. This hypothesis was coined by David Albert, the philosopher. Because the second law states that all isolated systems must increase in entropy and that they must evolve towards maximum entropy or thermodynamic equilibrium, then the universe (which is the only fully closed system) must have begun in a low entropy state, as it must increase as time increases, and that the universe is moving towards maximum entropy (aka thermal death). Although this is contested, it is the current practical explanation, and is explained in part by the universe starting in a close causal state (by which I mean small). "Loosely associating gravitational homogeneity with low-entropy and inhomogeneity with higher entropy, inflation is arguably a source of a low entropy "initial" condition." (Standford). This is not to be confused with the Standard Cosmological Model, which has a constant entropy over time but the temperature decreases with the adiabatic expansion on the universe. This Standard Cosmological Model with constant entropy would put the idea of the thermal death near the beginning of the universe (Prigogine 1989).

The horizon problem comes into play when we look at the homogeneity and isotropic nature of the cosmic microwave background (CMB). The CMB is a blackbody radiation and is in thermal equilibrium, which would imply that different parts of the CMB would be in the causal contact with one another. The particle horizon is the maximum distance that distinct particles could be causally related. We acquire the particle horizon distance from

$$D(t) = a(t)\int_0^t \frac{dt}{a(t)}$$

Where t=0 refers to the initial singularity. This problem was solved with the idea of inflation, therefore having a period of rapid accelerated expansion, and implying what we would previously have considered the Big Bang to come after inflation and recombination. Recombination was the period in which electrons and protons bounded together to make neutral hydrogen ($p + e^- \leftrightarrow H + \gamma$) as the ´fluid´ cooled. Inflation would solve the horizon problem, as long as inflation lasted a long enough period of time, which would be attributed to the slow roll approximation. The slow roll approximation in inflationary cosmology is when the kinetic energy (of the scalar field) must be significantly less than the potential energy of the scalar field. $\dot{\varphi} \ll V(\varphi)$. Because the universe on the small scale is not homogenous or isotropic, there is a need for the conditions of the big bang to have perturbations, more than the perturbations from a perfect fluid (how we can see galaxy formations). We know that inflation had to be for a long enough period of time to account for the thermal equilibrium of the CMB, but to also account for the fluctuations come from quantum variations. One of the fundamental properties of quantum mechanics is the uncertainty principle. The uncertainty principle asserts that precise measurements (like momentum and position) cannot be known. When we apply quantum variations to the inflation field, which is a function of time and space, allows for a spatial fluctuations, $\delta\phi(t, \boldsymbol{x})$, which are then coupled to fluctuations in time of the scalar field, $\delta t(\boldsymbol{x})$**,** meaning the time of inflation for different regions of space vary. If the time of inflation varies for difference regions of space, the local density will be different after inflation, $\delta\rho(t, \boldsymbol{x})$. Therefore, “inflation provides us with “natural” initial conditions” (Langlois 2008).

Other Hypotheses:

As an alternative to the problematic past hypothesis, Robert Penrose ”has proposed a principle to characterize the absence of initial gravitational radiation, which he calls the Weyl curvature hypothesis” (Smolin, 2014). This allows for a time asymmetry in early universe, that is only imposed on initial singularities. If it was imposed on all singularities then there would be no black holes. But “as pointed out by Weinstein, no electromagnetic radiation has ever been observed that does not plausibly point back to matter sources. (Smolin, 2014)

Julian Barbour also looks at an increase in structure of the universe causing an arrow of time. It is less to do with the growth of the universe and more to do with its changing shape. This increase in structure is then not looking at increasing disorder (entropy), which does get rid of the problem of why the entropy of the past was so much smaller. Barbour's theory is called Janus Points because it can account for time going in two possible directions (and therefore references the two opposing faces of Janus). (Barbour et al 2016)

2.5 Quantum Physics – Classical and Relativistic

Introduction

And when we thought general relativity threw cold water on us and our interpretation of time, now comes Quantum mechanics to go and further scramble our intuitions. The movement and meaning of space and time is so different in quantum that we still cannot understand the how of it all. We have experiments to hopefully explain enough of what is happening, but our overall grasp on why things work so differently when it is small is unknown. But to get back to time and quantum, we will first look at quantum entanglement and the quantum wave collapse and then at the double slit experiment.

Schrodinger's Cat:Quantum Superposition and The Double Slit Experimentt

The quantum superposition is most famously known by the metaphor "Schrodinger's cat". We've all heard it, but what does it mean? Mainly it implies discontinuity, and what does that imply about time? Well, if everything is quantized (discontinuous, discreet, does not flow) then what is causation, what is movement? What is direction?

Schrodinger's cat metaphor is that if there is a cat in a box with an atom that has a certain decay rate, if the atom decays, then it will trigger a reaction for cyanide to be released and kill the cat, and if it does not, then the cyanide does not get released and the cat lives. But the we know that particle is in a superposition of decay and not decayed until we open the box that contains the cat. Therefore, the cat is both in the possibility of alive and dead until we observe. Once we observe the superposition ‘chooses’, ie the wave collapses, and there is now only one possibility. With the observation, the outcome is known. But before the box is opened, the particle is in a superposition of both discreet places. It is not partially alive, or partially dead, or is definitely in one place, but somehow (illogically) in both and neither. “Quantum superpositions (at least on Bohr’s account) tell us that being/becoming is an indeterminate matter: there simply is not a determinate fact of the matter concerning the cat’s state of being alive or dead.” (Barad 2010, 252).

This is the Copenhagen interpretation, which appears to be experimentally accurate. “Spooky action at a distance’ is how Albert Einstein famously derided the concept of quantum entanglement – where objects [in such a state] instantaneously influence one another regardless of distance. Now researchers suggest that this spooky action in a way might work even beyond the grave, with its effects felt after the link between objects is broken . . . memories of entanglements can survive its destruction.”(Choi 2009, 24)
Does the memory of the future affect the past? If it does then we are looking at something new when it comes to time, but if memory affects the future then we are still just seeing the arrow of time, but in an oddly different form. This new form would reinforce the arrow of time, and with this it perturbates to a more fundamental level. The arrow was always seen in entropy, in the macroscopic, but if it is in the microscopic, then it is more than just an emergent force. It permeates everything, and might be the key to the ontological disturbance we have in quantum – that of particle/ wave duality. Reshaping our world will allow us to ask the right questions.

”Waves and particles are ontologically distinct kinds: waves are extended disturbances that can overlap and move through one another; particles are localised entities that singly occupy a given position in space one moment at a time. Light can't simply just be a wave and a particle, extended and localised." (Barad 2010, 252) "The nature of nature depends on how you measure it?" (Barad – Aarhus lecture).

" Einstein, who rejects quantum theory and is committed to holding onto a classical ontology, argues that this experiment would catch the entity in the act of behaving like a particle at the slits and behaving like a wave at the screen – exposing the deficiencies of the quantum theory.(…) Bohr's exuberance is hard to contain as he explains that Einstein's which-slit experiment beautifully demonstrated his Principle of Complementarity according to which an entity either behaves like a wave or a particle depending on how it is measured." (Barad 2010, 256). "The point, he argues, is not that measurements disturb what is being measured but rather what is at issue is the very nature of the apparatus which enacts a cut between 'object' and 'agencies of observation', which does not exist prior to their intraaction – no such determinate features or boundaries are simply given. What results is an entanglement – a phenomenon. The performance of the measurement with an unmodified two-slit apparatus results in a wave phenomenon, while the measurement with a modified two-slit apparatus (with a which-slit detector) results in a particle phenomenon. There is no contradiction, Bohr insists. Classical metaphysics has misled us. Entities do not have an inherent fixed nature." (Barad 2010, 256).

"The source of the problem is the interderterminancy associated with the statistical interpretation of the wave function. For Ψ (…) does not uniquely determine the outcome of a measurement; all it provides is the statistical distribution of possible results. This raises a profound question: Did the physical system "actually have" the attribute in question prior to the measure (the so-called realist viewpoint), or did the act of measurement itself "create" the property, limited only by the statistical constraint imposed by the wave function (the orthodox position(- or can we duck the question entirely, on the grounds that it is “metaphysical” (the agnostic response)? (Griffiths 2005).

”According to the realist, quantum mechanics is an *incomplete* theory, for even if you know everything quantum mechanics has to tell you about the system (to wit: its wave function), still you cannot determine all its features. Evidently. There is some other information, external to quantum mechanics, which (together with Ψ) is required for a complete description of physical reality.

The orthodox position raises even more disturbing problems, for if the act of measurement forces the system to “take a stand” helping to. Create an attribute that was not there previously, then there is something very peculiar about the measurement process. Moreover, in order to account for the fact that an immediately repeated measurement yields the same result, we are forced to assume that the act of the measurement collapses the wave function, in. a manner that is difficult, at best, to reconcile with the normal evolution prescribed by the Schrodinger equation.” (Griffiths 2005)

Quantum Wave Collapse

We will have to look at the microstates and macrostates of the universe to understand time. Time as we’ve seen works differently in a micro and a macro state, and frankly physics itself works differently at a micro and macro state. We have quantum in comparison to our classic laws. Particles work fundamentally differently in a quantum space than they do in a macro space. Most larger laws adhere in part to Newtonian dynamics (well GR once Einstein got involved). Fundamentally we've seen that quantum works in a way that isn't highly deterministic.

Looking at a particle, we must see its 'movement' or where it is. To do so one of our main equations is the Schrodinger equation:

$$i\hbar\frac{\partial\Psi}{\partial t} = -\frac{\hbar^2}{2m}\frac{\partial^2\Psi}{\partial x^2} + V\Psi$$

This equation explains the particle's wave function, ψ(x,t), with $\hbar$ being Planck's constant (ie $\frac{h}{2\pi}$). This wave function overall, "provided by Born's statistic interpretation" (Griffith 2005, 2), that is shows the probability of where the particle is, and to be more precise, $|\Psi(x,t)|^2$, is the probability density of finding that particle at the point x and at time t. It is not the precise place, for we do not know. Discussed later via the Copenhagen interpretation or the orthodox method.

You have a time independent Hamiltonian, and you have a probability of where a particle likely is. We found out that the 'orthodox method' is correct via John Bell's experiment in 1964. (Griffith 2005, 4). This experimental knowledge, that a particle is not in a definite place, until it is 'observed' also makes quantum indeterminate rather than determinate, and opens up that a foundational study of physics works differently than all forms of physics.

To explain the odd ways particles behave at a quantum level, we also have the Dirac Equation:

$\frac{h^2}{2m}\varphi = i\hbar\frac{d}{dt}\varphi$, which is similar to the Schrodinger equation as it explains the wave function and needs normalization, but the Schrodinger equation is based on the classical physics equation:$E = \frac{p^2}{2m}$, whereas the Dirac equation is based on special relativity counterpart ($E^2 = p^2c^2 + m^2c^4$). Both are more or less useful to different tasks. If we find the wave function of an observable (A) at t=t^*, the initial wavefunction for $t < t^*$is:

$$\psi_1(x) = \Sigma_n\psi_n u_n(x)$$

Once the measurement is taken, the wave function becomes

$\psi_2(x) = a_N u_N(x)$, for some value of N. The data for $t < t^*$ does not determine the index N, but does predict the probability that A will give certain eigenvalues, a_N:

Prob (A=a_N; ψ)=$|\psi_N|^2$

Regardless of description (many worlds, time-irreversible collapse, or decoherence), The "initial state does not uniquely determine the final state; and this is not due to lack of data, it is due to the foundational nature of quantum interactions"(Ellis 2005)

If done via the dirac equation, you would be looking at the state vector, |ψ⟩, as a linear combination of unit orthogonal vectors with u_n being an eigenstate of observable, A.

$|\Psi_1\rangle = \sum_n \quad c_n |u_n(x)\rangle$

The evolution of the system is through the unitary operator which is a standard evolution operator,

$i\hbar \frac{d}{dt}|\Psi_1\rangle = \hat{H}|\Psi_t\rangle$

When the Hamiltonian ($\hat{H}$) is time independent, the unitary operator is

$$\hat{U}(t_2, t_1) = e^{-\frac{i}{\hbar}\hat{H}(t_2 - t_1)}$$

Once a measurement (t = t*), the information is found in an eigenstate:

$|\Psi_2\rangle = c_N |u_N(x)\rangle$

and from this you find the probability density (or the probability of the outcome) (in Dirac formulation):

$p_N = c_N{}^2 = \langle \mathrm{eN}|\psi 1\rangle^2$

As seen below (from Ellis 2013), the wave function collapse is a time irreversible function.

$$|\psi_1\rangle = \sum_n c_n|u_n(x)\rangle \quad \longrightarrow \quad |\psi_2\rangle = c_N u_N(x)$$
$$Indeterminate \qquad Transition \qquad Determinate$$

"This is the event where the uncertainties of quantum theory become manifest (up to this time the evolution is determinate and time reversible)" (Ellis 2013, 4). This is where time's arrow comes into play. Not only does the final state not determine the initial state, the superposition comes before the eigenstate, and the values of the coefficients (u_n) are all but lost, and although we have some theoretical explanations (mentioned above), they cannot be shown (or have not been shown) via experiment. We can merely see the wave particle duality through the classic double slit experiment.

Notably though, quantum mechanics does not specify a direction of time. Within the unitary vector, t_1 and t_2 can be swapped and you will still get an equation for the unitary vector but with the opposite arrow. (Ellis, 2013)

"In the Schrödinger picture the operators corresponding to observables such as x, p, and S_z are fixed in time, while state kets vary with time (…). In contrast, in the Heisnberg picture the operators corresponding to observables vary with time; the state kets are fixed – frozen, so to speak – at what they were at t_0. (Sakurai 2014, 83).

Looking at time in quantum mechanics (either through the Schrodinger equation or the Dirac equation) you can see that space and time are treated differently. The space is treated as an operator ie:

$\hat{X}|x\rangle$=x$|x\rangle$, whereas time is a just a parameter without an observable in quantum mechanics. If time is made into an operator (which must satisfy $[H,T] = i\hbar$), it will be incorrect. It will either be self-adjoining and the Hamiltonian is unbounded below or it is anti self-adjoint. This would mean it is has an arbitrary negative energy or T is not an observable, as in "the context of ordinary Schrodinger Quantum Mechanics, no dynamical variable in a system with Hamiltonian bounded from below can act as a perfect clock in the sense that there is always a nonvanishing amplitude for any realistic dynamical variable to 'run backwards'" (Unruh 1989). The issue comes from not being able to integrate out the time components of the Hamiltoniam. (See calculation in Appendix BLAH).

Quantum Entanglement

Quantum Entanglement is what Einstein described as "spooky action at a distance". Much like the wave collapse in the previous section, quantum entanglement. A simplistic version of quantum entanglement is when a two particle wave function cannot be broken down to two one particle wave functions.

The consequences of quantum entanglement have in part to do with causality and the same issue that developed from the quantum superposition. Because the particles are entangled (ie they cannot be separated into a two particle wave function).

Quantized Time

We can also look at what quantized time would entail. It would mean that time had to. Be broken up into distinct parts – there is no such thing as a proper continuous flow, so there must be a minimum of discrete value. We would assume that to be the Plank time (10^-44 s) – which we cannot measure with a clock. Rovelli puts out that if that is the 'minimum interval of time' and that below that, "the notion of time does not exist- even in its most basic meaning" (Rovelli 2018, 84). He implies that if we look at the term continuous (Aristotle to Heidigger) we are looking at "subtly discreet". Everything is made up of packages, or parts, sometimes we just cannot see the space between. He equates this with plank length (10^-33cm): "the minimum limit below which the notion of length becomes meaningless". (Rovelli 2018, 86).

Relativistic Quantum Theory/ Quantum Field Theory

If we look into relativistic quantum theory, time can become an operator, but more commonly, space or position is demoted from an observable to just a parameter (Sakuri 2014). When we move from quantum mechanics to relativistic quantum physics (used in Quantum field theory and theories of everything), the space and time components are in the same position. The time component can become an operator over a parameter (Bauer 2013), but the more common way is to turn the space operator and time parameter into a four component spinor using the dirac equation to make space and time be on equal footing as it is in General Relativity (with the caveat that the time will still have a different sign than the space components). Using

$$(i\hbar\gamma^{\mu}\delta_{\mu} - mc)\psi$$

where ψ is not the normal wave function used in QM, and is instead a four component spinor. The components of the spinor are a function of the 4 dimensional spacetime $\underline{s} = (\underline{r}, ct)$, where $|s|^2 = (ct)^2 - \underline{r}^2$ which is Lorentz invariant. In this case, the space components are downgraded to labels instead of making t an observable.

There is asymmetry in the way we treat the time component in QFT when doing Feynman Path Integrals we integrate over all space in all three dimensions so we end up with Hamiltonians that are time dependent.

2.6 Quantum Gravity and Theories of Everything

There are 3 major contenders when we talk about theories of everything and time: Julian Barbour, Carlo Rovelli, and Lee Smolin. These three men have spent a large amount of their time on the question of time. All do adhere mainly to quantum gravity over other Theory of Everythings (like string theory) – and interestingly, they all think philosophy and other academic pursuits are paramount to figuring out this behemoth of a concept.

One of the main unanswered questions in physics is how quantum mechanics and gravity work together- for they are incompatible, and yet both are needed for specifical cases (like black holes and the 'big bang'. This type of cohesion lends itself to two types of philosophies in the search: "the timeless absolute" or the time being deeply fundamental.

Theories of Everything, but specifically I will be looking into Loop Quantum Gravity (LQG), like general relativity must be background independent. This background independence coincides with the theory of time being relationist (or relativistic). Whereas, Quantum Mechanics adheres closer to the idea of absolute time (working from classical physics and Newton's ideas on absolute space and time). However, with relativistic quantum theory, the idea of time must change to adhere to General Relativity which adhered to relationalism (and the ideas of Leibniz and Mach as explained in section 2.1.

Quantum Gravity is quantized geometry, and therefore there are physical states (like in quantum mechanics) that are then invariant based on the isomorphic and differentiable map between manifolds (diffeomorphisms) (Rovelli,Smolin, et al).

Loop Quantum Gravity is centered around the Wheeler DeWitt equation (realized by Ted Jacobson and Lee Smolin, and expounded on by Carlo Rovelli). This equation is "the fundamental equation in quantum gravity for the wave function of the universe (containing all information about the geometry and matter content of the universe), are necessarily time independent" (Ellis 2008).

The Wheeler DeWitt equation stems from the ADM formulism of spacetime. ADM formulism involved having the spacetime foliated into spacelike surfaces, (Σ_t) (shown in FigBLAH).

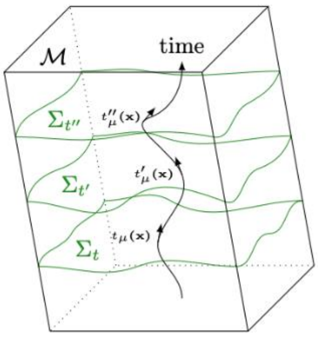


Fig 4 from Wheeler DeWitt Notes

Starting from the Hamilton Jacobi formulation, which does not depend on the time variable but on the 3-metric of an Einstein space and $S[q]$ is the action of a solution of the field equations in this region. These equations are equivalent to solving Einstein Equations.

$$D_a \frac{\delta S[q]}{q_{ab}} = 0, \qquad G_{abcd} \frac{\delta S[q]}{q_{ab}} \frac{\delta S[q]}{q_{cd}} + \det q\, R[q] = 0$$

Where $G_{abcd} = q_{ac}q_{bd} + q_{ad}q_{bc} - q_{ab}q_{cd}$, and R is the Ricci scalar of the three metric qab of a spacelike surface.

Where $\left[\left(q_{ab}q_{bc} - \frac{1}{2}q_{ac}q_{bd}\right)\frac{\delta}{\delta q_{ac}}\frac{\delta}{\delta q_{bd}} + detqR(q)\right]\Psi(q) = 0$

And in this case $\Psi(q)$ represents the wave function. (Rovelli et al, Smolin, Kamenshchik etc)

The Wheeler DeWitt would then have a ‘disappearing’ time component, and the variables of the system change together. This can be seen as a type of timelessness or a relationist (and relativistic) view of time. The time component is necessary on the foundational level, and when viewed, it can only relate events to one another.

Smolin and Rovelli work heavily in quantum gravity and use some of their time to look at time, and they came to different interpretations. Smolin believes time is fundamental, whereas Rovelli believes an emergent quality to time from the fundamental equation of thee Wheeler DeWitt doesn’t rely on the time variable. Smolin posits that the “problem of time is a key challenge that any complete background independent quantum theory of gravity must solve” (Smolin 2006).

Lee Smolin looks at a lattice structure made up of spin foams, which end up with an emergence of space, whereas time being fundamental. Rovelli on the other hand used the theory to disregard time, and look at the dynamics. The dynamics instead have to do with probability amplitudes for processes.

These are fascinating looks at the emerging concepts surrounding time, and to look at the question of whether time is fundamental or emergent. They do both rely on the theories surrounding Quantum Gravity over other theories of everything. The idea of time from these concepts can see a separation of looking at a continuous variable or a smooth geometry, but relies on quantum interactions between pieces of spacetime.

2.7 Entropy and Irreversibility

The fundamental inconsistency of time is its seeming irreversibility. As discussed previously, time is seen as a parameter, but a linear parameter. It goes in a single direction unlike other parameters in physics. This irreversibility feels to be obvious as people, common sense in a way. As often mentioned, you can break an egg but can't unbreak it. And as seen to be previously important, we are all mortal and can't change our lives. This arrow of time is seemingly what gives people (myself included) the main interest in time. But as shown before, although we are unsure why this is true, there are a few examples in our physical world that we can look at different concepts that uphold this irreversibility.

Irreversibility is seen in both macroscopic and microscopic concepts. This section will focus on the entropy gradient, the arrow of time's biggest and oldest ally. Irreversibility is also shown in the quantum wave collapse (section BLAH) and the block universe (section BLAH).

Second Law of Thermodynamics

The second law of thermodynamics was discovered by the research of many scientists (notedly Ludwig Boltzmann, Lord Kelvin, and Max Planck) (Entropy Non-Tech). Rudolph Clausius discovered that heat cannot transfer from a cold body to a hot body (whereas heat can transfer from a hot body to a cold body) (Rovelli, Order of time). This followed the first law of thermodynamics which is the conservation of energy:

$$\Delta U = Q - W$$

where ΔU is the change in the internal energy of the system, Q is the sum of the heat transfer, and W is the work done. The second law came about by looking into the question 'how efficient can we make a steam engine?'. What they discovered was the second law of thermodynamics:

$$dS \geq 0$$

Where S is the total entropy of an isolated system. In other words, the entropy of a closed system can never decrease, and will remain constant if and only if all processes are reversible. Therefore, if we look at the equation for the universe, then it would become, $dS>0$, because the total entropy of the universe must not only not decrease, but must also always increase. The total entropy of the closed system refers to both the internal and external exchange of the system as seen in figure BLAH

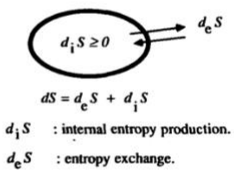
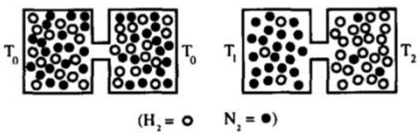


Fig 6 from Prigogine

The increase of entropy only applied to a closed system, as the internal and external exchange. But what is a closed system? Local entropy can decrease, but then must increase somewhere else outside of the system. This is seen consistently in the universe and critically on Earth. Decrease in entropy is necessary for life. A common example would be a fridge in the house. To make the inside of the fridge cold (and decrease the entropy within). This comes from adding energy to the system. The added energy (heat) will then increase in the house and therefore the system will increase in entropy when the system is looked at through the exchange of the internal entropy production and the entropy exchange outside the system. More fundamentally we can look at this through the lens of living things. This difference in entropy is necessary for life. Prigogine and Stengers considered life a part of a system called “dissipative structures”, which are “dynamic, self-maintaining systems including include cyclones, whirlpools, flames, and black holes and are characterized by importing useful forms of energy (free energy) and exporting (dissipating) less useful forms (entropy), particularly heat.” (Schrieber). As long as the systems are maintaining their system then they do not go into thermal equilibrium, and will only do so once they are no longer self-maintaining, in the case of living organisms, that is until death. (Schreiber). These are not fully closed systems, and are interacting with the larger system. If we keep going out and out, then the only 'true' closed system is the universe.

This irreversibility is often cited as the only physical law that distinguishes past and future. As Rovelli states: "the difference between past and future does not lie in the elementary laws of motion; it does not reside in the deep grammar of nature. It is the natural disordering that leads to gradually less particular, less special situations" (Order of time).
Beyond this macroscopic heat relation, entropy is often described by the disorder of a system, but what would that actually entail? The entropy is often looked at the heat of the system or at the microscopic patterns of the particles, hence disorder.



$$\frac{d_i S}{dt} = \underset{\geq 0}{\text{Thermal flow}} + \underset{\leq 0}{\text{Antidiffusion}} \geq 0$$

$$\frac{d_i S}{dT} = \text{"order"} + \text{"disorder"}$$

Figure 7 (from Progogine)

The isolated system will always move towards thermal equilibrium which will be towards its maximum entropy (as seen in cosmology that is part of the 'heat death' of the universe). Another way of looking at the concept of order and disorder is the number of possible states the system can be found in. The increase of entropy is therefore defined by saying there are more possible states the system can be in increases with time (Schrieber). Boltzmann's interpretation in the 1870s of the steam engine problem looked at the behavior of the microstate of the system.

This fundamental macro effect (which nothing seems to escape - not even Black holes), gives inherently an arrow to time and therefore a property on time that is not the same as space. So even when using QFT and Quantum Gravity, making time on the same level as space, there is always a difference. In a spacetime metric, the time and spacial components always have to have opposite signs (like in Minkowski space with a (-,+,+,+). And when we are doing dimensions, it is always even mentioned in its lowest form as a 1+1 dimension.

Boltzmann H-Theorem

The Boltzmann H Theorem is a theory as to how we have the second law of thermodynamics. The H Theorem was discovered by Bolzmann and does seem to explain the 2nd Law, but only with a low entropy beginning (and once again, why would we arbitrarily have a low entropy?). This theory uses mainly statistical mechanics to explain the increasing entropy of a system, using a very large amount of particles in an ideal gas. Classical mechanics and statistical mechanics: $H(f_t) = \int f_t(v) \ln f_t(v) d^3\bar{v}$

Where $\frac{dH(f_t)}{dt} \leq 0$, and$\frac{dH(f_t)}{dt} = 0 \; if \; f_t(v) = Ae^{-Bv^2}$ (stationary for Maxwell distribution)

This can also be written as $H(t) = \int h(t,\bar{r}) d\bar{r} = \int f \ln f \; d\,\bar{p}\; d\,\bar{r}$

In both formulations, H must be negative for the entropy to increase as $t \longrightarrow \infty$, $h(t,\bar{r})$ is the evolution of the density, which as stated before leads towards the Maxwell distribution.

This statistically shows that the collisions of the molecules on the time scale mathematically go display an increase in entropy of the system. Others (like Argonne) have looked at the H-

Thm based on quantum states, which agrees with the decreasing H-thm showing an increase in entropy. As Schreiber notes, the second law also does not necessarily mean an increase in disorder, but in fact is about “the likelihood of finding it in its original or any given state tends to approach the likelihood of finding it in any other state” (2010). This is then looking at the possibilities of state, and not in an arbitrary order. The definition of a type of order within the entropy gradient is often used as an argument against the definition of the arrow of time through the seemingly emergent property of the second law of thermodynamics.

Far and Close to Equilibrium

Interestingly, if we are looking at system close to equilibrium, we can see in Poincare’s Recurrence Theorem that a dynamical system can be periodical. The theorem explains that for any closed system, the system can return to its former state after a sufficiently long time. This is interesting as a note on entropy for then “therefore differene btw irreversibiliy and reversibility would only be the scale of observation” (Prigogine, 1989).

An interesting facet of our clearly entropic universe comes from what happens when something is far from equilibrium. We think of these as our fundamental ‘time cannot reverse’ images, like an egg breaking. Far from Equilibrium events are scale invariant, and “one important recent realization has been that there are two classes of singular break-up events: one in which the neck shape is universal since it does not remember the initial conditions, and one where there is memory of the early stages of neck formation and thus no universality” (Jaeger & Liu 2010). Condensed matter physicists are looking more into far from equilibrium dynamics, statistical mechanics just simply doesn’t work as well, as you can’t view it as a Gaussian distribution as easily or frequently. The dynamics of the system are unpredictable and can be “exhibiting for example slower, exponential decays, power-laws or additional peaks, so that catastrophic, but rare, events can dominate behavior." (Jaeger & Liu, 2010).

2.8 Research Gap

The topic of time permeates to every subset of physics and into biology and chemistry. This is a relatively brief overview of pertinent aspects of time in use and the thoughts surrounding the definitions of time. Because this is such an overview and a masters thesis, there are surely more areas to explore in different ways and different mathematical findings. People explore time in the fluctuations on quantum scales in condensed matter theory (briefly touched on in entropy). There is more literature on radioactive decay in its spontaneity and its relation to the arrow of time. The theories of everything section, delved mainly into Loop Quantum Gravity, but there are other theories of everything that utilize different concepts surrounding the use of time and dimensions.

There is also the look into the mathematical side of numbers and mathematics ultimate failing points (shown by Gödel's incompleteness theorems) and even in newer mathematical concepts, such as intuitionistic mathematics re-shaping indeterminism in physical theories. Mathematics would touch the most closely with physics as it is the language of physics, but because this topic is so profound on our thoughts and lives, scientists like Rovelli, Smolin, and Carrol have all expressed a need to utilize philosophy and biology – as Rovelli noted (2008), our brain needs to structure our thoughts, so the question of a progression is ingrained within how we are capable of thinking.

Chapter 3: Anthropology

3.1 Introduction (Aim and Rationale)

The issue of the concept of time in physics is plagues by our perception of reality. As seen in the previous sections, time still often lies in the nebulous ideas of science and philosophy. Our brains cannot separate time in a way that it can separate space, and the question has plagued people for centuries.

The push of physics is to understand the physical world, beyond our perceptions, to discover the workings of the world and to push past our prejudices. To understand beyond our limits. But with the cracking of philosophy and physics primarily in the early 20th century with the public debate between French philosopher Henri Bergson and physicist Albert Einstein, the physics community in part has lost sight of our own failings, and without knowing our prejudices, I believe we have hindered our sights.

Using the anthropological technique of the ethnographic interview (Spalding), I wanted to see the views of contemporary physicist insights into time.

As Spalding explains, the ethnographic interview is set out to understand the human perceptions, while understanding your own. The interview (as it is merely a social science) is fraught with difficulties and both the informant and the ethnographer's culture and personalities must be taken into consideration to get as much useful information as possible.

Aim

The aim of this section is to outline and justify the rational of this section of the section. Below will be an outline of my interview questions and research methods.

3.2 Literature Review

The issue of the concept of time in physics is plagued by our perception of reality. As seen in the previous sections, time still often lies in the nebulous ideas of science and philosophy. Our brains cannot separate time in a way that it can separate space, and the question has plagued people for centuries.

The push of physics is to understand the physical world, beyond our perceptions, to discover the workings of the world and to push past our prejudices. To understand beyond our limits. But with the cracking of philosophy and physics primarily in the early 20th century with the public debate between French philosopher Henri Bergson and physicist Albert Einstein, the physics community in part has lost sight of our own failings, and without knowing our prejudices, I believe we have hindered our sights.

Using the anthropological technique of the ethnographic interview (Spalding), I wanted to see the views of contemporary physicist insights into time. As Spalding explains, the ethnographic interview is set out to understand the human perceptions, while understanding your own. The interview (as it is merely a social science) is fraught with difficulties and both the informant and the ethnographer's culture and personalities must be taken into consideration to get as much useful information as possible.

Section 1: Methodology

1. Introduction

The aim of this section is to outline and justify the rationale of this section. Below will be an outline of my interview questions and research methods. I will then analyse and discuss my positioning within research and limitations.

There was a schism in academia between the sciences and the humanities. As seen in Chapter 2, the major break came in the early 20th century (coinciding with the major advances in

General Relativity and Quantum Mechanics). This schism was shown in relief with the open debate between Albert Einstein and Henri Bergson (Canales 2015, Covelli 2018, Frank 2012, et al) . This has in modern times led to prominent physicists publicly denouncing the use of philosophy, and leading to physicists not as openly researching and looking at the fundamentals of time as it could lean too much into metaphysics. I believe this is a detriment to the discoveries just around the corner as long as we can ask the right questions.

2. Research Questions

Before beginning this study, I discussed this need with my supervisor, Jens Hjorth. I lead the interest in physicists' ideas around questions of time in discussion of such a broad and ‘fundamental’ topic. We discussed the big questions I was looking at, and how these could be addressed. We came up with a list of people to ask, as the first stage of a research project involves gaining permissions officially and cooperation is not guaranteed (Cohen et al 2007).

My research is conceptually centered around my ‘big questions’ surrounding the topic of time. I wanted to look at how much time was actually taken into consideration by working physicists, and how they view the topic might define how they think on it or how they could answer questions.

One of the main key questions I asked outright at the end of the survey. I had open ended questions and these could devolve into further more specified questions.

1. Is Time fundamental or emergent?
    a. If time is fundamental, then why aren’t people looking into time as a more prominent aspect of the fundamental laws? (Why is it not fully considered in

the Standard Model?) We look at space and not as much at time, even though time is considered to be a fundamental aspect of space.

   b. If time is emergent, then where does it come into place in the Standard model?
   c. Why is time not as considered when looking at small vs large, when we cannot separate space and time as one of the main aspects of our force. Laws (gravity) – is this in part a reason why gravity cannot be properly seen in the same way as the other forces?

2. Can time only move in one direction?
3. Why are both quantum and entropy (two fundamentals of our world – space and time) probabilistic? Whereas the way in which we determine physical effects as deterministic?

3. Research Design

3.1 Choice of Research Method

The method of approach for gathering data was written interviews, some were written responses while others recorded their answers. All participants were given the same interview questionnaire (Appendix A). This was not a mixed method approach, and instead was an ethnographic, open ended interview style, where everyone was given the same questions with the ability to answer either written or orally (the majority opted to write their answers). Its diminutive size was a response to the common problem of low response rates in these types of data collection (Cohen et al 2011; Bell and Waters 2014), as it can be perceived as “an intrusion into the life of the respondent” (Cohen et al 2011).

Guided or focused interviews were chosen for both more of an open-ended structure in comparison to a questionnaire. This allowed for “freedom to talk about the topic and give their views in their own time”(Bell, 2014). And because it was also predominantly over email, the questions were focused and follow-up questions weren’t expected because of people’s busy schedules.

The interview questions were run by my advisor as well as an anthropology professor (Dr. Daniel Souleles at Copenhagen Business School) to try and diminish bias, because “interviewers are human beings and not machines, and their manner may have an effect on respondents'”(Sellitz et al 1962). Further limitations of the interviews were from the format - although the questions were in an order to try and diminish bias, the interviewees were able to see all the questions before their response. People also are not as free flowing in their responses when written versus when speaking face to face (Spradley), but tone and bias from my end was less on the interviewees in written form. But as Mishler has argued that authenticity, achieved through understanding rather than positive analysis may be stronger than validity in qualitative research (1990), so an interview form was preferred to a questionnaire or a mixed method approach.

My approach to epistemology was to adopt a structured interview. The first couple of questions could have been a questionnaire, but given the expected rate of response, an entire block interview was given to elicit a higher response rate to the valued questions with a baseline of understanding their background, in comparison to a mixed method approach. This was also borne out of the essential subjectivism in representing and evaluating people.

Having worked in education, studied in the United States (and with some of the participants), as well as knowing and working with physicists from Australia, I used an ethnographic approach for my method. This "participant observation enables researchers, as far as is possible, to share the same experiences as the subjects, to understand better why they act in the way they do" (Bell 2014).

3.2. Research Participants

The participants of the study are Western English speaking research physicists. Due to connections and number of questions, the size of the participant response was diminutive. All physicists involved were either in quantum or astrophysics research, and therefore had to intimately work with the concept of time on either the largest or smallest scales. The participants were a mixture of people I knew and strangers. All were given the opportunity to ask clarifying points, questions back, and the ability to be anonymous. The low number of responses does support Dencomble's claim that how participants are approached initially is a critical factor in affecting the response rate (2008). A small response rate of interviews is expected however for the depth and open ended nature (Bell 2014).

The first few questions of the interview were closed to establish their educational background and areas of study. All the participants worked in western countries (Western Europe, United States of America, and Australia), and all had their higher level education in the United States or Australia. It was a split of male and female professors, and all are full time professors and researchers. Of the interviewees, two of the professors were known personally to me (as I was their student). While their student, the concept of my interest in time and anthropology were not discussed, so I do not believe the findings would have been skewed, and just allowed for a greater depth to the participant observer.

3.3 Interview Process

All the interviews were arranged via email communication. With the busy nature of academia, this led to some people wanting to respond but said they did not have the time. Within the email, each participant was given explicit information on the board topic of the interviews and thesis (but broad enough not to bias their answers). All were given the ability to not be quoted or to remain anonymous. All the participants who responded to the interview questions were open to discussion, possible follow up, and none opted for anonymity. Because they were all conducted via email (and not face to face or over the phone), each interviewee was given a copy of the interview questions, and as this was a semi-structured interview (with a preference for a single session), and the participants were aware of the questions (Appendix A), along with the fact that I was not their active student but was also not a fellow professor (and therefore not a colleague), this allowed for relatively frank and honest responses. The aim and use of the semi structured interview was to enable more complex issues to be explored as an interview's aim is for " discovery rather than checking"(Denscombe 2008).

4. <u>Ethical Considerations</u>

I followed the guidance mainly from Bell and Waters (2014), Cohen et al (2011), and Denscombe (2008) for ethical guidelines for this section. Bell and Waters (2014) espouse confidentiality and anonymity as essential foundations of informed consent. There are key differences between these terms. Confidentiality is defined to be "a promise that you will not be identified or presented in identifiable form" (Sapsford and Abbott 1996 in Bell and Waters, 2014), whereas anonymity is defined to be the "promise that even the researcher will not be able to tell which responses came from which respondents". (1996 in Bell and Waters, 2014: 51). Given the type of interviews conducted and the form of reaching out, I was able to give confidentiality but not anonymity, which is something very difficult to achieve (Cohen et al 2011). Within this, no one asked for confidentiality, and all were aware that their interview and quotes could be used within this report. I hope that having the interviews done via email (and therefore having written consent) and transparent communication has allowed for an ethical finding and "greater rapport and trust between researchers and participants (Cohen, Manion, and Morrison, 2011)

5. <u>Limitations</u>

There are limitations to the research, as there will be with any such project. To begin, the participants were far reaching in scope. They were all educated and currently reside in the 'west', but they were from different continents and researched different areas of physics, and not everyone grew up in the west. This is then just a sample of thought and no broad conclusions can be reached. The amount of interviewees that responded to the questions and a certain amount of 'cold interviews' led to less familiarity and lower rate of response. There is also a clear distinction on length of response from audio recording the interview questions and email responses.

6. <u>Data Analysis</u>

To analyse the data, I assess in line with the research questions and the themes that arose from the literature. Because these were structured interview questions, the data was not built for easy answers, and therefore there was no attempt at statistical analysis. Therefore, following Denscombe (2008), the broad picture painted by the interviews was used for their social rather than statistical significance. Suggestions from Cohen et al (2011), were useful in with analysing the qualitative data:

- building a logical chain of evidence – noting causality and making inferences;
- clustering – setting items into categories, types, behaviour and classification";
- seeking plausibility – trying to make good sense of data, using informed intuition to reach a conclusion.

By using an interview (even if it is semi-structured) there are multiple interpretations often required in the analysis and there are "no single or correct ways to analyse and present" the qualitative data (Cohen et al 2011; Densombe, 2008). My aim is to analyse the data in a compelling and honest way to see the key perspectives of the interviewees.

Section 2: Findings

First I will look at my main questions. 1. Do physicists consider the notion of time in their research? I looked at this by asking (see Appendix BLAH) on their views of time in both an academic and personal setting. With my questions, I had internally thought about the association with particle physics and the standard model, but did not structure my questions in that direction, as they all were in different fields and I wanted to see how they contemplated the concept from their own perspective.

Physics has inherently dovetailed away from philosophy and appears to shy away from any contemplation that could be considered metaphysical. In many ways, this allows for a solid questioning of what we can see experimentally. Even in theoretical physics, where sometimes an advancement comes from messing with the mathematics of relatively known concepts (as looked at before say with the Boltzmann H Theorem and considerations of the quantum hidden variables), but they can go into explanations that cannot be shown experimentally (hidden variables being many worlds theorem), or at not experimentally in any way we can comprehend. The advancements in physics from the past 100 years or so (General Relativity and Quantum) seem to engender this separation, but in part, both the discovery of Quantum Mechanics and General Relativity occurred before the schism (which mainly occurred with the public debates between philosopher Henri Bergson and physicist Albert Einstein (Canales 2015), and some current physicists contemplating the broad, verging on philosophical topics, desire a need for philosophy (Rovelli 2018). And as large experimental discoveries in the 21st century shows, “Empirical results such as the detection of the Higgs particle and gravitational waves, and the failure to detect supersymmetry where many expected it, question the validity of philosophical assumptions common among theoretical physicists, inviting us to engage in a clearer philosophical reflection on scientific method” (Rovelli 2018)

I wanted to look at if and how perceptions and contemplations of time adhere to their work and if it was a question they contemplated.

Only one person seemed wary of a metaphysical contemplation (Prof Liliya Williams). Three of four of the interviewees worked in some form of cosmology or astrophysics, and yet they all differed on their definitions and contemplations on time.

“Time is something we use to measure change.” - Dr. Tamara Davis

“I would say that that's one of the more interesting unsolved questions in physics.” - Prof Liliya Williams

“As a consequence of the 2nd Law Thermodynamics [this would be a bit of work, but I'd remind them of some chemistry course they had in HS, where they, perhaps, were introduced to the concept of entropy....” Dr. Tim Halpen-Healy

“I would describe time as an emergent construct that at the level of our perception seems to be something that, you know, orders events one before the other. What exactly is it? We're still trying to understand” - Dr. Subodh Patil

Within the first half of the questions, the interviews did agree it wasn’t a concept we fully understand, and all brought up the arrow of time and entropy.

Most of the participants believed that notions of time adhere rather commonly among physicists, and assumed lack of knowledge in a lay person, with Professor Williams exclaiming, “I would avoid that conversation with a layperson!” Outside of Prof. Patil, who mentioned a philosophical contemplation with relation to mortality and religion, and Dr. Williams opted out of answering entirely, their perceptions of time do adhere to their physical knowledge. This is an interesting dichotomy in the idea of the flow of time (and their use of a monotonous time parameter -which would enable a form of flow), but also not believing a lay person to engage. To be fair to this question, without me able to speak to them, the layperson could be considered an unintellectual not just a non scientist or non physicist.

Three of the Four professors interviewed were cosmologists (Dr. Patil, Dr. Williams, and Dr. Davis), with Dr. Halpin-Healy was a condensed matter theorist. Dr. Halpin-Healy expressed the most worry about his answers being different from his peers, which should be noted for a collected belief that their concepts of time would be the same if not similar. Dr. Williams and Dr. Halpin-Healy both said that they did not use the 'flow' of time in their work, where Dr. Patil said that the idea of the flow of time "is what cosmology is" expounding on the idea of "breaking time translation invariance", and Dr. Davis specified that use the idea of flow in terms of treating time "as a continuous variable". And although Dr. Williams did note that she did not use the flow of time her work, she did say:

> "The standard answer is that, even though basic physical laws do not specify the direction of time flow, on large scales, where statistics and probabilities take over, the arrow of time is well defined. That explanation is probably partially true, but maybe not in detail."

And Dr. Halpin-Healy expounded,

> I'm concerned, research-wise, w/ the "emergence" of order in systems w/ many degrees of freedom; e.g., phase transitions, cooperative phenomena, etc. exhibited by superfluids, critical points, etc., as some external parameter
> like the temperature is varied"

The physicists collectively consider the notion of time in their research, but to varying degrees, regardless of a relative similarity in study (cosmology). Their concerns on time and views on time were shown to view time and their concerns around time (and mainly its arrow) in different ways. The condensed matter physicist was most concerned with the probabilistic nature of time, and was not concerned with the concept around time being reversible. The cosmologists all spoke of the reversible nature of time or idealised larger scales, and for Dr. Williams and Dr. Davis, the use of a type of arrow with a smooth flow of time was all that was necessary to ponder specifically in their research.
Their contemplations of the larger question of time did not adhere as much to their work. Although the definitions of time they used adhered to their field of study, the definitions, as I explained in Chapter 2 did seem to differ per physicist based on their field.

I then wanted to see if they contemplated this notion to see if it was fundamental or emergent and if this was considered when working in their field. The idea of time's emergence is more prevalent than fundamental, with Dr. Patil expressed surprise that it was the final question of the interview. The interviewees allowed for a caveat of the unknown for all though. Dr. Davis expressed that "we treat it as fundamental", and Dr. Williams said, "That's a tough question, but it does not affect my work in any way." The pull of focus on time on its inexorable link to entropy permeates all the answers. They all acknowledge that there is a notion, in reality, that there appears to be a direction of time, and the idea of emergence or fundamental is something that is more to do with the theoretical view of quantized spacetime or conformal field theory.

Chapter 4: Discussion

As viewed through the history of physics on time, we can see that the view of time is so fundamental to our (human's) thought, process, and understanding that it seems impossible to attempt an objective experiment (thought or physical) that could differentiate the ontological and epistemological theories around time. The entire way we as humans conceive of thought, entails a mixing of metaphysics and physics (as in the question of what and why around the concept of time). However, it is a feat we shall try to overcome none the less considering. The question of time is fundamental or emergent and how physicists could grapple with this question. The fundamental problem of having time being a way of thought, but also having it with the advent of GR, being bound to space. Can we have space be fundamental and not time? Must the fundamental concept of time be bound by the forward momentum of its seeming arrow?

Let us look at the arrow of time and entropy. Although we have the fundamental laws be time reversable – we cannot fathom ever see time not move in one direction. Why is time so unique? Looking at the question of fundamental or emergent, I want to look at the role of entropy in the arrow of time. As shown in part 1, The second law of thermodynamics states that in a closed system, entropy will never decrease. We do know however, in a non-closed system that the entropy can decrease. The decrease of entropy is shown most notably on earth and the development of life. Earth cannot be a closed system for me to be writing this thesis at this moment. And yet we have not seen an instance of reversing time, reversing physical phenomena, and the development of life (of evolution) allows for a physical representation of the arrow of time. We have history literally written in stone (carbon dating for one).

If we can decouple entropy and the arrow of time, then we can look further into where and why time works the way it does.
Time is fundamental to our experiments and laws, and yet few physicists study the nature of it. It being so fundamental to all of physics, we should look at the nature of it, and with this more appropriately look at the standard model.

Because the second law of thermodynamics also contends with the notion that it 'tends' as "in any process in which a thermally isolated system goes from one macrostate to another, the entropy tends to increase (Reif 1965)" we therefore have possibility of a non-deterministic law. Does non-determinism demonstrate our need to redefine how we constitute a law because a deterministic law is predicated on our current definition of duration.

When we look macroscopically, we see an arrow of time. The past and the future are fundamentally different, and the present is some sort of unfindable thing (like the beginning of a rainbow). If we concern ourselves with the notion that the past and the future are indeed not the same, and it is not merely a flaw of our sentience, then the microscopic and macroscopic are different – but how can time be different from up close versus far away?

This difference is forced upon the different notions of time – and can we even have a notion of time separate from space (I'll pretend for now as if we can).

The way in which we define a physical law implies a necessity for duration – but does not need an arrow – which seems to be the way of the world.

Does time imply causality? If time implies causality then can time not be fundamental? When we look at LQG and the Wheeler DeWitt equation, there where does causality go? Or is the universe more probabilistic? Is this probabilistic nature the coursing towards an emergent property of time allowing for an arrow? As Progogine state, "the basic problem is the conflictual situation between the static description proposed by classical physics, based on deterministic and time-reversible laws, and the world as we know it, which for sure includes probability **as** well as irreversibility as basic elements" (1989).

When looking at the query, 'is time fundamental or emergent?', there does not seem to be a consensus, and do not seem to be closer to answering that question, and part of the issue stems from not having a consensus on the definition of time. This is exemplified in both chapter 2 and chapter 3. The definitions of time (both on a philosophical view of ontology and epistemology and on the field of looking at time as a variable) are not concrete. These solutions often stem from theories of everything and the main proponents are from physicists looking at quantum gravity- but less in other fields. The theoretical cosmologist looks into these fields, but there are less examples of theories, and as seen via Chapter 3, it appears as though depending on the selection of study, the approximations are good to not have to look further.

Further, I believe the discussions of that time and space are on a conceptual level need to been looked at more in a cross academic way. There were few papers which dealt with different ideas in physics, and there was a call for not just looking at these questions from physics, but also from neurology, chemistry, biology, and even philosophy and the ideas surrounding how we can ask questions that would lead scientists closer to an answer, which would hopefully have an affect on the micro and macro state of the universe.

4.3 Conclusion

This is overarching look at the concept of time within physics. The overall view of time is seen in many different ways. It appears that two of the biggest concerns of the concept of time in physics arises from the schism of classical physics to quantum and relativistic physics. These differences can be seen in the philosophical view and on the view in the different branches of physics. From findings, it appears as if the arrow of time and its break with the irreversibility of fundamental equations is the greatest cause of contemplation, and where questions are formed.

References

Anderson, E. (2012) The Problem of Time in Quantum Gravity. Cambridge, UK. https://arxiv.org/abs/1009.2157

Anderson, E. (2014) Relationalism. 'Conformal Nature of the Universe 2013' at Perimeter Institute, Waterloo. Version 3. arXiv:1205.1256

Annas, J. (1975). Aristotle, Number and Time. The Philosophical Quarterly. 25(99): 97-113. https://www.jstor.org/stable/2217626

Barad, K. (2010). *Quantum Entanglements and Hauntological Relations of Inheritance: Dis/continuities, SpaceTime Enfoldings, and Justice-To-Come*. Derrida Today 3.2: 240-268. DOI: 10.3366/E1754850010000813

Barbour, J. (1999) The End of Time: The Next Revolution in Phyiscs (Oxford: Oxford University Press).

Barbour, J. (2009*). The Nature of Time*. Foundational Questions Institute Essay Competition. arXiv:0903.3489

Barbour, J, Koslowski, T. & Mercati, F. (2016). *Janus Points and Arrows of Time*. arXiv:1604.03956

Barbour, J. (2021). *Entropy and Cosmological Arrows of Time*. Banbury, UK. https://arxiv.org/abs/2108.10074

Bell, J. with Waters, S. (2014). *Doing Your Research Project* (6th Edn). Berkshire: Open University Press

Bergson, H. (1910). *Time and Free Will: An Essay on the Immediate Data of Consciousness. (Library of Phil.).* (F.L. Pogson, Trans.). Sonnenschein: London.

Bauer, M. (2013). *A Dynamical Time Operator in Dirac's Relativistic Quantum Mechanics.* Mexico. (http://arxiv.org/abs/0908.2789v3)

Baumann, D. *TASI Lectures on Primordial Cosmology*. Institute of Theoretical Physics, University of Amsterdam (2018) (https://arxiv.org/pdf/1807.03098.pdf)

Bunge, M. (1968). Physical Time: The Objective and Relational Theory. *Philosophy of Science*, 35(4), 355-388. https://www.jstor.org/stable/186253

Canales, J. (2015). *The Physicist and the Philosopher: Einstein, Bergson, and the Debate That Changed Our Understanding of Time*. Princeton University Press. https://doi.org/10.2307/j.ctvc7763q

Carroll, S. *Spacetime and Geometry: An Introduction to General Relativity*. Pearson New International Edition (2014)

Cohen, L., Manion L., and Morrison, K. (2018). *Research Methods in Education* (8th Edn). Abingdon, Routledge

Cortes, M & Smolin, L. (2017). *Reversing the Irreversible: From Limit Cycles to Emergent Time Symmetry.* Phys. Rev. D 97, 026004 (2018) *https://arxiv.org/abs/1703.09696*

Cortes, M. & Smolin, L. (2015). *The Universe as a Process of Unique Events*. Intstitute for Astronomy, University of Edinburgh. https://arxiv.org/abs/1307.6167v3

Denscombe, M. (2007) *The Good Research Guide: for small scale social research projects* (3rd Edn), Buckingham: Open University Press

Denscombe, M. (2008) Communities of practice: a research paradigm for the mixed methods approach. *Journal of Mixed Methods Research*, 2 (3)

Elitzur, AC & Dolev, S. (2002). Is There More to T? Why's Time's Description in Modern Physics is Still Imcomplete. *The Program for History and Philosophy of Science. https://arxiv.org/pdf/quant-ph/0207029*

Ellis, G. (2006). Physics in the Real Universe: Time and Spacetime. Mathematics Department, University of Cape Town. arXiv:gr-qc/0605049

Ellis, G. (2008). On the Flow of Time. Essay for the Fqxi essay contest on THE NATURE OF TIME arXiv:0812.0240

Ellis, G. (2013) The Arrow of Time and the Nature of Spacetime. Mathematics Department, University of Cape Town. https://arxiv.org/abs/1302.7291

Ellis, G & Rothman, T. (2009) Time and Spacetime: The Crystallizing Block Universe. Cape, South Africa: University of Cape Town. https://arxiv.org/abs/0912.0808v1

Gisin, N. (2020) Classical and Intuitionistic Mathematical Languages Shape Our Understanding of Time in Physics. Geneva: Switzerland https://arxiv.org/pdf/2002.01653.pdf

Giulini, D. (1994) Ashketar Variables in Classical General Relativity. http://arxiv.org/abs/gr-qc/9312032v2

Gorham, G. (2007). *Descartes on Time and Duration*. Early Science and Medicine: 12(1): 28-54. https://www.jstor.org/stable/4130293

Griffiths, DJ. (2005). *Introductions to Quantum Mechanics (2nd Ed).* Upper Saddle River, NJ: Pearson Education, Inc.

Jaeger, H & Liu, A (2010). Far-From-Equilibrum Physics: An Overview. Condensed-Matter and Materials Physics: the science of the world around us (National Academies Press, Washington, DC arXiv:1009.4874

Landau, LD & LIfshitz, EM. (Ed.) (1970). *Course of Theoretical Physics, Vol 5. Statistical Physics*. (2nd Rev and Enlarged Ed). Reading, CA: Addison-Wesley Publishing

Langlois, David. (2008) *Inflation, Quantum Fluctuations and Cosmological Perturbations*. GRECO, Institut d'Astrophysique de Paris (CNRS) (https://arxiv.org/pdf/hep-th/0405053.pdf)

Lloyd, S, Maccone, L, et al (2010) *The Quantum Mechanics of Time Travel Through Post-Selected Teleportation*. Phys. Rev. D 84, 025007 (https://arxiv.org/abs/1007.2615)

Lobo, F & Crawford, P. (2003). *Time, Closed Timelike Curves and Causality.* NATO Sci.Ser.II 95: 289-296 (arXiv:gr-qc/0206078)

Mach E (1960). *The Science of Mechanics*, Open Court (translated from the German)

Mavromatos, N. (2008). *CPT Violation: Theory and Phenomenology.* London: UK (http://arxiv.org/abs/hep-ph/0504143v1)

Mishler, E. G. 1990. Validation in inquiry-guided research: the role of exemplars in narrative studies. Harvard Educational Review, 60(4), pp.415-442

Muller, R. (2016). *Now: The Physics of Time*. New York, NY: WW Norton &. Company, Inc.

Morin, D (2008). Introduction to Classical Mechanics. Cambridge, UK: Cambridge University Press.

Newton, I. (1689). *Scholium to the Definitions in Philosophiae Naturalis Principia Mathematica*, Bk. 1; trans. Andrew Motte (1729), rev. Florian Cajori. University of California Press, Berkeley, 1934

Peskin, M. and Schroeder, D. (1995) An Introduction to Quantum Field Theory. Florida: Taylor & Francis Group LLC

Price, H. (1996) Time's Arrow and Archimedes' Point (New York: Oxford University Press).

Prigogine, I. (1984). The Rediscovery of Time. Zygon 19(4): 443-447

Reichenbach, H. (1958). The Philosophy of Space and Time. Dover: New York

Reif F. (1965). Fundamentals of Statistical and Thermal Physics. New York: McGraw-Hill.

Rovelli, C. (2008). *Forget Time*. FQXi Contest on the Nature of Time. arXiv:0903.3832

Rovelli, C. (2018). *Physics Needs Philosophy. Philosophy Needs Physics*. Foundations of Physics 48: 481-491. https://doi.org/10.1007/s10701-018-0167-y

Rovelli, C. (2018). *Space and Time in Loop Quantum Gravity*. Beyong Spacetime: The Philosophical Foundations of Quantum Gravity. https://arxiv.org/abs/1802.02382

Rovelli, C. (2018). *The Order of Time*. New York, NY: Riverhead Books

Ryden, B.(Ed.). (2017). *Introduction to Cosmology* (2nd ed.). Cambridge, UK: Pearson Education, Inc.

Sakurai, JJ & Napolitano, JJ. (2014). *Modern Quantum Mechanics (2nd Ed)*. Pearson Education, Inc

Savitt, S. (2002). "Being and Becoming in Modern Physics", in The Stanford Encyclopedia of Philosophy. Edward N. Zalta

Schreiber, A and Gimbel, S. (2010) *Evolution and the Second Law of Thermodynamics: Effectively Communicating to Non-techicians*. Springer Science+Business Media

Selltiz, D., Jahoda, M., Deutsch, M. and Cook, S.W. (1962) Research Methods in Social Relations, 2nd edn. New York: Holt, Rinehart and Winston.

Spradley, J. (1979) The Ethnographic Interview. Holt Rinehart & Winson, New York.
Srednicki, M (2007). Quantum Field Theory. Cambridge: Cambridge University Press

Stoica, OC. (2013) *On the Weyl Curvature Hypothesis*. Annals of Physics Vol 338. https://arxiv.org/abs/1203.3382v4

Turner, D. (2010) *Qualitative Interview Design: A Practical Guide for Novice Investigators*. The Qualitative Report Vol 15. No3: 754-760 http://www.nova.edu/ssss/QR/QR15-3/qid.pdf

Unger, R M. & Smolin, L. (2015). *The Singular Universe and the Reality of Time; A Proposal in Natural Philosophy* .Cambridge, UK: Cambridge University Press.

Von Franz, M. (1988). *Psyche & Matter*. Boston, MA: Shambhala Publications, Inc.

White, Michael J. (1989). *Aristotle on 'Time' and 'A Time'*. Apeiron: A Journal for Ancient Philosophy and Science. 22 (3): 207-224. https://www.jstor.org/stable/40913609

Zee, A. (2010) Quantum Field Theory in a Nutshell. New Jersey: Princeton University Press

Appendix A -Interviews
Interviews

1. Dr. Subodh Patil (recorded- transcription) - Universiteit Leiden (Netherlands)

1. Please explain your field of study/ your job?

My field of study has been physics, theoretical physics and I'm currently an assistant professor at Leiden University.

2. What is your background? (eg Where did you study? What country did you grow up?)

Well, my background is well, I'm. I'm Indian. I grew up in Hong Kong. Where did I study? I studied in the US, finished my PhD in Canada. Yeah. And I guess I mentioned I go up in Hong Kong.

3. How has your idea of time changed since studying physics?

How's my idea of time changed since studying physics? I think everybody's notion well, I mean I guess you have to ask since when right since childhood obviously like you know? What time is as a physical construct versus your intuitive notion of it has of course, been changed drastically first. When you encounter it in classical physics, it corresponds more or less to what you intuitively understand it as is this thing that just keeps. Sort of happening. When you first come across special relativity and you understand that in fact it is not a separate entity, but it somehow mixes with this thing that we identify as space and so therefore the underlying reality of it is space-time. And then when you get to general relativity and you understand that, you know all of this sort of responds to. The you know the material properties of the universe, of the you know, like, you know, putting matter in into a universe makes geometry in space-time different. And that's, you know, quite a radical radical shift. And that's sort of a a notion of time. As is understood at the level of relativity theory, now what it actually is, it's still a mystery. We don't actually know why there's this direction that we always seem to only want to go in One Direction. It would be as if you could only move left in One Direction. That's a bit strange. So the question of the arrow of time is something that occupies people who think about this kind of thing in cosmology. And we don't have any good answers yet, but I think it's fairly clear that operationally in terms of the fact that we're made-up of things that are metabolism depends on our or in our perception of time as as as biological entities depends on metabolising things. And that seems very intimately tied up with entropy. And so therefore, if you were to tell me that the hour of time corresponds to the direction in which entropy always increases, you know I I would find that very plausible. Of course, it's not a hard statement at this point.

4. How would you describe time?

a. To a layperson

b. To someone in your field?

Your 4th question is how would you describe time? A, to a layperson, B to someone in my field where, well to a layperson, maybe in the zone in my field I would describe time as an emergent construct that at the level of our perception seems to be something that, you know, orders events one before the other. What it exactly it is, we're still trying to understand, but that's how I describe it to a layperson. It's just an emergent concept of physics, of physical reality at the very, very fundamental level, all of our equations. At the fundamental level seem to be time reversible. But what happens is when you look at processes, there really does seem to be this quantity that seems to always increase, and we call that entropy, and so maybe that's kind of how I would also describe it to someone in my field. I guess my my answers aren't aren't going to be too far off. If you really wanted me to get technical about what I believe is time. What I believe time is to someone in my

field. I would say that we don't actually really fully know yet. We know that space-time that it's very, very ultimate ultimate level at the best that we can sort of resolve it at the small small scales is probably something very non geometric space itself. space-time itself is an emergent. Saying what it is, we don't know.
What would time be?
How would I describe time to some in my field? I would say we have bootstrapped our way into understanding the universe by assuming it's just this parameter that just keeps going. What it is really. We're still finding out.

5. How does your idea of time vary amongst your peers?
a. Amongst physicists
b. Amongst non-physicists
c. Does it differ amongst different peers in STEM?

So fifth question is, how does your idea of time vary among my peers among physicists? It really depends on what kind of physicist you are. So to a condensed matter physicist, it might correspond to the direction in which entropy always increases to someone with a string theory or tries to worry about, you know, the actual origins of what space-time is the answer would be we're still finding out we really we really have no idea. We know that it's possible to describe non G. Trick versions of space, but we've yet to be able to do that to time. Every time we try to mess with time as anything other than a continuous variable, it kind of messes up everything, so we don't know. Among non physicists I would, I would say my answer would be. Well, how the idea of time vary among them. I mean, I think it would just, most people wouldn't even think about it really. But if they were to, I think most non physicist understanding of time would not be too far off. What? We what we intuitively think of as just the direction that this keeps sort of going and it allows us to order events in a temporal. UM. Does it differ among peers and STEM? I would say that basically only physicists really get to ask the question fundamentally, what time really is so I don't really know how other people might conceive of it in other scientific fields, aside from that, which would be similar to what a layperson. Would think of it as.

6. How do you contemplate or work with time in your profession?

So how do I contemplate the six question? How do you contemplate or work with time in my profession? Well, I my one of the things I do is theoretical cosmology and time is, you know, definitely something that I deal with. But I again, I treat it at the level at which we can handle our equations. To handle it, which is that it is just more or less like this classical relativistic construction that just. You know it's a coordinate in a coordinate system and it mixes up with space depending on the coordinate system I put in, which depends on the amount of material stuff in the universe. Some of the more speculative things I've worked on in the past, the sort of stringy geometries, how time, how space-time might sort of. Emerge out of these things called matrix models, that sort of, you know, geometry isn't predefined. It sort of emerges out of something. How do I contemplate time in that is that I still have to treat it like a parameter in my theory, so it's still something we're struggling and myself I'm struggling to understand.

7. Have you ever studied or worked with the effects of entropy or the arrow of time? Have you thought it might not be an arrow?

Your seven questions. Have you ever studied or worked with the effects of entropy or the arrow of time? Yeah, I think I've already addressed that before. It's a working definition of what the direction of time is. I can't think of anything better you asking, have you thought it might not be an arrow? I guess anything in one dimension has a direction that's just a mathematical fact. So by. Is in like you know one dimension. You can order something left or right. It's unambiguous, so there's always going to be an arrow associated with time if it's A1 dimension. One thing how it might not be an arrow is if it was more than one dimension. Now the problem with that is you cannot make time more than one-dimensional because it actually makes all of our solutions to partial differential equations, which is the way we write down the laws of physics, is completely unstable, so we wouldn't even have a law physical laws if time were anything other than an arrow.

8. Is time reversible in principle (not practice) in your work and/ or does it fluctuated/ dilate?

Your 8th question is time reversible. In principle. I mean in, in in quantum field theory it you know well you know all of our equations are invariant under time. There's a symmetry called CPT invariance, which means if you simultaneously switch the charges of every particle in the universe, reverse the arrow of time. And P stands for parity. If you just flipped. If you, if you. If you flipped, you know, made the the the mirror, the universe, the mirror image of itself, everything would look the same. So time is indeed in principle reversible. In fact, our equations are completely time reversal invariant. Right.

Does it fluctuate or dilate? That's when you get into general relativity and yes, indeed it fluctuates, it dilates it's there's, you know, time dilation is a very well studied and intrinsic property of of space-time clocks move slower when they move faster that that we know. Cosmic slower the further down the gravitational field. So yeah, so so this is just at the level of what we know in physics.

9. Do you differentiate your thoughts on time in practice and in your life or do they adhere to a similar personal philosophy?

Your 9th question is do you differential thoughts on time and practise and in your life or the adhere to a similar personal philosophy? I mean, if you're asking by this like, you know, like how much do I think of how my daily life aside from mortality and, you know, the fact that, you know, the weeks just sort of go by and the days go by and have. To do things I don't really think about it that much. At least not in any deep sense. You know if, if if you know you're asking what is. A more sort of philosophical notion of time, that sort of informs my life well. I mean, I suppose the older I get, the more and more I kind of. You know, maybe the sense in which you know Buddhist, Hindu notions of cyclicity, kind of just sort of make sense. I can't justify that anything other than just sort of a dawning personal realisation about the nature of things, whether my physics informs that or not. I would say only partly. But yeah, I mean I think I I think in terms of you know how we view time and how I how I view you know time is a physical thing. I mean, the way I really view, if you like, you know my epistemology is I'm just something universe is doing and so and so are we all and so. The illusion that we have inside our minds of what time is, is is a very useful one because it helps us to navigate the world we in as biological entities. That is, have been evolved over over, you know, millions of years to to be to practically fit into the universe at the scale at which we have to operate in in order to hunt and and and reproduce. And so, you know, that's that's, you know, I try to be as consistent with. With reality and how I how I view the world. But that's how I view it, is that it's it's just a useful illusion that I'm feeling as a physical agent at a particular scale is that fundamental? Most definitely not. And So what is time at the fundamental level? I think I've addressed that before. We don't know.

10. How has your perception of time changed throughout your life?

o #10, how is my perception of time changed about my life? I think I kind of traced through that in answering my one of the previous questions, the previous questions about how my understanding of physics has informed my understanding of life. So in fact it has changed indeed a lot.

11. Does your study/ work with time conceptually marry with your perception of time?

The 11th question is how does your study work? Work with time? Conceptually married, my perception of time. I mean, you know, I mean, that's like asking, you know, how does? My understanding of physics. Affect my, you know, perception of the world. I don't walk around with a coordinate system, you know, putting on everything whenever I play a game of pool, I don't, you know, do equations in my head. I just sort of inhabit the universe. As an animal, intuitively. So I would say, you know, unless if you forced me to think about it, it doesn't. You know, I am just something universe is doing and I'm happy to go along.

12. Do you consider the effects of GR in your field of physics or quantum, and does it adhere to a Newtonian simplification of time?

#12 do you consider effective GRR in your field of physics? What does it? Does it adhere to intensification time? And the answer is yes. You know, as a cosmologist, of course. I I deal with, you know, time and time in cosmology, does it adhere to? Tony intensification, I mean Newtonian in the sense that you know, so most of it does not correspond to a Newtonian version of it because time is a flexible elastic thing that responds to the, you know, the material stuff in the universe. If you meant by does it? You know, I think by that if you meant, you know, some sort of an absolute thing that just takes, I would say it does not. Of course, you know my notion of my working definition time is that which general relativity has provided me up to scales at which you know, once you get to a sort of microscopic, you know, scale then it doesn't. And so at that scale, we don't know. So you know I think you know, physics is all about a nested series of understanding of the universe within certain approximations. And those approximations only need to be as good as you. Your resolution, your your ability to ask questions, the universe, and so far we have a pretty solid working model of it. And and that's fine by me.

13. Do you use the idea of the flow of time in your work?

So your 13th question is do you use the idea of the flow of time in your work 100%? That is what cosmology is. In fact, there's a way of actually classifying all of observational structures that we see in the early universe as simply the consequence of breaking time translation invariance. OK, so it's a very strict mathematical statement. Whatever you try to write down at the level of an effective field theory is some sort of theory where the universe has realised as having spontaneously broken time transition that actually determines the structures of how different observables in the universe actually hang together, and it's actually a very consistent and beautiful set of ideas. So need the flow of time, or rather the breaking of time transition variances means the universe is the same all the time, which clearly it isn't. If that was true, nothing would ever happen. And you know, I wouldn't even be recording this. So yes, the total time is very, very intrinsically tied up to the fact that anything ever happened in this universe. And that is why we do.

14. Do you consider time to be fundamental or emergent? Does it make a difference in your use of time in your work?

Your 14th question is something that I've I've alluded to quite a few times. I didn't realise this would be a 14 question. Do I consider time to be fundamental or emergent? It is. I do indeed believe. It is an emergent construction, but emergent means you know we are made-up of certain degrees of freedom. Those certain degrees of freedom will have an answer for what time is. If we were made-up of other degrees of freedom, would you have a different notion of time? And the answer is almost certainly yes. So does it differ my use of time in your… in my work, yes it does, because you know I am a theoretical cosmologist, but we are made-up of material particles for which time has a fairly well definable notion and arrow, and a way to study it. And it's. If, on the other hand, we were made-up of massless particles and all the universe was just made-up of massive things, time simply doesn't exist, right? It's time transition and variance. There is something else. Well, no, it just it just really is a very, very different universe. And this is stuff that we all kind of understand at the theoretical level. And you know, there are theories that are called conformal field theories where time absolutely doesn't have an operationally existing definition. The you know that that you know that that theory is completely time transition invariant. So nothing. And so yeah, I think that's that's that's the best answer I could give in a in a in, in this compact form that I can I I hope this is useful to you.

2. Dr. Tim Halpen-Healy – Barnard College, Columbia University (United States)

1. Please explain your field of study/ your job?

Physics professor, Barnard/Columbia, since Sept 1989.

2. What is your background? (eg Where did you study? What country did you grow up?)

Princeton BA, Harvard PhD, USA.

3. How has your idea of time changed since studying physics?

Yes, for sure....

4. How would you describe time?

   a. To a layperson

   As a consequence of the 2nd Law Thermodynamics [this would be a bit of work, but I'd remind them of some chemistry course they had in HS, where they, perhaps, were introduced to the concept of entropy....
   ;->

   b. To someone in your field?

   Again, 2nd Law; but much more focus on statistical mechanics and the important role of probability...

5. How does your idea of time vary amongst your peers?

   a. Amongst physicists

   Not much variation I'd imagine, but it's been a while since I've had occasion to shoot the breeze w/ colleagues, informally, regarding our slightly different(?) interpretations...

   b. Amongst non-physicists

   Hard to say...

   c. Does it differ amongst different peers in STEM?

   I'd guess that biologists & chemists are on the same page as physicists, although the last group, I suspect have a more mathematical attitude regarding the business...

6. How do you contemplate or work with time in your profession?

I'm concerned, research-wise, w/ the "emergence" of order in systems w/ many degrees of freedom; e.g., phase transitions, cooperative phenomena, etc. exhibited by superfluids, critical points, etc., as some external parameter
like the temperature is varied. The ordering process usually occurs at some magic temperature, but for that critical temp, is also a function of time & depends on the dynamics...

7. Have you ever studied or worked with the effects of entropy or the arrow of time?

Yes, I've studied it as a grad student, and also taught entropy in PHYS G4023-Statistical & Thermal Physics at Columbia, and more advanced graduate courses..

Have you thought it might not be an arrow?
In my book, it's just a figure of speech suggesting monotonic behavior....

8. Is time reversible in principle (not practice) in your work and/ or does it fluctuate/dilate?
For particle physicists, time is reversible, for condensed matter physicists, I think no, since they typically consider systems w/ Avogadro's number of particles, rather than an isolated system of 2 protons, let's say, colliding.
The Law of Large Numbers which underlies much of statistical physics dovetails w/ the notion of the thermodynamic limit; i.e. letting the number of particles go to infinity.

9. Do you differentiate your thoughts on time in practice and in your life or do they adhere to a similar personal philosophy?
Again, as a condensed matter theorist, I'd say no. The probability that all the molecules that have escaped from an open bottle of perfume will suddenly all reverse their individual trajectories and instantaneously flow back into the bottle is vanishingly small; not zero, but so small that it is negligible in my book...

10. How has your perception of time changed throughout your life?
I didn't learn about entropy till I was 18, but it wasn't until 3-4 yrs later that I actually calculated that vanishing small probability mentioned above.

11. Does your study/ work with time conceptually marry with your perception of time?

To the degree that I might "worry" about such things, I'd say yes....

12. Do you consider the effects of GR in your field of physics or quantum, and does it adhere to a Newtonian simplification of time?

Newton's absolute time got toasted by Einstein [SR], destroyed the notion of simultaneity; the latter is entirely relative.

13. Do you use the idea of the flow of time in your work?

Not explicitly, but again, the emergence of order typically occurs temporally and in some specified reference frame. Condensed matter physicists don't usually worry about how such things, e.g., how the Curie Point of a ferromagnet on my lab table might look to a spaceship that happens to be zipping by at 3/5 speed of light...
;->

14. Do you consider time to be fundamental or emergent?

I'd put my chips on "emergent", though Einstein (not a condensed matter theorist) might disagree.

Does it make a difference in your use of time in your work?
No....

3. Professor Liliya Williams – University of Minnesota (United States)

1. Please explain your field of study/ your job?

I am professor at the Minnesota Institute for Astrophysics at the Univ. of Minnesota, Twin Cities. I study cosmology, and more specifically propagation of light through the Universe, aka gravitational lensing. I am also interested in the nature of dark matter and how it interacts gravitationally with itself.

2. What is your background? (eg Where did you study? What country did you grow up?)

I was always interested in physical sciences, from the time I was in my early teens. I grew up in Moscow, and Bangalore. I was an undergraduate at Princeton, grad student at UW-Seattle. My two postdocs were at Cambridge, UK, and U Victoria, BC, Canada.

3. How has your idea of time changed since studying physics?

Most non-physicists do not realize that the fundamental physical forces do not indicate the direction of time flow. It was a big revelation to me to learn that, when I was a graduate student.

4. How would you describe time?

a. To a layperson

I would avoid that conversation with a layperson!

b. To someone in your field?

I would say that that's one of the more interesting unsolved questions in physics.

5. How does your idea of time vary amongst your peers?

a. Amongst physicists

b. Amongst non-physicists

c. Does it differ amongst different peers in STEM?

I am not sure; the subject usually does not come up because it borders on philosophical. I think at this time physics does not have all the tools necessary to fully answer that question.

6. How do you contemplate or work with time in your profession?

Most of what I do does not involve thinking deeply about time. In cosmology, cosmic time is a straightforward and easily calculable variable. Given a cosmological model it can be calculated based on the observed redshift of an object being studied. Cosmic structures evolve with time, and ages of galaxies and stars can usually be measured.

7. Have you ever studied or worked with the effects of entropy or the arrow of time? Have you thought it might not be an arrow?

My work on dark matter halos and their evolution does touch upon that subject, but only slightly. I do think about the question now and then. The standard answer is that, even though basic physical laws do not specify the direction of time flow, one large scales, where statistics and probabilities take over, the arrow of time is well defined. That explanation is probably partially true, but maybe not in detail.

Here's an anthropic answer (which I don't really subscribe to, but who knows..?)
It's interesting to consider what the Universe would have looked like without a well defined direction of time on macroscopic scales. Maybe a Universe could not have existed without it. Unpredictable direction of time's arrow that changes randomly would not be conducive to the evolution of intelligent life, and us asking about the arrow of time!

8. Is time reversible in principle (not practice) in your work and/ or does it fluctuated/ dilate?
YesI On microscopic scales, or even on larger scales in idealized situations: for example the motion of a planet around its star can be reversed. In practice because of friction and dissipation, motions of planets would not look the same going forward vs. backward in time.

9. Do you differentiate your thoughts on time in practice and in your life or do they adhere to a similar personal philosophy?

10. How has your perception of time changed throughout your life?

11. Does your study/ work with time conceptually marry with your perception of time?

12. Do you consider the effects of GR in your field of physics or quantum, and does it adhere to a Newtonian simplification of time?
I don't need to do that in my work, but when I do use time, it is perfectly well described by a simple monotonic function. I should add that even though time in GR is a more complex concept than in the Newtonian world, it is very different from the concept of time in the quantum context. I think the latter is less clear.

13. Do you use the idea of the flow of time in your work?
No, there is no need for that in my day-to-day work.

14. Do you consider time to be fundamental or emergent? Does it make a difference in your use of time in your work?
That's a tough question, but it does not affect my work in any way. I really do not know if time is an emergent property.

4. Dr. Tamara Davis (Australia)

1. Please explain your field of study/ your job?
I am an astrophysicist and cosmologist studying the expansion of the universe using supernovae and the distribution of galaxies.

2. What is your background? (eg Where did you study? What country did you grow up?)
I did an undergraduate double-degree in Arts/Science, majoring in philosophy and physics. I then did a PhD in astrophysics. All were in Australia.

3. How has your idea of time changed since studying physics?

I used to think time flowed evenly for everyone. Now I know its rate of flow changes depending on your motion relative to others.

4. How would you describe time?
a. To a layperson

a. Time is something we use to measure change.

b. To someone in your field?

b. I would use equations to demonstrate the specific definition of time I am referring to.

5. How does your idea of time vary amongst your peers?
a. Amongst physicists

I think we mostly agree, however there will be debates about whether block time means that there is no free will. There are also plenty of physicists who don't contemplate any deeper meaning of time than how it affects their experiments.

b. Amongst non-physicists

Many people don't appreciate that time is more than what their watches show.

c. Does it differ amongst different peers in STEM?

c. Not that I've noticed.

6. How do you contemplate or work with time in your profession?

We calculate using different times for different people based on their reference frame, and this can be important for our cosmological calculations. One example is when measuring the duration of an astrophysical event, if the source (e.g. a supernova) is moving away from us then it's duration will be longer due to time dilation. For example a supernova at redshift 1 (it emitted the light when the universe was half of its present size) that is moving rapidly away from us, the time we observe for the explosion is twice the time it took to explode.

7. Have you ever studied or worked with the effects of entropy or the arrow of time? Have you thought it might not be an arrow?

Yes I have worked with entropy. Yes I have considered entropy an arrow of time. I'm aware of the possibility that entropy will fluctuate and decrease occasionally but overall its use as an arrow of time is extremely practical.

8. Is time reversible in principle (not practice) in your work and/ or does it fluctuated/ dilate?

Yes, fundamental physical processes are time reversible. And time dilation is a constant aspect of our calculations in astronomy.

9. Do you differentiate your thoughts on time in practice and in your life or do they adhere to a similar personal philosophy?

Personally and professionally I have the same view of time.

10. How has your perception of time changed throughout your life?
Just my learning in physics has enhanced my understanding of the deeper nature of time.

11. Does your study/ work with time conceptually marry with your perception of time?
Yep.

12. Do you consider the effects of GR in your field of physics or quantum, and does it adhere to a Newtonian simplification of time?
Yes, we consider GR. It does not adhere to a Newtonian simplification.

13. Do you use the idea of the flow of time in your work?
We often treat time as a continuous variable (i.e. it flows). We also consider the possibility that time is discrete (quantised). Much like a table appears smooth but we know it is made up of atoms, similarly time appears to pass smoothly, but it is possible it also is made up of "atoms" of time (there are discrete times with nothing between them).

14. Do you consider time to be fundamental or emergent? Does it make a difference in your use of time in your work?
Usually we treat it as fundamental but the concept of space-time atoms I mentioned above could be considered as treating time as emergent. I usually think of the potential of gravity as being emergent from the collective behaviour of quantised space-time rather than time itself being emergent. But they could be two sides of the same coin.