The Indivisible Now: why time must be discrete.

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Discrete time has, rightly, not generally been taken very seriously with the standard conceptual framework for understanding reality. I say 'rightly' only because when fully understood, discrete time seems like nonsense or an impossibility from the perspective of our common sense experience of time. Yet perhaps the standard conceptual framework which is assumed is incorrect. In this paper I will outline an understanding of the nature of time which demands a questioning of reductionism and therefore challenges this framework, and claim it is an inadequate conceptual framework for describing and understanding reality. In particular, I outline here from empirical observation how the phenomena of Quantum Entanglement can support a conceptually irreducible reality.[1]

Empirical and philosophical arguments for a non-reductionist reality would mean that a continuously divisible time cannot be real, as such a model of time requires reductionism. In this paper I am claiming that for a reality which is composed of irreducible processes, which consequently define the properties of time, that all the information required in the "now" is not existent from taking a "sum" over all of the present moments ("parts") comprising this now. This new now analogously likened to the whole which is "greater than" the sum of its constituent parts. This implies that the now must be considered as an indivisible whole, and time must therefore be indivisible. The concept of random, potential change has first to be postulated as a fundamental principle of reality and is central to the arguments I make.

The necessity of questioning reductionism is that its philosophy is guiding the notion that time can be divided into an infinity of zero-duration time intervals, where each division gives a meaningful causal account of the higher or earlier interval. Yet any moment of time can be composed of processes whereby the information that is required for the next moment of time is real, and other processes where this information is *not yet real*[2]. Using this simple idea, I will argue that time must be *non-divisible*. This will be a conceptual foundational principle

[1] I have also used decoherence, strong emergence, and renormalisation to support my claims in my thesis on this very subject.

[2] This may be reflected in the statistical nature of reality, as formulated by Quantum Mechanics.

of my model of time, and such a model of reality necessitates a non-reductionist framework of reality. Here the divisibility is dictating the framework required, not vice-versa as seems to be the case for the conventional model of continuously divisible time.

This has the consequence that reality is made up of disjoint parts which are, on the whole, meaningful. This is not a crazy idea. For example, the phenomena of entanglement, or observing the creation of an interference pattern from a double slit one particle at a time, seems to display such behaviour. Strong proof of this is shown in the GHZ experiment[3] whereby a multi-particle entanglement gives experimental results which are the exact opposite to what you'd predict if the individual "parts" are considered to be real independent of the whole.

Therefore the question that must be asked is, "can the probabilistic behaviour of reality be explained by reductionism?" because if it can't be then continuously divisible time cannot be defended. An entangled pair has indeterminate individual properties, but as a whole has a defined relationship. This illustrates the concept I have in mind – where there is randomness on the "part" level, but order at the level of the whole. A crucial part of realizing this order is an irreducible, irreversible moment in time. The probabilistic nature of reality also illustrates to a degree this concept, whereby the probability of an outcome for a large system seems to be a property of a system only apparent "on the whole". This statistical nature of reality poses some tricky questions. If these reversible processes are statistical in nature then they are still determinate while being probabilistic. I question too whether the need to use a Lebesgue measure for probability distributions is a reflection of the whole dictating to the parts in a non-reductionist way. I claim this is quite an important question (or perhaps observation) which requires much deeper investigation and where the development of my ideas will lead.

In the next section, a conceptual consideration of the probabilistic nature of reality, which is formulated in the theory of Quantum Mechanics, can give some idea as to the importance of time's nature as reversible or irreversible, and furthermore a feel for why it must be non-divisible. Before starting that discussion, I acknowledge upfront that a firm conclusion is

[3] Matthew Daniell, PhD Thesis : Multi-Particle Entanglement. 2001.; Experimental test of quantum nonlocality in three-photon Greenberger-Horne-Zeilinger entanglement. Jian-Wei Pan, Dik Bouwmeester, Matthew Daniell, Harald Weinfurter and Anton Zeilinger. *Nature*. **403**, 515-518, 3 Feb 2000.

difficult to make regarding the questions which will arise due to the mysterious nature of the mechanism of the probabilistic nature of reality.

1.1 Probabilistic Nature And Reversibility.

For this discussion I will start with a simple system, a polarizer and horizontally polarized light. After being passed through a polarizer at 45^o, this horizontally polarised light is now polarized at either 45^o, or at -45^o, the probability of each possible outcome being equal.

Now consider if time is reversed. The time reversal I have in mind is the seemingly common notion of a reversal of the sequence of events, like a movie run in reverse. True reversal of time would require a total change of the laws of physics obviously. Yet here we are considering whether a reversal of the sequence of events is symmetric. Our output, light polarized at 45^o, would have to be in-sequence "traced" or reflected back through the polarizer (which is still oriented at an angle of 45^o). Doing this sequence of events would then give a new output whereby the light is purely transmitted through the polarizer with no reduction in intensity, because the light still has a polarization of 45^o, and not horizontal polarization like the initial sequence. Hence this example consequently has a macroscopic time[4] which is asymmetric.

Yet if we want the same conceptual process occurring in both the forward-in-time and backwards-in-time sequence, meaning that in the reverse sequence we now want a 50:50 projection of the light being passed through the polarizer, we would have to adjust the orientation of the polarizer in the reverse time sequence to be horizontal or vertical, and not at 45^o. Then stepping through a reversal of the initial sequence, the "outputted"[5] 45^o polarized light will be incident now on a polarizer horizontally oriented, which would give as output light either horizontally or vertically polarized with a 50:50 probability. Therefore for half of the "time" our system will recapture the initial sequence which would imply that time is symmetric, but for the other half we will get a different sequence to the initial one [6] and

[4] Meaning the ordering of events in time.

[5] That is the output from the forward-in-time example.

[6] When the light in the reverse sequence has a final polarization of vertical.

therefore conclude again, that time is asymmetric and non-reversible. This implies again that the individual events of statistical processes may not be 100% reversible[7].

Despite this reasoning, if we chose to insist that time is reversible, then a consequence of this would be that we insist that the only outcome of the second example[8] is that the 45^o polarized light will always give horizontally polarized light yet that is a deterministic view of reality and not probabilistic, contrary to how reality is viewed in the forward time direction[9]. If we suggest as a mechanism that all the surrounding conditions in the second reversed sequence have to be the same as in the forward-in-time sequence to ensure 45^o gives horizontally polarized light as an output to give a symmetric time, then that would imply that in the forward time direction, ie., the initial sequence, this actual event would therefore also have to be deterministic and not be probabilistic which is in contradiction to empirical observations and Quantum Theory.

Therefore the probabilistic nature of reality has consequences for the direction of time: a probabilistic process can't be divided, meaning time can't be continuously divisible. The second point of deterministic-v-probabilistic can be generalized beyond this polarization example.

If it is to be expected that there is no time dependence for the probability amplitude, ie. that there is a linear substance called time which is analogous to space which is isotropic[10], then the laws of physics are independent of when they act in time. This means that if reality is probabilistic now, it has to be probabilistic in the past and in the future. I claim that such a requirement will mean that time is **not** symmetric under a reversal of direction, and that there is consequently no such thing as a real, in existence, past.

These consequences of the non-symmetrical nature of time can be seen in two ways. Firstly, that to maintain the requirement that processes are probabilistic, then events would be, when reversed, also probabilistic, meaning that an event A which can have outcomes B and C with certain probabilities, may give result B in one direction of time, but result C in the reversed direction. This is not a reversal of the process of A going to B or C, but a repetition of the

[7] It is important to explicitly state that the probability itself, the statistics, can be reversible in time.

[8] The reverse sequence.

[9] Which was our initial example.

[10] Which is not my model but the currently accepted model by physics, as per the manifold.

event of A giving in the forward and reversed direction of time a result, a symmetric event as in the polarized light example. Therefore here there is not a reversal to the exact same past as would be expected if time was symmetric[11].

Secondly, a way that time can be considered to be non-symmetrical is that it is not accepted that reality is probabilistic in the reversed time direction. However isn't any deterministic process reversible?[12]

Any model of time must have functionality to allow probabilistic behaviour, yet the "mechanism" is not known as to how reality is probabilistic. Therefore a probability function can't be replicated in an algorithm and incorporated into modelling. There would also have to be a mechanism to allow discontinuous functions which would further facilitate probabilistic changes. I'd note too that probability is independent of "time", meaning that any change upon iteration won't influence the probability weightings resulting from the iteration mechanism.

In summary, I've argued that to conceptually allow the operation of empirically observed phenomena like randomness and probability, a non-reductionist understanding of reality is essential. This means that continuously divisible processes and therefore continuously divisible time cannot occur. This concept of reductionism is consequently inadequate as a framework for explaining reality. As a deeper, fundamental consequence of randomness or probabilistic behaviour, reality and time must therefore be indivisible, and as an outcome of such a conceptual framework be irreversible. This conclusion is examined and developed in more detailed in the next section.

1.2. Claim : Reductionism And Indivisible Time.

Having just shown that the nature of a quantum superposition, the probabilistic nature of reality which is at the heart of entanglement, is non-divisible, what does this mean for our notion of time? I claim that it means that time must be indivisible, which consequently requires a non-reductionist conceptual framework for reality.

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[11] Implying the past is not existent.

[12] I am arguing here from the would-be reversed time as having implications for the forward time direction.

To argue for this in a little more detail, firstly consider the essence of time as a sequence of information from the future into the past. The nature of time as a timing mechanism[13] is a more mechanical, arbitrary property, and not what I am considering here. Strictly speaking any entangled system must be considered as a whole, meaning its elements of reality can't be considered individually as being determinate. The entangled system for a pair of photons for example is a non-divisible system.

Secondly, as previously discussed, time being connected with physical properties implies various properties time itself must have, and in the case of non-reducible properties, I am generalizing one of these properties. Or rather, perhaps we should take it to be a meta-property[14], because many of the non-reductionist systems from which we gain understanding of their behaviour are valid at specific regimes. This may suggest they are an exception to the rule, not to be generalized. However I would instead say that if they display this behaviour, and the laws of physics are isotropic and unchanging in time, then any time region of the universe must have this functionality. Furthermore, if a system can exhibit non-reductionist behaviour, then it should also be able to display reductionist behaviour. The converse of this is not true.

The essence of non-reductionist behaviour is that the whole cannot be explained from a knowledge of the constituent parts. Information about the whole is not constituted from information about the parts. The whole must be considered as a single entity. The analogous properties these processes would confer on time would be such that the next (future) moment is not knowable or determined by knowledge of the constituent "nows" of the present. The present now must rather be considered as a whole, non-divisible into causative parts. Hence this would be contrary to the requirement of infinite divisibility of the continuous now. Therefore I claim that time must be indivisible.

I have provided more detail to these arguments elsewhere[15], and show empirical examples (quantum chaos, strong-emergence, renormalisation) of the non-reductionist nature of reality, which can't support a continuously divisible reality. The examples I have chosen are varied and allow a generalisation of the claims I have made here. Furthermore they aim to provide

[13] For example a frequency.

[14] A "higher" property which governs the behaviour of other collective properties of reality.

[15] In my PhD thesis on this paper's topic.

detail to the questionable regime regarding non-reductionist behaviour where it could be argued that there are still "parts" involved in the processes. This implies they are divisible and therefore time while not being continuously divisible is nevertheless not indivisible, pre-emptively addressing possible objections to my claims.

1.3 Justification From The Quantum Uncertainty Principle?

To continue developing the conceptual justification for my model of time as indivisible, I'd like to start with "the" basic foundational concept of quantum mechanics, the Uncertainty Relationship. The model of time I am developing is one where the behaviour of processes is primary, and it is from them that I claim our experience of time is obtained. Therefore it is essential that these processes be viewed and understood quantum mechanically, one of the best and most accurate descriptions of reality and therefore processes by physics to date. Furthermore, and analogously relevant to the topic of this paper, at its development quantum mechanics was able to explain experimental phenomena the existing continuous theories couldn't, by discretizing the energy spectrum of a system. Does this success simplistically suggest that processes themself should be considered as being discrete, and therefore likewise time? Or how are processes to be understood from a quantum mechanical point of view?

The Uncertainty Relationship was initially proposed by Heisenberg in the early days of the development of Quantum Mechanics. While its formalism was widely accepted as it allowed the new theory to explain the atomic structure of matter and give agreement with experimental observations, conceptually there was strong debate on how it should be understood. On the one hand, Heisenberg claimed that his Uncertainty Relationship $\delta x \delta p \approx \hbar$ implied that the simultaneous measurement of the atomic particle's position and momentum is not possible, and therefore the particle lacks simultaneously definite position and momentum, and that the processes being described involved *discontinuous change*.

Bohr, another of the founding "fathers" of the theory, claimed on the other hand that all processes were *continuous*, and starting with the energy $E = \hbar f$ and momentum $p = mv$ of a particle he argued that the highest possible accuracy in defining the energy and momentum of the "wavefield" is when $\Delta x \Delta \sigma \approx \Delta t \Delta v \approx 1$, [16] which involves Fourier analysis using an

[16] Here σ represents the wavenumber, the inverse of the wavelength.

infinite superposition of waves. This energy-time Uncertainty Principle cannot directly be used to support time quantisation. It has a different status to the position-momentum uncertainty relationship due to the fact that Quantum Mechanics doesn't have a time operator. Therefore a commutation relationship between operators can't be used to define an uncertainty relationship. Instead, it more accurate to consider the uncertainty relationship $\Delta E \Delta t \approx 1$ as an energy parameterization relationship, with the energy being bounded from below as stipulated by the quantisation of Quantum Mechanics.

With both of these Uncertainty Relationships, Bohr was concerned with the complimentarity of the observables being considered, meaning that their description in terms of conservation laws are mutually exclusive of those of space-time referencing. One way of interpreting Bohr's explanation of this relationship seems to philosophically support the notion of discrete time. Consider that Δp is a change in momentum of an object, where momentum is the mass times the velocity ($p = mv$) of a quantity. Velocity is defined as the change in position with time, and the mass can be taken as "constant'' for the discussion. Conceptually examining this relationship, one could take it as saying that the position's change and the change-in-position-in-time do not overlap, implying that a position cannot simultaneously exist and change. A continuous variable to define time would violate this requirement as it would allow an interval of zero time. Likewise, a mere change in the metric of any coordinates to a discrete dx and dt would still violate this Uncertainty relationship if there is a notion of continuous change still persisting in describing a process.

Yet Bohr didn't come to such a conclusion but instead took the position that the relationship defied classical[17] descriptions and interpretations. This Uncertainty Relationship highlights the nature of reality which still escapes understanding, and at its heart contains questions about the discrete-v-continuous descriptions of reality and the ontological or epistemological nature of realities being considered. Yet it cannot be claimed that this relationship conceptually implies time is discrete.

Quantum mechanically, it is possible to claim that the energy, position, or momentum (or any observable being considered) can have precisely defined values. The uncertainty is not one of experimental inaccuracies in measuring these values. Such noise can make it difficult to

[17] Meaning the conceptual formalism of classical mechanics.

precisely define the value of such an observable, yet the ħ quantum limit is much smaller than any noise, implying ontologically these values do exist, with an intrinsic uncertainty.

A recent experiment has questioned the central claim of Heisenberg when he formulated his Uncertainty Relationship. His general concept was that the uncertainty was between the precision of a measurement and any disturbance this measurement must create. These two quantities he proposed must satisfy his Uncertainty Relationship $\epsilon(x)\eta(p) = \hbar$. Yet in 2012 [18] it was experimentally shown to be incorrect. Using weak measurements information was obtained about a system before and after a strong measurement was made, allowing Heisenberg's Minimum Disturbance Relationship to be violated. Yet a different inequality was found to be obeyed, which does still seem to imply there is a limit as to how much knowledge is obtainable about such quantum systems. Therefore from this one could conclude that the Uncertainty Relationship refers to an intrinsic uncertainty in all quantum states or reality.

The general form of this is given[19] as

$$\Delta A = \sqrt{\langle A^2 \rangle - \langle A \rangle^2}$$

which hasn't been experimentally violated.

It is also not possible to claim that the Uncertainty Relationship has implications for the simultaneous measuring of the position and momentum for example, as was commonly thought, or the measurement of complimentary properties of a state. Again, modern theoretical and experimental advancements of Quantum Heterodyne measurements[20] suggest that it is possible to simultaneously obtain information about the position and momentum of a particle and that these values exist as a continuum.

Therefore a general understanding of this relationship is that for a large number of identically prepared states, the individual results of position and momentum measurements on these systems will give results which agree with a probability distribution which has a minimum variation according to the Uncertainty Relationship.

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[18] Rozema, L. A. et. Al. "Violation of Heisenberg's Measurement-Distance Relationship by Weak Measurements." Phys. Rev. Lett. 109, 100404. 2012.

[19] H. P. Roberston, Phys. Rev. 34, 16. (1929).

[20] Gerard Milburn. Phys. Rev. A 36, 5271–5279 (1987).

The debate regarding the understanding of the Uncertainty Principle continued between Bohr and Einstein, and became crystalised in the famous EPR paradox (Einstein-Podolsky-Rosen). In this thought-experiment, an entangled state was considered and it was claimed that measuring the position of one particle in this superposition state would allow perfect knowledge of the complimentary property (eg. momentum) of the other particle in the entangled pair without a measurement being made on the particle, thereby violating Heisenberg's Uncertainty principle. To get to this conclusion it was assumed by Einstein that the particles in this entangled state have well defined properties, which exist independent of any measurement (known as Elements of Reality). John Bell formulated his famous Bell inequality to challenge this notion that these elements of reality exist, deriving an inequality which can't be exceeded using classical concepts of physically independent properties existing prior to measurement. However, quantum mechanically this inequality would be violated, and experimentally this violation has been strongly verified.

Therefore reality has an intriguing property that the distribution of outcomes of identical measurements on identically prepared states/systems will vary such that a relationship such as the Uncertainty Relationship will hold. This is not an artifact of the formalism of commutation and its conceptual meaning either (as implying measurements are or are not reversible), as shown by Condon.[21]

The interesting thing to me is that there is a minimum. However this uncertainty is to be understood, it has a limit, implying a limit to the amount of information that exists for processes. Considering what a maximum uncertainty might mean, I'd suggest that equal probability would imply maximal uncertainty.

Therefore this would imply that a flow of time, or a moment of time which is represented by a process which is defined by an individual component of the whole system, has an information content which is not "complete". That is to say, the next outcome of the process, or the equivalent in my model, the next moment in time, is indeterminate at the existing process or moment.

[21] "Remarks on Uncertainty Principles." E. U. Condon. Science. Vol. 69, 1796. Pp. 573-574. (May 31 1929).

This highlights the intrinsic indeterminism of reality as described by Quantum Mechanics and empirically verified. All that can be described are "classical"[22] outcomes of measurements which obey the statistical uncertainty of the Uncertainty Principle over a number of "identical" measurements. It can't be concluded as to what exists other than these measurement outcomes, therefore in terms of information, the classical outcomes of experiments are "complete" but other than that this "completeness" can't be concluded from a quantum perspective. The analogous of these measurements for a process would be a decision being made, which would then define a process and distinguish it from the next one, or similarly[23] one time moment from the other. It is stressed that this uncertainty relationship is referring to systems involving non-commuting variables.

Therefore this lack of information implied by the Uncertainty Principle is to be understood as meaning these processes must be considered as a whole, indivisible into their parts/components. This idea supports the core principle this paper, one which I believe is an original justification for my claiming time cannot be continuous.

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[22] Conceptually generally meaning macroscopic, defined by Classical Mechanics, where things are said to exist.

[23] According to my conception and model of time.