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Re-thinking geometrogenesis: Instantaneity in quantum gravity scenarios

Silvia De Bianchi[1,2] **and Luciano Gabbanelli**[2,3]

[1] Department of Philosophy, University of Milan, via Festa del Perdono 7, 20122 Milan, Italy
[2] Department of Philosophy, Universitat Autònoma de Barcelona, Campus UAB 08193 Bellaterra, Barcelona, Spain
[3] Institut de Física d'Altes Energies (IFAE), Faculty of Sciences, Campus UAB 08193 Bellaterra, Barcelona, Spain

E-mail: `silvia.debianchi@unimi.it`

Abstract.

Recent Quantum Gravity approaches revealed that spacetime emergence opens conceptual difficulties when the theory allows for cosmological scenarios compatible with geometrogenesis. In particular, it appears extremely difficult to think of an a-temporal transition from a non-geometric to a geometric phase and vice versa. In this paper we advance the proposal of a concept of atemporality, i.e., instantaneity that is suitable for the description of the transition occurring among fundamental phases from which spacetime emerges in some Quantum Gravity approaches, including Group Field Theory and its cosmological implications. After discussing the ontology at different levels of spacetime emergence in a theory of Quantum Gravity in Section 2, we shall focus on the definition of the notion of instantaneity to interpret the atemporal transition of geometrogenesis (Section 3.1), thereby arguing that atemporality dominates at Renormalization Group flow fixed points (Section 3.2). In Section 4, we apply for the first time our notion of instantaneity to the study of geometrogenesis in the context of tensorial Group Field Theory and we conclude by suggesting that atemporality plays a significant role for the understanding of our world at different scales.

1. Introduction: Spacetime emergence and the problem of atemporality

Throughout the long history of philosophy, we learned that the question "What is time?" is an insidious one, potentially leading to misunderstanding and confusion. An entire new field, the philosophy of time, flourished in the last decades in order to clarify the nature and the structure of the concept(s) of time, and different positions characterize the academic debate in an almost ubiquitous way.[1] However, even more problematic is to assess and develop the notions of temporal non-locality, atemporality and timelessness.[2] The difficulty, if not the non-sense,[3] of

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[1] For an overview of the state of the art of the philosophy of time, see Bardon (2013) and Callender (2011). For studies relevant to the elaboration of the present study, see Meincke (2019) and Strobach (2013).

[2] In studies on quantum foundations, recent work by Adlam 2018; Adlam 2022 emphasizes the need to go beyond temporal locality and to explore a relational approach to temporal nonlocality within the Internal Quantum Reference Frame Programme. However, what we are proposing in the current paper is even more radical as shown in Sections 3 and 4.

[3] Among arguments in philosophy against atemporality, consider, for instance, Wittgenstein's take on atemporality: "If the world of data is timeless, how can we speak of it at all? The stream of life, or the

talking about an atemporal world is one of the major challenges for current philosophers, but it also represents a priority for practitioners of some Quantum Gravity approaches, especially for those admitting the emergence or the disappearance of space and time, and in particular for those supporting approaches predicting models compatible with the geometrogenesis scenario. The latter is compatible with solutions letting time and/or space emerge above the Planck scale, and it has been associated to a phase transition in various approaches, including Quantum Graphity and Group Field Theory. The conceptual difficulty associated to geometrogenesis consists in the fact that it denotes a phase transition from a non-geometric to a geometric phase. In other words, geometrogenesis should be interpreted as an atemporal transition. Since we completely lack a philosophy of atemporality,[4] it seems thus that philosophers cannot provide any new conceptual ground to support research programs in Quantum Gravity admitting forms of atemporality or atemporal transitions. Indeed, current studies in the philosophy of physics attempts at accommodating what physicists identify as emergent spacetime, proto-time and other similar concepts, but a deep analysis of atemporality is still missing. Yet, we claim that one cannot fully grasp the relationship between temporality and atemporality without considering current debates on emergence and recent research in theoretical physics.[5]

Recent works by Huggett and Wüthrich (2018); Wüthrich (2019); Calamari (2021) advanced some proposals according to which we should start thinking of time as being emergent from atemporality in Loop Quantum Cosmology (LQC). Le Bihan (2018, 2019) also points to this question as a fundamental one to advance in the philosophical understanding of spacetime structure. However, these studies also suggest that it is almost impossible to avoid temporality when talking about phase transitions, such as geometrogenesis and do not offer a positive description of the special kind of a-chronicity needed in approaches, such as Quantum Graphity, Causal Dynamical Triangulations (CDT) or Tensorial Group Field Theory (TGFT) that allow solutions including geometrogenesis.[6]

In this paper, we want to explore in which sense and under which conditions one can talk about atemporality in terms of instantaneity. Second, we aim to sketch out the basis of our proposal for an ontology of phase transitions that can produce a shift in the naïve claim that an atemporal world is not epistemically accessible to us. Therefore, more than asking questions about time, what we are urged to do in the specific context of Quantum Gravity, is to address the relevant question: "What is atemporality?". Before characterizing atemporality as instantaneity, we reconstruct the salient aspects of the ontology that can be associated to temporality and atemporality in Quantum Gravity and we will do so by investigating a recent proposal by Oriti (2018) regarding levels of spacetime emergence. We shall briefly discuss them from both an ontological and epistemological standpoint. In Section 3 we shall introduce a suitable notion of

stream of the world, flows on, and our propositions are so to speak verified only at instants. Our propositions are verified only by the present". Wittgenstein, Philosophical Remarks V, sec. 48.

[4] The lack of a theory of atemporality might be observed not only among those philosophers reflecting upon the notion of spacetime emergence, e.g., Wüthrich (2019), but the impossibility of a theory of atemporality is also supported by those rejecting the idea of spacetime emergence, as in the case of Esfeld (2021).

[5] Indeed, when talking about 'emergence' there is an inevitable reference to the notion of passage or transition, i.e., something emerges from something else. This is precisely the sense of emergence that philosophers of physics see as problematic, Huggett and Wüthrich (2018), yet there is a lack of a standard definition of emergence that embraces different approaches to the appearance of spacetime. Butterfield and Isham (1999, 2001) provided a general and instrumental definition that is widely used by theoretical physicists, but not sufficient to grasp the complexity of the implications that current theories of quantum gravity generate for our conception of space, time, and atemporality. A worth-mentioning work on emergence in Quantum Gravity is Crowther (2018) exploring the inter-theory relations of Quantum Gravity, thereby offering a definition of emergence clearly differentiated from reduction.

[6] For geometrogenesis as possible implication of GFT see Oriti (2007), of quantum graphity see Konopka et al. (2006), of covariant LQG (with spin foam models) see Delcamp and Dittrich (2017) and for CDT see Mielczarek (2017); Mandrysz and Mielczarek (2019).

instantaneity (Section 3.1) and we will then apply it in the context of GFT condensate cosmology (Section 3.2). In Section 4 we investigate the atemporal transition from non-geometric phases and geometrogenesis in the specific context of Tensorial Group Field Theory (TGFT). We will conclude with future perspectives to test the notion of instantaneity, such as those involving asymptotic silence or Zeno regions in black holes, which in turn can have an impact on both philosophy of physics and philosophy of time.

2. Quantum gravity and levels of emergence

Oriti (2018) introduced a multi-layered scheme applicable to any Quantum Gravity approach describing four levels of emergence, each of them representing possible moves associated to the aim of recovering the continuum and classical notions of spacetime. In table 1, we sum up these four levels, each of which has been associated by us to notions of temporality/atemporality. We also show where phase transitions occur associated with atemporality. Before describing the levels of interest, a caveat is in order here. The four levels are not necessarily implied by each other. In other words, one can have a formalism that considers just Level 0 of emergence because it deals with continuous quantum fields as it happens in quantum general relativity, even if most of quantum gravity approaches, Oriti suggests, deal with all levels of emergence, but treat the mathematical entities pertaining to Levels 1, 2 and 3 as mere tools to reach the ontological level of interest, which is Level 0. This is a consistent generalization, but up to a certain extent. Indeed, when we are explicitly using approaches to QG implying phase transitions, as clearly happens at Level 3 of emergence, there is some physical meaning to be attributed to the implications of the transition from non-geometric to geometric phase, i.e., to geometrogenesis, and we are not just using mathematical tools to reach Level 0 of emergence. It is also worth mentioning that precisely this third level of emergence attracted our attention and triggered our attempt at characterizing the atemporality associated to this transition.

Table 1. Oriti's levels of emergence and our characterization of the objects of interest and notions of temporality/atemporality at each level.

Level	Object	Phase Transitions	Temporal or Atemporal Notions
0 (ground)	continuous fields	no	temporality
1	discrete entities	no	proto-time and/or proto-space
2	phases	yes	atemporality
3	geometrogenesis	yes	atemporality (instantaneity)

The lower level (Level 0 or ground level) encompasses more traditional ideas that attempt to present a theory of quantum gravity as some sort of a quantization of general relativity. According to Oriti, one can introduce new properties (or, equivalently, remove some features) for the fundamental entities that could provide the necessary characteristics to speak of a first level of emergence. At Level 1, we abandon the formalism of quantizing the (continuum) gravitational and matter fields and introduce new types of discrete degrees of freedom endowed with a different quantum nature. The Hilbert space is rather built with pre-geometric degrees of freedom, usually with combinatorial structures, labeled by algebraic data only, see Oriti (2014a). These structures are not merely in a quantum superposition, but their eigenstates do not allow a chronogeometric interpretation at all, see Wüthrich (2018). Therefore, the mathematical space of the theory is radically different from the one described in the previous level, being fundamentally discrete, non-spatiotemporal and lacking some important features of space, time and/or spacetime, Huggett and Wüthrich (2012).[7] Approaches encompassed under this characterization start with an underlying microscopic theory in which no straightforward reference to a spatiotemporal geometry is to be found, as for instance in Markopoulou (2009).

Level 1 of emergence implies the transition from discrete structures to the continuum, thereby raising the so-called problem of the continuum limit in discrete Quantum Gravity approaches. At this level, the emergence of spacetime is realized in a stronger sense, since it is achieved through collective properties of non-spatiotemporal entities. The novelty is that this emergence is addressed by moving along the growing numbers of fundamental building blocks and is achieved by exploring their collective properties. Therefore, some kind of multi-level ontology should be taken into account for both fundamental and collective entities/properties. For instance, in Oriti's view, it is possible that the fundamental entities, although not fully spatiotemporal, carry at least seeds of the emerging spatiotemporal notions, at least in some sectors of the same theory and under certain approximations. If concrete seeds can be identified, then a proto-spatiotemporal characterization of some of the properties of these seeds can be determined. These proto-spatiotemporal features may include notions like adjacency and succession. However, in our view, succession should not be treated on the same level of "ordering".[8] Thus, we prudently suggest that both adjacency and succession are nothing else but possible expressions or results of an internal ordering.

The further step constitutes Level 2 of emergence, according to which the same pre-geometric degrees of freedom that have been characterized at Level 1 are defined through their quantum dynamics and therefore postulated as meaningful in a physical sense. With the increasing number of them, collective effects start assuming relevance in providing continuum notions. However, similarly to any system composed by many interacting degrees of freedom, the continuum limit is generally not unique, leading to different macroscopic phases, each characterized by different effective dynamics with different emergent properties and macroscopic observables. In a sense, one can claim that the underlying microscopic quantum system combines itself into very different types of emerging macroscopic systems, and each of them is regarded as a disjoint phase.[9] This reinterpretation of fundamental constituents as interacting entities that can be collectively associated in phases, some of which are non-geometric, constitutes a novelty that affects ontology at a deeper level and introduces the need of defining atemporality. The fact that these phases are now understood as collective phenomena naturally makes the spatiotemporal or geometric attributes of the quanta completely meaningless. At this level, spacetime is understood as an approximate notion of the collective entities erasing any microscopic detail for the dynamics of the macroscopic phase. Therefore, the emergence resulting from these non-spatiotemporal degrees of freedom needs to be produced in a more radical way than in the previous level. Specific techniques or approximations such as coarse-graining are needed for the proto-spatiotemporal features to appear, and they are supposed to ground spatiotemporal observables and/or their

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[7] According to de Haro and de Regt (2018), the degree of connection between the microstructure of the theory and the concepts belonging to classical spacetime varies from one theory to another. For instance, in LQG the interpretation of the constant $\ell = 8\pi\gamma\ell_{Pl}^2$ as a 'quantum of area' and indeed, since the area (and volume) operators come quantized in units of ℓ, justifies that LQG seems more tied to a classical spacetime interpretation than other theories such as causal sets or GFT. It is worthwhile to mention that areas and volumes are by no means directly interpreted as classical geometric quantities, but rather as classical limits of operators with a discrete spectrum, and in terms of states that can be in superpositions of eigenvalues.

[8] In our view, internal ordering encompasses succession and adjacency and it is more fundamental, because without ordering we could not speak of anything else but proto-spatiotemporal features and we could not determine any order of atemporality.

[9] The existence of disjoint Hilbert space sectors with stable solutions to the classical (non-linear) field equations makes one consider strict analogies with different phases of statistical mechanical systems and/or with inequivalent representations of local field algebras in quantum field theory. Each phase can be associated with a given non-linear field equation and thus one can ascribe a physical meaning to each disjoint physical world Strocchi (2008, 4-6; 28).

dynamics. These procedures are performed in some specific phase, only for some specific values of the macroscopic parameters (such as the coupling constants). Nonetheless, under the very same techniques or macroscopic approximations, not all phases rely on continuum spacetime and geometric characteristics. Therefore, concepts such as locality (or localization), geometry or even continuity are erased from the ontology of quantum entities.

Among the scenarios that arise from the interacting quanta, some Quantum Gravity approaches identify the phase transition from a non-geometric to a geometric phase. This phase transition defines Level 3 of emergence. To show the existence of such a transition, i.e., geometrogenesis, in which the system becomes ordered in such a way that it can be described under a suitable approximation in terms of fields that live on a four-dimensional spacetime manifold with a metric obeying Einstein's equation, depends on how each particular theory of quantum gravity is constructed.

In our view, among various approaches GFT is particularly interesting because in it we can identify condensed phases. The ontology of GFT thus suggests that individual spacetime quanta are a priori mathematical entities, but collectively and in analogy with condensed matter systems they embody a physical behaviour represented through phase transitions. For this reason, we suspect that a pure epistemological reading of these levels of emergence is not sufficient and must also rely on an ontology of phase transitions in order to account for what Oriti (2018, 2021) labelled as Level 3 of emergence, i.e., geometrogenesis. The relevance of studying geometrogenesis and to provide an ontology of phase transitions has several implications for the philosophy of physics and for cosmology. Indeed, among the different interpretations for the different possible phase transitions available, the natural hypothesis for geometrogenesis is associated to overcoming difficulties associated to the Big Bang singularity.[10] Let us recall one of its realizations in LGQ cosmology. In some models, see for instance Bojowald (2011), this process is understood as a continuous region from a purely spatial state with no notion of time. Brahma (2020) argues that this transition represents "the emergence of time in LQG", while Huggett and Wüthrich (2018) define it as the "(a)temporal emergence of spacetime". However, since any particular model is far from being fully developed, none of them accurately explains what is meant by time 'emergence'. The only concrete 'before' that can potentially be conceived involves the idea of extrapolating local and directed time beyond its own domain of applicability. According to Huggett and Wüthrich's (2018) suggestion, this very weak and novel sense of 'before' could be understood as a past limit relative to the arrow of time in the effective direction towards the non-temporal region. Therefore, this *locus*, which does not have any temporal extent and where all time-like curves of the effective spacetime converge, can be conceived as an initial state of a dynamics that requires a sufficiently broad and novel understanding.

In what follows, we shall propose an alternative view to this proposal. To account for what Oriti (2018) called levels of emergence of spacetime, we need a deeper analysis of the ontology of phase transitions, and we must produce a suitable conceptualization of atemporality as instantaneity, such that the conceptual difficulty of thinking of a transition from atemporality to temporality and vice versa (not only in GFT, but also in LQC and any approach to quantum gravity implying geometrogenesis) is overcome. Yet the literature presented the problem of finding a fundamental description of geometrogenesis in terms of an a-chronic transition from

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[10] In these models, the idea of geometrogenesis as a replacement for the Big Bang competes with the alternative idea of a bouncing scenario, where the Big Bang would connect two macroscopic phases of the theory: the 'trans'-big-bang physics is a precise mirror image of the 'cis'-big-bang physics, except that the spatial orientation is inverted. The latter has been discovered in the simplest hydrodynamic description of the system, see for instance Gielen et al. (2013); Oriti (2017); Oriti et al. (2016); de Cesare et al. (2016). Another possibility can be found in Wüthrich (2022), according to which two universes are connected at the Big Bang and the latter is reinterpreted as the birth of two twin universes, reconciling both assumptions to some extent.

a non-geometric to a geometric phase. But what if we conjecture that our physics allows us to think of the co-presence in the world of atemporality and time and that this is instantiated in phase transitions? What if we find a suitable description of atemporality to play a role in geometrogenesis, as it plays a role in any phase transition?

3. Investigating atemporality: instantaneity as function of atemporal transitions

We will now introduce the main aspects characterizing our approach to atemporality as instantaneity in Subsection 3.1, and connect them to current research on geometrogenesis as one possible implication in both GFT condensate cosmology and Tensorial Group Field Theory in Subsection 3.2.

3.1. Beyond temporality: instantaneity

Let us start with a preliminary reasoning based on the picture sketched in the previous Sections. From a purely philosophical standpoint, our first move is 1) to clearly reject any statement that atemporality equates eternity. However, we can concede that eternity could be just one type of atemporality. Furthermore, we assume that 2) the "Now" or presentness is out of the representation of the temporal series, i.e., it cannot be defined in terms of ordering of succession. One can certainly divide operational time in parts, but still, one is performing nothing but a geometrization or a spatialization of what we call "time". Finally, we want 3) to distinguish the "Now" from the instant in order to remove the idea and any associated semantics according to which time can be divisible in instants. These three premises allow us to rephrase the problem as follows: is there a notion which designates a kind of atemporality which is identifiable or that can assume meaning in empirical processes but that is also out of the time flow and that is heterogeneous enough with respect to spacetime? Such a notion is the function of atemporal transition to be understood in terms of instantaneity and we will associate it to non-trivial critical points in phase transitions. In other words, we want to characterize a form of atemporality that can give meaning to geometrogenesis understood as a-chronic transition.

Our concept of instantaneity has nothing to do with that of being part of time. We claim, indeed, that we can consistently think of forms of atemporality that can be operationally useful to describe very special objects and processes without geometrizing atemporality. In order to spell out our definition of atemporality in terms of instantaneity consider the following argument. Let R a superset containing two complementary sets:

$$R \supseteq \{A, -A\} \tag{1}$$

In set theory this simple characterization of a set is valid for a superset R, if and only if we assume locality and the principle of contradiction. This leads to the classical example discussed by Wittgenstein (1929) according to which Bob and Alice cannot sit on the same chair at the same time t.[11] However, since we are interested in formalizing atemporality we forget about the time t to define the properties of our superset. Furthermore, atemporality must be characterized as instantaneity in which no order of succession is present (since we are not even interested in defining proto-time in scenarios such as those described at geometrogenesis). Thus, in the absence of an order of succession, what is left to us is to use a logical formula to express the co-presence of two complementary sets. By dropping temporality out of the scene, we also abandon the notion of locality.[12] Furthermore, it is perfectly possible to think of the sets A and $-A$ as

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[11] In Wittgenstein (1929) it is clearly stated why and how, due to the principle of contradiction, logic forces us to think that Bob and Alice cannot sit on the same chair at the same time. Wittgenstein also highlights the limits of such a view, but does not offer any application of this insight to physics.

[12] It is worth noting that combinatorial non-locality is precisely what characterizes the structure of tensor models and tensorial GFT, thus our definition of instantaneity applies to both models even if the RG flow and their potential fixed points differ from those of tensor models.

co-present in R, i.e., Bob and Alice can sit on the same chair, because even the chair is not under scrutiny here, the chair or place does not make any sense. To give a simple and concrete example of what instantaneity does, we can think of it in analogy to qubits. Consider the simple case of a qubit of two states in superposition:

$$|\Psi\rangle = \frac{1}{\sqrt{2}}\left(|\uparrow\rangle + |\downarrow\rangle\right) \tag{2}$$

To the qubit no univocal solution given by a sharp state is provided. However, by changing the basis $\frac{1}{\sqrt{2}}$, we can obtain a sharp single result:

$$|\Psi\rangle = |+\rangle \tag{3}$$

Thus, just like the superposition of states of the qubit can be “unlocked”, one can expect to obtain the same for instantaneity, e.g., an ordering of succession or proto-temporal structures, or fluctuations of the topology can give rise to more coherent, non-degenerate systems or to a sharp state of the qubit. However, this would be less radical than our notion of instantaneity. Consider again our qubit, but this time as containing two entangled states:

$$|\Psi\rangle = \frac{1}{\sqrt{2}}\left(|\uparrow\uparrow\rangle + |\downarrow\downarrow\rangle\right) \tag{4}$$

No change in the basis can disentangle them, they are entangled. This corresponds to what we call a “locked-in mode” in instantaneity. Both states are co-present and prima facie we cannot decide which of them constitutes the qubit, because both do so at once, just like the superset R is constituted by both sets at once. By focusing on the first state of the qubit, the second one is implied and in no time we can pass from one to the other, simply because mathematically one immediately implies the other and vice versa. This specific function of atemporal transition according to which the co-presence of two opposite or disparate states is coherent and not contradictory is instantaneity and it can be consistently employed to describe the atemporal transition at fixed points of RG flow for geometrogenesis and to think of the co-presence of two states at any critical or tri-critical point in phase transitions (See Section 4).

From this we first infer that instantaneity is connotated by the undecidability of the two states, as well as by spatial non-locality derived from temporal non-locality (Co-presence Postulate). Indeed, just like we cannot decide whether one of the two entangled states connotates the qubit, we cannot decide whether a specific state is at a critical point in phase transitions, nor we can say the contrary, but just admit both states in an indistinguishable region.

We now introduce a second postulate, i.e., the Postulate of Exclusion in order to justify our definition of instantaneity as function of atemporal transition. The condition for not having any order of succession in the instant is the exclusion of all sub-spaces of the states of a qubit or, to in analogy with set theory, the exclusion of any sub-sets of the opposite or disparate sets contained in R. However, in order to think of an instantaneous switch un-locking any possible ordering and therefore also the proto-spatiotemporal ordering of succession and/or adjacency one needs to include the excluded subspaces under the opposite state.

Be A and $-A$ two opposite sets and a_2 a subset of A. In order to have instantaneity and therefore the co-presence of two states at the critical point in phase transitions, a_2 and any other subset must be excluded. From this Postulate, the following corollaries follow:

Corollary 1: a_2 is contained in $-A$ iff A does not contain a_2 within it. $-a_2$ is contained in A iff $-A$ does not contain $-a_2$ within it.

Corollary 2: a_2 must be an external subset A.

Corollary 3: $-a_2$ must be an external subset of $-A$.

Therefore, the instant is unique and indivisible. We cannot divide A because it has no parts of it within it, and vice versa, we cannot divide $-A$ because it has not parts of it within it (Postulate of Exclusion). Since the two states contain just parts of their opposite, it only depends on a switch of subsets, whether one transition as sudden change can occur from A to $-A$ or vice versa.

We used analogies taken from qubits and set theory in order to spell out some features that instantaneity can possess. These are just analogies because we find several difficulties in expressing with language what atemporality is. However, we now proceed in applying our notion of instantaneity to phase transitions. At the critical point we find an indistinguishable region. Thus, not only there is no spatio-temporal property associated to the critical point, but at it sub-states or sub-phases are indistinguishable. We therefore infer further properties of instantaneity, i.e., indivisibility and uniqueness. However, as we tried to spell out above, instantaneity can contain the determinable sub-states defining the phases associated to the co-present sets of A and $-A$. For instance, one can say that $-A$ contains $a_2 \dots a_n$, and vice versa that A contains $-a_2 \dots - a_n$. Moreover, one can say that instantaneity stems for the absence of any subsets at the critical point, e.g., states are indistinguishable at the critical point.

Thanks to this characterization of instantaneity, one can remark that this notion of atemporality spells out that the substates or subsets are in a "locked-in mode" and captures the co-presence at a critical point of different states. Thus, the Co-presence Postulate and the Postulate of Exclusion ground the atemporal or a-chronic representation of transitions and define the mutually excluded sub-states or sub-spaces of the two co-present states as determinable states of possible phases. Let us now deepen our study and test the applicability of instantaneity in specific GFT approaches on the ground of our suggestion to consider geometrogenesis.

3.2. Instantaneity, RG fixed points and phase transitions in GFT

Our proposal cannot be successful if it is not related to the content proposed by current approaches and problems discussed in quantum gravity, including attempts at unifying it under the idea that quantum gravity is a theory of complexity that should be described by many equations of state, Mielczarek and Trzésniewski (2018). This complexity can be captured by means of a multi-layered ontology as Oriti (2018) suggests and in our view, GFT is particularly interesting because in it we can identify condensed phases of extreme interest for the cosmological implications they can have. GFT formalism postulates a microscopic description of the fundamental atoms of spacetime, proving a starting point for studying both the statistical mechanics and the effective dynamics of a large number of them Oriti (2014b). Their collective behaviour is tentatively identified with continuum and geometric physics, being both emergent and approximate. The methods for extracting macroscopic and collective structures from the fundamental quantum dynamics are generally used in quantum many-body theory, but in a background independent context by using coarse graining techniques and renormalization group; see Finocchiaro and Oriti (2021) for recent developments. These methods allow the change from the atomic description to the hydrodynamic approximation. In Oriti (2021), the hydrodynamic approximation is presented as case of radical ontological emergence,[13] and geometrogenesis is presented as one possible implication of GFT condensate cosmology. The geometrogenesis scenario allows us to describe the emergent universe in analogy with a quantum condensate (fluid) resulting from the collective condensation of the underlying degrees of freedom. This transition cannot be a temporal process since it separates time from its disappearance in the underlying non-spatiotemporal quantum phase. One possibility is to understand it as the outcome of a possible evolution in the phase diagram of the theory, namely it can be understood

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[13] This categorization lies on the fact that the basic structures are different entities at both sides of the emergence process. On the one hand, we deal with discrete entities. On the other, we are in need of an ontology of continuous fields which are defined as being collectively emergent. However, these approximations are just a matter of description of the emerged system, and the ontology of different phases only depends on changes in the theoretical framework (see Section 2 above).

as a flow in its time-independent coupling constants, as a sudden becoming or switch from a non-geometric and non-spatiotemporal phase to a geometric one. These phases cannot be causally connected or temporally distinguished, since these concepts are dissolved.[14] Therefore, this transition characterizes a sort of a-chronic emergence where time does not play any role. In Section 4 we shall identify how to portray instantaneity at critical point in TGFT, but before doing so, we would like to point out that in the current state of the art of GFT cosmology –see Gabbanelli and De Bianchi (2021); Gielen and Sindoni (2016) for reviews in this topic–, the existence of condensate phases with a tentative continuum geometric interpretation is a working hypothesis and deeper insight on renormalization group techniques for understanding such phase structures is required. The phase diagram of theory shows various phases (Level 2 of emergence) that can have or not physical meaning, they can be geometrical and non geometrical, but in what Oriti labeled as Level 3 of emergence, i.e., geometrogenesis, we can identify a specific form of atemporal transition. The notion of instantaneity allows us to think of the transition from a non-geometric to a geometric phase without contradiction, because it defines the *atemporal non-place* where the transition occurs. In other words, instantaneity represents the condition for thinking of atemporal transitions, but it does not determine in anyway whether the critical point triggers the transition to geometric phases or to non-geometric ones. In other words, since it is a condition or a function for atemporal transition, it has no directionality because it is out of time. We have emphasized that at the critical point we witness an a-chronic transition in which time does not play any role, actually no typical length scale is encountered. Thus, instantaneity is attributed to the critical point of the phase transition, and this move concretely facilitates our representation of geometrogenesis in analogy with critical phenomena. If we draw an analogy between critical phenomena (including renormalization group transformations used therein) and geometrogenesis, we can investigate its critical region.

A critical region is a fluctuation-dominated regime of the system. Exactly at the critical point, the system has an essentially different property, i.e., the absence of a typical length scale, Nishimori and Ortiz (2010), §1.4, p. 9. This means that one parameter (e.g., effective temperature) does not change by a renormalization group transformation if the system is at the critical point. Thus, when the critical point corresponds to a fixed point of the renormalization group transformation, it is fundamentally atemporal and we identify it with the *locus* of instantaneity.[15] In the case of GFT condensate cosmology, since the mean-field theory does not hold at and near the critical point, we witness the co-presence of indistinguishable phases at the critical point and even if one can better grasp the properties of critical regions in different phases, no refined RG flow technique can distinguish the phases at the fixed point. Thus, our concept of instantaneity describes through the Co-presence Postulate and the Postulate of Exclusion the atemporality and the indistinguishability of phases that characterize fixed points. Furthermore, this concept still allows us to identify the emergence of geometric phases, by including possible subspaces to be ordered or parametrized out of instantaneity, for instance, one after the other or one next to the other, thereby generating connection of fundamental degrees of freedom or succession and other proto-spatiotemporal properties.

Indeed, it is worth noting that GFT approaches to geometrogenesis appeal to renormalization techniques using the universality class concept that eliminates inessential details and allows focusing on increasingly macroscopic properties of the systems. An important consequence of universality is that quantities describing essential features of critical phenomena, e.g., critical

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[14] Although non-spatiotemporal analogues can be found, e.g., causation without time Baron and Miller (2014, 2015); Tallant (2019), we are not going to deepen this issue.

[15] Of course, according to our definition of instantaneity this is a no-place. The major consequence we see in the cosmological scenario is thus the impossibility of identifying an exact moment of the transition from the non-geometric to the geometric phase and therefore any question regarding the beginning of the geometric phase does not make sense anymore.

exponents, are specified only by factors such as the symmetry of the system, range of the interactions, and its spatial dimensionality (the connectivity of its elementary degrees of freedom, such as spins in the Ising model in case of a definition of the system on a lattice). This means that two apparently different critical phenomena can share the same critical exponents, one in the Ising model, for instance, and the other in a simple liquid, as long as both are in three dimensions. These two distinct physical systems belong to the same universality class in such a way that a model of magnetism shows the same critical behaviour as one for the simple liquid. Behind this behaviour there is a physical explanation depending on the fact that many characteristics of the system gradually recede as the renormalization-group transformation proceeds and eventually only essential factors, e.g., the spatial dimensionality and the symmetry of the system, survive. Thus, to rely on universality class is fundamental in order to study the relevant symmetries of GFT and those of condensed matter physics. In the current state of the art of GFT cosmology, more work is needed to determine under which conditions phase transitions and different phases can truly exist. Whether and how macroscopic continuum phases emerge remains an open issue together with the exact representation of geometrogenesis as physical atemporal transition. Furthermore, the consequences of this phase transition are expected to be measurable, being possible imprints of the universe dynamics testable, e.g., the physics of cosmological perturbations in the very first instants of the history of the universe, in particular in the CMB spectrum, Gielen (2015, 2019); Marchetti and Oriti (2021); Pithis and Sakellariadou (2019). Nevertheless, it is worth mentioning that the quantum degrees of freedom are expected to have consequences when forming collective structures. Indeed, if no phenomenology at any scale can be associated to the quantum world, whether associated to their quantum properties per se or to collective macroscopic effects, then the quantum entities are no more than mathematical tools, and the non-geometric and non-spatiotemporal phases would have no reason to be considered as physical or philosophically interesting. In what follows we provide insight on the reasons why the atemporal character of the transition dubbed geometrogenesis should attract our attention, at least from the conceptual standpoint.

4. Omega region and Ginzburg parameter: looking for a signature of instantaneity in geometrogenesis

In recent studies based on TGFT, geometrogenesis is associated to a phase transition modeled through the Landau-Ginzburg theory, see Marchetti et al. (2022). Therefore, we have an interesting case study that can be extracted from Marchetti et al. (2022), in order to exemplify what instantaneity looks like in TGFT and in geometrogenesis scenarios.

The Landau-Ginzburg theory of second-order (continuous) phase transitions is, in fact, a *phenomenological* theory which provides a description of the fluctuations determining the critical point. Near a critical point, two or several different phases, with almost the same free energy, are competing to determine the ground-state (or low-energy states). Therefore, relatively small fluctuations in the system would lead to drastic effects.

When studying the behaviour of the Ginzburg parameter Q, for values of $Q \gg 1$ large fluctuations dominate and the critical point $\mu \to 0$ shows the signature of a divergence that dramatically leads to the impossibility for the Ginzburg-Landau mean-field theory to hold. In other words, no measurement nor observable can be associated to the critical point, no time and no space can make sense at $\mu \to 0$ and therefore no correlation can be measured therein. However, thanks to the Landau-Ginzburg theory, we can identify around the critical point a region Ω in which and of which at least we can tell that two phases are co-present (in agreement with the Co-presence postulate) and that they are indistinguishable. Since the Ginzburg-Landau theory is used in describing a physical abrupt phase transition, just like geometrogenesis is supposed to imply, it means that at critical point, when $\mu \to 0$ and $Q \gg 1$ at criticality, instantaneity dominates the transition, and Q should be understood as the triggering leading to a physical process. In other words, to think of an a-chronic transition is not only possible but necessary in this case.

Nevertheless, as highlighted in Marchetti et al. (2022), when $Q \ll 1$, correlation length makes sense again, and both local and non-local geometrical variables can be computed. Fluctuations of the order parameter Φ averaged over a region Ω are small compared to the order parameter Φ_0, averaged over that region, and the mean-field theory is applicable, and the two-point function of the fluctuations is encoded by a correlation function adapted for the case in which the Ginzburg parameter appears as $|Q| \ll 1$. The behaviour of Q is of extreme importance at the transition and also the specification of the region to be averaged over should depend on statistically relevant correlations up to distances of the order of the correlation length. Since local and non-local degrees of freedom enter in different ways in the dynamics of the models, it is preferable to differentiate a priori independent parameters that might contribute to long-range correlations that appear regardless of the physics of the phase transition and that are the result of asymptotically diverging contributions.

It is worth noticing that the behaviour of the Ginzburg parameter does not simply tell us that fluctuations are large at critical point, but Marchetti et al. (2022) have found the role played by the relevant symmetry group of GFT, namely due to the noncompactness and hyperbolic nature of the Lorentz group, we can always find a transition towards a phase with non-vanishing expectation value of the field (operator) and that this phase transition is always self-consistently described in terms of mean field theory. Since such configurations are highly populated by GFT quanta, this is evidence for the existence of an interesting continuum geometric approximation to be studied in mean-field language, in such TGFTs. Such phases had so far only been conjectured to exist for Lorentzian GFT models and had been used as a working hypothesis for the TGFT condensate cosmology program, where cosmological dynamics is also extracted from the TGFT mean-field hydrodynamics, albeit around non-uniform field configurations. Out of technicalities, all this means not only that main characteristics of instantaneity are embodied at critical point: indistinguishability, co-presence of phases, non-locality understood as impossibility to compute probability distribution and correlations, absence of time, impossibility to order successive states and so forth; it also means that depending on the properties of symmetry groups, one can find conditions under which instantaneity is “unlocked”. This in turn shows that it is deeply wrong to equate atemporality with eternity or an enduring ‘Now’ and that physics needs the notion of instantaneity to make sense of atemporal transitions, such as geometrogenesis.

Nevertheless, what is less obvious and more problematic is the philosophical interpretation of instantaneity in this context. Should we attribute to it an ontological meaning? Or should we rather be happy with a pure epistemological interpretation of it? For the time being, we conclude that:

(1) Geometrogenesis is a phase transition showing the signature of atemporality.
(2) It not only can but must also be thought of in terms of a-chronic transition, at least on the ground of the Landau-Ginzburg theory.
(3) The critical point of an atemporal transition from a non-geometric to a geometric phase embodies the characteristic of instantaneity.
(4) Instantaneity is an epistemological tool that enables us to think of atemporal transitions, such as geometrogenesis, without contradiction.
(5) From the purely physical standpoint, instantaneity cannot be associated to observables: it rather denotes the absence of them and the maximum decoupling of correlations.

Finally, we have some other hints of possible scenarios in which atemporality dominates. For instance, in regions near black holes singularities behaving like Zeno regions, physicists identified asymptotic silence, and we have evidence of the fact that from a semi-classical regime one can pass to a region of maximally decoupled points, connotated by the disappearance of causality and the collapse of the light-cone; see for instance Eglseer, Hofmann and Schneider (2021, 2017), Carlip (2012). However, we have to further investigate whether atemporality in terms of instantaneity applies to these cases or whether we need to elaborate a different notion of another kind of atemporality. Studies in the fields of LQC and QG also highlight where and under which conditions we detect asymptotic silence; Eichhorn, Mizera and Surya (2017), Mielczarek (2013). However, and this will be the subject of our future work, Quantum information theory could help in detecting the conditions under which these Zeno regions can “speak”, and it does so by showing the conditions under which states in the region are maximal entangled and cannot be disentangled. If it is possible to show that there are conditions under which these regions can start “speaking” again and thus exit the asymptotic silence, we will be entitled to infer that at various scales temporality could come into being from atemporality. We therefore envisage a huge change of perspective in future studies in the philosophy of physics and the philosophy of time if and only if the study of instantaneity is taken seriously into account, together with the latest development of quantum information theory applied to Quantum Gravity scenarios and extreme quantum and cosmological regimes.

5. Conclusion

In this paper we tried to characterize for the first time and formalize the a-chronic phase transition of geometrogenesis suggested by some Quantum Gravity models. We grounded our proposal of instantaneity on what we labeled ’Postulate of Exclusion” and “Co-presence Postulate” in Subsection 3.1. Any discussion of atemporality certainly raises many new conceptual issues that can modify current philosophy and its relationship to cosmology in the light of recent scientific debates on quantum gravity. This reflection inevitably bear implications for the philosophy of physics and further studies will test whether a promising new field of research in defining such an under-explored concept like instantaneity might prove to be necessary for a future theory of quantum gravity. What is far more interesting for the time being is that we provided a notion of atemporality, by challenging ideas that have been crystallized and consolidated throughout centuries regarding the divisibility of time in instants, the equation of atemporality with eternity or eternal presentness. We would like to stimulate scholars in different areas to explore the extraordinary multiplicity of questions that can be addressed by dropping out the idea that only temporality and spatiotemporality can be formalized. Second, the present contribution emphasized the possibility of thinking of geometrogenesis in atemporal terms. This does not imply that we provided evidence for the existence of this physical transition, rather we just tried to make it consistent with its cosmological implications and the general framework of GFT and TGFT. Furthermore, several open questions arise also for physicists in these contexts. For instance, what happens to specific hydrodynamic observables across the phase transitions? Is there any remnant of them that can be constructed out of the fundamental degrees of freedom? The notions of background independent and non-spatiotemporal evolution must be consistently developed in the ‘theory space’ that characterizes the chosen quantum gravity formalism. A realization of this type of evolution can be found in some specific renormalization group schemes, yet it remains obscure whether one can find some relevant notion of proto-temporal evolution, some parametrization of the flow through these non-geometric phases which may coincide with some useful observables that would provide emergent notions of time within the continuum phase. If the answer is affirmative, and since in the context of the hydrodynamic approximation the only ontology is that of fields, then the only physical observables emerging from the corresponding quantum observables are relations among the values of these fields. Therefore, in the context of the relational framework, some selected fields are the only structures that can be used to define clocks and rods, or more generally, reference frames labelling manifold points, and by doing so, spacetime and evolution of other fields. This ontology could be based on the quantum degrees of freedom behaving collectively and in an emergent manner, something that still needs to be fully investigated. However, philosophers can fruitfully proceed by introducing an ontology of phase transitions, which could accommodate descriptions of fundamental collective phenomena by framing them in a more complex idea of the world which also admits atemporality at critical points and proto-temporality at other scales depending on which phase transitions are of interest and the ontology they bear with them.

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References

Bardon A 2013 *A Brief History of the Philosophy of Time* (Oxford: Oxford University Press)

Baron S and Miller K 2014 Causation in a timeless world *Synthese* **191**(12) 2867–86

Baron S and Miller K 2015 Causation sans time *American Philosophical Quarterly*, **52**(1) 27–40

Bojowald M 2011 *Quantum cosmology: A fundamental description of the universe* (New York: Springer)

Brahma S 2020 *Emergence of time in loop quantum gravity* (Beyond Spacetime: The Foundations of Quantum Gravity) ed N Huggett, K Matsubara and C Wüthrich (Cambridge: Cambridge University Press) pp 53–78

Butterfield J and Isham C J 1999 *On the emergence of time in quantum gravity* (The Arguments of Time) ed J Butterfield (Oxford: Oxford University Press) pp 111–68

Butterfield J and Isham C J 2001 *Spacetime and the philosophical challenge of quantum gravity* (Physics meets Philosophy at the Planck Scale) ed C Callender and N Huggett (Cambridge: Cambridge University Press) pp 33–89

Calamari M 2021 The metaphysical challenge of loop quantum gravity *Studies in History and Philosophy of Science Part A* **86** pp 68–83

Callender C 2011 *The Oxford handbook of philosophy of time* (Oxford: Oxford University Press)

Carlip S 2012 *The small scale structure of spacetime* (Foundations of Space and Time) ed G Ellis, J Murugan, A Weltman (Cambridge: Cambridge University Press) pp 69-84

Crowther K 2018 Inter-theory relations in quantum gravity: Correspondence, reduction, and emergence *Studies in History and Philosophy of Science Part B: Studies in History and Philosophy of Modern Physics* **63** pp 74-85

de Cesare M, Pithis A and Sakellariadou M 2016 Cosmological implications of interacting group field theory models: Cyclic universe and accelerated expansion *Physical Review D* **94** 064051

de Haro S and de Regt H 2018 Interpreting theories without a spacetime *European journal for philosophy of science* **8**(3) pp 631–70

Delcamp C and Dittrich B 2017 Towards a phase diagram for spin foams *Classical and Quantum Gravity* **34**(22) 225006

Eglseer L, Hofmann S and Schneider M 2017 Quantum populations in Zeno regions inside black holes *Preprint* arXiv-1710

Eglseer L, Hofmann S and Schneider M 2021 Quantum populations near black-hole singularities *Physical Review D* **104**(10) 105010

Eichhorn A, Mizera S and Surya S 2017 Echoes of asymptotic silence in causal set quantum gravity *Classical and Quantum Gravity* **34**](16) 16LT01

Esfeld, M 2021 Against the dissapearence of spacetime in quantum gravity *Synthese* **199** 355–69

Finocchiaro M and Oriti D 2021 Renormalization of group field theories for quantum gravity: new scaling results and some suggestions *Frontiers in Physics* **8** 552354

Gabbanelli L and De Bianchi S 2021 Cosmological implications of the hydrodynamical phase of group field theory *General Relativity and Gravitation* **53**(66)

Gielen S 2015 Identifying cosmological perturbations in group field theory condensates *Journal of High Energy Physics* **10**

Gielen S 2019 Inhomogeneous universe from group field theory condensate *Journal of Cosmology and Astroparticle Physics* **02**

Gielen S, Oriti D and Sindoni L 2013 Cosmology from group field theory formalism for quantum gravity *Physical Review Letters* **111** 031301

Gielen S and Sindoni L 2016 Quantum cosmology from group field theory condensates: a review *Symmetry, Integrability and Geometry: Methods and Applications (SIGMA)* **12** 082

Huggett N and Wüthrich C 2012 Emergent spacetime and empirical (in)coherence *Studies in the History and Philosophy of Modern Physics* **44**(3) pp 276–85

Huggett N and Wüthrich C 2018 The (a)temporal emergence of spacetime *Philosophy of Science* vol 85(5), ed A Woody (Cambridge: Cambridge University Press) pp 1190–203

Konopka, T, Markopoulou, F and Smolin L 2006 Quantum graphity *Preprint* hep-th/0611197

Le Bihan, B 2018 Space emergence in contemporary physics: why we do not need fundamentality, layers of reality and emergence *Disputatio* **10**(49) 71–95

Le Bihan, B 2019 Spacetime emergence in quantum gravity: functionalism and the hard problem *Synthese* **199**(2) pp 371–93

Mandrysz M and Mielczarek J 2019 Ultralocal nature of geometrogenesis *Classical and Quantum Gravity* **36**(1) 015004

Marchetti L and Oriti D 2021 Effective relational cosmological dynamics from quantum gravity *Journal of High Energy Physics* **25**

Marchetti L, Oriti D, Pithis A and Thürigen J 2022 Phase transitions in TGFT: a Landau-Ginzburg analysis of Lorentzian quantum geometric models *Preprint* arXiv:220904297

Markopoulou F 2009 *New directions in background independent quantum gravity* (Approaches to quantum gravity: Toward a New Understanding of Space, Time and Matter) ed D Oriti (Cambridge: Cambridge University Press) pp 129–66

Meincke, A S 2019 The disappearance of change: Towards a process account of persistence *International Journal of Philosophical Studies* **27**(1) pp 12–30

Mielczarek, J 2013 Asymptotic silence in loop quantum cosmology *AIP Conference Proceedings* vol 1514, no 1 (American Institute of Physics) pp 81–4

Mielczarek, J 2017 Big bang as a critical point Advances in High Energy Physics *Article ID* 4015145

Mielczarek J and Trzésniewski, T 2018 Towards the map of quantum gravity *General Relativity and Gravitation* **50**(68)

Nishimori H and Ortiz G 2010 Elements of Phase Transitions and Critical Phenomena (Oxford: Oxford University Press)

Oriti, D 2007 Group field theory as the microscopic description of the quantum spacetime fluid: a new perspective on the continuum in quantum gravity *Proceedings of science (QG-Ph)* **030**

Oriti, D 2014a Disappearance and emergence of space and time in quantum gravity *Studies in History and Philosophy of Science Part B: Studies in History and Philosophy of Modern Physics* **46** pp 186–99

Oriti D 2014b *Group field theory and loop quantum gravity* (In Loop Quantum Gravity: The First 30 Years) ed A Ashtekar, J Pullin (World Scientific: Singapore) pp 125–51

Oriti D 2017 The universe as a quantum gravity condensate *Comptes Rendus Physique* **18** 235

Oriti D 2018 *Levels of spacetime emergence in quantum gravity* (Philosophy beyond spacetime: Implications from Quantum Gravity) ed C Wüthrich, B Le Bihan and N Huggett (Oxford: Oxford University Press) pp 16–40

Oriti D 2021 The complex timeless emergence of time in quantum gravity *Time and Science* ed P Harris and R Lestienne (World Scientific)

Oriti D, Sindoni, L and Wilson-Ewing E 2016 Emergent Friedmann dynamics with a quantum bounce from quantum gravity condensates *Classical and Quantum Gravity* **33** 224001

Pithis A G A and Sakellariadou M 2019 Group field theory condensate cosmology: An appetizer *Universe* **5**(6) 147

Strobach, N 2013 *The moment of change: A systematic history in the philosophy of space and time* vol 45 (Springer Science & Business Media)

Strocchi F 2008 Symmetry breaking *Lecture Notes in Physics* 732, 2nd edition (Springer)

Tallant J 2019 Causation in a timeless world? Inquiry: An Interdisciplinary Journal of Philosophy **62**(3) pp 300–16

Wittgenstein L 1929 Some remarks on logical form *Aristotelian Society Supplementary Volume* vol 9(1) (Blackwell Publishing on behalf of The Aristotelian Society) pp 162–71

Wüthrich, C 2018 The emergence of space and time *Routledge Handbook of Emergence* ed S Gibb, R F Hendry and T Lancaster (Oxford: Routledge) pp 315–26

Wüthrich, C 2019 When the actual world is not even possible *The Foundation of Reality: Fundamentality, Space, and Time* ed G Darby, D Glick and A Marmodoro (Oxford: Oxford University Press) pp 233–53

Wüthrich, C 2022 One time, two times, or no time? *Einstein and Bergson 100 Years Later: What is Time?* ed S Gozzano, E Coccia, R Ronchi and A Campo (Berlin/Boston: de Gruyter) pp 209–30