Fractal of period spacetime sequences as a framework for an interoperable metaverse

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FRACTAL OF PERIODIC SPACETIME SEQUENCES AS A FRAMEWORK FOR AN INTEROPERABLE METAVERSE

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ABSTRACT:

This paper proposes a new conceptual framework for the creation of an interoperable metaverse seamlessly incorporating AI and blockchain technologies. To achieve this, current issues of interoperability within the discipline's state-of-the-art are first identified. Next, a new virtual ontology of the interoperable metaverse is proposed, inspired by recent developments in assemblage theory and in specific concepts by Gilles Deleuze, Manuel DeLanda, and Paulo de Assis. In the third and fourth parts of this paper, a new technical solution is presented: a taxonomy of *Periodic Spacetime Sequences*, devised for practical implementation of a new distributed version control system. This solution could offer an innovative framework for the interoperable metaverse, which could be built using the proposed taxonomy.

KEYWORDS:

metaverse, interoperability, assemblage theory, Shepard tones, Periodic Spacetime Sequences

> The mental image of the world around you which you carry in your head is a model. One does not have a city or a government or a country in his head. He has only selected concepts and relationships which he uses to represent the real system. (Forrester, 1971. p. 3)

INTRODUCTION - THE PROBLEM OF INTEROPERABILITY

The term *metaverse* was first introduced in Neal Stephenson's novel "Snow Crash" (1992) as a 3D virtual imaginary world where anyone can socialise, create, explore, and display [2]. In that novel, the metaverse is shared over the worldwide fiber-optics network and can be accessed with special virtual reality goggles. In October 2021, Facebook Inc. changed its name to Meta and announced its shift of focus to building the metaverse [3]. Often referred to as the next iteration of the Internet, the concept was quickly adopted by the industry and many companies announced their attempts to build their own independent virtual worlds and associated markets. A general and well-known problem with such an approach is that those worlds are often incompatible with each other.

As observed by Gadekallu et al. [4] the metaverse should be created through the fusion of numerous digital realms, which is not the case with currently available, disjointed platforms. The user cannot create and use one account with a single payment infrastructure to participate in many virtual worlds. The interactions between them should be enabled in-between various compatible applications. Similarly, Yang et al. [5] make a point that metaverse should be interoperable such that users can exchange virtual assets from one platform to another. Further, they argue that a solution could lie in building the metaverse in a decentralised manner, with the use of blockchain technologies. A key feature of blockchains, as defined by Summers [5] is that they allow management and verification of the history of an asset while removing the necessity to trust in a centralised supplier. "On the other hand, recent advances in AI bring solutions to overcoming the challenges of metaverse development, such as big data analytics, AI-empowered content generation, and intelligence deployment" [5]. According to many authors [4, 5, 9], the integration of blockchain and artificial intelligence - with their ability to distribute and generate virtual assets - is foreseen to become a major trend for the development of intelligent and secure decentralised virtual worlds, and they should be fused with the metaverse - bringing a variety of opportunities, triggering new technological innovations and industrial transformation.

Some issues of technological interoperability are already being addressed within separate disciplines contributing to the metaverse development. For instance, an open-source 3D graphics framework - Universal Scene Description (USD) developed by Pixar's studios [7] - is used in many software applications for graphic design such as 3ds Max, Blender, Houdini, Maya, and Omniverse. Its universality already gained USD the title of the candidate for "the HTML of the metaverse" [8]. Yet still, there is no single standard defining a virtual asset, that would enable building an interoperable metaverse with seamless adoption of blockchain and AI technologies.

As pointed out in [4], the key challenge for metaverse interoperability is the challenge of the interoperability in blockchains - in the existence of several public blockchains in different virtual worlds that do not share a common language. An application-level solution to the problem of blockchain interoperability was proposed in [10]. Madine et al. stated that the lack of cross-chain interoperability in blockchains can be attributed to two of their fundamental aspects: smart contracts that cannot be upgraded and thus cannot support future solutions, and the fragmentation of the types of technologies that blockchain systems use, such as consensus algorithm, architecture, and development framework. Lafourcade et al. in [11], claimed that interoperability is impossible under the classical definition of blockchain, which is, by construction, made to be self-sufficient (no blockchain can rely on external data for asserting the validity of a transaction). They prove that under classical definitions, it is impossible to make a blockchain that interacts with anything other than itself. If relaxing the definition, they show that it is possible to create two interoperable blockchains, but doing so is equivalent to creating a "2-in-1" blockchain, with two ledgers.

Tasca & Tessone in [12] state that currently blockchain development is in the stage of "fermentation" caused by "technological uncertainty due to the evolution of the blockchain into alternative technological paths". They further argue that "a heterogeneous development combined with a lack of interoperability may endanger a wide and uniform adoption of blockchains in our techno- and socio-economic systems", and identify concerns connected to heterogeneity. These are for instance: prevention of the innovations in blockchain, prevention of consistency in drafting laws and policies related to the regulation of blockchain, and decreasing the clarity in the academic research. To prevent this, they create a taxonomy of blockchain components and their layouts which encompass: the identification, description, nomenclature, and hierarchical classification of blockchain components. They make it clear that "this is different from constructing an ontology that would be more focused on the study of the types, properties, and interrelationships of the components and events that characterise a system". As observed by Summers in [6], while blockchains can be very powerful, they are however not for everything. There are certainly some downsides to using them such as resource hunger in comparison to other methods of storing and working with data. Thus, the developer should always ask whether a blockchain infrastructure is inevitable for the proper functioning of the created system.

A problem of this nature is already observed in the common blockchain standards for non-fungible tokens (NFTs). Files of NFTs are commonly stored in decentralised storage networks relying on content-based addressing such as IPFS. A content identifier (CID) is given to the shared file, chunks of which are distributed among different peers. Further, NFTs metadata links to the distributed file. Both blockchains and IPFS are de-centralised peer-to-peer systems. Although they are complementary, their infrastructures and objectives are different. Blockchains cryptographically secure information about digital ownership, while IPFS is used for distributed file storage. As observed by Forrester in [1], speaking about social systems:

> In a hierarchy of systems, there is usually a conflict between the goals of a subsystem and the welfare of the broader system. (Forrester, 1971, p. 22)

Transposing this observation to the relations between the metaverse and blockchain technologies, one can question whether a framework for the interoperable metaverse should at all be based on blockchains. To answer this question, I propose first a virtual ontology for such a system, and then a taxonomy of the components of such an ontology. Maybe the aims of the interoperable metaverse are not the same, but only complementary to the ones of the blockchain systems. While the distributed virtual reality infrastructure aims to keep the interoperability of the virtual assets together within the shared spaces, it does not necessarily have to be its goal to also keep it secure - a task that could be perfectly accomplished by existing blockchain networks, possibly living on top of such an infrastructure. Thus, a set of rules should be defined not for control and security, but rather as a kind of virtual ontology, a system imitating the evolution of the physical world in spatiotemporal dimensions. In this paper, I would like to present the groundwork done to create such a system by first proposing a new virtual ontology, and then an appropriate taxonomy of elements for the construction of the virtual spacetime.

Assemblage theory for the metaverse

This section discusses selected concepts from assemblage theory, that might be very relevant for the development of a new virtual ontology for an interoperable metaverse. It is not my purpose to explain assemblage theory or properly reconstruct its core concepts, which is far beside the scope of this paper, but to draw an important alternative to the current notions of virtual spacetime. To perform this task, I will support myself with two primary sources. Paulo de Assis in "Logic of Experimentation" [13] proposes a new image of musical works, based upon the notions of strata, assemblage, and diagram. I will attempt to display that his ontological developments presenting a musical work as a dynamically-located assemblage of musical entities based on the interplay between its *actual* and *virtual* parts through *intensive processes of individuation* can be expanded to any virtual asset. This shall create an ontological introduction for the presentation of a new algorithm devised for the practical implementation of a new distributed version control system in the next section of this paper. My second source is Manuel DeLanda's "A New Philosophy of Society" [14], in which the author develops an assemblage theory for the description of a dynamic model of community - networks as multi-scale assemblages of social structures such as bodies, buildings, neighbourhoods, cities, etc. A crucial link in the works of both authors for building a framework seamlessly integrating virtual assets with social structures - that I intend to present throughout the next paragraphs - is the notion of locality of structures within the *topological spaces of possibilities* in the interplay of *virtual* and *actual*.

Assemblage theory, a set of concepts for addressing problems of transformations, instability, and indetermination in complex systems, can be traced back to French philosophers Gilles Deleuze and Felix Guattari in their joint works from the 1970s and 1980s. According to DeLanda, assemblage theory describes processes of establishing historical continuity of dynamic entities, such as communities, but not only: assemblage is meant to "apply to a wide variety of wholes constructed from heterogenous parts." (DeLanda, 2006, p. 3). As compactly described by De Assis, the ontological views of Deleuze could be summarised with three interrelated domains:

> One is the domain of actual *individual singularities*, of materially existing and observable products of natural and human invention, which can be defined by their extensive properties, by their length, area, volume, weight, number of components, and so on. Next, there is a domain of *intensive processes* (transduction), defined by differences of potential, flows of energy, phase shifts, and critical thresholds (...). They link the individual singularities to the *universal singularities* that remain virtual, some of which are more likely to be actualised than others (*topological singularities*). Finally, there is the domain of virtual *structure*, the *topological space of possibilities*, which diagrammatically maps the universal singularities, and that accounts in a purely

immanent way for the regularities (but also for the inconsistencies) in the processes and in the individuations. The virtual *diagram* cannot exist without the actual and virtual singularities that build it. Nothing would happen in the world without the continuous relay of intensities from the virtual to the actual, and vice versa. This leads to an ontology that is processual, immanentist, and based upon difference (different/ciation), a difference that is conceived not negatively, as lack of resemblance, but productively, as that which drives dynamic processes. (De Assis, 2018, p. 61)

The term *virtual* was not established in connection to virtual reality. On the contrary, for Deleuze, both *virtual* and *actual* are real components of the world – the *virtual* exists here-and-now, having the potential to appear (emerge) in the plane of consistency through *intensive processes of transduction*. Both *actual* and *virtual* entities should be understood as fluent spatiotemporal states of matter rather than their definitive labels. In complex systems, they are constantly subject to *intensive processes*. The theory of assemblages anticipates the existence of a *virtual structure*, the *topological space of possibilities*, a certain kind of mapping of the possible number of combinations in which one *singularity* can *topologically unfold* itself in the process of *transduction* - by constantly shifting its actual state to the next, choosing one of the probable *virtual unfoldings* (*topological singularities*) from the topological *diagram* of probabilities. As emphasised by De Assis:

The complete space is a collection of all possible states that the system can have. Crucially, Riemann also discovered that some points more probably *occur* than others—these are called *topological singularities*. As there are too many possible points in a system (all its *universal singularities*), we cannot map them all. Instead, we can map the topological singularities (also called *attractors*). This is what permits a replacement of hierarchical *categories* and of the *necessary and sufficient* conditions for those categories: a topological space of possibilities, where individual singularities are actualised entities, and universal singularities are virtual points. It is the virtual network of connectors between those topological singularities that makes the *structure* (the *diagram*) of a dynamic system. As Deleuze famously stated, "the reality of the virtual is *structure*". (De Assis, 2018, p. 59-60)

Interestingly the application of this concept to the metaverse generates an idea to construct a single method (based on the concept of diagram) with a known structure of *spaces of possibilities* for constantly analysing and modelling spatiotemporal changes in such a complex temporal network, encompassing this network on all levels of assemblage - from actualisations of a single asset, through actualisations of collections of assets, to actualisations of whole social networks. It is crucial that such a method would provide a framework for a procedural analysis - not in an *organismic* sense, which DeLanda explains as *relations of interiority* in which "the component parts [of an organism] are constituted by the very relations they have to other parts in the whole." (DeLanda, 2006, p. 9) - but through *relations of exteriority*, in which "a component part of an assemblage may be detached from it and plugged into a different assemblage in which its interactions are different" (DeLanda, 2006, p. 10-11). Thus, such a diagram would not provide a mapping of objects with their relations of interiority, but it could provide an overlook of spatiotemporal limits of *transduction* for a given *topological singularity*, and only within the analysed space itself. A process of analysis conducted based on such a *diagram*, would not describe a process with a set of only stable *actual singularities*, but with a set of encapsulated *topological unfoldings*. In parallel, any spatiotemporal object could be synthesised by a superposition of many such unfoldings. In that sense, such a method would not be structuralist, since it would describe a process through relations of exteriority. As defined by Guattari in [15]: "the diagram is conceived as an autopoietic machine which not only gives it a functional and material consistency but requires it to deploy its diverse registers of alterity, freeing it from an identity locked into simple structural relations".

De Assis creates a new image of musical works, based "on the interplay between its actual and virtual parts by means of intensive processes of individuation" (De Assis, 2018, p. 72). He explains that "What traditionally, or at least for the last two hundred years, have been called "musical works" are specific zones, or partial elements of something that can be more aptly described and thought about in terms of musical multiplicities, which are fabricated by intensive processes that generate virtual structures and actual things." (De Assis, 2018, p. 61). The concept that the work of art is constituted by an assemblage of many *virtual* and *actual* elements (scores, audio recordings, program notes, etc.) and their actualisations (different interpretations in concert, different notions of the work in academic lectures, private conversations, etc.) is the core of De Assis thought in this book, further explaining the notions of this concept for the music performer and artistic researcher. Transposing his concept to the metaverse, any artistic and non-artistic asset could be characterised by the same notion of the constantly evolving assembly - a spatiotemporal collection of objects under the name of a virtual asset. What follows, such assemblies could be analysed within a framework of a specifically designed *diagram*. Before presenting such a *diagram*, I would like to refer to one more concept of De Assis, transposable to the metaverse if adapted with the use of my *diagram*.

In a chapter containing eight different ways of thinking through notions of Gilbert Simondon's concept of *transduction*, De Assis speaks about Deleuze and Guattari's concept of *haecceity:*

(…) a concept that theorises the emergence of a singularity at any given scale and field—from molecular encounters, to geological clashes, landscapes, hours of the day, human thought, arts, and so on. (…) a haecceity is a passage, a singular point in space–time that dramatises space–time itself, curving

> it, folding it, giving it transient form and temporal structure (De Assis, 2018, p. 148).

On top of this definition, De Assis proposes a new concept in relation to performing arts (music, dance, theatre, performance) that he called a *micro-haecceity*:

> a temporal radicalisation of the concept, collapsing it into an infinitesimal fraction of a second, into the radical here-and-now of the evolving performance. Such radical micro-haecceities would be characterised by intensive negentropic properties, by an almost instantaneous time of existence, and by following one after the other at very high speed (De Assis, 2018, p. 149).

As he further explains, a pianist performing a musical piece here-and-now navigates high-speed successions of a musical score (prolonged singularities) (De Assis, 2018, p. 149). Musical events happen in an organised order with certain probabilities of being actualised in (potentially) slightly different ways, but still (most probably) within the *topological space of possibilities,* which, in this case, are interpretations of a musical score. Transposing the concept of micro-haecceity to the metaverse, in which all levels of assemblage would be based on a special type of *diagram* allowing for synthesis and analysis of spacetime in terms of *multiplicities* of *topological unfoldings*, we can imagine that similarly to the pianist navigating high-speed successions of musical material, observers in the virtual spacetime would navigate (*transduce*) themselves throughout the interactive, constantly evolving, and self-composing virtual realities.

Transduction is a continuous process of energy transformations that enables the actualisation of certain configurations of events as *multiplicities*. In this process, topology becomes more important than geometry: "figures and shapes are not placed *in* space [geometry]; they constitute spaces in/of their own [topology]." (De Assis, 2018, p. 150). Thinking about generating and tracking a spatiotemporal evolution of parts of the metaverse in terms of assemblage theory, assets should not be perceived as stable three-dimensional models that would be then subject to a computer program for controlling their behaviour (such as in game engines and programs for graphic design). On the contrary, intensive processes within the *topological space of possibilities* should be the only forces that enable the movement of assets within the framework. Thus, the notion of diagram provides an abstract overview of possible events, which emerge as a result of above-mentioned intensive processes.

Fractal of Periodic Spacetime Sequences - Strange Loops and Shepard Tones

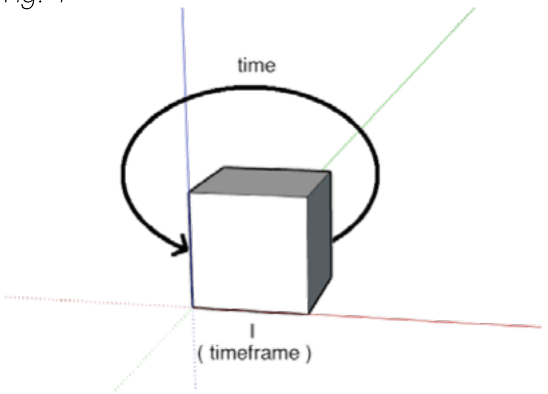
Inspired by Douglas Hofstadter's concept of strange loops[1], in my scheme of the diagram, I use mathematical periodic sequences to represent spatiotemporal movements in topological spaces. In mathematics, periodic sequences can be defined

1 "The "Strange Loop" phenomenon occurs whenever, by moving upwards (or downwards) through the levels of some hierarchical system, we unexpectedly find ourselves right back where we started." [16]

as sequences in which the same terms are infinitely repeated. A progression of terms in a sequence is a progression of recurring discrete time steps. The simplest object of that sort is a periodic sequence with period 1 (a constant function). Since there is only one, constantly repeating timeframe {a1}, an object symbolised by the repeated number is stable and always present.

In fig. 1, this periodic sequence is presented in three spatial, and one temporal dimension. The presence of this object is stable in time - the same object remains present in consecutively repeating timeframes due to the notion of *coding* (a process which I further explain in the next section).

Fig. 1



In a periodic sequence with two terms (let's call it a *sampling rate 2*) there are two constantly repeating timeframes {a1, a2}, and only one of them can be *actual* at any given time. Topologically, it does not matter if this sequence started from the first or the second term because its continuation remains the same. Let's call this feature a *rotation* - any periodic sequence can start from any of its terms (any of its *rotations*). Now, let's assume that sometimes the process of *transduction* (execution of periodic sequences of timeframes) occurs quicker than it can be traced by the perception of observers. For instance, for the human eye, the limit of perceived visual frames is around 30-60 Hz (frames per second). For the human ear, the limit of audible sound is on average between 20 Hz and 20 kHz. In case the received signal is oversampled, only a selection of the original signal can be received, and some terms are skipped by an observer's perception. Applying this concept to the periodic sequence with only two terms {a1, a2}, if every second term would be skipped, this would generate two different periodic sequences with only one repeating term {a1} or {a2} (depending on which term would be skipped). If every third term of this sequence would be skipped, the sequence would not change since the oversampled sequence would be identical to the original sequence {a1, a2}. Let's call this operation a *skip*. As demonstrated, in periodic sequences with two terms this operation does not create any new periodic sequence.

In the case of a periodic sequence with three terms {a1, a2, a3}, skipping every second term creates a periodic sequence with different order of terms {a3, a2, a1} - the same progression, but reversed in time. Thus, periodic sequences with three terms (*sampling rate 3*) have two possible *skips* (the original progression and the original progression in reverse).

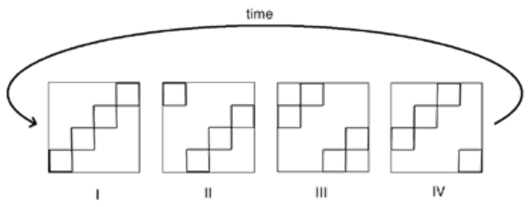
For periodic sequences with four terms {a1, a2, a3, a4}, a new feature appears when skipping every second term, since such generated progression does not include all of the original terms and two possible progressions can be created with the same *skip*. In this case the two possibilities are: {a1, a3, a1, a3} or {a2, a4, a2, a4}. A feature of one *skip* generating more than one progression, where each of them does not have all the terms from the original sequence is a *transposition*. Skipping every third term of the periodic sequence with four terms (*sampling rate 4*) provides the original sequence in reverse {a4, a3, a2, a1}.

So far, I have described a *diagram* of changes (*topological unfoldings*) in one time dimension for a space referring to only one single point. A *structure* (*diagram*) is an infinitely large list of periodic sequences (*topological singularities)* with p-terms and their possible modifications (s*kips* and *transpositions*) generalised to n-dimensions. Generalising a point to more spatial dimensions initiates a question of how to distribute the terms of periodic sequences (in these dimensions) in a way that they would be still periodic.

In 1964, Roger Shepard, a cognitive scientist at Stanford University, presented a Shepard tone as an aural illusion of infinitely raising or decreasing pitch [17, 18]. Shepard tones are musical loops with gradually increasing or decreasing musical scales. When reaching the last discrete step of the loop, a musical scale gradually and seamlessly continues its movement at the beginning of the next iteration of the loop. The illusion effect is achieved by the combination of this setting and the application of special dynamic weights for each note. Shepard tones are examples of periodic sequences with 1 spatial and 1 temporal dimension as musical chords (described by multiple pitch values forming a topological line) progress in time. In such a setting, any amount of terms (for instance pitches in a musical chord) can be assigned to a periodic sequence with any amount of time steps. For instance, six spatial terms {a1, a2, a3, a4, a5, a6} can be assigned in a Shepard tone-like setting to any periodic sequence. In *sampling rate 2,* the first sample would be {a1, a3, a5}, and the second {a2, a4, a6}. In case of *sampling rate 3*, the first term would be {a1, a4}, the second {a2, a5}, and the third {a3, a6}. If the *sampling rate* is equal to the number of spatial terms, then each timeframe will contain one term: {a1}{a2}{a3}{a4}{a5}{a6}. If the sampling rate value is higher than amount of terms, for instance *sampling rate 10*, then some timeframes will be empty: {a1}{a2}{a3}{a4}{a5}{a6}{ }{ }{ }{ }. Next, previously defined modifications can be applied to the generated sequence, for instance *sampling rate 10, skip 2, transposition 1, rotation 1* generates a sequence {a1}{a3}{a5}{ }{ }{a1}{a3}{a5}{ }{ }. To create an aperiodic sequence, one more parameter should be established to describe the number of terms from a periodic sequence that should be included in the final sequence - a *period*, for instance: *sampling rate 10, skip 2, transposition 1, rotation 1, period 6:* {a1}{a3}{a5}{ }{ }{a1}.

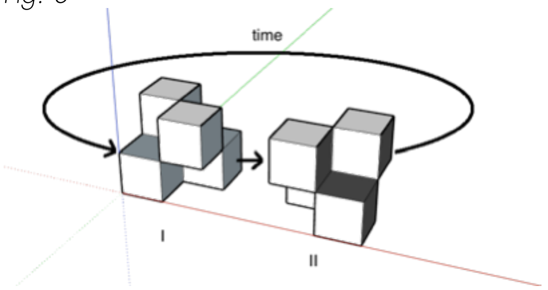
Shepard tone-like periodic sequences can be further generalised to 2 spatial + 1 temporal dimension (moving image), 3 spatial + 1 temporal dimension (moving objects in 3D space), and more. In the case of 2 spatial + 1 temporal dimension, the time dimension becomes the second spatial dimension, creating 2-dimensional planes in which time movement is *transduction* through all of the rotations of that image (the effect remains a movement of a barber's pole, see fig. 2).

Fig. 2



In the case of 3 spatial + 1 temporal dimension, all 2D rotations are positioned one after another on the z-axis, and the movement in 3D space is a periodic sequence of them rotating through the z-axis (see fig. 3).

Fig. 3



The number of *sampling rates*, *skips*, and *transpositions* is universal no matter the number of dimensions and localised terms. They can be visualised in a form of a universal shape (with *skips* in verses, and *transpositions* in columns) - an infinitely growing fractal that I call a *Fractal of Periodic Spacetime Sequences* (fig. 4 presents - bottom to top - its first 20 *sampling rates*). It is a list of *topological singularities (spacetime sequences)*, which further can be subject to the processes of *coding* and *territorialisation,* to assemble and describe events in the metaverse (concepts explained in the next section of this paper).

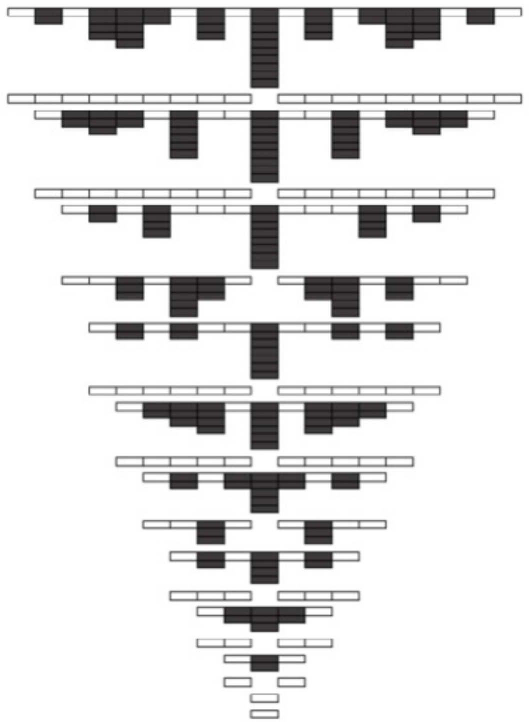
Amounts of *transpositions* and their rotations for any *skip* can be calculated algorithmically in the following way [18]:

For *skips* where: *sampling rate* % *skip* = 0:
- the amount of *transpositions* = *sampling rate* / (*sampling rate* / *skip*),
- the amount of *rotations* = *sampling rate* / *skip*.

For *skips* where: *skip* > (*sampling rate* / 2) && *sampling rate* % (*sampling rate* - *skip*) = 0:
- the amount of *transpositions* = *sampling rate* - *skip*,
- the amount of *rotations* = *sampling rate* / (*sampling rate* % *skip*).

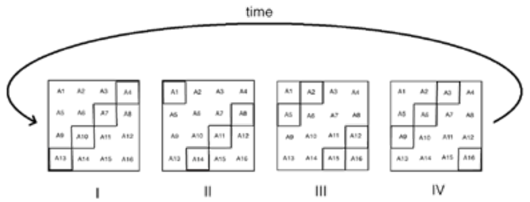
For other *skips*:
- *skips* have no *transpositions* because skipping will change the order of samples without missing any samples,
- the amount of each *skip's rotations* is equal to the *sampling rate*.

Fig. 4



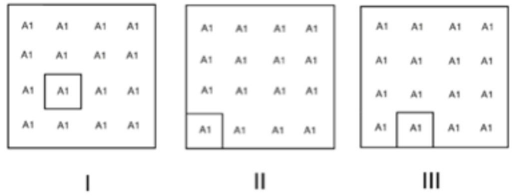
Looking again at the progression of timeframes in fig. 2, intuitively we might think that it depicts a movement of objects (represented by squares) on a 2-dimensional plane, but terms in a sequence should rather be understood as binary states. They describe whether - in a given timeframe - an object is present (*actual*, its binary state is "true"), or not (*virtual*, its binary state is "false"). The location on a plane is always bound to the same object - it is the state of presence of that object that is described by periodic sequences (fig. 5).

Fig. 5



Changes of the location of a given object in an n-dimensional space of any size can be analysed as changes of binary states in space where every term is the same object (fig. 6). In object-oriented programming, objects can contain other objects, which means that the term {a1} can contain (consist of) multiple multidimensional periodic sequences of object, which can then contain further objects and so on.

Fig. 6

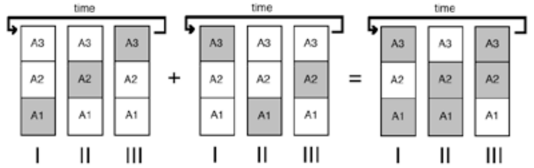


Synthesis and analysis of assets

In every *Periodic Spacetime Sequence* alone, an object is "true" only for the duration of one timeframe, as - in the process of *transduction* - the binary state of each object is constantly changing. What is more, each location contains only one object at any given time (either in a "true" or "false" state). In this section, I will demonstrate that any digital asset can be synthesised and analysed with a set of *Periodic Spacetime Sequences*. My method for synthesis and analysis of virtual assets implements notions of two processes (*coding* and *territorialisation*) allowing synthesis and analysis of sequences in which objects remain stable for any duration, and each location can contain any number of objects.

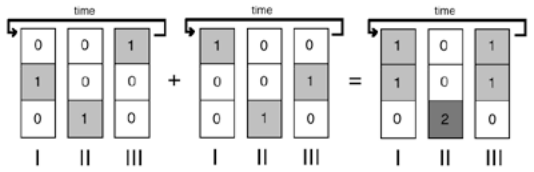
Coding relates to the identity of an assemblage, providing information about which entities (bodies and regulations) belong to it. In my interpretation of this concept, it is a process that makes an object stable in time for longer than one timeframe. As presented in fig. 7, the process of *coding* occurs when - in the result of superimposing two or more periodic sequences with each other - the binary state of an object remains "true" (grey colour) in two or more consecutive timeframes. If the example in fig. 7 would be used for music notation where each timeframe would represent the length of a quarter note, then as a result of this operation, each of the notes (objects) started in the leftmost progression as quarter notes, would become halftones.

Fig. 7



Processes of *territorialisation* "define or sharpen the spatial boundaries of actual territories. (…) [The concept of *territorialization*] plays a synthetic role, since it is in part through the more or less permanent articulations produced by this process that a whole emerges from its parts and maintains its identity once it has emerged." (DeLanda, 2006, p. 13-14). The implementation of my notion of this process enables the synthesis of sequences in which there can be more than one object in one location. For instance, in music notation, this could mean that a note is louder, in graphic design that there is more of a certain colour in a certain spot on the canvas, in a 3D space that one element of the landscape is heavier than another element, and in the metaverse that there is more than one observer in the same (public) location (the notion of which I further explain in the next paragraph). In fig. 8, the process of *territorialisation* during the synthesis of the periodic sequences can be observed in the binary states of objects - 0 for objects with a "false" state, 1 for objects with a "true" state, and 2 for locations where there are more than 1 "true" state objects as the result of synthesis.

Fig. 8



Any multidimensional array can be analysed as a set of *Periodic Spacetime Sequences*. A proof that it is possible is that for any multidimensional space, in the *Fractal of Periodic Spacetime Sequences* there is a *skip* that has a number of *transpositions* equal to the number of unique terms (objects) in a given array. These terms can be further positioned at any of the samples with the use of *rotations* to find the position of each term in a given sequence. It means that any asset based on multidimensional matrices can be analysed with *Periodic Spacetime Sequences* using at most one periodic sequence per each localised object. *Rotations* containing each object of a given periodic sequence, where there is only one object with a "true" state per each *rotation* can always be found in the *skip* equal to the number of unique terms, with a *period* equal to the multiplication of the *sampling rate* and the number of unique terms (in the analysed sequence). For instance, I have previously presented in [18] that Bach's Minuet 2 from Cello Suite no 1 can be analysed note-by-note by 144 *Periodic Spacetime Sequences*.

While there are many potential applications of this method - including audio, score, graphics, video generation, analysis, and modelling of 3D assets in time - I believe that it would find its best applications in the metaverse, because it allows not only a precise description of assets, but also information about changes of their locations against each other on multiple levels. A big advantage of this method is that multidimensional data can be analysed with elements that are abstract from the amount of used dimensions - *Fractal of Periodic Spacetime Sequences* is a universal shape, which means that both: data notated in 4 dimensions and data notated in 1 dimension can be analysed with the same system. This data would have to be further translated to determine whether a matrix is for instance an image or an audio file. A framework for the interoperable metaverse that I propose would not include mechanisms of translation, leaving the standard open to interpretation of creators, developers, and artists, enabling decentralised formation of the metaverse.

Framework's architecture – observers, blockchains, and AI agents

DeLanda in [14] develops an assemblage theory for the description of a dynamic model of community - networks as multi-scale assemblages of social structures such as bodies, buildings, neighbourhoods, cities, etc. He explains his notion of *territorialisation* as a process giving shape to social structures:

> The concept of territorialization must be first of all understood literally. Face-to-face conversations always occur in a particular place (a streetcorner, a pub, a church), and once the participants have ratified one another, a conversation acquires well-defined spatial boundaries. Similarly, many interpersonal networks define communities inhabiting spatial territories, whether ethnic neighbourhoods or small towns, with well defined borders. (DeLanda, 2006, p. 13)

Further, he explains that similarly to assemblages such as organic and inorganic matter, social systems also possess their own diagram, and changes in social assemblages are also subject to the notion of *spaces of possibilities*:

> (…) while persons, communities, organizations, cities and nation-states are all individual singularities, each of these entities would also be associated with a space of possibilities characterized by its dimensions, representing its degrees of freedom, and by a set of universal singularities. (DeLanda, 2006, p. 30)

Envisioning a framework that would combine the previously mentioned new image of musical works of De Assis (my notion for the construction of any digital asset) with the social notion of assemblage theory of DeLanda, I would like to propose a scheme consisting of three interrelated layers of assemblage as a framework for the interoperable metaverse. First is a layer of a single asset, where *Periodic Spacetime Sequences* determine the structure of an asset. In the second layer, periodic sequences determine the movement of multiple assets (multiple first layers) in relation to each other in one space. The third layer is a space in which the positions of all spaces (second layers) are described. Now, let's imagine that this system is stored on a local machine and there is only one user (*observer*) interacting with it. *Observer* owns all three layers of assemblage in a form of a multidimensional matrix analysed with a set of *Periodic Spacetime Sequences*. As in the previously mentioned example of De Assis, in which musicians *transduce* musical works in their performances, *observers transduce* (*observe*) the metaverse as it progresses in time. The history of the system is updated when observer modifies the state of any object by adding or removing *Periodic Spacetime Sequences* on any of the three layers of assemblage. Even thought the system is in constant movement, it is the change to the system caused by the *observer* that generates the notion of time. Such a local system is a private metaverse.

A public space can be created by sharing the ownership of assets, spaces, and spaces of spaces with other *observers* in the fourth, distributed layer of assemblage in which the ownership can be controlled by *Periodic Spacetime Sequences* too, in a setting where observers are the terms of a periodic sequence put on top of lower layers of assemblage. The information in digital systems (such as a graphic or an audio file) can always be copied. This creates a problem of consensus - how to make all *observers* agree which version of the metaverse is true. In blockchains, the concept of non-fungible tokens is not to prevent the copy, but to establish a community that agrees on the ownership of certain assets. Similarly, different blockchain networks can be used on top of the proposed framework maintaining their separate communities. The interoperability of the system lies in its architecture based on *Periodic Spacetime*

Sequences. For instance, a copy of the metaverse could be minted on blockchain A. Participants not agreeing on the shape of the metaverse in blockchain A, can mint a copy of that metaverse on blockchain B from now on developing as a separate space. Thus, it is not a new special blockchain that should be established for the creation of the interoperable metaverse. The metaverse is not a system - it is a mental model operating on the notions of private and public spaces distributed in many networks, interoperable on the low level of their architecture.

Time in such a metaverse is dependent on the moving component. This raises a question of how can self-evolving assets develop in the world which only exists when observers manipulate it. A solution is to grant a status of an *observer* also to AI agents. Humans or such computer programs could control a human-like avatar, but also an asset of a growing plant, an interacting digital animal, or a weather system. Thus, AI agents together with humans, also play a role of *observers* and move the time of the metaverse forward. AI models are already commonly trained on multidimensional matrices making them immediately interoperable with the envisioned notion of the metaverse. They could help us better understand, govern and manipulate the virtual environments by understanding changes both on the level of assets and on the level of social structures.

Conclusions and Further Work

In the course of this paper, a new conceptual framework for the creation of an interoperable metaverse was presented, inspired by specific concepts of assemblage theory, and working on the newly proposed taxonomy of n-dimensional periodic sequences. This solution could offer an innovative approach not only to future practical implementations of the metaverse, but it could also serve immediately as a method for synthesis and analysis of various digital assets. This method has to be further explored both on a technical level (as a system), and through artistic experiments, developing a novel method for interdisciplinary computer art.

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