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ORIGINAL RESEARCH

A Functional - Helix Conceptualization of the Emergent Properties of the Animal Kingdom: Chronoception as a Key Sensory Process

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Abstract

Teleological theories are often dismissed in the study of animal behaviour, because of both the anthropomorphic element, and the paradox of retro-causation. Instead, emergent properties of animal systems, such as those which drive behaviour and decision making, are generally deemed to be non-purposeful. Nonetheless, organisms' interactions with the environment, including sensory processing, have long been subject to biological study, and the resulting models include Jakob von Uexküll's functional circle (part of his 'Umwelt Theory'). The functional circle is modelled on an assumption of three- dimensional space containing matter and energy, and one-dimensional, linear time. Moreover, the function of such models relies upon feedback within biological systems, and generally assume that the functional feedback loops close. I argue that this is impossible, because a feedback loop cannot go back intime to close itself, and so whilst it may approximate closure in space, it does not close in the dimension of time. To address this problem, I propose a conceptual model where time is treated as having a three- dimensional structure, and is measured in terms of past, future, and subjective present, termed the 'period,' 'present' and 'phase,' respectively. Space and matter, meanwhile, occur as a two-dimensional intersect, in which three-dimensional emergent properties which occur ion time are embedded. The model relies on functional helices rather than circles, and the loops of each helix (unlike circular loops) never achieve closure. I explain how this therefore results in a biological system, based on both feedback and anticipatory probabilities, which is both autopoietic and teleological. I also provide examples of how the concept can be applied, using foraging behaviour as an example. I further propose the theoretical origin of such a system is 'timing' and 'rhythm,' both of which I argue have their origins in single cellular organisms' chemotaxis and the associated gradient descent search.

Keywords Animal behaviour · Cognition · Functional circle · Consciousness · Teleology · Time

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Introduction

The aim of this paper is to produce a conceptual model of animal consciousness, which integrates cognitive emergent properties, behaviour, and the environment, whilst treating emergent properties as entities distinct from the body and physical matter, albeit embedded in physical matter and space. The model also employs a teleological approach to demonstrate organismal agency and autonomy. Teleology and goal-directedness of animal behaviour have historically been dismissed by the biological sciences because goal directed behaviours are perceived as being anthropomorphic i.e., a non-human animal consciously 'trying' to achieve a predicted desired end-result (or direct the course of evolution). This is generally not deemed to be consistent with the results of empirical scientific studies (Riskin, 2020), and yet empirical studies to date tend to avoid teleological interpretations of empirical data.

However, complex systems such as the nervous system in animals generate emergent properties broadly referred to as 'consciousness' or the 'mind', which can be described as a complex product of the functional parts (Bhalla & Iyengar, 1999). Whilst Bhalla and Iyengar (1999) focus on the structure and function of the physical components, such as neural signalling pathways, Chalmers (1995) takes a holistic approach, and discusses the concept of consciousness itself, e.g., how it is characterized, and how it is understood and studied by researchers. Chalmers (2006) goes on to distinguish between 'strong' and 'weak' emergence, with strong emergent properties, such as 'consciousness', having a more significant impact than weak emergence, the latter of which can, for example, be observed in the 'behaviour' of automata. Further, developments in the field of epigenetics have provided evidence to support the theory that organisms can act with agency to affect their environment and shape their evolutionary trajectory (Noble, 2021). Furthermore (and significantly) when addressing issues regarding agency and its relations to deterministic models of behaviour and evolutionary biology, Wright (1972, p. 206), states that "*…determinism can fail without affecting the goal-directedness of the behaviour*" i.e., a behaviour, or behavioural state can be indeterminate yet goal-directed. Thus, there are strong arguments to integrate teleological theory into our understanding of animal behaviour and cognition, and the evolution of consciousness.

Nonetheless, whilst Matsuno (2016) posits that retro-causality exists on a quantum level, and may therefore have driven prebiotic evolution by allowing the chemical and molecular reactions which eventually formed living organisms, the difficulty with teleology remains that in living systems (and at a whole-organism level), end-processes cannot dictate the process itself. Retro-causation remains impossible due to the limitations imposed by one-directional time in a space-time continuum.

Theories have been described which aim to describe how the problem of retro-causation can be overcome, one example being Babcock's and McShea's (2021) 'Field Theory'. The theory proposes that 'fields of attraction' explain goal-direction in biological systems. One explanation as to how such a field could arise in animal behaviour, is that a field of attraction occurs due to mathematical attractors in the complex living organismal system, and in the environment. Concepts such as 'needs,' 'desires' and 'intentionality' can be explained by an organism's perception of the internal and external environment where, for example, subjective experiences such as 'hunger' are the means by which an organism searches for and processes resources in the physical requirement to acquire energy and nutrients. Whether functioning due to mathematical attractors or not, explaining how 'fields of attraction' function in applied evolutionary and behavioural biology still potentially poses a problem when establishing field theory as a truly teleological system i.e., why would an individual be attracted to an object if there was not first a need or desire for the object? Social learning does not account for the behaviour of the first individual that is attracted to a novel object, and nor does it account for a field of attraction to a particular object in an individual of a solitary living species or the occurrence of the phenomenon across a species where populations are isolated from one another (unless it arose independently on each occasion). It is possible that this phenomenon could be explained by serendipity and an initial chance encounter with the object, which results in net gain to the organism; thus, the evolution of the system (both at an individual and population level) involves the development of fields of attraction as the system's individual components (i.e., individual organisms) increase their tendency to move toward the object as their 'needs' are fulfilled. Nonetheless, for a chance-encounter to result in a field of attraction, the mechanism for the object to act as an attractor must have been present in the first instance. This leads to a causality dilemma in teleological explanations: which came first; the need, or the attraction to the specific object?

However, there is an alternative explanation which encompasses field theory, and allows for teleology in animal behaviour and cognition, without focussing on a single 'need' or 'intention' driving a field of attraction toward a novel object or environment. That explanation is best illustrated by using the example of a mind game developed by two prominent mathematicians, Anatole Beck, and David Fowler.

A description of the game was published in 1969, in Warwick University's publication, "Manifold", and it is called 'Finchley Central' (Beck and Fowler, 1969, a link to the article is in the appendix). Finchley Central is the name of an underground train station in London, UK, yet the station has also lent its name to the eponymous two-payer mind game, 'Finchley Central'. Each of the two players calls out the name of a London underground station, in turn. The winner is the player who first calls 'Finchley Central,' and yet should the first player call 'Finchley Central' as their opening move, *the game will not commence*. Thus, the usual rules of winning are inverted; the aim is not to win, *but to avoid losing*. The game of 'Finchley Central' therefore demonstrates the underlying principle of a model describing how teleological organisms can work mathematically. The 'goal' (or purpose) of the system is not to achieve a particular end and 'win' (or move along a single 'field of attraction to an end point'); the goal is to avoid death whilst maximizing the perpetuity of genetic material and culture into subsequent generations, or more simply, *to avoid losing*. The 'game' in this teleological system, is the life of the organism. Therefore, the immediate goal or purpose of a behaviour does not need to be fixed as one specific defined object or outcome. Rather, specific goals can be selected and adapted to avoid the system failing, similar to Taylor's 'principle of selection' described by Wright (1972), citing Taylor (1964).

Whilst the ‘principle of selection’ may appear to solve the retro-causation problem in teleological theories, because an individual’s life history is treated as being non-deterministic, the causal difficulties posed by temporal restrictions are not entirely resolved. Whilst the ‘principle of selection’ allows for plasticity in choice, the outcome of the choice cannot be guaranteed, so statistically, the organism must make more ‘correct’ choices than ‘incorrect’ choices in novel situations, in order to learn or develop desirable behaviours which lead to successful goal-directed outcomes. The greater the number of available choices, the lower the probability of the choice having a successful, or even neutral outcome. The difficulty therefore still arises that a feedback loop (and the information it contains) cannot travel back in time to close itself in a living organism, and so the system relies on chance to play a significant role in tipping the balance toward ‘successful’ outcomes.

Despite this, feedback loops are fundamental components of biological systems, controlling physiological, cognitive, and behavioural mechanisms in the animal kingdom. The problem with presenting them as cybernetically controlled ‘closed loop’ feedback systems, however, is not only that they cannot travel back in time to close, but that at the point the loop apparently closes, the complex dynamic system in which it is embedded has changed. This means that with the passage of time, the object which is the closure- point has also changed. Thus, feedback loops only ever close at an approximate point in physical, three- dimensional space in which the emergent property is embedded, at a future point in time.

To overcome this problem, I therefore propose an ‘open-loop model’ or helical model of animal biological systems, and incorporate both functional-loop, and anticipatory processes to describe the emergent properties of animals as a teleological system. Such systems include animal behaviour, cognitive and decision- making processes, emotion, and therefore, complex concepts such as consciousness and ‘the mind’. By combining teleological goal-directedness with these other constructs, I aim to both describe an emergent cognitive and affective system and explain how the model can be applied to animal behaviour and cognition. The three theoretical approaches I specifically aim to incorporate are cybernetics, Uexküllian ‘Functional Circles’, and Rosen’s ‘Anticipatory Systems Theory’.

Cybernetics

Norbert Wiener published his seminal work on cybernetics in 1948, and it is still in print today. The sub- title of the book is “Control and Communication in the Animal and the Machine” and the premise is the fundamental aspect of feedback in complex systems (Wiener, 2013). A feedback system is vital; it provides information, in the form of meaningful empirical data from the internal and external environment to organisms with respect their nutrient and fluid intake, orientation in space, temperature, gas exchange, disease/injury status, excretory systems, and other homeostatic mechanisms:- the essentials of life itself (Wolkenhauer & Mesarović, 2005). Moreover, cybernetic systems mediate social relationships as organisms interact to transmit and share information. Indeed, the common definition found in animal behaviour (Bradbury & Vehrencamp, 2011) is that communication involves information being transmitted, which then alters the behaviour of the receiver. Thus, communication acts as feedback from the social environment, which controls the behaviour of the interpreter. Unlike radical behaviourist theory, however, the feedback is not a binary stimulus-response algorithm, where ‘reinforcement’ and ‘punishment’ controls behaviour, as described by Catania (1984); cybernetic control allows for complex dynamic processes and statistical probabilities governing biological and cognitive processes, giving rise to organismal agency. Whilst Catania (1984) argues that Skinner’s radical behaviourism does not use observable behaviours simply to represent cognitive processes, it would be difficult to defend this argument, as cognitive processes (or even simple neural processes) control behaviour. Consequently, cybernetic controls allow for complexity, choice, anticipation of environmental events and embodied responses to the environment, making cybernetic systems fundamental to biological control systems. Nonetheless, there are alternative theories to ‘pure’ cybernetic systems, which draw on the prominent element of cybernetic control; feedback. I will use two of these models to describe a novel approach to cybernetic control of living systems, and these are von Uexküll’s ‘Functional Circle’, which is the basis for Umwelt Theory, and Rosen’s Anticipatory Systems Theory, which is derived from the concept of ‘Relational Biology’ and relies on feedback between natural models, and an organism’s internal formal models or schema.

Von Uexküll’s ‘Umwelt’ and the ‘Functional Circle’

Perhaps one of the most well-known (and sometimes misunderstood) theories relying on feedback loops in biology is Jakob von Uexküll’s Umwelt theory, and the ‘Functional Circle” (Kull, 2019). More than simply a phenomenological approach to studying animals, the Uexküllian model is a cybernetically controlled functional loop, whereby an organism receives feedback from the environment which in turn affects internal physiological and cognitive processes, before influencing the organism’s behaviour, and ‘closing’ the circle at the object in the environment which initiated the loop (Brentari, 2015). The effector processes enable the organism to adapt and changes its behaviour in response to feedback. Thus, in response to sensory input, the organism acts upon its environment, including other individuals in the environment, and as a result, further feedback is generated for the organism, causing a series of discrete Euclidean functional circles in time. The whole process is mediated by semiosis, or sign- processes (Cerrone & Mäekivi, 2021; Kull, 1998). However, the problem with this representation is the dimension of time. For such a functional loop to close, it would be necessary for the semiotic process either to stop time or travel back in time to close at the point it began. Spatially, the former would not be problematic in a static system; the functional loop closes, and the system responds accordingly. However, a dynamic system is constantly in a state of change over time and thus, it would be impossible spatially for the loop to close at the same point in the system it began. In the latter case, it is not possible for a loop to travel back in time to close itself, according to current understanding of unidirectional time. Whilst this did not pose a problem for von Uexküll’s vitalist approach to biology, current teleological approaches (which focus on goal-directedness of the organism rather than external factors driving evolutionary and behavioural processes), do not support the idea that organisms are 'designed' to fit their habitat niche by external agencies or forces.

An example of the temporal phenomenon which is problematic in teleological theory can be observed in shark foraging behaviour, as a shark follows a chemical trail to its prey. Sharks track chemical plumes in water (Gardiner & Atema, 2010) and respond to the timing of the arrival of each molecule at one of the nares (Tricas et al., 2009). In the case of detection of the chemical molecule, there is no loop- closure because the molecule is detected by receptors within the olfactory epithelium, a signal is then sent to the central nervous system and the shark adjust its orientation in the water, producing a linear rather than a circular effect. Nonetheless, perception of the molecule guides the behaviour of the shark, so that it moves toward the source of the molecule. At that point in time, however, the 'object' is simply a chemical molecule, not the prey item itself. If the molecule is expelled from the shark's body, this will occur at a later point in time than when it entered the olfactory epithelium, and whilst it may fundamentally be the same molecule, it is dissolved in a solution, forming chemical bonds which are different from those when it arrived at the shark's perceptual apparatus. Thus, the molecule has essentially changed in nature since it was detected. Moreover, the shark is now inhabiting a different locus in the ocean from where it detected the molecule. The sequence of events, however, continue as the shark detects further molecules which direct its behaviour and movement, sometimes possibly even detecting the same molecule again, until the 'loop' is closed at the point the prey is encountered and attacked. This means that with the passage of time, the closure point changes until the shark reaches its prey and the functional circle finally appears to close; hence, functional circles only ever close at a future point in time.

Arguably, this example of a shark tracking an odour plume could rely on attractor processes described by Babcock's and McShea's field theory, and yet it differs significantly in that the process is iterative and relies on semiotic guidance toward the final outcome. Nonetheless, my previous criticisms of Field Theory apply:- does the 'need' and 'intention' precede the attraction, and if so, how were the necessary sensory receptors in place to generate a field of attraction for the shark in the first instance?

To answer the apparent paradox, if the goal of the shark is shifted toward avoiding hunger and malnutrition, then the issue of whether the need or presence of an attractor came first is resolved. The semiotic meaning of the odour molecules becomes one of avoidance of the absence of a necessary resource; there is no specific necessity for the shark to 'need' this one particular odour molecule or what it represents (a specific prey item). It is not pursuing a specific attractant, but being guided away from hunger. Thus, this model also provides a potential explanation of how species are able to diversify into environments where resources are scarce and must be sought via exploration of the environment, and for species to evolve to exploit a multitude of resources. The odour molecules are semiotic markers on the field of attraction, which guide the shark not to one specific cognitive goal, but to a point in space and time where it can avoid the deleterious consequence of not acquiring nutrients. The sensation of hunger creates a negative feedback loop which, when the sensation becomes too intense, causes the animal to take action to avoid the sensation. Indeed, foraging behaviour often involves iterative sampling of objects in the environment via different sampling methods (even when the objects are unfamiliar) rather than an immediate attraction to a particular food source, as demonstrated by Nonacs and Soriano (1998), Krebs et al. (1978) and Towner et al. (2016).

This example therefore supports the proposal of a helical model of emergent properties, with the incorporation of both teleological and cybernetically- controlled feedback processes. Nonetheless, the 'Functional Circle' does not operate in isolation. It is a complex component of a web of interacting functional circles, some originating from within the organism itself, such as those circles beginning from the organism's internal homeostatic mechanisms or (in Uexküllian theory) the 'Innenwelt'. Thus, to describe the proposed model, I will introduce another theory which deals with such complexity; that of 'Anticipatory Systems Theory'.

Rosen's Anticipatory Systems Theory

Robert Rosen's 'Anticipatory Systems Theory' (Rosen, 2012) postulates that organisms have an internal model of their own system, as well as a model of the environment. This allows an organism to compare the natural systems' responses to the environment to its own formal internal model or schema of the environment and of optimal system functioning (Vega, 2018). Thus, an individual is able to predict and respond to changes in the environment very rapidly, before the environmental change even occurs, via a dynamic functional feedback system (Rosen & Kineman, 2005) which has the features of a cybernetically controlled system, but with the added dimension of using feedback to formulate predictions; i.e., the organism learns what to predict and expect based on probabilities and prior information, and can therefore adjust its behaviour accordingly, depending on predicted environmental conditions. Essentially, there is a phase- shift between the organism and its anticipatory schema, which gives rise to a feedback system between the two models. However, again, as with von Uexküll's functional circle, a problem arises in that the functional system can never match anticipated projections to achieve full closure: i.e., the anticipatory system will never match actual future environmental conditions precisely. An anticipatory model based upon stochastic environmental variables will never have complete fidelity to actual environmental conditions, and thus optimal functionality, and so functioning will usually be sub-optimal (except for random chance events where anticipated conditions match actual conditions). Indeed, in the worse- case scenario, the anticipatory model will be entirely incorrect. Whilst an organism is potentially able to avoid catastrophic events and adapt to pursue goal- directed behaviours, it is constantly playing 'catch- up' with an ever- changing environment (internal or external), and if the environment becomes chaotic, the system will inevitably fail because an unpredictable environment cannot be anticipated.

However, there is a significant paradox created by Rosen's Anticipatory Systems Theory, which creates a causal loop. The paradox arises because, by anticipating (but not knowing) future events, an organism can bring about the very set of circumstances which it anticipates. An example is the phenomenon of vocal alarm calls, which are a feature found across animal taxa with vocal capabilities. Alarm calls are given to alert conspecifics to the presence of a predator and thus indicate the anticipation of danger and attack (Shelley & Blumstein, 2005). Paradoxically, however, alarm calls may also alert the predator to the presence of its prey, thus resulting in the anticipated predatory strike. Whilst the alarm call can be predicted to bring about some survival advantage to the individual and group from an evolutionary perspective, by anticipating a hazard and responding to the anticipated hazardous event, the organism risks bringing about the very environmental conditions it anticipated.

Thus, to summarize the two models; von Uexküll's model allows for plasticity in a stable environment (Tønnessen, 2009), but responses are unpredictable and relatively slow. They do not allow for anticipation; they are reactive processes, albeit more complex than a simple binary stimulus-response mechanism, because they are dynamic and occur at every level of organisation, from cellular to whole-organism. Rosen's system, meanwhile, relies on anticipation and gives a 'best fit' prediction, allowing for rapid, proactive and responsive change in a stochastic but predictable environment (Gare, 2019). Nonetheless, it is also relatively inflexible in an unpredictable, chaotic, and harsh environment (the latter defined as being an environment where survival chances are low) because an organism can only anticipate its future state if the environmental parameters are known and predictable. Despite the apparent problems posed by unpredictable and harsh environmental conditions, anticipatory systems can exist and adapt in unpredictable and hazardous environments, but to maximise their potential they must combine both reactive, and proactive anticipatory processes. By combining von Uexküll's 'Functional Circle' and Rosen's anticipatory system to create a complex teleological model, such a system can be achieved. To model this system, however, it is necessary to model emergent processes such as decision making, cognitive processes, and unconscious control of behaviour - including autonomic system function - using non-Euclidean helices to describe cybernetic control, rather than the 'Functional Circles' employed by von Uexküll.

A Helical Model of Emergent Functional Systems in Animals

The conceptualization of the proposed model relies upon a multi- dimensional space. Emergent properties arise from physical processes and structures, represented as being a two-dimensional intersect with the emergent properties' dimension. Emergent properties are (for the purposes of the model) assumed to occur within a three- dimensional representation of time; indeed, these are the semiotic processes relied upon in Uexküll's theory. However, referring to Fig. 1; because each 'open loop' in the helix is one individual, isolated component of a complex web of helical sign- process, including those of internal physiological systems, the organism's memory gives rise to a complex internal schema, as described by Rosen's model. Referring to Fig. 2: in the proposed model, time (not physical space) is viewed as being three- dimensional. Time has three distinct aspects: the present, the period and the phase. The present is represented by the two-dimensional area, where points on the horizontal axes intersect with the vertical axes, and this area represents physical

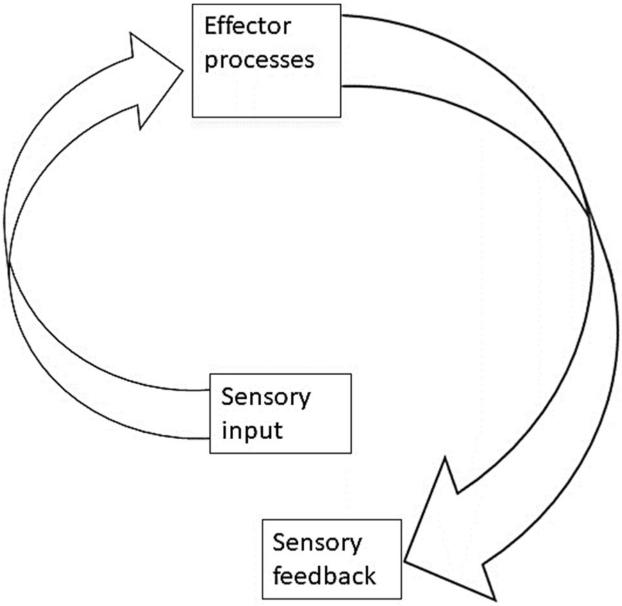

Fig. 1 A reinterpretation of an Uexküllian Functional Circle, which does not close either in time or space. One period of a helical model of feedback which moves in three-dimensional time

'space' and 'matter' (i.e., the body of the organism and the environment it inhabits). The intersect of space and time moves as time progresses in one direction, and the model therefore represents both the external, objective passage of time at the point of intercept, and the internal subjective experiences of the organism via the helical loop. In summary:- time is represented as a three- dimensional object, through which two-dimensional space and matter move.

Each functional loop is not presented as a closed loop; rather, the form is a helix which progresses through phases in multi-dimensional time, and whilst approximate closure of the loop may occur in space, it does *not* occur in time. The model thus describes a system which is constantly moving toward a state of closure, but which can never achieve full closure because a functional loop cannot travel back in time to close itself. Moreover, the dynamic system in which the loop is embedded changes as the system moves away from the point the functional feedback process begins; hence the closure in space is an approximate, and not a complete, closure of the loop.

The static model (or a series of functional circles, where time is standing still) can be described thus:

$$\text{present (p)} = \overline{AB}$$
$$\text{space (s)} = \cos(\text{present})$$
$$\text{time(t)} = \sin\ (\text{present})$$

Helical motion (torsion) occurs as the process (originating in, and embedded in space) moves through time:

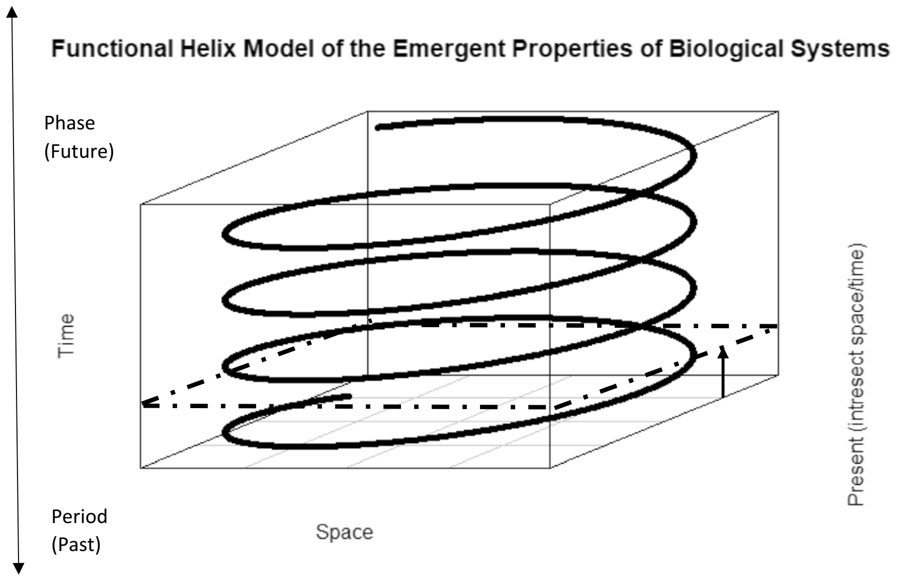

Fig. 2 Helical model of emergent properties of animal systems such as cognitive processes. As a two-dimensional space moves through three- dimensional time, the intersect between physical space (and matter) and time gives rise to an organism's 'present'. The period (before the intersect) and phase (after the intersect) represent the past and the future. The dashed line shows the intersect, which is continuous with space, and which forms the 'present' in time. The intersect moves in time, but not in space. Figure developed in R, using code taken from Ligges and Maechler (2003); Ligges and Mäechler (n.d), CRAN R Project (sec. 4.1.1.)

$$\begin{array}{ll} \mathrm{p} = n \text{ (intersect of s and t) } \mathrm{t}\frac{3}{\mathrm{s}} \rightarrow & \mathrm{p} = n2 \\ \mathrm{s} = \cos(\mathrm{p}) & \mathrm{s} = \cos(\mathrm{p}) \\ \mathrm{t} = \sin(\mathrm{p}) & \mathrm{t} = \sin(\mathrm{p}) \end{array}$$

Thus, a construct of a teleological emergent system is described as occurring in three dimensions of time (memories, predictions and the subjective present): however, each loop of the helix (and the starting point of the loop), is influenced by the periodic aspect of time, which is integrated into space and matter (specifically, the organic structures and systems of the organism) as an internal model or schema, based upon memory and experience. Moreover, the organism itself is embedded in a physical environment, represented in the model as 'space'. The degree of closure of each feedback loop (or the pitch and angle) in space is indicated along the horizontal axis, and represents the degree from which an organism has deviated from its homeostatic axis, as well as the duration for which the deviation occurred.

In this speculative model, the continuous nature of time, which moves at a non-variable rate as it is bisected by space and matter, means that anticipatory and predictive processes therefore occur in the form of memory and learning. These processes can guide the avoidance of deleterious consequences of behaviour and decision-making, as the organism essentially becomes a conduit carrying 'meaningful' information through time. This anticipatory process is reliable in guiding cognitive processes and behaviours which are goal directed, and also serve to avoid the risks of death, injury, disease and loss of resources, unless the environment becomes unstable and unpredictable. At the point the environment becomes unpredictable, the periodic 'memory' aspect of time becomes redundant. A switch to purely teleological goal directed behaviour, regardless of risk, becomes the adaptive response, as the system functions to continue to move forward in time and close functional loops, rather than avoiding external influences (such as injury and pathogens) which cause destabilization of the organismal system. Thus, in an increasingly unstable environmental system, the most beneficial choice for an individual is to continue to meet internal homeostatic needs on a reactive basis, whilst habituating to danger and risk. Similarly, when environmental conditions are predictable and risk is sufficiently low, anticipatory behaviours again become the adaptive strategy, and the organism is able to both meet its own physiological and cognitive/ affective needs, and avoid destabilization of its homeostatic systems by avoiding potential risks and hazards. Moreover, reciprocal behaviours in social species become advantageous as individuals can meet the cost-benefit demands of altruistic behaviour, whilst anticipating reciprocation in the future.

The failure of the functional loops to close entirely is what drives teleological, goal- directed processes toward stabilisation around a homeostatic axis, whilst anticipatory processes, based on extrapolation from a 'periodic phase' internal model, drive one-directional torsion of the helix in time. The system is autopoietic, because the functional loops never fully close. Instead, they form helices which continue to propagate as the individual changes, adapts, and responds to environmental conditions. Therefore, the teleological system is both open- ended yet also goal-directed, as the organism is driven to avoid loss (death, illness, injury or failure to reproduce) and also uses memory and learning to focus behavioural efforts, based upon an internal schema and probabilities, when environmental conditions allow. Moreover, the model allows for an apparent (or metaphorical) 'sideways' movement in time, and thus describes phenomena such as empathy and communication, where one organism 'shares' the helical pathway (or timeline) of another.

I will illustrate the functioning of the model using food- acquisition behaviour as an example, because hunger can be viewed as being mediated by a functional feedback loop which can never fully close. While eating, digestive and other physiological processes continue using energy, and surplus chemical energy is stored ready for use. Thus, even when an organism experiences satiety, the processes involved in the sensation of hunger and appetite (those processes which stimulate foraging behaviour) continue, even while the organism is consuming food, because energy is being used. Appetite and the associated consummatory behaviour form a dynamic systems process, which only ceases when the organism dies. In essence, the system is open-ended; a property which has been demonstrated by Gatherer and Galpin (2013) to allow Rosen's 'Metabolism- Repair System' (or M,R system) which describes an abstract metabolic pathway, to be modelled computationally. Nonetheless, the system is also goal-directed as the organism regulates the system's energy conversion and utilization to avoid malnutrition, disease, and death, and deterministic from within the parameters of the options available to avoid the latter.

The necessity for a biological system to remain open-ended in order to stay alive can therefore be demonstrated by foraging behaviour. Foraging engenders risk, including the risk of predation, and when foraging in groups, risks are associated with competition and agonistic encounters (Grand & Dill, 1999). Failing to provide for nutritional needs, however, would result in an organism's certain decline and death. In unpredictable and harsh (low survival rate) environments, responding to 'hunger' and meeting nutritional needs will engender a potentially enhanced risk (Fenneman & Frankenhuis, 2020), yet the risk is offset by the certainty of death in the absence of nutrition. In other words, when death is a near certainty, an individual may as well pursue a specific goal- directed behaviour (foraging to avoid hunger). When environmental conditions are relatively static, factoring risk into a foraging strategy and offsetting the potential cost against the projected benefit is possible, based on past- experience and anticipated environmental conditions. Thus, an organism can move between anticipatory and purely goal-directed processes which are regulated by feedback from the environment (or a combination of both) depending on the environmental conditions. The effect is illustrated in Table 1, using a game theoretical approach, and assigning 'value' to both strategies, with a maximum value of 3:

It is acknowledged, however, that the described helical model gives rise to an apparent paradox; complex biological systems are simultaneously deterministic and indeterminate. In actuality, however, the paradox does not exist, because the system is indeterminate within a set of deterministic parameters imposed by the physical environment, including the anatomy and physiology of the organism itself. To illustrate this again using foraging behaviour as an example, a foraging terrestrial mammal such as a meerkat has a number of choices in the event it encounters a hazard whilst foraging, such as a predatory raptor. It can produce social mobbing calls, it can flee, it can take cover and/or freeze (Graw & Manser, 2007), all of which allow the individual agency, meaning that the outcome of the encounter is far from predetermined. However, a meerkat cannot, for example, fly away to escape capture, it cannot simultaneously forage and hide, nor can it directly attack an aerial predator. Therefore, the system (i.e., the cognition and behaviour of the individual meerkat) is open-ended and indeterministic within a set of deterministic parameters imposed by the physical biological and environmental system.

A completely open-ended system which does not have parameters imposed by the physical environment cannot exist in the physical realm. Nonetheless, such as

Table 1 Teleological and anticipatory processes in response to changing environmental conditions: A Game Theory approach to an organism switching between a purely teleological goal directed behaviour, and goal directedness with anticipatory processes

	Goal- directed	Anticipatory	Net effect
Static environment	+3	0	+3
Stochastic environment	+1	+2	+3
Harsh, chaotic and unpredictable environment	+1	0	+1

system is the basis for emergent properties such as imagination and human cultural phenomena, including art, literature and folklore, and the human concept of ‘magic.’ Whilst these phenomena (and others like them) can exist within the emergent property known as the ‘mind’ and moreover, can be expressed in the physical world via language and other media (Brady, 1998; Gell, 1988), in the physical, material realm, they exist as concepts which guide and drive human behaviour and endeavour. Even so, these phenomena are not limitless and completely indeterminate. Literary fiction, surrealist art, and folklore (to name but a few examples) exist within the constraints of human experience (or the ‘phase,’ described in the model), and manifest as cognitive phenomena where causal links are perceived between observed occurrences in the physical world where (according to current observable reality) there can be none. Nonetheless, parameters of the physical world exist, in that it is impossible for an imagination to produce a concept which has no basis in known reality.

Discussion

The described model, whilst not conforming to physical space-time dimensions, solves the problem of functional loops being unable to travel back in time, and thus semiotic processes seemingly ‘stopping’ time. It also solves the problem of retro-causation in teleological processes; if the goal is to avoid losing using a best-fit prediction based on past-experience, then behaviour which occurred in the past is not influenced by the outcome of the goal- directed behaviour in the future. Instead, an organism has avoided a potentially fatal outcome by influencing events toward one of a number of beneficial options driven by biological need, thus demonstrating the basis for how a field of attraction can arise. The field of attraction becomes an iterative process whereby an organism gradually moves toward a minimisation of error and a ‘least wrong’ solution, based upon semiotic feedback. Adjustments are made along the way in response to changing environmental conditions. In summary, a specific ‘goal’ is initially never formulated nor reached, but biological needs are responded to at definitive points in time, allowing the organism to continue on its trajectory throughout its life span. However, as more and more information is accrued semiotically, a higher proportion of specific goal-directed behaviours can be enacted, and an identified goal (e.g., foraging for a specific nutrient source; mate choice) is pursued. The three aspects of time in the model are thus representative of memories and past experience, an organism’s present (which is subjective and thus a relative value), and predictions of future events, albeit within a stochastic environment. It is also significant that, for emergent properties such as cognitive processes and the mind, or consciousness, subjective time is no longer linear. These points have important implications for memory studies, particularly in non-human animal species. Suddendorf and Busby (2003), for example, claim that the existence of Mental Time Travel (‘MTT’) in non- human animals is unsupported due to autonoesis not being demonstrated (citing, for example, Clayton’s and Dickinson’s (1998) experiments of scrub jays). However, using the described helical model, this claim can be challenged. The memory that an event occurred, and predictions of future environmental conditions influencing an individual’s behaviour, are not phenomena that require a complex understanding of 'self' as being the locus of direct causation; nor does it mean that in non-human animals, apparent MTT is simply a causative process. Moreover, an episodic-like memory does not have to be declarative. MTT can involve a prediction based up periodic pitch of functional helical loops mediating behavioural processes, i.e., 'rhythm,' and thus, is posited as a form of pattern recognition which creates a temporal schema, rather than a causative linear sequence of events.

Rhythm is a universal, cross-cultural dimension of music (Ravignani et al., 2016) and has also been identified as a significant component of animal cognition, underpinning behavioural processes, signalling and communication (Kotz et al., 2018). Moreover, processes involving memory, previously only thought to occur in higher organisms, have even been found in simple eukaryotic microorganisms, where they are based upon methylation and demethylation of proteins. Indeed, 'memory' is a feature of bacterial chemotaxis (Vladimirov & Sourjik, 2009; Lan & Tu, 2016) with proto-rhythm or 'timing' being found as part of bacterial foraging, which relies on gradient descent searches (Lewis, 2021 citing Vladimirov & Sourjik, 2009; Dasgupta et al., 2008). Thus, a likely origin of rhythm and pattern recognition can be found in single- cellular organisms' behaviour, and the fundamental basis for the functioning of the functional-helix model is the formation of rhythmic patterns. It is therefore rhythmic patterns, occurring over time, which are recognised, rather than the specific causal events and spatial loci usually assumed in traditional concepts of episodic memory and MTT. The latter rely on memories founded in visual, olfactory, tactile, proprioceptive and acoustic information, yet they misguidedly disregard the much over-looked sensory dimension of chronoception. Indeed, are not all biological senses, which detect waveforms, forces, and shapes, fundamentally reliant on the perception of time? When we recall a visual image, do we not recall a collection of shapes, patterns and colours which all occurred simultaneously at a single point in time? Given that, are we not therefore recalling a timestamp in a continuous flow of complex sensory input?

Remarks on Helices

The helix (as a mathematically described structure) has many interesting properties. Unlike the spiral, which widens or tightens (depending on perspective) around an axis or single point, helices can vary in the pitch of the tangential curve, but the diameter of the curve does not change consistently in size to either increase or decrease the curve's diameter in relation to the axis. Found throughout the biological realm (for example, the double helix of DNA (Depew & Wang, 1975), protein structures such as those found in collagen (Fidler et al., 2018), the tendrils of climbing plants (Isnard et al., 2009) and snail shells (Schilthuizen & Haase, 2010)), the helix has significant properties such as high tensile strength and flexibility which allow it to store mechanical energy. Further, helical structures are also dynamic and resistant to perturbation due to their flexibility. Significantly, such properties are also required by an organism's emergent properties, for it to survive in, and engage with, unpredictable, challenging and sometimes hostile environments.

Moreover, a peculiar feature of the described model is that it turns in time, and therefore, mathematically, it has properties similar to a model of a torsion spring, the latter often being used as a component of mechanical machinery (Jiang & Henshall, 2000). The difference between the model presented in this paper and a torsion spring is, of course, that the biological model is not formed from matter. However, torsion of the helix is driven by organismal energy conversion and expenditure- either via physiological cognitive processes (chemical and electrical energy) or via an organism's behaviours (kinetic energy). Similarly, a torsion spring to which a shear or torque force has been applied stores energy until it is released as mechanical energy. Thus, both systems are storing energy before converting it from stored or potential energy to mechanical or kinetic energy. This provides a useful model of animal behaviour:- animals (indeed, living organisms) form a system which converts, stores, and then releases energy. However, this is not the only physical system where the formal model of the system features a helical form, and from which similarities can be drawn with a biological system. Charged particles moving through a magnetic field are described as following a helical pathway (Zampetaki et al., 2013) and the path described is thus similar to the presented model's representation of a living organisms travelling through its lifespan.

At the present time, it is not possible to give a physical definition of the emergent properties of biological systems such as the mind and consciousness, and it is possible that such a description may always be outside the reach of science. Nonetheless, philosophically, mathematical formalism makes it possible to describe decision making processes, anticipatory processes, and an organism's relationship with its environment as it moves through its life span. Despite the complex nature of such emergent properties (including the concept of 'life' itself), such properties can be said to be derived from energy and matter, as exemplified by the 'four E's of embodied cognition':- 'embodied, embedded, enactive and extended', a comprehensive background to which is given by Shapiro (Ed) (2014). Whilst a charged particle is moving through a magnetic field, following a uni-directional vector trajectory as it orbits an axis, an organism is making a similar trajectory through time, as it orbits its homeostatic equilibrium in a dynamic, teleological state. In the same way that the particle responds to magnetic forces which influence its trajectory, so too does an organism respond to goal- directed 'forces' or motivational 'drives' which maintain homeostasis and sustain life, as well as the propagation of living organisms via reproduction. Eventually, via fatal injury, disease, the ageing process, or a combination of all three, homeostasis can no longer be maintained, and the helical structure loses its integrity as death ensues.

Conclusion

The proposed multi- dimensional model, which describes rhythmic, autopoietic and teleological processes as occurring in three-dimensional time, has significant potential in cognitive, semiotic and biological sciences. It could be used to form the basis for a future understanding of the emergent properties of biological systems in animals, because such systems are not part of the material domain in space-time, and thus do not need to be conceptualized as such. Instead, consciousness, including cognitive processes and sensory perception, gives rise to a schema which transcends the physical boundaries of space-time. Whilst emergent properties originate from, and are embedded in, physical organic matter which exists in three-dimensional space, they occur only in time. Time, therefore, is the most important domain for biological organisms, with chronoception being key to biological processes. Whilst the idea that a vast number of animal species cannot be described as 'conscious' no longer holds any scientific validity, it would be a mistake to discard mind-body dualism entirely; however, both mind and body can be viewed as a construct where both mind and body are obligate symbionts.

Appendix 1

A copy of The University of Warwick's magazine 'Manifold' describing the 'Finchley Central' game can be found here: https://ianstewartjoat.weebly.com/manifold-3.html.

The article is titled 'A Pandora's Box of Non-Games' by Anatole Beck and David Fowler.

Ed. Ian Stewart.

(Accessed on 25 January 2021)

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Declarations

Conflict of Interest There are no conflicts to declare.

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