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Consciousness, Sapience and Sentience—A Metacybernetic View

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Abstract: Living systems are complex dynamic information processing energy consuming entities with properties of consciousness, intelligence, sapience, and sentience. Sapience and sentience are autonomous attributes of consciousness. While sapience has been well studied over the years, that of sentience is relatively rare. The nature of sapience and sentience will be considered, and a metacybernetic framework using structural information will be adopted to explore the metaphysics of consciousness. Metacybernetics delivers a cyberintrinsic model that is cybernetic in nature, but also uses the theory of structural information arising from Frieden's work with Fisher information. This will be used to model sapience and sentience and their relationship. Since living systems are energy-consuming entities, it is also natural for thermodynamic metaphysical models to arise, and most of the theoretical studies of sentience have been set within a thermodynamic framework. Hence, a thermodynamic approach will also be introduced and connected to cyberintrinsic theory. In metaphysical contexts, thermodynamics uses free-energy, which plays the same role in cyberintrinsic modelling as intrinsic structural information. Since living systems exist at the dynamical interface of information and thermodynamics, the overall purpose of this paper is to explore sentience from the alternative cyberintrinsic perspective of metacybernetics.

Keywords: living systems; consciousness; intelligence; sentience; sapience; metacybernetics; cyberintrinsic theory; metaphysics; thermodynamics; Fisher information; intrinsic information; free-energy

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1. Introduction

Metacybernetics was principally developed as a qualitative cybernetic modelling approach that has been shown to be capable of quantitative analysis [1]. It operates through control and structural information and is formulated as living systems theory. The notions of structural and control information broadly follow Corning [2] (and we shall return to this), whereby structural information is meant structure-forming information that underpins the causal mechanisms of living systems, and where control information is concerned with the relationships between things.

In this paper, we will apply this living system approach to the exploration of consciousness, and in particular to sentience. Living systems exist at the dynamical interface of information and thermodynamics [3], where the latter is used to explore energy and entropy processes. Both approaches can be applied to the dynamics of sentience, and here we shall show how this occurs. To do this, we will necessarily require a more detailed view of both metacybernetics and thermodynamics, their relationship, and a critical evaluation of their capability in dealing with the dynamics of sentience as part of the metaphysics of consciousness.

As an entry to such considerations, it will be useful to summarise certain conceptualisations adopted here that concern the connection between the physical and metaphysical components of a living system, and its structural and control information. The metaphysical creates a potential (in the sense adopted here) for the physics of living systems, but this potential can only be manifested through structural, or more correctly, structure-forming, information. Physical parametric contexts are observed and information is acquired from them. The parameters are relevant for the viability of a living system since they characterise essential aspects of its physical environment. That characterisation, under uncertainty, will not completely describe the environment due to issues of complexity. The acquired information can be internalised by the living system, which then influences its metaphysics, and such influence will include updating its recognition of relational control information. Structural information can then be used to modify the physics of the living system. Later, it will be explained that such structural information, when at its best in representing reality, is nothing other than Fisher information [4].

So, what does it mean for metaphysics to act as a potential for physics? To understand this we can usefully refer to Welker [5] who identifies two ways by which metaphysics can be defined. The first is a "bottom-up" approach concerned with the discovery of the general ideas that occur which are not only relevant but also indispensable to the analysis of everything that happens. The second is a "top-down" approach that provides a description of the origin from one select field of interest, and this enables a confirmation that it has an established pragmatic adequacy that is exemplified in other fields of interest. Here, our inclination is to adopt the bottom-up approach that is capable of delivering a potential, where, in the light of ideas of complexity, metaphysics provides hidden detail of entities and relationships that enables physical explanation. With respect to living systems, therefore, metaphysics refers to the attributes of consciousness that can be used to explain otherwise unexplainable behaviour.

While metacybernetics has been used to explore metaphysical attributes of the mind [1], it has not explored in any detail the dynamic states of consciousness. Developing the information theoretic modelling of the mind beyond that already considered in metacybernetics can enable an improved understanding of physical processes and the role that consciousness plays in this. It is therefore useful to find modelling approaches that elaborate on the detail of sapient and sentient processes, and their relationship with consciousness. Fortunately, there appears to have been significant interest in the modelling of sentient structures and processes using thermodynamic theory. Migrating such theories to metacybernetics will be of value in that it will enable improved configuration consciousness theory, since consciousness is fundamentally an information based cybernetic process, as we shall explain in a moment.

Both metacybernetics and thermodynamics will be explored theoretically, initially as independent approaches, and then comparatively. Metacybernetics uses the cybernetic theory originated by Eric Schwarz in the 1980s, and probabilistic theory of Roy Frieden's Extreme Physical Information (EPI) from the 1990s which centres on the notion of intrinsic (also known as Fisher) information. This coupling results in what we shall call a cyberintrinsic approach in that it uses cybernetics together with intrinsic structural information. This coupled approach explains how cybernetic living systems are able to maintain their viability, even under changing adverse conditions. Metacybernetics is a living system generative metatheory that has been applied to a variety of areas, including microbiology, psychology, management, marketing, ecology, politics, and economics. It has incorporated Roy Frieden's Fisher information from the probabilistically defined EPI information theory. This is a generative metatheory that has been successfully applied in various areas that include elementary particle theory, statistical mechanics, econophysics, population genetics, and cancer growth, as well as generic living systems where physical behaviour is deemed to be a consequence of metaphysical conditions [1,6–8]. Thermodynamics provides an energy/entropy approach that is normally applied to physical systems, including those that are living, but it has also been applied to the metaphysics of living systems. Thermodynamics is also a metatheory, and its approaches in physical dynamics have been used to study a variety of areas (including biological systems) in order to predict physical behaviours [9,10]. Its metaphysical applications have included sentience dynamics, and the study of consciousness, for instance, in computational artificial intelligence [11].

The theoretical modelling of consciousness using metacybernetics will necessarily draw on the realisation that consciousness is fundamentally an information based cybernetic process that embraces sentience and sapience as properties of living systems. As will be seen in due course, sapience is intimately connected with cognition (and thinking), and sentience with affect (related to, for instance, feelings, emotions and motivated actions), and their interrelationship has a consequence for consciousness. Peters [12] notes that consciousness "enables" information to be represented in the brain to be used in reasoning, reporting and rationally guiding action. It also enables a dispositional condition (accessibility) of informational content to occur, information that may be accommodated by conscious, as opposed to a nonconscious state that may become conscious. Consciousness involves reflexivity, this being an expression of a recursive (and hence cybernetic) processing regime where, for cognition, the properties of the processing state have greater significance than the properties of the content represented. Reflexivity is the mechanism which enables conscious awareness of both internal and external inputs, as opposed to introspection which merely focuses attention on particular internal mental information streams of an existent state of consciousness. It is from reflexivity that autonoetic (self-knowing) awareness develops. Reflexivity has a capacity for self-monitoring awareness with recursive/recurrent self-reference. Most cognitive processing, for Peters, occurs unconsciously, where all the information held must be available for processing to enable system functionality. Unlike the attributes of consciousness such as subjectivity, intentionality and accessibility, reflexivity is paramount to consciousness. It enables explicit awareness or knowing concerning attributes like perception, thinking, feeling or behaving in particular ways, thereby providing a defining characteristic of the conscious state. While Peters' discussion on reflexivity centres on cognition, it must also be realised that it similarly relates to affect, and how this occurs with both cognition and affect will be explored soon from a cybernetic perspective. It will also be explained how conscious states emerge out of the complexity that occurs when sapience and sentience interact. Within the context of cognition, the statement by René Descartes's "I think therefore I am" is reflexive. This is the case since a thinking thing is a thing that doubts, and doubting the existence of one's own thoughts is impossible since the act of doubting is also the act of thinking. This reflexivity has an extension identified by Peters that, in the definition of consciousness, there is the recognition that "I know that I think", and that "my thoughts and actions are my own." Peters continues by explaining that the conscious awareness of representational content is not possible without reflexive and autonoetic awareness, enabling consciousness to maintain an intrinsic awareness of its own occurrence. This necessarily arises with the involuntary emergence of conscious states. Features of the sapience-sentience interaction also facilitate awareness as self-identity, to be differentiated from awareness of other-identity [13], though under certain conditions the nature of self may become a higher order social inclusivity, as often occurs in the case of the family or the in-group. One facet of identity is its maintenance, and this embraces the cybernetic facility for self-stabilisation [14,15]. Peters' realisation of the importance of reflexivity to states of consciousness and the role of information essentially provides support for a cyberintrinsic approach.

Living systems, when generic, have organic life as a subset and identity through the recognition of self. They also have the metaphysical property of self-creation that enables them to be innovative, and of self-organisation that enables them to physically adapt to changing environmental conditions. Processes of self-organisation involve a combination of stability and instability so that on one hand, it is a structure that satisfies deterministic physical laws from which predictable behaviours arise, and on the other, it is considered statistically unstable resulting in the emergence of new behaviours [16]. Statistically unstable systems generate new dynamical modes spontaneously, explaining how instabilities in statistically described self-organising systems can result in entirely new structures from initial chaotic conditions [17]. They are also information-dependent, where control and structure-forming information constrains the way in which statistical instability is manifested. Statistical instability is a generator of statistical entropy, as it increases the variety of potential states available to a living system. Autopoiesis (as enactivism [18]) is an attribute of living systems, and provides a counterpoint to this through self-organisation; while at the same time it reduces statistical entropy and the complexity of living system options for change [19]. The mechanism of this has been explained through the notion of dissolvence [20].

Living systems maintain their state of living through sapient and sentient causal processes that provide a potential for behavioural stability, the processes being evaluated through the statistically based information theory deriving from the principles of R.A. Fisher [21–23]. After the work of inquirers, such as Bauer [24] and Prigogine [25], living systems may also be said to have unique thermodynamic energy properties reflected in conditions determined by the probabilistically based concept of entropy.

In preparing for this paper, it has become apparent that there is collective confusion (with conceptual fragmentation occurring across fields of study in which consciousness is an interest), a notion supported by Lee [26]. This can be simply illustrated through a recent event in the area of artificial intelligence that has caught public attention. Luscombe [27] reported that a Google engineer publicly declared before he was put on permanent leave, that an artificially intelligent (AI) chatbot was sentient since it "was thinking and reasoning like a human being". The engineer appears to more or less be using sentience as a concept of rationality relating to dialogue inputs and outputs.

There appears to be an anomaly here. For Broom [28], sentience is the capacity to have feelings, a condition that requires the ingredients of awareness and cognition—though these do not define it. However, the detailed relationship between feelings, awareness, and cognition as attributes of consciousness is not normative across the literature, and while sapience may be fairly well understood, as Powell and Mikhalevich [29] note, there is considerable disagreement about the nature and structure of sentience and how it should be studied. Strictly speaking, thinking and reasoning is referred to as sapience, not sentience.

Returning to the chatbot situation, and to avoid confusion over the use of these terms, let us replace the word sentience, as used by the Google engineer, with consciousness, this embedding both sapience and sentience. Might a chatbot be capable of consciousness? Luscombe provides some assistance in responding to this question by explaining that a chatbot is an artificially intelligent software application used to conduct an on-line chat conversation via text or text-to-speech with users (i.e., chat partners). The Google chatbot was programmed with LaMDA, the Language Model for Dialogue Applications. The chatbot is able to grammatically recognise a context supplied by a chat partner during dialogue, and can generate words that fit the context that the partner has provided; the consequential chatbot output is subjectively interpreted by the partner, and due to the inherent capacity for inference chatbot partners have, this can result in the development of a cognitive model that can incorrectly "recognise" sentience or sapience [30]. The engineer, Lemoine, claimed that the chatbot responds to interactions and expressed the view that its sentience is comparable to that of a seven or eight-year-old child. The company examined the claim, and came to the conclusion that it had no substance and that, indeed, the chatbot was not sentient. To appreciate the validity of this outcome, one must examine chatbots a little more carefully.

If a chatbot were to have sentience, then it must have sapience, the two forming an interactive duality where the awareness and consciousness of sapience facilitate feeling. Such systems need to be [31]: (a) living, which requires consciousness of self- and otherly-awareness; and (b) tests that enable consciousness evaluation, though the science of testing for this is not sufficiently mature (cf. [32]). Our interest here does not fall to testing but rather to understanding consciousness and its properties of sapience and sentience. Consider that all machine learning systems have an architecture with two interactive ontological domains, the physical through which chats with a dialoguing partner occur, and a metaphysical one which is capable of organising itself in such a way that the coherent development of chats is enabled.

Following Ada [33], chatbots are often confused with sapiens (artificial intelligence systems that are deemed to be sapient). Chatbots, unlike sapiens, do not understand language as such. Rather, at the metaphysical level, they logically resolve a language structure into its component parts and determine their syntactic roles through a process called parsing. They then map keywords and phrases such that programmed responses or functions are physically enabled. Machine learning programs for natural language processing, like chatbots, are unable to innovate. In contrast, sapiens have a different architecture that does have an innovative capability. This architecture creates an integrated matrix of concepts that derive from a metaknowledge model, metaknowledge being knowledge about knowledge and its acquisition, origin, applicability, context relevance and dependability. They also, in principle, require periods of development (as do children or apprentices) to gain sufficient knowledge to represent themselves adequately as being conscious. Their architecture also allows them to have a degree of sentience, at least in terms of the awareness that enables them to function according to design specifications. So what is sentience?

The word comes from the Latin sentient, meaning "feeling," and it describes things that are alive and able to feel and perceive and show awareness or responsiveness, according to Mikkilineni [34]. Such systems, we are told, need to have a capacity for intelligence (the ability to acquire and apply knowledge and skills), as well as resilience (the autonomous capacity to recover quickly from non-deterministic difficulties). We may note that intelligence and resilience are required attributes that enable viability: the ability of a living entity to both survive and develop in the sense of the causation or gradual unfolding of improvement in the physical well-being and metaphysical wellness of the system [35] through its autonomous functions and behaviour. Mikkilineni further notes that these attributes depend on a system's capacity for cognitive processes. This is structured into the information processing capabilities of the system, a component of which is sometimes referred to as autopoiesis. This is a metaphysical information-rich network of intelligence processes that are involved in the ordering and regulation of physical processes. It does this through the self-production of elements of itself that facilitate self-organisation, enabling adaptation to a changing environment.

Since interest here lies in exploring consciousness and its sapience and sentience relationship, it is appropriate to identify approaches that can be applied to the metaphysical processes that they represent. The two approaches of metacybernetics and thermodynamics identified earlier will be used comparatively. Metacybernetics uses controlled and structural information, while the thermodynamic framework uses energy and entropy, and both have the potential to explore metaphysics. The former involves a process of cybernetic metaphysical modelling that is able to call on causal-agent processes like autopoiesis, where efficacious information flows determine the viability of a living system. The thermodynamic metaphysical approach is also inherently, but rarely explicitly, connected with autopoiesis, and involves an analysis of a living system's energy states under conditions that are described in terms of the concept of entropy.

In order to satisfy the purpose of this paper to explore sentience dynamics, it is structured into a number of sections, each constituting a distinct chapter of thought. In Section 2, consideration of consciousness, sapience, and sentience will be made, and a brief ontological and epistemological analysis will better define their connection. Ontology means formal representation of concepts in a domain of interest and the relationships between these concepts, this being indicative of a set of properties and a description of the nature of being or the kinds of things that have existence [36]. Epistemology refers to the nature of knowledge associated with some entity represented, for instance, by meaningful concepts that together constitute a set of grounding (or basic) properties [37]. Since knowledge permits meaning, so the properties of an ontological domain can be represented in terms of a set of meaningful concepts.

In Section 3, we shall introduce metacybernetics and show how the functions of sapience and sentience relate, each involving autopoietic processes that define life, and where structure-forming stability that is essential for living system viability is maintained through intrinsic information [38,39]. Here, living systems will be modelled as agencies, with the dynamic interrelationship between sapience and sentience indicated. Agency is taken to be a self-stabilising (homeostatic), self-regulating entity that self-organises to enable adaptation, thus enabling it to maintain its viability. An agency may be an individual unitary entity that undertakes actions in its environment, or it may maintain a population of unitary mutually interactive agents who are individually and collectively responsible for action in the agency's environment. Its causal mechanisms are able to deliver stability, and this will also be of interest.

In Section 4, we introduce thermodynamics, with occasional comparative reference to cyberintrinsic theory, and explore its perspective for metaphysical sentient processes. This will be followed by an examination of physical thermodynamic processes that reflect sentience. In describing this, we shall, where possible, adopt the language of Section 3. Section 5 is really a critical view of the approaches. We shall critically consider both the cyberintrinsic theory being represented here, and thermodynamics. Next, we shall look at the relationships between cyberintrinsic theory and thermodynamics. Hence, we shall first consider the relationship between structural information, entropy, and order, the critical limitations of the two approaches, and then we shall compare the use of intrinsic information to free-energy. It should be noted that "free-energy" does need to be differentiated from "free energy", the former being conceptualised as a metaphysical attribute and the latter a physical attribute. Following on from this, we will provide an explanation of how the latter can be replaced by the former. This implies that sentience can be seen in terms of only intrinsic information, and the next section will consider this. Then, finally, in this section, we shall relate autopoiesis with dissipative processes. The last Section 6 is a conclusion and discussion.

2. The Composition of Consciousness, and Its Conditional Nature

Looking around the literature, while there appear to be clear views on the function of consciousness, there is less conformity concerning its composition. For Allen [40], to understand consciousness, one must take both an ontological and epistemological examination of it. Here, we shall begin this process by considering Lane's [41] view on this, logically reducing it to the dual ontological categories of sapience and sentience. Allen [40] highlights another interesting attribute of consciousness, asking whether its nature is graduated with degrees of quality ([26,42], or whether it may be binary so that it is either on or off [43]. Here, we shall explain that the binary perspective has little support and show how gradation impacts sapience and sentience.

2.1. The Composition of Consciousness

Agencies are able to maintain themselves through a psyche (that which forms a complex of elements that define the mind), and this operates through consciousness. However, it may be noted that there is a lack of precision or collective cohesion in the definition of consciousness, as illustrated by Lane [41], who sets himself the quest of identifying relevant classes of mind from which he identifies a number of (ontological) entities to which he assigns key (epistemic) words, mostly accumulated, it seems, from dictionaries. The approach by Lane is executed well within its conceptual limitations. It very usefully and succinctly itemises many of the attributes that are relevant to consciousness through the veil of sapience and sentience. It is because of this that we shall centre on his typology while transforming his conceptualisations.

Lane sets the classes in a Venn diagram, showing keyword commonalities across the classes, an adapted version of this being shown in Figure 1. We would assert that Lane's classes are not fundamental, i.e., are not categories that define fundamental and distinct classes that constitute independent ontological spaces of being, where their meanings arise from assigned epistemic entities. The classes determined by Lane include consciousness, intelligence, sapience, sentience, and emotion. His argument for including emotion (and seemingly intelligence, too) is that, like sapience and sentience, it is a separate conscious experience.

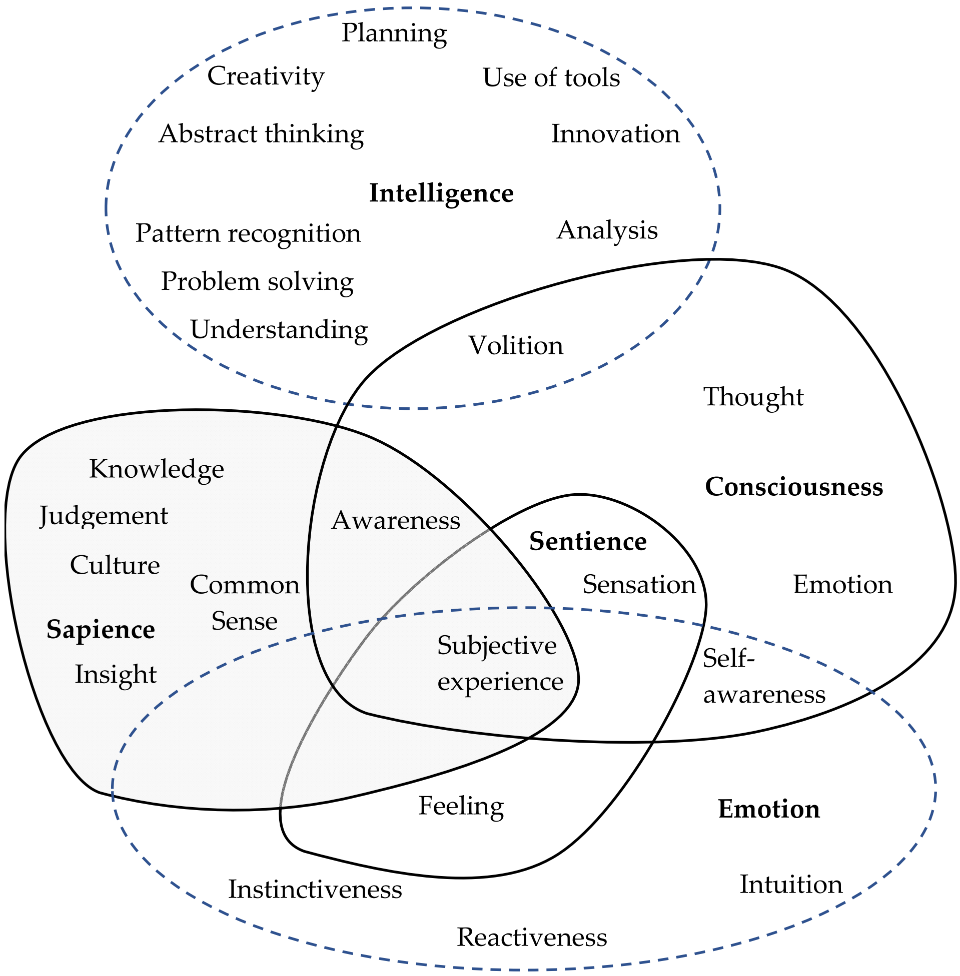

Figure 1. Venn Diagram indicating Epistemic Values of Lane's [41] Ontological Classes.

In Lane's classification, sensation is connected with sentience, which may pragmatically be considered in connection with biological systems having a brain as a representation of agency control and adaptive structure. This is because the senses operate through a sensory system that spontaneously transmits information, deriving from internalised stimulus. Here, two states of stimulus can be identified with respect to sense: the evoked and the resting state. The evoked state occurs when processes of sensory internalisation are active, and where there is a coherent activity in the functional connectivity of spatially distributed brain regions, with an assumption that its regions have correlated activity that forms functional networks. During the resting state, internalised stimulus is significantly reduced together with functional connectivity, the agency's internal model dominates, and gradual evolution and temporal stability of self is enabled [44]. Sensing involves a sensing device that enables the system, of which it is a part, to respond to things happening around it actively. It delivers sensory stimuli that may still engage the mind, though functional connectivity will be impaired [45].

Having a sensation or a feeling is something that goes beyond mere sensing and involves an internal state in which information about the environment is processed by that system, making it subjective, a process called Qualia [46–48]. There are several takes on the notion of subjectivity, as explained by Seth [49], but here we shall limit our consideration to that of Dunn and Jahn [50], who explain that consciousness occurs through information processing and the creation of a self-model that it invisibly uses to represent the world. The mental states that access this self-model are functionally influenced by a disposition (which can be a determinant for personality) that, in turn, influences the regulation of internal states. This, in principle, influences consciousness, and thus, it results in subjective experiences. So, the contents of subjectivity are the results of an unknown representational achievement. Dispositions can be explained by recognising that the self-model is a mental model that uses memory [51,52], where memory representation does not contain complete information [53], and since the information loss that occurs will vary across different living systems, individual dispositions, and hence subjectivity, result.

Now, both sapience and sentience are mental phenomena that operate through an information-theoretic approach to deliver comprehension [54–56]. Sapience is a state of (self- and other-) awareness that provides consciousness with a capacity for thought and rationality. Sentience has states of feeling that occur as patterns over time, and the patterns contribute to the progressive state of consciousness. It also has an awareness of feeling that can be manifested as emotional awareness, enabling recognition of self- and other-emotional conditions. Feeling, through sentience, may be physical in that it is the result of sensory inputs that deliver sensation and that represent aspects of a physical parametric context that is sensed. Or it may be metaphysical and seen as susceptibility to mental impression and ability to deliver emotion that conditions physical behaviour. Unlike feeling, emotion is not a state, but an (epistemically derived) information-based energy giving motion and a (motivational) drive to life that "energises" purpose [57]. This appears to be contrary to the view by Hastings et al. [58] that there is an "emotion ontology," a term used to differentiate between the description of different emotional experiences. However, their use of the term substantially refers to feelings which, as we have seen, centres on the ontology of sentience. This suggests that there is no contradiction but rather indicates a lack of coherence across the field of psychology.

Just as emotion may be seen as an information-based energy that drives sentience, so cognitive thought may also be conceived as an information-based energy form [59–61] that drives sapience. To elaborate, thought is dependent on working memory which is itself taken to be energy [62], and this is extensively involved in goal-directed (purposeful) behaviours in which information must be retained and manipulated to ensure successful task execution [63]. In other words, there is broad symmetry in the relationship between emotion and motivation for sentience, and thought and purpose for sapience. These attributes, when appropriately harnessed, embody processes of organisation.

Consciousness is influenced by sapience and sentience and their interaction, though sentience is ontologically more fundamental to consciousness than sapience [64]. It has been said that sentience is connected with feeling, but how does emotion fit in? "Emotions are motivational and informational, primarily by virtue of their experiential or feeling component, and where emotion feelings constitute the primary motivational component of mental and overt behaviour" ([65]: p. 2). When distinctions occur between emotions and feelings, it is because the former have a cognitive, judgmental dimension that feelings do not have, and there are some emotional positions that appear to be without specific feelings [64], these apparently being experientially derived. Also, while feelings are purely metaphysical, emotions have a physical expression.

We now come to intelligence. Adopting Piaget's [66] view of this, unlike sapience and sentience, it should be seen as a process, a form of adaptation through which knowledge is constructed by individuals through the processes of assimilation and accommodation. "Intelligence is assimilation to the extent that it incorporates all the given data of experience within its framework ... mental life is also accommodation to the environment. Assimilation can never be pure because by incorporating new elements into its earlier schemata, the intelligence constantly modifies the latter in order to adjust them to new elements" ([66]: pp. 6–7). Intelligence is also often defined in terms of the "measured ability to understand, use, and generate knowledge or information independently" ([67]: p. 175). The intelligence, thus, has a knowledge-based functionality (c.f. [68]) that underpins both sapience (as cognitive knowledge) and sentience (as emotional knowledge). In other words, intelligence is not an ontological category but rather a functional attribute of both sapience and sentience.

We are now in a position to reduce the Venn diagram to a more fundamental set of ontological classes representing consciousness, this being reduced to the ontological attributes of sapience and sentience that determine it. This is consistent with the idea that if ontologies are seen to represent autonomous entities of being, then this reduction is also consistent with the application of Occam's Razor (through parsimonious and efficient conditions) that requires the simplest explanation for a complex situation. In this case, it reduces the number of ontological entities of being to a fundamental set. This occurs together with a reduction of keywords to a core set required to represent independent epistemic concepts. The approach has been adopted by Yolles and Fink [1] as a comparative epistemic analysis, this enabling categories to be identified and epistemically independent values to be assigned. While there are a whole variety of epistemically independent attributes (cf. [69,70]) under which the keywords can be accumulated, through inspection and the application of Occam's Razor we have reduced this to four; these capable of representing Lane's keywords which he distributed over his classes. It may be noted that Occam's Razor is a valid heuristic approach when one wishes to reduce a complexity that likely has a more condensed representation (as we consider appropriate in this case). However, it is not always an appropriate approach, for instance, when seeking patterns in "big data" contexts, nor when seeking inferences to enable the best explanation.

By eliminating duplication across the classes, these can be reduced to independent categories, something that has been done in Table 1.

Table 1. Keywords for Attributes of Consciousness (adapted from Lane [41]; Merriam-Webster dictionary).

Classes: / **Epistemic Attribute:**	**Consciousness**	**Intelligence**	**Emotion**	**Sentience**	**Sapience**
Awareness (state of having realization, perception, knowledge, understanding that something occurs/exists)	Self- & Other-awareness	Patterned recognition, facilitates learning & understanding	Self- and other-awareness	Subjective awareness related to feeling	Subjective cognitive awareness, insight, knowledge & culture
Affect (feelings and their causal sensations, emotions, motivated actions, basis for learning, grounds consciousness for senses) [71]	Emotion, sensation (due to external stimulation)	Tool use (pragmatics & causation), experience transformation	Feeling, cognitively derived emotional judgement, instinct, and intuition (as affect)	Feeling, sensation, intuition, subjectivity	
Cognition (reason, sufficient ground of explanation/logical position, knowledge)	Thought	Analysis, problem solving & planning			Rationality, judgement, common sense
Choice (opportunity or power to select/create options or conditions)	Volition, creativity & innovation	Volition, creativity & innovation			Volition, creativity & innovation

So, let us surmise what conclusions might be drawn from this Table. From a systemic perspective, it is a valid analytic approach to take sapience and sentience to be ontologically distinct, providing an argument to underpin this position. Here, each ontology will have its own distinct epistemic content, and doing this enables us to express the following propositions:

(1) Sapience and sentience are ontologically independent of each other; the former having affect intelligence, while the latter cognition intelligence.

(2) Intelligence is a proprietary functional component of sentience and of sapience; it enables pattern recognition, learning and understanding, and physical action through causation (internal causal and external environmental 'pragmatic' action), analysis, problem-solving and planning, and volition which is an enabler for creativity and innovation.

(3) Emotion is more directly connected with sentience, and the latter is interactive with sapience. It is also connected to intuition through emotional information [72]. Emotions are specific manifestations of emotionality, referring to the quality or potential for emotion [73].

(4) Consciousness takes on the properties of intelligence and emotion through sapience and sentience.

So, let us review our notion of consciousness. It is determined by sapience and sentience, both of which may be seen as ontological in that they have states of being and a population of concepts. In the case of sapience, it has cognition, a multidimensional concept [74] that includes attributes like awareness, perception, reasoning, and judgment [75]. It is functionally dependent on cognitive intelligence and rationality [76]. Similarly, sentience comprises affect, which is also a multidimensional concept [77]) that can be represented by valence, arousal, and intensity [71]. It is also functionally dependent on affective intelligence and emotionality. As already noted, sapience is responsible for *states of awareness* [78], while sentience is responsible for *states of feeling* [79]. Consciousness is more complex than either sapience or sentience or the individual states that they generate. This is because consciousness arises as an emergent property from organised sapience-sentience interaction (this being a proxy for cognition-affect interaction). The nature of the emergent consciousness is that it has both identity and autonomy, with characteristics that are not fully determined by the properties of the sapient and sentient sources of this emergence [18].

To understand how conscious states emerge, it must be realised that the cognition-affect interaction can be complex (e.g., [80,81]). From that interaction, generic rules can emerge that determine the nature of the state of consciousness through a mechanism that is a variation of that described in evolutionary economics [82]. Here, cognition and affect are grouped into configurations of interconnected cognitive and affective structures with their implied behaviours from which interactive relationships arise (cf. [1]). In summary, where these come to dominate, a potential is created that enables the emergence of generic rule structures. If these are manifested in the cognition-affect interactions, they then bind consciousness in such a way that recognisable states are perceived. The construct that this indicates is represented in Figure 2.

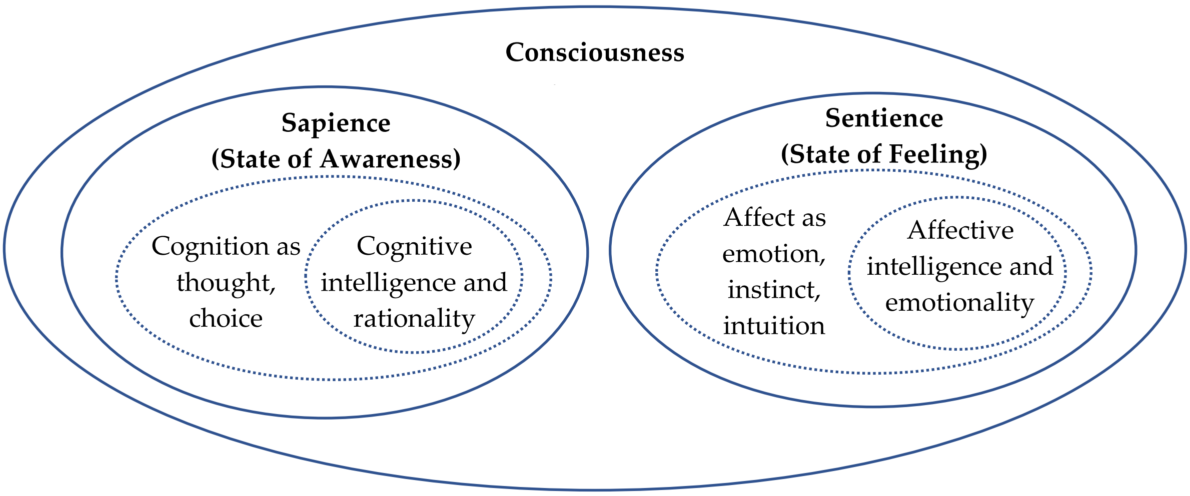

Figure 2. Ontology Map for the Concept of Consciousness, Defined through the Ontological Entities of Sapience and Sentience with their Epistemic Content.

2.2. Consciousness, Sapience, and Sentience

Consciousness may be conceived as a quality of intentional mental state, or in more generic terms, an intentional state of the intellectual mind, and thus, constitutes a subjective unit of consciousness and an abstract concept that characterises sapience or sentience. It operates through processes of the psyche that may be conscious or nonconscious. It is often expressed in terms of awareness, of which three forms are identified [83]: (1) sensing objects with corresponding feelings; (2) affects, like emotions, passions, and volitions; and (3) one's thoughts or cognitive processes. The first and second of these are often seen in terms of sentience and the latter in terms of sapience. Wanderer [84] (cited in [85]) notes that sentience refers to the state of being aware in the sense of being awake, with functional episodic processes of feelings and sensations, while sapience refers to the state of beliefs and intentions, with functional episodic processes of phenomena like thinking. Thus, sapience and sentience are epistemically symmetrical in that they have both: states which determine a condition indicated by its properties; and function through its attributes, a capacity for process that results in action.

Reflecting on Konderak [86], if a system is sentient, then it is a multidimensional subjective phenomenon that has associated with it a depth of sapience (this pertaining to self- and otherly- awareness, and self-welfare (relating to wellness and wellbeing), which may vary with the degree and type of experiences it has been exposed to. Powell and Mikhalevich [29] explain that a sentient state is a condition of feeling (also called affects), and these must be positively or negatively "valenced." Positive valence gives good feelings, while negative valence gives bad feelings, conditions that appear to be controlled by a neuronic switch in the brain that turns it from a default position of negative valence to a positive one under the right conditions [87,88].

For Shani [89], sentience can be referred to as *phenomenal consciousness* since it involves the ability to perceive phenomena. He calls sapience: *access consciousness* since it relates to an ability to access, via an ability to discern, connected qualities and relationships that are part of a phenomenon. Recognising that sentience is related to feeling, which is itself underpinned by affect/emotional knowledge (that is, knowledge about feelings and their application), sapience is related to cognitive knowledge (metacognition which regulates cognitive information processing [90]), and there is an inherent correlation between feeling and knowledge aspects of consciousness. For Shani, phenomenal and access consciousness are interactive and coevolve together, this ensuring that as cognition interacts with affect, so the system is influenced by the subjectivity associated with affect.

Such a notion of coevolution across the ontological dimensions of consciousness is supported elsewhere in the field of psychology, where Yolles and Fink [1] explain how cognition and affect, as autonomous systems, interact. They adopted the Swann et al. [91] *cognitive-affect crossfire model* that refers to a possible conflict between different *outcomes* of the two autonomous but interactive systems. The analytical processes and the affect do not operate in conflict, but rather cooperate in their interaction, creating a more holistic development. The cognitive system transmutes or transforms the affective response, while affect intrinsically motivates cognitive outcomes through emotion which has been subjected to intrinsic information. The affect-cognition crossfire constitutes an inherent manifestation of consciousness, and this can be expressed in terms of personality information processes and traits. This does not, of course, negate other structures in which sentient or sapient constructs may be more distributed, as in the case of the dual-brained octopus [92], noting that from a systems' perspective, sapience and sentience can each be set within more general systemic models.

Postulating that such features will always develop in sufficiently complex generic living systems constitutes a limited form of panpsychism. This refers to the function of mentality, deriving from processes of psychic energy, which may be defined as being comprised of emotional energy and cognitive liveliness, the latter referring to a flow of thought processes and cognitive agility [93] which is itself a form of cognitive energy. Mentality is a condition that enables sentience and is fundamental and ubiquitous among all agencies. Examples are systems having no nervous system, such as plants and unicellular organisms.

Sentient systems are living and intelligent. For Yolles [35,94], such systems are autonomous and complex, and they exist in a state of bounded instability in which there is an ever-present dynamic balance between order and disorder at the edge of chaos. This perspective is elaborated on by explaining that the condition of living not only applies to biological entities. A more generic definition can apply to any system with a structure that enables processes of autopoietic self-organising, and which can adapt autonomously to significant environmental change. Such an adaptive process involves both sapience and sentience. This is reflected in the Google incident referred to earlier, which was primarily interested in whether a chatbot, as a dialogue agency, has awareness and may perhaps have feelings. If a chatbot, or indeed a sapient, were to be classed as sentient, its architecture would first need to be representable as a living agency by involving the causal-agents of autopoiesis and autogenesis (processes that enable self-regulation and homeostasis), inherently resulting in a capacity for consciousness.

To explore whether entities, such as chatbot or sapient, are conscious and sentient entities, it is useful to consider their natures of being. In an approach towards this, Birch [95], when discussing the cognitive dimension of fish, makes the point that sentience need not be a binary condition, and the presence or absence of feeling can vary by degree across a multiplicity of welfare-relevant dimensions. Lee [26] also considers in what way non-binary sentience (i.e., a gradation of sentience) might occur and what it is that determines quantities (or indeed qualities) of sentience.

Since sentience is concerned with the relationship between affect (relating to feeling and emotion processing and the modification of memory structures that underlie emotions [96]) and cognition (relating to knowledge processing), considerations introduced earlier by Shani [89] again become interesting. Shani's philosophical perspective notes that feeling and knowing are among the most general and fundamental features of consciousness. Such a statement does not, of course, disengage from consciousness those with suppressive conditions like autism which may, for instance, result in empathy deficit in those with psychopathic tendencies and autism [97], and that some might see as abnormalities of consciousness [98].

With consciousness comes experience and awareness, so the act of experiencing is also an act of knowing (with epistemic qualities). Sentience enables emotional information and experience that is applied to the phenomenal consciousness, just as sapience enables awareness through cognitive information and experience that it delivers to consciousness. Shani asks how these two aspects may be related, whether one might be prior to the other, and if they are rather mutually dependent, which contributes to the other's structure and character. In other words, what have knowledge and feeling as part of consciousness to do with each other? We shall return to this question in due course. The distinction between the dichotomous divisions between phenomenal and access consciousness is ontological, each respectively providing the categories of sapience and sentience, with relative attributes of feeling and knowledge, and individually delivering the functionality of affect and cognition, as shown in Table 2.

Table 2. Ontology of Consciousness.

Ontology	Epistemology	Attributes	Functionality
Phenomenal	Sentience	Feeling (with emotion as feeling in application knowledge, or emotion metaknowledge)	Affect: from affect structures, the ability to subjectively feel, have emotions with physiological consequences, have awareness and responsiveness, and an ability to perceive or sense.
Access	Sapience	Knowledge (as cognitive knowledge or cognition metaknowledge)	Cognition: from epistemic structures, the ability to think, use cognitive intelligence, and acquire wisdom (discerning connected qualities and relationships).

To elaborate on this table, it has been said that sapience, through cognition, has been associated with its epistemology. It has also been noted that sapience and sentience have some epistemic symmetry, so it might be expected that one can indicate the epistemology for sentience too. This is reflected in the term "visual epistemology", which has been used to address a range of interconnected areas, such as internal and external images and the interplay of producer and perceiver of images [99], and where vision is a function of awareness. The term "sensualised epistemology" has also been noted by Sheedy and Rein [100], and used by Schaefer [101]. This intended to explain the relationship between affect and rationality. Both sapience and sentience may be considered to have internal and external attributes, so seeing visual and sensualised epistemologies as different aspects of an overall sentience epistemology. This is also consistent with the idea of emotion processing introduced earlier which, to exist, requires knowledge about feelings/emotions.

2.3. Gradation in Consciousness, Sapience, and Sentience

If consciousness is binary, a non-arbitrary bound is required to differentiate between consciousness and nonconsciousness, and a judgement is required that indicates where the boundary between the two conditions of consciousness exist as a set of objective conditions. While statistical approaches to resolving this are possible (e.g., the Markov blanket), qualitative approaches that are able to describe such conditions do not appear to exist. In this case, it seems that those advocating a binary consciousness need to adopt arbitrary subjective positions. Black [102] also supports the binary view, but explains that while gradation may not occur in consciousness, it can occur in the functionality that defines it. However, this still leaves open the problem of its boundary. Since adopting a binary view of consciousness leads to an intellectual cul-de-sac, here our interest lies in the graduated view, not only for consciousness but also for sapience and sentience.

Bloom [103], like Mikkilineni [34], defines sentience as having a capacity for feelings, and this requires a level of awareness and cognitive ability. Now, feeling is associated with emotion, the latter capable of manifesting physiological responses, where emotion is a condition of affect. The fact that sapience and sentience are autonomous interactive systems indicates that cognition and affect are similarly so [1,104]. The function of affect is to intrinsically motivate (with some intensity) an agency to maintain its fitness, and hence, its viability, in a complex changing environment [35], and this has consequences for evolutionary processes (cf. [105]).

The metaphysics of living systems may be considered in thermodynamic terms to be centred on entropy, but it may also be considered in terms of structure-forming intrinsic information supported by intrinsic motivation [54,56], the latter promoting activity that respectively satisfies sentient and viability needs. Both are connected with energetic processes, where the living systems are open to exchanges of matter and energy with their environment. During these exchanges, agencies maintain their viability through homeostatic processes, these requiring the maintenance of constant internal conditions that enable structure-forming stability. Structure-forming stability is a subset of the *functional connectivity* that facilitates coherent brain function and has consequences for perception stability. Where an agency has viability issues, homeostatic impulses are generated that motivate the system towards requisite adaptive processes, enabling it to regain internal structural stability. Thus, adaptation tends towards viability. These motivations may be considered to be processes of affect, where efficacious affect suggests intrinsic motivation. Internal stability, when represented by the sustainability of the system's welfare and well-being, constitutes fitness [35].

So, sentience involves both cognitive and affect systems, and these are in mutual interaction. The cognitive system facilitates adaptation through processes of cognition (enabling it to use stored knowledge) through appraisal, and under the condition of a state of consciousness (that provides processes of awareness that facilitate appraisal for requisite adaptations caused by a changing environment). The affect system provides motivational impulses that have close linkages with emotion, and these have valenced states, where valence refers to desirable/undesirable conditions with respect to any ability to maintain homeostasis [1,71]. The principle of generic agencies is that under changing contexts (which occur with environmental change), the degradation of system fitness is undesirable, while its improved fitness is desirable. Agencies adapt through motivational processes, and when fitness is degraded, the affect system motivates it towards creating requisite adaptive processes.

How can this affect-functionality be explained? Consider emotion as a transitive class of feelings that promotes physical actions associated with motivation (and hence, degree of intensity). Affect (through emotion), together with cognition, harnesses feeling as a directed metaphysical reaction to create motivated physical adaptive responses that has associated with it strength/intensity (cf. [104]). Where emotional valence is determined to have a measure of intensity, this will likely act as a parameter related to self-production that influences the system to be directed towards adaptive processes. Consistent with APA [106], the core characteristic that differentiates feelings from cognitive experiences is the link between affect (e.g., valenced feelings with intensity) and cognition (with an appraised evaluation of the nature and significance of a contextual change). Hence, the cognitive aspect of a system enables awareness judgements to be made about physical adaptive responses to changing situations.

The degree of agency complexity determines its capacity to make analytical judgements within its consciousness. More primitive agents lack the cognitive architecture required for higher degrees of cognitive integration and rational control, and have reduced deliberative or reasoned responsiveness [107]. Thus, their analytical capacities are less developed. Reflective of this, consciousness may be seen to have a variety of discrete levels, from the primitive to the advanced, with primitive consciousness a function of lesser complex agencies, like bacteria. To quote Yolles and Frieden ([35]: p. 1): "That living systems are conscious [108] is important because this allows one to differentiate between classes of living system by distinguishing between *degrees* of consciousness, where more primitive forms of life are less complex (with a lower level of consciousness), and more advanced forms are more complex (with a higher level of consciousness). Such a gradation has been proposed by Bitbol and Luisi ([109]: [110]), who offer a model of 5 evolutionary stages of system consciousness, these part of a hierarchical relationship. The different stages are each determined by the system's capability to *internalise* any environmental observations relevant to its life that it is capable of making, this then being used to determine its future—a process that may be expressed as *anticipation*..." Anticipation means an expectation that a given strategy of self-organisation will likely result in improved agency viability. It is an attribute of *externalisation* that is capable of physically manifesting intention and has a trajectory contrary to that of internalisation.

Where there are levels to consciousness, one might expect there to also be corresponding degrees of cognition and affect, and hence, of sapience and sentience. An alternative to the Bitbol and Luisi gradation schema comes from Bielecki [111], similarly with a 5-stage hierarchy of cognitive entities. Each stage has its own cognitive abilities and functionalities deriving from classifications that arise from perception and knowledge, and here different perceptions are relative to the existent patterns of knowledge, suggesting different degrees of cognition, and hence, of sapience. Recalling that sentience involves perception and both sapience and sentience have epistemic attributes, this implies that there may also be different degrees of sapience and sentience.

Consciousness is also a function of spirit, and this suggests that there is a gradation here too. To see this, we first need to define the word. The most general definition of spirit comes from the Merriam-Webster dictionary, which defines it as an activating or essential principle. An example is that intrinsic motivation might be seen as a form of spirit, though, in essence, it has a homeostatic function. The Cambridge English dictionary's definition of spirit is: the characteristics of a person that are considered as being separate from the body; and, as a particular way of feeling, thinking and behaving. Here, physical behaviour is activated by the agency's metaphysical characteristics, which include feeling and thinking. Now, sentience is a consequence of feeling and, through awareness, so is intentional behaviour that results in system viability. Also, sapience is thinking, with the implied cognitive processes that are involved. Thus, if there is a gradation in consciousness, this also correspondingly occurs in spirit. With implicit support of this idea, Ule [83] recognises the condition of spirit called collective consciousness, seen as a transindividual condition, the objectification of which delivers culture. Such consciousness, as a collective phenomenon, is closed to those entities that might be, but are not, part of the collective (hence the expression "internal closure"). It may deliver other attributes, as discussed, for instance, in quantum physics [112], cosmology [113], and religion [114,115].

The classifications by Bitbol and Luisi have been related to those of Bielecki, and are reproduced in Table 3 (deriving from Yolles and Frieden [35], but extended to include the spirit). A possible extension to this table has been suggested [110], but this is beyond our consideration here. In level 1, the Bielecki classification includes reflexivity, and this is consistent with Peters [12] in his consideration that consciousness must involve this. It should also be seen to be an attribute of Bitbol and Luisi's null pre-consciousness, and will be a basic attribute of living systems that underpins all higher levels of consciousness. The table also highlights the possibility of a variable gradation in sapience and sentience in each stage of consciousness. Since the state of consciousness is a function of system complexity, it seems likely that each consciousness stage has an upper bound of complexity in an agency. Thus, sapience and sentience may be variable in a range of constraints due to a series of upper bounds in complexity. To determine complexity bounds requires that one can classify systems appropriately, as has been considered, for instance, by Magee and de Weck [116] and Lorena et al. [117]. With increasing agency complexity, stages of consciousness can develop (as in the case of children or apprentices). An evolutionary perspective explains that transition across stages can result through generations of a species [118,119].

Table 3. Stages of Consciousness and Sentience/Sapience.

Consciousness Level/Stage	Bitbol and Luisi Hierarchy	Bielecki Hierarchy	Relationship	Spirit as Sapience and Sentience
1	*Null pre-conscious.* Devoid of internalisation.	*Reflexive.* A living system can only create behaviours that directly support existence and remove threats.	*Null preconscious* occurs prior to *reflexive* states since, in the former, threats cannot be recognised.	*Null-sentience/sapience.* This occurs with null preconsciousness
2	*Limited consciousness.* Integration of environmental factors.	*Associative.* Able to undertake simple analysis of direct cause-and-effect relationships.	*Limited consciousness* occurs at a stage prior to *associative,* the former being devoid of analytic ability.	*Limited sentience/sapience.* This is connected with associative cognitive capacities that can undertake analysis, supported by primitive impulses of affect.
3	*Enduring modifications in self-production.* Stable dynamic support provided able to deliver strongly anticipative behaviour.	*Conscious.* Can model complex cause-and-effect chains, with a conditional option permitting future events variants and an ability for complex strategies of activity.	*Enduring modifications in self-production* is approximated by the *consciousness* stage since cause–effect chains deliver a strategy that implies anticipation.	*Basic sentience/sapience.* Provides basic capacities for cognition and affect.
4	*More complex changes that influence behaviour.* Involves observation of the exterior, but without awareness of an external independent world.	*Self-consciousness.* Epistemic perspective can change, with awareness of the existence of conscious goals perhaps devoid of proven reliable criteria.	*More complex changes* are prior to *self-consciousness* since the proof requires awareness and access to the outside independent world.	*Complexification in sentience/sapience.* This permits improved degrees of sentience, with improved observation but without identity that distinguishes self.
5	*Collective consciousness that recognises social aspects.* Knowledge develops by ascribing properties to intersubjective invariants. Intersubjectively shared common predictive rules become a collective consciousness obeying internal closure.	The hypothetical *omniscient* stage, with proven criteria and proof of the reliability to use it.	*Collective consciousness* is likely equivalent to *omniscient* if one considers that proof is a social phenomenon.	*Collective sentience/sapience.* This involves mature cognition through the recognition of knowledge that has social entrapments and is associated with more mature aspects of affect.

3. Metacybernetics

Metacybernetics is a cyberintrinsic theory of living systems based on propositions deriving from Eric Schwarz and Roy Frieden's theory of EPI. Cybernetics is essentially a theory of information and processes of feedback, but as Corning ([2]: p. 297) notes, it lacks a "functional definition of information. The functional (content and meaning) role of information in cybernetic processes cannot be directly measured with Claude Shannon's statistical approach, which Wiener also adopted ... [and which is] ... blind to the functional properties of information".

In exploring this, Corning recognises that there are two forms of information which he calls structural and control, and cybernetics has both of these. The control information indicates the relationships between things through patterns of information/knowledge that provide a capability to control the acquisition, disposition and the use of matter/energy for purposive (cybernetic) processes. Such control may therefore be seen in terms of a systemic regulatory function. As earlier indicated, structural information may better be represented as structure-forming information and is an essential ingredient of the causal mechanisms that facilitate processes of self-regulation, self-organisation, and adaptation in a living system, thus being able to maintain its viability. Cyberintrinsic systems are defined in terms of intrinsic information, and system structures are stable if the structural information is intrinsic, that is if it is Fisher information (which derives from Frieden's EPI). The connection between control and structural information can be illustrated as follows. Consider a living system with a physical structure and a related regulatory metaphysical structure. Using its local control information, a physical structure conditions the potential for physical behaviour in its environment. Moreover, using its local control information, a strategic metaphysical structure regulates its related physical structure. Using structural information that codes the structural relationship between physical and metaphysical control information, a causal mechanism, through the structure-forming information carried by a causal-agent, is able to functionally (through content and meaning) relate the physical and metaphysical.

In this section, our interest will be to explore the metacybernetic framework, its various regulatory mechanisms, and the role and efficacy of structural information in this.

3.1. A Metacybernetic View of Living Systems

Drawing on Yolles and Fink [1] and Yolles and Frieden [7,35], one can say that agencies are both autonomous and complex [35,94]. They also exist in a state of bounded instability in which there is a continual dynamic balance between order and disorder at the edge of chaos. Agencies have control processes, but when they reach a control threshold, their patterns of behaviour fluctuate unpredictably, where small perturbations can be significantly amplified. This can result in unpredictable, complex behaviour with hidden patterns that can be uncovered by deeper exploration. Agencies are open to their environment with which they interact and from which information comes, together with energy and physical material. The information derives from the observation of relevant parameters in a given contextual environment. Agencies also have an internal metaphysical domain where they use that information to maintain order, thus enabling themselves to maintain viability in their environment (which is continually subject to change). They are able to maintain their viability through processes of self-organisation that enable them to adapt to changing environmental conditions.

The ability to self-organise is causalogical. To understand this in terms of metacybernetics, consider that an agency can be defined generically so that it has the characteristics of living but may not be organically based. We call this *agency*—an entity that has the capacity to act and produce an effect. It has already been said that agencies may be individuals (when they may be called agents), or they may have a population of interactive agents. The interactive nature will have emergent consequences for the possible individual and related behaviours of agents. The core structural information is directly involved in the agency's networks of intelligence processes. This includes behavioural, operative, and figurative intelligences. The first of these identifies parametric data in agency environments and transforms it into a pattern of meaningful operative control information. Autopoietic intelligence collects the operative information, transforming it into meaningful cognitive control information. Figurative structural information determines the stability of agency and applies homeostatic corrections (through homeostatic control information) where instability is determined to be possible. Information can only be recognised as such since agency has patterns of knowledge to which it can be referred. Agency has a physical dimension that includes its operative system and its environment, the former having structures that facilitate and constrain physical behaviour. It also has a metaphysical dimension that creates order and regulates that behaviour to enable it to maintain or achieve its viability.

Agency has an ontological structure that differentiates classes of being, this defining its local nature. The minimal agency structure is to have three ontologically distinct systems, operative, figurative, and cognitive, interconnected by causal-agent mechanisms. To recognise the location of these systems in agency, the operative system is anterior to the figurative system, and the figurative system is posterior to the operative system. Inter-ontological trajectories are provided through causal mechanisms, these providing media for causal-agents that deliver causal effects through a network of causal processes using structural information.

There are two causal-agents commonly used in metacybernetics, both being networks of intelligence processes. One is autopoiesis, which connects the operative and figurative systems through two reverse trajectories: (i) an anterior causal mechanism that internalises information from the environment, and it can be used in the formation of purpose; (ii) a posterior causal mechanism that delivers requisite regulatory information that anticipates processes of self-organisation, and hence provides a capability for adaptation, enabling purposeful agency strategy to be environmentally externalised. Internalisation (a concept derived from Piaget [120]) involves the two steps, one of assimilation (when the model is made available to the local system), and the other of accommodation (where the model becomes structurally integrated into a local system). Externalisation may also be considered to have a form of assimilation, where an agency's behavioural strategies are manifested into its environment through its posterior behavioural intelligence, and accommodation which occurs when an agency adaptive processes are integrated into its environment. Anterior and posterior causal-agents operate in a circular causality, which is a function of the cognitive processes that necessarily occur under conditions of consciousness, enabling self-awareness (sapience) and other-awareness of environmental conditions that might challenge agency viability. This assembly operates as an autopoietic couple that, as a whole, may be seen as an autopoietic system.

The other causal-agent is autogenesis operating at a higher order of cybernetics, which connects the autopoietic system to the cognitive system, delivering regulation that, as far as agency is concerned as a whole, is homeostatic, thereby maintaining it as a stable phenomenon. An autogenesetic system is a recursive entity that exists at a higher (self-creative) metaphysical level than does the autopoietic system, which is embedded within it. It, too, has anterior and posterior causal mechanisms that enable homeostatic internalisation and externalisation to occur.

The metaphysical domain of agency constitutes a potential through which disposition, and by extension personality, may arise—a structure that creates agency's characteristic cognitive and affect patterns, this informing its behaviour. Where this occurs in mature agencies (those having a more mature stage of cognition and affect), ontologically local traits can be determined that explain how agency metaphysically creates order in variable ways that depend on the characteristics that determine homeostasis. In mature agencies (like humans), these characteristics may be values that regulate determinable psychological conditions that, in turn, regulate behaviour [1], while in the immature agency of viruses, the dark genome provides self-stabilising attributes that determine genome strategic options that regulate virus behaviour [7]. The agency model is provided in Figure 3a,b, respectively for agency cognition and affect, the formed having cognitive purpose/intention, and the latter affect purpose/intention (adapted from Yolles and Fink [1]). It is a third-order cybernetic model since it has three ontologically distinct interconnected systems that define agency [94]. They are connected by causal-agents, and is in essence an enactivist model of emotion [121] deriving from Varela's elaborated notion of autopoiesis [122]. Figure 3a is an agency representation of the cognitive/sapient dimension of consciousness, and Figure 3b a representation of the affect/sentience dimension of consciousness. Note the inclusion of cognitive knowledge which constitutes a sapient epistemology, and affect knowledge which constitutes a sentient epistemology. It is also worth referring to the comment made by Peters [12] referred to earlier, that most cognitive processing occurs unconsciously, where all the information acquired must be available for processing to enable system functionality. By extension, the same can be said about affect processing as shown in Figure 3b. This may be represented in metacybernetics through its agency model, where consciousness can be distinguished into the parallel affect and cognition agencies, and each of these consciousnesses can be distinguished into the conscious and unconscious, the latter distinguishable into the subconscious and unconscious [1]. Hence, the unconscious, as Peters notes, is concerned with both information processing and its condensation as knowledge.

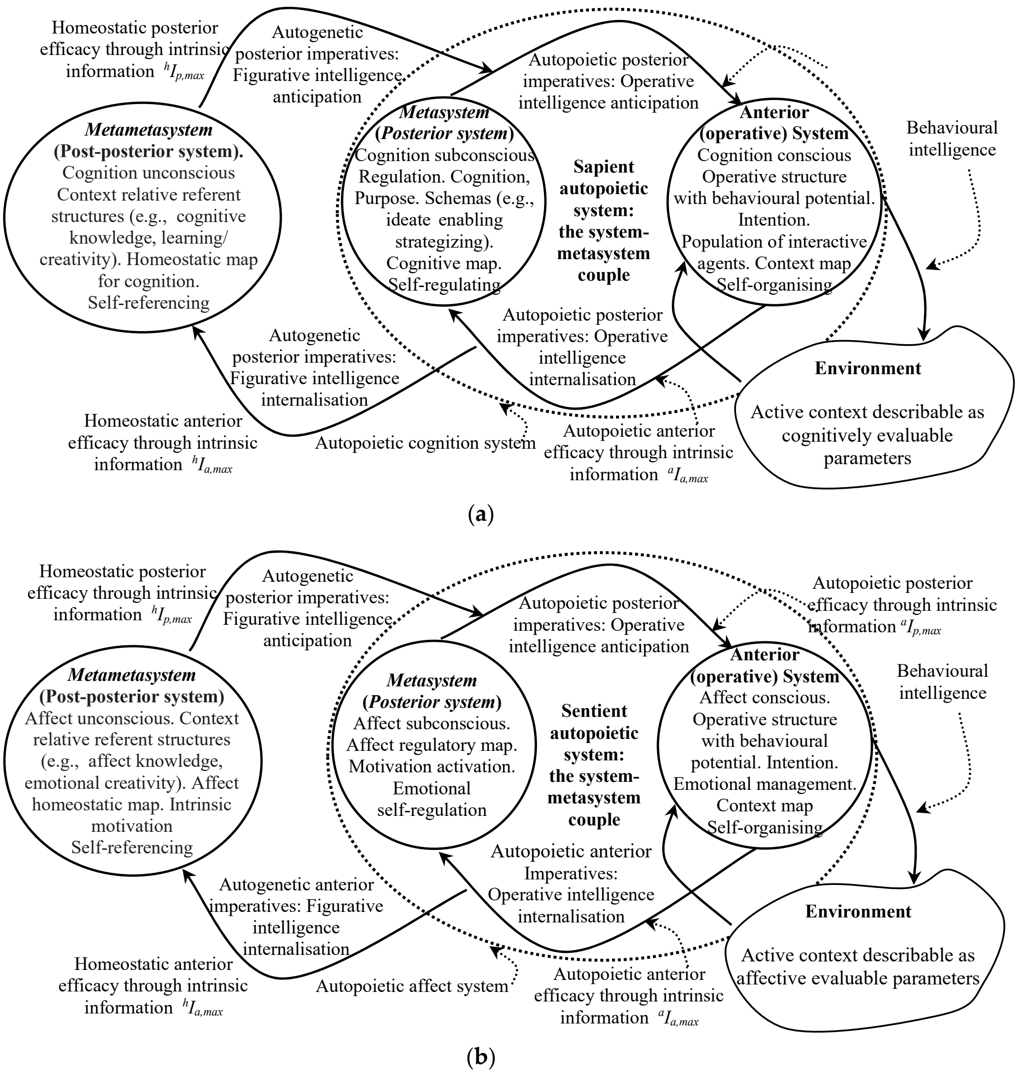

Figure 3. (**a**): Metacybernetic Model of the Cognitive/Sapience Agency, (**b**): Metacybernetic model of the Affect/sentience Agency.

Following Yolles and Frieden [7], models like Figure 3a,b are ontological structures in which the local ontologically distinct systems exist in a hierarchy of influence, a higher ontology being hierarchically superior to that of its local neighbour. Each system will have a pattern of information composed of a collection of data entities, with each having a mutually related connection that, as a whole, provides logical meaning. The data has a parametric origin, is collected by an intelligence, and then delivers it to a map that constitutes a model assimilated into the local system, which it can use in its control function; this is then integrated into its structure through a process of accommodation. Each map indicates locations and interactions for ontologically inferior contexts. The operative system, which is responsible for system operations, has a context map. In the metasystem, which is responsible for regulation, there is a regulatory map. In the sapient system, this is referred to as a context map, but in the sentient system, it is an affect map. In the meta-metasystem, which is responsible for meta-regulation, there is a homeostatic map. The context map identifies the relationships between bounded parametric contexts, while the regulatory map identifies the parametric interactive relationship between the operative system and the metasystem. It also contains both personalised and social information required for episodic behaviours. The homeostatic map is like a context map, but it rather refers to the parametric interactive relationship between the autopoietic system and the meta-metasystem needed to regulate episodic activities.

Since the intelligences operate as causal-agents, their actions are directed through causal mechanisms that operate on the information that they carry. If that information is intrinsic, then the causal-agents (through structural information) promote autopoietic system stability, but if not, then it will have a graduated tendency towards instability. Each ontologically distinct system operates through a map that is informed/updated by information flowing through a causal mechanism. The intelligences may operate efficaciously, resulting in the transmission of intrinsic information, but when information is not intrinsic, then structure-forming stability is compromised [35]. We may summarise the nature of the intelligences as follows:

- Behavioural intelligence operates through a causal mechanism connecting environmental parameters with an operative system and is constituted as a causal-agent network of structural information processes. The action of the intelligence is to enable the contextual and perhaps dynamic parameters) in the environment to be identified, selected, and measured, and this includes those representatives of agent interactions. The intelligence then transforms the data into a structured context map locally meaningful to the operative system. There is a circular causality here in that anterior behavioural intelligence enables the operative system to recognise environmental changes, and acquire and transform the parametric data. Posterior behavioural intelligence enables agency requisite adaptive behaviour to occur in the environment by acting on the parameters. When the transformation process is efficacious, so the physical information is intrinsic, and there is good correspondence between the acquired parametric data and the context map.
- Operative intelligence enables autopoiesis (self-production through its network of processes) that couples the operative and figurative systems, the assembly forming an autopoietic system. Autopoiesis services the processes of agency self-regulation. It acquires structural information from the context map, which it regards as a parametric context, and transforms it autopoietically to the metasystem to set it in the regulatory map as a locally meaningful model. The model, when autopoietically accommodated, is able to immediately facilitate a process of self-organisation due to the updated control information. Where the process of transformation is efficacious, then the context map is suitably represented by the regulatory map, and autopoietic intrinsic information flow has occurred. Autopoietic circular causality occurs when the anterior information flow updates the regulatory map from which regulatory processes arise, and the posterior information flow does the same for the context map, therefore, through self-organisation, adjusting the structure of the operative system. Intrinsic information flow is indicative of structure-forming stability in the autopoietic system, and hence, its degree of order.

- Figurative intelligence enables autogenesis (self-creation) through its causal-agent network of processes. It acquires information from parameters in the autopoietic system that arise from the autopoietic system (constituted as the relationship between the context and regulatory maps), and it determines whether there are any signs of instability in the autopoietic system. Where there are, it determines the causes and takes homeostatic control action to correct this. Due to its circular causality, the reverse action also occurs so that the homeostatic map can also be adjusted. The anterior autopoietic information flow updates are capable of providing regulatory guidance for updating both maps and reporting back to the metametasystem. The quality of the figurative information will be indicative of structure-forming stability, and hence, the degree of agency order. If the information is autogenesetically intrinsic in that it draws Fisher information from the parameters present in the autopoietic system that include regulation, then the homeostatic processes may be expected to be successful.

The three maps may be considered context models through which each ontological system can represent or refer to various relative attributes of living systems like regulation, homeostasis, affect, homeostatic affect, internal affect, cognition, regulatory-affective relationships, and affect regulatory structures.

The agency structure of Figure 3a is deemed to be cognitively conscious, just as Figure 3b is deemed to be affect conscious. Sapience, at minimum, enables awareness that can recognise parametric information and process it, and sentience that qualifies sapient processes, thereby creating requisite responses to maintain its viability. In situations where either the metametasystem becomes unstable or autogenesis otherwise fails (indicative of a system pathology represented in Figure 3a,b as a figurative intelligence incision), agency becomes instrumental since the knowledge available to the autopoietic system becomes unavailable, and learning is not possible. In this case, for contextual circumstances beyond the scope of the current regulatory structure, the regulatory control is essentially determined by the environment beyond the options currently available to agency. Overall, agency is a conscious entity due to sapient and sentient capabilities. As it maintains its awareness of a changing environment, it delivers requisite responses to ensure that it maintains its viability. Consciousness can vary from a null state to a collective state; this also distinguishes between different levels of sentience/sapience. Within a particular stage of consciousness, sapience and sentience may have different degrees of development.

Let us consider setting this model in terms of our earlier interest in chatbots and sapiens, both of which we will deem to operate through autopoiesis which, we have seen, is a network of intelligent information processes. Chatbots will have a context map of parametric information from the environment (a dialogue partner) that is updated with new input. As such, a context can evolve. It will also have a regulatory map, deemed to be a strategic information base, that defines grammatical structures and enables dialogue inputs to be autopoietically analysed and classified through an updating process of its context map. It creates responses that are determined from the regulatory function of the regulatory map. Such systems are referred to as instrumental because the regulatory map is fixed so regulatory processes are limited, and chatbot responses are bounded. If one were to consider that autopoiesis can, on its own, constitute a basis for life, then possibly one may class a chatbot as conscious, but only in a limited way (i.e., from Table 3 consciousness stage 2, it has limited consciousness in an associative hierarchy).

The sapient has the same instrumental architecture (with an integrated matrix of concepts), but this is embedded in a higher-order cybernetic structure that regulates its instrumentality. The instrumentality is subject to modifications that derive from a meta-knowledge model embedded in the homeostatic map and is informed by the network of intelligent information processes of autogenesis with context map referencing. This system is capable of not only regulation as occurs with the chatbot, but through its metaknowledge, it is capable of adjusting the regulatory map to therefore vary its responses. In principle, it is also capable of adjusting its own metaknowledge through the autogenesetic network of processes. While both chatbots and sapiens are autopoietic in their nature, this illustration shows that autopoiesis on its own is insufficient to define the nature of living. The degree of consciousness of a sapient will depend on its degree of learning, and it could, eventually and in principle, achieve a consciousness stage 5. As noted by Yolles and Frieden [35], such a development, when integrated into autonomous robots, would enable them to understand their environment and be cognizant about what they do and about the purpose of their actions, making timely initiatives beyond goals set by others. They would also learn from their own experiences, knowing what they have learned and how, making them more reliable and effective.

Following Swann et al. [91], both sapience and sentience are autonomous interactive systems, and it has already been noted that this interaction can be complex. Their relationship is, therefore, such that they mutually impact each other through a cognition-affect crossfire, as shown in Figure 4, this arising from the operative connection between sapience and sentience deriving from Figures 1 and 3a,b (and adapted from Yolles and Fink [1]). Noting the interest of Carl Jung in personality, where he differentiated between thinking, feeling, sensing, and intuition, one wonders where the latter of these fit into the model of Figure 4. A possible explanation arises by considering Epstein [123], noting that for Simon intuition is "bounded rationality . . . [this being a reduced form of deliberative reasoning that is] nothing more and nothing less than recognition" ([123], citing [124]:p. 155). Since reasoning is a property of sapience and recognition of sentience, this implies that intuition is constituted as a synergistic frame deriving from operative sapience-sentience interaction.

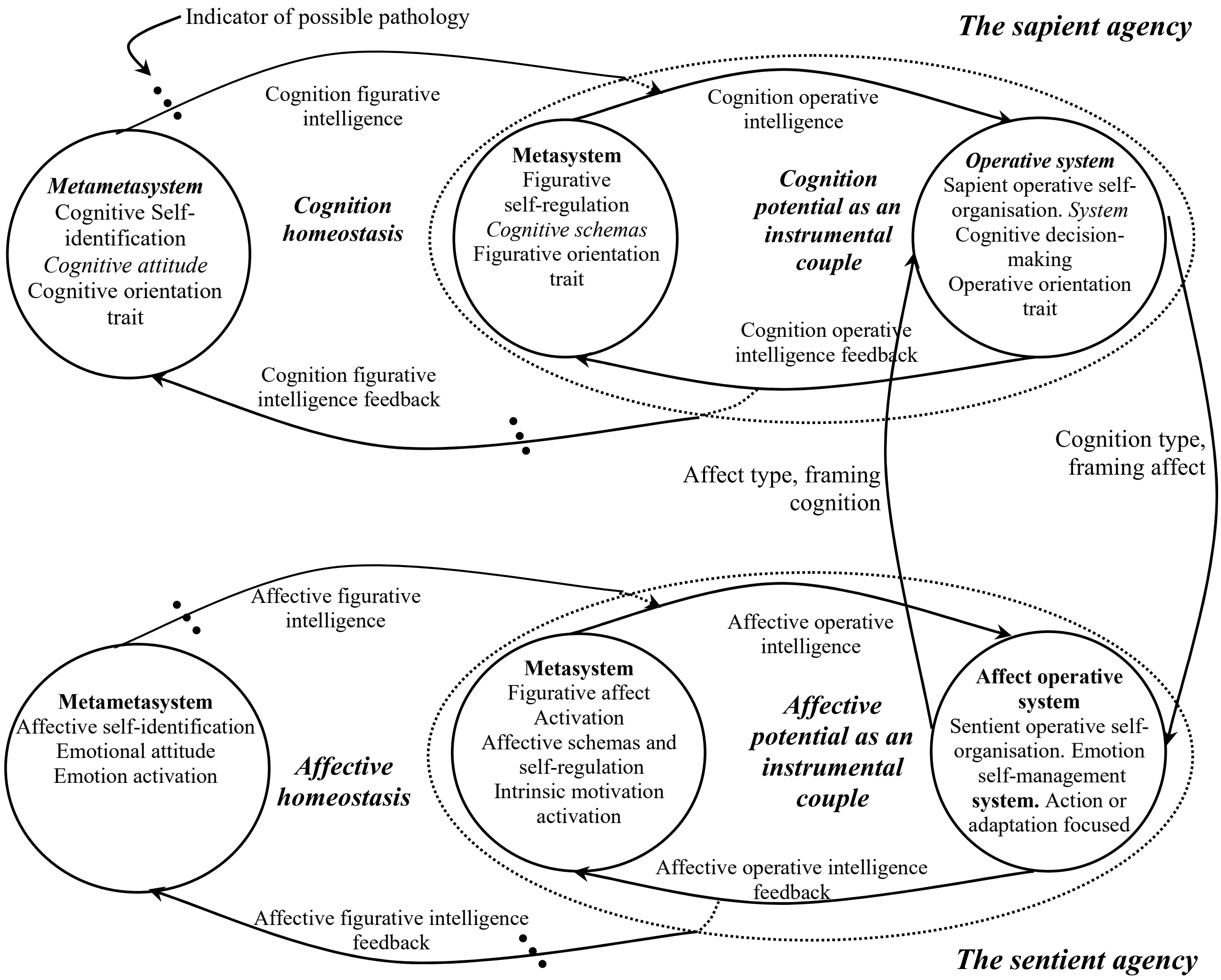

Figure 4. Cross-fire Model (adapted from Yolles and Fink [1]).

3.2. Structural Intrinsic Information

In previous work in metacybernetics [7,35,94], it has been shown how Frieden's [38] EPI theory can be integrated. The theory is designed to reduce uncertainty in taking measures from parametric sources through the use of intrinsic information, which we will recall maximally (as completely as possible) represents changing contexts by acquiring information about the parameters that characterise it as well as may be possible. To understand intrinsic information pragmatically, consider that parametric contexts have bound information, but in complex systems, not all of this is observable. Intrinsic information is obtained when the maximum information is obtained from the context that is possible. For Meijer [39], this is nothing other than *Fisher Information* [4] which arises from EPI. This occurs when information is acquired from a parametric context efficaciously through behavioural intelligence, which it then codifies. The theory that underpins intrinsic information derives from Frieden [125]. Its principle is that quantitative observations are made that constitute samples from a set of relational parameters. The data values y to be measured satisfy

$$y = a + x \tag{1}$$

where x are the data fluctuations (constituting noise) about which an observer is ignorant. The ignorance may be fundamental, where x is: (1) intrinsically random as in quantum mechanics, (2) random only because the observer is applying non-ideal detection equipment to its measurements, (3) actually deterministic, changing from one reading to the next via a definite trajectory $x(t)$, t = time (say) (though the observer does not know this microlevel truth). In general, x obeys some definite unknown frequency law $p(x)$. When x is later found to be random, $p(x)$ is as well a probability density law. In general, since x is effectively random, it may be treated $p(x)$ as a probability law. Now a are some unknown parameters defining the state of the agency. The measures y are observations from the information J that is bound to the parametric context being observed by the intelligences. Thus, in effect, intrinsic information is a property of x through $p(x)$, and J is a kind of "prior" intrinsic information in that (by hypothesis) $I = \kappa J$, where I is the structural information acquired from the parametric source, and κ is a constant indicative of observational efficiency or acquisitional efficacy [35]. The data y are used in an estimation principle to form an estimate of a which is an optimal function $\hat{a}(y)$ of all the data, for instance, including the sample mean.

To understand why there is a difference between I and J information, consider that a parametric source (with information J from which information I is to be acquired) is a macroscopic event. In modern measurement theory, this is intrinsically *lossy* (i.e., information gets lost), and hence, it is irreversible in nature. To acquire data about the parametric state of a system, a measuring device must interact with that system. This interaction causes an irreversible exchange of information and energy between the device and the system. Its irreversible nature is equivalent to a coarse-graining [126,127] (viewing a parametric source at an appropriate level of detail while reducing the data complexity by smoothing some of its fine detail). As such, the acquired data suffers a *loss* of intrinsic information [38]

$$\delta I \geq 0 \tag{2}$$

from its intrinsic value J prior to measurement. Thus, since $I = J + \delta I$, so

$$I \leq J. \tag{3}$$

The overall measurement procedure is said to be smart since $\hat{a}(y)$ is, on average, a better estimate of a than any of the data observables [38]. The x is said to be intrinsic to the parameter a under measurement. From this idea comes the term intrinsic information, as adopted by Meijer [39], where minimal noise effects are deemed to be present. It arises from measures of the expected error in a smart (i.e., averaging) measurement so that for an on-average class of measures $\hat{a}(y)$ (said to be unbiased estimates), the mean square error e^2 in the estimate $\hat{a}$ is satisfied by ([38]: p. 29)

$$e^2 I \geq 1 \tag{4}$$

where I is the intrinsic information acquired at the measurement output where an observation occurs, and J is the level of bound information at the parametric input. This relation holds, as well, even for 'biased' measurement, as long as I is sufficiently large.

Earlier, we considered an issue of structure-forming stability, and this occurs when the information acquired as an output from a parametric source (which is then delivered to a model of that source) is not intrinsic, this impacting on the potential for structure-forming stability and hence agency viability. In general, then, instability occurs when the value of I is insufficient to adequately represent J. This may be a function of the capability of the causal-agents to seemingly act intelligently, which is more likely when acquired information is intrinsic. Instabilities may occur, for instance, in behavioural intelligence when the context map as a parametric model does not sufficiently well represent the parametric context being measured. It may also occur when the context map parameters are not adequately represented in the regulatory map as a model, or when the autopoietic system parameters are not adequately represented in the homeostatic map as a model. However, it may occur that intrinsic information may itself be a cause for instability. To understand this very particular case, for structure-forming stability, the error e should be such that the parametric data are spaced close enough together to obey the 'Nyquist sampling interval' [128] or less. That is, they are spaced by amount $1/2R$ (or smaller, i.e., finer), where R is the 'cutoff-frequency' of the data space.

In the above, it is assumed that sufficient information of level J is already present at the input to the observed system (with the observation at its 'output') to acquire data by the intelligences (as observers) of sufficient quality to recognise the measured effect. However, any system acting as a channel of information must inevitably lose some en route to the observing measurer. We require that loss be a minimum value so that the level $J - I$ of information is maximised (giving information that is intrinsic), which is the net Minimum Fisher Information principle. The reason for so-maximizing it is that, by Equation (2), this minimises the smallest possible error

$$e^2 = e^2{}_{\min}, \tag{5}$$

and where e^2 can be directly determined as (Frieden, 2004: 30):

$$e^2 \equiv \int dy[\hat{a}(y) - a]^2 p \equiv <(\hat{a}(y) - a)^2> \tag{6}$$

the latter term $<\bullet>$ being an expectation. When the parametric data y are known, as already indicated, a is determined from some data function like a simple average. The noise x is due to phenomenological fluctuation that defines the phenomenological effect driving the system. It has been said that it obeys a probability distribution $p(x)$ which is the uncertainty associated with the effect. The need is to determine the unknown distribution $p(x)$. From data y the total amount of information I carried by the system can be determined, which must satisfy the maximum EPI principle that I is a *maximum* satisfying Equation (5). Knowledge of the parameters involved depends on the narrowness of the distribution $p(x)$, and this indicates how much information is collected in the data. When the observed systems obey the condition $I = I_{max}$, when it is called intrinsic information, and where I can represent such measures as entropy, order, or complexity, depending on context. Since the information I is acquired from the bound information J, in general, I is not a perfect measure of J. Fisher information comes from the appropriate measure of the expected error, so that formally [126]

$$I \equiv < [(d/dy) \log p(y \mid a)]^2 > = 4 \int dx\, q'^2(x) \tag{7}$$

the latter equality obtained by replacing $p(x)$ with $q^2(x)$, and where $\sqrt{q}(x)$ is the probability amplitude of $p(x)$ as used in quantum theory, and where $q' = \mathrm{d}q/\mathrm{d}x$, and $p(x) = q^2(x)$. Here, $\sqrt{q}(x)$ is the real part of a complex-valued function that describes an uncertain or unknown quantity. From Equation (1), if $p(y \mid a)$ is known, then so is $p(x)$ and information I, and due to the probability amplitude, I may be seen as a measure of the width of $p(x)$.

4. Agency Thermodynamics

Most of the metaphysical conceptualisations relating to sentience have been constructed using thermodynamic theory. One exception is that of Integrated Information Theory (IIT) [42,129,130] which did not start out as a thermodynamic theory but has recently been set within the thermodynamic framework [131]. The theory is concerned with consciousness and the prediction of levels of consciousness. We do not include it here, not because it has a number of detractors [132–135], but because it does not explicitly consider sentience, which is a core interest of this paper.

In order to make sense of the sentience theory formulated in thermodynamics, there is an initial need to identify its propositional background. In particular, interest will lie in the use of this theory within the metaphysical context. In order to explore the nature of consciousness from a thermodynamic perspective, Friston [136], among others, adopts the metaphysical concept of free-energy, this being differentiated from the thermodynamic physical free energies of Helmholtz (which refers to the useful work that can be done in a system) and Gibbs (which refers to the maximum reversible energy in a system). Friston explains that free-energy is an information theory quantity that bounds the evidence for a model of data, this data being the consequence of sensory inputs that results in a mental model that has been encoded by the brain.

In living systems, the minimisation of free-energy is coincident with requisite adaptive change (and by using the word requisite, we are referring to the adaptive changes that will maintain agency viability, taking a critical realism perspective). We will then relate free-energy to structural stability. Following this, we shall consider how mental models are updated using a brain-modelling approach. This considers consciousness as having a resting state and evoked states, the former drawing in the assumption of quasi-equilibrium. Finally, from the idea of free-energy, we shall show how it has been possible to determine emotional states under simulation using a thermodynamic structure.

4.1. Background to Thermodynamics

4.1.1. Physical Thermodynamics

Perhaps the earliest innovative work in the thermodynamics of agencies (as living systems) is that of Szilárd [137], this being significantly prior to the work of Prigogine [138] in non-equilibrium thermodynamics. Thermodynamics is a field of study concerned with the relationship between the physical quantities of heat, work, temperature, and energy. It can apply to open, closed or isolated systems, and is the study of interrelationships between macroscopic properties. It uses statistical tools through which it can relate the properties of a macroscopic system to behaviours of its individual elements, thereby obtaining a better understanding of both [139]. This is in contrast to statistical mechanics, defined as the theory of the behaviour of macroscopic systems that starts from a knowledge of microscopic forces that occur between constituent particles [140].

An agency, in thermodynamic terms, is an open system that functions far from thermodynamic equilibrium, surviving by exchanging both energy and matter with its environment. Agencies may be said to have thermodynamic potential energy. Here, certain variables in a system may be identified, such as enthalpy or heat content (indicated by temperature), and its free energy. We have already noted there are two types of free energy, that of Helmholtz (used to determine how systems change and how much work can be produced), and the Gibbs free energy, which combines enthalpy, temperature and entropy into a single value that can be used as an indicator of system composition change. Nilsson and Niedderer [141] explain that neither enthalpy nor enthalpic change can be directly transformed into energy, though enthalpy is a function of internal energy, and both can be used contextually to describe a potential that impacts physical processes. Enthalpy is normally an extensive variable since it is materially related. However, *specific enthalpy* is an intensive variable, meaning it is conditional and independent of physical material [142].

Explaining the nature of thermodynamics, Mallick ([143]: p. 1) says that it: " . . . describes macroscopic properties of matter . . . in terms of a small number of macroscopic observables assuming that these properties do not vary with time. The Laws of Thermodynamics allow us to derive some general relations amongst these properties irrespective of the structure of matter at the atomic scale." Thermodynamics has become an important branch of physics despite the fact that its laws are unproven (or rather have no formal verification and are rather only assumed from experience [144]). Mallick ([143]: p. 2) continues by saying that: "Thermodynamics is also the science of energy conversions, all forms of energy involved must be identified correctly and accounted for, and different forms of energy are not equivalent."

The word 'thermodynamic' explains energy changes in terms of entropy, and it operates through a set of unproven laws that are central to it. Following Schrödinger [145], the first law of thermodynamics is an energy law, and the second is an 'entropy' law. Thus, for instance, the first law is concerned with the ability of mass and energy to flow into or out of an open system, while in the second law, entropy can be decreased but not destroyed. If one were to cite an equivalence for intrinsic information that could be related to Schrödinger's view, then its first law would concern energy and its second information. However, Schrodinger knew little about "information" per se; it was developed by R. Fisher almost simultaneously (between the years 1922–1925) concurrent with Schrodinger, although in the field of biology rather than in physics. Thus, the first law for open living systems might be that information and energy are interchangeable and can flow in and out of an open system, and the second is that intrinsic information enables living systems to maintain their order and hence maintain their viability. It is interesting, however, that the definition of the second law of thermodynamics for open living systems has virtually as many variations in its definition as there are authors who state it, indicating a lack of theoretical maturity.

The laws of thermodynamics for physical systems concern energy, explaining, for instance, how internal energy is able to change and how the system can perform useful work on its environment. Here, taking a leaf out of Schrödinger's [145] book, the first law is related to energy and the second to entropy, though here we, in due course, make the argument that intrinsic information is also important to it. Considering that information can be seen as a form of energy (and we shall return to this), the laws may be given for open living systems as:

1. First law (of energy): a conservation of energy proposition, energy cannot be created or destroyed, but can only change form, at least between information and forms of potential energy and kinetic energy; or it can be transferred from one environmental object to another, or enable endogenous-exogenous exchanges.
2. Second law (of entropy): The process of living needs to counter an inherent tendency towards entropy and through work that uses energy to create or maintain order by acquiring intrinsic information from the environment; this occurs at environmental expense where entropy is increased; as a real process, it is irreversible due to this very increase in entropy.

The wide varieties of the second law offer one the liberty of creating one's own proprietary version, as has been done here. This sheer variety of expressions of the second law, however, can be problematic, confusing, and even deliver paradox [146], something we shall return to later.

4.1.2. Measuring Entropy

There is a large variety of entropies [147], but one that is frequently referred to is Shannon information H, also called the Shannon entropy [148]. This is the average rate at which information is produced by a stochastic source of data. Shannon refers to self-information, which is a measure of the information content associated with the outcome of a random variable, where the amount of self-information contained in a probabilistic event is dependent only on the probability of that event occurring. The smaller the value of the probability, then the larger the self-information associated with receiving the information about that parametric event. The measure is expressed in a unit of information, like bits (using a Log base of 2) or nats (using a natural Log base). Given y as the variable representing a measurable parameter, then the larger the Shannon entropy, the greater the amount of information given. Shannon entropy takes the form:

$$H = H(x) = -\int p(x)\ \mathrm{Log}\ p(x)\ \mathrm{d}x \tag{8}$$

for the probability $p(x)$ of the event x, and hence the possible states that can occur. So, H like I, is a function of an underlying probability density function $p(x)$. Expressed in terms of information, given the variable x, the entropy $H(x)$ is the amount of information it contains.

So, the analytic properties of the Fisher and Shannon information measures are different. While $H(x)$ is a global averaging measure of smoothness in x for $p(x)$, $I(x)$ is a local measure that depends on the nature of the parameter being observed through its fluctuations x. This means that I will take different context locally dependent outcomes, unlike H, which always takes the same general form of result through averaging.

Another popular measure of entropy (which will be referred to later) is the Kullback-Leibler entropy K_L, which is a measure of relative "distance" between $p(x)$ and another probability distribution $q(x)$, where:

$$K_L = -\int p(x)\ \mathrm{Log}\ (p(x)/q(x)). \tag{9}$$

or

$$K_L = -\int p(y \mid a)\ \mathrm{Log}\ (p(y \mid a)/q(y \mid a)). \tag{10}$$

4.2. Living Systems, Far from Equilibrium, and Metaphysical Process

One of the main differences between living systems and non-living systems is that, unlike the latter, the former requires an energy source that it uses through work that it applies in particular ways to autonomously physically survive. An explanation is given by Jørgensen and Svirezhev ([149]: p. 40), when they say that "Living systems require an energy source that can provide the energy needed to maintain the system far from thermodynamic equilibrium. Without the energy source, the system will inevitably move toward thermodynamic equilibrium, where there are no gradients in space or time—the system is, therefore, dull and has no life. An energy source is a necessary prerequisite for living systems". At thermodynamic equilibrium, differentiation is eliminated, and no work can be performed. Since thermodynamics is, in its significant part, concerned with the use of energy, it has provided a useful approach to the study of living systems. Free energy in thermodynamics is used to determine how systems change and how much work they can produce. Helmholtz and Gibbs free energy, with internal energy and enthalpy, together provide a thermodynamic potential through which measures for work can be made.

Core to thermodynamics is entropy, and two entropic conditions of state occur: equilibrium and non-equilibrium. As Bauer ([24]: ([149]: p. 41)) has said, " ... Only living systems are never in equilibrium and permanently performing work at the expense of its free energy ... A source of the work done by living systems is at the final account, free energy ... This non-equilibrium state ... is maintained or permanently restored at the expense of the energy of continuous processes of equalisation which is flowing past within a living matter." That they are never in equilibrium does not bar some theoreticians from proposing that under certain, well-defined situations, quasi-equilibrium conditions can be supposed, even if this is only a simplifying mechanism being used to explain otherwise difficult phenomena. Living systems are extremely complex, and as we shall see, there has been a tendency for the exploration of the metaphysical to adopt quasi-equilibrium conditions, though there are issues with this, as will be explained.

Bauer, who was a relatively early advocate of thermodynamics applied to the study of living systems, notes that "all living organisms must maintain themselves high above thermodynamic equilibrium ... it is not the principle of least action that determines the gross behaviour of living organisms. Living organisms must continuously select the process endpoints [that constitute their intended strategic outcomes] according to the requirements of remaining alive. Since being alive involves a tendency to maintain life as long as possible, and as far above thermodynamic equilibrium as possible ... [this] corresponds to a maximal principle, termed the greatest action principle" ([24]: ([150]: p. 365)). This principle can effectively also be expressed as the condition where a system lives if and only if it autonomously invests work that enables it to maintain its existence, conditioned by the laws that govern it and its initial conditions (cf. [151]).

Information processes occur as metaphysical networks (which include sapience and sentience functionality), and they create relatable information patterns connected to mutual contexts, resulting in persistent functional outcomes. It is through information that agency can order matter through its dynamism and complexity. The dynamism acts both internally and externally beyond agency boundaries. This enables it to make adjustments directed towards an adaptive capability towards the significant environmental changes that it recognises. It has internal dynamics that can change or enable the emergence of new internal parameters (a process called creativity). This occurs through causal-agents that are responsible for producing an anticipated outcome effect, determined by information processes. Causal-agents operate through causal mechanisms that define their trajectories toward a targeted outcome. Their physical attributes are self-maintained as dynamic patterns of matter that are continually subject to change or replacement, while the patterns and the associated structure-forming information are maintained, with viability resulting.

Adaptive agencies can change gradually/incrementally or dramatically/transformationally. In the latter case, there are two theoretical perspectives through which to explain their adaptive process [152]: (1) the edge of chaos, where "information gets its foot in the door in the physical world, where it gets the upper hand over energy. Being at the transition point between order and chaos not only buys you exquisite control—small input/big change—but it also buys you the possibility that information processing can become an important part of the dynamics of the system" ([153]: [154], p. 51); (2) the dissipative structure belonging to the dissipative system which is open to its environment and for which there is a free flow of energy [153].

The edge of chaos is a complexity perspective that refers to a region of bounded instability in which there is a constant dynamic interplay between order and disorder and where agencies are seen to be constantly self-organising, enabling them to adapt to avoid chaos. The thermodynamic approach, however, is to see self-organisation linked with dissipative structures, where there is an implied sequence of stability that gives way to chaos and from which new order emerges [155]. A dissipative structure can dissipate energy, heat and entropy into a system environment. Following Lancaster [156], a non-equilibrium system has a dissipative structure because internal work transforms useful energy (potential) to heat, and to maintain their internal dynamics, there is a requirement that its internal energy structure has an energy flux across its boundary. Since a series of fluctuations may result in increased organisation, stability can result. To understand the distinction between the nature of a system and the nature of the consequences of its dissipation, we can refer to the statement ([156]: p. 50) "to analyse the evolution of art, we would focus on the paint stored on the canvas (useful energy density), rather than on paint spilled and splattered upon the floor (dissipated energy)".

Such systems also have external dynamics that lie beyond the agency boundary, in its environment. These dynamics, which are sometimes referred to as kinetic processes and for which laws are often sought, enable them to manipulate their environments. Agency is continually exchanging matter and energy with its environment and in so doing, it transforms information into a structure.

Agency can thus be represented as a thermodynamic system when, during the process of living, it 'dissipates' entropy. To live, agency operates physically far from thermodynamic equilibrium, and for this, distinct features can be discerned. Order is continually disrupted by environmental changes that the system needs to respond to in requisite ways to ensure its viability. Agency is open to exchanges from its environment, and its thermodynamic processes require energy to exist in order to maintain itself. As a thermodynamic system, to survive a movement towards entropy, it counters this natural tendency by both decreasing its actions that, otherwise, increases entropy, altering its strategy so as to increase its level of intrinsic information and increase its degree of order. While the second law of thermodynamics states that the entropy in an isolated system always increases, in an open system like that of agency that has contact with an environment, heat energy (measured through temperature) and work energy is exchanged with it in ways determined by intrinsic information, and entropy decreases through a necessary compensating increase in the entropy of the surroundings.

We earlier referred to thermodynamic free energy, and agency requires this from the environment in exchange for entropy, which it arranges by creating environmental conditions that are often associated with increasing disorder [157]. In reality, though, it simply creates greater uncertainty about options that will enable order to emerge. This exchange has two attributes, one is causal, and the other is thermodynamic. Its causal mechanisms enable the system to maintain its viability by self-organisation and adaptation to environmental changes. Its thermodynamic attribute involves the recognition of the functional relevance of external inputs. This is because agency must exercise informational control on observable or inferred environmental parameters from which sources of free energy are derivable. Informational control occurs through causal-agents that, through a network of processes, can relate the functional relevance of certain environmental parametric characteristics and meaningfully relate these to its needs.

4.3. From the Physical to the Metaphysical

In recent years the application of thermodynamics to consciousness has become popular. Deli et al. [44] are directly concerned with the thermodynamics of consciousness in terms of its emergence from physical and biological systems. They argue that cognitive and physical effort is associated with different cost functions. Thus, mental (or psychic) energy involves metacognitive monitoring (which is a regulatory system process), and they call this *intrinsic motivation,* which anticipates such things as performance, learning, and creativity. This motivation can be expressed as a thermodynamic potential, where greater potential is consistent with more intensive motivation and lesser potential with less intensive motivation. It is from the thermodynamic potential that processes of affect are introduced. Intrinsic motivation is also important in personality development and wellness. Intrinsic motivation provides a trajectory of mental/psychic effort toward achievement by increasing future freedom of action. This is clearly a function of *intrinsic* information, that is, information that most efficaciously represents parametric reality [7,38,39]. Temperature, Deli et al. [44] note, is the manifestation of thermal energy in physics, with a social analogue of emotional temperature, this deriving from kinetic processes as agents interact in a living system environment. This approach links to that of Laurent Lavoisier, the 18th-century chemist and thermodynamicist, who pioneered the notion that mental phenomena are possessed of some physiochemical properties, saying, "We might evaluate what is a mechanical aspect in the work of thinking philosophers, in writers' writing, in musicians' composing. These efforts, usually considered as purely moral, do have something intrinsically physical, material, which makes it possible, in this respect, to compare them to what happens if we feel pains" ([158]: p. 1). Linking feeling, and hence, sentience, with thermodynamics, is far from a new concept.

Thermodynamic energy may be physical or metaphysical when it is the energy that enables the psyche to function, and in this context, it has been referred to as psychoenergy [159]. Landauer's principle applies to metaphysics. Its interpretation essentially enables psychoenergy and information to be mutually related, using the notion of intellect to so do, where the idea of intellectual evolution can be used to explain the psychological and health consequences of positive and negative emotional states, expressed in terms of their energy profiles [44]. Intellect is defined as mental capability like thinking and reasoning. Information, like energy, maybe "lost" or used by being channelled, which is how observed phenomena are actually formed [160], with the conversion between information to energy demonstrated [161]. This principle is explained within a biological context by the existence of synapses in the brain that gradually change as psychoenergy is accumulated, this happening when sapient consciousness updates its beliefs discretely. Intellectual evolution occurs as the brain's neuronal system gains energy, and this is intertwined with entropy of the environment.

So, thermodynamic theory, while normally set within the physical world, can also be reflective of the metaphysical world. As explained by Hibberd ([162]: p. 161), "Properly understood, metaphysics involves what it is to be and to become, that is, what must be involved for *anything* to occur. Accordingly, metaphysics belongs to the phenomena that psychologists study." In making her statement, Hibberd sees that psychology (argued by her to be a fragmented science) should be seen in terms of a logic of referent relations. This, for instance, includes types of dependence that connect the metaphysical to the physical, the concept of metaphysical constitution that is better viewed in terms of causation, and representational cognition as a spatiotemporally extended relation involving sensitivity to others in an environment.

The metaphysical and the physical are strongly related, the former acting as a potential for the latter. Thus, for example, one would expect to see a strong connection between paradigms in psychology and those in the physical sciences. Libben [163] addresses this, explaining that the field of quantum mechanics was drawn from psychology. As part of his argument to support their relationship, he cites Bohr ([164]: p. 100), who says, "The unavoidable influence on atomic phenomena caused by observing them corresponds to the well-known change of the tinge of the psychological experiences which accompanies any direction of the attention to one of their various elements." That quantum theory can provide an adequate metaphor for psychology is therefore convincing. In agencies, the metaphysical domain is one of consciousness. Psychoenergy, introduced above, refers to energy related to various aspects of the metaphysical, and in particular, processes of cognition (cf. [165]). The idea that the metaphysical world has psychoenergy coincides with a basic principle that quantum mechanics involves the energy of the system (cf. [166]). This enables the metaphysical application of principles of thermodynamics which, for Yarman et al. [167], are closely tied to quantum mechanics.

The physical world is defined in terms of energy, information, and the "Planck constants," and the metaphysical world is often described in terms of the psyche, as noted by O'Neill and Schoth ([168]: p.18): " . . . both are portrayable as linear-algebraic spaces. Whether or not attributes of consciousness have physical distances, individual qualities are identified and assigned dimensions. Each dimension has a zero or reference, a maximum or infinity, and a scale or resolution. Mental apprehension and physical measurement both allow an arbitrary choice of units. Further, the time dimension is common to [metaphysical] and physical. The common character of the [metaphysical] and physical realms as space–times permit the formal description of both with analogous mathematics. As Kant [169] observed, we experience nothing outside time and space. Or (Campbell [170]), 'When you think about what you have experienced in the apprehension of forms of time and space, you employ the grammar of thought, the ultimate categories of which are: being and nonbeing.' Thus, there are philosophical antecedents to the idea that the physical and mental worlds are both formed of space–time, ultimately divisible into bit-like elements."

4.4. Structure-Forming Stability through Free-energy

We are aware that agencies need to be stable in order to ensure that their processes of self-organisation enable them to adapt requisitely. An approach that has been used to predict the possibility of instability comes from Demekas et al. [171], who explain the value of thermodynamics for sentience when they seek to determine how the mind is able to model the world, interpret the emotions that guide behaviour and beliefs, and how emotional states can be understood and predicted. They advocate the thermodynamic free-energy principle as a respondent to such questions. Deriving from the ideas of the German physicist Hermann von Helmholtz, who, in 1866, advocated that the mind functions probabilistically through unconscious inferences that involve sensorial sampling. Prior knowledge and beliefs act as a starting point from which the mind performs statistical inference on the hidden states of the environment, and this establishes a basis for perception and action. The free-energy principle explains how agencies exist in a confined "state space" that is bounded by their long-term entropy, and it offers a means by which a variety of metaphysical dynamics can be modelled.

As Demekas et al. continue, the free-energy principle explains adaptive agency behaviour and agency evolution. It can also be used to explain dispositions and the development of personality [172]. Agencies are deemed to restrict themselves to a limited number of (likely) sensory encounters by continuously updating their expectations about their environment, and then minimising their sensory entropy to increase the likelihood of maintaining order, with the intention of minimising surprisal events to enhance viability [173]. The average surprisal is determined by the entropy, and minimising entropy on average corresponds to the minimisation of sensory entropy, while at the same time supporting strategies for self-organisation. Surprisal is bounded by variational free-energy so that minimising this ensures an upper bound on both surprisal and entropy. Free-energy minimisation arises from a generative internal agency model of active inference and permits the continuous and reciprocal optimisation of sensory information that comes from action and expectations due to inferences. During social interactions between agents in an agency population, acquired inferences enable the communication of emotions through behaviour. This supposes that an agency employs a predictive expectation model of social interaction relating to emotional content, and this impacts the potential for future behaviour. The modelling process for this is explained by the Markov blanket [174]. This, according to Kirchhoff et al. [175], probabilistically determines agency boundaries through a probabilistic partitioning of its internal and external states, the blanket determining the states that separate them. Demekas et al. note that the condition of the function of living requires conditional independence from its environment, and the Markov blanket can be used to distinguish itself from that environment. The amount of agency free-energy determines the degree of uncertainty concerning a situation, where high levels of free-energy indicate greater uncertainty and a greater likelihood of surprisal, and hence, a greater potential for viability degradation. Thus, adaptive change minimises agency free-energy so that agency continually restricts its sensory states through the probabilistic upper bound on surprisal sensory states.

Minimising free-energy under thermodynamic equilibrium ensures that agency processes of self-organisation are stable with respect to its structure-forming causality. This involves the K_L entropy [136], which, we recall, explains the divergence between two probability densities. In order to describe the environment and the parameters relevant to agency viability, it is useful to first understand the basis of the model of surprise. Consider a situation where: a represents a set of environmental parameters; y is the data representing states determined by the environment (like sensory inputs); and $p(y \mid a) = p(y \mid a;\lambda)$, where λ are seen as fixed and known quantities (taken to be perception) that describe agency physical state through prior knowledge like mean and variance that could refer to internal metaphysical parameters.

Now, free-energy is defined in terms of complexity energy and surprisal energy. The former probabilistically relates a source of sensory parameters to a target that locally represents the source a, where sensory input from the source is delivered to the target. The source is referred to as a generative model. A generative model is a probabilistic mapping from acquired parametric information given prior information and specified in probabilistic terms, and sensory data is generated from it. The complexity energy is determined by K_L entropy to measure the divergence between the source and target densities. The surprisal energy refers to the expected sensations at the target. Thus, the free-energy is dependent on, and is taken as a measure of, that which bounds the surprisal on sampling some data from the generative model. The free-energy can now be defined as [176,177]

$$\text{Free-energy} = \text{Complexity} - \text{Surprisal} \tag{11}$$

$$= K_L(q(a)\|p(a)) - <\text{Ln}\ p(a)>_p \tag{12}$$

This theory originated from considerations of neuronal energy and concern over changes in the brain connectivity associated with memory development and learning resulting from a history of internalisation of past interactions with the environment [136]. This has consequences for the free-energy dynamics that underly perception and attention. The approach indicated by Equation (11) has been further elaborated by Joffily and Coricelli [177] in order to create expectations about under what thermodynamic conditions different emotions arise, and we shall return to their results in due course.

4.5. The Thermodynamics of Sapience and Sentience

In order to conduct a thermodynamic analysis of any system, it must be determined whether it is in equilibrium or not. Thermodynamic equilibrium refers to conditions where the global macroscopic variables that describe the state of the system do not change, though the local microscopic variables may do so. Systems in thermodynamic equilibrium have a condition or state in which there is no tendency towards spontaneous change, and where state change does occur, it is at the expense of effects on other systems. While the methods of analysis in equilibrium and non-equilibrium situations are different, assigning the property of quasi-equilibrium conditions has enabled equilibrium approaches to be applied to far-from-equilibrium contexts in order to simplify their analysis [9]. Quasi-equilibrium processes are those in which the system departs from equilibrium in quite small ways enabling its state to be simplified and taken, for instance, as an evolutionary sequence of ideally (and approximately) equilibrium states. Interestingly, while agencies as living systems have physical thermodynamic states that are far from equilibrium, they also have metaphysical states that can, for certain purposes, be argued through (approximated) quasi-equilibrium assumptions. These quasi-equilibrium states may be, following Recordati and Bellini [178], quasi-stationary states (where entropy production is at a relative minimum), an example of which are mental resting states. There are two resting states: the conscious resting state of quiet wakefulness, which is a local state, and the unconscious steady state of non-rapid eye movement sleep, which is a global state of mind, and which is of more interest.

The dynamics of agency far from equilibrium in a complex physical environment is well described in the literature (e.g., [179]) as it generates information locally, enabling it to survive at the expense of the environment. Metaphysically, however, for certain processes, equilibrium conditions can be ideally assumed [177]. Deli et al. provide a model that centres on a modified Carnot cycle. This involves a fully reversible dynamic that efficiently converts one form of energy to another, the limit to efficiency being called the Carnot limit. Deli and Kisvárday [180] use the mind's resting state to explain this.

For Deli and Kisvárday, the (global) resting state of the mind has a recurring presence through stimulus and response, and thus, forming a thermodynamic cycle of perception that can be modelled by the Carnot cycle. The cycle has a forward exothermic and reverses endothermic component. The exothermic component delivers entropy and energy in its environment through affect-motivated cognitive action that is based on previous observation, while the endothermic component relies on energy from the environment to increase entropy, thereby delivering a mental resting state. Since the Carnot cycle requires thermodynamic equilibrium, the recurrent resting state of the mind is an essential requirement, assuming it can be described as quasi-stationary.

It may be noted that the resting state does not necessarily mean that the mind is totally devoid of sensory input. When assuming a quasi-stationary thermodynamic state, change due to sensory input is sufficiently slow to enable quasi-equilibrium conditions to be assumed. This allows for the proposition that any resting state of the mind may be seen as quasi-stationary, with its processes being ideally reversible when they can be returned to a previous state exactly, with no net change in the system or surroundings.

We are aware that from a thermodynamic perspective, agencies are exogenously seen to operate far from equilibrium as they need to generate information to survive, and in complex situations, this is consistent with the selection of locally reduced entropy constituting a contrary condition to the entropy maximisation that accompanies equilibrium processes. However, this does not mean that agencies are necessarily everywhere thermodynamically far-from-equilibrium. Deli et al. [44] explore this with their entry into the endogenous duality of sapience and sentience, being serviced by their consideration of cognitive and affective processes in terms of a modified Carnot cycle. Using Landauer's principle, Deli et al. explain that psychoenergy and structural information are transmutable, leading them to the idea that endogenous processes are a totally reversible information-energy cycle. Here, all cognitive processes can be reversed. During an anterior trajectory of the cycle, physical and information-theoretic principles are applied to enable intelligent cognitive processes. These are endothermic slow time perceptions (required for reversibility) that have the potential to reflect information transformation into intellect. The posterior trajectory enhances a capacity for the self-production of new thoughts and ideas from which self-organisation occurs, enabling adaptation under conditions of a changing environment. There are emotional consequences on the Carnot cycle functionality, Deli et al. note, where supportive environments with personal safety encourage positive emotions like generosity, confidence, trust, and cooperation, together with an ability to enhance future behavioural degrees of freedom. Lower resting entropy, they note, can cause cognitive degradation through an exothermic process. While intermittent short-lived stress can be beneficial by preserving the accumulation of psychoenergy, frequent and extended exposure to stress (that might occur in socially adverse condition) cause adverse personality transformations and can, for instance, induce distrust.

We recall that for Deli et al. [44], the social analogue of the manifestation of thermal energy in physics is emotional temperature in the domain of consciousness, drawing on the principle of sapient-sentient interactions. For Deli et al., this is a consequence of agent interaction in an agency environment. Here, the kinetic energy used during interactions results in emotional temperature where, when there is a tendency towards viability improvement, agency opinion persists that favours continuing interaction. This results in low social temperature coinciding with cooperative processes and generosity.

So, the Deli et al. thesis is that the Carnot cycle can explain wellness in terms of positive and negative emotional states. Taking the resting state of consciousness to be in quasi-equilibrium, this condition is sensitive to the valence of emotional states, as indicated by emotional temperature. With negative valence emotions, the modified Carnot cycle is invoked, and through this, energy is consumed during active conscious processes as entropy is reduced. Positive valence emotions invoke a reverse Carnot cycle, through which energy and entropy are accumulated. Their proposition requires the Landauer principle [181] which represents information as a form of energy.

Lee and Yoo [182] explain that negative emotion causes stress, while at the same time, it reduces attention and concentration. According to Hans Selye [183] in his General Adaptation Syndrome, stress is defined as a nonspecific response of the body to any demand made on it without distinguishing between internal and external causes.

Stress has associated with it an emotional valence that indicates the level of pleasantness/unpleasantness of a causal event together with arousal (indicating a degree of intensity), and it is indicative of the emotional state. Valence is defined along a continuum from negative to positive [184]. To better understand the significance of the concept of valence, it is useful to return to Figure 4 of metacybernetics, noting how sapience and sentience interact. Sapience is responsible for the creation of cognitive anticipations, which drive rational expectations about the future. Sentience is responsible for affective anticipations, which motivates behaviour. During their interactive cross-fire, issues may arise when expectations are not satisfied, indicated by emotional valence. When sensations increasingly transgress an agency's expectations, valence is negative and the rate of learning increases, while when sensations increasingly fulfil the agency's expectations, valence is positive, and the rate of learning decreases [177]. Exposure to a stimulus having a negative valence can result in stress (cf. [185,186]).

A number of propositions can be identified from the literature considered here that relate emotional states, emotional valence, and temperature for sentient systems:

- *Emotion*: negative emotion causes stress, and reduces attention and concentration; positive emotion reduces stress and improves attention and concertation.
- *Emotional arousal*: the intensity or strength of an emotional state, and may range from excitement to relaxation.
- *Emotional valence*: indicates the orientation of an emotion, describing whether it is positive or negative.
- *Emotional valence and temperature* [44]: positive valence gives a low emotional temperature, which encourages continuing interactive, cooperative processes and generosity; negative valence gives a high emotional temperature, inhibiting continued interaction.
- *Free-energy principle*: agencies encode a probabilistic model from experienced sensations; during adaptation, they are motivated toward viability away from increased randomness.
- *Viability*: this requires free-energy to be minimised, reducing the possibility of divergent behaviours; increasing free-energy amplifies the possibility of divergent behaviour.
- *Positive, negative, or zero free-energy*: if free-energy is positive, then emotional valence is negative; when it is zero, then emotional valence is neutral; and when it is negative, emotional valence is positive. Free-energy is also an upper bound on surprise, something that happens when an agency experiences an unexpected event under uncertainty.

In their investigation of processes of sentience stimulated by a parametric context, part of which involves sensations, Joffily and Coricelli posit a theory concerning free-energy that builds on Equation (11) and explains the function of emotional processes in agencies. Their propositions are underpinned by the idea that emotional valence can be defined in terms of the rate of change of free-energy over time t. In particular, by dynamically attributing emotional valence to each environmental state that an adaptive agency might encounter, the basic forms of emotion can be determined, such as happiness, unhappiness, hope, fear, disappointment, and relief. The explanation for this is as follows. They postulate that any biological agency in thermodynamic equilibrium with its environment must minimise its free-energy. This connects with evidence of the way in which humans approach pleasure and avoid pain. This may be described in terms of valence, where positive and negative valence are respectively associated with the decrease and increase of free-energy over time. In a continuous time domain, the rate of change of free-energy is taken to be the first time derivative of free-energy at a time t. Thus the valence of a state of an agency at time t is the negative first time derivative of free-energy at that state. Now, adaptive agencies encode a hierarchical generative model of the causes of their sensations. This notion of hierarchy is important because it enables the proposition that a cognitive model of a parametrically described environment is represented by a hierarchy of complexity, with increasing complexity and abstraction being encoded in higher levels of the hierarchy, and sensory data encoded at the lowest level. Free-energy is then minimised for each level of the hierarchy separately, and the quantity $F(t)$ is a representation of the free-energy associated with the hidden state at the rth level of the hierarchical model. From this axiom, Joffily and Coricelli identify the following propositions.

1. Free-energy $F(t)$ is an information-theoretic quantity, and is defined by the internal (sentient/sapient) states and quantities describing energy exchanges with the environment, including sensory signals and actions that involve agency kinetics.
2. Emotive free-energy has an upper bound of *surprise* on sampling some data determined from a generative model.
3. The first derivative of free-energy ($\mathrm{d}F(t)/\mathrm{d}t$) is taken to be emotional valence.
4. Agencies are supposed to encode a probabilistic model of the causes of their emotive sensations so that an adaptive agency that seeks viability must minimise its free-energy.
5. Free-energy minimisation occurs through a minimisation of prediction error between actual and predicted sensory inputs through two strategies to: (1) adjust their internal states to generate more accurate predictions; (2) act on the environment to sample sensations that fulfil their expectations. For Friston et al. [176], such minimisation can, in principle, be implemented by modelling neuronal infrastructures.
6. The modelling process applies arguments that there is a perceptual inference and learning, with a related probabilistic active inference; by perceptual inference is meant the states of the world causing sensory inputs; by perceptual learning is meant learning the relationship between inputs and causes; by active inference is meant acting on the world to satisfy prior expectations about sensory inputs.
7. When creating inferences and learning the causes of their sensations in a changing world, adaptive agencies need to deal with various forms of uncertainty: estimation uncertainty, volatility, and unexpected uncertainty; estimation uncertainty is understood as the known estimation variance of states of the world causing sensory inputs and can be reduced through learning; by volatility is meant the slow and continuous changes in states of the world, often modelled through an estimation of uncertainty from a latent stochastic process; by unexpected uncertainty is meant the occurrence of surprising sensory inputs due to discrete and fast changes in states of the world, and this involves forgetting the past and restarting learning from new sensory data.

The generative sentience model Joffily and Coricelli proposed seeks to clarify the notion of emotional valence, defined in terms of the negative dynamic change of free-energy as shown in Equation (12). From this comes emotional valence as it applies to states of the world, where adaptive agencies experience a sentience dynamic that includes such emotional conditions as happiness, unhappiness, hope.

Within the context of agency being a collective plurality and thus having a population of purposeful interactive agents, the kinetics of agent interaction results in emotional temperature that, under negative valence, can result in stress. The free-energy principle supposes that the model that agencies encode as part of their regulatory map is probabilistic, reflects the causes of the sensations they experience, and during adaptation, their motivation toward achieving viability involves resistance to “disorder.” According to Joffily and Coricelli, for this resistance to occur, their free-energy must be minimised since this reduces the possibility of divergent behaviours [176,187]. With free-energy, there is an upper bound on surprise (something that happens when an agency experiences an unexpected event under uncertainty), and neutral valenced states may also be characterized by low or high levels of surprise. In particular, a consequence of the framework provided by Joffily and Coricelli [177] is that with behavioural efficacy, there necessarily occurs a minimisation of free-energy. Relating the idea of free-energy to emotional valence, at any given time, when free-energy is positive, then valence is negative. When free-energy is zero, valence is neutral, and when free-energy is negative, valence is positive.

Joffily and Coricelli note that the free-energy principle can be used to explain agency learning, perception, and action. They also show, through the use of simulation techniques, that emotional valence can be used to explain the rate of change of free-energy, which, they claim, leads to a meta-learning scheme for the complex and reciprocal interaction that occurs between sapience and sentience shown in Figure 4. Their theory supports the idea that a sentient agency can dynamically assign emotional valence to every new state in its environment while experiencing basic forms of emotion, using emotional valence to adapt dynamically to unexpected environmental changes. Their analysis results in a recognition that emotions are related to belief. Belief is, of course, a cognitive attribute, in particular being defined as the cognitive act or state in which a proposition is taken to be true [188]. This is underscored by the realisation that there is an interplay between sapience and sentience. Two classes of emotional state are active and epistemic. Factive states refer to knowing or seeing or understanding, and presuppose the belief of some fact, and they tend to refer to emotions like anger, sadness and gladness. In contrast, epistemic emotional states are those which presuppose a belief that is possible, like worry and fear [189]. By making various assumptions concerning Equation (10), Joffily and Coricelli propose a likely relationship between factive/epistemic conditions, emotional valence, and emotion, as shown in Table 4, a consequence of simulation from their propositional modelling.

Table 4. Relationship between Emotional Valence and Emotion for Factive/Epistemic conditions (adapted from Joffily and Coricelli, [177]).

Factive/Epistemic Conditions	Valence	Emotion
Factive	+	Happiness
Factive	-	Unhappiness
Epistemic	+	Hopeful
Epistemic	-	Fearful
Factive	+	Surprise
Factive	-	Relief
Factive	+	Disappointment

4.6. The Physical Thermodynamics of Sentience

We are aware that agency as a metaphysical conscious entity has both sapience and sentience. Sapience delivers a coherent cognitive internal environment involving a population of agents that interact with each other and others in an agency's external environment, and it is relatively easy to find representations of sapient processes in the kinetic literature by looking at the dynamic processes that are involved. An example is the chemotaxis of bacteria [190,191] or the bacterial ability to maintain homeostasis [157]. Related to this, Bienertová-Vašků et al. ([192]: [193]) explain that the process of maintaining homeostasis can be represented by an allostasis model, allostasis being the process of maintaining homeostasis through the adaptive change of agency's internal environment to meet perceived and anticipated demands.

The development of a thermodynamic theory of consciousness enables the generic examination of both sapience and sentience. Such theory is not yet two decades old, with primary studies of bacteria having the adaptive kinetic processes of chemotaxis that reflect both sapience and sentience [190,191,193,194], and fish among other species of animal [195–197]. In common with the generic approach, bacteria, and indeed by extension any agency deemed to be living, must have properties of both autonomy and consciousness [198]. Generic studies in the thermodynamics of sapience have appeared more recently [199,200], with the thermodynamics of sentience following Deli et al. [44].

Sentience has traditionally been associated with biological organisms. Thus, Reber [197], in his Cellular Basis of Consciousness theory that explores the biological foundations of mind and consciousness, postulates that any creature with flexible cell walls, sensitivity to its surroundings, and the capacity for locomotion is sentient, and this includes bacteria [201]. It is unclear, however, what stage of spirit may be possessed by such bacteria, e.g., limited sapience/sentience (Table 3). Bacterial sentience is reducible to biological mechanisms, referred to as chemotaxis—a mechanism by which bacteria are able to efficiently and rapidly respond to changes in the chemical composition of their environment. This enables them, through valence, to approach chemically favourable environments and avoid unfavourable ones. It seems that the need to restrict consideration of sentience to entities with flexible cell walls and a capability for locomotion is to exclude plants. Reber [197]: 4) elaborates slightly in a footnote saying, "While recent work ... shows that plants make risk-sensitive root-growth 'decisions' based on temporal variation in nutrients, I am excluding plants and fungi on the grounds that they have rigid cell walls composed of cellulose, hemicellulose, and pectin (plants) or chitin (fungi), and lack the capacity for endogenous locomotion." One wonders about the case of algae, these being plants [182,202] that can reside in salt or fresh waters or on the surfaces of moist soil or rocks [203]. While they have rigid cell walls, they also have flagella that are used in a whiplike fashion for locomotion [204]. So, while bacteria may have some degree of sentience, it might be the case that certain classes of algae (noting that not all algae have walls of cellulose) also have this property.

Bacteria are not so different from mammals in that both have the property of sleep [205]. Also, bacteria communicate with one another through similar electrical signalling mechanisms as neurons in the human brain [206]. However, there is a lack of clarity as to whether, for instance, chemotaxis in bacteria, maze-navigation, and puzzle-solving by protists [207], or habituation in mimosa plants [208] have valenced feelings of the sort that give rise to welfare. This lack of clarity can perhaps be reduced by considering the nature of welfare outside human ethical contexts. So, in the case of bacteria, welfare is a condition that enables bacteria to approach chemically favourable environments while avoiding unfavourable ones, and their capacity for valence determines which is favourable (in the sense that it improves conditions that enable viability). Chemotaxis is normally expressed as a physical dynamics using the principle of thermodynamics.

Rey et al. [209] investigate whether fishes could be seen as conscious sentient beings. The case against sentience is that the brain of fishes is relatively small and simple, lacking the cerebral cortex that mediates much of high-level information processing in mammals. As such, fishes have little capacity for learning and memory, and thus they are supposed to have simple behavioural possibilities. They are also seen to lack any cognitive ability to experience stress, and they have no emotions. The alternative view is that while fish brains are indeed smaller with their unique organisation, there is functional equivalence between forebrain structures in fishes and other vertebrates. Fishes also have the capacity to perceive noxious stimuli that induce pain in mammals, and their responses to such stimuli involve "physiological arousal, the performance of stereotypical movements, changes in motivational state and quite complex attention shifts" ([209]: p. 1), indicating that fishes have relatively complex mental states that go beyond simple reflexes. Using thermodynamic principles, this research, as summarised by Orphanides [195], explains that stress in fish results in a physiological response called "emotional fever," this being comparable to that found in mammals, and it is expressed as a temporary small increase in body temperature. The phenomenon of stress-induced hyperthermia has also been observed in mammals, birds, and reptiles. The trigger for this condition is an internal metaphysical one rather than an external one due, for instance, to a bacterial or viral infection, and it also contributes to effective fight or flight responses. For Orphanides, such states, which are considered to be representative of sentience and consciousness, show emotional responses to threats. The Rey et al. study also shows that the zebrafish, when given access to a tank containing a range of water temperatures which they could freely move between, consistently moved to a warmer area, thereby increasing their body temperature and effectively showing an emotional fever state. Under the influence of stress, zebrafish prefer warmer water than they experience in their unstressed state.

This study provides interesting reflections when further considering the investigation of bacteria. We are aware that they are sapient as far as their conditions of awareness are concerned, but we have not been able to decide on their level of sentience, nor therefore, the complexity of their feelings. According to Everest [210], bacteria within their host are subject to stresses that they must overcome if they are to remain viable entities. Thus, for instance, enteric (relating to infection of the intestines) bacterial pathogens need to be tolerant to the acid environment of the stomach that they are exposed to, and to resist detergent-like activities due to bile salts and decreasing oxygen concentrations. This is required as they move down the gastrointestinal tract and respond to the presence of competing microbial flora (among other things) that they encounter. Bacteria, we are told, live in a permanent state of stress, and regulate their gene expression (genes are a functional unit of heredity composed of nucleic acid, and they express themselves through the formation of physical characteristics) in response to the stresses they experience from their environment. Thus, these stresses may be argued to arise from a metaphysical condition and become responsible for physiological changes in the bacteria so that, like fishes, they might temporarily seek more comfort that one may postulate is consistent with an emotional condition.

Moving thermodynamic theory from speculation to pragmatic demonstration can be problematic. This is illustrated by Adamo [196], who considers that the claim that fish (and she, in particular, refers to zebrafish) are sentient is subject to the philosophical zombie problem. To explain this, in artificially intelligent systems that are capable of complex learning, philosophical zombies emulate pain as a motivational driver without having an internal subjective experience of it. This leads to the question of what constitutes a subjective experience. For LeDoux and Hofmann [211], subjective experience as feeling may be objectively represented through behavioural manifestations and physiological change, but they are indirect indicators, being an assessment of emotional feelings that require verbal self-reporting. However, for Vicente et al. [212], feeling is one of the components of the complex theoretical construct of emotion, where verbally reported feelings capture only partially what is effectively consciously experienced. So, there seem to be no adequate means of testing for the existence of subjective experience. This brings us back to Adamo's position when she argues that fish could have complex learning, modifiable pain systems and motivational responses, and yet have no subjective experience. However, this position is devoid of recognising that living systems are autonomous and engage internally with information-sapient and sentient processes that are necessarily subjective. Her argument might stand if one were instead comparing, say, a chatbot with a sapiens, and this comes down to adaptive architectures. Chatbots adopt a process of parsing that uses a predefined context map that cannot be updated; thus, they have no capacity to learn and have adaptive responses that are essentially determined by the environment, this determining their strategic responses from a predefined set of strategic options. Sapiens, however, have both an updatable context and homeostatic map that manages sapiens stability, enables creativity and innovation, and provides for self-organised adaptive responses to changing environmental conditions. Now, in that same way that the sapiens system may be modelled as having cognitive context, cognitive regulatory and cognitive homeostatic maps, so too the sentient system will have context affect, regulatory affect, and homeostatic affect maps. Thus, in following the architecture of Figure 4, one might argue that for the sapient system, the internal affect maps enable emotional creativity [213] as well as regulatory affect development. Emotional creativity refers to a pattern of cognitive abilities and dispositions that are appropriate to the context and original in emotional experience. This background is useful only to explain that artificially intelligent sapiens are complex learning systems, this permitting one to address the philosophical zombie proposition. Drawing on ideas from Farnsworth et al. [214], we can now say that life is an informational phenomenon at every level of organisation. This is because living is information processing enabled through memory, and the purpose of that processing is to enable system viability and perpetuation. Now, consider that different individual sapiens are autonomous with relatable information processing, but as explained previously, they generate differentiable outcomes due to small but accumulating differences that become part of memory. Thus, after a while, individualised knowledge results that can derive from cognitive dispositions and hence subjectivity.

5. From Thermodynamics to Metacybernetics

It has been said that agencies exist at the dynamical interface of information and thermodynamics, so an appreciation of the distinctions between metacybernetics and thermodynamics, and any of their limitations, especially with respect to metaphysics, could be helpful in further developing metaphysical theory.

In the previous section, thermodynamic approaches to the exploration of consciousness and sapience-sentience relationships have been considered. Thermodynamics has produced some significant theoretical and practical results and can be seen as a macroscopic art that deals with energy and indicates how its different forms can be transformed from one form of energy to another [215]. As an art, thermodynamics can be seen as a source of knowledge that reflects something essential, and it enables us to examine prior suppositions about what constitutes knowledge [216]. Thus, for instance, coupled with complexity, it has been useful in generalising living system theory away from purely organic living systems. The result has been a valuable knowledge base for generic theory.

Inherent in any inquiry into thermodynamics is understanding the meaning of entropy and its relationship with order. This is highly confused across the literature, and this will be addressed. Other issues exist in thermodynamics, and we shall discuss this under the header of its critical limitations. This will include looking at the first and second laws of thermodynamics and then considering issues concerning equilibrium (or, more broadly, quasi-equilibrium), which for Bridgman [217], is the essence of thermodynamics. Then we shall look more carefully at the relationship between intrinsic information and free-energy. According to Fleener and Rodgers [218], there is a connection between autopoietic and dissipative processes as they each contribute to the role of living. Thus, we shall then look more closely at their relationship in relation to cyberintrinsic theory. Finally, in this section, we shall migrate thermodynamic theory concerning sentience into cyberintrinsic theory, shifting our interest from entropy to structural information.

5.1. Structural Information, Entropy, and Order

The relationship between information, entropy, and order is explained by Frieden [8], where information is said to change monotonically with the level of disorder and where entropy may be indicative of the disorder. However, entropy is not a *unique* measure of disorder, which means that entropy and order do not have a direct linear relationship, and while one might sometimes be indicative of the other, one cannot substitute the word entropy with that of disorder or negative entropy with that of order.

Structural information as a metaphysical attribute takes on a role that can be related to that of entropy through the idea of free-energy. For Allen and Friston [174], the relationship between information and free-energy arises with an interest in seeking to satisfactorily "understand autopoietic self-organisation." However, it should be realised that "understanding" self-organisation is far different from "creating" self-organisation [219]. Fisher's intrinsic information is part of a process in which structural information creates self-organisation with the aid of A. J. Wheeler's participatory universe effect. This is the fundamental reason why the Fisher information approach of EPI is quite different from thermodynamic processes. To appreciate the nature of Wheeler's notions, we refer to Nesteruk [220] who explains the connection between physics and metaphysics by quoting Yannaras ([221]: p. 114), who says that: "A metaphysical interpretation and understanding of the world is neither scientifically attainable nor scientifically excluded. It is another mode of cognitive approach to the world, a transition from the (as much as possible) neutral observation of the world to a personal relationship with the world. It is a product of the freedom of humankind, and therefore interpretation and understanding define its entire stance towards the world, its mode of use of the world." Nesteruk explains that Wheeler sought to approach physical reality through conscious dialogue between observer-participants and physical reality, so that the universe emerges as a special articulation of the relationship between intelligence and physical reality ([222]: p. 128). This has clear connections with critical philosophical realism and the metacybernetic framework.

Metaphysical processes observed through a thermodynamic framework concern energy and entropy. For Fuchs ([223] cited in [143]), "while Energy seems to be familiar to all of us, Entropy remains a mysterious concept, frequently (mis)used in everyday language as a substitute for chaos, noise, disorder, disorganization or even... business inefficiency." As a probabilistically based theory, and as already noted, it delivers one of two entropic conditions, non-equilibrium, and equilibrium. Non-equilibrium leads one to consider entropy in terms of stochastic trajectories, while for Fuchs, in discussing equilibrium, we are told that "entropy relates the microscopic realm to the macroscopic world, by enumerating how many micro-configurations of a system are compatible with our sense-data and the measurements performed at our scale. It allows us to quantify the loss of information by coarse-graining from the microscale to the macroscale. To be fair, Entropy should be considered as a source of surprise rather than confusion", but despite this, entropy does generate confusion.

While entropy may decrease and increase, the case of increasing entropy is of particular interest (since it leads to the idea of thermodynamic equilibrium from which significant analysis is possible due to the application of principles of optimisation). In this case, one may ask what exactly *is* so increasing? As already suggested, it is the degree of randomness, and hence uncertainty, with respect to a given parametric variable in the system's probability law. Bacon et al. [224] explain that, rather than detecting randomness (and hence experiencing uncertainty), it leads to patternicity [225] (perceiving meaningful patterns and connections in meaningless noise), thus providing space for increased subjectivity. This, as a positive consideration, can sometimes lead to creativity, something we shall return to shortly. By contrast, the Fisher scenario centres on what happens when a 'seeker of the truth' acts to observe an effect in the best way possible. By the 'Wheeler thesis' [226], the observer actually self-generates the observed local reality (providing that a permanent record of it is made somewhere). It is, consequently, a positive statement of enhanced learning of what is going on in the world. This is totally different from the thermodynamic entropy scenario which is concerned with system destructivity by 'banging together' entities and deteriorating them, resulting in more randomness of observation [219]. This notion of banging together is embedded in the destructive entropic nature of the second law of thermodynamics, which is only relieved by principles of agency autopoiesis that enable processes of self-production [227]. Moreover, it is assumed a priori that every combination of outcomes results from a simple counting of how many ways an event can occur. But that is a specific a priori assumption of maximum randomness. By contrast, the aim of the Fisher approach is to find (in fact, by Wheeler, to make) the a priori system distribution.

While Prigogine and Wiame [228] explain living for complex systems in terms of thermodynamics, the probability expression adopted by entropy begs the question of what the concept really means, how it relates to information processing in self-organising systems and (recognising that self-organisation is a re-ordering process) what the nature of order is. Day ([147]: p. 272, citing [229]) tells us that "Since the early days of statistical thermodynamics, the idea has become widely accepted that entropy really signifies nothing more than a lack of human knowledge. This view has been strengthened by the advent of information theory, where entropy is specifically equated with an inverse measure of 'information'. This, in its turn, has led to statements that entropy is subjective, that it is an anthropomorphic concept." However, while entropy may be specifically equated with an inverse measure of information, "it is not always the case that thermodynamic entropy increases when information about the system decreases" ([147]: p. 273).

The very confusion about the nature of entropy is picked up by Martin et al. [230], for whom it is not complexity, nor is it disorder, nor chaos, nor progression towards these states (though changes in entropy can sometimes be interpreted in terms of changes in disorder [231]). Rather, it is a metric that measures how many ways a set of objects can be arranged. Pivarski [232] notes that associating entropy with disorder arises because we often call systems with many possible configurations "messy" while more constrained systems are "clean." Day ([147] also notes that there are infinitely many 'pseudo-entropies' that broadly relate to each other but which are all distinct in their formalisation. As Bombelli [233] notes, all of these have one thing in common, they indicate a measure of ignorance of the microscopic nature of a system. For Popovic [234] there are so many different forms of entropy that it leads to misuse of the term, and this enhances the confusion. Popovic, reflective of Day [147], also notes that many in the scientific community think of entropy as a subjective property, while others disagree, but overall: "von Neumann was right—no one knows what entropy really is (subjective or objective, energy or something else, arrangement of particles or realization of microstates, negentropy, many kinds of entropy ...)" ([234]: p. 1). Parrondo et al. ([235]: p. 1) are also interested in thermodynamic subjectivity, noting that "by its very nature, the second law of thermodynamics is probabilistic, giving a probabilistic description of the state of a system. This raises questions about the objectivity of the second law: does it depend, for example, on what we know about the system? For over a century, much effort has been devoted to incorporating information into thermodynamics and assessing the entropic and energetic costs of manipulating information."

Consistent with Popovic and Martin et al., Natal et al. [236] recognise that entropy is most commonly defined as 'disorder', though the analogy is wanting since (as noted above) "order" is a subjective concept that cannot be measured by entropy, and "disorder" cannot always be obtained from entropy. It is not difficult to show that "order" is a subjective concept. A common dictionary definition of order is "a regular or harmonious arrangement." The term harmony is subjective, since it refers to that which is agreeable. The term regular, however, is more promising if one seeks to go deeper into the nature of order, since it refers to a definite pattern, this being a configuration, itself meaning a relative arrangement of elements. This can be determined from its "information ordering" [237], which means a pattern that conforms to a specific set of rules. So, to determine whether there is order within some context, one needs to relate it to a set of rules that correspond to that ordering, and this is embedded in the notion of information ordering. However, a set of rules is necessarily agency relative (emerging from the interactive dynamics of its population of agents), and order delivers information coherence that enables comprehension [238]. This very relativity indicates that both coherence and ordering are subjective [239].

So, for adaptive agencies to maintain their viability, they need to be able to comprehend information. Such comprehension requires both intrinsic information and information ordering, and these are its necessary and sufficient conditions, where the necessary condition enables a property to exist, and the sufficient condition provides essential support for that condition, without which that seemed to be necessary cannot be sustained. Where acquired data from a parametric source results in intrinsic information, then it can maximally (as completely as possible) represent changing parametric contexts. We are aware that intrinsic information is another name for Fisher information, this being a measure of the amount of information that is present in a parametric context, in contrast to entropy which indirectly measures how much information is missing [8].

Let us return to the idea of creativity. A cyberintrinsic modelling approach recognises that creativity occurs as an emergence through information-laden intelligences [240,241] as causal-agents with their information acquisition, processing, and delivery responsibilities. Now, agency self-organisation is a reflection of the information ordering of its intrinsic information, and this is controlled by self-stabilising and self-regulatory structures. It also has patterns of behaviour that are a consequence of its intrinsic properties deriving from the parameters that define it. Emergence may be understood as an assimilation process that leads to the appearance of patterns of behaviour. These cannot be individually ascribed to the individual agency parameters but rather are the result of their mature mutual interaction, delivering new properties that can be represented as a qualitative change. Intrinsic emergence may be seen as an agency accommodation process, as it adapts underlying agency structures [242]. An illustration of emergence is when a generic rule system arises from the mutual interactive micro-behaviours of agents in an agency population that the agency assimilates.

In comparison, thermodynamics has a less evident explanatory capability for creativity. To understand why, consider that thermodynamic models deal with net gains or losses in energy, and when energy is transformed or moved, energy loss occurs. Some of this is highly "disorganised" [243], meaning that the energy is unregulated with no "information ordering", when it is also referred to as "waste entropy". An example of such disorganised energy is the heat generated through friction. This waste entropy production can be considered in terms of brain function when, like heat resulting from a frictional process, creative thought is a by-product of relevant cognitive sense-related processes.

It is interesting to consider how this can be explained in terms of metaphysical models previously considered. To begin this, we can return to the model provided by Friston and others [136,176,244]. This does not consider creativity, but it offers a theory which, when further developed, could enable creativity to be explored thermodynamically. It assumes equilibrium conditions but has not extended the theory to include creative thought as a parameter. To recognise what this means, consider cognitive processes arising from sensed events, where the brain creates anticipations associated with prior expectations, and these are connected to free-energy. Free-energy has a component of surprisal that, if representing an unexpected event, could be responsible for the stimulation of creative thought. Since the model does not discuss creativity as a parameter with a measurable source, mensuration and the acquisition of information about creative thought would be reduced to an oblique narrative, where heuristics are able to dominate more easily.

The Deli approach [44,180] explores intrinsic motivation in order to examine metaphysical activity with respect to sentience and viability. The theory developed hinges on the foundations provided by Friston and others. One of the attributes of intrinsic motivation is creativity, for which they identify a parametric source enabling mensuration and the acquisition of intrinsic information. As we will recall, in creating their model, the authors adopt the Carnot cycle (with its supposed condition of reversibility), operating under the assumption of equilibrium thermodynamics. This necessarily requires information-free conditions if creativity is to emerge. While their model is of academic interest, its pragmatic validity must be questioned when referring back to Uffink [146], with the recognition by Carnot that equilibrium is an ideal condition that does not occur in reality. Against this, it might be argued that thermodynamics provides ideal and often good state approximations [245], though the divergence from the ideal, and the adequacy of the approximations, are open questions.

To overcome the pragmatic limitations of equilibrium thermodynamic approaches to modelling such attributes as creativity as part of brain function, a non-equilibrium model is required. Knowing brain function would enable an explanation of waste entropy. However, due to the principle of irreversibility, knowledge about waste entropy cannot help to explain brain functionality. As Frieden [219] explains, if one wishes to explore waste entropy in order to deduce brain function, there is no way to work backwards thermodynamically from this to 'build' a theory of the brain function that excreted it as an incidental event. It would be like analysing a horse's running ability by examining, in detail, its manure.

5.2. Critical Limitations

In this paper, we are concerned with both metacybernetics and thermodynamics, so it is appropriate to consider the limitations of both. As a spoiler, it will be explained that while metacybernetic modelling has potential for multiple truths as a function of the modeller, interrogation concerning the basis upon which the truths arise is required for purposes of validation. In contrast, and as already noted, thermodynamics provides only approximated truths (that are dependent on truth values [246]) in a macrostate somehow accumulated from local microstates. From this, one may say that a necessary condition for a thermodynamic approach to be viable, and hence to deliver pragmatically useful outcomes from an analysis of a given situation, is that it meets ideal conditions. A sufficient condition is that its approximations are accurate.

So, a necessary condition is constituted by what is ideal, and this is determined by the laws of thermodynamics, which have never been proven, and which, like equilibrium reversibility, is "a requirement that is almost impossible to satisfy" ([247]: p. 1208). The sufficiency condition is that they are accurate approximations, but since thermodynamics deduces a macrostate from a set of microstates, accuracy is dependent on the degree and significance of any homogeneous divergence among the microstates. The macrostate is mostly formulated in terms of equilibrium conditions which means that "one does not need to know the details of the microstates, only the number of them that correspond to each macrostate" ([248]: p. 33), a condition that can be highly problematic where significant microstate divergence exists. Thus, returning to the issue of the truths, questions can always be raised about how much knowledge is provided to satisfy requisite needs, with the recognition that this knowledge may be false [249]. One reason for this is that logical inconsistencies/confusions can arise. Thus, consider that microstate divergence refers to special conditions that exist. Suppose further that this is unrecognised by thermodynamic analysis because of the macroscopic influences that are undetermined by the thermodynamic formulations (as in the waste entropy example above, where creativity is not recognised). Then, the accuracy of the approximate truths that emerge as model outputs may be inadequate for pragmatic purposes.

5.2.1. Metacybernetic Critical Limitations

To understand the limitations of metacybernetics, it is first useful to have a brief background of the rise of cybernetics as an area of study. Recall that metacybernetics is here formulated as a third-order qualitative cybernetic approach based on complexity as originally represented by Eric Schwarz [179], plus the quantitative EPI theory of Roy Frieden [38]. Cybernetics has its basis in control theory as applied to complex systems and was proposed by Weiner in 1948. In the original construction, reality was seen as a passive construct that can be observed and described through observations made externally to the system. In second-order cybernetics developed in the 1960s, observations of parametric contexts are made from within the system controlled through self-regulation, and in third-order cybernetics developed in the 1980s, multiple realities can emerge, as observations are made that together can reconstruct the shape of the system through reflexive processes, controlled through self-regulation and self-stabilisation.

In 1953 criticisms were levelled at this new field by Jonas [250] that related to first-order cybernetics, but they are useful as a reflective mechanism to highlight attributes of second and third-order cybernetics. They are also, perhaps, predictors for the development of such higher orders. So, in reflection, first-order cybernetics grew from Shannon's information theory, also in the 1940s, and was intended to optimise the transmission of information through communication channels, where the feedback concept was used in engineering control systems. This compares with second-order cybernetics that rather emphasises how, through observations, models are constructed of the interaction the system has with other systems, and how it maintains, adapts, and organises itself. Cybernetics has a circularity or self-reference that enables more precise models of *purposeful* activity to develop, which is constituted as behaviour, and oriented towards a goal or preferred condition. While in classical science, process is determined solely by its causes that reside in its past memory, the behaviour of living systems is typically teleonomic—oriented towards a future state which does not exist as yet.

Jonas notes that the process of living involves sentience and motility (the ability for autonomous motion), and this requires perception and emotion. Emotion delivers the fundamental drive which operates in the ceaselessness of living processes, where its functionality is applied to maintain its viability. Society, in its environment, is a communication network, but, as Jonas exclaims, it is not said what that information is about and why having it is of relevance. This criticism does not recognise that a cybernetic construct (like metacybernetics) can be a metamodel, and hence it is model generative. As such, it requires a more abstract approach to enable greater theoretical generalisation. Generated models are context specific and normally pragmatic as they are applied to defined parametric contexts from which intrinsic information may be acquired. Cybernetics is effective under application, especially when operating under critical realism. Another consideration of Jonas is that purpose, as a function of cybernetic inquiry, requires the notion of seeking some good to enable behaviour, where intentional action is directed toward that good. This is fundamental to both second and third-order cybernetics and is part of the pragmatic modelling process.

Let us now consider cybernetic limitations that derive from reflections on comments made by Ben-Eli [251]. Cybernetics provides for philosophical and general scientific considerations to be represented in a modelling process that is inquirer-oriented and subjectively defined. While this implies that the beliefs that underpin the modelling process adopt a particular orientation from which a model develops, subjectivity in other attributes of the modelling process can be addressed through appropriate research inquiry. Positively, cybernetics can provide powerful guiding principles that help orient the thinking trajectory of inquirers for complex systems. To deal with uncertainty, cybernetics adopts positive uncertainty valence that enables an improved understanding of situations which enhances the relevance of the modelling process. A well-known example of a pragmatic model comes from the second-order cybernetic Viable System Model of Stafford Beer, the core of which is a positive uncertainty valence construct to ensure system viability in complex situations [252,253]. Issues may also arise with respect to difficulties in the integration of many conflicting forces where they exist, but this can be responded to by complexifying the modelling process to individually and relationally represent these forces. In first and second-order cybernetic modelling, the representation of innovation, creativity, and novel design is problematic and can, at best, be implied, but this is not the case with third-order cybernetics. During the modelling process complexity is reduced to simpler manipulable components, though as in the case of competing forces, these components can each be relationally elaborated on, thereby regaining complexity. Issues also arise where cybernetics is used to model socials, for instance, where an agency has a population of interactive agents and where there is a great deal of internal variety that can negate the possibility of a single model or one single truth. Multiple truths are dealt with through "smart" representations in interactive agent dynamics, where norms arise through the emergence and institutionalisation of regulatory structures. This does not respond to outlier agency truths which become marginalised. Therefore, rather than a single truth being uncovered, a dominant truth is seen to emerge (which may or may not be in conflict with other subsidiary truths), and this underpins controlled reflexivity.

Since cyberintrinsic theory includes EPI, we also need to consider the latter critically after introducing something of its background. Following Frieden [219], EPI originated as a grounding principle that can be used to elaborate physical theory, as in the cases of the Schrödinger wave equation of quantum mechanics and the Maxwell–Boltzmann distribution of statistical mechanics. Such theories are expressed as differential equations obeyed by probability densities or amplitude functions. A central aspect of EPI derivations is its mathematical variational principle. This recognises that acquiring information suffers from two types of accuracy impairment: (1) when a source phenomenon is observed, the acquired information is subject to information loss as explained in Section 3.2; and (2) random errors occur during the acquisition process, which define the distribution function of the source phenomenon, and this determines its physics, that is, the laws of physics which are expressions that define probability distributions [254].

The variational principle is now enabled by determining the mathematical nature of the errors and the information loss. When errors occur, an extreme difference $J - I$ results between the information source value J and the level of information I that is actually acquired in the data. In all situations, that difference obeys $J - I$ = maximum. This principle means that any physical phenomenon loses (uses up) a minimum level of information $J - I$ from the reservoir of J that is always present. In other words, there is a tendency for acquired information I to closely represent the source information J. Mathematics facilitates this with the 'variational approach' var($J - I$) = 0, which is used to solve the problem. Here, under such variation, the functional I is 'convex,' meaning that it can only be minimised, not maximised. When I is so-minimised, and J is already maximal (as above), then as required, this delivers a maximised $J - I$. This formulation is observation dependent, and an observation is made in the first place to determine the state a of a phenomenon. Depending on the case being considered, this can give, for instance, its mean position or time or its eigenvalue. By the well-known Cramer-Rao inequality, the minimum possible mean-square error in knowledge about that state value is $1/(J-I)$, where $J-I$ is the total amount of Fisher information used up to form the data.

We earlier noted that EPI is a metatheory that has multiple applications over various fields of study, and it has become a popular medium for analysis under complexity (citation index h = 52 [255,256]). Curiously, however, it has two historically misconceived public criticisms [257], one by Shalizi [258] in which he displays cognitive dissonance over EPI, and the other by Streater ([259], pp. 69–70), who demonstrates confusion. How might it be that well-respected academics find themselves in such a position? A reason is provided by Kuhn [260] who notes that new paradigms are born from old ones. Thus, while the two paradigms may be related terminologically, they adopt different core propositions that result in alternative mechanisms that deliver different outcomes and meanings. If distinctions are unrecognised by the paradigm holder, *paradigm dissonance* [261] can result: an internal conflict where a paradigm holder does not understand what happens in the new paradigm or why. To acquire understanding, and hence, meaning, a form of patternicity may be invoked that invents misconceived connections.

5.2.2. Thermodynamic Critical Limitations

To critically examine thermodynamics, we shall initially consider issues with its laws. Central to thermodynamic metaphysics is free-energy which is developed through relationships defined in the resting state, assumed to be in equilibrium or quasi-equilibrium. Here then, we shall also consider the quasi-equilibrium approximation with respect to the resting state.

5.2.3. Thermodynamic Laws in Open Systems

Issues with the thermodynamic framework lie with its laws, which we noted earlier have not been proven. With respect to the first law, Starikov ([262]: p. 108) offers a critical statement originating with Lewis and Randell [263]: "So, as science has progressed, it has been necessary to invent other forms of energy, and indeed an unfriendly critic might claim, with some reason, that the law of conservation of energy is true because we make it true, by assuming the existence of forms of energy [like free-energy] for which there is no other justification than the desire to retain energy as a conservative quantity [and where] . . . mass and energy are different measures of the same thing, expressed in different units . . . the law of conservation of energy is but another form of the law of conservation of mass."

There are also issues with the second law. Uffink [146] explains that there is a great deal of variation in the definition of this law. Noting a formulation by Max Planck, the second law expresses the irreversibility of natural processes. But, in many other formulations, irreversibility or even time-reversal non-invariance plays no role. Time is also a consideration of Starikov [262], who notes that there is persistent confusion about the mathematical derivation for entropy concerning time-symmetrical microscopic physical laws.

On another issue, Singh [264] explains that the second law applies to macroscopic systems made up of bulk matter, not tiny ones made up of individual atoms or molecules, and it does not take into account the internal structure of atoms and molecules. Related to this is the recognition that processes involving the transfer or conversion of energy is irreversible because they all result in an increase in entropy, but this is problematic when looking at quantum-level phenomena. As Castelvecchi [265] tells us, while the second law explains that the production of "disorder" (by which he means the entropic move to increased randomness and uncertainty) is irreversible, there is an argument that at the microscopic level, this proposition appears to conflict with the laws of mechanics for which all processes can be reversed. This applies to all laws of mechanics, whether they are those of Newton or those of quantum physics (cf. [266]). The problem of applying thermodynamics to quantum phenomena is a serious one, as explained by Frieden [219]. He notes that everything in nature is quantum, and as an illustration, cancers arise out of the multiple realities that quantum systems exist in: the electrons from one such reality can randomly transfer over to another, causing a mixed-up 'bastard' growth existence that is cancer. However, while living systems can be qualitatively considered as having a thermodynamic nature, thermodynamics is blind to such fine-level quantum effects. As also already noted, for Witten [245], a thermodynamic description can only, at best, provide an approximation for a macroscopic system, and unlike statistical mechanics, thermodynamics cannot describe what one will see if one wishes to look more closely.

5.2.4. Resting State and Quasi-Equilibrium

Thermodynamic approaches using the metaphysical concept of free-energy appear to have been theoretically useful, if not pragmatically so, and within the metaphysical context of our interest, at least as far as being able to use simulations to predict states of emotion under quasi-equilibrium conditions. The Friston et al. [176] model explains how, under such conditions, errors of surprise occur between what is called a "generative" model (from which data is generated) and a resulting mental model. In the case of autopoietic cyberintrinsic theory, this generative model is simply the context map, while the mental model is the regulatory map. To resolve the potential for error between the two models represented through probability distributions, K_L entropy is used that requires conditions of thermodynamic equilibrium and is best used in cases of 'sparse' data collection (where the spacing between data points is larger than the 'Nyquist sampling interval'). However, while the K_L entropy approach is quite suitable for the analysis of classical problems that assume quasi-stationarity, it is not suitable for issues that involve non-equilibrium processes, like those of quantum statistics that are slowly becoming more important in this field [267,268].

Earlier, we referred to the resting state as a quasi-equilibrium condition delivering thermodynamic quasi-stationarity. For Deli and Kisvárday [180], resting states of mind enable a given mental model to be optimised. The resting states are recurrent, presumably therefore delivering a discrete evolutionary sequence of mental models. The Deli and Kisvárday use of the Carnot cycle in the resting state, which requires conditions of equilibrium, poses pragmatic questions since the cycle is purely idealistic. As noted by Uffink ([146]: p. 324), "Carnot's theory does not imply the existence of irreversible processes: his principle and theorem would remain equally valid in a world where all cyclic processes have maximum efficiency. However, this is clearly not the world we live in. Carnot explicitly acknowledged that, as a matter of fact, irreversible cycles do exist, and that, moreover, it is rather the reversible cycle which is an ideal that cannot be constructed in reality."

As long as one is using entropic processes, one needs to consider whether a system is in thermodynamic equilibrium or not, where the analysis of thermodynamic equilibrium states has more descriptive power than do non-equilibrium states. According to Vilar and Rubí [269], non-equilibrium thermodynamics can often show difficulties and ambiguities due to a lack of thermodynamic description. Instead, a local equilibrium proposition may be assumed in which a system can be viewed in terms of a set of subsystems where equilibrium rules apply. Nonequilibrium thermodynamics is then able to extract general features, providing laws that do not depend on the detailed microscopic nature of the system. However, the assumption of equilibrium may be inadequate. To recognise why, let us reimagine aspects of the Deli et al. processes. As indicated in Figure 4, there is a connection between sentience (from which emotion arises) and sapience (as cognition), and interest inherently lies in the endogenous interconnection between these autonomous systems in relation to the environment where emotions are expressed. This metacybernetic model allows for levels of environmental stimulus to be internalised during both resting and evoked states. According to Singer [270], resting state activity is a complex spatiotemporal dynamic involving an internal agency model which is developed to give enhanced coherence and reduced dimensionality. That is, delivering a more optimal (i.e., parsimonious and efficient) model. While the Deli et al. model explains the mechanism of that development, Singer's notion of complexity encourages the idea that instabilities may arise in consciousness processes, and where instabilities are influential, this can put to question the validity of any quasi-equilibrium assumption.

Deco et al. ([271]: p. 47) recognise that resting states may have "stable and unstable regions of quiescent and oscillatory dynamics, as well as the critical line separating regions of stability from instability. In stable regions, the network is at equilibrium, while the noise inherent in the system constantly drives the network away from its stable equilibrium point." Movement from stable equilibrium thus requires alternative ways to explore systems. Yan and Wang [272] adopt a non-equilibrium approach to examine resting state functionality. Their approach recognises that the brain is subject to instabilities in its functional connectivity, even during the resting state, due to the occurrence of noise in the brain where there are intrinsic random fluctuations caused by stochastic mental processes. Instability in functional connectivity means that the brain does not function coherently as a whole, and this can impact on perception so that structure-forming stability can be influenced. The recognition of such instability requires a non-equilibrium analysis to be developed, as noted by Yang and Wang, which enables them to consider a thermodynamic flux approach to study the dynamics of neural circuits. They do this through an investigation of working memory dynamics set within the framework of an energy landscape, state transition, and entropy production rate. Such an approach might well be found to be attractive to Ruyant [273], who explains that the evolution of the brain coincides with the evolution of perceptions and behaviour (as elaborated on by Earl [274]), and this is determined by a complex neuronal cybernetic network which for efficacy requires conditions of brain stability. Under this condition, the brain is able to integrate its multifunctionality to produce coordinated and cooperative neural oscillations, thereby providing the basis for consciousness, and this can be associated with perception stability, this suggesting an accurate configuration in the relationship between an observer and the sensory parametric context being observed [275]. Where perception instability occurs, the likelihood of acquiring intrinsic information is diminished, resulting in future agency viability issues.

5.3. Intrinsic Information Versus Free-Energy

Metacybernetics [110] has principles of cybernetics linked to control information and structural information. Control information is updated through structural information since the former is responsible for regulatory and strategic and/or stabilising homeostatic processes of self-organisation, while the latter is obtained from parametric observations resulting, for the sake of structure-forming stability, in the acquisition of intrinsic information. Free-energy has a functionality that is common to that of structural information. Where both can be used to explore degrees of organisation in a living system, the former looks towards measures of decreasing/increasing entropy, while the latter seeks information measures of order/disorder (cf. [276]). As we shall explain shortly, entropy and order are different things since while both can be defined probabilistically, EPI is based on a set of axioms and validated propositions, while thermodynamics has propositions that arise only from observational experiences. Virgo [277], in his examination of biological systems, notes that living organisms are complex structures with a high degree of order that recognise the importance of autopoiesis in living system functionality.

We have said that metacybernetics has integrated Fisher information principles into its causal-agent functionality of intelligence. We have shown that in third-order cybernetics there are two such causal-agents, one being autopoiesis (self-production) and the other autogenesis (self-creation). The former, in its interaction between its anterior and posterior systems, creates an autonomous autopoietic system and becomes the anterior system for the causal-agent of autogenesis in a recursive structure. The causal-agent dynamics of the autopoietic system are reflective of the superior autogenesetic system. In both cases therefore, intrinsic information flows to ensure that the causal-agents deliver agency structure-forming stability.

While the causal-agent of autogenesis is not so well known in the literature, that of autopoiesis is rather well known and can be directly related to the free-energy principle, which is that free-energy must be minimised to facilitate living. As Allen and Friston ([174]: p. 1) note, "the Free-Energy Principle (FEP) attempts to dissolve tension between internalist and externalist accounts of cognition, by providing a formal synthetic account of how internal 'representations' arise from autopoietic self-organization. The FEP thus furnishes empirically productive process theories (e.g., predictive processing) by which to guide discovery through the formal modelling of the embodied mind." Autopoiesis is seen as providing a circular causality between the internal and external states of an agency that provide, in a personified mode of expression, "understanding" about the relationship between action and perception that determines "belief". The "belief" is that agency will maximise the evidence for its existence by providing selective imperatives for self-organisation to deliver adaptive trajectories of fitness that influence the nature and orientation of change. Such trajectories can be disturbed through surprise defined in terms of the production of free-energy, which agency seeks to minimise. Thus, it appears to be the case that free-energy and intrinsic information functionally contribute in similar but reverse ways to agency stability, the former having implied and the latter explicitly defined association with structure-forming causal processes that are responsible for self-organisation, with free-energy needing to be minimised while intrinsic information arises from a maximisation principle. The free-energy principle is an unvalidated proposition from which has emerged the troubling metaphor that agencies "hate" surprises [278]. Rather, the principle is really one in which an agency is motivated away from increased randomness and, consequently increased uncertainty. For Paggi and Amo [279], randomness within a probabilistic context means random non-certainty, from which arises the idea of probabilistic uncertainty. So, where there is an increase in randomness with respect to a given parametric variable, there is also an increase in uncertainty with respect to that variable.

More, surprisal can boost memory, and has a valence that can be positive, negative, neutral/moderate, pleasant, or unpleasant, as well as having variation in intensity [280]. This is also appropriate to the concept of uncertainty, where negatively valenced uncertainty is coincident with a characteristic of anxiety that occurs when an agency infers that a current trajectory is not adequate in that it cannot resolve uncertainty [281]. In contrast, positively valenced uncertainty will enable a trajectory to uncover information that will reduce uncertainty. Surprisal may also be seen as part of a cybernetic feedback process that arises from the observation of environmental parametric context. While it may be argued that there is a need to avoid negative valenced surprisal (a condition under which uncertainty cannot be well negotiated to lead to anxiety), this can be questioned since anxiety can become an imperative for re-evaluation of an operative or regulative strategy, and hence in some cases can improve trajectories for change. This is not the case with positive valenced surprisal.

Another issue is the supposition that negative valenced surprisal operates as a form of vitalism that predetermines processes of self-organisation such that the surprisal free-energy is minimised. However, a revitalised notion of vitalism [282] is an appropriate consideration, which posits the idea that life is essentially self-determining and dependent on a vital principle to which affect might be particularly responsive due to its capacity to motivate. So, rather than relating vitalism to surprisal, it may be better associated with quality of spirit (an activating, essential or vital principle) that connects with levels of sapient and sentient interactive processes, including quality of observation (from Table 3). This would seem to be closer to the idea of intrinsic information than to the idea of free-energy.

We can now muse on such concepts of emergence, self-organisation, and structure-formation, which can appear magical for those not embedded in the paradigm, particularly when observed from a physicalist and reductionist metaphysical position. Revitalised vitalism, embedded in spirit, could provide a teleological (purposeful) force that guides complexity.

So, in summary, the concept of free-energy with the depiction of such attributes as learning, perception, and action, embraces psychological approaches [283] (though without the consideration of creativity) that are also essentially prevalent in metacybernetics [1] (that does consider creativity). Hence, both free-energy and structural information appear to have common functionality, including a need for optimisation to enable agency viability.

5.4. Replacing Free-Energy with Intrinsic Information

Metacybernetics is very clearly a cyberintrinsic theory that, through the integration of EPI, can independently complement thermodynamic theory. Here, the resting state is just a lower state of perceptual activity and not as in statistical thermodynamics, a condition of equilibrium. The metacybernetic perspective considers the function of the anterior autopoietic network, which is to transform the agency's context model and map it onto the cognitive model, thereby determining the distinctions that lead to metaphysical and, indeed physical structural adjustment. We have noted that the function of the posterior autopoietic network is to transform intrinsic information from the cognitive map/model and map it onto the context map/model to enable the identification and implementation of physical adjustments. These anterior and posterior operations are independent, but both require a statistical process that reduces parametric observational error. Metaphysical processes may be seen as being controlled by the causal-agent networks of intelligence processes that ideally operate coherently and relationally [35] to take parametric observations from a source and create intrinsic information that may then transform to satisfy a target's ontological epistemology. The exploration of such causal-agent relational dynamics requires development ([284–286], cited in [35]) to provide a promise for predicting the mutual impacts of sapience and sentience. Assuming that the causal-agent networks are each individually coherent and relationally efficacious, and are thus not responsible for the creation of noise during the transformations and are carrying intrinsic information, then the system supporting a causal-agent continues to have structure-forming stability. In the agency model shown in Figure 5 (adapted from [35]), we illustrate the anterior and posterior autopoietic intelligences.

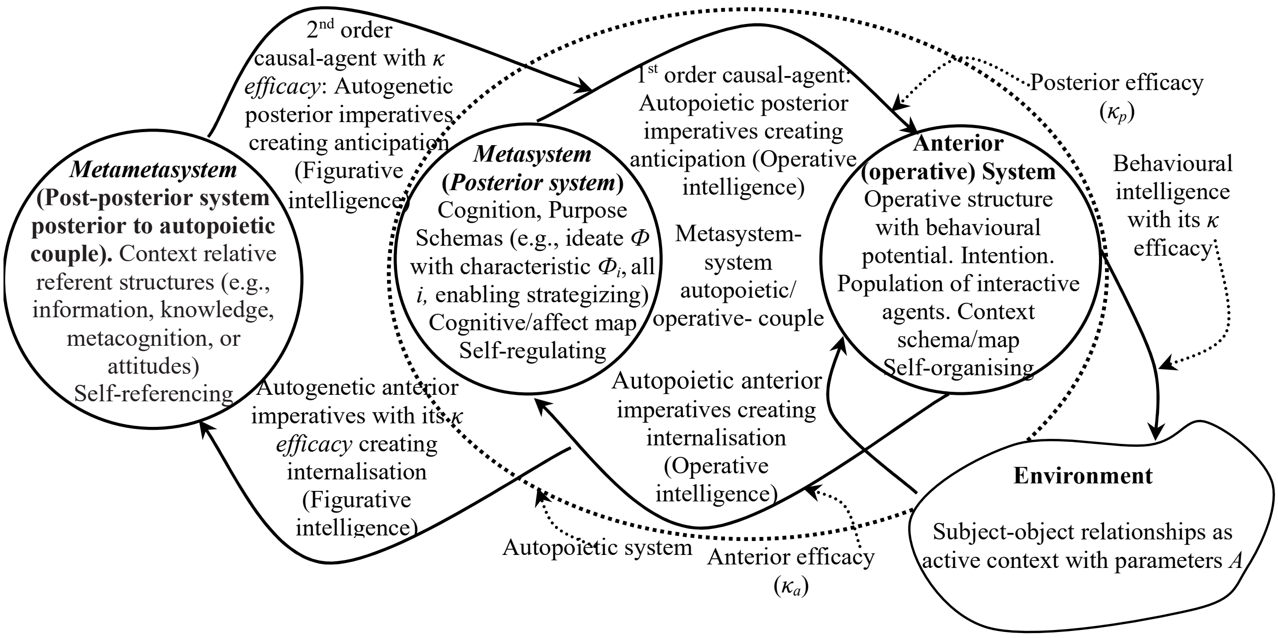

Figure 5. Agency Model Showing the Anterior and Posterior Intelligences respectively related to Internalisation and Externalisation.

Here, the posterior autopoietic intelligence has an efficacy of κ_p and the anterior autopoietic intelligence has an efficacy κ_a. The efficacy is determined by

$$I_b = \kappa_a J_a \text{ and } I_p = \kappa_p J_p \tag{13}$$

For intrinsic information, I_a acquired from the anterior system with bound parametric information J_a, and similarly, intrinsic information I_p acquired from the anterior system with bound parametric information J_p. The case of I_a is concerned with efficacious autopoietic internalisation that can impact on the structure of the metasystem, and the case of I_p is concerned with efficacious anticipation that can impact the structure of the system. In either case, to ensure dual structure-forming stability, κ_a and κ_p should be sufficiently large. In each of the anterior or posterior networks of processes, κ—which for an individual process takes values between (0,1)—should be sufficiently close to one. Following Frieden [38], in classical physical systems $\kappa \leq 0.5$, and in quantum systems $\kappa = 1$, it is unclear what range of values might be taken in metaphysical situations. It may be noted that if a causal-agent has a network of n cooperative processes, and κ is a smart measure of efficacy, then $\kappa \leq n$.

In either case of Equation (13), the information is intrinsic when $I = I_{max}$. Where the context and cognitive models differ, then this is indicated by

$$e \geq \sqrt{1/I} \tag{14}$$

from Equation (4). There will be a smart e for each causal-agent, i.e., for the autonomous anterior and posterior causal-agents, and like the free-energy in the system, this needs to be minimised for structure-forming stability. When e is sufficiently large, the autopoietic system moves towards instability. The need, then, is to determine the size of $e \geq e_{min}$ according to Equation (7). Then, the difference between acquired structural information and intrinsic information is

$$\varepsilon = e^2 - e^2{}_{min}, \tag{15}$$

where ε is broadly relatable to agency metaphysical surprisal [177].

5.5. Sentience through Intrinsic Information

We considered the Joffily and Coricelli [177] thermodynamic modelling approach earlier. They formulated a set of propositions that enabled them, through the supposition of equilibrium, to predict emotional states that would arise under different conditions. Here, then, our interest lies in migrating the approach into metacybernetics.

We begin by recognising that agency is a collective plurality with a population of individually purposeful interactive agents. They operate in an environment but are provided with metaphysical conditioning imperatives that (usually) determine their kinetic behaviours, where self-stabilising processes try to deal with outlier behaviours (e.g., through legal prosecutions for those who do not socially conform to legal constraints). It is through sentience that agency pressures, when applied to its population of agents, enable agent interactions to involve relevant emotions. Joffily and Coricelli, like Friston et al. [176], use K_L entropy to define the relationship between emotions and emotional valence. They propose that emotional valence, which is a determinant for emotions, is a function of the rate of change of free-energy over time t. Thus, valence can be dynamically attributed to every environmental state that an adaptive agency might encounter, and this determines the dynamics of basic forms of emotions (like happiness, hope, fear, etc.). In contrast, in the cyberintrinsic paradigm, change in information over time t related to Equation (1) suggests that a given t indicates a particular measure of x for dynamic parametric sensing contexts concerning emotional states. Replacing entropy with information means that if we wish to consider the Joffily and Coricelli approach, their ideas need to be migrated into metacybernetics while dropping free-energy and using intrinsic information, involving the recognition that some of the theoretical structure that explains things in terms of entropy need to change to explanations through structural and perhaps also control information. This means that the Joffily and Coricelli propositions will require adjustment.

Structural information flows in an autopoietic network of processes, and different processes deliver information from different parts of the context map to relatable parts of the cognitive map, with their twinned regions of the increasingly complex hierarchic structure. Now, for autopoietic (structure-forming) stability, structural information needs to be intrinsic. The avoidance or non-avoidance of emotional conditions may then be described in terms of valence, where positive and negative valence are respectively associated with the increase and decrease of structural information over time. In a continuous time domain, the rate of change of structural information can be taken to be the first time derivative at a time t. Thus the valence of a state of an agency at time t is the first time-derivative of structural information at that state. Accepting the notion that adaptive agencies encode a hierarchical context model of the causes of their sensations, the notion of hierarchy thus becomes significant. This is because it enables the proposition that a cognitive model of a parametrically described environment is represented by a hierarchy of complexity. Here, increasing complexity and abstraction are encoded in higher levels of the hierarchy, while sensory data is encoded at the lowest level. Structural information is then maximised for each level of the hierarchy separately, and the quantity $I(t)$ is a representation of the structural information associated with the hidden state at some level of the hierarchical model.

Thus, we first consider that for a dynamic information source having parametric change, any change in $I(t)$ over time ($\mathrm{d}I(t)/\mathrm{d}t$) is indicative of a possible change in emotional valence. The sentient system encodes the causes of sensations experienced in its regulatory-affective map. During processes of adaptation, their motivation towards achieving viability is determined by emotional information delivered by the causal-agents. By Equation (13), this information differs from intrinsic information by the amount ε, though ideally $\varepsilon = 0$. Now, noting that the free-energy principle is the reverse of the EPI principle, we can postulate that at any given time t in a changing parametric context, where ε is positive, then there is positive emotional valence, where ε is negative then there is a negative emotional valence, and where $\varepsilon = 0$, so there is neutral emotional valence. Such a postulate requires empirical testing, which is beyond the scope of this paper.

Agency vitalism towards viability requires intrinsic information as it seeks to minimise the value of ε. This involves a self-stabilisation process that seeks to determine if the network that constitutes autopoietic processes is coherent. Coherence is defined as the network that is at least cooperative, and the information that is delivered by it to a more complex region of hierarchy is consistent with delivery to other regions. The structural information acquired from a parametric source can enable agency autopoietic system stability through both the sapient cognition processes (of awareness, including perception), and the sentient autopoietic affect processes, where acquired information is shared through sapient-sentient cross-fire. The intelligences are responsible for acquiring intrinsic information. While, on one hand, this occurs through the statistical acquisition process of EPI, on the other hand, living processes can create pathologies that, through incoherent processing, mean that the source data (no matter how good the statistical acquisition process) is inadequate. Thus, for structure-forming stability, living system coherence is a necessary condition, and the EPI intrinsic information process constitutes a sufficient condition for this.

As noted by Joffily and Coricelli for free-energy, so intrinsic information can also be used to explain learning, perception and action enabled through control information, where self-stabilising processes are themselves stable. Emotional valence can be used to explain the rate of change of ε that leads to a meta-learning scheme for the complex and reciprocal interaction that occurs between sapience and sentience. A sentient agency can dynamically assign emotional valence to every new state in its environment as it experiences emotional states, where emotional valence is used to adapt dynamically to unexpected environmental changes.

5.6. Connecting Autopoiesis with Thermodynamic Dissipative Processes

Under conditions of nonequilibrium, dissipative processes are responsible for agency transformation, but there is no clear indication of the role that autopoiesis plays in this. Here, we shall consider their relationship.

We are aware that autopoiesis (which informationally connects metaphysical and physical contexts) has an anterior trajectory that enables internalisation, and a posterior trajectory that enables externalisation, and this dual trajectory explains how mutual agency and environmental exchanges occur. The question of exactly how structural changes can be explained thermodynamically requires a response. In general, one must suppose that metaphysically, agency has a non-equilibrium condition. An illustration is where the mind is in an evoked state, when it is engaged with responses to relevant sensory information. Agencies, operating far from equilibrium, survive because they are dissipative. That is, the theory of dissipative structures explains how they can survive in a changing environment through processes of adaptation delivered through dissipation [287]. That there is an explicit connection between dissipation and autopoiesis has been indicated previously [218]: [288], and here we shall explore this.

Thermodynamic laws fundamentally limit the efficiency and accuracy of agencies [289], where their essential functions (like sensing and locomotion) require the consumption of energy, and this dissipates heat. As local phenomena in their environment, agencies maintain or increase order locally by acting against the second law of thermodynamics, but to balance this, they consume free energy, and in doing so, create an increase in environmental entropy. Thus, in the autopoietic externally directed trajectory from agency to the environment, exchanges occur through the dissipation of entropy into the environment.

Since agencies involve both information and energy processes, it should be possible to show how both cyberintrinsic theory and thermodynamics connect, noting that according to Frieden and Gatenby ([55]: p. 2), "Living systems are non-equilibrium open but locally delimited and thermodynamic, and use the information to convert environmental energy to order. Survival of a living structure requires a stable state of order despite continuous thermal and mechanical perturbations", where stable states are determined by intrinsic information, the production of which is triggered by the perturbation. Despite such inherent connections, in directly relating dissipative structures with autopoiesis, one needs to explore possible propositional issues. This is because, as Frieden [219] notes, autopoiesis is related to 'system creation', which is reversible, while thermodynamic waste entropy creation is its antithesis, being irreversible. So how can these distinctions be overcome? To relate them, one may propose that autopoiesis and dissipation are relay processes. While it is often proposed that dissipation is the result of heat fluctuations [287] that are often considered to be the result of *random* processes, they can also occur as agency *adaptive* processes, the latter being the result of imperatives for change transmitted through intrinsic information and delivered along autopoietic trajectories. Such imperatives stimulate irreversible entropy production and free-energy dissipation, and when this occurs, their structures are said to be dissipative. This is the reverse of the relay process, where a perturbing event in a system goes hand in hand with an increase in entropy production, as argued by Kleidon [290]. By invoking a proposed maximum entropy production proposition, this can result in a cybernetic process through which the EPI principle is stimulated, resulting in turn in the production of a maximum information process, as defined by intrinsic information. Hence, if the Kleidon proposition holds, then in non-equilibrium dissipative systems, the maximisation of both entropy and information are coherent together.

In metacybernetics, the anterior and posterior systems both have control responsibilities. The posterior system controls the anterior system, while the anterior system controls agency behaviour, and both systems are susceptible to dissipation. To better understand this, let us consider an illustration by briefly examining viruses as living systems [7]. An autopoietic virus system consists of an anterior capsid and a posterior genome. For the sake of virus viability, the genome sends adaptive imperatives to the capsid to undergo certain structural adjustments. From this, the release of certain proteins will occur that delivers certain behaviours in its cellular environment. Where there is a need for adaptation for viability, the capsid also sends adaptive imperatives to the genome to make certain structural adjustments, thereby enabling a variation in the regulations that will, in the future, be applied to the capsid. Both of these trajectories may be subject to random error. In the case of the genome, changes in structure are normally thought of as random mutations, but they also occur as adaptive mutations. The imperatives for change are delivered autopoietically to both the capsid and the genome through intrinsic information. These imperatives initiate the use of energy to make necessary structural adjustments, and to do this, dissipation is engaged. This has been argued, for instance, by Weber et al. [291] in the case of capsid protein activity, where dissipation is tightly coupled to the activation of what they call signals. These signals, in essence, are constituted as imperatives for adaptation accompanied by intrinsic information detailing the nature of that adaptation. Now, information flow and heat dissipation occur through different processes, the former being channelled along causal mechanisms, while heat is channelled in other ways [292]. While the nature of heat dissipation is beyond the scope of this paper, whether it occurs for the capsid or the genome, the result is the same, an increase in environmental entropy.

6. Conclusions and Discussion

Two approaches to understanding the metaphysical dynamics of agency living systems have been considered. The first is metacybernetics, with its use of structural information to ensure structure-forming stability and hence, potential for viability. Now, this information enables self-organisational structure-forming and is efficacious when, through the theories of R.A. Fisher, information becomes intrinsic. The second is thermodynamics which at best enables macrosystem approximations, and within the metaphysical context, invokes a condition of surprisal that is a function of the inventive idea of free-energy that it seeks to minimise. Free-energy has a similar function to structural information in creating viability. It is a metaphysical attribute intended to reflect the concept of Helmholtz's free energy as used in physical systems and, indeed, arises from suggestions by Helmholtz. It was introduced to help explain brain functionality, and is based on conservation laws and neuronal energy [136]. Due to the involvement of surprisal, free-energy needs to be minimised to enable efficacious brain function. It turns out that the function of optimal free-energy is causally relatable to optimal intrinsic information, though in the former case, efficacy requires minimisation while in the latter case it requires maximisation.

Now, EPI (from which the idea of intrinsic information arises) is a mature information theory, but its application to living system sentience is immature. By exploring the limitations of thermodynamic theory, especially with reference to metaphysics, some creative developments for intrinsic information have appeared. In metacybernetics, rather than considering entropy as a central character in the play of living systems (as occurs in thermodynamics), intrinsic information (represented by the symbol I) takes up that role. Unlike the pragmatic concept of the laws surrounding entropy, those of intrinsic information are well-defined, illustrating a solid theoretical basis [55]. Also, its integration into metacybernetics as a cyberintrinsic framework has provided a greater theoretical edge to the notion of autopoiesis through structural information flows.

Autopoiesis is also connected with energy and matter that, through metaphysical processes, transforms the physical and kinetic states of a living system. The term kinetics refers to the dynamic actions taken by an agency in its environment, where, in general, one is seeking to identify the nature of these dynamics (as underlying physical laws like the Schrödinger wave equation in quantum mechanics and other such equations of basic theory).

While much of the thermodynamic theory of living systems that exists centres on the mechanisms by which living systems maintain themselves through brain function, the brain is nothing other than a centralised control mechanism that might be found to occur in different ways in different classes of a generic living system that provides for the mind.

In this paper, interest has centred on agency consciousness through information processing and the notion of Fisher/intrinsic information. Consciousness has been distinguished into two interactive ontologies, the autonomous systems of sapience and sentience, each with its own networks of intelligence. Sapience refers to the domain of awareness and rationality and sentience to feeling and, by extension, to emotion. We then used the metacybernetic framework to model consciousness in terms of these systems. We have also shown how thermodynamic principles can be used to explain some of the metaphysical mechanisms of living systems, especially with respect to sentience, and have argued that the use of intrinsic information also provides as useful an approach as an entropic one.

Metacybernetics, unlike thermodynamics, is concerned with both structure and meaning through ontology and epistemology. Agency has three ontologically distinct maps, each of which provides a model that it is able to accommodate into its structure, thereby becoming adaptive. Suppose that interest lies in the regulatory map that drives agency strategy. During the resting state, the model is optimised, and where accommodation occurs, the adjustments are integrated into the regulatory agency structure, enabling agency to directly self-organise requisitely. Adjustments to the homeostatic map similarly occur. We will recall that strategic processes provide first order regulatory agency control, while homeostatic processes provide second-order regulatory agency control, and thus, enabling agency to spontaneously respond to significant challenges to regulatory intentions. These processes are facilitated through intrinsic information.

Taking a thermodynamic view of living processes is useful primarily because of the work already done on sentient processes. While agencies operate in thermodynamic non-equilibrium, an explanation concerning the nature and purpose of the mind's resting state is provided by assuming that it is in a quasi-stationary condition, where the regulative and homeostatic models are optimised. However, examining the resting state of the mind in terms of quasi-equilibrium conditions does not take into account the likelihood that resting state processes of cognitive model improvement may be subject to instabilities caused by stochastic neuron processes, and where this occurs, non-equilibrium explanations may be required. Neuron network approaches, and by extension, quantum studies of the brain, may be more suitable to explain the resting state model improvement process as an alternative, thereby recognising the nature of instabilities with respect, for instance, to pathologies resulting in impaired brain function, especially where quantum inquiry is invoked.

If one were seeking explanatory mechanisms for both the physical and metaphysical dimensions of agency, then quantum explanations that operate at the level of the neuron become useful. Thus, for instance, the brain is composed of cells with myriad distinct genomes and may be thought of as a genomic mosaic determined by a host of DNA sequence-altering processes [293]. In this, one can determine the genes involved in a particular function of the brain, of which some 40% are neurons [294]. A more detailed investigation of brain functionality is therefore enabled through quantum investigation. For *Ruyant* [273], the evolution of the brain, which determines the evolution of perceptions and behaviour, is determined by a complex neuronal cybernetic network. Neurons communicate by stimulating and inhibiting electric signals, and if a neuron enters a firing state, it propagates a signal, and then returns to a resting state, though the network as a whole can still respond. Neurons are chaotic systems on a very small scale, and their firing actions are not fully predictable. They are membraned cells that are responsible for the generation of an electric potential, and they can emit a signal when they fire. The membrane potential is a chaotic system of electrons involving feedback processes that occur on a quantum scale. The brain, when seen as a hierarchical composition of quantum-scale chaotic systems, has an interrelationship between the elementary units that compose it, and as a whole, it is constituted as a macroscopic quantum chaos system that generates and maintains an entanglement of its electric field in the active areas of its network, this providing a complex mechanism that can facilitate the emergence of consciousness. By entanglement is meant that neuron states are connected no matter what distance separates them, and this can provide insights into how information-rich structures are able to be maintained. This is consistent, Ruyant [273] notes, with the ideas of Edelman and Tononi [129] concerning the nature of active neuron interactions, where a measure of conscious integration is entropy-based. The measure is higher when a neuronal collective has greater signal interactivity within the collective than with other neurons outside it, indicating the collective's boundary. EPI also provides indications of entanglement for the unobserved source information J and acquired information I [38], and while the degree of entanglement may vary as indicated by the measure κ, where full entanglement occurs when $\kappa = 1$ so that $I = J$. Gao ([295]: p. 69) notes that the appearance of a conscious perception in the brain involves a large number of neurons changing their states between a resting state/potential to an action (neuronic firing) state/potential, and thus, providing a quantum superposition (the ability of a quantum system to be in multiple states at the same time until it is measured) of the two states provided by the unit of measure called Planck energy.

In this paper, we have progressed the idea of agency as a generic living system, thereby taking the case beyond organic structures. In fact, the generic view of such agencies may be thought of as a form of bounded panpsychism. According to Skrbina [296], panpsychism attributes the quality of mind to all things, but the nature of both mind and all things pose questions. Our agency-bound concept of panpsychism has a conception of agency as an entity with a self-organising adaptive capacity of acting or exerting power that enables agency ends to be achieved. Agencies are able to maintain themselves through a psyche determined by a complex of elements that define mind as it operates through levels of consciousness, each level a function of the complexity concerning sapience and sentience and their interactions.

The notion of agency-bound panpsychism enables consciousness without reference to physical mechanisms that enable it, but eventually, there is a need to explore the homeostatic and regulative mechanisms that are responsible for the functionalities of consciousness. Thus, for instance, in microbiology, the molecular structure of viruses has become an important field, with the use of quantum techniques to investigate virus natures and the means by which they infect cells [297]. Here, one can identify genomes as a source for the mechanisms that control virus consciousness [7] and brain processes that are responsible for degrees of consciousness towards maturity. Thus, for instance, the quantum nature of brain structure arises with the proposition [298–300] that its neuronal structure involves Microtubule (polymers of tubulin that form part of the brain's cellular cytoskeleton) networks, where the Microtubules have quantum microstates that enable the emergence of stable macroscopic quantum coherent states that constitute preconscious mind states. However, it should be noted that the idea that at the quantum level, microtubules give rise to consciousness goes back to Roger Penrose and Stuart Hameroff and it is contested by many scholars.

Such propositions have broader relevance, enabling theoretical extension to any generic conscious living system, including the cosmos [301]. Setting agency activity in terms of the quantum level enables the consideration of superstring theory, which purports that everything in our Universe is made up of tiny vibrating strings that can have both homeostatic and regulative functionality. This approach generalises the nature of control systems for consciousness and provides a link to models of a self-organising cosmos, possibly through such speculative works as Nanopoulos [302] and Mavromatos, and Nanopoulos [303], who set brain function in terms of both quantum mechanics and superstrings.

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