information

Article

The Central Dogma of Information

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Abstract: Info-autopoiesis or the self-referenced, recursive, interactive process of information self-production that engages all living beings in their efforts to satisfy their physiological and/or relational needs relies on Bateson's difference which makes a difference. Living beings, as active manipulators/observers of their environment, derive meaning from the sensorially detected motion of matter and/or energy in the Universe. The process of info-autopoiesis in humans is found to be triadic in nature and incorporates the simultaneity of a quantitative/objective perspective with a qualitative/subjective perspective. In this process of meaningful engagement with the environment, humans create and transform endogenous semantic information into countless expressions of exogeneous syntactic information, which is synonymous with ordered material structure and artificial creation. Other humans can interpret exogeneous syntactic information and uniquely transform it into semantic information that can take multifarious forms. This asymmetrical process is the basis to postulate the central dogma of information that states 'info-autopoiesis results in endogenous semantic information that irreversibly becomes exogeneous syntactic information'. In other words, once the artificial, syntactic world, including machines, created by humans comes into being it can only be interpreted by others, i.e., it does not necessarily convey the same intended meaning to all. Additionally, these artificial creations only recognize, extract, create, transmit, preserve, store, and utilize syntactic information, unable to transform syntactic information into semantic information. In other words, our resourceful capacity for syntactic creation does not allow for creation of artificial beings with comparable capabilities as us for meaning making. It suggests that our dreams for sentient artificial general intelligence and superintelligence are misguided and parallel the central dogma of molecular biology which states that 'once (sequential) information has passed into protein it cannot get out again'.

Keywords: information; gregory bateson; info-autopoiesis; Claude E. Shannon; syntactic; semantic

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1. Introduction

There is an extensive history associated with the term information [1–9], yet it retains a patina of mystery and elusiveness, reflected in the following influential quote, 'Information is information, not matter or energy. No materialism, which does not admit this, can survive at the present day' [10]. This postulate places information on the same fundamental and objective level as matter and/or energy, leading to its wide acceptance as such in numerous influential works by Wheeler [11], Stonier [12], Yockey [13], Lloyd [14], Umpleby [15], Burgin [16], Floridi [17], Vedral [18], Hidalgo [19], among others. Furthermore, Bynum quoting Wiener shows the wider context in which information is relevant,

> "Information is a name for the content of what is exchanged with the outer world as we adjust to it, and make our adjustment felt upon it. The process of receiving and of using information is the process of our adjusting to the contingencies of the outer environment, and of our living effectively within that environment. The needs and the complexity of modern life make greater demands on this process of information than ever before. To live effectively is to live with adequate

> information. Thus, communication and control belong to the essence of man's inner life, even as they belong to his life in society [20]."

Wiener considers information in a dynamic human-organism-in-its-environment context as being easily identifiable and usable for our purposes in nature, and in our social life. However, this quotation leaves much to the imagination of the reader, as one could easily ask, how is information identified and processed by humans to have access to its bountifulness?

To answer this question requires that we naturalize the definition of information using two different but complementary approaches. A first approach requires examining the etymological origin of the word information, showing its derivation from the Latin stem informatio, which comes from the verb informare (to inform) in the sense of the action of giving a form to something material; and as the act of communicating knowledge to another person [2,3,21,22]. This dualistic interpretation implies that human beings in-form matter and/or other living beings by interactively shaping their form and thinking/behavior through communication, respectively.

The second way to naturalize information is to rely on the definition of information by Bateson as 'a difference which makes a difference' [23]. This dynamic view of the process of cybernetic human actions, or constitutive absence [24], may be revealed as engaging every instant of our lives. Determining differences is the source for satisfaction of our most fundamental physiological needs such as breathing and eating, changing our surroundings by acting on our environment, and when engaged in discussions with others. Actions guided by constant and recursive resolution of differences by sensory organs that keep our internal milieu within homeorhetic bounds and/or help us achieve our objectives by a learning process. This continual learning process allows us to deal successfully with our environment. In this process we inform objects and subjects while interactively and reciprocally informing ourselves by our interactions with said subjects and objects. This is information that only exists for the human-organism-in-its-environment engaged in these interactions and responds to its physiological and/or relational needs. In summary, the dynamical nature of Bateson's dictum on information is fully compatible with its etymological origin. Living beings inform and are informed by their interactions with their environment by way of their embodied actions and sensory organs to discover the non-living and the living.

The bountifulness of matter/energy are expressions of environmental spatial/temporal motion/change as information that is of utmost importance to humans-in-their-environment. This is what Wiener (1954) refers to as " . . . a name for the content of what is exchanged with the outer world as we adjust to it, and make our adjustment felt upon it. The process of receiving and of using information is the process of our adjusting to the contingencies of the outer environment, and of our living effectively within that environment" [20]. We need to emphasize that matter/energy are fundamental quantities, while noticeable environmental differences (information) are derived quantities and only useful to living beings to satisfy physiological and social needs in their dynamic interactions with their environment. The identification of differences/information in always moving matter/energy is fundamental to our existence. In this dynamical engagement, the brain as an ever-developing organ mirrors the physical environment in its organization, and simultaneously envisions and acts to transform its environment in her own image.

Previous work by the author is relevant in posing the fundamental problem of information as a first step in obtaining an answer to the question of how living beings become what they become. Formally, the fundamental problem of information seeks to identify how a living being, in a self-referential process, develops from a state in which its knowledge of the living-being-in-its-environment is almost non-existent to a state in which the living being not only recognizes the existence of the environment but also sees itself as part of the living-being-in-its-environment system. This allows a living being not only to self-referentially engage with the environment and navigate through it, but also to transform it in its own image and likeness [25]. Additionally, to answer the challenges that

this fundamental problem poses requires the discovery and application of the process of info-autopoiesis, or the self-referenced, interactive, and recursive process of information self-production of all living beings in their efforts to satisfy their physiological and social needs [26].

The neologism info-autopoiesis (info = information; auto = self; poiesis = creation, production) should not be confused with autopoiesis (auto = self; poiesis = creation, production), a notion conceived and developed by Humberto Maturana and Francisco Varela that emphasizes ' . . . what takes place in the dynamics of the autonomy proper to living systems' [27] (p. xvii). Varela is clear that in autopoiesis ' . . . informational and functional notions need not enter into the characterization of the living organism, as they belong to a domain different from the relations that define the system' [28] (p. 37). Further, 'the notions of information and purpose are dispensable'. Thus, ruling out information in the conceptualization of autopoiesis, though Varela might have had a change of heart when he stated that 'In retrospect, I believe this question needs further development' [28] (p. 38). A more thorough treatment of the differences between info-autopoiesis and autopoiesis is given in reference [26] (pp. 201–202).

The word 'dogma' in the title might bring forth visions of unyielding forthrightness by the author in the eyes of some readers. To allay fears of any kind it is worth relying on the dictionary definition of 'dogma' (https://www.merriam-webster.com/dictionary/dogma) (accessed on 19 June 2022) as 'something held as an established opinion' as well as 'a point of view or tenet put forth as authoritative without adequate grounds'. These definitions are like a scientific claim framed as a postulate. Clearly, this wording is meant to bring forth argumentation and questioning as to the validity of the 'central dogma of information'.

This paper consists of five sections to better define and situate the ramifications of the process of info-autopoiesis, the self-referenced, recursive, interactive process of information self-production that engages all living beings in their efforts to satisfy their physiological and/or relational needs. First, a critical review of Shannon's theory of communication allows the identification of the role of syntactic and semantic information in the info-autopoietic process. Meaning-making (semantic information) is endogenous (internal) to the communicating individual, while exogeneous (outward) expressions can only occur as syntactic information. Second, the process of info-autopoiesis is shown to be critical to the transmutation of sensory perceptions into meaning-making (endogenous semantic information) and its externalization (exogeneous syntactic information) in multifarious forms. Third, careful consideration of exogeneous information including all creations by living beings leads to the postulate of the central dogma of information. Fourth, similarities may be shown to exist from considering a parallel construction of the central dogma of molecular biology. Last, the findings are discussed, leading to a summary, discussion and conclusions.

2. Shannon's Communication Theory: A Critical Appraisal

Figure 1 shows a block diagram of the elements of the general communication system underlying the Mathematical Theory of Communication [29], central to the establishment of 'Information Theory' as a discipline. The information source 'produces a message or sequence of messages to be communicated to the receiving terminal'. The transmitter 'operates on the message in some way to produce a signal suitable for transmission over the channel'. For example, 'in telegraphy we have an encoding operation which produces a sequence of dots, dashes and spaces on the channel corresponding to the channel'. The channel is the 'the medium used to transmit the signal from transmitter to receiver', which accumulates noise from multiple sources in its path, some predictable, some not. The receiver 'performs the inverse operation of that done by the transmitter, reconstructing the message from the signal'. Finally, the destination 'is the person (or thing) for whom the message is intended'.

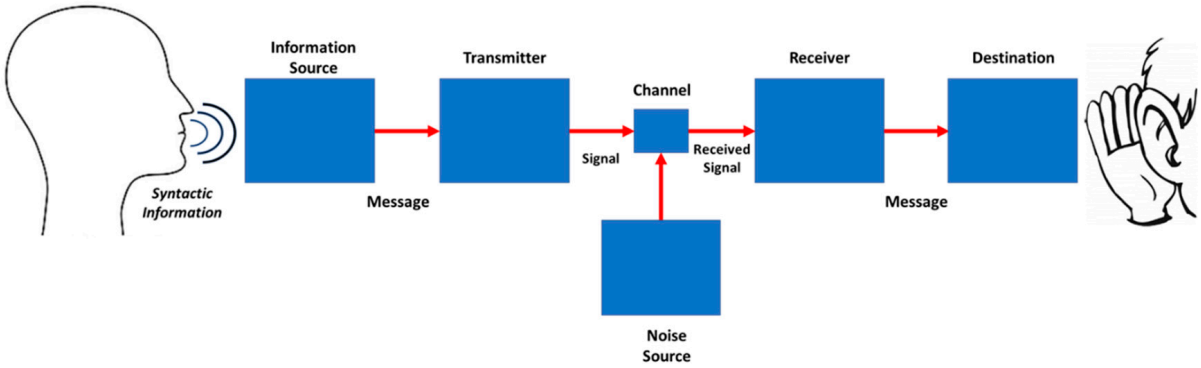

Figure 1. The communication process (adapted from [27]).

The fundamental problem of communication is defined as 'that of reproducing at one point either exactly or approximately a message selected at another point' [29]. Though the messages may be syntactically crafted to have meaning, these semantic or meaningful aspects of communication are irrelevant to the engineering problem, though in some instances the engineering aspects may reveal or imply semantic content. This communications system can be mathematically analyzed in detail, incorporating probabilistic prediction, in the effort to recognize the originally sent message from all possible messages that could have been sent.

Shannon's purpose in devising this analysis was to understand and solve the problem of communication from an engineering perspective, emphasizing the syntactical aspects of communication. The syntactical aspects refer only to the potential ordering of the transmitted messages according to the rules of syntax or syntactics. The impact of these developments on digital communications is everywhere to be seen. If we are to naturalize the process of communication, we might ask if there are missing elements that would merit inclusion for a more comprehensive analysis. For example, how does the sender of the message come up with the message that is to be coded for transmission? What is the historical and technical process that allows humans to develop the technology, design, build and use the apparatus that allows communication to take place? More fundamentally, how do humans come to be in a position not only to produce advanced technological developments, but to be able to express themselves to take advantage of their use? Phylogenetically, it is not too long ago that we were living a hand-to-mouth existence where communication was at best by signs and/or direct oral communication. Ontogenetically, we develop from a state in which we can hardly communicate to a state in which oral communication is second nature to us. These questions seem relevant if we are to understand information from a more general perspective. Not having ready answers to these questions suggests that we may suffer from alienation, or an inability to recognize our handiwork in the products of our labor. It is easy to forget that our handiwork created the described communication system that we are describing. Further, there is a human being at the left-end and right-end of the communication system in Figure 1. The human being at the left-end generates a message, the result of an internal or endogenous process of creation of semantic information or information that has meaning for her, codes it as external or exogenous syntactic information in the form of speech, which the communication apparatus subsequently digitally codes as syntactic information and sends to the human being at the right-end. After the digitized message acquires noise in the channel, it is denoised and decoded in the receiver to become synthesized speech, which reaches the ears of the human being at the right-end. That individual must then decode the synthesized syntactic speech and decode/interpret the message based on prior experience and knowledge. This process leads to recognized syntactic information and interpretation as semantic or meaningful information for the recipient. The same message might have different meanings to different individuals.

In this process we also seem to suffer from fetishism, or an attribution of inherent value, or powers, to the messages that we code and decode. We seem to have the power to effortlessly speak into a communication system and then listen to a response and effortlessly decode what we hear. The postulate that information is a fundamental quantity of the Universe in addition to matter/energy [12,30–32] appears to be true since the information in coding and decoding messages is effortless and readily accessible. In the case of the communication system devised by Shannon, no explanation needs to be given as to why we might be able to code a message at the left end of Figure 1, and then understand the decoded message that we become privy to after receiving it at the right end of Figure 1. The differences that we learn to encode and later discover with our sensory organs as information or as 'differences which makes a difference,' mean something to us. In this learning process, living beings inform matter/energy and vice versa.

In-forming matter/energy interactively and recursively takes place in several ways: by actual manipulation of matter/energy to consume it as nourishment; to create speech sounds; to create all the objects that are part of the artificial world that we conceive and surrounds us; and to have the ability to communicate either by our own resources or technological developments. Shannon/syntactic information is synonymous with artificial creation of analogue and digital ordered physical structure as exemplified above, even when climate change is a concern. Only living beings can give meaning to their sensory experiences and to express them as syntactic constructions. However, machines created by humans can generate syntactic information, without the need for meaning-making, in response to the design constraints imposed by their designers.

Currently, information is produced and consumed by humans and by machines designed and built by humans. Humans produce and use Information and Communication Technologies (ICTs) such as wireless radios, cybernetic control mechanisms, encryption machines, cell phones, digital televisions, satellite communications, the internet, social media, etc. Messages are composed by humans/machines, coded, optimally transmitted as communication signals, and received, denoised, decoded and interpreted by humans/machines. This is the basis for the information age with humans at its center. We are no longer constrained to the use of only our primary senses to engage with nature but are fully capable of expanding our sensory range by artificial creations. It is commonplace to use satellites to predict the weather; video cameras for surveillance in our cities; infrared, and ultraviolet sensors to keep track of food production; Magnetic Resonance Imaging to look inside our bodies; satellites to assess vast expanses of space and time, to become interstellar travelers. All these technological wonders act to expand our sensorial capabilities beyond what our five primary senses allow.

Summarizing, Figure 1 illustrates the communication process that takes place between two humans. The one on the left-end can externalize Shannon/syntactic information after an internal semantic/syntactic process to communicate with the one on the right-end. The human being on the right-end internalizes the received Shannon/syntactic information to produce her own semantic interpretation. This process of self-production and self-interpretation of information is what needs to be unveiled and appreciated. The next section deals with this process of self-production and self-interpretation of information, or info-autopoiesis [26].

3. Info-Autopoiesis

The naturalization of information allows us to view information as a process of informing as well as being informed by the environment, in the context of Bateson's 'difference which makes a difference'. The process of informing the environment is a process of Shannon/syntactic information, a process synonymous with the creation of ordered artificial structure from matter/energy, and of communication with other humans. This section specifies the process of being in-formed by the environment through a process of self-production of information without which it would be impossible for a living-being-in-its-environment to inform the environment.

An important characteristic of Bateson's definition of information is its self-referential, subjective, interactive, and recursive nature emphasizing the self as the center in ascertaining differences that make a difference by way of our senses, motivated by satisfaction of physiological and social needs, to develop our ability to act on our environment. A mother taking care of her infant is an example that illustrates the satisfaction of the physiological and relational needs of both. The infant is fed in a nurturing environment, noticing the differences between being hungry and being satisfied, between being cold and comfortable, between being soiled and clean; the mother ensures the care and survival of the out-of-the-womb infant with her milk, her warmth and her care while showing experience in doing so, and passing on that experience to the infant. All instances of detecting differences in this example require a commensurable comparison between two instances of spatial/temporal sensory data for a living being (though the paper refers to living beings and humans interchangeably, the context of such reference should help to clarify the meaning to avoid anthropocentric connotations) to recognize or process a difference, i.e., two sensory maps that are spatially/temporally separated. A commensurable comparison results in qualitative/quantitative differences physically recorded in our brain in malleable and mutable neural networks that, after further continued excitation pertinent to the satisfaction of physiological and social needs, lead to related learning. Learning leads to developing human capabilities to act successfully and recursively in our dynamic environment. What the brain processes are the detected spatial/temporal differences in incoming signals from the various (touch, auditory, olfactory, gustatory, or visual) sensing organs, i.e., information.

Another notion advanced by Bateson is that for humans, ideas and information are fundamentally synonymous [23]. These differences/ideas permit the discernment, categorization, description, and sharing of our learning, orally or otherwise. We can extend our memory into the world using drawings, figurines, phonology and/or symbols. The differences/information/ideas that are reflections of the material nature of our world in the neural circuits of our brain find themselves reflected into our world in multifarious physical forms and actions. A bonus is the fact that information may be built upon information, i.e., higher levels of differences, information, ideas may be scaffolded on top of lower levels of differences, information, ideas, never losing the intrinsic connections that such a process demands.

The fundamental problem of information is the basis for the phylogenetic and ontogenetic development of a living-being-in-its-environment and contextualizes the process of what it means to be informed by the environment. A living-being-in-its-environment, in a self-referential, recursive and interactive process, develops from a state in which its knowledge of its environment is almost non-existent to a state in which the living being not only recognizes its environment but also sees itself as part of that environment. This allows the living being to self-referentially deal with the environment to transform it in its own image and likeness [25,26]. This is another way to identify the process of info-autopoiesis (information-self-production) or of describing how a living-being-in-its-environment informs matter/energy and vice versa [26]. In short, 'info-autopoiesis is the process of self-production of self-referenced, interactive, recursive information engaging all living beings in their efforts to satisfy their physiological and/or social needs'.

The image to the left of Figure 2 shows a simulation of an organism embedded in its environment. A more general context for this simulated organism-in-its-environment is that it is representative of any living being, from bacteria to multi-cellular organisms, with appropriate modifications. Two essential connections exist between the organism and the environment. The first, shown directly connected to feedforward and feedback loops, relates to the single sensory element that is the intermediary between the external environment and the internal milieu of the organism. This sensory element is a stand-in for millions of sensory elements that define each sensory organ in the human body. The second connection is the capacity of the organism-in-its-environment to physically impact the environment, either directly or by other means, including our body, tools, and machines in the case of humans. It is represented by an ACTION that results in an ACTION

RESULT to the environment. These two essential and complimentary connections define an asymmetrical relationship between the organism and its environment. The environmental noise that impacts the sensory organs of the organism is not a mirror reflection of the actions of the organism on the environment, though they are not unrelated. The sensory organs (touch, sound, light, smell, taste) are the only window to the environment that allow actions by the organism on the environment to successfully allow for satisfaction of physiological and/or relational needs.

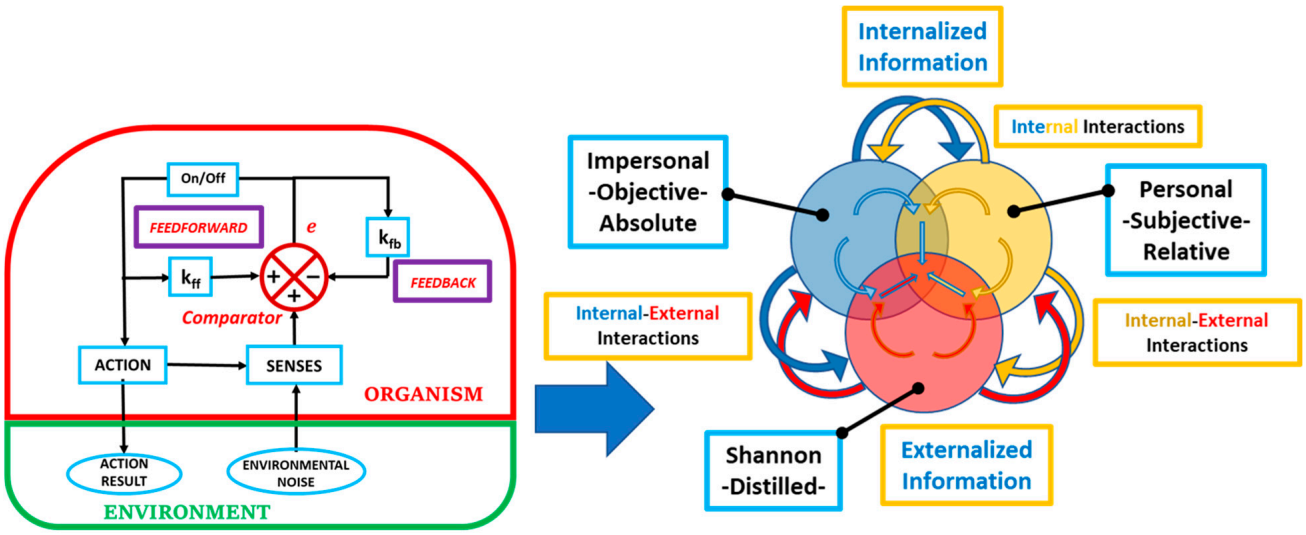

Figure 2. The living-being-in-its-environment and info-autopoiesis.

The direction of the arrow heads in the organism-in-its-environment image on the left side of Figure 2 shows the flow of signals that begin as noise in the environment, transform into information useful to the organism, and end up as an action exerted on the environment. The transduction role of each sensory element changes the physical (touch, sound, light) or chemical signals (smell, taste) of environmental noise to a corresponding electrical signal or action potential. Once inside the organism, the transduced signals are transformed at a Comparator that concentrates the sensory, feedback (ek_{fb}) and feedforward (ek_{ff}) signals to interpret them as information, difference or error (e). The feedback and feedforward factors, k_{fb} and k_{ff}, respectively, are a function of the needs of the organism-in-its-environment. The On/Off switch is a means to control the amplitude of information or error e to elicit an ACTION, only if its value is above a certain threshold [26,33]. It is in this sense that info-autopoiesis governs the self-referenced, recursive and interactive self-production of information by the organism to satisfy physiological and/or social needs. This info-autopoietic process guides the organism-in-its-environment toward finding meaning in its circumstances, due to the association between the spatial/temporal information that is produced and the related circumstances. For example, the organism-in-its-environment has physiological energy demands that need to be met if it is to continue functioning. To that end, it is tuned to cues in the environmental white noise that leads it to recognize those cues, above everything else, to satisfy them. The motivation of the organism is satisfaction of physiological and/or relational needs, not survival per se. What is important for the organism is its concrete, not abstract, reality. This applies to all our senses, individually or in combination, that are geared to detect these cues to recognize useful environmental dynamic invariance [25,34–36].

The image on the right side of Figure 2 shows how the process of info-autopoiesis as a sensing-information-action process results in a triadic relationship involving endogenous (internal) and exogenous (external) information relevant to the organism-in-its-environment. Endogenous components of information are Personal-Subjective-Relative

(PSR-I) and Impersonal-Objective-Absolute (IOA-I) information. Exogeneous components of information are Shannon-Distilled (SD-I) or syntactic information [25,35,37].

The circle identified as embodying Personal-Subjective-Relative information (PSR-I) identifies information considered in the context of the dictionary definition of these words [34,35]. A first-person perspective and a qualitative assessment are also implied by PSR-I. PSR-I is intra-subjective arbitrarily generated information whose motivation originates in the satisfaction of physiological (internal and external) and relational needs, where feelings and emotion play an important role. Physiological and relational needs change with time and the context of specific individuals. Our PSR-I remains exclusive to our internal lives, except when we exteriorize our feelings and/or emotions, in the form of artistic and non-artistic gestures, language, poetry, symbols, etc.

The intra-subjective, interactive organism-in-its-environment is sure to encounter physical objects and other living beings that cause pain/harm in its efforts to satisfy its physiological and/or relational needs. To avoid those environmental hazards, the organism relies on making predictions to sidestep those environmental occurrences. Those predictions might relate to the PSR-I of the organism-in-its-environment, but they might also manifest its experiences of pain/harm and pleasure/help in its interactions with its environment. Repeated pain/harm leads the organism to take notice to realize that it has access, however small, to the beginnings of Impersonal-Objective-Absolute information (IOA-I), similarly considered in the context of the dictionary definition of these words. Moreover, IOA-I implies a third-person perspective and a quantitative assessment [34,35].

The interlacing of the PSR-I and IOA-I circles in the right side of Figure 2 shows the interdependence of IOA-I and PSR-I, though PSR-I is primary. The interlaced and overlapping arrows opposing each other, shown outside the information circles, imply the dependent processing and recursive interactions between these information types where it is easy to lose track of which is primary. Both PSR-I and IOA-I are internal or endogenous, accessible to the organism, though inaccessible to outside scrutiny. The constant interactions of PSR-I with IOA-I allow preferences and beliefs to take center stage and gain access to greater objectivity, avoiding solipsism, in contradiction with Maturana and Varela [38]. Not all PSR-I leads to IOA-I, but the part of IOA-I that is outside of PSR-I may be regarded as potential IOA-I. For example, the realization that interacting with a sharp object may hurt can be expanded to include all sharp objects as having that ability. The human-organism has an interactive and recursive relationship with its environment promoting the dependence of PSR-I on IOA-I, and vice versa.

The intimate relationship between individual PSR-I and IOA-I, both internal to the organism, can only be accessed if an individual is willing to share its contents by external expressions. Such expressions may take the form of language, gestures, pictographs, musical instruments, sculptures, writing, etc. Coding permits the distillation or externalization of PSR-I and IOA-I transforming them into Shannon-Distilled information (SD-I) or externalized (exogenous) syntactic information. This is precisely the process that occurs in composing a message as shown in Figure 1, where SD-I is the basis for this syntactic artificial world which we inhabit. This implies that SD-I is secondary to PSR-I and IOA-I, and that SD-I cannot exist independent of PSR-I and IOA-I. The interlacing of the PSR-I, IOA-I and SD-I circles is to express their dependent connection. Additionally, note the three sets of intersecting and overlapping arrows connecting PSR-I, IOA-I and SD-I, respectively. The intertwined relationships influence the way in which we live and act out our lives so that it becomes difficult to give precedence to any of them.

The arrows inside the information circles showing a triadic relationship display the flow of information toward the region of triadic overlap. This region benefits from the interaction of PSR-I, IOA-I and SD-I. One can but wonder if this is the sweet spot of the highest expressions of human thought and action.

In summary, PSR-I and IOA-I are the internal or endogenous components of information that initially result from an internal meaning-making process of info-autopoiesis leading to semantic information. The externalization of PSR-I and IOA-I results in SD-I or

the external or exogenous expression of information, which can take multifarious forms such as language and all kinds of artifacts that are representative of syntactic information and/or syntactic constructions, which is synonymous with ordered material structure and artificial creation. These human syntactic creations are all around us and make up the artificial world that is the basis of our human comforts.

4. Info-Autopoietic Communication

Figure 3 illustrates a more succinct representation of the info-autopoietic process of transformation of sensory signals to semantic and syntactic information previously shown in Figure 2. Sensory signals are the basis for our interactions with the environment in seeking the satisfaction of our physiological and/or relational needs through a process of info-autopoiesis that enables meaning-making and its externalization in a triadic process involving Personal-Subjective-Relative (PSR-I), Impersonal-Objective-Absolute (IOA-I) and Shannon-Distilled (SD-I) information. It evolves from internalized (endogenous) semantic information to externalized (exogeneous) syntactic information. In this instance of oral communication, the externalized, syntactic information is in the form of sounds.

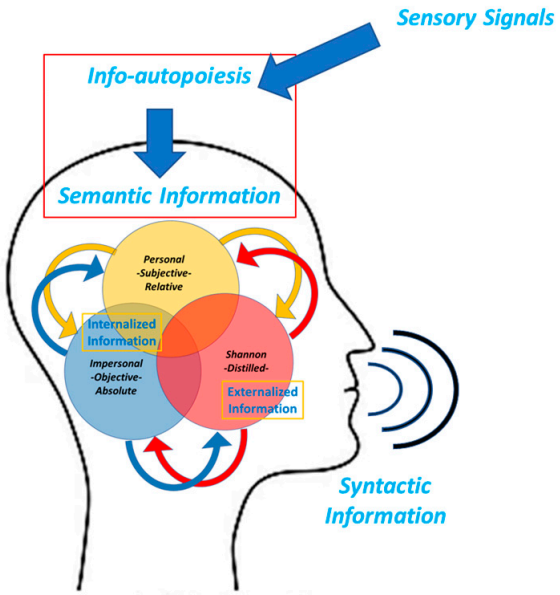

Figure 3. Info-autopoiesis of sensory signals into semantic and syntactic information.

Figure 4 shows a more elaborate and realistic representation of Figure 1 where an info-autopoietic individual Organism 1 on the left side of the figure communicates with a similar individual Organism 2 on the right side of the figure. Organism 2 may be considered just part of the environment for Organism 1, and vice versa. We neglect all other interactions of the organisms with the environment. Each organism is subject to the endogenous and exogeneous triadic info-autopoietic process involving $(PSR\text{-}I)_1$, $(IOA\text{-}I)_1$ and $(SD\text{-}I)_1$ for Organism 1 and $(PSR\text{-}I)_2$, $(IOA\text{-}I)_2$ and $(SD\text{-}I)_2$ for Organism 2. This allows asymmetrical recursive interactions and interactive communication between the organisms. This results in the development of an Intersubjective Space in a Shared Universe between the organisms due to an exchange of (SD-I), shown clearly in the upper center of Figure 3 by the designated intersection between the two circles designated as $(SD\text{-}I)_1$ and $(SD\text{-}I)_2$. It is only by the exchange of syntactical information that these two organisms can interact and communicate. In this asymmetric exchange the syntactical information needs to be interpreted by everyone to communicate effectively.

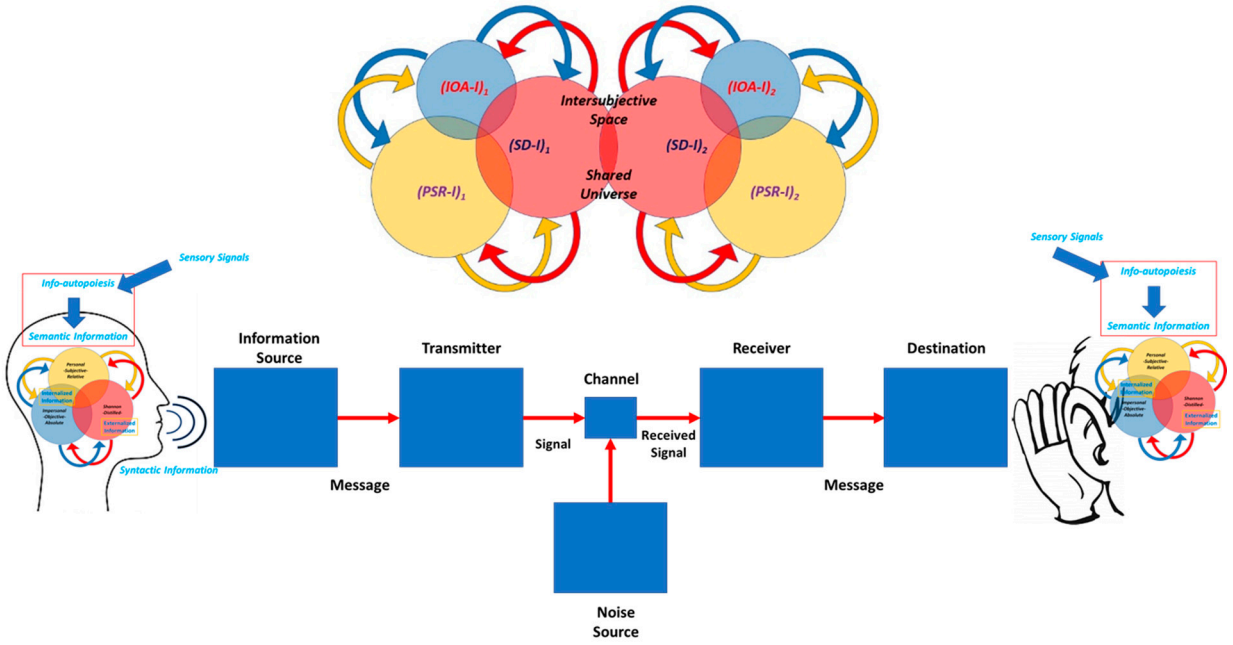

Figure 4. Info-autopoietic communication: sensory signals transform into semantic and syntactic information.

In summary, living beings are at the center of all information recognition, extraction, creation, transmission, preservation, storage, and utilization. What began as sensory signals became PSR-I, evolved to IOA-I, and are externalized as SD-I, in a transformation process from endogenous semantic information to exogenous syntactic information. This process led to corporal signs, language, pictographs, sculptures, music, writing and digitization as expressions of exogenous information. In this technological progression in the generation of exogenous syntactic information, the centrality of human beings has been obscured and mystified. The role of Figure 3 is to summarize the process of info-autopoiesis as a process of the triadic transformation of the sensory experience of a living-being-in-its-environment into information or 'a difference which makes a difference,' by producing internal and external information. Internal information takes the form of semantic information. External syntactic information is synonymous with artificial creation with its inherent limitations for semantic expression.

5. The Central Dogma of Information

The process of info-autopoiesis shows that living beings are the creators of all existing information in a reciprocal and interactive process of informing and being informed by nature. Differences/information take the form of internalized (endogenous) and externalized (exogenous) information. Endogenous information exists internal to the human body, in our central nervous system, in the form of preferred pathways where synaptic changes in organization are brought about by our sensory and activity experiences as the result of sensorial information and ideation. Allowing for the manipulation of differences/information in the human brain and the development of a rich internal life involving Personal-Subjective-Relative (PSR-I) and Impersonal-Objective-Absolute (IOA-I) information as semantic information. Shannon/Distilled (SD-I) or exogenous syntactic information results from the unavoidable interaction of the human organism with its environment to satisfy its physiological and social needs. From our earliest origins, we have info-autopoietically evolved to more complex exchanges with other human beings, leading to human communication and language development. Eventually, info-autopoietic activity accelerates and refines the life-long process of producing PSR-I, IOA-I and SD-I to further the development of the intersubjective spaces between humans. With exogenous information expressed as gestures, pictographs, wall paintings, stone artefacts, sculptures,

musical instruments, etc., etc. Cultural traditions are passed down from generation to generation using orality as a storehouse of cultural traditions and knowledge.

The next momentous step in SD-I production is the development of writing and writing tools. The development of writing begins with the practical need for more permanent accounting practices in Mesopotamia in the fourth millennium BC, evolving from simple pictographs towards more structured signs representing word sounds. This was followed by the creation of the printing press in the 15th century, leading to the propagation of manuscripts at lowered cost. The quasi-permanence of print media limits the re-use of its content. The discovery of electromagnetism and the electromagnetic spectrum in the 19th century brought about the next revolution in SD-I creation. The reproduction of the human voice and its broadcasting through the ether by analogic means was possible. However, it is only with the advent of the need to improve the efficiency, precision and reach of oral and written communication that digital information and communications technologies gained impetus. Shannon promoted the connection between Boolean algebra and electronic circuits [39]. This development and others were the key to the digital revolution and bringing about the information age [40–42], leading to the ultimate conversion of SD-I into binary digits, or bits, capable of being processed in electronic digital systems. Enabling the storage, processing, and transformation of exogenous information from the heads of its authors into machines; machines that are our companions in their different incarnations. Digital information is akin to any other physical object which can be manipulated and transformed using technologies designed by humans.

Throughout this technological evolution, multiple informing technologies have been created. We have evolved from attempts to control our environment to that of attempting to control our inner selves. Many times, we have failed to control our developments such as fire, deforestation, hunting, energy sources, nuclear energy, farming, etc. We currently find ourselves facing the COVID-19 pandemic amid a growing global warming crisis. This shows that information establishes and shapes our institutions and their influence in our societies which are at the same time and interactively impact us. The pervasiveness of the digitalization process in our societies, over which we have lost control, is due to this unavoidable mutual interaction. Digitalization is just one more technology that creates the challenge of controlling its proliferation and impact, with its unparalleled capacity to encourage exponential growth as we artificially inform our environment [43–45]. This effect is easily identifiable, especially since the middle of the 20th century, in metrics such as the power of computation per constant dollar, the number of transistors per unit area, Moore's law of integrated circuits, the number of wireless bits per unit time, the cost of bit transmission, the cost of sequencing the genome, 3D printing, the speed of development of mRNA vaccines, and many other examples. It is an element that is now pervasive in our societies, that accelerates the process of societal processes and change. It is difficult to predict when it will end.

In summary, living beings are at the center of all information creation, recognition, extraction, transmission, preservation, storage, and utilization. What begins as PSR-I evolves to IOA-I and SD-I, in a transformation from endogenous to exogenous information. This progression toward generation of exogenous information encompasses many technological wonders that expand our sensorial capabilities beyond what our five primary senses allow. Yes, the process of info-autopoiesis is a powerful force for externalization of information by humans. However, a somber limitation of these capabilities is that it is based on syntactic creation. Information gets out from all living beings as syntactic creation, from its origin as semantic information. Once externalized, all syntactic creations can only be internalized again as sensory signals that again go through a process of info-autopoiesis or generation of PSR-I, IOA-I and SD-I. This means that these syntactic creations can never be internalized again in the form of semantic and/or syntactic information, either by its creator or by self-similar beings. For this reason, it is possible to formulate the central dogma of information which states that 'info-autopoiesis results in endogenous semantic information that irreversibly becomes exogeneous syntactic information'. The intent here is to draw

a parallel to the central dogma of molecular biology [46] which deals with the transfer of sequential information, and states that "once (sequential) information has passed into protein it cannot get out again" [46].

We would like to show that both dogmas share the commonality of syntactic information needing to get out to influence their environment. A more careful examination of both might yield other commonalities of endogenous processes that evolve into exogeneous processes. A major implication of the central dogma of information is that does not allow for artificial creations with capabilities for meaning-making, suggesting that our dreams for sentient artificial general intelligence and beyond are misguided.

6. Revisiting the Central Dogma of Biological Sciences

Figure 5 is a reproduction of a manuscript by Francis Crick [47] in which the central dogma of molecular biology is first revealed. It is an attempt by Crick to encapsulate the state of knowledge about DNA in a simple diagram, and to express it as "Once information has got into a protein it can't get out again," where the "arrows show the transfer of information." Crick is referring to information as "the sequence of the amino acid residues, or other sequences related to it." This view of information seems more in accord with Shannon (1948) than with the view of Bateson of information as 'a difference which makes a difference' [23].

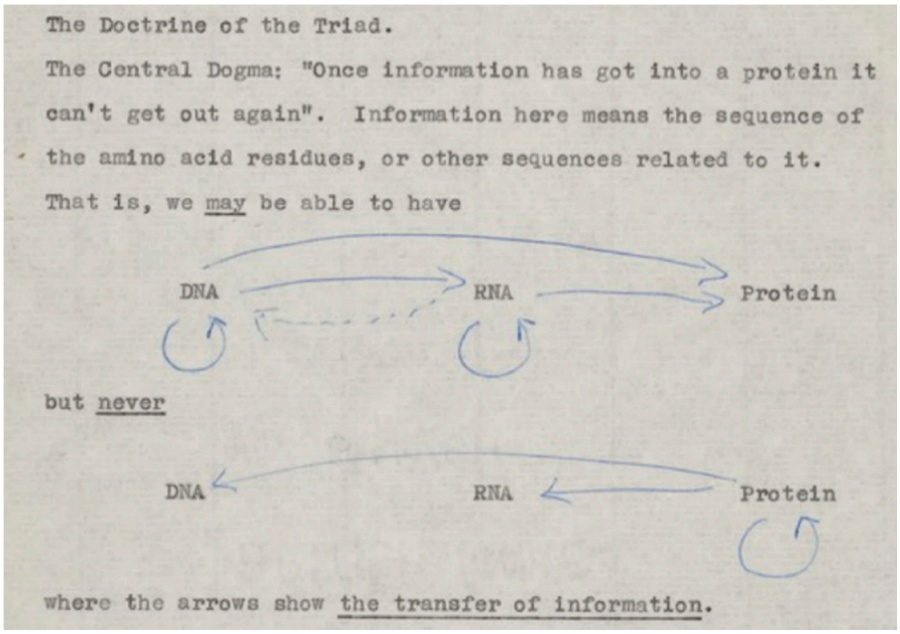

Figure 5. The central dogma of molecular biology [47].

In 1970, Crick again reaffirmed the importance of the central dogma of molecular biology [46]. The central dogma of molecular biology relates to the transfer of information within a prokaryote cell. Figure 6a parallels the top drawing of Figure 5 and makes clear the various flows of information that are possible:

- Three general transfers (DNA Replication, Transcription and Translation)
- Three special transfers (RNA Replication, Reverse Transcription and Direct Synthesis)

Notice that Reverse Transcription is shown both in Figures 5 and 6a as tentative, as reflected by the discontinuous line arrow, but was later found to occur [48–50].

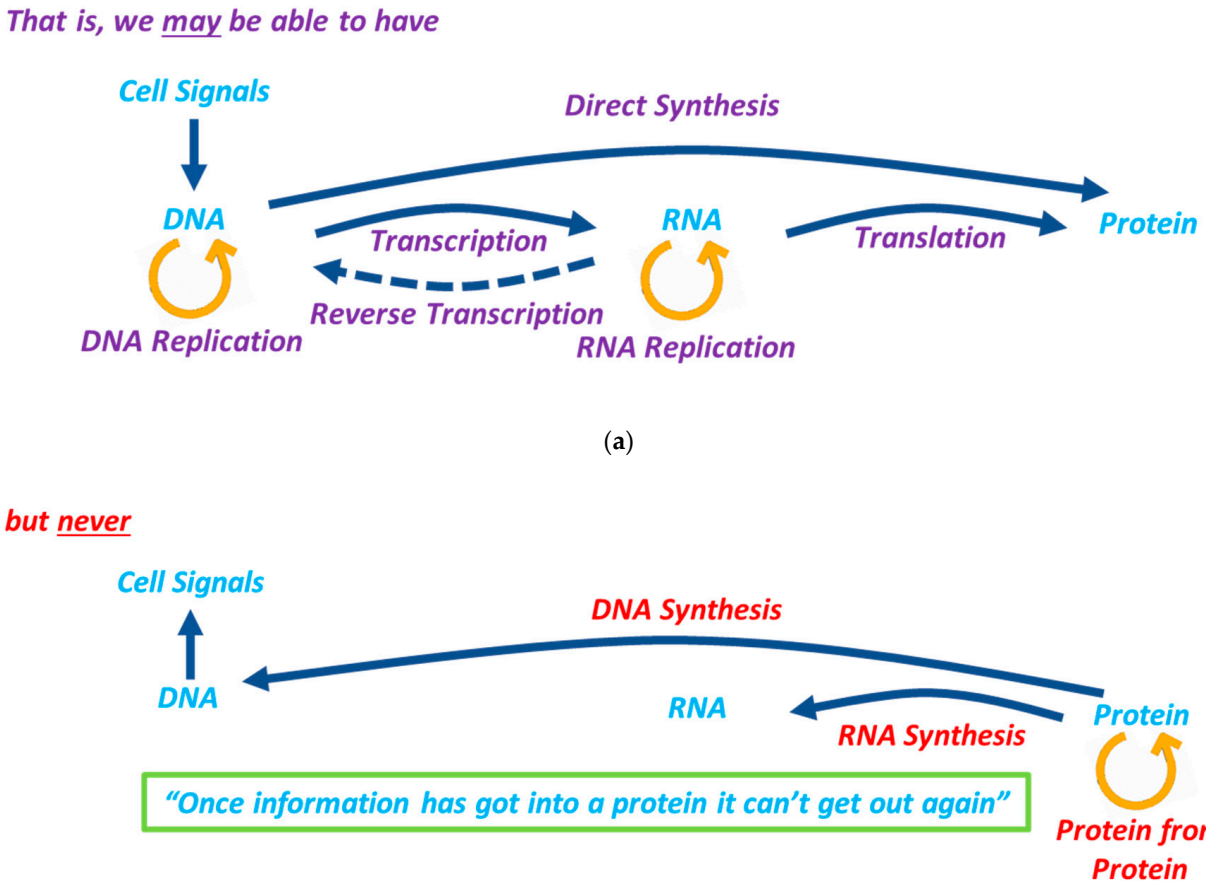

Figure 6. The central dogma of molecular biology: (**a**) The possible in genomic flow of information; (**b**) The impossible in genomic flow of information.

Figure 6b parallels the bottom drawing of Figure 5 to show the flows of information that are not possible:

- Three unknown transfers (Protein from Protein, RNA Synthesis and DNA Synthesis)

Figure 6b is really an illustration of the central dogma of molecular biology, i.e., "Once information has got into a protein it can't get out again."

The use of the wording of 'Central Dogma' used by Crick is unfortunate, since it initiated a long polemic discussed by Cobb [51] stating,

> "In one aspect of the central dogma, Crick was mistaken. In reality, the 'Central Dogma' was anything but a dogma. Crick later claimed that he had not properly understood the meaning of 'dogma'—Jacques Monod had to explain to him exactly what it meant. An indication of the truth of this assertion can be seen in the lecture when he states that the name that he has coined emphasizes the speculative nature of the idea—a dogma is not speculative. As Crick later acknowledged, a more accurate description would have been 'basic assumption' [17]. This does not sound quite so sexy, but it would have removed a lot of subsequent misunderstanding. Perhaps if Crick had not used such a dramatic turn of phrase, many subsequent critics would not have become so exercised about the question."

Whatever the motivation of Crick, it certainly helped to focus the discussion on the transfer of information within the cell. In the end, it seems that if emphasis is placed on

what is not possible instead of what is possible, Crick's assertion is correct. To that effect Crick [44] states,

> "On the other hand, the discovery of just one type of present day cell which could carry out any of the three unknown transfers would shake the whole intellectual basis of molecular biology, and it is for this reason that the central dogma is as important today as when it was first proposed."

One detail shown in Figure 6a,b that is not part of the hand-drawn sketches in Figure 5 is the added 'Cell Signals" label which is representative of the ability of a cell to receive, process, and transmit signals from its environment and within itself [50]. Cell signals may be considered as the environmental effects that influence the transfer of information in the cell. This aspect is more pertinent to the discussion below that deals with a comparison between the two central dogmas of information and molecular biology.

An important discussion of the central dogma of molecular biology is that by Hoffmeyer [52], bringing forth a biosemiotic perspective with which this paper is in alignment. Not only does it go into a historical recount of how semiosis fits into the explanation of many seemingly disparate issues, but also how it fits in relation to living things, and incorporates a 'Peirce inspired semiotic analysis of natural processes'.

Hoffmeyer does do an excellent job at clarifying and putting into context Crick's Central Dogma of Molecular Biology and in identifying a different approach to the role of DNA, RNA and proteins. Specifically, Hoffmeyer states [52] (p. 7),

> "In a Peircean perspective there is nothing that 'flows' from DNA to RNA to protein. Instead what goes on is semiosis, i.e., the organized cellular system interprets the digitally coded messages in the chromosomes according to the changing contexts in which the cell or the organism finds itself."

The rejection of Crick's central dogma and digitalism takes center stage as Hoffmeyer rejects the limited thinking of modern scientists. Info-autopoiesis, while not using a semiosis explanation, does view self-production of information as a central feature of DNA that allows the cell or an organism to pursue satisfaction of physiological and/or relational needs, as explained below.

7. Comparison between Info-Autopoiesis and Genomic Flow of Information

Figure 7 shows side by side simplified diagrams of info-autopoiesis in a human being and the genomic flow of information in a prokaryote. What is clear in both instances is that the human being and the cell are in continuous interaction with their environment. The human being responds to 'Sensory Signals' that allow info-autopoiesis to govern its actions in its environment in pursuit of satisfaction of its physiological and/or relational needs. In a similar way, the cell responds to 'Cell Signals' that direct the genomic flow of information to best respond to the environment also in pursuit of satisfaction of its physiological and/or relational needs.

In the case of the human being, info-autopoiesis governs the self-production and flow of information starting from 'Sensory Signals'. The Central Nervous System is an organ that allows the processing of electrical signals (info-autopoiesis) for meaning-making (semantic information) so that the human body can engage in syntactic information generation that allows for its continued renewal. In other words, internally the human being produces semantic information which guides its expression through actions that externalize syntactic information and mold matter to satisfy its physiological and/or relational needs.

Similarly, the prokaryotic cell is subjected to 'Cell Signals' of many kinds that guide its response and actions in the environment. The cell genome (DNA) may be considered as a biochemical organ for meaning-making (semantic information) internal to the cell nucleus that results in the production of proteins (syntactic information) external to the cell nucleus. In other words, DNA allows syntactic information generation in the form of proteins so that the cell acts on the environment in pursuit of satisfying its physiological and/or relational needs. This also means that there is not information in DNA per se, thus

no 'genomic flow of information'. Rather, the genomic functions that exist perform the self-production of semantic information internal to the cell nucleus, from which syntactic information is externalized.

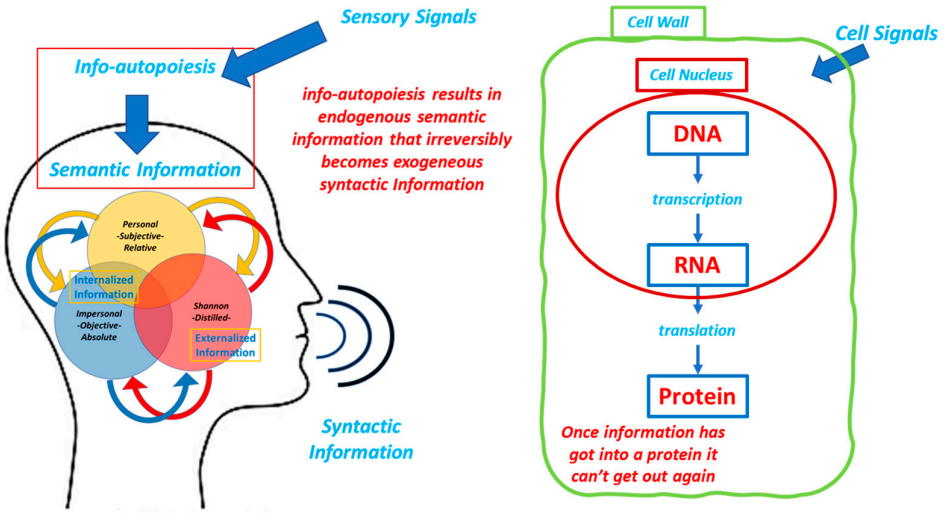

Figure 7. A comparison between info-autopoiesis and genomic flow of information.

This perspective allows the reconciliation of the self-production of information of both a human being and a prokaryotic cell from the perspective of Bateson's 'difference which makes a difference'. To illustrate this, Figure 8 shows a parallel portrayal of the central dogma of information to that of the central dogma of molecular biology in Figure 6. Previously, the central dogma of information was stated as 'info-autopoiesis results in endogenous semantic information that irreversibly becomes exogeneous syntactic information'. Now, to word it in a parallel fashion as the central dogma of molecular biology it is phrased as 'once semantic information has got into syntactic information it can't get out again'.

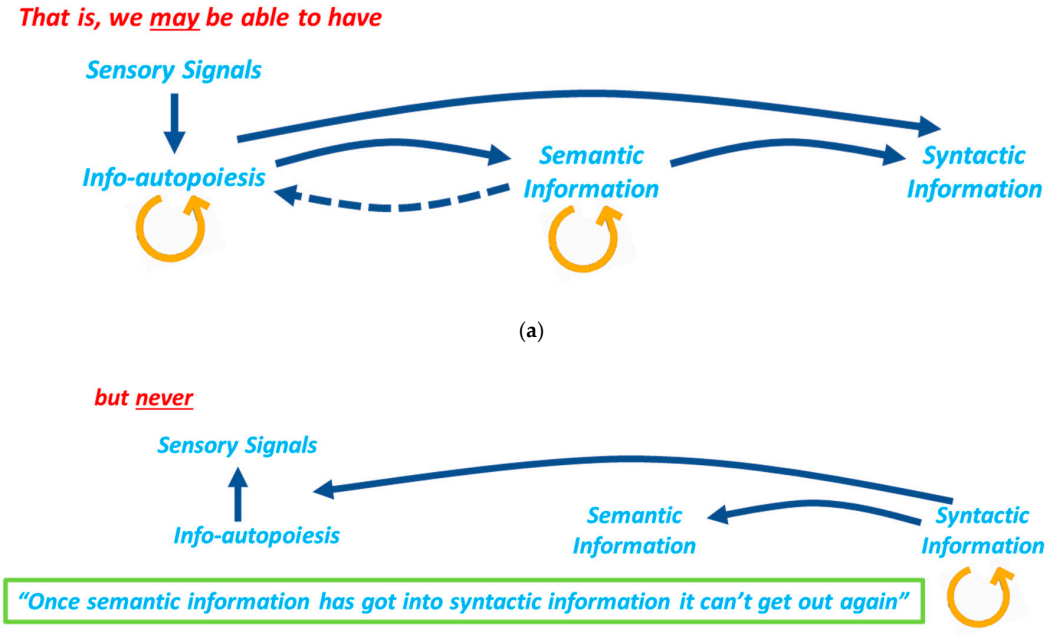

Figure 8. The central dogma of information: (**a**) The possible in the flow of information; (**b**) The impossible in the flow of information.

Comparing Figure 6a to Figure 8a we find the following parallel relationships:

Cell Signals ↔ Sensory Signals: which permit the organism to establish a means of access to the environment with the potential to understand the environment through repetition and recursion. It is only through these signals that the respective organism can interact with the environment.

DNA ↔ Info-autopoiesis: which requires interpreting DNA as a biochemical organ for meaning-making (of transcription of DNA into semantic information as mRNA) internal to the cell nucleus; and info-autopoiesis as the self-referenced, recursive, interactive process of transcription or rearrangement of electrical signals in the Central Nervous System (CNS) for meaning-making (into semantic information).

RNA ↔ Semantic Information: RNA embodies the result of meaning-making by DNA; and Semantic Information is the result of the info-autopoietic process.

Protein ↔ Syntactic Information: RNA translates into Proteins outside of the cell nucleus; and Semantic Information translates into Syntactic Information outside of the human organism.

The essence of both the central dogma of molecular biology and the central dogma of information lies in a comparing Figure 6b to Figure 8b. In each instance we need to recognize that there are three unknown transfers that can never occur: For the prokaryotic cell: Protein from Protein, RNA Synthesis and DNA Synthesis; for the human being: Syntactic Information from Syntactic Information, Semantic Information from Syntactic Information, Info-autopoiesis from Syntactic Information. It is a time-tested fact that the three unknown transfers strictly hold for the central dogma of molecular biology. As to the three unknown transfers for the central dogma of information a cursory review shows that they hold as well, after gaining a clear understanding of info-autopoiesis. A cautionary note is that if only one instance is found that contradicts this, the central dogma of information falls apart.

Let us briefly examine each of the three unknown transfers associated with the central dogma of information to at least gain some understanding of their validity:

Syntactic Information from Syntactic Information—let us consider a written text in digital form as an example of syntactic information. We might then ask, can this piece of written text act on its own to create a different piece of written text? The same thing can be asked of any human artifact, whatever its nature and the result is that it is as inactive as when it was created. Some might wonder whether artificial intelligence (AI) might fall outside of this sphere of artifacts since much has been done in the field of AI. AI relies mainly on computations performed by a computer that depend on software. The software and computer used are syntactic human products. They can only act because of human actions. Neither can act on its own. Whether a cursory or a deep dive is carried out to explore this issue, the result will be the same: it is not possible for syntactic information to generate other syntactic information, except by the action of a human.

Semantic Information from Syntactic Information—The generation of semantic information from syntactic information is another impossibility. Looking again at the example of generated written text, what we find is that when another human looks at the written text, she will need to interpret it to generate semantic information. Additionally, each different individual that looks at it might find different semantic meaning. This is the lesson learned from Shannon (1948) and the mathematical theory of communication.

Info-autopoiesis from Syntactic Information—This is another instance where once syntactic information is generated the only access that humans have to it is through our senses. Using our sensory organs, we gain cognition of it so that we can interpret the syntactic information in front of us and give it meaning through info-autopoiesis. The result is that we can never gain access to syntactic information directly by info-autopoiesis.

In short, this comparison of the central dogma of molecular biology and the central dogma of information shows many common features. The main common feature is that both a prokaryotic cell and a human are living organisms-in-their-environment that must satisfy their physiological and/or relational needs to prosper. The cell and the human

exhibit an ability to process 'cell signals' and 'sensory signals,' respectively. In the case of the cell, DNA takes care of biochemical processing these signals (transcription) in the nucleus to produce semantic information in the form of mRNA, which through translation outside the nucleus produces syntactic information in the form of proteins. Or 'Once information has got into a protein it can't get out again'. In the case of a human, sensory signals are info-autopoietically processed in the central nervous system to endogenously produce semantic information which on externalization becomes exogeneous syntactic information. Or similarly, 'once semantic information has got into syntactic information it can't get out again'.

8. Summary and Discussion

The etymological origins of 'information' express its dual nature as human actions capable of informing matter and/or other living beings by interactively shaping their form and thinking/behavior through communication, respectively. In a similar way, Bateson's dynamic way of looking at the world as 'a difference which makes a difference' [23] implies a process of cybernetic human actions engaging every instant of our lives. Thus, Bateson's dictum on information is fully compatible with its etymological origin. Information is fundamental in the dynamic interpretation of reality by humans. This allows, in their embodied sensing-information-action interactions with their environment, the discovery of the non-living and the living.

A critical review of Shannon's theory of communication shows that humans communicate by the externalization of syntactic information in the form of oral or written communication. The query that needs an answer is whether semantic information is the basis of syntactic information and the origin of semantic information. What is true is that behind the 'information source' is a person, where the semantic information originates, since that person wants to communicate with another person. Info-autopoiesis, or the self-referenced, recursive, interactive process of information self-production that engages all living beings in their efforts to satisfy their physiological and/or relational needs, provides an explanation for the origin of semantic information as well as syntactic information. Based on Bateson's difference which makes a difference, it allows the discovery not only that information is not an absolute quantity, but rather a derived quantity, useful to living beings, from the sensorially detected motion of matter and/or energy in the Universe. All living beings have this unique capability of detecting spatial/temporal differences or information that allows its use to derive meaning as active manipulators/observers of their environment. For the human-organism, the process of info-autopoiesis is found to be triadic in nature and incorporates the simultaneity of a quantitative/objective perspective with a qualitative/subjective perspective. This requires the endogenous interaction of Impersonal/Objective/Absolute Information and Personal/Subjective/Relative Information, which results in exogeneous Shannon/Distilled Information. In engaging with its environment, the human-organism develops from a state in which its knowledge of the human-organism-in-its-environment is almost non-existent to a state in which the human-organism not only recognizes the existence of the environment but also sees itself as part of the human-organism-in-its-environment system. This allows a human-organism not only to self-referentially and meaningfully connect with the environment and traverse through it, but to even alter it in its own image and likeness [25,26].

Meaning making (semantic information) is endogenous (internal) to the communicating individual, while exogeneous (outward) expressions can only occur as syntactic information. Syntactic information is synonymous with ordered structure and artificial creation and can take multifarious forms, from speech and writing to the most complex machines and impacts on the environment. The result is the artificial world that currently exists due to the development of digitalization of matter/energy resulting in exponential growth and increasing loss of control of our artificial world. This leads to the postulate of the central dogma of information that states 'info-autopoiesis results in endogenous semantic information that irreversibly becomes exogeneous syntactic information'.

The central dogma of information plays an important role in delimiting the reach of info-autopoiesis, by pointing out that the externalization of information by living beings is limited to syntactic information. This realization limits the reach of humans into the realm of what is possible for them to create. Recent groundbreaking work in synthetic biology [53,54] where " synthetic multicellular assemblies can also replicate kinematically by moving and compressing dissociated cells in their environment into functional self-copies" may seem to contradict this dictum. However, as a work of synthetic biology, after initial human syntactic intervention, it relies on yet unknown elements that allow spontaneous replication to occur but on terms that the newly created synthetic organisms control as info-autopoietic beings. Additionally, though there is no mention in this paper of the role that information plays in the life of single cells, it cannot be otherwise. It is widely known that cell signaling [55] from external and internal sources are an integral part of cell life. While it can be stated that info-autopoiesis is an integral part of the life of a cell, it is postulated that the central dogma of information is equally applicable.

In revisiting the central dogma of molecular biology, it is possible to find many parallel relationships with the central dogma of information: between cell signals and sensory signals, DNA and info-autopoiesis, RNA and semantic information, and protein and syntactic information. It also is possible to affirm the unknown transfer in the central dogma of molecular biology as 'once information has got into a protein it can't get out again,' and the central dogma of information similarly as 'once semantic information has got into syntactic information it can't get out again'.

All these findings have a common and fundamental basis, i.e., that information does not exist in the environment; rather, information is self-produced by living beings through sensorial interactions with the environment motivated by the need to satisfy physiological and/or relational needs. Info-autopoiesis results in endogenous, semantic information, which becomes exogeneous, syntactic information, which is synonymous with ordered structure and artificial creation. Syntactic information does not have the capacity for meaning-making, whatever its configuration. For example, all our basic sciences, including physics, chemistry, biology and mathematics are syntactic constructions, hence science cannot encompass life. Similarly, arguments that we inhabit a Universe that is a simulation [56] based on computations are demonstrably false, since computations can only be syntactic even if performed by imagined unknown superbeings. Hence, semantic creations are not possible as we are endogenously semantic beings. Comparably, sentient artificial general intelligence or superintelligence [57] is not achievable either since it is dependent on syntactic computations by syntactic machines. As noted above, the notion of meaning-making is beyond the capabilities of any machine, no matter how sophisticated.

9. Conclusions

In conclusion, info-autopoiesis or the self-referenced, recursive, interactive process of information self-production that engages all living beings in their efforts to satisfy their physiological and/or relational needs is a powerful way to look at living beings in general, from a single cell to multicellular beings. Leading us to postulate the 'central dogma of Information' that states 'info-autopoiesis results in endogenous semantic information that irreversibly becomes exogeneous syntactic information', which when compared to the wording of the 'central dogma of molecular biology' may be more succinctly stated as 'once semantic information has got into syntactic information it can't get out again'.

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References

1. Capurro, R.; Fleissner, P.; Hofkirchner, W. Is a unified theory of information feasible? A trialogue. *Inform. Forum* **1997**, *1*, 36–45. [CrossRef]
2. Capurro, R.; Hjørland, B. The concept of information. *Annu. Rev. Inf. Sci. Technol.* **2003**, *37*, 343–411. [CrossRef]
3. Capurro, R. Past, present, and future of the concept of information. *TripleC Commun. Capital. Crit.* **2009**, *7*, 125–141. [CrossRef]
4. Hofkirchner, W. Chapter 1: The Dawn of a Science of Information. In *Emergent Information—A Unified Theory of Information Framework*; Hofkirchner, W., Ed.; World Scientific Publishing Co. Pte. Ltd.: Singapore, 2013; pp. 3–34.
5. Pattee, H.H. Epistemic, Evolutionary, and Physical Conditions for Biological Information. *Biosemiotics* **2013**, *6*, 9–31. [CrossRef]
6. Hofkirchner, W. Emergent Information. *When a Difference Makes a Difference . . . TripleC Commun. Capital. Crit.* **2013**, *11*, 6–12.
7. Hofkirchner, W. How to achieve a unified theory of information. *TripleC Commun. Capital. Crit.* **2009**, *7*, 357–368. [CrossRef]
8. Logan, R.K. What Is Information?: Why Is It Relativistic and What Is Its Relationship to Materiality, Meaning and Organization. *Information* **2012**, *3*, 68–91. [CrossRef]
9. Gleick, J. *The Information—A History, A Theory, A Flood*; Pantheon Books, Division of Random House, Inc.: New York, NY, USA, 2011.
10. Wiener, N. *Cybernetics: Or Control and Communication in the Animal and the Machine*; John Wiley: New York, NY, USA, 1948.
11. Wheeler, J.A. Sakharov revisited: "It from Bit". In Proceedings of the First International A D Sakharov Memorial Conference on Physics, Moscow, Russia, 21–31 May 1991; Nova Science Publishers: Commack, NY, USA, 1992.
12. Stonier, T. *Information and Meaning—An Evolutionary Perspective*; Springer: Berlin/Heidelberg, Germany, 1997.
13. Yockey, H.P. *Information Theory, Evolution, and the Origin of Life*; Cambridge University press: Cambridge, UK, 2005.
14. Lloyd, S. *Programming the Universe*; Alfred A. Knopf: New York, NY, USA, 2006.
15. Umpleby, S.A. Physical Relationships among Matter, Energy and Information. *Syst. Res. Behav. Sci.* **2007**, *24*, 369–372. [CrossRef]
16. Burgin, M. *Theory of Information—Fundamentality, Diversity and Unification*; World Scientific Series in Information Studies; World Scientific Publishing Co. Pte. Ltd: Singapore, 2010; Volume 1.
17. Floridi, L. *Information: A Very Short Introduction*; Oxford University Press: Oxford, UK, 2010.
18. Vedral, V. *Decoding Reality—The Universe as Quantum Information*; Oxford University Press: Oxford, UK, 2010.
19. Hidalgo, C.A. *Why Information Grows: The Evolution of Order, from Atoms to Economies*; Basic Books: New York, NY, USA, 2015; 232p.
20. Bynum, T.W. Flourishing Ethics. *Ethics Inf. Technol.* **2006**, *8*, 157–173. [CrossRef]
21. Díaz Nafría, J.M. What is information? A multidimensional concern. *TripleC Commun. Capital. Crit.* **2010**, *8*, 77–108. [CrossRef]
22. Peters, J.D. Information: Notes toward a Critical History. *J. Commun. Inq.* **1988**, *12*, 9–23. [CrossRef]
23. Bateson, G. *Steps to an Ecology of Mind: Collected Essays in Anthropology, Psychiatry, Evolution, and Epistemology*; Chandler Publications for Health Sciences; Ballantine Books: New York, NY, USA, 1978; Volume 28, 545p.
24. Deacon, T.W. Emergence: The Hole at the Wheel's Hub. In *The Re-Emergence of Emergence: The Emergentist Hypothesis from Science to Religion*; Clayton, P., Davies, P., Eds.; Oxford University Press: Oxford, UK, 2008; pp. 111–150.
25. Cárdenas-García, J.F.; Ireland, T. The Fundamental Problem of the Science of Information. *Biosemiotics* **2019**, *12*, 213–244. [CrossRef]
26. Cárdenas-García, J.F. The Process of Info-Autopoiesis—The Source of all Information. *Biosemiotics* **2020**, *13*, 199–221. [CrossRef]
27. Maturana, H.; Varela, F. *Autopoiesis and Cognition—The Realization of the Living*; D. Reidel Publishing Company: Dordrecht, The Netherlands, 1980.
28. Varela, F.J. Describing the logic of the Living. The Adequacy and Limitations of the Idea of Autopoiesis. In *Autopoiesis: A Theory of Living Organization*; Zeleny, M., Ed.; Elsevier North Holland: New York, NY, USA, 1981; pp. 36–48.
29. Shannon, C.E. A Mathematical Theory of Communication. *Bell Syst. Tech. J.* **1948**, *27*, 379–423. [CrossRef]
30. MacKay, D.M. *Information, Mechanism and Meaning*; MIT Press: Cambridge, MA, USA, 1969.
31. Dretske, F.I. *Knowledge and the Flow of Information*; The MIT Press: Cambridge, MA, USA, 1981.
32. Floridi, L. *The Philosophy of Information*; Oxford University Press: Oxford, UK, 2011; Volume 18, 405p.
33. Burgin, M.; Cárdenas-García, J.F. A Dialogue Concerning the Essence and Role of Information in the World System. *Information* **2020**, *11*, 406. [CrossRef]
34. Cárdenas-García, J.F. Distributed Cognition: An Ectoderm-Centric Perspective. *Biosemiotics* **2013**, *6*, 337–350. [CrossRef]
35. Cárdenas-García, J.F.; Ireland, T. Human Distributed Cognition from an Organism-in-its-Environment Perspective. *Biosemiotics* **2017**, *10*, 265–278. [CrossRef]
36. Cárdenas-García, J.F.; Castro, D.R.; Soria de Mesa, B. Object Discernment by "A Difference Which Makes a Difference". *Biosemiotics* **2018**, *11*, 27–40. [CrossRef]
37. Cárdenas-García, J.F. Information Ethics in the Information Age. *Cosm. Hist. J. Nat. Soc. Philos.* **2018**, *14*, 147–166.
38. Maturana, H.; Varela, F.J. *The Tree of Knowledge: The Biological Roots of Human Understanding*; Shambhala Publications, Inc.: Boston, MA, USA, 1987.
39. Shannon, C.E. A Symbolic Analysis of Relay and Switching Circuits. *Trans. Am. Inst. Electr. Eng.* **1938**, *57*, 713–723. [CrossRef]
40. Castells, M. *Communication Power*; Oxford University Press Inc.: New York, NY, USA, 2009.

41. Turing, A.M. On Computable Numbers, with an Application to the Entscheidungsproblem. *Proc. Lond. Math. Soc.* **1937**, *s2-42*, 230–265. [CrossRef]
42. Turing, A.M. Computing Machinery and Intelligence. *Mind* **1950**, *59*, 433–460. [CrossRef]
43. Kurzweil, R. *How to Create a Mind: The Secret of Human Thought Revealed*; Viking: New York, NY, USA, 2012; 336p.
44. Ali, A. From Amazon to Zoom: What Happens in an Internet Minute in 2021. Technology 2021. Available online: https://www.visualcapitalist.com/from-amazon-to-zoom-what-happens-in-an-internet-minute-in-2021/ (accessed on 23 November 2021).
45. Thilmany, J. 5 Industries Where Big Data Brings Big Returns. Topics and Resources 2021 11/15/2021. Available online: https://www.asme.org/topics-resources/content/big-data-brings-big-returns (accessed on 23 November 2021).
46. Crick, F. Central dogma of molecular biology. *Nature* **1970**, *227*, 561–563. [CrossRef] [PubMed]
47. Crick, F. Ideas on Protein Synthesis—Part of Francis Crick (1916–2004): Archives, in PP/CRI/H/2/6. 1956. Available online: https://wellcomecollection.org/works/xmscu3g4 (accessed on 23 November 2021).
48. Baltimore, D. Viral RNA-dependent DNA Polymerase: RNA-dependent DNA Polymerase in Virions of RNA Tumour Viruses. *Nature* **1970**, *226*, 1209–1211. [CrossRef] [PubMed]
49. Temin, H.M.; Mizutani, S. Viral RNA-dependent DNA Polymerase: RNA-dependent DNA Polymerase in Virions of Rous Sarcoma Virus. *Nature* **1970**, *226*, 1211–1213. [CrossRef] [PubMed]
50. Central Dogma Reversed. *Nature* **1970**, *226*, 1198–1199. [CrossRef] [PubMed]
51. Cobb, M. 60 years ago, Francis Crick changed the logic of biology. *PLoS Biol.* **2017**, *15*, e2003243. [CrossRef]
52. Hoffmeyer, J. The central dogma: A joke that became real. *Semiotica* **2002**, *138*, 1–13. [CrossRef]
53. Ebrahimkhani, M.R.; Levin, M. Synthetic living machines: A new window on life. *iScience* **2021**, *24*, 102505. [CrossRef]
54. Kriegman, S.; Blackiston, D.; Levin, M.; Bongard, J. Kinematic self-replication in reconfigurable organisms. *Proc. Natl. Acad. Sci. USA* **2021**, *118*, e2112672118. [CrossRef]
55. Alberts, B.; Hopkin, K.; Johnson, A.; Morgan, D.; Raff, M.; Roberts, K.; Walter, P. *Essential Cell Biology*, 5th ed.; W. W. Norton & Company, Inc.: New York, NY, USA, 2019.
56. Bostrom, N. Are We Living in a Computer Simulation? *Philos. Q.* **2003**, *53*, 243–255. [CrossRef]
57. Bostrom, N. *Superintelligence: Paths, Dangers, Strategies*; Oxford University Press, Inc.: Oxford, UK, 2014.