

Editorial

## Biosemiotic Entropy: Concluding the Series

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**Abstract:** This article concludes the special issue on *Biosemiotic Entropy* looking toward the future on the basis of current and prior results. It highlights certain aspects of the series, concerning factors that damage and degenerate biosignaling systems. As in ordinary linguistic discourse, well-formedness (coherence) in biological signaling systems depends on valid representations correctly construed: a series of proofs are presented and generalized to all meaningful sign systems. The proofs show why infants must (as empirical evidence shows they do) proceed through a strict sequence of formal steps in acquiring any language. Classical and contemporary conceptions of entropy and information are deployed showing why factors that interfere with coherence in biological signaling systems are necessary and sufficient causes of disorders, diseases, and mortality. Known sources of such formal degeneracy in living organisms (here termed, *biosemiotic entropy*) include: (a) toxicants, (b) pathogens; (c) excessive exposures to radiant energy and/or sufficiently powerful electromagnetic fields; (d) traumatic injuries; and (e) interactions between the foregoing factors. Just as Jaynes proved that irreversible changes invariably increase entropy, the theory of true narrative representations (TNR theory) demonstrates that factors disrupting the well-formedness (coherence) of valid representations, all else being held equal, must increase *biosemiotic entropy*—the kind impacting biosignaling systems.

**Keywords:** agreement condensation; biological signaling systems; biocontrol systems; biosemiotic entropy; Bose-Einstein condensation; cancers; encephalopathies; fit-get-rich network theory; information theory; pathogens; pragmatic information; synergistic effects; true narrative representations (TNRs)

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## 1. Background and Introduction to the Central Thesis

This is the closing entry for the special issue on *Biosemiotic Entropy* [1]. It looks toward the future on the basis of theory and known factors that tend to increase *biosemitic entropy* by disrupting biosignaling systems. This twelfth paper of the series highlights critical definitions and explains the theory serving as a ground for the preceding papers and certain spin-offs. It points to salient empirical findings, and gives a telescopic abstract rather than a detailed summary of the entries. Interested readers can get more details from published abstracts and from the entire articles of the series that are all freely accessible. Each one was written and published as if it were an independent contribution to the general stream under the *Entropy* banner though each paper is plainly marked as an item in the special issue on *Biosemiotic Entropy*. Also, each one addressed the special problem posed for the series: contributors were asked for an argument (preferably with experimental evidence) “pro, con, or offering any alternative to the idea that corrupted biological messages account for (but, of course, are not limited to) anaphylaxis, preeclampsia, sudden death syndrome, immune disorders, autism, and so forth” [1]. Here are some snapshot highlights of each element in the series in the order in which they were published.

Davidson and Seneff led off by examining “sudden death syndrome” [2]. They showed how fouling biological communication systems can produce a cascade of problems leading to catastrophic system failures. Entry two, by Hartzell and Seneff [3], presented empirical evidence that impaired sulfate metabolism is a probable causal factor in autism. The third article, by Dietert and Dietert [4], took a developmental, cross-generational approach showing how misregulated inflammation owed to corruption of epigenetic programming, immunotoxicity, and insufficient incorporation of commensal microbes from fetal development forward can account for chronic diseases downstream.

Entries four and five, by Seneff, Davidson, and Liu [5,6], examined aluminum and acetaminophen exposures as contributing factors in autism spectrum disorders. They generalized cholesterol sulfate deficiency as a causal factor, not only in autism, but also in precipitating preeclampsia and pernicious anemia. Entry six, by Seneff, Lauritzen, Davidson, and Lentz-Marino [7], showed how endothelial nitric oxide synthase, with the help of sunlight, is probably involved in manufacturing cholesterol sulfate. They broke new ground in showing how disruption of colloidal suspension and capillary flow for want of sunlight-based or dietary sulfur is virtually certain to contribute to diabetes, cardiovascular, and other degenerative disease conditions.

In number seven, Gryder, Nelson, and Shepherd ([8]; also see [9], a spin-off not in the special issue) explained how the healthy state of cells “rooted in genomics, strictly orchestrated by epigenetic regulation, and maintained by DNA repair mechanisms” can be disrupted at multiple levels. Corruption of genetic messages by substitution, deletion, insertion, or fusion is known to cause epigenetic misregulation that can lead to malignancies. The authors capsulized the hope that “the biosemitic framework” may enable “more effective explanatory hypotheses for cancer diagnosis” consequently leading to better profiling and therapy. Entry eight, by Seneff, Lauritzen, Davidson, and Lentz-Marino [10] explored ways the encephalopathies falling under the “autism” label may be compensatory reactions to paucity of sulfate caused in part by environmental toxins, lack of sunlight, and insufficient dietary sulfur.

In item nine, Samsel and Seneff [11] examined theoretical and experimental evidence for the suppression of cytochrome P450 and amino acid biosynthesis by a ubiquitous environmental glycoposphate toxicant. They showed how the biosemiotic noise created by the widespread use of such a toxicant can contribute to a host of disparate conditions such as infertility, cancer, and Alzheimer's. In item ten, Kosoy [12] expanded the theme of interactions across communities not only of microbes but also the hosts to infectious parasites, microbes, and pathogens. Like the Dieterts, Kosoy argues for molecular, genomic, organismic, population, and ecological contexts of interaction.

In entry eleven, Mae-Wan Ho [13] argues that Crick's "central dogma" [14] by which DNA rigidly controls RNA outputs, which in turn fully control proteins, is over-stated. She argues, on the basis of research since the 1970s, that genetic modification in real time enables a dynamic and fluid interplay between RNA and DNA. For this reason, she contends that it is necessary to take account of epigenetic interactions. She argues that artificial genetic modifications must drive the natural systems toward increased biosemiotic entropy—which, as is explained below, at a maximum is tantamount to the death of organisms in shallow time and even extinction in a few generations in an extended temporal perspective.

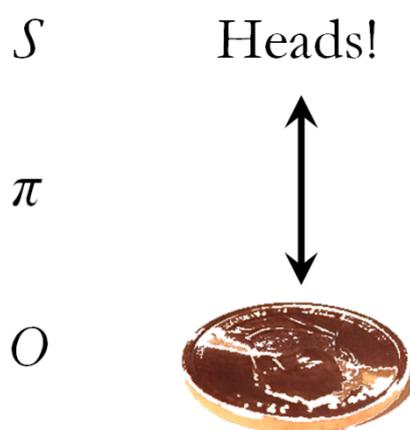
While it is true that physics has often attained a higher level of rigor in its theories and predictions than have so far been attained in biology, in this paper an obvious exception to that generalization is discussed. The tendency for biosemiotic entropy (to be defined more explicitly below) to lead to disorders, diseases, and ultimately to death applies, so far as is known in the sciences, to all living organisms [15]. It is the purpose of this paper to show why this result flows necessarily from the nature of what contributors to this special issue have called *biosemiotic entropy*. At any rate, the prediction of universal mortality is certain and inviolable at the organismic level, and for reasons spelled out in contributions by Davidson and Seneff [2], the Dieterts [4], Gryder *et al.* [8], Samsel and Seneff [11], and Ho [13], it appears that irreversible *biosemiotic entropy* in the human genome is on an accelerating course toward mortality on a grander scale.

## 2. A Little Background

The idea for this series on *Biosemiotic Entropy* began with a paper for an earlier special issue edited by Søren Brier [16] that focused on "the antithesis of entropy" [17]. Later, the positive term *pragmatic information* [18], the gold-standard of linguistic *content* (*i.e.*, *meaning* in its most concrete and ordinary sense) which is the kind found in true narrative representations (TNRs) [18–24], was proposed. A TNR is simply a faithful report of a sequence of actual events experienced by one or more competent observers. Examples in the sciences would include all valid reports of experiments that are interpretable and replicable, precisely up to the level of their interpretability and replicability. An intriguingly relevant and complex experimental report presumably qualifying as a TNR is the widely read, much cited, and celebrated production of a Bose-Einstein condensate of rubidium atoms by Eric Cornell and colleagues in 1995 [25,26]. In ordinary experience, to use a simpler and extremely familiar example, reducing the elements of a TNR to the critical formal elements that all of them must possess, suppose that a coin toss results in the coin landing with the HEADS side up—where the capital letters merely suggest reference to the HEADS side of the physical coin itself rather than whatever words might be used to report the physical outcome of the coin toss. If the person judging the toss reports, "Heads!" when the coin lands, and, in fact, the coin has landed with its HEADS side up rather than its TAILS side up, the

representation is a TNR. For all possible TNRs, whether as complex as the report of the achievement of the Bose-Einstein condensation by Cornell and colleagues, or as simple as the truthful report of the result of a coin toss (Figure 1), on a purely formal basis must involve a coherent fit between a string of symbols,  $S$  (broadly construed as one or more words in one or more languages, a text of any length, a sequence of pictures, diagrams, or any meaningful string whatsoever in any language or language-like system of representations), an intelligible pragmatic (actual) mapping relation,  $\pi$ , that connects the string,  $S$ , systematically to its actual fact(s) set in a sequence of real events designated as the object,  $O$ , of the TNR. Let the string,  $S\pi O$  represent the formal relations underlying every such TNR as shown in Figure 1.

**Figure 1.** Illustration of the formal components of every TNR.



Such a dynamic system of relations, has certain unique logical properties that make TNRs the gold standard for fixing the meanings of abstract conventional language systems (English, Chinese, *etc.*) and also of all meaningful sign systems in general (including biosignaling systems). Three completely general propositions can be proved: One or more TNRs are the only source for the *relative* (i) *determinacy* of any fact or sequence of facts—meaning the discovery of what those facts are; (ii) *connectedness* between any known facts of experience; and (iii) *generalizability* of the particular content of any abstract representations whatsoever. The qualifier “*relative*” simply means that the *determinacy*, *connectedness*, and *generalizability* of any given TNR<sub>*i*</sub> must be strictly contained within the relational system expressed in its  $S\pi O$  relation. To prove the foregoing propositions some groundwork must be laid with a series of proofs pertaining to the essential concepts at issue. Following C. S. Peirce’s “exact logic” [27], the method introduces no concepts or distinctions without first proving their necessity.

Peirce described some of the results of applying such a method as follows: “The first things I found out were that all mathematical reasoning is diagrammatic and that all necessary reasoning is mathematical reasoning, no matter how simple it may be. By diagrammatic reasoning, I mean reasoning which constructs a diagram according to a precept expressed in general terms, performs experiments upon this diagram, notes their results, assures itself that similar experiments performed upon any diagram constructed according to the same precept would have the same results, and expresses this in general terms. This was a discovery of no little importance, showing, as it does, that all knowledge without exception comes from observation” ([28] pp. 47–48). Peirce also insisted, contrary to Whitehead and Russell ([29]; also see [30]), that it did not seem to him that “mathematics depends in

any way upon logic” although “logic cannot possibly attain the solution of its problems without great use of mathematics. Indeed, all formal logic is merely mathematics applied to logic” ([31], volume 4, paragraph 228). The distinctness of Peirce’s approach to formal (mathematical) logic consisted in his logic of relatives [32], as elaborated somewhat by Tarski [33,34], where Peirce proved that even the most abstract signs can only attain meanings through relations with known facts. It is true as one reviewer suggested that sometimes it is possible to simply “stipulate” meanings for certain terms such as *entropy*, but even that reviewer acknowledged that it is essential to “defend” such stipulations. According to Peirce, and given results to be presented in this paper, the basis for any such defense, must ultimately come down to connecting our thinking, no matter how abstract it may be, back to the ordinary world of experience in which we observe and take note of known facts. Peirce expressed the central premise of his general theory of signs, or *semiotics* in these words in a brief paper he titled “The Fixation of Belief”:

*“The object of reasoning is to find out, from the consideration of what we already know, something else which we do not know. Consequently, reasoning is good if it be such as to give a true conclusion from true premises, and not otherwise. Thus, the question of its validity is purely one of fact and not of thinking”* [35] (pp. 2–3).

Following Peirce’s method of diagrammatic construction, proving the propositions concerning the *determinacy*, *connectedness*, and *generalizability* of TNRs, proceeds by Euclid’s classical method of construction (anticipating by centuries the diagrammatic method of reasoning described by Peirce). It was by construction that Euclid both proved the existence and unique properties of equilateral triangles [36]. That kind of diagrammatic construction, it may be argued, is augmented by Peirce’s proofs of the law of the excluded middle [37] in mathematical logic. To begin with, we prove that TNRs exist. This is accomplished by constructing an argument to deny their existence: it must take a form where the objecting party says something like, “I deny that any TNRs exist.” But supposing only that the denial involves an intelligible reference to the OBJECTOR (the physical person raising the objection), through a well-formed  $S\pi O$  relation, which the objection must do if we are to understand the pronoun “I” as referring to the OBJECTOR in the manner of the diagram in Figure 1, it comes out that every such denial itself contains a TNR; therefore, all such denials are self-refuting. Thus, by Peirce’s law of the excluded middle (if the denial of proposition  $x$  is necessarily false, then  $x$  is necessarily true), the existence of TNRs is proved.

Next, we note that every TNR can be modified, by construction, enabling the production of one or more fictions from it. All that is required to construct a fiction from a TNR is to degenerate some part of the known factual component,  $O$ , of that TNR to an imaginary rather than a real material status. Using the example TNR in Figure 1, if a person flips a coin that turns up HEADS and that result is reported truthfully, the one-word utterance, “Heads!” can serve to convey the outcome. But, for any such TNR, it is possible to imagine any number of hypothetical possibilities which we will term *fictions* that are less complete (less well-formed) than the initial ( $S\pi O$ ); but in which all the elements excepting the fictionalized part are, by the nature of the construction, kept the same. Keeping all else equal will be referred to as the *ceteris paribus* constraint.

Returning to the coin toss which actually came up HEADS, consider derived fictions: keeping all else the same, we could imagine that the coin toss came up TAILS, or that the coin never reached a

zenith and continued rising into outer space on the toss, or that it was magically transformed into a space ship which all the persons present in a huge stadium promptly boarded and escaped from earth to the planet Xenon, *etc.*, *ad infinitum*. But to construct any such fiction, the constraining truth-relation between the elements  $S\pi O$  must be relaxed so that the  $O$  (or some part of it) onto which the  $S$  is mapped as in Figure 1, in the fiction is no longer present in the real material world of the coin, the person tossing it, the physical forces that constrain the toss, and so forth. To show the relaxation of the constraints on the TNR, let  $\underline{O}$  (written with an underline to suggest a blank to be filled by the imagination of the interpreter/producer of the fiction) be regarded as a non-existent hypothetical element,  $\underline{O}$ , that must be supplied not by any actual fact but by the constructive imagination of one or more users of the known string of symbols,  $S$ , enabling the construction of the fictional  $\underline{O}$ . Now, let  $S\pi\underline{O}$  represent the formal description of every such fiction where the underlining merely calls attention to the fact that all or some part of the object in question must be supplied by the producer and/or interpreter(s) of the fiction.

Parenthetically, it must be noted here that in constructing any such a fiction from a given TNR, the only source for the legitimacy of the fictional part of the sign relation that is constructed—that is, the  $\underline{O}$ —is whatever meaning(s) may be conventionally associated with the particular  $(S\pi\underline{\quad})_i$  that purports to express the fictionalized part of the  $O$  in the initial system of relations in  $(S\pi O)_i$ . If the conventional meanings of the  $S$  in any fiction should be relaxed, so that any  $\underline{O}$  in the universe of possible candidates might be used to fill the blank, the fictional expression would become completely empty of any particular meaning. It would be uninterpretable. A strict proof of this claim will be given below, but for now, let it be noted that for any given fictional  $\underline{O}$ , the capacity of sign-users to conjure it up (to imagine it) depends entirely on whatever combination of signs may be used to represent it. Setting that fact aside momentarily, it is already clear that any given well-formed  $(S\pi O)_i$  can be experimentally degenerated to a fiction by blanking out the actual  $O$ , as in  $(S\pi\underline{\quad})_i$  where it remains for the producer/interpreter of the fiction to supply the missing  $O$ —that is, to conjure the fictional part of the sign system  $(S\pi\underline{O})_i$ . For every such constructed fiction, the fictional part makes the whole necessarily less complete than the corresponding TNR from which it is derived. Absolutely any *real argument* (in the logical and grammatical sense of the term *argument*—that is, taking the term *argument* to mean an entity, in this case a material one, that could be or is perceived and that can be pointed out in some way), or any real property, action, or event involving such an argument, can be degenerated to derive a fiction from a given TNR. To illustrate, in Figure 1 the main arguments that could be degenerated by construction include the coin, the person tossing it, the physical context of the coin toss, and so forth. If any argument (or relation between arguments) is real in the manner required by a given  $(S\pi O)_i$  relation that is a TNR, the argument(s) must be extended in time and space linking it (or them) to events leading up to the coin toss (say, a football game), the events leading away from it (the outcome of the game), the nature of the coin enabling it to be tossed, the capacities of the coin-tosser making the toss possible, and so on and so forth, all are drawn into play in the real world of any TNR.

It follows that a degenerative construction of a fiction from any given TNR produces several invariable results. The most important is that whatever element is fictionalized is no longer supported by a real fact in the  $\underline{O}$  part of the former TNR. For another, in order to construct the  $S$  representing the fictional  $\underline{O}$ , to preclude the fiction being presented and taken as a TNR, the length of the  $S$  string must be increased (perhaps in words, by a facial expression, by intonation, or by some combination of

surface forms in the  $S$  part of the  $TNR_i$ ) to show that the  $\underline{Q}$  (or some aspect of it) is to be taken as fictional. As a result it follows for all possible fictional constructions that might be derived from any  $TNR_i$  that we might select from the whole universe of TNRs, all else being held equal (that is, provided the process of construction conforms to the *ceteris paribus* constraint), the fiction must always be physically less complete than the  $TNR_i$  from which that fiction is constructed. Thus, inequality (1) is certain to hold for every such fictional construction, and by such construction, the following inequality is proved:

$$(S\pi O)_i > (S\pi \underline{Q})_i \quad (1)$$

where the symbol “>” is taken to mean “is more well-formed than”.

Next, suppose any given fictional  $(S\pi \underline{Q})_i$  is mistaken for a TNR. We can always construct such an error from any given  $(S\pi \underline{Q})_i$  by degenerating it further to a form where the  $S\pi \underline{Q}$  mapping contains the error of supposing that some fictional element is physically real. For instance, suppose it is claimed (or thought) that the coin toss has turned up TAILS when in fact, HEADS was the actual result. The error, by construction, provided the *ceteris paribus* constraint is maintained in the constructive process, is always going to be less well-formed than the formal system underlying the corresponding fiction from which the error is derived. Let the string,  $(\mathcal{S}\pi \underline{\mathcal{Q}})_i$  represent any such degenerate instance constructed from a TNR where the slashes on both  $S$  and  $\underline{Q}$  indicate that both parts of the error need to be replaced in order to convert it all the way back to a fully coherent and well-formed TNR. In the example taken from the coin toss, if the mistaken  $\mathcal{S}$  at hand, “Tails!” is not the one needed (that is, because the actual toss came up HEADS and not TAILS), it also comes out that the actual result of the coin toss is not the fictional one falsely believed to be TAILS, but which is HEADS. The actual  $O$ , is HEADS and not the fictional  $\underline{Q}$ , which is mistaken for TAILS,  $\underline{\mathcal{Q}}$ . Thus, to construct such an error from a given fiction, respecting the *ceteris paribus* constraint, there are two elements that must be physically degenerated. By the same token to get all the way back to a completed  $S\pi O$  relation both those degenerated elements in the error,  $(\mathcal{S}\pi \underline{\mathcal{Q}})_i$ , must be changed. In the degenerated construction, to show by notation that the fictional object,  $\underline{Q}$ , is mistaken for a fact in the error, we add the slash,  $\underline{\mathcal{Q}}$ . By construction, then, inequality (1) can be expanded as shown in inequality (2), in which the added inequality, and the sequential order of the series is also proved *ceteris paribus* for any such construction:

$$(S\pi O)_i > (S\pi \underline{Q})_i > (\mathcal{S}\pi \underline{\mathcal{Q}})_i \quad (2)$$

Further, we prove by the same methods of construction that a deliberate deception derived from an error, must result in a further degeneracy such that the  $\pi$  element in the string is also corrupted. For any given error designated as  $(\mathcal{S}\pi \underline{\mathcal{Q}})_i$ , it must always be possible by construction to create a still more degenerate lie,  $(\mathcal{S}\cancel{\pi} \underline{\mathcal{Q}})_i$ . The strikethrough on  $\pi$  indicates that the mapping relation in the lie is also corrupted, and, we know that for every lie, this additional corruption is deliberate. As a result, we can further expand the series of inequalities in (2) including the one at the right just proved for inequality (3):

$$(S\pi O)_i > (S\pi \underline{Q})_i > (\mathcal{S}\pi \underline{\mathcal{Q}})_i > (\mathcal{S}\cancel{\pi} \underline{\mathcal{Q}})_i \quad (3)$$

In actual experience, of course (as an anonymous reviewer commented on a prior draft), a lie cannot succeed unless it resembles a TNR. But that, though true, is beside the point. The derivation of any lie by construction from the error that it represents as a TNR shows that the *ceteris paribus* constraint can be met while constructing the lie which will always be less well-formed than any error, fiction, or

TNR, from which it may be constructed in the manner described for inequality (3). Therefore, inequality (3) is proved.

But a still greater degeneracy (in the sense of diminished well-formedness) can be produced by scrambling the components of the surface form of the  $S$  in any lie. We can extract the  $S_i$  from any of the relations in inequality (3), keeping all else equal by construction except for the scrambling or other physical degeneration of the  $S_i$  (by adding noise, for example), the  $S_i$  can be converted into unintelligible nonsense. This construction can be done by degrees where the starting  $S_i$  is always the same but the resulting derivations become less and less intelligible as they approximate that vague limit where the string can no longer be recognized as a string of symbols in any language-like system at all [18]. Let all such nonsensical strings, ones that are not intelligible with respect to any particular fact(s) or fiction(s), but that remain recognizable as a string of symbols resembling those of some language, be represented as  $\underline{S}_i$ . Then, by construction, on account of the fact that any intelligible  $\pi$ -mapping onto any particular  $O$  according to the conventions of the language underlying the string is obscured by the deliberate corruption of the particular  $\underline{S}_i$  in question, given the *ceteris paribus* constraint observed in its construction,  $\underline{S}_i$  must always be less well-formed than the predecessor from which it has been constructed. Any such  $\underline{S}_i$  merits the notational underlining by virtue of its having been fictionalized, and the strikethrough because it has also been further corrupted deliberately so as to make it even less intelligible than any lie. The underlying  $S_i$  is retained, however, to show that the initial symbol string,  $S_i$ , resembles the strings of whatever language from which it has been derived. Otherwise, failing to resemble any such language or language-like string altogether,  $\underline{S}_i$  would devolve to a random physical ensemble of chaotic elements, but not a string of symbols of any particular recognizable kind. However, by construction, we can always leave the corrupted  $\underline{S}_i$  short of complete chaos so that the resulting string is at least recognizable as approximating a string in the system from which it was constructed. An example, might be, “!tilas” (a scrambled version of the word “Tails!”) having been derived from the lie that a coin toss of HEADS has actually resulted in TAILS. Any such form,  $\underline{S}_i$ , in any of the relations to the left of the last inequality of (4), therefore, must be better formed than  $\underline{S}_i$  and the next to last inequality in (4) is proved. Also, if the degeneracy of  $\underline{S}_i$  is maximized so the underlying  $S_i$  can no longer be associated with any language system whatsoever, the last inequality of the series, where all vestiges of  $S_i$  are fully removed from the physical ensemble and the result is designated as  $\_i$ , is also proved by construction:

$$(S\pi O)_{i>} > (S\pi \underline{O})_{i>} > (\underline{S}\pi \underline{O})_{i>} > (\underline{S}\pi \underline{O})_{i>} > \underline{S}_i > \_i \quad (4)$$

Given the foregoing, we can prove that for any given TNR<sub>*i*</sub>, written  $(S\pi O)_{i>}$ , which may be drawn from the unbounded universe of TNRs, to the extent that all else is held equal, as in the constructions underlying the inequalities of (4), there cannot be any representational relation, other than a different TNR, that is more perfect relative to the facts that  $(S\pi O)_{i>}$  embraces than  $(S\pi O)_{i>}$  itself. Again applying Peirce’s law of the excluded middle [37], suppose a shorter or more efficient relation, or a longer more explicit one, call either of these  $(S\pi O)_e$  can be constructed. In every such case, if the successive constructions from  $(S\pi O)_{i>}$  are compared against  $(S\pi O)_e$ , the inequalities need not hold because the *ceteris paribus* condition is violated in any such comparison by the greater or lesser efficiency of  $(S\pi O)_e$ . However, all of the inequalities, for all possible comparisons are restored if the more explicit (or more efficient, and it does not matter which direction we go) starting point,  $(S\pi O)_e$  is merely

retained throughout the construction from start to finish throughout the series shown in inequalities (4). That is, if the initial element is  $(S\pi O)_e$ , and if the *ceteris paribus* condition is maintained in constructing the rest of the series of (4), all of the inequalities must hold for the same reasons as already established in prior proofs. Therefore, for all possible comparisons of the sort spelled out in (4), the inequalities must hold and the case generalizes to all possible TNRs without exception: thus, provided only that the *ceteris paribus* condition is met, absolutely any and all possible TNRs that might occupy the position of  $(S\pi O)_i$  at the extreme left-hand side of (4) are necessarily at a limit of well-formedness and the nonsense strings at the right hand side—namely,  $\underline{S}$ —are the nearest of any sign relations in the series to the limit of complete undecipherability designated as  $\underline{i}$ . Again applying Peirce's law, if all meaningful signs excepting  $\underline{i}$  have some decipherable relation to purported facts (perhaps completely fictional and even impossible ones; or only the facts accounting for in the meaningless but physically identifiable surface forms of a given string,  $S$ —e.g., the letters, phonemes, phonetic features, strokes in a writing system, amino acids from some protein, isolated bases from a sequence of base pairs in DNA, or atoms of some deconstructed polymer, and so forth), it follows that if there are any supposed signs having no decipherable connection to any purported facts, they cannot be meaningful signs. Therefore, the universe of all possible meaningful signs must be contained within the limits of the sign relations specified by the inequalities of (4): the limit at the high end of well-formedness (fully decipherable meaningfulness) consists in the class of TNRs and complete chaos at the opposite extreme consists in nonsense strings degenerated to the point that the symbols are no longer recognizable as symbols of any particular kind.

Now, with the foregoing proofs in hand, we can prove the general propositions stated above concerning *determinacy*, *connectedness*, and *generalizability*. To illustrate the empirical validity of the proof of each of those propositions, it is possible to refer to a rigid series of steps universally followed in a predictable sequence, both by individuals and by groups of age cohorts, in child language development. The series of steps to be pointed out can be amplified with respect to detail, but the research literature in child development from the prenatal period through birth and on toward maturity never, so far as is known, violates the empirical sequence that can be derived in a straightforward manner from the inequalities of (4). However, it is only to render the proof, which will follow below, easy to understand, that the proof will first be illustrated through the major milestones of child language development. The milestones follow a pattern that is perfectly predicted and explained by the series of inequalities in (4). Details are spelled out in other publications [38,39], so only highlights need to be given here. From the start, the first major  $S\pi O$  mappings attained by children in language development always involve and depend on TNRs.

Almost immediately after birth, by seeing mom's moving articulators as she speaks while mom is holding the baby close enough for the baby to both hear the voice and see the face, the voice, serving as a peculiarly familiar  $S$  is  $\pi$ -mapped to her face, a heretofore unknown  $O$ . All this occurs within a few minutes after birth as mom holds and talks to the baby. Sai [40] showed in 2005 that babies deprived of the necessary TNRs (mother speaking while the baby sees mother moving her articulators in perfect coordination with the rhythms of her speech) cannot recognize mother's face until and unless the needed TNRs are provided. Within about six months, the normally developing baby will become able to demonstrate comprehension of various TNRs supplied by someone else in the native language (mother's language) that the child is acquiring [41]. That is, the child will be able to understand quite a

few names and action words spoken by someone else in the presence of the person or thing named or the action performed. In each such case, the TNR consists of the  $S$  (some word or phrase)  $\pi$ -mapped onto its respective  $O$ . By about 12 months the child will be able to produce an intelligible “first word” consisting of an approximation to the same sort of TNRs the infant has previously understood from the productions of more mature sign-users who already know the language the child is in the process of comprehending and producing [42].

Next we can prove that the inequalities of (4) already show explicitly why the child must begin with TNRs in language development: from the infant’s point of view, it is easy to appreciate the fact that a fictional reference as in  $(S_u\pi\_)_i$  where the baby is called on to imagine the missing  $O$  on the basis of an as yet unknown  $S_u$  cannot work as a basis for initializing the meaning of the unknown  $S_u$  because the only basis for filling in the blank is prior knowledge of the meaning of  $S_u$ . But, the baby has no such prior knowledge of the meaning of  $S_u$  because that  $S$  has not yet been deciphered by the child. Thus, for the baby who is trying to figure out the meaning of  $S_u$ , the missing imaginary fictional element is of no use at all and the  $O$  of  $S_u$  in the fictional  $(S_u\pi\_)_i$  cannot be supplied on the basis of the unknown meaning of  $S_u$ . Adults can appreciate the difficulty of the infant when presented with a completely unfamiliar word in an unknown foreign language. If, by contrast holding all else equal,  $S_u$  is accompanied by a TNR where the  $O$  of the  $(S_u\pi O)_i$  sign relation is present to be examined, then the physical manifestation of the material content of  $S_u$  can be abstracted from the  $O$ . However, the fact that the nature of the  $O$  cannot be abstracted from a fictional  $(S_u\pi O)_i$  relation transitively carries over to the rest of the series in (4). That is, it follows that if a fictional representation cannot supply the meaning of an  $S_u$  much less can an error  $(S_u\pi Q)_i$  or a lie  $(S_u\pi Q)_i$  or a nonsensical string made from the same unknown  $S_u$  to get  $\underline{S}_u$ . Thus, it is proved that it is impossible to initialize the first meaningful  $S_u$  in an unknown language by relying on a fiction, error, lie, or string of nonsense constructed from that same  $S_u$ . The proof is formally consolidated for all possible cases by noting that if a learner should luckily stumble (by a happy accident) to the correct  $O$  from any of the degenerate (less well-formed) sign relations in (4), the confirmation that the meaning had correctly been understood and/or applied would have to come in the form of one or more TNRs taking the form  $(S_u\pi O)_i$  followed by  $(S_u\pi O)_{i+1}$  and so forth, until the confirmation of the mapping as valid, assumes the form  $(S\pi O)_n$ , where  $n$  is the number of repetitions of the TNR mapping necessary to enable the learner’s discovery of the meaning of the former  $S_u$ .

As a result of the former proofs, always keeping in play the *ceteris paribus* rule, several empirically testable inferences about language acquisition follow: (a) that the solving of the meanings of one or more TNRs absolutely must occur before any fictions (of the same level of complexity, abstractness, etc.) can be comprehended or produced; (b) that some fictions must logically be comprehended before any errors (*ceteris paribus*) can be explained by the child; (c) that some errors must be understood before (*ceteris paribus*) lies can be differentiated from them by the child; and, (d) the strangeness and difficulty of producing (deciphering, remembering, etc.) a truly random sequence of symbols from any of the foregoing (*ceteris paribus*) in any language, by any language-user whatsoever, is also accounted for. In fact, as already shown, research on child language acquisition strictly confirms the implicit order of the inequalities in (4). The proof just concluded in the immediately preceding paragraph already shows why a fiction, cannot provide an adequate basis for initializing meanings in an unknown language, as is confirmed by empirical evidence [22]. Language development studies confirm that TNRs

come first in child language acquisition and are followed in about a year by fictions [38–43]. Then, the ability to construct explanations of errors linguistically comes a year or more later than fictional uses of language sometime between the ages of 4 and 5 years for most children [44], and the capacity to explain the difference between an error and a lie is developed later still usually between the ages of 6 to 8 years [45]. Thus, the developmental sequence implicit in the inequalities of (4) is empirically demonstrated as valid in normal child language development.

With all the foregoing in hand, only a few more steps are needed to prove that for all possible meaningful representations falling between the extremes to the left and right sides of the inequalities of (4), only TNRs are *relatively well-determined* in the material world with respect to the conventional meanings of their representational strings,  $S$ . The relative *determinacy* of TNRs is dependent, as we saw with respect to the problem of initiating the meaning of any unknown  $S_u$ , on the association of that  $S_u$  through some  $\pi$ -mapping with some known object,  $O_i$ . However, provided only that the *ceteris paribus* constraint is held in place, it follows that absolutely no fiction, error, lie, or string of nonsense can be as well-determined as the TNR(s) from which it (or they) may be derived. Similarly, only TNRs are *relatively well-connected* to the world of experience as represented by TNRs. From the foregoing proofs, it already is evident that failing to achieve the relative determinacy of TNRs with respect to material content (given that the *ceteris paribus* constraint is imposed), fictions, errors, lies, and nonsense, respectively, also fail with respect to getting themselves connected to the material world. Therefore, insofar as (and just exactly to the extent that) the world of experience is connected in its own parts, only TNRs have what has been called *connectedness*. They have this formal property only insofar as they are actually established relative to the material world, but they absolutely have it in greater abundance than any constructed fiction, error, lie, or string of nonsense (provided the *ceteris paribus* constraint strictly holds). Finally, with respect to *generalizability*, TNRs enable (authorize) any sign-user to apply any given  $S_i$  from any TNR $_i$  not only to the particular  $O_i$  onto which that  $S_i$  is validly  $\pi$ -mapped, but to the extent of their similarities (with the *ceteris paribus* constraint still in play), the content abstracted from the particular  $O_i$  can be generalized to all similars. However, no such generalization is possible *ceteris paribus* from the corresponding fictions, errors, lies, or strings of nonsense that can be constructed from any such TNR $_i$  on account of the fact that there exists no well-determined  $O_i$  nor any valid connection through a particular  $\pi_i$ -mapping to enable such a generalization.

Thus, the so-called pragmatic perfections of TNRs are proved: provided that the *ceteris paribus* rule is satisfied, only TNRs are relatively well-determined, well-connected, and generalizable. From these relative perfections (strictly formal ones) which are absolutely unique to TNRs, it follows that meaningful signs in language-like systems depend for their meanings on valid pragmatic mappings. Just for the sake of illustration, linguistic TNRs, fictions, errors, lies, and nonsense strings can be described informally and parallels with genetic systems can be suggested as follows:

### TNRs

In linguistic systems, a TNR is simply a true report of an actual physical event or state of affairs, e.g., *The new access road to the Old Settlement in Lafayette was finally opened on 14 August 2013*. An example of a TNR in a biological signaling system could be found in the faithful mapping of a sequence of codons in a gene into the requisite RNAs leading eventually to one or more functional physically produced proteins.

### **Fictions**

An example of a fiction in a linguistic (cognitive) form would be imagining the bright sun shining through my study window when a Louisiana downpour is underway. Or, in biological representations, fictions can be found in unexpressed genes.

### **Errors**

Errors in linguistic discourse are so common that they need no further exemplification. However, in biology, classical examples are found wherever a given coding polymer, for example, happens to be misconstrued downstream. Some errors may be benign, but others apparently lead to one of about 6000 or so genetic disorders [46].

### **Lies (or Deceptions in General)**

Lies too can occur in biology as well as in linguistic discourse. Organisms can misrepresent themselves or their products with the evident purpose of deceiving. In linguistic discourse, lies are intentional and even in biological systems harmful bacteria, viruses, and prions [47,48], like snakes in the grass, *seem to disguise themselves* for the purpose of deception. Whether or not such an intention exists is unimportant. The physical facts result in real deception.

### **Nonsense Strings**

With respect to nonsense, in discursive strings, the only requirement is that the forms used must be recognized as derived from some known language or language-like system. In biological systems, nonsensical forms may be found in the disassembled bits and pieces physically left over from necrosis, apoptosis, or some systemic injury or disease. In vaccination protocols, fragments of animal proteins left over from the manufacture of the material injected generally qualifies as nonsense, though the immune systems of the organism may be confused into treating the fragments as pathogens (leading to allergies) or as indicative of cellular disease resulting in auto-immune diseases where defense (and repair) systems attack the cells, tissues, and whole organs of the self-same body they would otherwise defend [17,47,48].

## **3. Situating the Foregoing in Traditional and Contemporary Conceptions of Entropy**

With the foregoing proofs and illustrations in mind, it remains to situate them in the context of traditional and contemporary conceptions of entropy. Given that contemporary uses of the mathematical theory of information sometimes misrepresent entropy, as Adami [49,50] has noted, and as Jaynes [51] had anticipated, and also taking account of the remarkable complexities of the linguistic and biological signaling systems at issue, it is essential to consider what is meant by the terms *information* and *entropy* in the biosemiotic context. To set the stage for the discussion to follow, which one anonymous reviewer argued is “irrelevant” to the study of biosemiotics, consider the following quote from Jaynes, E.T. [51]:

*“It is interesting that, although this field [the study of entropy and information] has long been regarded as one of the most puzzling and controversial parts of physics, the difficulties have not been mathematical. ... It is the enormous conceptual difficulty of this*

*field which has retarded progress for so long”* (p. 392).

Jaynes was not alone in judging entropy difficult to conceptualize. Chemist F. L. Lambert [52] (p. 66) quoted James C. Maxwell [53] who said, “it is to be feared that we shall have to be taught thermodynamics for several generations before we can expect beginners to receive as axiomatic the theory of entropy.” John Von Neumann reportedly told Claude Shannon to use the term *entropy* because “nobody knows what entropy is” ([52], p. 66). Lambert also cites Francis Sears who asserted that “there is no concept in the whole field of physics which is more difficult to understand than is the concept of entropy” ([52], p. 66). Later on, Shannon’s definition of *information* would be faulted by Weinberger in 2002 [54] for having left out the real content of messages, and in 2010, Brier would conclude in this very journal that *Shannon-type information* “is not a sufficient concept for understanding cognition and communication” ([55], p. 429). So, what are the concepts of *information* and *entropy* in Shannon’s theory, and how must they be amplified, if at all, when they are extended to biosignaling phenomena including physical, biochemical, genetic, epigenetic, proteomic, cellular, organismic, linguistic, and social systems?

Following the classical work of Jaynes [51], and the contemporary writings of Adami [49,50], in the special issue on *Biosemiotic Entropy*, the term *entropy* has been taken (and is understood here in this final entry) as a measure of ignorance or uncertainty concerning something we might wish to find out, some *information*, ultimately providing useful knowledge about the world. In the framework described by C. S. Peirce in his paper on “The Fixation of Belief”, if it is so that “reasoning is good if it be such as to give a true conclusion from true premises, and not otherwise” and if it follows from the general theory of signs as proved in Peirce’s “logic of relatives” [32] and as argued here in the foregoing section on TNR theory that the validity of reasoning is strictly a matter of “fact and not of thinking” then it must also be true that the contrast between *information* (what we know) and *entropy* (ignorance and uncertainty) is also be a question “purely ... of fact and not of thinking” ([35], pp. 2–3). We cannot merely stipulate what entropy is and then produce some arbitrary defense of that stipulation. We must appeal to known facts along the lines of proofs in the prior section of this paper grounded in those of Peirce and Jaynes.

In his foundational paper on the mathematical theory of information, it is true that Claude Shannon [56] began by setting aside what has been termed *pragmatic information* [18]—the kind of content that is determined by TNRs connected to the material world of experience. Shannon [56] wrote:

*“Frequently the messages have meaning; that is they refer to or are correlated according to some system with certain physical or conceptual entities. These semantic [sic; actually pragmatic in the case of “physical” entities and semantic in the case of “conceptual” ones] aspects of communication are irrelevant to the engineering problem. The significant aspect is that the actual message is one selected from a set of possible messages”* (p. 379).

Abstracting from the pragmatic facts pertaining to physical entities, relations, and events involving them—Shannon proposed an idealized (narrowly focused) definition of *information*. Its measure, as he described it mathematically, for any given message was the unlikelihood of that particular message being selected (*i.e.*, reproduced, understood, or whatever) from a finite set of equally likely messages. He was clear in limiting the term “messages” in his theory to their surface form—that is, to the sequence of letters, sounds, syllables, dots and dashes, zeroes and ones, or whatever abstract symbols

in which the surface forms of those messages might be manifested. If words and phrases of a text were involved, in Shannon's theory, the criterion of transmission was tied exclusively to the surface forms of the letters, spaces, and marks of punctuation manifesting words, phrases, and higher units. That is to say, he never pretended to make any effort to decipher those surface forms or link them to their (correlated) pragmatic meaning(s).

Yet, those who would elaborate and generalize Shannon's theory of information, most notably Jaynes [57–60], and more recently Landauer [61] and Adami [49,50], would re-emphasize the correlation of any meaningful message containing information with whatever that message purports to be about. Ultimately, every meaningful message must be about physical measurements, observations, or facts that can be observed (or in Peirce's terms "diagrammed" in some way) in the material world. Valid information at the end of the road must always be of the pragmatic kind—that is, real information, the pragmatic kind of information, must be about entities, events, and relations in the physical realm. Adami plainly implies this in his 2012 paper where he explains that biological information must be about the world in which the organism exists, so that the information can aid in practical decision-making. Adami refers to the decision-making aspect of information as a "colloquial" view, and it happens to be one that was explained and illustrated by Jaynes [62] in his Brandeis lectures in the summer of 1963. In those talks, and in his other writings, Jaynes anticipated Landauer's [61,63] argument insisting on the physical nature of valid information, and Adami in 2012 [50] has not only accepted Landauer's insistence that *information* must have some physical manifestation, but Adami also supposes that valid information must enable less risky, more appropriate choices—ones better suited to the environment in which the organism finds itself. Adami [50] writes:

*"Colloquially, information is often described as something that aids in decision-making. Interestingly, this is very close to the mathematical meaning of "information," which is concerned with quantifying the ability to make predictions about uncertain systems. Life—among many other aspects—has the peculiar property of displaying behavior or characters that are appropriate, given the environment. We recognize this of course as the consequence of adaptation, but the outcome is that the adapted organism's decisions are "in tune" with its environment—the organism has information about its environment. One of the insights that has emerged from the theory of computation is that information must be physical [61]—information cannot exist without a physical substrate that encodes it" (p. 50).*

All this was anticipated by Jaynes. In his Brandeis lectures, he illustrated the "colloquial" definition of information with respect to ordinary decision-making [62]: "An automobile driver can make a sharp left turn at any time; but his common sense [pragmatic information] usually tells him not to" (p. 170). Following Boltzmann [64], Jaynes [58] proposed, as noted above, to define *entropy* loosely as a measure of "ignorance" but he went further in reference to the second law of thermodynamics by proving that "irreversibility is not merely a loss of human information; it is an experimental fact" (p. 172). In doing so, Jaynes made clear that loss of information (increase in entropy) in thermodynamics and in quantum mechanics is not merely abstract but is necessarily physical.

As Adami [49,50] has explained, the physical side of information can be illustrated by thinking of a piece of tape that may contain a message written in DNA, RNA, or some other language about some

state of affairs in the world. A given length of tape can be thought of as a series of blanks in a discourse not yet constructed, or bearing in mind the proofs of the inequalities in (4), we may retro-engineer Adami's metaphor and think of a filled out piece of tape that can be systematically degenerated, *i.e.*, made less complete by construction, by erasing some or all of the filled out elements in the string. In the case of complete erasure, the blank tape contains nothing but ignorance (empty space that might be filled by potentially informative discourse) and such an empty Adami-tape can represent Shannon's *entropy*. If, the tape is filled with an actual string of symbols,  $S_i$ , by contrast, the knowledge about the world contained in the string, to the extent that there is any, can be construed as *information*. The blank that can be inserted anywhere in a given string of symbols,  $S_i$ , by erasing some part becomes analogous to the unknown meaning of  $S_u$  confronting the child who must initiate the meaning of a "first word"; or, to take another illustration, it is like the problem confronting researchers trying to decipher the first symbol of the "genetic code"—which in fact was UUU representing the amino acid phenylalanine [65]; or for yet another example it is like the problem of Champollion in beginning to figure out the hieroglyphic symbols on the Rosetta Stone representing the known name, *Cleopatra* [66]. The trick is to find an  $O$  we recognize so we can figure out the meaning of some previously unknown symbol,  $S_u$ —again, in Peirce's terms, by considering "what we already know" we must figure out "something else which we do not know" ([35], p. 3), or in the words of Jaynes we must use "information" (knowledge) to resolve "entropy" (ignorance or uncertainty) [58]. Or, to use the simplest illustration derivable by construction from the diagram of Figure 1 and from the proofs of the inequalities of TNR theory, the difficulty of filling any given blank space in a string,  $S_i$ , is analogous to the problem of filling in the missing  $O$  in a fictional representation with an unknown  $S_u$ .

Generalizing Adami's illustration and definitions, and imposing the *ceteris paribus* constraint, if a meaningful message of a given length is written on the tape in the symbols of some known language (English, Chinese, DNA, RNA, *etc.*), it is possible to measure the *information* the tape contains in terms of the unlikelihood of that particular string,  $S_i$  of a given length, say,  $n$ , being drawn at random from the symbols of the given language that might have been used in a completely random attempt to express whatever meaning is in fact expressed by  $S_i$ . Assuming only that the *ceteris paribus* constraint is maintained, if  $n \geq 1$ , the unlikelihood of selecting a string of length  $n + 1$  is greater than that for  $n$  while the difficulty of guessing an entire string of length,  $n - 1$ , must be less than the unlikelihood of randomly selecting the correct  $S_i$  at length  $n$ . So, by mathematical induction, the Shannon-type *information* of any given  $S_i$  (all else being held equal) is dependent on the language in question and the length of the string for any string whatever that might be selected in that language. Whenever we erase some part of the Adami tape so that the erased element must now actually be supplied by guessing or by a random selection from all the possible elements in the given language that might fill the blank created by the erasure, we have reduced the *information* contained in  $S_i$  and have correspondingly increased its *entropy*.

The greater the unlikelihood of randomly selecting the right message, the greater the uncertainty or entropy of the potential message. By the same token, the greater the unlikelihood of the random selection of any actual message from a given set of possibilities, the greater the information contained in the meaningful message, if it is provided. In this sense, entropy and information are like two sides of the same coin. As Adami [49] put it: "Randomness is in some ways the 'flip side' of information, and is called *entropy* in information theory" (p. 1087). In 2012, looking to biological applications,

Adami [50] urged that an organism's "fitness is reflected in information" (p. 52) and the sort of information resulting in fitness must be "about its environment" (p. 50); and, conversely, the loss of such information, can result in an "error catastrophe" through "an accumulation of deleterious mutations, and thus ... a loss of information" [49] (p. 1092).

Clearly, entropy and information are different conceptually, though as Adami [49] noted, they are "often misrepresented in the literature" (p. 1087). A common error is to suppose falsely that entropy and information are the same concept. In fact, they are more dynamic opposites than the HEADS and TAILS sides of a coin. In special cases, where the measurement of information and entropy are equal, the claim that they are identical may be relatively harmless, but in other instances, the same assertion can lead to absurd conclusions. For instance, if "entropy" as Richman and Moorman [67] assert "as it relates to dynamical systems, is the rate of information production" (p. 2039), an endless series of absurdities follow including this one: *If entropy is set at its theoretical maximum, by erasing every bit of meaningful text on all the Adami-tapes in the universe, according to the statement of Richman and Moorman, information production should accelerate to a maximum.* But any such conceptual absurdities are precluded by a correct understanding of Shannon's theory and its valid extensions by Jaynes, Adami, and others.

In the light of the proofs by Jaynes concerning the second law of thermodynamics, and the subsequent work of Adami, Kenneth D. Bailey is surely correct in arguing that a "sustainable system must, by definition, ensure that its entropy level does not rise to the maximum, as maximum entropy is tantamount to system death" [68]. Whereas Bailey is clearly referring to the shallow time of an organism or a few generations of them at most, Adami [49] has generalized to deep time in noting that "loss of information" (that is, an increase in entropy) owed to cumulative "deleterious mutations" can lead to an "error catastrophe" (p. 1092). In any case, if the *ceteris paribus* constraint is held in place, increasing levels of biosemiotic entropy, designated as  $H_\beta$ , can be roughly designated in the terms *healthy*, *injured*, and *dead* justifying the series of inequalities (where the symbol "<" is used in its conventional way) between the fuzzy classes [69,70] designated by those terms in (5):

$$H_{\beta \min} \cong H_{\beta \text{ healthy}} < H_{\beta \text{ injured}} < H_{\beta \text{ dead}} \equiv H_{\beta \max} \quad (5)$$

The empirical minimum of *biosemiotic entropy*,  $H_{\beta \min}$ , can be defined and approximated in the fuzzy class of healthy organisms. All else being held equal by construction it follows for all existing healthy individuals, as the life span increases irreparable injuries must accumulate up to the point of fatality. Therefore, the entropy of biological communication systems,  $H_\beta$ , must increase over time in every individual. Sources of such injuries include macro and micro level physical collisions between bodily objects, as well as cumulative injuries owed to pathogens, toxins, radiation, and interactions between all injurious factors. Some injuries can be repaired in part, but for reasons spelled out most clearly by Jaynes [51], the clock cannot be turned backward and some of the effects of the injuries like visible scars inevitably must remain. Thus, the longer the life span of any individual, the greater the likelihood that the tipping point of cumulative injuries will lead, as they must, to detectable symptoms followed eventually by the death of the organism. In their most innocuous form, we refer to the evidence of inevitable cumulative injuries as *aging*, but in increasingly severe instances we refer to them loosely as *conditions*, *disorders*, *diseases*, *syndromes*, and the like. In the end—owing to the principles spelled out most clearly in the second law of thermodynamics as generalized to Shannon's information theory

and to quantum physics by Jaynes [51], the cumulation of  $H_\beta$  must invariably end in a catastrophic breakdown of the critical biosemiotic systems required to sustain life.

Putting the argument, in the form made familiar by Shannon, given a community of competent sign-users who know and share the conventional signs of TNRs expressed in that language, and who have access to the same common world through shared experience, supposing only that any instantiated  $TNR_i$  can be assigned a probability  $p_i \approx 1$  of being comprehended as intended, Shannon-type information [56], constrained by its pragmatic content [18], is at a relative maximum for any  $TNR_i$  while Shannon-type entropy for any  $TNR_i$ , relative to the less well-formed classes, must be at a theoretical minimum. Therefore, based on the definitions from Shannon, Jaynes, and Adami, and from the proofs given earlier, we may write the following series of inequalities between the approximate equations at both ends of (6):

$$0 \approx H_{TNR} < H_{fiction} < H_{error} < H_{lie} < H_{nonsense} < H_{-} \approx -\log \frac{1}{\infty} \quad (6)$$

Shannon [56] evidently had such pragmatic aspects of meaning in mind when he qualified his mathematical equations and proofs by the following caveat: “The real justification of these definitions [of *information* and *entropy*], however, will reside in their implications” (p. 11). Shannon himself evidently had pragmatic implications in mind—that is, implications pertaining to observable facts. In fact, Shannon’s notion of entropy does give the right results in simple and obvious pragmatic cases—ones that are particularly relevant to linguistic and biological messages—as can be seen in the coin toss example of Figure 1. Examining those implications will also show why pragmatic information must be included in a general theory of information as various scholars have already noted.

#### 4. Pragmatic Information as Essential

Although Shannon set pragmatic information aside, Jaynes, Adami, and Landauer, to name only a few of the leading lights, showed why we must bring it back into play. Shannon took the optimally simple case of a flipped coin. Elaborating only slightly, a flipped coin can be used to show how the pristinely simple mathematicization applies to TNRs, and how pragmatic information figures in the equations and inequalities already expressed in (1)–(6). Suppose that an unbiased coin is flipped and lands HEADS up and we truthfully represent that to be the case as in Figure 1. Given the Boltzmann/Shannon formulation of (7):

$$H = -K \sum_{i=1}^n p_i \log p_i \quad (7)$$

where  $K$  is any “choice of a unit of measure” [56] (p. 11).

Let  $H$  represent the entropy of a set of probabilities  $p_1, \dots, p_n$ . In the coin toss example represented by a TNR reporting the HEADS result,  $n = 2$ . In such a case, the probabilities can be represented as  $p_1 = 1$ , the likelihood that the reported HEADS result is true (which it must be if the report is a TNR) and  $p_2 = 0$ , the likelihood that the possibility of TAILS has been realized, which can be completely ruled out as that possibility is contrary to the TNR in hand.

In such an optimally simple case, just as desired by Shannon [56] in thinking through the crucial “implications” (p. 11) of his proposed measure, “ $H = 0$  if and only if all the  $p_i$  but one are zero, this

one having the value unity. Thus only when we are certain of the outcome does  $H$  vanish. Otherwise  $H$  is positive.” This he pointed out is the intuitively desired result for a measure of uncertainty and in the same context, he also noted: “For a given  $n$ ,  $H$  is a maximum and equal to  $\log n$  when all the  $p_i$  are equal (*i.e.*,  $\frac{1}{n}$ )” (p. 11). In the case where  $n = 2$ , if the coin toss is unbiased and the TNR reporting its outcome has not yet been produced by a competent and honest observer,  $p_1 = \frac{1}{2}$  and  $p_2 = \frac{1}{2}$  and  $H$  is at a maximum where the respective probabilities sum to unity yielding  $\log 2$  as the value from Equation (7). Thus, in this optimally simple case, a TNR reporting the HEADS result has maximum information value with respect to its  $O$  (object) and a minimal entropy value ( $H = 0$ ).

Shannon went on to develop a simple proof that unity divided by  $n$  for any  $n$  gives the maximum  $H$  which is, again, the intuitively desired result showing maximum uncertainty. The fact that any probability in the set  $p_1, \dots, p_n$  greater than  $\frac{1}{n}$  must reduce  $H$  is obvious in the coin toss example where  $n = 2$  as Shannon explained. If the coin is biased so that it always comes up HEADS,  $H$  goes all the way to 0. That same result follows, if for any given coin toss, the result is reported in a TNR,  $H$  goes all the way to 0, which is the intuitively required result. But, Shannon notes, any advance knowledge concerning a yet to be determined outcome will tend to lower our uncertainty, thus, reducing  $H$ , so any probability in the series,  $p_1, \dots, p_n$ , that is greater than  $\frac{1}{n}$ , will have the effect of reducing  $H$ ; therefore the maximum uncertainty of any distribution of  $n$  probabilities is given by  $\log n$ . It was precisely this property of probability distributions that enabled Boltzmann [64] to develop his  $H$  theorem and Jaynes later to develop “the maximum-entropy” principle [57–58].

More recently Hemmo and Shenker [71], agreed with Rolf Landauer [61] that “information is not a disembodied abstract entity; it is always tied to a physical representation . . .” (p. 3309; also see [63] by Landauer). Similarly, we recall that Adami [49] has argued that the “physical complexity of a sequence [of a biological polymer, for instance] refers to the amount of information that is stored in that sequence *about* a particular environment” (p. 1087). That is to say, biological polymers have pragmatic information. Moreover, as Hemmo and Shenker have demonstrated, any meaningful representation presupposes a situated interpreter located in the space, time, material world. Generalizing to the biological systems of representation, the analog of the situated observer would have to consist of the living cells, tissues, and organs of the organism capable of registering and interpreting biological signals. In supposing the existence of sign-users (competent interpreter/observers), in any case, Hemmo and Shenker necessarily (perhaps inadvertently) acknowledge the sort of connection of sign-users to whatever actual representations they may construct, and, again, to pragmatic information.

The positing of a role for one or more situated observers is not so strange as it might seem—even to a mathematician (or any theoretician) accustomed to thinking of abstract equations. They may seem devoid of any subjective element and not to need any material observer(s), but even Einstein had to appeal to distinct perspectives of observers (intelligent and competent sign-users) to formulate the special and general theories of relativity [21,72]. Similarly, to explain the meanings associated with the flipping of a coin, or the real integers, 1, 2, 3, ..., the cardinal and ordinal sets, Cantorian (or Peircean) orders of infinity [73–75], or any linguistic or mathematical abstractions, TNRs are absolutely required (per the proofs of 1–4 above). What is more, TNRs cannot exist without competent observer/interpreters. In fact competent observer/interpreters are required to enable the acquisition or use of any conventional sign system.

As Hemmo and Shenker have illustrated, valid representations require experience in the mesoscopic realm of material entities in some accessible region of space and time where competent and intelligent observers are invariably situated at definable coordinates. The upshot of this idea, one that I propose to call the *pragmatic theorem*, is that any content expressed in conventional (linguistic, mathematical, or any kind of abstract and even partially arbitrary) signs is dependent on the instantiation of those signs by applying them truthfully to facts already known to (or discoverable by) one or more competent observers [18,23]. Upon examination of their formal properties, as elaborated earlier in this paper, it comes out that TNRs must involve the faithful mapping of a symbol (or sequence of symbols) through the actions of one or more observer/users of the conventional signs of a shared language onto one or more known entities, relations, and events in space and time. If there were no TNRs, no conventional language could be learned, and, none could exist. In effect, there could be no pragmatic information in any context.

Charles S. Peirce proved what I am calling the pragmatic theorem in a variety of ways but especially in his logic of relatives [32]. The same idea was expressed somewhat more narrowly by Alfred Tarski who showed that all meaning is parasitically dependent on true representations [33,34]. Putting the case a little more explicitly, it is crucial for observers who share a common language to be able to express representations that are set in correspondence with facts in a manner that accords with the conventions of their common language(s). What the pragmatic theorem shows is that to discover those conventions, for the conventions themselves to exist, TNRs are required to instantiate them.

## 5. Agreement at the Foundation

At its bedrock foundation, information from the pragmatic perspective is completely dependent only on the peculiar kind of agreement found in TNRs. If that agreement gets disrupted, processing is made more difficult and communication tends toward a breakdown. However, the success of communication depends exclusively on the agreement between the surface forms and their deeper meanings which are known through the mapping diagrammed in Figure 1. It does not depend at all on the surface forms in and of themselves. This fact can easily be proved in natural languages by translation. Nearly perfect translation of TNRs is possible *in principle* across very different languages, e.g., English and Mandarin Chinese, and, experimentally, near perfect translation has been attained with coherent fictional narratives as demonstrated some years ago by Suyi Xiao [76] in radically diverse surface forms. Thus, different strings of symbols can express virtually the same meaning. Similarly, paraphrase within a given language, also shows that surface forms can be changed drastically, perhaps completely, while the deeper meaning remains the same. It is also possible to produce countless examples where the very same string of symbols represent entirely different facts. For all of these reasons, it is essential to look to the agreement between the  $S\pi O$  elements as the arbiter of meaning.

In the final analysis, surface forms lack any ultimate authority with respect to meaning because, as C. S. Peirce [77] argued, everything depends on mere consistency—agreement across representations with respect to their deeper meanings. Peirce argued that we know facts only through representations of them, so, if the representations are set by mapping relations in complete agreement with their facts, those representations have “all the truth that the case admits of” (p. 257). In terms of the proofs given above, in order for a TNR to qualify as such, it is only essential for the three elements,  $S$ ,  $\pi$ , and  $O$  to

be in agreement with each other. If the facts at hand in the  $O$ , deliver all that is claimed about them by the string of signs,  $S$ , that is  $\pi$ -mapped onto  $O$  (that is to say, there is nothing in  $O$  to contradict anything asserted in the  $S$  string), then the  $S\pi O$  relation is said to be true. However, the truth of any TNR depends exclusively on the agreement of the string  $S$  with the facts  $O$  onto which  $S$  is  $\pi$ -mapped.

Even though Shannon concerned himself exclusively with surface forms of messages, he was nevertheless clear in 1948 that his whole theory was dependent on agreement. Shannon [56] wrote:

*“The fundamental problem of communication is that of reproducing at one point either exactly or approximately a message selected at another point”* (p. 379).

When Jaynes in 1957 generalized Shannon’s theory to probability and statistical inferences as well as classical and quantum mechanics, Jaynes [57] insisted on conceptual agreement (the TNR, factual kind) as the basis for his generalization of the mathematical expression of entropy as well:

*“The mere fact that the same mathematical expression  $-\sum p_i \log p_i$  occurs both in statistical mechanics and in information theory does not in itself establish any connection between these fields. This can be done only by finding new viewpoints from which thermo-dynamic entropy and information-theory entropy appear as the same concept”* (p. 621).

Jaynes set out to show the two types of entropy to agree with each other to the point of identity as a matter of fact. In doing so he reinstated, in principle, the pragmatic aspect of information that Shannon had set aside. In the second part of his argument, Jaynes [58] generalized the Shannon-type entropy to time-dependent and irreversible processes in phenomena tending toward maximum entropy where all information is lost, and in other papers [59,60,62], he generalized the argument still further to incorporate quantum electrodynamics including, in principle, the Bose-Einstein condensation of an ideal gas [78–82], and other quantum states [83].

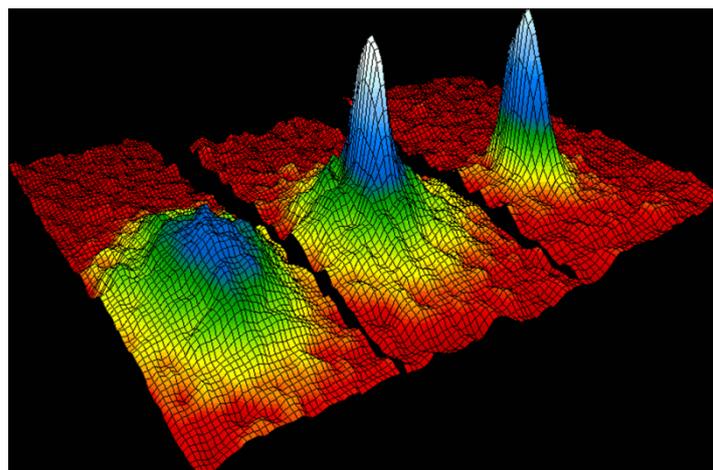
It would turn out that the Bose-Einstein prediction would be confirmed in the condensation of real rubidium atoms [25,26] and would become the metaphorical model for large-scale agreement phenomena manifested in complex internet systems, citation networks such as the Web of Knowledge [84,85], and in neuronal networks of the human brain [86]. The importance of such phenomena where vast numbers of atoms, people, or communities come into “agreement” (an abstract form of shared coherence; also see [83,87]), though easily taken for granted, merit critical examination in terms of information and entropy. While it is true from a thermodynamic perspective, as one anonymous reviewer commented on an earlier draft of this paper, that the BEC requires a near complete removal of all heat from the ensemble of rubidium atoms leading to a phase state of nearly maximum thermodynamic entropy, as physicist Mae-Wan Ho (personal communication, circa 7 November 2013) argued, the BEC represents a quantum state of near perfect coherence (information). It would be a conceptual error, in the larger discourse of experimental physics, to suppose that the BEC came about as a consequence of random forces or anything analogous to what we have termed *biosemiotic* (or discursive) *entropy*.

On the contrary, the achievement of the BEC reflects nearly 70 years of advances in information and technology after the Bose-Einstein prediction was first published [78–81] and it required nearly four decades of development after Jaynes [57–58] had extended the second law of thermodynamics to quantum phenomena. Fully seven decades elapsed from the first publication of the Bose-Einstein

theory before Cornell and colleagues were able to conceive, design, carry out, and report the first successful experimental BEC [25,26].

The experiment reported in 1995 (see Figure 2), involved creating a bowl-like container (a force field) that would allow energetic rubidium atoms (those retaining heat) to escape by jumping over the edge of the containing space. By progressively lowering the edge of the containment space, the temperature of the remaining atoms could be brought closer and closer to the theoretical limit of absolute zero until the condensation occurred. The accomplishment won Eric Cornell and Carl Wieman a Nobel Prize in physics in 2001 [26]. Shifting gears, as it were, from the level of the purely physical BEC in a nearly homogeneous monatomic gas, to the level of linguistic interactions across the world, the BEC was followed by a discursive condensation phenomenon of a similar sort. By 4 July 2014 the original report of the BEC [25] had generated 4330 citations on the Web of Science. This rather large number of citations suggests a convergence of viewpoints showing profound agreement that the achievement of the BEC is important. Even a tutorial for researchers seeking to replicate the result, on the same date, had also been cited 1129 times [82]. The information on which such agreements are achieved is the very antithesis of discursive entropy. Metaphorically speaking imagine how many empty Adami-tapes had to be filled up before a sufficient level of knowledge about the world could be achieved so as to enable the attainment of the Cornell and Wieman result.

**Figure 2.** A distribution of rubidium atoms in gas supercooled to about 170 billionths of a degree above absolute zero producing the condensation predicted by Bose–Einstein [78,79] as reported by Anderson, *et al.*, 1995, in *Science* [25]. **Left:** before the Bose–Einstein condensate appears. **Center:** after the condensate appears. **Right:** after the condensate is nearly pure. This image is in the public domain as a work of the United States Federal Government, specifically an employee of the National Institute of Standards and Technology, under the terms of Title 17, Chapter 1, Section 105 of the US Code. Retrieved 30 July 2013, from [88].



Just as the condensation itself is an amazing departure from a random event, similarly, the agreement of so many researchers—many of them reading and then citing the experimental report from diverse starting points and backgrounds—manifests a departure from randomness like the BEC itself. It is true that the condensation of rubidium atoms, is real, physical, and thermodynamic in character, while agreement on the importance of such a result as manifested in thousands of citations is

abstract, discursive, and linguistic in nature. Both, however, are real and show the high density of information and relatively low entropy of TNRs. Various phrases to describe the agreement phenomena at issue have been used including “first-mover-advantage,” “fit-get-rich,” and “winner-takes-all” [84–86]. All such phenomena are fundamental manifestations of the sort of correlation between a representation given in a string  $S$  that is systematically  $\pi$ -mapped onto a complex  $O$ . The foundation for the discursive (information-based) agreement attained in all such instances consists in representations of the TNR variety. Without such representations, neither the BEC nor any “fit-get-rich” phenomena of any kind, could be produced or observed in any context. In linguistic TNRs, it is evident that the agreement between the three components is so complete that each of the three parts of a TNR represent the same unity. It is for this reason that Peirce could say, in cases of such agreement, that the representation has all the truth that the case allows [77].

Although in 1965, Chomsky [89] did claim to base his theory of language on an “ideal speaker-listener, in a completely homogeneous speech-community, who knows its (the speech community’s) language perfectly and is unaffected by such grammatically irrelevant conditions as memory limitations, distractions, shifts of attention and interest, and errors (random or characteristic) in applying his knowledge of this language in actual performance” (p. 4), such an extreme idealization, is unnecessary. As Shannon [56] demonstrated (p. 14), successful communication does not always depend on perfect (complete) agreement. In fact, ordinary experience shows that language users commonly produce and understand complex strings in the language(s) they know in spite of the errors, hesitations, false starts, do-overs, and so forth that often occur. Communication often succeeds in spite of the imperfections in the strings produced. Such successes are evidently possible on account of the fact that actual messages physically coded in real languages tend to have fairly high *redundancy*—a term that can be measured explicitly in experimental contexts as Shannon demonstrated in 1948.

In many studies since then [22,24,90–96], variations on Shannon’s method for constructing graded approximations to standard strings have demonstrated that so long as the *ceteris paribus* requirement is respected (by using precise counter-balanced repeated-measures designs) scrambling the letters, words, phrases, sentences or paragraphs of a linguistic text, or deleting the  $n$ th word of a meaningful string produces results consistent with the inequalities of (4). As strings are made less coherent (more degenerate), the approximations become measurably more difficult to process [22,24]. Evidently, based on empirical studies, genetic polymers also appear to be resistant to distortion, or even complete erasure in some cases, thus displaying a similar kind of pragmatic redundancy as is found in linguistic discourse—e.g., see Gryder, Nelson, and Shepard regarding the error correcting powers of genetic systems [8]. Error correction, however, depends entirely on making a string of signs agree with some underlying meaning or some model string, and thus with some system of facts known through TNRs. At the foundation we still find agreement discoverable only through TNRs.

## 6. Conclusions to the Series

Why should a series of articles on *Biosemiotic Entropy* appear in a physics journal? For one reason, as I have argued from diverse points of view and relying on various methods in this last paper in the series, *all information systems must deploy messages in some physical form*. For another reason, the series fits well here, as is demonstrated in the eleven preceding contributions to the series

(not to mention the papers from the still earlier series edited by S. Brier also in this journal), because *the success of biosignaling systems depends on a discursive kind of coherence*—the kind of true representations that connect surface forms of symbol strings with facts. The series has shown that the internal coherence of biosignaling systems can be disrupted from the level of nanoparticles upward through atoms to molecular polymers (DNAs, RNAs, proteins, prions, and viruses), to bacteria, individual cells, pathogens, gut biota, tissue systems, organs, whole organisms, and right on up to societies of interacting communities of organisms. With respect to such biological signaling systems as are already partially understood, as in what is known of natural language systems, it is evident that just as certainly as factors disrupting discursive coherence make discourse harder to produce, comprehend, recall, and process, factors increasing *biosemiotic entropy* tend to cause disorders, diseases, and mortality. At the bedrock of all the distinct levels of signaling systems that can be disrupted, we find the generalization of the second law of thermodynamics by Jaynes.

It seems almost uncontroversial to say that *coherence is critical to successful communications in any context—physical, biological, or discursive*, and one reviewer of two earlier drafts of this paper even argued that it is trivial to say that. But the underlying premise of this whole series is valid for mathematical equations, for representations of physical processes, for biological signaling systems, and for linguistic discourse without any known exceptions. As demonstrated here in various Peircean type proofs and with empirical evidence from many experimental contexts, it is also true that factors which tend to disrupt coherence in communication systems, contribute increasing entropy to those systems. This series has explored some of the ways factors known to increase *biosemiotic entropy* tend to cause disorders, diseases, and mortality. One of the most persuasive and perspicuous applications of TNR theory in the series is the article by Gryder, Nelson, and Shepard [8] regarding the etiology of cancers (also see [9]). Given the fact that agreement between distinct physical manifestations of representations is important to the attainment of any coherence in any representational system of any kind, it follows that the traditional concepts of physics concerning the nature of entropy are bound to be applicable to such physical manifestations of information systems in general. Working out the details of such applications will not be easy or painless to the guardians of those long-revered fictional boundaries that separate departments of mathematics and physics from biology, psychology, linguistics, and so forth. However, unless researchers and theoreticians risk crossing those boundaries, how will it be possible to reasonably pursue the goal of preventing unnecessary injuries that tend toward an undesirable catastrophe?

As noted in one of the many translations of the famous Chinese writings loosely translated, *The Art of War* attributed to Sun Tzu, preventing conflicts is better, less costly, and more effective, than winning conflicts after they have begun [97]. The translator's Preface to one of the many editions of that compilation in English includes the observation that "the peak efficiency of knowledge and strategy is to make conflict altogether unnecessary" (p. xi). To take just one case in point, will not some of the costs of cancers become avoidable with improved understanding of their etiology? Even in unpreventable disorders and diseases, gains in understanding of etiology are likely to enable improved diagnosis and treatment. Therefore, it is hoped that this series on *Biosemiotic Entropy*, with its uncontroversial basis in mainstream physics, has been elaborated enough with respect to abstract discursive and biological signaling systems to enable progress toward preventing at least some of the many avoidable disorders, diseases, and fatalities.

## Conflicts of Interest

The author declares no conflict of interest.

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