

CHAPTER 5

WHAT IS THE SCOPE OF BIOSEMIOTICS? INFORMATION IN LIVING SYSTEMS

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Abstract: Because biology involves so many scalar levels and entrains so many aspects of Nature, the notion that it is essentially a direct consequence of genetic information is questioned. After discussing some general points about information and semiosis, the hegemony of genetics is rejected on the grounds that: basic cellular phenomena are generic for micellar systems, and that the overall pattern of development is generic for dissipative structures, and that supramolecular information emerges during development, and that closely similar forms and functions can emerge at the scale of organisms and above in distantly related genealogical lineages. During the course of the paper I suggest that various epigenetic systems may be semiotic entities

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INTRODUCTION

We may well ask ‘where *is* biology located’? The problem here is that biology as a discourse ranges over several levels of scale (thereby subsuming dynamics over several orders of magnitude), from populations – even species and ecosystems! – to macromolecules within cells (Hoffmeyer, 1996, Salthe, 1998). This may be contrasted with the commonly held notion within the discourse that biology is essentially a product of genetic information.

Using the specification hierarchy of integrative levels (Salthe, 1993, 2002a) to organize our thinking about Nature, we have, for example:

{physical dynamics {chemical recognition/reactions {biological forms
{sociopolitical arrangements}}}}

This hierarchy is interpreted as {lower integrative level {higher integrative level}}, with a lower level giving rise to the next higher, which in turn integrates (contextualizes, regulates, interprets) all those lower than it. The lowest integrative level where biology is known to have a recognizable footprint is in the chemical (i.e., material) realm, where, for example, it generates accumulations of chemicals against diffusion gradients. It is generally considered that we have the basis of biology when differences between individuals of kinds of molecules (in biology, macromolecules) come to ‘make a difference’ (Bateson, 1971) in the results of local chemical reactions. In contrast, at the purely chemical integrative level, small differences between molecules of the same kind would have no significant consequences globally upon chemical reactions.

We may ask whether, in view of the fact that what characterizes biology most deeply is the presence of molecular level information held in the genetic system, would it not be reasonable to suppose that biology is fundamentally nothing more than the ramified consequences of a highly specified kind of chemistry? Unless we subscribe rigorously to a bottom-up ideology, biology’s range (reach or footprint) over so many scalar levels (Salthe, 1985), as in:

[species [population [organism [cell [macromolecule]]]]]]

would seem to argue against this. Only if all of biology could be completely explained as the direct result of effects generated by proteins could it reasonably be taken to be just an elaboration of chemistry. As a hint of where I will go in this paper, note that, even though the chemical integrative level gives (and must also originally have given) rise to biological phenomena, these in turn integrate chemical processes under biological regulation – by way, for example, of deploying substrates and depleting end products in various patterns within particular regions. Indeed, one could say that biology harnesses (Polanyi, 1968, see also Ulanowicz, 2004) chemistry to its own ends.

INFORMATION AND SEMIOSIS

As a preliminary, I will delimit the concept of ‘information’ as I conceive it. From information theory we know that information is engendered by a decrease in uncertainty, or by a reduction in the variety of possibilities. More important in the present context, materially, (i.e., thermodynamically), information acts as any constraint (restrictive or enabling or both) on entropy production – which is to say, on anything at all that might happen in the natural world (Salthe, 2003b). It is in this connection that information can become associated with meanings¹, thereby becoming a semiotic concept, given that its presence or effects as constraint makes a difference to some system of interpretance (sensu Salthe, 1998, see also Spinks, 1983²; and see the Appendix). Now, here we have implicitly circled back again to the information theoretic view because it would necessarily have to be a system of interpretance that could evaluate whether a decrease in uncertainty relevant to its

interests has occurred. Failing that, there could be no decrease in uncertainty, since that would require a system of habits and expectations to be in place to begin with. Furthermore, I note that in the context of complex systems, complication requires some classification scheme to diminish the number of significant states that a system must recognize. If we examine the number of possible states a complicated system might access [see, e.g., the analysis of the immune response in Calvano et al. (2005) or of protein interaction networks in Rual et al. (2005)], it becomes clear that only certain states in a very large number of possible ones could have significance for any finite system. This requires a standing reduction in the number of meaningful states by way of classifying recognized differences in only a few of the many degrees of freedom afforded by complexity, which few then carry the information used by, and meaningful to, the system. A functional complex system must, therefore, be able to classify its own states as well as those of its surroundings, and so must necessarily have information..

INFORMATION AND HISTORY

We can proceed further using Pattee's (1977, 1982) distinction between dynamics and informational constraints. Informational constraints are configurations that modulate entropy production. As a radically out- of- equilibrium, presumably isolated system, the main business of Nature must be to return to thermodynamic equilibrium (Salthe, 2002b, 2003a, 2004a) by way of dissipating all energy gradients (Schneider and Kay, 1994). Underwritten fundamentally by gravitation, organizations, forms and masses, as well as matter itself, have all erected barriers to a quick passage of the world to the 'blessed' equilibrium state. Every form is potentially a constraint on energy dissipation, instituting friction on the dissipative process, generally slowing it down (Lotka, 1922). Such informational constraints, in their role of informing natural processes, are prominent among the objects of semiosis (which I take to be the construction and interpretation of meaning as mediated by signs², and the Appendix). A very simple abiotic example of informational constraint would be a ridge in the pathway of running water, imposing friction upon its flow.

Constraining configurations like this are generally the results of historical contingencies – and so information generally is instituted, and therefore meanings mediated, by the effects of history, at all scales. These effects tend to be preserved because the material world is sticky and easily marked, this being supplemented in biological systems by the process of preservation of genetic marks by natural selection. Eventually new marks may obliterate older ones (think of craters on the moon), but usually not completely. Erasing information (instead of just modulating it) is in fact extremely difficult in the material world, usually consuming considerable effort and energy to get to where every trace has been deleted. In biology this can take many generations of natural selection gradually diminishing the representation of some genetic information in the gene pool of a population, after which even more activities must transpire before it will be eliminated completely by way of genetic drift.

Here we may note that natural science has been almost completely concerned with ahistorical possibilities (e.g., the typical function of mitochondria in a cell, or the average mode of generation of storms by way of energy gradient dissipation, or the normal course of development of a kind of embryo or in the main sequence of stars), in which history is obliterated statistically, whereby variety of values is decreased down to just a few statistical moments, establishing average values as the normal data of science. But in the context of the Big Bang even the universal constants of Nature could be thought of as the results of history. I should acknowledge as important exceptions to the nomothetic focus of natural science, that we do have, e.g., cosmology, historical geology, and evolutionary biology, which seek as part of their practice to pinpoint when and in what sequence various particular events occurred. However, even here statistics are often used as tools to establish likelihoods of precedence. And so, historically acquired information as such (unassimilated by statistics), has had only a small place among the facts of natural science.

In biology, genetic information imposes constraints on chemical dynamics, the results of which go on to inform the activities and generation of dynamic micro- to mesoscopic forms – living cells. This information then continues to inform cellular behavior to the effect, among other things, of generating emergent macroscopic forms, like layers of mucus, syncytia, organisms, colonies, and their populations. These in turn participate in megascopic ecosystemic activities organized around energy flows emanating from the dissipation of energy gradients. Thus, using the scale hierarchy format (Salthe, 1985), we have for example: [ecosystem [population [organism [cell [macromolecule]]]], the levels here, [megascopic [macroscopic [mesoscopic [microscopic]]]], being separated by average dynamical rate differences of at least about an order of magnitude (Salthe, 2004b) which keeps the levels functionally separated at different scales.

I note here in passing that, important as genetic information is at the molecular level, there is as yet no understanding of how the genetic system could have evolved (see some thoughts in, e.g., Guimaraes, 2006). This remains at present the major unsolved mystery in biology. Here we will merely accept this microscopic level of information as being present, and proceed from there, even when discussing, below, some aspects of the origin of life.

REPRESENTATION IN DNA

Biology assumes its ecological role – increasing the variety of energy gradients being dissipated, as well as increasing the thoroughness of some of that dissipation to heat energy (Salthe, 2004a, 2005a) – when different historically generated ‘versions’ of the informational macromolecules (mutants) become associated with dissipative structures in different types of locales, or with different energy sources. These associations, which are mediated in biology by the diverse adaptations of organisms and free living cells, establish formal causes of meaning (i.e., what?, where?, how?), and are the sources of biosemioses spanning several levels of scale. Thus, a kind

of organism or colony finds itself successfully reproducing its genetic information in a given habitat in a given biome, living in a given Umwelt, working a given ecological niche (Salthe, 2001). This genetic information, whose interpretation by the involved cells was in part responsible for the success, is in that way reproduced as well. Biosemiosis results in increases in mutual information between locales and their non-constitutive occupants over time (Collier, 1998), a process that is understood in biology today as mostly the results of natural selection. In that model, initially adequate accidental relationships between biological systems and their environments become gradually refined into better adaptations – or, indeed, the biological system may just manage to hold on when faced with the exigencies of environmental change (viz., the ‘continual deterioration of the environment’ of Van Valen, 1973 – see Salthe, 2005b).

So macroscopic to megascopic environmental associations are what afford meanings for the microscopic sequence information in nucleic acids, as interpreted by mesoscopic systems of interpretance (cells, organisms) successfully engaged in macroscopic niche transactions. (See the Appendix for restatement in more detail.)

These semiotic associations are conceptually related to Dawkins’ (1982) “extended phenotype” concept, wherein a nucleic acid sequence is held to be capable of representing the combined informational constraints held in environmental configurations extending from cells outward even to as large a scale as climatic weather patterns. The genetic information consulted by cells reflects aspects of those cells, and, since they are doing well in an organism or colony, it reflects to a degree aspects of these as well. Since that organism or colony is successful in a given habitat in a given biome, these too are to some degree reflected in that information – which could therefore be expected to be different in a different biome.

But careful consideration of these relations shows that the simple notion of an actual transition of meaning across levels of scale, characterized as these levels are by dynamics of very different rates, cannot really be the case. Meanings represented in DNA sequences reflect relations that overall can be modeled as the scale hierarchy: [climatic region [biome [population [organism [cell [macromolecule]]]]]], interpreted as [higher level [lower level]], with increasing span of numbers of individuals as we go down to lower levels. Meaning cannot normally transit directly through these levels, but cascades from level to level, and is transformed (transduced) at each one. The information present at any given level of scale is made possible by informational configurations at the next lower level, and contextualized by configurations at the next higher level, which have permitted it to thrive (Salthe, 1985). This means that configurations at every level function immediately as informational constraints in respect only to the next lower level. So a pattern of weather, say, would have – as such – no meaning for a cell within an organism, because that cell relies for its effective information on cues only from conditions within the organism itself. The organism, however, can respond to changes in weather. So, e.g., a hurricane, as such, cannot touch a cell within an organism even if it destroys the organism. So meanings in this system are transformed over a cascade of downward constraint relations. For example, the scouring pressure of a

waterfall is 'too far away' in scale to carry meaning for an algal cell growing in a colony on its rocks. The layer of slime secreted by the colony of cells is here interposed between a cell's DNA and the rushing water. In this case the DNA would hold information relative only to some glycoproteins or mucopolysaccharides, with no direct reference at all to flowing water.

So, accumulated information in the DNA of, say, an algal cell at any moment might be parsed, for example, as: [winter [ice [many neighbors [metabolic pattern X [increased molecular stability]]]]]. It is true that genes coding for proteins would be 'judged' with respect to all these levels simultaneously. Frequent failure of a given kind of protein to function adequately for a cause traceable to some fluctuation beyond normal at any one of these levels, even if the protein's function would have been adequate relative to conditions at all the other levels, could result in death of the cell. Now, this, however, would not be a direct transit of information across all the intervening levels because arrangements at any of these other levels might have been able to compensate for the fluctuation so that the function in question would not have been so severely challenged by an effect of that fluctuation. Thus, information at any genetic locus is potentially contextualized by all the information in the genome, and – crucially – configurations at other loci, some referring to configurations or activities at different levels of scale, could compensate for stress bearing upon the product of a given genetic locus, thereby preventing the action of selection. Since meanings reflected in a given gene product are contextualized by meanings reflected in many others, which could either support or problematize its function, no locus can be said to hold, by itself, information about any biological activity.

THE ORIGIN OF LIFE

Materially, ecosystems were originally just abiotic energy flow landscapes holding dispersed energy gradients, minerals and other potential resources (Ehrensward, 1960, Odum, 1971). These systems fostered chemosyntheses globally powered by the sun, as well as locally in some places by vulcanism. These were powerful energy sources, the tremendous magnitude of whose energy flows would have prevented development beyond relatively simple proto-living systems because they would disrupt more delicate micro- and macroscopic forms almost as soon as they formed. Solar intermittence was therefore necessary to provide a dark period for molecular and supramolecular folding into least free energy configurations with enhanced stability. And the presence of shaded ledges could also have been the sites of further complication, as well as any other more temperate locales that would have been reached by turbulent dispersal away from submerged outlets of terrestrial heat energy which had driven concatenations of chemosyntheses (Corliss, 1988).

The origin of life – that is, the emergence of replicability of linear macromolecules that can betoken meaning – needs (whatever its mechanisms were) to have been fostered by macroscopic dissipative structures mediating the required energy flows and resources. Some of these dissipative structures plausibly later became co-opted into the biological system proper, becoming in that process more defined and

complicated. Eventually they would function as the very focused systems of interdependence that we know as organisms, colonies and symbiotic associations. These would continue to be dependent upon their local megascopic ecologies, to which they would have become especially adapted for energy, materials and waste sinks. It should not be thought that the microscopic structure and functioning of the cell itself was a particular product of biology, without abiotic precursors. Sydney Fox's extensive work on proteinoid microspheres (reviewed in 1988) showed that these could perform many of the functions of living cells – maintenance of internal difference, including charge separation between inside and outside, division, fusion, growth, and other functions. Once formed, they are quite stable, but do show the effects of aging. As well, when artificially fossilized, they do not differ from some Precambrian microfossils (Francis et al, 1978). The point I am getting at here is that many cell functions are generic for enclosed microscopic physicochemical systems like micelles, and do not depend, as such, upon genetic information (Salthe, 1972).

SUPRAGENETIC INFORMATION

Species

Once an array of genetic information is being replicated, copies of it can get transported to other areas, some perchance with similar enough ecosystemic conformations to allow tentative colonization. Successful colonization by an informed system is mediated by meanings evoked from its own configuration/conformations (which are generated in contemporary biological systems by translation of DNA 'messages' during development) if the system happens to find itself in a supportive environment. Successful colonization of different habitats isolated from each other would allow the preservation of different genetic arrays, eventually generating different biological species, each related to, and eventually adapted to, a different habitat. Species can be said to hold ownership of the biological information embodied in the nucleic acid arrays held within cells and organisms, even though their scale is very much larger than that of the actual informational molecules. We know this because local extinctions of populations do not necessarily eliminate a species' information in these locales, as there may be other populations of the same species elsewhere which can supply immigrants for repopulation (Eldredge, 1989). Furthermore, no single population, any more than any individual organism or cell, will have all the genetic variants belonging to a species. So the species is the actual storehouse – and indeed the owner – of genetic information, deploying it by way of mediating dispersal of its organisms or their propagules. This is managed either by the shape and location of its areography (Rapoport, 1982), or by way of organismic and propagule dispersal abilities coded for in its genes. So, even if one assumes that the most characteristic biological information exists in nucleic acids, it must be admitted that it is deployed through the agency of species. Since this involves at least some material constraints independent of genetic information, as in the areographic pattern of a species occupation of space, or in migration routes learned

by its organisms, so species have a separate existence as systems of interpretance (somewhat, perhaps, in the way that a bank has an existence separate from the money it manipulates).

As an exercise in pansemiotics, we might consider species as systems of interpretance in more detail. We first need to cast our thoughts upward in scale, so that, as observers, we see them as if smaller than ourselves. We would then see a species' areographic range looking rather like a carelessly assembled amoeba, with parts of its pseudopods dissociated from the main body, which itself does not occupy space fully, but rather with greater or lesser aggregations of the organisms or cells that form its 'atoms'. There are as well gaps between its populations, which are its reproductive organs. These are connected by way of gene flow carried by immigrants from one to another, which, if our observation scale is large enough, we would see scooting back and forth between them. Now, considering Peirce's triadic formulation of semiosis (see the Appendix), we must contrive to find a species' interpretants, the signs it 'attends', and the objects it is relating to. The external objects of importance to it are various environmental properties. The signs it is attuned to are the environmental affordances that it is particularly capable of constructing out of environmental raw materials, should the latter be present. Such an affordance might be, say, soils of a given pH with just the right amount of shade during a given season and time of day. Its interpretants are emigrant populations established by what seem to be wayward propagules or organisms. Note that Peircean semiotics is an abstract system of relations that is capable of being overlaid upon any complex enough material system. Resistance to this procedure would likely be driven by refusal to open up observational scale, motivated by pragmatic rather than philosophical concerns.

Convergent Evolution

With this issue we have broached the general problem of where biology exists more explicitly. A major phenomenon to support my perspective here is convergent evolution (Conway Morris, 2004, Willey, 1911). This is the situation whereby quite distantly related biological lineages generate similar anatomical organs, organisms, or even whole ways of life from different ancestors that were not similar in these respects, and whose genetic information therefore could not have been the same. Perhaps the most famous example is the independent evolution of essentially the same kind of eye in both vertebrates and cephalopods (squids, octopi and cuttlefish). Being only very distantly related, fishes and squids, for example, do not generally resemble each other closely other than by being streamlined for swift motion in water – this being a very general adaptation easily conceived as the separate results of natural selection in different lineages. Moving swiftly through the dense medium of water requires this shape of any organization that takes up that way of progression, and is such a general requirement that almost any starting point could be molded in this direction – even people have invented submarine boats! Another such example would be the evolution of woody trees in many different plant lineages. Such very general similarities need not be reckoned to show convergent evolution.

The focusable eye, however, is quite a different matter. It is a complicated arrangement of cornea, lens and retina, capable of focusing light from different distances. The key point for us here is that the genetic information involved in this eye must be completely different in the two lineages under consideration. The alpha-crystalline proteins in the vitreous humor of the lens were found to have very different conformation when comparing those from mammals and squids immunologically. This raises a key point here. Genetic information is today accepted as the basis of biological form, yet here we see that such form can exist independent of the information in that basis. It is well to note here also that evolution has produced a number of completely different kinds of eyes among animals, and so it is not the case that an eye, for some unknown lawful, nomothetic reason, must always have the same form. So it is as if the focusable eye, as an independent form, is enlisting different informational tokens to code for it in different biological lineages, thus acting like a 'deep structure' in Nature.

An interesting example of a kind of evolutionary convergence is the iterative evolution of the same suite of multiple body forms (pikes, panfish, eels, etc.) in three fish faunas that replaced each other after major periods of extinction throughout the fossil record – the paleoniscoids were followed by holosteans, who were replaced by teleosts. These faunas independently evolved these same forms starting in each case from a more typical fish form, and since they were not closely related, the genetic basis of these forms in the different lineages must have been quite different. The teleosts, who are still with us, and so known in more detail, have evolved many other kinds of 'bizarre' forms which, since we don't know the earlier faunas nearly as well, we cannot say whether they were represented in them. A favorite example of mine to illustrate evolutionary convergence is the comparison between one kind of bizarre fish – seahorses – with chameleons, because these two are basically so different in underlying structure, and in habitat as well. And, of course, they are not closely related genetically. These two vertebrates are similar in size and in a bushwhacking mode of predation, lurking or creeping slowly along on vegetation, then striking swiftly. Both are cryptically colored, both have slender prehensile tails, and both have independently moving eyes as well. Furthermore, seahorses bear live young, and so do some chameleons. Such examples of evolutionary convergence are particularly notable in light of the fact that evolutionary biologists today use only Darwin's descent-with-modification model of evolution, conceptually delivering only a diverging process of evolutionary change. In any case, we see that organismic forms at the macroscopic level have a potential existence independent of the particular microscopic configurations of gene arrays.

Habitus

Another way to problematize gene hegemony in biology is to consider exactly where a species' form might be said to exist. Darwinian biology has established the fact of individual variability in details of form, linking this with concurrent variability among individual genomes. Yet individuals of given species can generally be

identified as members of that species with little trouble. Each is individually different, yes, but in some larger sense all are the same. The concept of ‘habitus’ is useful here. For example, the North American sugar maple tree has a well-known egg-shaped form in middle age when free standing, yet the branching pattern producing that form differs in every individual. This overall form is even preserved when two or three individuals grow so close to each other that they share in producing it. The branching pattern of growth is certainly directly influenced by genetic information, as can readily be seen by comparing the twigs of different species (say, ashes contrasted with maples). Even individuals of one species can have clearly visible branching pattern differences; individual sugar maples can be consistently more, or less, densely twiggy for example. As well, the branching pattern responds easily to environmental perturbations, and yet somehow that overall egg shape of this kind of maple is regulating overall growth of these trees. Mushrooms are interesting in this way as well, it having been noted that the mycelial hyphae making up the mushroom cap are haphazardly tangled together in a way that does not prefigure, or in any way relate to, the species-specific shape of the cap (Bonner, 1952). It is as though the mycelia were poured upward into a mold. So a species has a form which it imposes upon its individual participants, but which cannot be said to be imposed directly by way of a chain of information originating in microscopic genetic transcripts, which could be said to directly produce, for example, the process of branching of twigs. No doubt a geneticist could suppose that some sort of cellular interpretation of environmental cues allows this kind of regulation. If so, it needs to be demonstrated.

At a larger scalar level there is a related phenomenon – the migratory routes of various animals. These are quite stable, and cannot plausibly be represented in the genome, but are learned by individuals from their parental generation. The ability to learn would be, of course, a genetic predisposition, but the actual routes themselves exist only as used. This may be another kind of information that could be said to be “owned” by species, or at least by populations.

Genetic Discourse

I will note here that genetic information shows up in biology discourse as differences between individuals, or species; to the extent that these are similar, genetic information is not invoked, and is discursively irrelevant. Once an inheritable difference is discovered, it is true that searching the DNA will likely uncover a difference therein that can be understood as the underlying informational distinction that can be preserved by inheritance in a population. Yet it remains the case that in the absence of phenotypic difference there is no reason to invoke genetic information – and of course there might be genetic differences that are phenotypically neutral as well. This latter point obviates the argument that phenotypic difference is no longer required to find genetic difference given modern gene sequencing technology. Without correlation to phenotypic difference, however, genetic difference is semiotically meaningless – ‘neutral’ (the exception here is

their discursive use in taxonomy). The import of this would be that, for example, the presence of four limbs in all tetrapods is not a fact related to genetics. Discursively, genes code only for differences, while materially they provide the means for recording those differences. It might even be said that genes create differences, in the sense of stabilizing them.

It has recently been argued that, besides genes, organisms inherit many other 'resources for development' (Griffith and Gray, 1994). First and foremost we should note here the biological system itself, either a daughter cell or a propagule, which clearly are systems of interpretance with respect to the genetic information. No genetic information exists, or is passed on, independently of them. Even viruses have some non-nucleic acid parts. But there is more. Consider local mycorrhizal relationships among plants, or beaver dams and pack rat nests, both of which are inherited within a primary family. And there are trails in the mountains that have been used by deer for many generations. Plants inherit environments that have been favorably modified by their immediate progenitors, as when certain trees and shrubs in dry habitats produce very flammable leaves which accumulate around them to the point where they eventually ignite, burning out competitors that are not, like them, capable of surviving the flames. Then there is the extended family in many mammals and birds – flocks, packs and herds of related individuals, functioning as units. It might be said that these resources could not be exploited except by systems having a particular array of genes, but it is clear that these examples show that biology is much more than a molecular phenomenon. Molecular information in genes functions as switches and placeholders in a much larger material system, itself maintaining non-genetic informational constraints.

What appears to be the case is that macroscopic biological forms, produced after all by nothing more than physico-chemical processes, were implicit – even immanent – in Nature prior to being co-opted by genetic systems by way of a "genetic takeover" (Cairns-Smith, 1982, see also Odum, 1971).

Ecological Equivalence

Robust biological forms independent of genetics exist even at the megascopic level of the biome. There are a number of well-known examples. The pine barrens vegetation is very similar up and down the sandy coasts of eastern North America, even though most of the species existing in the separate regions north and south are not the same. In this case, for example, two very distantly related lineages have produced a striking plant with a curly wooly body that lives draped over tree branches without contact with soil. In the north this is the old man's beard, a lichen, while down south it is the flowering plant (a bromeliad), Spanish moss. A famous example of biome level convergence is the existence of nearly identical Mediterranean vegetation forms in Australia and California, as well as in the Andes Mountains, all regions having similar climatic regimes. We must conclude that potentially accessible forms (deep structures in the structuralist sense) exist at many levels of scale in the world, and can be represented indirectly in coded form in the

microscopic gene arrays in living cells by quite different arrangements. That is to say, we have evidence for stable meanings at all of these levels – ecosystemic and organismic as well as molecular. And so organisms, as such, and biomes, appear to be genuinely semiotic entities, and inform us that biology is not essentially only a microscopic, molecular phenomenon, even if genes are essential to understanding it. Here is an interesting quote from Guenther Stent (1981) on this point:

Consider the establishment of ecological communities upon colonization of islands or the growth of secondary forests. Both of these examples are regular phenomena in the sense that a more or less predictable ecological structure arises via a stereotypic pattern of intermediate steps, in which the relative abundances of various types of flora and fauna follow a well-defined sequence. The regularity of these phenomena is obviously not the consequence of an ecological program encoded in the genomes of the participating taxa.

I should not close this section without noting the extensive mycorrhizal connections between plants in a flora, mediated by various fungi linking plants through their root hairs. These connections suggest the possibility of supraorganismic individuality, as it is known that substances are passed from plant to plant by this route.

Development

Reaching even further afield from genomes, it is interesting to see that processes often held to be biological (and therefore presumably under regulation by genes) are actually found throughout dynamical material systems. A case in point is the pattern of development during ontogeny. When examined using very general informational and thermodynamic criteria, it can be seen that all dissipative structures, living and abiotic, follow the same general pattern, which can be described with four rules, as follows (Salthe, 1993, see also Ulanowicz, 1997):

- (1) There is an asymptotic increase in size, in information content, in orderliness, and as well in gross energy throughput (power).
- (2) There is an initial increase up to a peak, followed by a gradual decrease, in mass specific power, these three phases (peak included) being constructible as the developmental stages, immaturity, maturity, and senescence. Dissipative systems thus exist as higher level developmental trajectories, (immature → mature → senescent), ending naturally in failure followed by recycling. Because of the development of senescence, it is often said that dissipative structures move during their existence toward a mass specific minimum entropy production regime, but few natural ones get anywhere near that before getting recycled.
- (3) There is an increase in internal stability, involving increases in stereotypic behavior which produce loss of flexibility, demonstrating for an outside observer an increasing predictability of internally generated activity.
- (4) Consequent upon the increasing rigidity devolving from (3), there is a decrease in stability to perturbations.

Since this pattern is found in ecosystems and even in abiotic dissipative structures like tornadoes and hurricanes, it cannot be the case that this important developmental trajectory was an invention of biology, requiring genetic information to be passed on to future generations. Rather this canonical pattern is more like a law of matter, 'inherited' by biological systems from their abiotic precursors as a condition for existence as dissipative structures

CONCLUSION

I believe I have demonstrated that there is more information bearing upon biological systems than just that carried in their genetic arrays, and that we must therefore suppose that biology is semiotically more than the consequences of cells interpreting genetic information.

For one thing, the basic microscopic forms and functions of cells appear to be generic for micellar structures, and so these chemical level properties were apparently just co-opted and stabilized by living systems. Therefore, no special information regarding these structures (like the bimolecular leaflet form of the cell membrane) needs to be supposed to be carried in genes. As well, biological systems have inherited the canonical developmental system (Salthe, 1993) that appears to be generic for dissipative structures. Beyond these, and more particularly biological, are forms assumed by organisms as revealed by a species' habitus, which emerges from processes mediated by gene products but seemingly cannot be directly derived from them. This implies some sort of emergent, supramolecular information. Then we have forms involved in phenomena of ecological equivalence, particularly as revealed by convergent evolution, which do not seem to have any connection to genetic information at all, and are the best observations in biology for suggesting the possibility of deep structures in Nature. This view is further enhanced by examples of similarities of whole vegetations at a much greater than organismic scale.

From these considerations, it seems most reasonable to assume that the major role of genetic information in biology has been to stabilize spontaneously emergent material forms and to provide access to structural attractors, which is to say, to harness informational constraints present generally in Nature. (Subsequent elaboration of structure was of course facilitated by genes.) Biological processes appear to have led to the emergence, therefore, of semiotic systems of interpretance at several scalar levels, and so, while biology's key invention – the genetic system – has been the basis of its success, this success was attained only by conspiring with informational properties at large in Nature.

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NOTES

¹ I elaborate here on what I intend by “meaning” and “sign”. Meaning is a degree of matching of indications from an external object’s counterstructures (von Uexküll, 1926) with a system of interpretance’s forms or categories, increasing that system’s sensitivity and readiness relative to that object, as embodied in its constructed interpretants (see Appendix). A sign is the focus of mediation of meaning. A system of interpretance constructs a system of signs – its Umwelt (von Uexküll, 1926, Salthe, 2001) – from its lexicon of meanings. A pansemiotician would suggest that these relations can be generalized throughout Nature.

² A system of interpretance is a locale capable of relating to another (called the ‘object’) by way of generating interpretants, via the process of semiosis (see figure in the Appendix), some of which interpretants then facilitate interaction.

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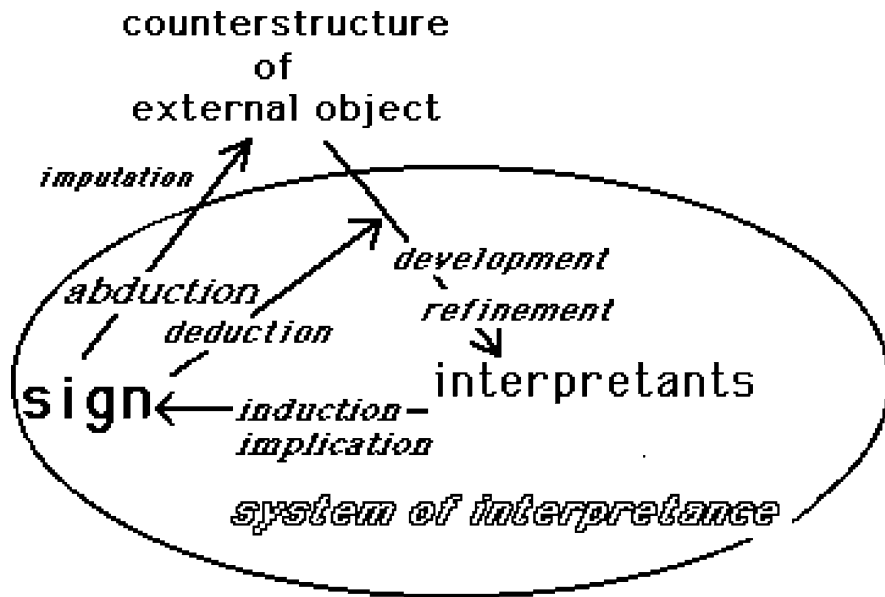
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APPENDIX

This figure shows a system of interpretance engaged in semiosis, as understood in the triadic formulation of C.S. Peirce. I have supplied terms that would be used in human discourse in order to facilitate understanding. However, I intend that these relations should be generalizable to any systems in Nature, providing that they have the requisite complexity for the mapping. As human systems are more specified, or just better known than others, this would usually require simplification of the diagram. Interaction – between some of the system's interpretants and the object – is not represented here.

In biology and in general, macroscopic to megascopic environmental associations generate the objects of semiosis, and so are what afford meanings for the microscopic sequence information in nucleic acids, as interpreted by mesoscopic



systems of interpretation (cells, organisms) successfully engaged in macroscopic niche transactions. Biological interpretants range from induced enzymes in cells to organismic behavioral reactions. Signs in these two systems are constructed as perceptions based on sensations. In cells these involve various transport processes mediated by chaperones. It should be noticed that sensation and perception are themselves (systems of) interpretants.