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Article

Emergence and Evolution of Meaning: The General Definition of Information (GDI) Revisiting Program—Part 2: The Regressive Perspective: Bottom-up

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Abstract: In this second part of our inquiry into the emergence and evolution of meaning, the category of meaning is explored from the manifestation of reality in its corresponding level of interaction towards the interpretation of such reality (the first part deals correspondingly with an appropriate top-down approach). Based on the physical constraints of manifestation through electromagnetic waves, which constitutes the base of animal vision, we analyze the limits of the meaning-offer of such a manifestation, which allows us, on the one hand, to compare the efficiency of natural evolution in the reception of such meaning-offers; on the other hand, to analyze the conditions of developing agency able to acknowledge the reality underlying its manifestation. Regarding the complexity of such an agency and its related pragmatic response, we distinguish different levels, which allow the development of the General Definition of Information (GDI) properly, with respect to interpretation, as advanced in the first part, throughout nature. As we show at the end, our approach provides new grounds for the Unified Theory of Information (UTI) Program, as well as the possibility for bridging other approaches in the converging fields of information, meaning, computation, and communication.

Keywords: philosophy of information; unified theory of information; electromagnetic theory; meaning; perception; biosemiotics

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1. Introduction

> "*… Our uncultivated eyesight […] cannot show us any other more notable parts. […] But we are practised in the discipline which discloses the causes of things, shakes off deceptions of eyesight, and carries the mind higher and further, outside of the boundaries of eyesight*." (Kepler, Epitome of Copernican Astronomy, IV, §I.1 [1])

Though it can be clearly recognized that Kepler, here, refers to the problem of the astronomer who intends to reflect the world properly, it is something that can also be extended to many other cases of acknowledging and reckoning with a confronted reality, even in the everyday perception. This is the quest of the *regressive perspective* in the emergence and evolution of meaning, from the very bottom of the bulk and limited materiality of sensing the world towards its intellection.

In the first part of our GDI revisiting program (The current article constitutes the second part of our inquiry, developed in its progressive and regressive perspectives respectively. It is important to highlight that many of the concepts here used and the criticism to Floridi's approach are properly addressed in the first part [2]), we offered an alternative to Floridi's epistemological account of emergence of meaning, in which a progressive perspective was provided based on current insights of physics and the understanding of agency throughout the hierarchy of complexity from fundamental agents—at the pre-geometrical level—to physical systems, organisms, cognition, consciousness and societies. This vision enabled us, on the one hand, to regard *energy* and *information* as two fundamental aspects of the same underlying structure of the world, related to the *potentiality* of *realization* or *selection* of *changes*, respectively (which are, in turn, dynamically and evolutionary *actualized* in *matter* and *structure*, respectively); on the other hand, to consider the emergence of *autonomous agency* as comprising at the same time: *meanings* (as the courses of efficient and functional actions with respect to eventual interactions within its context, embodied in constraints which enable the driving of work) and *information* (as what enables the selection of courses of action for both the fulfillment of agent's needs and the participation in natural games within its context) [2]. Furthermore, as we have stated, observation occurs at a given level of interaction within the hierarchy of complexity and therefore observables—unlike Floridi [3]—belong, at the same time, to an ontological and epistemological level ([2], Section 5). This *onto-epistemic* stance offers, indeed, a ground for the regressive perspective we are intending in this second part. Here the challenge, as stated by Kepler, concerns the essential limitation of what is actually given by observation with respect to the reality the observer intends to reckon. That is, how the informee unveils the meanings already possessed in the manifestation of reality at a given level of interaction.

As we shall see in Section 2, the manifestation of reality (as it occurs by means of the electromagnetic field around an object, which in turn enables vision) is an emergence in itself. Therein, the interacting parts at the lower level give rise to a sort of regularity in its surroundings. But as we shall prove, the structure of the constituent parts is strictly out of reach from these regularities. According to the electromagnetic theory, it can be shown that the manifestation of an object within a volume has a maximal complexity which states a strict limit to what can be properly reckoned from the object. Moreover, there is a fundamental ambiguity with respect to the structure which could eventually produce the same manifestation. These two characteristics establish: on one side, a natural

limit to the complexity of what can be reckoned; and on the other, the strict requirement of guessing and creatively imagining the world in order to properly reckoning the underlying reality.

The aforementioned *onto-epistemic* stance takes particular relief in the next section (Section 2.2) where we comparatively analyze the limits of the sensing apparatus with respect to the previously investigated limits of the manifestation of objects, showing that animal vision (unlike Floridi's stagnated observables, as argued in [2], Section 3) is very well adapted to the physical limits of the manifestation of objects, though biased by the leeway and constraints of the evolutionary path (in turn dependent of the evolution of autonomous agency; In the first part of our GDI revisiting programme [2], we have generalized Kaufmann's concept of *autonomous agency* throughout the hierarchy of complexity. See Kauffman's works [4–6]). This implies that observables and sensing devices, further from being given—as in Floridi—they tend to adapt to the "constraining affordances" of the manifestation of the object (paraphrasing Floridi). Thus, these "constraining affordances" can be visualized as proto-meanings at the outset, from which further meanings can arise within the interactive frame of the autonomous agency, to which the observer belongs.

From the viewpoint of what is physically given by the manifestation of an object, we seek in Section 3 what can actually be reconstructed from the original structure of the manifesting object. As shown therein, only an equivalent object can actually be reconstructed which in any case requires some kind of guessing. Therefore observation entails what can be branded as *hermeneutical agency* in the first place. By comparing the complexity of the object with the complexity of its manifestation, the feasibility of achieving a correct reckoning of the transcendentally intended object is mathematical analyzed.

In Section 4, an evolutionary perspective of the sensing of reality is developed generalizing the paradigmatic analysis of animal vision developed in previous sections, and distinguishing the following levels of response: objective, cognitive, reflexive, and socio-ethical; thus, throughout the hierarchy of living complexity, from simple organisms to complex societies. By these means, we provide some insights into the decisive problem of the emergence of reflexive meaning and its evolution to which we also referred to in the first part.

In the *concluding remark*, we compare our approach—in both its progressive and regressive perspectives—with other frameworks advanced in the converging fields of information, computation, cognition, and communication, showing that our scaffolding provides new grounds for the development of the Unified Theory of Information Program as proposed by Hofkirchner and others, as well as the possibility for bringing among different endeavors to common challenges.

2. Manifestation of Reality as Emergence

As we argued in the first part [2] and recalled above, at each level of the hierarchy of complexity the co-operating parties produce an action whose course constitutes the *meaning* of the corresponding agency. This meaning produces in nature new regularities, new classicities on the upper levels, which are emergent in both ontological and epistemological senses; ontologically emergent, because they represent properties which are not reducible to the mere superposition of the properties of the involved parties, but essentially dependent on the rules of interaction; epistemologically, because these regularities constitute the environmental uniformities that agents—at the macrolevel—can sense.

Although we might consider different kinds of sensing, vision constitutes a paradigmatic and highly developed way of sensing the environment, quite extended throughout animal species. It entails the reception of the electromagnetic radiation coming from objects which generally scatters an illuminating homogeneous radiation (at least homogeneous in comparison to the heterogeneity of the scattered radiation). Abstracting the means of sensing this radiation, we can regard this scattered field surrounding the object as the manifestation of the object itself, or as *potential observation*, which is indeed emergent to the underlying reality—as we will see by analyzing the nature of such radiation—in the sense that it is not the mere superposition of its parts but a result of its constituting interactions within the environment—of specific electromagnetic properties. This emergence, in which the reality causing the actual manifestation is contingent to the manifestation itself (*i.e.*, it can be produced by an open set of equivalent objects), imposes to the subject of observation an ontological boundary with obvious epistemological consequences. Further epistemological boundaries are given by limitations of the electromagnetic sensing apparatus of animal vision.

2.1. Physical Limits of the Manifestation of Reality

Although the normal case of observation is constituted by the scattering of an illuminating radiation, the problem of perception is actually related to the attention on the heterogeneities due to the scattering field, therefore it is reasonable to focus on the equivalent problem of observing a set of electromagnetic radiating sources—then overlooking illumination. If we hypothetically knew the set of radiating sources, the question of how they manifest over a domain of potential observation $\mathcal{D}$, as illustrated in Figure 1a, can be directly handled by the usage of the Maxwell equations. The straightforward linearity of these equations allows us to apply superposition in order to find out the field distribution over the domain of interest. This problem is commonly named "forward problem". However, the problem of perception is opposite: the field distribution in an observation domain—the retina—is to some extent *given*, while the related source distribution is *intended*. This is usually referred to as "inverse problem". According to the electromagnetic uniqueness theorem, there is a unique solution of the field distribution surrounding the sources whenever it is given either the electric or the magnetic field at any surface enclosing the sources, for instance at surface $\mathcal{S}$ in Figure 1 (*cf.* [7]). Hence, there is a degree of freedom corresponding to which surface is selected; in other terms—as could also be argued using Schelkunoff's equivalent theorem [8]—a volumetric distribution is obviously undetermined by a surface distribution. The contingency of the actual source distribution with respect to the actual manifestation constitutes a basis for speaking of manifestation as emergence: it is the co-operation of the parts related to the organization of the field produced by each part which manifests as a whole. This represents an ontological limit directly related to the epistemological boundary of delving into the object enclosed by $\mathcal{S}$.

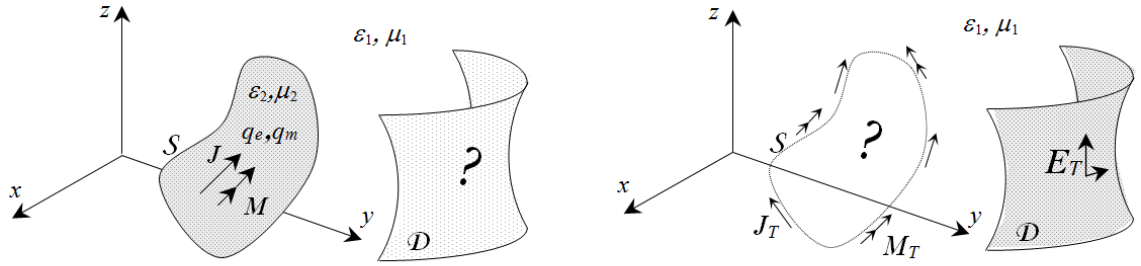
The feasibility to solve the inverse problem can be handled in terms of complexity of the information provided by the electromagnetic fields generated by the object. In fact, the complexity of an electromagnetic field of wavelength λ is strictly limited (as one of us has proven elsewhere [9–12]):

(i) There is a minimal distance between independent intensity values, which is $\lambda/2$ for an arbitrary observation (*sampling theorem for arbitrary observation*) and $\lambda d/2a$ for observation at a distance

d from an object within a ball of radius *a* (*sampling theorem for distant observation*). This minimal distance can also be regarded as the size of the smallest perceivable details (or heterogeneities).

(ii) The maximal Kolmogorov complexity of the field produced by a source within a ball or radius *a* is limited to $N = 32\pi(\tau a/\lambda)^2$ (*complexity theorem for radiation field*), where $\tau \geq 1$ stands for an excess of the maximal spatial frequencies with respect to $2\pi/\lambda$ at $\mathcal{S}$, related to the relative presence of evanescent modes in the vicinity of the object.

Figure 1. (**a**) In the *forward problem*, the linearity of the Maxwell equations provides a straightforward solution; (**b**) In the *inverse problem*, the uniqueness and equivalent theorems limit the problem to the determination of a superficial distribution.



(a) Forward Problem (b) Inverse Problem

Concerning this maximal complexity, it is interesting to point out, on the one hand, that no matter how big the complexity of the object is, the field distribution surrounding the object cannot be bigger than *N*; on the other hand, that such complexity depends on a^2, thus on the area of the surrounding boundary, not on its volume; consequently, the ambiguity provided by the radiation of the object with respect to its volumetric structure corresponds to one dimension (see note [13]). Nevertheless, though *N* constitutes a natural boundary of what can be given by the field generated by an observed object, this is just a maximum rarely reached by such field, and—what is more important to the problem of reckoning the object upon its manifestation—by the complexity of the object itself, say, N_O. It is clear that if $N_O > N$, finding out the structure of the object from its field is out of reach, the question is then whether the observation is enough for finding out the structure of the object in case of $N_O < N$.

This isolated regard of the manifestation of an object with independence of the observer should not be interpreted as a pure realist or objectivist stance. It is, indeed, the interaction with the environment what is here considered since the space where the electromagnetic field takes place is much more than nothing (in the sense of ontological emptiness), it has a structure, which can be expressed in terms of electric permittivity and magnetic permeability. With respect to the observer, the validity of our classical electromagnetic analysis implies that the observer has a small effect in the whole field distribution. Therefore, the field distribution around an isolated object can be regarded—under this assumption—as *potential observation*.

2.2. Limitations of the Sensing Apparatus

Whilst the aforementioned limitations are independent of any sensing ability, it is also worth considering how the sensing structure of animal vision is adapted: on one hand, to the physical limitations of the electromagnetic radiation; on the other, to the leeway and constraints offered by the

evolutionary path, as can be—for instance—observed through comparison between vertebrate and cephalopod vision. This viewpoint represents a significant difference to Floridi's account of data and the *Levels of Abstraction* (LoA, which are in turn constituted by *observables*): whereas in Floridi the LoA are given, we try to explore what can be regarded as its emergence. We consider that such emergence is linked—using Floridi's terminology—to the "*constraining affordances*" of data, for whom only the *Gradients of Abstraction* are susceptible of emerging through the corresponding *behaviors* (which are nothing but reference at the end, as argued in the first part, and consequently only epistemological emergences are properly considered and these in a very limited sense: [2], Section 3.1; *cf.* [3]).

Comparing the physical limits of the electromagnetic fields—regarding the distribution of details—with the structure of the retina, we observe that the distances between photoreceptors are within the boundaries stated by the aforementioned limit (i): whereas the minimal expected distance between independent values of the electromagnetic field is 0.2–0.4 μm for visible spectra (400–800 nm), the minimal distance between photoreceptors (corresponding to its maximal density at the fovea of human retina) is 2.2 μm on average, and 1 μm for animals with maximal visual acuity (some birds), which clearly does not surpass the physical limits [14,15]. Moreover, regarding the gap between physical and vision details, we might ask why the vision apparatus of some species did not evolve to reach the physical limit—particularly considering that it could provide an adaptation advantage. For finding out an answer to this reasonable question, we should consider at least two important constraints of vertebrate vision:

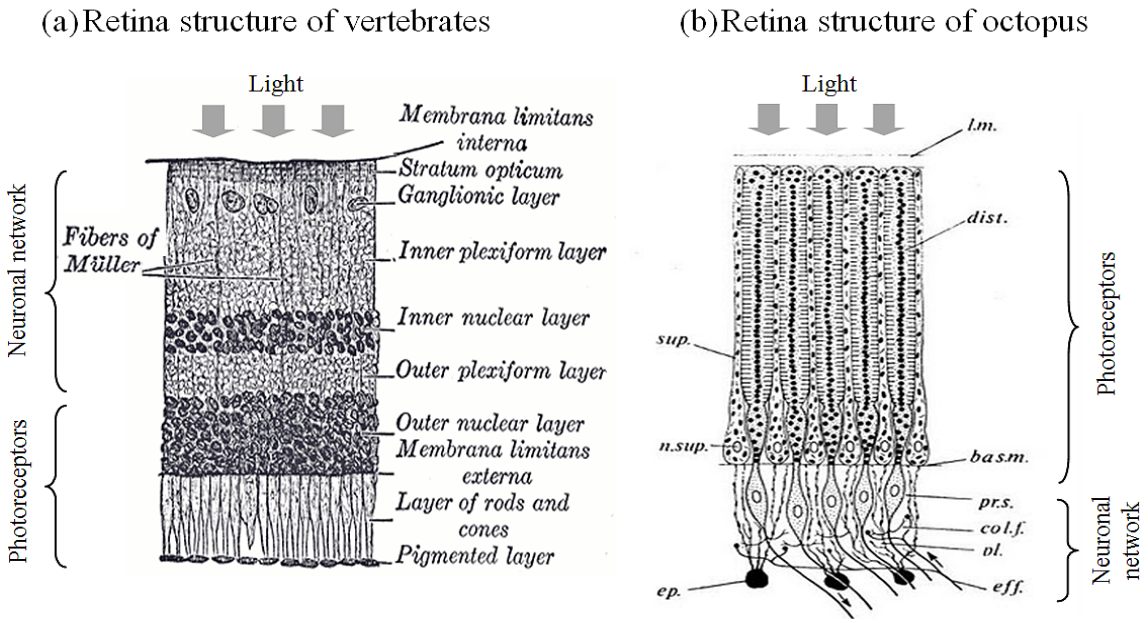
(1) *Diffraction* at the photoreceptors due to the nervous network located over the photoreceptors layer as shown in Figure 2a (which is the most common case for camera-type eyes, though not for cephalopods for instance, which vision—Figure 2b—though functionally similar, followed a different evolution path with respect to vertebrates since about 600 million years ago [16,17]);
(2) *Spherical aberration*, due to the roundness of the eyeball structures, which therefore decreases if the eye size increases.

Besides fine disturbances due to the former, its weight clearly increases if the eye size also increases (since dispersion happens through a longer distance); therefore both constraints impose an antagonist pair which distances vision acuity from the possibility of perceiving the heterogeneities actually present in the electromagnetic field. As argued in [15], the peculiarities of bird vision probably allows a best compromise in which the minimal distance between independent values of the field at the photoreceptors layer is about 1 μm. But, beyond this relative optimal, the question is why vertebrate vision did not evolve as in the cephalopods, locating the photoreceptors above the neuronal network. To this respect *Lamb's hypothesis* [16] offers a suggestive explanation.

Animal photoreceptors are either of rhabdomeric- or ciliary-type. The former are common in invertebrate, the latter in vertebrate vision. However, ciliary-type photoreceptors are also present in most organisms for non-visual purposes (sensing light for regulating circadian and seasonal rhythms), whilst rhabdomeric-cells subsist in vertebrates, though transformed into projection neurons. By means of primitive evolution of vertebrate, in abyssal dark environments, the photosensitive rhodopsin of ciliary photoreceptors experimented a change conferring to these photoreceptors higher sensitivity than what is achieved by rhabdomeric ones. This advantage allowed the colonization of dark ecological niches (probably just for circadian and seasonal regulation at the outset). In this context rhabdomeric photoreceptors became useless adopting a new role: transmitting and processing signals to the brain.

Since—in the former topology—these photoreceptors were directly located where the light comes from, this topology imposed a constraint that could not be reverted causing that the neuronal network was developed above the photoreceptors and therefore producing the aforementioned drawback (1). Nevertheless, the advantage provided by the given evolution concerning sensibility is clearly expressed by the fact that vertebrate rods are susceptible by only one photon, therefore reaching the strict physical limit to this respect.

Figure 2. Comparison of the structure between (**a**) vertebrate and (**b**) octopus retinas. In vertebrates, the light must pass through the transparent neuronal network causing dispersion before it reaches the photoreceptors (of *ciliary*-type), whilst in the retina of the cephalopods the photoreceptors (of *rhabdomeric*-type) are immediately under the membrane limiting with the vitreous body. (The illustration has been elaborated using illustrations from Gray [18] and Young [19]).



But coming back to the fact that visual acuity—even in birds—is somehow distant from the *potential manifestation* of reality, analyzed in the previous section, we can state that given the constraints of the evolving structure, the sensing apparatus agrees with the maximal heterogeneity that such type of structure can get to detect. Recalling Thom's semiological approach [20–22,23], as summarized in the first part ([2], Section 5.2), the eye morphogenesis can be visualized in terms of a *chreod* action which mediates—in the situation of conflict represented by the coexistence with other living beings—the complexity of the manifestation (so to speak, meaning of the first order) with the complexity of the sensing (meaning of the second order).

Besides the aforementioned antagonist limitations of animal vision, there is another major constraint which is worth considering:

(3) The lack of sensibility to phase variations of the received field, which implies—as one of the authors has shown [9]—the unfeasibility to determine a unique distribution over a surface bounding the object from the observation at just one surface (e.g., the retina of one eye).

In this respect, it is interesting to notice that natural evolution has solved this constraint through combination of two eyes, even though camera-type eyes probably evolved from the pineal gland, thus without bilateral symmetry at the outset. On the one hand, this is coincident with the mathematical analysis of the electromagnetic field distribution—limited to amplitude values, *i.e.*, without phase variations—since there is a biunivocal relation between the field amplitudes over two separate surfaces and the full field distribution (in amplitude and phase, which in turn allows reckoning the field at any other part of the surrounding space); on the other hand, we observe here again the aforementioned morphogenetic development which mediates between the meaning offer of the electromagnetic field and the sensing apparatus, as can be observed by following Lamb's hypothesis for the evolution of vertebrate vision [16].

But to understand this morphogenetic dynamic in the unveiling of the meaning inherent to phase variations, some beneficial driving of energy has to be distinguished in order to explain the merging of meaning through an agent's action. In this case, the emergence of the bilateral symmetry in the evolutionary path has to be justified from the starting point in which the light-detecting organ only served for circadian regulation. To this end, it can be suggested that even for a very simple eye, composed by few photoreceptors (even by only one), the distinction of the light directivity can be efficiently achieved through a synchronic combination of the light detected by two separate photoreceptors, one at each eye (similarly to an interferometer, or an array antenna composed by two elements). That this separation happened on the horizontal direction can be firstly explained by the fact that the vertical component of light is fixed in abyssal depths, secondly because there are other means for vertical orientation based on gravity sensing, as available even at the cell level. Therefrom, after the organ has already acquired the function of detecting light directivity, the aggregation of photoreceptors in each eye (following a same ordering rule) could be developed in the course of unveiling the complexity already possessed by the electromagnetic field. That this reached up to a limit, imposed by the topological constraints of the photoreceptor through the chain of adaptations (which can be visualized in terms of situations of conflict, recalling Thom's approach), is what we argued above.

3. Emergence of Intention: Closing the Hermeneutical Cycle

Turning back to the analysis of the physical problem as stated in Section 2.1: in case of $N_O < N$, the observation of the object could be enough—from the viewpoint of the necessary information amount—for grasping a proper idea of its volumetric distribution. However, since there is in principle an unlimited number of inner structures whose projections over a bounding surface are equivalent, as well as an undetermined number of projection surfaces, such an "idea" (or model of the observed reality) should be achieved based upon some guesses, assumptions or *a priori* knowledge of the inner structure. These can be interpreted as the semantic or algorithmic ground for reconstructing the object, in the sense of the algorithmic information theory [24], but considering the very evolution of these semantic grounds, it can also be visualized in terms of Thom's *logoi* dynamics, referred to in the first part (*cf.* [2] Section 5.2; *cf.* also [20–22]).

However, disregarding this evolutionary perspective of interpretation, to which we will return afterwards, the limits of interpretation can be better analyzed by properly posing the problem of observing an object within a bounded region, and assuming that the interaction level in which

observation takes place can be well described by the Maxwell's relations, to which also the previous physical analysis (Section 2.1) refers. This obviously corresponds to an idealized situation, but, on the one hand, natural observation tends to it (as we proved above); on the other, it serves to evaluate the limits of what natural observation can achieve.

3.1. Physical Limits of the Meaning-Offer

According to theorems (i) and (ii) together with the aforementioned equivalent theorem [8], it can be shown that a useful way to make the inverse problem well-posed is by locating N equivalent tangent point sources over $\boldsymbol{\mathcal{S}}$ regularly spaced at a distance $\lambda/2\tau$:

$$\hat{\mathbf{s}}(\mathbf{r}) = \sum_{i=1}^{N} \hat{\mathbf{s}}_i \delta(\mathbf{r} - \hat{\mathbf{r}}_i') \tag{1}$$

where: $\hat{}$ is here generally used for symbolizing guessing (or variables corresponding to the model of the object), $\{\hat{\mathbf{r}}_i'\}$ is the set of locations of the equivalent point sources, and $\hat{\mathbf{s}}_i$ represents the intensity of an equivalent point source situated at $\hat{\mathbf{r}}_i'$. The space of equivalent manifestations,

$$\hat{\boldsymbol{\Psi}}(\mathbf{r}) = \mathbf{G}(\mathbf{r}) * \hat{\mathbf{s}}(\mathbf{r}) = \sum_{i=1}^{N} \hat{\mathbf{s}}_i \mathbf{G}(\mathbf{r} - \hat{\mathbf{r}}_i') \tag{2}$$

generated by the space of equivalent source distributions $\{\hat{\mathbf{s}}(\mathbf{r})\}$, is equivalent to the set of eventual manifestations of any arbitrary inner (discrete or continuous) volumetric distribution. (In the appendix, some details are provided about how to interpret these mathematical entities physically, as well as how to derive them from the Maxwell relations).

If—for the sake of simplicity—we suppose that the real source is described by a set of N_O Dirac delta distributions of different amplitude and position within the volume enclosed by $\mathcal{S}$:

$$\mathbf{s}(\mathbf{r}) = \sum_{i=1}^{N_O} \mathbf{s}_i \delta(\mathbf{r} - \mathbf{r}_i') \tag{3}$$

whose manifestation is given by:

$$\boldsymbol{\Psi}(\mathbf{r}) = \mathbf{G}(\mathbf{r}) * \mathbf{s}(\mathbf{r}) = \sum_{i=1}^{N_O} \mathbf{s}_i \mathbf{G}(\mathbf{r} - \mathbf{r}_i') \tag{4}$$

Despite the formal similarity of Equations (2) and (4) it is worth emphasizing the relevance of the differences N *vs*. N_O, and $\hat{\mathbf{r}}_i'$ *vs*. $\mathbf{r}_i'$. On one side, Equation (2) is directly related to the maximal complexity of the field distribution N, no matter to which actual (volumetric) distribution is linked, and the proper distribution of $\{\hat{\mathbf{r}}_i'\}$ ensures the independence of the fields generated by the equivalent sources. On the other side, N_O refers to the actual complexity of the volumetric source distribution, being $\{\mathbf{r}_i'\}$ the locations where the sources actually are. Thus, due to the independence of $\{\mathbf{G}(\mathbf{r} - \hat{\mathbf{r}}_i')\}$, Equation (2) is invertible, whereas there is no warranty about the invertibility of Equation (4). Furthermore, since $\boldsymbol{\Psi} \in \{\hat{\boldsymbol{\Psi}}\}$, it is possible to determine a unique equivalent distribution belonging to $\{\hat{\mathbf{s}}\}$ and compatible with $\boldsymbol{\Psi}$:

$$\hat{\mathbf{s}}(\hat{\mathbf{r}}') = \boldsymbol{\Psi}(\mathbf{r}) * \mathbf{G}^{-1}(\mathbf{r}) \tag{5}$$

which—as illustrated in Figure 3—can be conceived as the *meaning-offer* of $\boldsymbol{\Psi}$ upon the semantics described by Equations (1) and (2), which does not refer to what is really there, but to what can be generically manifested by an arbitrary source distribution enclosed by $\mathcal{S}$.

Figure 3. On the left: spaces of (supposed) reality and manifestation of the object, when the complexity is constrained to N_O punctual heterogeneities; on the right: spaces of manifestation (or information) and meaning-offer on the observer (subject) side, whose complexity is constrained to N punctual heterogeneities. The real structure of the object (here determined by N_O values and positions) remains veiled to the subject, whereas a projection in the space of N point heterogeneities can be achieved.

Reality	$\mathbf{s}(\mathbf{r}) = \sum_{i=1}^{N_O} s_i \delta(\mathbf{r} - \mathbf{r}')$	
Message (manifestation)	$\boldsymbol{\Psi}(\mathbf{r}) = \mathbf{s} * G(r) = \sum_{i=1}^{N_O} s_i G(\mathbf{r} - \mathbf{r}'_i)$	$\hat{\boldsymbol{\Psi}}(\mathbf{r}) = \hat{\mathbf{s}} * G(r) = \sum_{i=1}^{N} \hat{s}_i G(\mathbf{r} - \hat{\mathbf{r}}'_i)$
Meaning-offer		$\hat{\mathbf{s}}(\{\hat{\mathbf{r}}'\}) = \sum_{i=1}^{N} \hat{s}_i \delta(\mathbf{r} - \hat{\mathbf{r}}') = \boldsymbol{\Psi}(\mathbf{r}) * G^{-1}(\mathbf{r})$
	Reality and Manifestation of the emitter (object)	What is offered to the receptor (subject) concerning the object

3.2. Unveiling Reality: Hermeneutical Agency

But returning to the case in which $N \gg N_O$—which is a rather typical case if we disregard small scale heterogeneities and consider the low entropic objects we usually deal with—the real complexity of both the object and its manifestations is much smaller than the complexity corresponding to Equation (5), then some representation could be found in which the description becomes shorter. The simpler the description, the better it can be cleaned out from noise and therefore it is received cleaner. Nevertheless, it is well known that—according to Turing's halting theorem—there is no recursive method to decide if the minimal description is actually achieved. It is thus a question of proper guessing, of finding out a proper semantics which allows the interpreter to achieve a better representation compatible with the observed manifestation. This action is carried out by an *hermeneutical agent* who similarly to how nature enabled the emergence of the manifestation through the co-operation of the radiating parts, the cycle of interpretation is closed by creatively constructing a possible path for the emergence of the given manifestation, though it remains opened in virtue of the possibility of finding an even more efficient description. Being the hermeneutical agent a part of nature, nature can recognize itself.

The fact that the real object is not merely given by its manifestation makes the task of interpreting or modeling the object transcendental. By considering the hermeneutical subject and its activity on its material flesh as well as its hermeneutical activity we are moving within the frame of *transcendental materialism* as thorough developed by one of the authors [25]. Given our formulation of the *hermeneutical agency*, it is reasonable to consider that the hermeneutical task consists of reducing as

much as possible the complexity of the representation, which always remains as an open task: on one hand, because one can always strive for grasping new notes of the object; on the other, because there is no sure means to know that the minimal description has been achieved for the given data.

This evolution of hermeneutic agency can be nicely exemplified beyond the case of visual perception by the historical development of the astronomical system: Tycho-Brahe's model represents an important advance with respect to Ptolemaic system by stretching the observation; whereas Kepler's model represents a more efficient hermeneutic agent with respect to the former by simplifying the descriptive means, as it has been discussed by one of the authors [10]. Another interesting example for the evolution of hermeneutical agency within scientific advance (also therein discussed) is clearly illustrated by the superseding of the systems of living species of Aristotelian type (as e.g., the Linnaean taxonomy) by others of evolutionary type (as Darwin's evolutionary taxonomy).

4. The Levels of Interpreting Reality

Through evolution of complexity, the sensing apparatus increases its own complexity, which in turn causes an increase in the complexity of the related responses and representation means. As we have seen in Section 2.2, the improvement of the sensing means drives the autonomous agent towards the meaning-offer of the physical manifestation of objects, which in turn implies an increase in the ambiguity concerning the relation of what is given by sensation and what can be found out therefrom.

At a lower level of complexity, the sensing apparatus offers a small ambiguity with respect to what is signalized. In the extreme case, minimal sensing would only signalize that something has changed in the environment—which in addition, constitutes the primordial note of any sensing—though without further precision. We can also speak of minimal sensing whenever what is signalized is of the kind: there is light; it is daytime; it is cold; there is too much acid, *etc*. In an evolutionary sense the specific sensing of the agent enables an adaptive finding of a proper "*objective response*" that must be stored in the organic codes (in the sense of Barbieri [26], as referred to in the first part [4] and clarified below). In higher complexity levels, the ambiguity—provided by sensation with respect to what is signalized—increases, bringing about the need of improved means of representation and memorizing in order to solve such ambiguity, which enables the emergence of *reflexive response*, and *hermeneutical agency*.

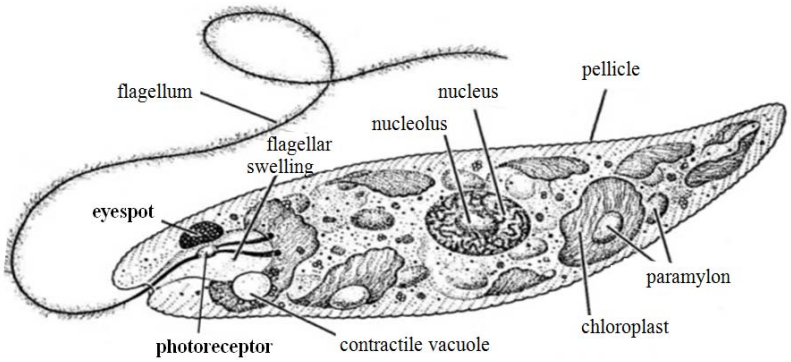
For the sake of clarity we can speak of four differentiated levels of response with regard to the sort of sensing the manifested reality, which can be typified as: *objective*, *cognitive*, *reflexive*, and *socio-ethical*.

4.1. Objective Response

The cell provides a paradigmatic case of *objective response* which is also present at systems of higher complexity—as it constitutes its basis. A cell, in general, has several means of sensing the environment and adapting to those variations which are relevant for its survival. Since we have been dealing with visual sensing, it is here interesting to consider the minimal case of seeing as represented, for instance, by the unicellular organisms of the genus *Euglena,* illustrated in Figure 4. These cells have an eyespot apparatus which filters sunlight into the photo-sensitive structures at the base of its flagellum. This eyespot enables the cell to sense the strength and direction of light, and straightforward to move accordingly towards a medium of moderate light, away from darkness and bright light. (In the Euglena the afferent structures of

the cell—Sensing the environment—are directly connected to the efferent ones—the flagellum which causes the necessary movement towards a more suitable environment. *cf.* [27,28]). The ambiguity of perception is here very low: the strength of light is high or low, and it comes from this or that direction. And it is also low the accuracy in the determination of the environmental state.

Figure 4. General anatomy of a Euglenoid cell (The illustration has been elaborated from the artwork in Purves [29]).



Generally speaking, in the *objective response*, the meaning is substantiated in the organic structure (constituted in the Euglena by the photoreceptor, the eyespot, the flagellar swelling, the flagellum, and a contractile vacuole, linked by topologic, and mechanical and chemical relations), in which, a set of constraints enable an effective utilization of energy. However if—in an evolutionary sense—we observe it diachronically, these constitutive relations are established with respect to its effectiveness in offering an adaptive benefit. The dynamics of these relations (constraints for the proper driving of work) are substantiated in the corresponding evolution of genetic codes (in the sense of Barbieri [26]). Genetic codes offer at the same time means to the memorizing of effective constraints—namely, meanings—and change of these constraints for further adaptations.

From the viewpoint of our understanding of information: the light comprises in the first place—besides energy—the meanings of the directivity in the driving of energy and its amount. Such meaning-offer is in itself the result of an interaction with the real space. To this respect, we can speak of first-order meaning and first-order interaction. However, this meaning-offer or first-order meanings represent a potentiality with respect to the selection of change in the cell for a proper driving of energy, which constitute second-order meanings. The action of the cell allows the actualization of its structure, which in this example implies some tropism, based upon the received information. The cell as an autonomous agent performs an effective driving of energy for the benefit of the cell in its survival. We can thus speak of proto-hermeneutics since the preliminary meaning-offer has to be actualized within the meanings of the cell, materialized in the organic structures, which produce fixed actions with respect to the given interaction. Therefore, the response and its related meanings are objective in the sense that they comprise a fixed reaction and an objectivized mechanism of response.

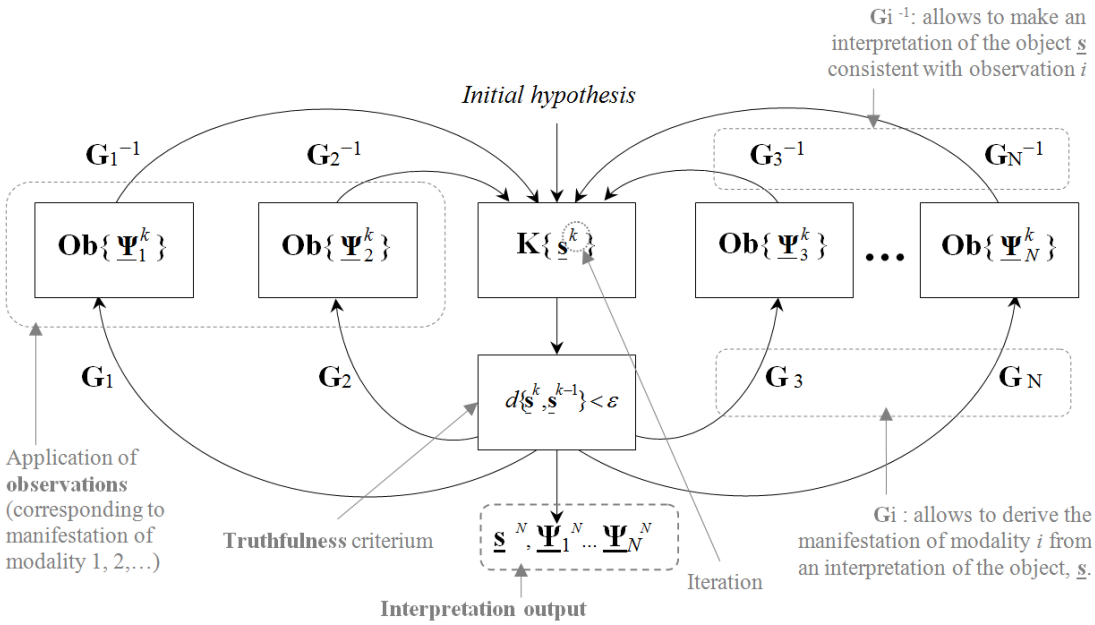
4.2. Cognitive Response

In the *cognitive response*, the complexity grows alongside the formalization means for the apprehension of reality, which in turn requires the ability of guessing within the ambiguity given by

the sensing and the manifestation of reality itself (as analyzed in Section 2.1). Comparing the sensing of the cell, mentioned above, with the animal vision: both the ambiguity and the information about the observed reality increases significantly. Grasping more notes of reality—particularly if they have different modality, for instance, visual and tactile notes as discussed in [12]—the ambiguity, left by some partial perceptions (e.g., a visual percept), can decrease although new kinds of ambiguity may appear. Probably, it is a clue of perceptual evolution, the completeness of percepts, through adapting new ways of sensing for given environments and given agencies, as it could be the case of the two eyes vision argued in Section 2.2 for solving the ambiguity of phase-less light reception at the retina.

This completion of sensing by different modalities can be represented by the algorithm depicted in Figure 5 (adapted from the generalized method of successive projections developed by one of the authors for the tackling of inverse problems [9]). Since all percepts must be consistent with the interpretation of the object, it can be shown that—in virtue of the convexity of the linear relations $\mathbf{G}_i$, which linkage between interpreted objects and what is observed can be expressed by Equation (2)—the solution asymptotically converges towards a stable solution through successive and recursive application of observation-data. A tolerance with respect to the achieved stability of the solution, represented by the parameter ε, constitutes a pragmatic compromise which can be easily mapped in human perception. Such tolerance represents the referred open character of perception and implies a truthfulness criterion significantly different to the one proposed by Floridi in his Correctness Theory of Truth ([3], Chapter 8).

Figure 5. Algorithmic approximation to the completion of percepts by different sensing modalities (based on the method of successive projections developed for the solution of inverse problems [9]). **Ob**{ } represents the combination of the observation of modality *i* with the non-observed manifestation, as provided by the previous interpretation of the object through $\mathbf{G}_i$ (which in turn links the interpretation of the object $\underline{\mathbf{s}}$ with the manifestation of modality *i*). Whereas **K**{ } represents the constructive (at any iteration) through $\mathbf{G}_i^{-1}$ based upon such combination of observable and non-observable manifestation.



Unlike the linearity of relations $\mathbf{G}_i$—as referred to in Section 3.1—in case of cognitive subjects, non-linear relations—mediated by memory—are established between sources and phenomena, achieving a much faster algorithmic convergence. Furthermore, since different neuronal subsystems specialize in the response given to different sensing modes, instead of the successive application of sensing data, the cognitive response simultaneously apply different sensing modalities, which—though operative equivalent—offers an adaptive benefit regarding time-efficiency.

If we understand the algorithm here depicted as the agent activity in which actualized information (within the cognitive structure, which in turns actualizes the interpretation of the object, **K**{ }) is computed upon the information provided through observation **Ob**{ } (including previous computations), the model offers significant alignment with the *info-computationalism*, as advanced by Dodig-Crnkovic [30]. However, we consider of fundamental relevance the distinction hereby established between information and energy, as well as between potential and actual information (the latter represented by structure), which in Dodig-Crnkovic's approach seem to be blurred.

To the issue of the actualization of the cognitive structure, at this level of complexity (*i.e.*, higher than objective response but lower than reflexive one), neuronal-epigenesis, learning, and memorizing play a significant role. *Learning* in the specific environments where animal life is going to be developed (often through games of immature animals) probably enables the acknowledging of relevant objects with which the animal will have to deal with. By means of this acknowledgment, stored in the animal *memory*, the ambiguity of sensing is solved and can be directly related to a behavior which is in a large extent determined by the genetic code (though its weight is lesser for higher animals). Therefore the apprehension of reality can be directly linked to a particular response (or better say, to a complex set of responses), in which the efficiency of the animal agency is found (related to the adequate driven of energy for the animal itself). As long as the response is fixed, we cannot speak of reflexive response; in the extent that the ambiguity of the apprehension of reality is solved in the cognitive system and its related memory, we cannot speak of objective response.

4.3. Reflexive Response

In the *reflexive response*, since the response to the apprehension of reality is not fixed once and for all, offering through evolution a growing open character, the interpretation, though also mediated by learning (stored by memory), is left open to further revision, deepening, correction… as particularly observed in humans. It is however worth remarking that responses of *objective* and *cognitive* type—referred to above—are in a large extent present in humans. For instance, it is an "objective response" the immediate removing of the finger that is pricked by the rose spine. Indeed the repertoire of human responses of this kind is really extensive. Certainly, most of our somatic and visceral activity is regulated by inner and outer sensing, unconsciously imposed, and frequently by means of a neuronal communication not passing through the cortex. Nevertheless, it is also a remarkable feature of our nervous system, in which evolved connections coexist with more primitive ones, that the cortex holds the possibility of interfering with the "objective responses"—though with some delay. This is because the spinal cord transmits the sensitive impulses simultaneously upwards and downwards (*cf.* [31,32]). We can observe this feature as a consequence of the aforementioned "leeway and constraints of the evolutionary path" (Section 2.2).

In any case, besides this coexistence of responses of lower complexity, it is characteristic of the reflexive response that the apprehended reality can be directly sensed as reality itself and not only as stimulation, *i.e.*, as what produces a reaction for the adaptation to the sensed changes. Being the manifestation of reality essentially ambiguous or incomplete (for physical manifestation—as shown in Section 2.1—there is a degree of ambiguity corresponding to one dimension with respect to the space of representation, which can be, for instance, the four dimensional space-time) reality is sensed by the reflexive agent as fundamentally opened, in two senses: (i) with respect to the very object as something that has to be further fathomed; (ii) concerning to its connection with the environment to which it can be bounded by different functionalities. This is particularly the case of sensing objects in cultural contexts (including its related technical means, social, as well as political and economic relations). In agreement with "perceptual functionalism" (as developed by Brunner *et al*. [33]) or Foerster's perceptual epistemology [34,35], we can state that perception, driven by subjective dispositions, necessities and objectives, has a sort of hypothetical character susceptible of modification, deepening and correction. But according to Gestaltpsychologie the creative abductions that are needed in the hermeneutical process, requires a structured and holistic apprehension of the *interpretandum* as a whole (including its connections with the environment).

The example given above (Section 3.2) of scientific discovery illustrates both the openness of hermeneutics, linked to an evolutionary arrow, and the structuration of the wholeness (in which reduction of complexity of the interpretation is a sign of effectiveness of the related agency). By this means, interpretation operates as nature: it searches for the simplest means (*i.e.*, most effective with respect to used resources) for defining the agency in which the observed reality is involved. Since the course of action of the autonomous agent constitute its own meaning, when the interpretation is correct, the reflexive and the objective meanings (or their intensive and extensive aspects) agree (*cf.* [2], Section 3.2).

4.4. Social and Ethical Response

In the *social response*, the autonomous agent is defined by the relations established among reflexive agents, substantiated roles and moral behavior. In the emergence of *social agency*, there is often no reflection on the involved benefit, though cultural semantics leave a degree of openness concerning the involved relations, which enable trial and error, but also free interpretation by means of which the imagination of new relations can offer shortcuts in the search of improved adapted agency. *Political agency* can be conceived as aligned to the latter, while many situations reported by anthropologists offer excellent examples of both. For instance, the family structure studied by Claude Levi-Strauss [36]—particularly the Australian systems—or the interesting case of change in the ecological conditions mapped in the "Asdiwal story", reported by the same author [37]. As he analyzed, a clear semantic openness was exhibited only in the time in which new relations were sought until a new ecological equilibrium was achieved. Interestingly, the semantic openness is closed through new bipolar distinctions adapted to the new relations. This points to a relevant feature of *cultural symbolic universes* which meanings are adapted in normal conditions to *effective agencies*: offering closure—often blocking intentional agencies at the lower level—when agency is effective; exhibiting growing degrees of openness when the corresponding agency is not any more effective.

Whenever the agency is stable, the meanings of the related semantic universe constitute the constraints which appropriately drive the energy to produce work in benefit of the social agency itself. *Moral* values constitute an important means for building constraints at this level of complexity.

Particularly in the cases in which there is an intentional search of new social agencies, it is possible to speak of self-reflection. The subject has to interpret herself in the social wholeness. Retrospectively she can fathom her biography immersed in social, cultural and historical worlds; prospectively, she can imagine possible utopias (in the sense of Bloch) in a creative search of more appropriate agencies. This self-reflection of the appropriate relations for the driven of social action constitutes the *ethical* reflection in itself. It targets at the objective of finding a more appropriate agency, which can be very well symbolized by the Spinozist proposition we quoted at the beginning of the first part: "The more perfection a thing possesses, the more it acts and the less it suffers, and conversely the more it acts the more perfect it is" [38].

5. Concluding Remark: Towards a Common Understanding of Information and Meaning (Plea for a Unified Theory of Information)

As we mentioned at the beginning of the first part of this GDI revisiting program, our inquiry into the foundations of meaning throughout nature in both the progressive and regressive perspectives (complying with the scientific knowledge of the world) was intended for clearing the road to the development of a Unified Theory of Information (UTI) as proposed by Hofkirchner and others [39,40]. We therein stated the dependence of this success with respect to a well-established foundation of physics, able to unify the theories of relativity and quanta. Though this has not yet being achieved, we have adopted hereby a vision which—being consistent with deep-rooted theoretical and experimental accounts—enables us to unfold an evolutionary understanding for the emergence of complexity and meaning in physical, biological, cognitive, and social systems; visualizing emergence in a sense that is ontological and epistemological at the same time (and can also be understood as emergence of classicities). Such insights enable to devise the General Definition of Information (GDI) proposed by Floridi throughout nature properly; regarding information alongside its related meaning as fundamental aspects of the structure of the world.

We estimate that the approach hereby advanced meets all the requirements of the UTI program as enunciated by Haefner ([41], pp. xv–sq), offering additionally sound foundations for its development. However, our viewpoint is not ranged along the thought expressed by Fenzl and others that "formalism [is] of merely secondary importance" [39], not because of the sheer purpose of attaining a nice formalized theory, neither for achieving quantitative scaffolds to assess how much is to gain or to lose, but because—as we have discuss through both parts of our inquiry—it is the "form" (either in potentiality or actuality) that is in the core of the "new" in reality, of the emergence and dynamics of agency, of the emergence and dynamics of meaning. Therefore, formalism is of major importance whenever it targets at a proper mapping of the dynamics of form in reality, and particularly regarding qualitative features.

With respect to the herein tackled levelism of interpretation (in which the regressive perspective has been developed), our proposal and the one developed within the frame of UTI by Fenzl, Hofkirchner and others [39,40] are significantly lined up; but it is here worth mentioning a relevant

distinction. The latter considers three fundamental levels: (i) *self-restructuring*; (ii) *self-reproducing*; (iii) *self-re-creation* [42]. Whereas (i) comprises self-referential semiotics aligned to *objective* responses, and (iii) comprises self-anticipation semiotics aligned to *socio-ethical* responses; we have split (ii)—originally comprising self-representational semiotics—in *cognitive* and *reflexive* responses. This distinction is indeed noteworthy concerning our review of GDI and the formal aspects of UTI: (a) in the level of cognitive response, representation is lesser flexible, being attached to fixed observables (in the sense of Floridi) or to stabilized *logoi* (in the sense of Thom); (b) in the level of reflexive response, the representation means are more flexible (say, {**G**i} are in question, *i.e.*, the relation between the alleged reality and its manifestation), being attached to the non-fixed observables; thus emergence of the LoA as not considered by Floridi, or *logoi* dynamics in the sense of Thom.

But besides these endeavors towards a general understanding of information and meaning, there are others worth considering as to envisioning eventual synergies. We have previously referred to Dodig-Crnkovic's *Info-computationalism* and its alignment—besides the mentioned differential nuances—with respect to modeling interpretation at the level of cognitive response (though *info-computationalism* is actually proposed as to model throughout all levels of complexity) [30]. Not far from this approach, and covering what we have identified as reflexive and socio-ethical responses, one of the authors has advanced a computational approach to the modeling of research processes in which not only deductive and inductive paths are focused, but particularly the fundamental role of creative abductions [43,44].

Staying at the formal aspects, the categorical approach provided by Burgin in his General Theory of Information (GTI) offers an interesting toehold [45,46]. Indeed, as we have upheld at both the progressive and regressive perspectives, the underlying structure of the world can be well modeled as to the general aspects of emergence through category theory (*cf.* appendix 6 of the first part [2]). On the other hand, we have highlighted information as one fundamental ingredient for general agent dynamics (namely as potentiality for the selection of proper changes). Hence, the GTI seems to be valuable for the development of a UTI in both qualitative and quantitative senses, particularly considering the proven consistency with well-established theories of information. Nevertheless, recalling the aforementioned shyness with respect to formalization within the UTI project, we also cherish the need of stressing the modeling of information throughout nature in consistency with its related scientific knowledge. Insofar we consider such development should rely on the sciences, requiring a seamless consistency. Hence, a UTI should be neither a *philosophia prima* as Floridi defends, nor a mere formalizing toolkit; rather a suitable *philosphia ultima* (as one of the authors has defended elsewhere [47]), providing by those means an appropriate scaffold for the understanding of information in relation to other fundamental aspects of the world throughout the sciences—though neither reducing to them nor putting aside fundamental questioning.

Concerning the kernel question of the emergence of meaning, Brier's *Cybersemiotics* [48,49] shows also some parallelism with our approach, which similarly develops an understanding of emergence in joint-venture with a general understanding of information. However, differently to Brier, we give a step forward as to consider the foundation of meaning not only upon the "sign games" played by living beings, but also upon what might be named "spin games" played at the very world foundation—at pre-geometrical levels, as argued in the first part. Moreover, unlike in the cybersemiotic approach, we deem information to entail meaning in the first place—as we have discussed in extent—though we

agree in the necessity of elaborating meanings of higher order through living, cognitive and social agency, as argued in the previous section.

The terms of *message* and *messenger* as proposed by Capurro's *Angeletics* [50,51], can be used to visualize the meaning-offer and the first-order interaction determined by a particular agency, as referred to in Section 2 (for instance the interaction which enables the emergence of the electromagnetic field). As far as the existence of the messenger constitutes a necessary condition for the message, in our scaffold, it is the first-order agency that is needed for the emergence of meaning in the first place—even at the most fundamental level. But, insofar the existence of an appropriate recipient enables the hermeneutical disclosing of meanings, it is the second-order agency (rooted in the same possibility as the first-order one) that enables the emergence of second-order meanings and even the unveiling of the first-order ones. (In similar terms, one of the authors has shown the complementarity of both programs in a recent contribution [10].)

6. Summary

The proposed "skeleton-of-the-world" provides as well a proper path to the hierarchical evolution of complexity as a regressive one for interpreting and modifying reality. The key-player in the advancement through the levels of complexity is the autonomous agent, through which emergence occurs in both ontological and epistemological senses (creating novelty in nature, and making that nature acknowledges itself). For illustrating the regressive perspective we have paradigmatically focused on how regularity (including its constitutive constraints) emerges in nature from the electromagnetic interaction that can be acknowledged by a detection device adapted to the very constraints of the given regularity. As we have observed, through natural evolution, this is certainly achieved, though additionally constrained by the leeway of the evolving structure. In any case, the very constraints of the emergence of the manifestation have a further and fundamental consequence: properly reckoning the reality underlying the manifestation requires a hermeneutical agency even at relatively low levels of cognition. From a qualitative distinction of such agency, we differentiated among levels of complexity linked to different types of pragmatic response since hermeneutical agents are pragmatic agents at the end.

Finally we have stressed that our proposal contributes to the erection of a Unified Theory of Information according to a reviewed GDI which allows visualizing information in nature altogether, complying with the scientific development and being able to collaborate with other approaches in order to achieve a better understanding of information, computation, meaning, interpretation and evolution of complexity. These groundings do not certainly escape to the cognitive meta-theoretical view we justified at the end of our first part [4], according to which we "model the world by inventing theories" in relation "to the cognitive constraints this same world is imposing upon" us.

Appendix

Relation between Electromagnetic Sources and Fields (Object *vs.* Manifestation)

The problem of radiation, stated above, can easily be analyzed by considering the Maxwell equations for a given frequency $\omega = 2\pi f$:

$$\begin{aligned} \nabla \times \mathbf{E} &= -\mathbf{M} - i\omega\mu\,\mathbf{H} & \varepsilon \cdot \nabla \cdot \mathbf{E} &= q_e \\ \nabla \times \mathbf{H} &= \mathbf{J} + i\omega\varepsilon\,\mathbf{E} & \mu \cdot \nabla \cdot \mathbf{H} &= q_m \end{aligned} \tag{A1}$$

where **E** and **H** stand for the intensity distributions of the electric and magnetic field, respectively; **J** and **M** for electric and magnetic current densities; q_e and q_m for electric and magnetic charge distributions; and ε and μ for the electric permittivity and magnetic permittivity of the medium.

The problem of relating the wave fields to the sources can be simplified through definition of the well-known vector potentials **A** and **F**:

$$\begin{aligned} \mathbf{E} &= -i\omega\left\{1+\frac{\nabla\nabla}{k^2}\right\}\mathbf{A} - \frac{1}{\varepsilon}\nabla\times\mathbf{F} \\ \mathbf{H} &= -i\omega\left\{1+\frac{\nabla\nabla}{k^2}\right\}\mathbf{F} + \frac{1}{\mu}\nabla\times\mathbf{A} \end{aligned} \tag{A2}$$

which verify the wave equations directly related to the current distributions **J** and **M**—being k the wave number, $k^2 = \omega^2\varepsilon\mu$:

$$\begin{aligned} \nabla^2\mathbf{A} + k^2\mathbf{A} &= -\mu\,\mathbf{J} \\ \nabla^2\mathbf{F} + k^2\mathbf{F} &= -\varepsilon\,\mathbf{M} \end{aligned} \tag{A3}$$

Through (A3) the vector potentials can be described as linear superposition of Green distributions $G(\mathbf{r},\mathbf{r}') = \dfrac{e^{-ik|\mathbf{r}-\mathbf{r}'|}}{4\pi|\mathbf{r}-\mathbf{r}'|}$, where $\mathbf{r}'$ represents the position of a punctual source, **r** the position in which the field is evaluated:

$$\begin{aligned} \mathbf{A}(\mathbf{r}) &= \mu\iiint_{V'}\mathbf{J}(\mathbf{r}')\cdot G(\mathbf{r}-\mathbf{r}')dv' = \mu\mathbf{J}(\mathbf{r}) * G(\mathbf{r}) \\ \mathbf{F}(\mathbf{r}) &= \varepsilon\iiint_{V'}\mathbf{M}(\mathbf{r}')\cdot G(\mathbf{r}-\mathbf{r}')dv' = \varepsilon\mathbf{M}(\mathbf{r}) * G(\mathbf{r}) \end{aligned} \tag{A4}$$

being V' the volume of the source object, * the tri-dimensional convolution. Using these vector potential definitions, the electric and magnetic field intensity distributions can also be derived, which can be described in terms of generalized Green tensors:

$$\begin{bmatrix}\mathbf{E}(\mathbf{r})\\ \mathbf{H}(\mathbf{r})\end{bmatrix} = \begin{bmatrix}\mathbf{G}_1(\mathbf{r}) & \mathbf{G}_2(\mathbf{r})\\ -\mathbf{G}_2(\mathbf{r}) & \dfrac{\varepsilon}{\mu}\mathbf{G}_1(\mathbf{r})\end{bmatrix} * \begin{bmatrix}\mathbf{J}(\mathbf{r})\\ \mathbf{M}(\mathbf{r})\end{bmatrix} = \mathbf{G}_{E,H}(\mathbf{r}) * \mathbf{s}(\mathbf{r}) \tag{A5}$$

where **s**(**r**) denotes generalized sources (electric and magnetic).

Since according to the uniqueness theorem, the field **E**, **H** is unique whenever the superficial distribution of either the tangent electric **E** or the magnetic **H** is specified on $\mathcal{S}$, it is enough to focus on just one of the fields (or any combination of both), symbolized by $\boldsymbol{\Psi}(\mathbf{r})$—as the phenomenon of the source-object: $\boldsymbol{\Psi}(\mathbf{r}) = \mathbf{G}(\mathbf{r}) * \mathbf{s}(\mathbf{r})$.

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