Enformation Theory — Part I:

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From *Nothing* to *Something*[⋆]

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Abstract. Facing the diversity of model structures that are proposed for mastering data today, it is perhaps time to look back at the *first principles*. For example, here one studies the consequences of the very deep fact: somehow *everything must have started from chaos*. To make evolution possible, some kind of *inherent semantics* has to be implemented to reach basis for *optimization*. It seems that *enformation offers a starting point for emergence of structures*.

1 Introduction

What is *data*, and why does it need to be *understood*? — Data (or measurements, observations) is needed to model the systems beyond that data. But it is not only so that the data would passively reflect the system; the observable data that the system actively generates is its means to affect the world and interact with it. Indeed, as will be explained, it can be said that *data is the means for a system to make its mark*, to be visible, or to *exist*. And the relationship is not one-directional; it is such data generated by systems that is the "nourishment" to other systems, something that they live from, and what they compete for; it is their experienced environment where they have to survive in. The desire to understand data changes to the *need of understanding systems and their interactions through data*. — Tough claims here!

The deepest questions about existence boil down to the dilemma *why there is something instead of nothing*. Indeed, it is (relatively measured) bigger leap from "nothingness" to *epsilon* than there is from that epsilon to any further structures; thus, philosophically oriented issues deserve a lengthy discussion of their own here, in this Part I. And as such emergence is assumedly so rare, the "births" or "seeds" are replicated in the fractal compositions of later more complex structures in Part II. The wider view, putting emphasis on the environment, is presented in Part III. Further, the eventual collapse of structures (or the unavoidable death of the alive dynamics within the structures) is studied in Part IV, and the integrative view, or a view over "system systems" is shown in Part V.

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2 Conceptualizing the chaos

So, here we start from where there is nothing yet. The viewpoint is that of an individual: why does it bother to *emerge*? How is "meaning" defined when *not even the individual exists yet*?

To proceed, one needs some rigid starting point. Here, it is assumed that the *implicit goal of nature is to understand itself*, meaning that *information is crucial.* — Such claim is, of course, very bold, even strange, and it can be understood only in retrospect; the corresponding *evolutionary perspective* is discussed in Sec. 4, and it all will become clear in Parts II to V.

Anyhow, accepting the above view about the centrality of information, it has to be operationalized, and for this purpose some further assumptions are needed. Assume that the world consists of a huge number of some kind of infinitely small entities; they are so elementary that all their properties can be characterized in terms of a set of real numbers. — Later, when more complicated structures are employed, the same assumption is still applied: all their *attributes* can be decomposed into a (large) set of real numbers; *structural complexity* is changed to *dimensional complexity*. These attributes are all that can be observed; one even has to identify all objects in the world with their measurable attributes, in the spirit of Leibniz.

The basic entities are so minuscule that, in the current resolution, they cannot be seen individually, one can only see the net effects (sums) of large amounts of them, or averages of their property values. It is the *statistical expectations* that can only be observed. The individual property values are random, but because the entities are identical, the value distributions are the same.

Typically, it is assumed that there already exists some structure in the world. This structure is reflected in the distorted distributions, and many methods (like *independent component analysis* (ICA), etc.) are based on the detection of these abnormalities. The problem is that there are infinite amounts of possible distribution distortions, and there is no single direction to go in analyses; there cannot exist a homogeneous theory then. Now, on the other hand, an opposite assumption is made: there exists no structure whatsoever to start with.

Counterintuitively, if there is such complete chaos in the world, with no visible *a priori* structure, there is a strong methodology available for extracting information about it.

According to the *central limit theorem*, the observed property distributions, being essentially sums of identically distributed variables, must be *Gaussian*. This *normal distribution* is specially simple as there are only two *moments* that are needed to completely characterize the distribution; these are the *mean*, or the *first moment*

$$\mathrm{E}\{z_\iota\}, \tag{1}$$

and the *second moment*

$$\mathrm{E}\{z_\iota^2\}, \tag{2}$$

assuming that the variables z_ι are used to denote the property values, ι being some running index, and E is the *expectation operator*. Alternatively, instead of the second moment, the same information is present in *variance* $\mathrm{E}\{z_\iota^2\} - \mathrm{E}\{z_\iota\}^2$. A set of such first and second order moments is all one can know about the world.

Information storages are called *models* (this model view will be elaborated on in Part II). Understanding the world means constructing *good* models, where noise and unnecessary details are abstracted away. In this spirit, averages (expectations) are the basic approach to *coarsening*. And, indeed, elaborating on the mean values alone would not offer new possibilities; but the "averages of the squares" is something more interesting.

The mean values $\mathrm{E}\{z_\iota\}$ correspond to the "visible world" that is present in a single momentary glimpse. On the other hand, variance is (strictly speaking) not even defined for a single sample; variations based on $\mathrm{E}\{z_\iota^2\}$ correspond to some kind of *changeability* between snapshots in the world, being a somehow fluid and invisible phenomenon, nonexistent in the static view. It turns out that concentrating exclusively on the second moment in what follows, the *nature of changing* in the world can be captured, in the true Heraclitean spirit. Even more provocatively, along the lines that are studied later, one could say that whereas the mean values represent readily visible *matter* in the world, the variation models explain the underlying *structure* beyond that matter.

The claim here is that *capturing the (co)variations makes it possible to understand the essence* of what exists: the seemingly fixed structures in the world are based on *stable attractors*, and the mundane matter only fills the created lockers within those structures.

3 Natural semantics

The claim here is that to store the acquired information, nature itself is constructing some kind of models of the data around it. — There is an interesting challenge here: the human-made models are always constructed for some special *purpose*, the model properties reflecting the application needs; now, to make assumptions about the "natural model", facing the multitude of alternatives, one should answer the question *what are the aspirations of nature?* For what purpose is the acquired information to be used?

To answer this, one has to attack the deep questions about *meaning* and *semantics*. What is seen as *relevant* in the world?

One has to adopt the somewhat circular idea of *extreme empiricism* here: everything that is important in the world changes that world somehow, and these changes must be observable to be regarded important. And everything one can experience about the world comes through observations; this means that everything that is relevant is assumed to be present in the data, the *most relevant* being also *the most visible*, as seen by some "data hungry" entity.

> To *exist* is to *become observed*. But the observer needs not be human; *nature itself* will do. The question is not whether a falling tree makes a sound without a human listening to it; more appropriately, *a subject exists only if some other object is affected by it*. And, in the inverse way:

> extending the idea of Protagoras, one can say that *a system is a measure of its world* (enformation theoretic system to be defined later).

Nature also wants to *make its mark* (and as nature operates in an extremely distributed manner, this hubris characterizes all its local entities). According to Gregory Bateson, the key is *differences that can make differences*. Such differences are now represented by the quantities $\mathrm{E}\{z_\iota^2\}$.

Why do the variations have the capacity to make difference, or change the world? — It turns out that the squared quantities typically have the dimension of *physical energy*: for example, $\mathrm{E}\{v^2\}$ for velocity v is proportional to kinetic energy, and $\mathrm{E}\{i^2\}$ for electric current i is proportional to electrical energy. Thus, they really have the concrete power to change the environment.

Perhaps the relevance of the second power can be motivated so that the *dot product* is the simplest scalar abstraction of vector-form phenomena.

Furthermore, in non-physical environments, for example, similar expression captures *Fisher information*, again something that can more or less explicitly be seen as a valuable asset. The key point is that semantics is here assumed to come from "below", from the world, rather than from "above", from some universal mastermind. — Because the same principles are applicable in physical and mental realms, it seems that *ontogenesis* and *epistemogenesis* can have something in common, and, furthermore, it is perhaps possible to reach *interobjectivity* (not only *intersubjectivity*): man-made models can, too, capture the *essence* of natural systems.

In the adopted framework, the second moments are thus assumed to contain the formal kernels of natural semantics. This quantity deserves a name of its own; from here on,

$$\mathcal{E}\left\{z_\iota^2\right\} \tag{3}$$

will be called **enformation**, or *energetic information*. In this expression, the *emergence operator* $\mathcal{E}\{\cdot\}$ is employed instead of the mathematically rigid expectation operator, because the determination of enformation depends on the *visibility horizon*, the actually experienced range of environment (temporally *or* spatially). Anyway, both operators are equally linear, and they behave in the same way in mathematical formulas (in the case of matrices, the operators are applied elementwise).

Later, it turns out that separated units of variation are just noise; the real potential lies in correlated variations, or in expressions like $\mathcal{E}\{z_\iota z_{\iota'}\}$.

4 Evolution and optimality

Above, it was assumed that for some reason nature strives towards gaining more enformation. Is this not mere nonsense; where would such goal-directedness emerge when there are no intelligent actors involved?

The "will" is just an illusion as the totality of elementary behaviors is seen from above. When there is resource available somewhere, those actors that have access to it become more visible (as studied above), while the less fortunate ones perish. As seen from far enough, when individuals cannot any more be identified, it seems that activity has been migrating towards the enformation sources. And if there *are* some random migrations, the lucky ones get rewarded; it can be concluded that *all visible net activity can be interpreted as enformation pursuit*. Similarly, if there are different interaction strategies among actors, it is the most efficient one that receives most of the enformation, thus becoming more and more prominent. Seemingly, there is an active competition taking place; however, the actors do not know about each other, they just stay in their local environments reflecting the amount of enformation available to them, natural "selection of the fittest" taking care of the *evolution*.

As seen from above, there is yet one useful abstraction available: it is that of the notorious *vitalism*, being based on some *élan vital*, or *vital force*. Today, mechanistic explanations alone are allowed in science; however, if the *why* questions are not addressed, the strongest models remain inaccessible. When speaking simply of *flow of enformation*, the discussions remain technical, and the *teleological* problem setting is avoided: the activity is not *pulled* by some external *primus motor*, but *pushed* by internal, more or less well-understood processes, without any explicit goal. — Indeed, in Part III, an approach towards a *general theory of life* is presented.

The flow of enformation can be utilized as a guideline when modeling evolution in its fractal universality. And the quest for understanding evolution is of ultimate importance.

Slightly extending the observation of Theodosius Dobzhansky, one can say that *nothing in complex systems makes sense except in the light of evolution*. One could even speak of *universal evolution*, as everything changes all the time at all levels, local actors yearning for enformation (traditional view of evolution corresponding to the slowest-scale changes). No structures in nature are fixed but they only reflect some dynamic balances between tensions; the optima change as the world changes.

Evolution is not just a random sequence of steps, but (in the enformation theoretic setting) it is a more or less consistent trajectory towards the (ever-changing) local optimum. This optimality pursuit is a practically valuable guideline when searching for the "right" model, because there is only one best route that has to be checked; this way, the number of remaining free parameters becomes minimized, for example. This optimality thinking has to be applied on all levels, in models and in their convergence processes. — It is of course possible that nature itself has not yet found the optimal solutions; in that sense one could speak here of *metabiology*, just as well as one can speak of *metaphysics*, etc.

There is one major benefit what comes to the adopted starting points: as the enformation to be maximized is essentially a quadratic form, one knows that *the optimizing functions and routines must be essentially linear*. And if something is *linear*, it is *straightforward!* This linearity does not only promise easier times theory-wise — there is also promise of real applicability, even plausibility, as linearity means *scalability of models* beyond "toy worlds". Thus, it can be claimed that *nature itself also tries to implement linearity in its systems*, even though the components and tools it has available are hopelessly nonlinear ...

Linearity sounds like a dead end: one already knows the fundamental limitations of linear systems. But what comes to their expressive power, it seems that there are still surprises awaiting: never underestimate the asymptotic power of *feedback!*

5 Maximizing enformation

When operationalizing the above ideas, some additional assumptions about the surrounding world still have to be made. First, the variables can have different *roles*; assume that among the variables z_ι, there are n *activities* and m *resources*:

$$\begin{cases} \bar{x}_i, \text{ where } 1 \leq i \leq n & \textbf{activities}\text{: diffusion flows, reactions, ...} \\ \bar{u}_j, \text{ where } 1 \leq j \leq m & \textbf{resources}\text{: potentials, force actions, ...} \end{cases}$$

The activities introduce *dynamic states*, implementing some kind of *integrative action*, so that there is *inertia*. However, all variables $\bar{x}_i$ and $\bar{u}_j$ here represent steady-state values after the short-range transients have decayed, so that the hairy dynamic details can be ignored.

One can now define the *enformation theoretic system* as the set of activities $\bar{x}_i$ that "see" the same set of resources $\bar{u}_j$ and weighting of those resources; that is, the system variables share the view of the world (or their *semiosis* works in the same way). It is assumed that the system is simpler (in this case, lower-dimensional) than its overwhelmingly high-dimensional environment, so that $n \ll m$.

The resources are the "masters" and the activities are the "slaves". Everything originates in the environment (determined by the variables $\bar{u}_j$), so that the emerging systems (determined by the variables $\bar{x}_i$) are some kind of *mirror images* of that environment. In theory, one only needs to know the environment (the data history) to know the system.

Second, something has to be assumed about the *interaction mechanisms* among the variables, or *spread of activation*. One can introduce some kind of *generalized diffusion* from all resources to the activity variable $\bar{x}_i$ so that in steady state there holds

$$\bar{x}_i = a_{i1}\bar{u}_1 + \cdots + a_{im}\bar{u}_m. \tag{4}$$

The parameters a_{ij} are some kind of *diffusion coefficients* that reveal how effectively the "inputs" affect the state. In practice, the values of these parameters can be determined, for example, by the physical structure among the localized variables; this means that their values can *adapt* if the locations of the "variable carriers" change.

Now, it is the expression (4) that is the basis for the emergent physical structures: whereas the inertial variable $\bar{x}_i$ acts like a *short-term memory*, the parameters a_{ij} together act like a *long-term memory*, constituting the "hardware" for the emergent model, the essence of the system. How do they realize this task? — Everything is based on virulent enformation pursuit (as seen from above).

When both sides in (4) are multiplied by $\bar{x}_i$, and when the emergence operator is applied after that, one has an expression for the acquired enformation in the entity $\bar{x}_i$:

$$\mathcal{E}\left\{\bar{x}_i^2\right\} = a_{i1}\mathcal{E}\left\{\bar{x}_i\bar{u}_1\right\} + \cdots + a_{im}\mathcal{E}\left\{\bar{x}_i\bar{u}_m\right\}. \tag{5}$$

This expression has a bounded maximum only if one applies some constraints; one can assume that the norm (or "energy") of the vector a_i remains (at least momentarily) constant:

$$\begin{array}{ll} \text{Maximize} & a_{i1}\mathcal{E}\left\{\bar{x}_i\bar{u}_1\right\} + \cdots + a_{im}\mathcal{E}\left\{\bar{x}_i\bar{u}_m\right\}, \\ \text{while} & a_{i1}^2 + \cdots + a_{im}^2 = \mathit{constant}. \end{array} \tag{6}$$

Applying the technique of *Lagrange multipliers*, one finds out that

$$a_{ij} = q_i \; \mathcal{E}\left\{\bar{x}_i\bar{u}_j\right\}, \tag{7}$$

where the new free parameter q_i is called the *coupling factor*. If all potentials are collected in the vector $\bar{u}$ and all induced activations are collected in the vector $\bar{x}$, and when all q_i are collected on the diagonal of the matrix Q, one can express the local operations (4) compactly in an equivalent matrix form applying the (uncentered) *sample covariance matrix* $\mathcal{E}\left\{\bar{x}\bar{u}^{\mathrm{T}}\right\}$:

$$\bar{x} = Q \; \mathcal{E}\left\{\bar{x}\bar{u}^{\mathrm{T}}\right\} \bar{u}. \tag{8}$$

This *Hebbian-style adaptive operation principle* that couples the system (characterized by $\bar{x}$) to its environment (characterized by $\bar{u}$) is the key to the global system-level properties. The basic principle is that if the incoming signal and the present activation correlate, the connection becomes stronger. This fundamental idea was observed first in neuron systems by Donald O. Hebb some 60 years ago.

— Now something has been reached: not very much, but the *epsilon*. The *enformation* has been spotted, and its flow has been captured in a concrete formula. Model structures emerging from (8) have been studied under the name *neocybernetics* (see [1]); a brief introduction to the technical neocybernetic system properties are presented in Parts II and III, and wider views in Parts IV and V.

6 Tools for understanding emergence

Now a concrete formulation for enformation transfer has been found. However, one has to remember that the formula just captures a shadow of the dynamic phenomenon. One has to remember that the same challenges are still hounding us, and they need to be kept in mind: the *essence of changing* is not easy to understand.

This difficulty has been distorting wise men's thinking through ages, starting from Plato, who claimed that as change is so difficult, *it must be just an illusion*, and concentrated on the eternal ideas since then — misleading the whole Western philosophy since that. And still in our times, Ludwig Wittgenstein stated that *the world consists entirely of (static) facts* — everything that is real is here and ready, there is no room for something that *not yet is*.

Still, *changing is the essence* of systems. In the spirit of *process philosophy*, things in general are more about *becoming* rather than *being*. Even the most general of theories, *system(s) theory*, fails to see the big picture:

> To emphasize the generality of systems theory, one can (jokingly) define the research object, or the "system" as a *system*. This means that one can utilize *intuition*, the marvellous human cognition and pattern recognition capacity: if you can recognize something as an independent entity, it qualifies. In this spirit, *a rabbit is a system.* — But as has been observed, human is not so good in "dynamic" recognition tasks ...
>
> For example, study that *rabbit* a bit closer. A single rabbit cannot capture the idea of "eternal rabbitness", because without mates, it soon dies of extinction. And even the whole population starves to death without an appropriate environment. Where, then, are the "boundaries" of one independent living bunny?
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> In systems theory, the *boundaries* of a system, and its *inputs* and *outputs* are basic concepts. However, now the boundaries vanish; and, as all interactions are bidirectional, the inputs and the outputs get blurred, the system becoming *pancausal* (as will be studied later). — Still, the rabbit *is* a relevant category, but only as a *stable attractor* in the dynamic biological realm; seemingly fixed structures are just dynamic balances on the slower time scale.

One reason for the thinking difficulties is our *language*. As Wittgenstein observed, one cannot think outside the borders of language. — The natural language needs to be extended!

Our problem now is that natural language is *one-dimensional*, it uses *crisp symbols*, and it makes it *difficult to study time-dependent phenomena*. On the other hand, *mathematics* makes it possible to define appropriate concepts and such "reasoning rules" for them that *operate from the bottom*:

- *Statistical tools* make it possible to filter noisy variables so that abstractions can be found; with real variables non-integer quantities can be manipulated.
- *Differential calculus* makes it possible to study change and infinitely small quantities, letting them *emerge*.
- *Linear algebra* makes it possible to study cycles and long time scales, and, specially, *infinity* can then be attacked.
- *Matrix methods* make it possible to manipulate high dimensions and, what is more, distributedness.

In mathematics, generally, interpretations are left aside, the "reasoning" being carried out separately, and the domain field interpretations are applied only afterwards. Now, however, *syntax and semantics must not be separated!* The claim here is that when one concentrates on the enformation and follows its flow (the enformation being the kernel of semantics), one studies only relevant structures, not all mathematically possible ones. Only then *emergence* of interesting phenomena can take place autonomously without the intervention of some “intelligent designer”. And only then the wealth of real life data can be automatically managed.

References

1. *Neocybernetics — Pragmatic Semiosis by Complex Adaptive Systems.* Research pages accessible in Internet through http://neocybernetics.com.