# An answer to Einstein's quip

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Traditionally, *information* is considered as negentropy (Brillouin). By definition, then:

- the sum of a quantity of information (negentropy) and an equal quantity of entropy is 0;
- information (Shannon, but also Kolmogorov) is "insensitive to coding" (one can "encrypt" and "decrypt" as much as one wishes but the information content will not be lost, in principle).

Since Kolmogorov and many others, very relevant notions of *complexity* in discrete frames have also been widely developped.

When I started this project, I believed that these ideas, of which the applications are numerous, are not sufficient for an analysis of the *living state of matter*. So, I invented a name for the team without knowing neither what we were doing nor heading. The project consisted, in particular, to … give a meaning to its very title, as I had no idea of what could be ever proposed as an alternative (an extension?) of the notions above, taking care of … (proper biological) form and information.

In biology, DNA (usually considered as digital information) is surely the most important component of the cell, but it is also necessary to analyze the *organization* (what we called "morphological complexity") of the cell and of the organism, as an observable specific to biological theoretization.

We have thus proposed the notion of *anti-entropy* to define biological complexity (quantified in terms of complexity of cellular, functional and phenotypical differentiation): in short, it may be understood as (a component of the) "information specific to the form", or to the intertwining and enwrapping of biological levels of organization, such as given by integration and regulation activities. Its use in metabolic balance equations has produced a certain number of results mentioned in several articles (see http://www.di.ens.fr/users/longo/download.html ). We have, in particular, examined systems far from equilibrium and analyzed diffusion equations of biomass over biological complexity as anti-entropy, following Schrödinger's "operational method" in quantum mechanics (which has indeed been made possible by this "broadening" of the notion of information to organization as anti-entropy). This has enabled to operate a mathematical reconstruction of this diffusion, which corresponds to the paleontological data presented by Gould for the evolution of species. An analysis of anti-entropy in ontogenesis has also been described.

Anti-entropy is compatible with information as negentropy, but it must be considered as an extension, in a logical sense, of the thermodynamics of entropy. Typically:

- the production of entropy and that of negentropy are summed in an "extended critical singularity", an organism, never 0;
- as it is linked to the spatial form (information about a "form"), anti-entropy is "*sensitive to coding*", contrarily to digital information (it depends on the dimensions

of embedding manifolds, on folds, on singularities…).

In short, over the last height years, thanks also to various collaborations and to the monitoring of five theses, we have compared physical (dynamic) randomness with algorithmic randomness (at the center of *algorithmic theories of information*); we have enriched the theory of criticality (extended, for biology); we have added anti-entropy (a "*geometrical* extension" of the notion of *information*) to fundamental thermodynamic (in)equalities and balance equations; we have begun modeling biological rhythms and time in two-dimensional varieties, a rather original geometrization of time (and a quite useful one, for the digital simulation of cardiac rhythms we are currently developing). The basic idea has been that the notion of information, in biology, must be extended to that of organization, as a specifically biological observable. The scientific finality of this work may also entail important epistemological consequences: it participates to the epistemological debate regarding the notion of information, the updating of its theoretical principles and their possible evolution, on the basis of their interactions with physics and biology.

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