On Individuality, Emergence and Information Preservation

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The question of defining an individual object in the most general sense is of deep importance. An implicit notion of individual objects is deeply rooted in classical natural philosophy, particularly in classical physics. The advent of quantum physics, but also the physics of condensed matter and complex and collective systems, and finally systematic approaches to life sciences, ecology and sociology have increasingly made clear that the concept of individuality is not an obvious, clear-cut notion, but has to be forged out of the collective dynamics of the systems considered.

Usually, the notion of individual objects has to be specifically defined for any system under consideration. It would, however, be more desirable to have an approach that could be universally used for a larger class of systems, typically dynamical systems. Ideally, the system should decompose into "individual" subsystems in a natural (canonical) fashion which does not require any structural assumptions beyond the system itself.

An inspiration how such a mechanism may look like is e.g. the natural decomposition of the collective dynamics in crystals into individual oscillatory modes, *phonons* (Born and Huang 1954). If symmetries are present, they even pre-induce a prior dynamics decomposition structure in a universal fashion (Adams 1969; Rudin 1990). This shows how additional aspects of structure can be seamlessly worked into a definition of a canonical partition into subsystems. The universality of above approach is limited by the fact that it requires the systems to be linear.

An approach to decompose also nonlinear systems in a natural fashion is undertaken in the field of synergetics (Haken 1983). The natural decomposition of dynamical systems near fixed points into stable, central and unstable manifolds is reinterpreted in a heuristic way, separating *fast foliations* and *slow manifolds* in the system (Mees 1981). The slow parameters (*master modes*) of the system dynamics are said to "enslave" the fast degrees of freedom (*slave modes*). The *master modes* can be construed as emerging from the system dynamics. This system decomposition into individual subsystems emerges naturally from the system dynamics and is therefore not limited to the "eye of the beholder" (Harvey 2000).

Above notions of individuality and emergence can be further generalized using information theory. Haken (2000) takes a step towards an information-theoretical view of synergetics; it is well-known that dynamical systems can be well described using information theory (Wolf 1999; Deco and Schürmann 2001); the dynamics is translated into the information-dynamical language via an a priori choice of the space partition. However, as argued above, it would be desirable to have an approach where the decomposition emerges naturally from the structure of the dynamical system and is not imposed upon it.

Indeed, close analysis of the simplest (linear) dynamical systems already provide a natural motivation for an adequate approach. They provide a *complete* decomposition of the system into *independent* subsystems which are *individually predictable.* These three aspects can be directly formulated in an information-theoretic fashion: if 1. a general dynamical system (discrete or continuous, deterministic or stochastic) is decomposed in such a way that the totality of subsystems always provide complete information about the state of the total system, 2. these subsystems are informationally independent from each other's dynamics and 3. the individual subsystems maximally preserve information, we consider this decomposition a natural emergent partition of the system into individuals. The impact of the concept is explored in several examples.

The present concept goes beyond the related concepts of Independent Component Analysis and clustering by deterministic annealing by introducing a temporal dimension. The individual subdynamics can be interpreted as closed subsystems. In non-ideal scenarios one can expect that the subsystems would be only partly informationally autonomous; in addition, one would obtain a hierarchy of subsystems with different degrees of independence. This would provide a useful perspective to model biological super-organisms, organisms, and organelles; it would allow to cover both the aspect of information exchange between different units and the structural organization of the system. Evolution is then just a specific form of system dynamics. Evolutionary transitions or important events will be reflected by structural changes in the identified hierarchy. A detailed study of the ability of the model to incorporate these effects is the topic of current research.

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