Reconstruction failure: questioning level design

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EPOS II — 2nd Workshop on Epistemological Perspectives On Simulation
October 5–6, 2006 — Brescia, Italy

Models aim at rebuilding certain aspects of real phenomena using some given level of description, complex system science in particular endeavors at rebuilding complex high-level behavior from more simple, more reliable and better-understood "atomic" mechanisms at an allegedly lower level. Simulation-based models are frequently used, as analytical solutions are seldom available and limited to singular, possibly non-realistic hypotheses. In turn, the simulated system should correctly render the evolution of a selection of high-level stylized facts. To this end, a reductionist attitude is usually adopted; in other words, modeling efforts are focused on low-level items only — for instance, when attempting to rebuild psychological laws by iterating neural activity, the simulation relies on neuron-based properties and dynamics in order to reproduce psychological properties and dynamics, which are then traditionally said to "emerge".

Here, we intend to review and comment the appraisal of unsuccessful models and corresponding simulations, then discuss in a broader framework the epistemological consequences of failed reconstructions on model and level design.

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1 Reductionist approach

Micro-founding the higher levels. In a reductionist setting, models rely on low-level items which are thus in charge of the whole reconstruction. Low-level properties must therefore be first translated into high-level properties by a projection function P expressing the higher level H from the lower level L, such that $P(L) = H$. The higher level H may even be described in the "natural language" of a given discipline (psychological mechanisms, sociological features), whereas L usually corresponds to more formal and simple descriptions (neural states, relationships between agents).

To achieve successful reconstruction, low-level dynamics observed through P must be consistent with higher-level dynamics, that is, a sequence of low-level states projected by P should correspond to a valid sequence of high-level states. More formally, denoting by λ (resp. η) the transfer function of a low-level state L (resp. high-level state H) to another one L' (resp. H') — in short, $\lambda(L) = L'$, $\eta(H) = H'$ — this means that P must form a *commutative* diagram with λ and η so that (Rueger, 2000; Nilsson-Jacobi, 2005):

$$P \circ \lambda = \eta \circ P \tag{1}$$

The goal of the reconstruction is to equate the left side of Eq. 1 (high-level result of a low-level dynamics) with its right side (direct outcome of a high-level dynamics).

Commutative reconstruction. Commutativity is the cornerstone of the process: should this property not be verified, the reconstruction would fail. Typically, one already has η—often an empirical benchmark under the form of a series of measurements, or at least a well-established theory (that is, a more or less stylized η)— and the success of the reconstruction endeavor depends on the capacity of "$P \circ \lambda$" to rebuild η. This argument actually remains valid whether the underlying model is simulation-based or purely analytical: either, rarely, analytical proofs are available (e.g. gas temperature reduced to molecular interactions), or, more likely, if analytical resolution is hardly tractable, only (generative) proofs on statistically sufficient simulation sets are possible, using several initial states L. This is plausibly an empiricist attitude, yet each simulation is a proof on a particular case (Epstein, 2005) so the reconstruction may be considered a success as long as Eq. 1 holds true for statistically enough particular cases.[1] Equivalently, an analytical solution can be considered as a (possibly infinite) set of potential simulations whose outcome is known *a priori*.

Hence, for η is the objective of the reconstruction, when commutativity does not hold the failure must be due either to λ or to P. If we stick to the fact that H is always correctly described by the mapping $P(L)$, then this entails that λ misses something and must be jeopardized: $\lambda(L)$ is invalid with respect to η, otherwise $P(L')$ would equate H'. Solutions consist in improving the description of the low-level dynamics. In this paradigm, reductionism could fail only for practical reasons, for instance if a technically intractable λ is required to obtain commutativity.

2 Emergentist approach

Alleging an independent higher level. Despite this, it may also be that reductionism fails for essential reasons: even with an ideally perfect knowledge of λ, reconstruction attempts fail because H is inobservable from L: "Psychology is not applied biology" (Anderson, 1972). Here the whole is more than its parts, and H enjoys some sort of independence, even when acknowledging that everything is grounded in the lower level — this refers traditionally to the *emergentist* position (Humphreys, 1997; Kim, 1999). In many cases where reductionism actually fails in spite of a solid and reliable λ, complex system methodology tends to agree with this emergentist stance.

What to do with such "irreducible" emergent phenomenon in a simulation, or in a model? Either one considers that the emergent phenomenon has no causal power, making it a mere epiphenomenon. Yet, by being irreducible to what is being modeled at the lower-level, it is unlikely that a model, a fortiori a computer-run simulation, could inform us about such an epiphenomenon. One would then consider that the emergent phenomenon has causal powers onto the lower level. But again, it is unlikely that a simulation would help us in this regard: this would mean that a computer program creates something that in turn has

[1]For an extensive discussion on the wide spectrum of criteria, accurate or less accurate, that make a simulation-based model successful, see (Küppers & Lenhard, 2005).

an effect within the program and within what the modeler has asked the computer to do. Likewise, a model itself would not be eager to exhibit such causal feedback — this would in fact be as if someone, writing and deriving equations, was perturbed in *the very writing of these equations* by an invisible hand which adds some formulas here and there.

One would thus hope that neither a simulation nor actually any kind of model suffers "downward causation" (Campbell, 1974), which would hence be bound to exist in the real world only. In this latter case, to render this the modeler would in any case require influences between both levels; in other terms, η would be enriched to take L into account, $\eta(L,H) = H'$, and λ would take H into account by assuming downward causation: $\lambda(L,H) = L'$.[2] But assuming the lower level to cause high-level phenomena which in turn have a downward influence on low-level objects is nonetheless likely to raise inconsistency issues regarding low-level property violations (Emmeche *et al.*, 2000); that is, one is likely to model something that is not even (causally) valid in the real world. As Bitbol (2006) sums up:

> *Consider the crucial case of "downward causation", namely causation from the emergent level to a basic level : from the social to the mental level; from the mental to the biological level; and from the biological to the physical level. Within their predominantly substantialist framework of thought, the emergentists are inclined to require productive causal powers of the emergent properties on the basic properties. And nothing of the sort is in sight. At most, one can find ways of seing some complex mutual interactions of large numbers of basic components as "trans-scale" causation.*

Levels as observations. To avoid strictly dualist models and epistemological concerns, one should consider that properties *at any level* are instead the result of an observational operation (Bonabeau & Dessalles, 1997; Gershenson & Heylighen, 2003; Bitbol, 2006): the only emergence is that of several modes of access to a same process, where each observation level may yield overlapping information. Information from some level *specifies* the dynamics of another level, and dynamics could be rewritten as $\lambda(L|H) = L'$ and $\eta(H|L) = H'$. Knowing for instance that

[2]In such an emergentist setting, models then simulations would thus attempt to intertwine high-level objects in the low-level dynamics in order to rebuild emergent phenomena. This is formally close to dualism, at least in the simulation implementation.

the higher level has a far slower time-scale, one could fruitfully bind the low-level dynamics to some high-level parameters, thereby significantly easing the understanding of the low-level dynamics.

Obviously, high-level reconstruction strictly from valid low-level models is possible only when the higher level is deducible from the lower level. When the reconstruction fails despite robust λ and η, one must envisage that the chosen lower level L does not yield enough information about H.

3 Questioning level design

This leads to a significant change in viewpoint: first, there is no "substantial" reality of levels, which a simulation is allegedly trying to reproduce, but an observational reality only.[3] Consequently, there is no reciprocal causation between levels, but simply informational links: higher and lower levels are simultaneous observations of a same underlying process that *may or may not* yield overlapping information about other levels. Most importantly, some phenomena cannot be rebuilt from some given lower level descriptions — not because of higher level irreducibility but because of an essential deficiency of the lower level description. Put differently, it is not that the whole is more than its parts, it is that the whole we are observing at a higher level is more than *these* parts we focused on. Slightly paraphrasing the way (Bedau, 1997) presents the puzzle of emergence, this argument suggests that if an emergent phenomenon is somehow autonomous from underlying processes, then this emergent phenomenon is constituted and generated not only by these underlying processes. In this respect, reductionism makes the intuitive yet audacious bet that there is a ultimate level which yields enough information about any other "higher" level, at least in principle — which, when it works in some particular cases, gives the impression that a high-level phenomenon is *reducible*, while in fact it is simply *fully deducible*.

Rethinking levels. More to the point, what should happen when simulating, for instance, neural activity in order to provoke the emergence

[3]This situation is moreover clearly consistent with the means of a simulation: all significant operations are indeed happening *in silico*.

of a psychological phenomenon like learning, while in fact there are crucial data in glial cells which would make such attempt irremediably unsuccessful (Pfrieger & Barres, 1996)? As such, emergentism could be a dangerous modeling approach. Yet, reductionism would not be more helpful by assuming the existence of a lowest level for which projection functions P onto any higher level do exist. When neurons are the lowest level, attempting to model the emergence of learning could also be a problem.

Similarly and to provide another example, a social network model ignoring crucial semantic features which in fact determine real-world interactions is likely to enjoy a limited success. It is not unfrequent that some social network-based community emergence model would seek to reconstruct knowledge communities without having recourse to any semantic space. In this case, "social glial cells" may just have been ignored. In contrast, what constitutes the vocabulary and the grammar of the corresponding simulations—agents, interactions, artifacts, etc.— may well need to be enriched in order to explain several key features in e.g. knowledge-based social networks. Yet, the belief that a social network is obviously sufficient to reconstruct many real-world social structures seems to be widespread, even when such attempts appear to require incredibly and possibly unrealistically complicated dynamics.

Therefore, it may be mandatory to rethink levels. A rather frequent need is that of a third "meso-level", deemed more informative than the macro-level, while more assessable than the micro-level (Laughlin *et al.*, 2000). In contrast, introducing new levels could also be simply more convenient — harmlessly because levels are merely observations. Rather than claiming that each level exists as such, substantially, this comes to just claiming that observation devices exist as such. Note however that using algorithms which build automatically and endogeneously a new simplified level based on low-level phenomena (Crutchfield, 1994; Clark, 1996; Shalizi, 2001) should not be sufficient: such tools are powerful for detecting informative, relevant patterns; however the new high-level description is just a clever projection P whose efficiency is limited when lower levels are not informative enough — an automatic process cannot yield an essentially new vision on things from already deficient levels.

In an equivalent manner, it is unlikely that any automatic process or methodology could be able to decide whether some level design or dynamics is respectively insufficient or inaccurate towards a given reconstruction task. Our point is nonetheless to underline that efforts should not necessarily be focused on improving the dynamics of a given level, using a fixed ontology — whereas this latter attitude could be encouraged by a reductionist or emergentist stance, as is often the case.

Concluding remarks

On the whole, mistakes are not to be found necessarily in λ, η nor in putative projection functions; but rather in the definition itself of levels L and H. In front of unsuccessful models and simulations, we hence suggest that reductionist and emergentist attitudes in designing models and appraising simulation failures may make it harder to detect ill-conceived modeling ontology and subsequent epistemological dead-ends: some high-level phenomena cannot be explained and reconstructed without a fundamental *viewpoint change* in not only low-level dynamics but also in the design of low-level objects themselves — e.g. introducing *new* glial cells or *new* semantic items, artifacts. As suggested above, social and neural network models, at the minimum, could benefit from such hindsight.

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