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Reconstruction Failure: Questioning Level Design

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Complex system science aims at rebuilding complex high-level behavior from more simple, more reliable and better-understood “atomic” mechanisms. Corresponding models make a frequent use of simulation-based reconstructions, as analytical solutions are seldom available and limited to particular, possibly non-realistic hypotheses. In turn, the simulated system should correctly model the evolution of a selection of high-level stylized facts, while a reductionist attitude is usually adopted, i.e. by modeling only low-level items — e.g. rebuilding psychological laws by iterating neural activity only: the simulation focuses on the properties and dynamics of neurons to reproduce psychological properties and dynamics, which are then traditionally said to “emerge.” Here, we intend to review and comment the appraisal of unsuccessful simulations, then discuss in a broader framework the epistemological consequences of failed reconstructions on model and level design.

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Commutative reconstruction. In a reductionist setting, models rely on low-level items which are thus responsible for 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*. 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 l (resp. h) the transfer function of a low-level state *L* (resp. high-level state *H*) to another one *L'* (resp. *H'*) — in short, l *(L)* = *L'*, h (*H*) = *H'* — this means that *P* must form a *commutative* diagram with l and h so that [13, 15]:

$$P \; o \; l = h \; o \; P \qquad (1)$$

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).

Commutativity is the cornerstone of the process: should this property not be verified, the reconstruction would fail. Typically, one already has h —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 h)— and the success of the reconstruction endeavor depends on the capacity of "*P o* l" to rebuild h. 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 [8] so the reconstruction may be considered a success as long as Eq. 1 holds true for statistically enough particular cases — for an extensive discussion on the wide spectrum of criteria, accurate or less accurate, that make a simulation-based model successful, see [11].

Hence, for h is the objective of the reconstruction, when commutativity does not hold the failure must be due either to l or to *P*. If we stick to the fact that *H* is always correctly described by *P(L)*, then this entails that l misses something and must be jeopardized: l *(L)* is invalid with respect to h, 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 commutativity requires an intractably complicated l.

Alleging an independent higher level. Despite this, it may also be that reductionism fails for ontological reasons: even with an ideally perfect knowledge of l, reconstruction attempts fail because *H* is inobservable from *L*: "Psychology is not applied biology" [1]. 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 [10]. Influences between both levels are required, in other terms, h is enriched to take *L* into account, h (*L,H*) = *H'*, and l may be enriched to take *H* into account, when assuming “downward causation” [4]: $\mathtt{l}\,(L,H) = L'$.

In many cases where reductionism actually fails in spite of a solid and reliable $\mathtt{l}$, complex system methodology tends to agree with this emergentist stance. In an emergentist setting, models then simulations would thus attempt to intertwine highlevel objects in the low-level dynamics in order to rebuild emergent phenomena. This is formally close to dualism, at least in the simulation implementation. Assuming the lower level to cause high-level phenomena which in turn have a downward influence on low-level objects is however likely to raise inconsistency issues regarding low-level property violations [7]; that is, one is likely to model something that is not (causally) valid in the real world.

To avoid strictly dualist models and epistemological concerns, one should consider that properties *at any level* are instead the result of an observational operation [2, 3, 9]: 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 $\mathtt{l}\,(L|H) = L'$ and $\mathtt{h}\,(H|L) = H'$. Obviously, high-level reconstruction from valid low-level models is possible only when the higher level is deducible from the lower level. When the reconstruction fails despite robust $\mathtt{h}$ and $\mathtt{l}$, one must envisage that the chosen lower level L does not yield enough information about H.

Rethinking levels. 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.[1] 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. 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*.

More to the point, what should happen when simulating, for instance, neural activity in order to provoke the emergence of a psychological phenomenon like learning, while in fact there are crucial data in glial cells which would make such attempt irremediably unsuccessful [14]? 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

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

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 [12]. In contrast, introducing new levels could also be simply more convenient — harmlessly because levels are merely observations. Note however that using algorithms which build automatically and endogeneously a new simplified level based on low-level phenomena [5, 6, 16] 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.

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On the whole, mistakes are not to be found necessarily in $\mathtt{l}$, $\mathtt{h}$ 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 deadends: 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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