A Theoretical Framework for the Study of Socio-Technical Systems

Working Paper

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Abstract

Introduction

Scientific Context

The structural misunderstandings between Social Sciences and Humanities on one side, and so-called Exact Sciences on the other side, far from being a generality, seems to have however a significant impact on the structure of scientific knowledge [Hidalgo, 2015]. In particular, the place of theory (and indeed the signification of this term itself) in the elaboration of knowledge has a totally different place, partly because of the different *perceived complexities*[1] of studied objects : for example, mathematical constructions and by extent theoretical physics are *simple* in the sense that they are mostly entirely analytically solvable, whereas Social Science subjects such as humans or society (to give a *cliché* exemple) are *complex* in the sense of complex systems[2], thus a stronger need of a constructed theoretical (generally empirically based) framework to identify and define the objects of research that are necessarily more arbitrary in the framing of their boundaries, relations and processes, because of the multitude of possible viewpoints : Pumain suggests indeed in [Pumain, 2005] a new approach to complexity deeply rooted in social sciences that "would be measured by the diversity of disciplines needed to elaborate a notion". These differences in backgrounds are naturally desirable in the spectrum of science, but things can get nasty when playing on "common" terrains, typically complex systems problematics as already detailed, as the exemple of geographical urban systems has recently shown [Dupuy and Benguigui, 2015]. Complex System Science[3] is presented by some as a "new kind of Science" [Wolfram, 2002], and would at least be a symptom of a shift in scientific practices, from analytical and "exact" approaches to computational and evidence-based approaches [Arthur, 2015], but what is sure is that it brings, together with new methodologies, new scientific fields in the sense of converging interests of various disciplines on transversal questions or of integrated approaches on a particular field [Bourgine et al., 2009].

[1] We used the term *perceived* as most of systems studied by physics might be described as simple whereas they are intrinsically complex and indeed not well understood [Laughlin, 2006].

[2] for which no unified definition exists but of which fields of application range broadly from neuroscience to quantitative finance, including e.g. quantitative sociology, quantitative geography, integrative biology, etc. [Newman, 2011], and for which study various complementary approaches may be applied, such as Dynamical Systems, Agent-based Modeling, Random Matrix Theory

[3] that we deliberately call that way although there is a running debate on wether it can be seen as a Science in itself or more as a different way to do Science.

Objectives

Within that scientific context, the study of what we will call *Socio-technical Systems*, which we define in a rather broad way as hybrid complex systems including social agents or objects that interact with technical artifacts and a natural environment[4], lies precisely between social sciences and hard sciences. The example of Urban Systems is the best example, as already before the arrival of approaches claiming to be "more exact" than soft approaches (typically by physicists, see e.g. the rather disturbing introduction of [Louf and Barthelemy, 2014], but also by scientist coming from social sciences such as Batty [Batty, 2013]), many aspects of urban systems were already in the field of exact sciences, such as urban hydrology, urban climatology or technical aspects of transportation systems, whereas the core of their study relied in social sciences such as geography, urbanism, sociology, economy. Therefore a necessary place of theory in their study : following [Livet et al., 2010], the study of complex systems in social science is an interaction between empirical analysis, theoretical constructions, and modeling.

We propose in this paper to construct a theory, or rather a theoretical framework, that would ease some aspects of the study of such systems. Many theories already exist in all fields related to this kind of problems, and also at higher levels of abstraction concerning methods such as agent-based modeling e.g., but there is to our knowledge no theoretical framework including all of the following aspects that we consider as being crucial (and that can be understood as an informal basis of our theory) :

1. a precise definition and emphasis on the notion of coupling between subsystems, in particular allowing to qualify or quantify a certain degree of coupling : dependence, interdependence, etc. between components.

2. a precise definition of scale, including timescale and scales for other dimensions.

3. as a consequence of the previous points, a precise definition of what is a system.

4. the inclusion of the notion of emergence in order to capture multi-scale aspects of systems.

5. a central place of ontology in the definition of systems, i.e. of the sense in the real world given to its objects[5].

6. taking into account heterogeneous aspects of the same system, that could be heterogeneous components but also complementary intersecting views.

The rest of the paper is organized as follows : we construct the theory in the following part, staying at an abstract level, and propose a first application to the question of co-evolving subsystems. We then discuss positioning regarding existing theories, and possible developments and concrete applications.

Construction of the theory

Perspectives and Ontologies

The starting point of the theory construction is a perspectivist epistemological approach on systems introduced by Giere [Giere, 2010]. To sum up, it interprets any scientific approach as a perspective, in which someone pursues some objective and uses what is called *a model* to reach it. The model is nothing more than a scientific medium. Varenne developed [Varenne, 2010] model typologies that can be interpreted as a refinement of this theory. Let for now relax this possible precision and use perspectives as proxies of the undefined objects and concepts. Indeed, different views on the same object (being

[4] geographical systems in the sense of [Dollfus and Dastès, 1975] are the archetype of such systems, but that definition may cover other type of systems such as an extended transportation system, social systems taken with an environmental context, complicated industrial systems taken with users, etc.

[5]

complementary or diverging) have the property to share at least the object in itself, thus the proposition to define objects (and more generally systems) from a set of perspectives on them, that verify some properties that we formalize in the following.

A perspective is defined in our case as a dataflow machine M (that corresponds to the model as medium) in the sense of [Golden et al., 2012] that gives a convenient way to represent it and to introduce timescales, to which is associated an ontology O in the sense of [Livet et al., 2010]. We include only two aspect (the model and the objects represented) of Giere's theory, making the assumption that purpose and user of the perspective are indeed contained in the ontology.

Definition 1. *A* perspective on a system *is given by a dataflow machine $M = (i, o, \mathbb{T})$ and an associated ontology O. We assume that the ontology can be decomposed into atomic elements $O = (O_j)_j$.*

The atomic elements of the ontology can be particular elements such as agents or components of the system, but also processes, interactions, states, or concepts for example. The ontology can be seen as the rigorous description of the content of the perspective. The assumption of a dataflow machine implies that possible inputs and outputs can be quantified, what is not necessarily restrictive to quantitative perspectives, as most of qualitative approaches can be translated into discrete variables as long as the set of possibles is known or assumed.

The system is then defined "reversely", i.e. from a set of perspectives on a system :

Definition 2. *A* system *is a set of* perspectives on a system *: $S = (M_i, O_i)_{I \in I}$, where I may be finite or not.*

Note that at this level of construction, there is not necessarily any structural consistence in what we call a system, as given our broad definition could allow for example to consider as a system a perspective on a car together with a perspective on a system of cities what makes reasonably no sense at all. Further definitions and developments will allow to be closer from classical definition of a system (interacting entities, designed artifacts, etc.). The introduced elements of our approach help to tackle so far points three, five and six of the requirements.

Precision on the recursive aspect of the theory One direct consequence of these definitions must be detailed : the fact that they can be applied recursively. Indeed, one could imagine taking as perspective a system in our sense, therefore a set of perspectives on a system, and do that at any order. If ones takes a system in any classical sense, then the first order can be understood as an epistemology of the system, i.e. the study of diverse perspectives on a system. A set of perspectives on related systems may in some conditions be a domain or a field, thus a set of perspectives on various related systems the epistemology of a field. These are more analogies to give the idea behind the recursive character of the theory. It is indeed crucial for the meaning and consistence of the theory because of the following arguments :

- The choice of perspectives in which a system consists is necessarily subjective and therefore understood as a perspective, and a perspective on a system if we are able to build a general ontology.
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Ontological Graph

We propose then to capture the structure of the system by linking ontologies. Therefore, we choose to emphasize the role of emergence as we believe that it may be one practical minimalist way to capture quite well complex systems structure[6]. We follow on that point the approach of Bedau on different type of emergences, in particular his definition of weak emergence given in [Bedau, 2002]. Let recall briefly definitions we will use in the following. We assume that emergence can exist under the three following forms :

[6] what of course can not been presented as a provable claim as it depends on system definition, etc.

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Definition 3.

Definition 4.

Minimal Ontological Tree

Scales

Finally, we propose to define scales associated to a system. Following [Manson, 2008], an epistemological continuum of visions on scale is a consequence of differences between disciplines in the way we developed in the introduction. This proposition is indeed compatible with our framework, as the construction of scales for each level of the ontological tree should result in a broad variety of scales

Application

The particular case of geographical systems

[Dollfus and Dastès, 1975]

Modularity and co-evolving subsystems

Discussion

Conclusion

References

[Arthur, 2015] Arthur, W. B. (2015). Complexity and the shift in modern science. Conference on Complex Systems, Tempe, Arizona.

[Batty, 2013] Batty, M. (2013). *The new science of cities.* Mit Press.

[Bedau, 2002] Bedau, M. (2002). Downward causation and the autonomy of weak emergence. *Principia: an international journal of epistemology*, 6(1):5–50.

[Bourgine et al., 2009] Bourgine, P., Chavalarias, D., and al. (2009). French Roadmap for complex Systems 2008-2009. *ArXiv e-prints.*

[Dollfus and Dastès, 1975] Dollfus, O. and Dastès, F. D. (1975). Some remarks on the notions of 'structure'and 'system'in geography. *Geoforum*, 6(2):83–94.

[Dupuy and Benguigui, 2015] Dupuy, G. and Benguigui, L. G. (2015). Sciences urbaines: interdisciplinarités passive, naïve, transitive, offensive. *Métropoles*, (16).

[Giere, 2010] Giere, R. N. (2010). *Scientific perspectivism.* University of Chicago Press.

[Golden et al., 2012] Golden, B., Aiguier, M., and Krob, D. (2012). Modeling of complex systems ii: A minimalist and unified semantics for heterogeneous integrated systems. *Applied Mathematics and Computation*, 218(16):8039–8055.

[Hidalgo, 2015] Hidalgo, C. A. (2015). Disconnected! The parallel streams of network literature in the natural and social sciences. *ArXiv e-prints.*

[Laughlin, 2006] Laughlin, R. B. (2006). *A different universe: Reinventing physics from the bottom down.* Basic Books.

[Livet et al., 2010] Livet, P., Muller, J.-P., Phan, D., and Sanders, L. (2010). Ontology, a mediator for agent-based modeling in social science. *Journal of Artificial Societies and Social Simulation*, 13(1):3.

[Louf and Barthelemy, 2014] Louf, R. and Barthelemy, M. (2014). Scaling: lost in the smog. *arXiv preprint arXiv:1410.4964*.

[Manson, 2008] Manson, S. M. (2008). Does scale exist? an epistemological scale continuum for complex human–environment systems. *Geoforum*, 39(2):776–788.

[Newman, 2011] Newman, M. (2011). Complex systems: A survey. *arXiv preprint arXiv:1112.1440*.

[Pumain, 2005] Pumain, D. (2005). Cumulativité des connaissances. *Revue européenne des sciences sociales. European Journal of Social Sciences*, (XLIII-131):5–12.

[Varenne, 2010] Varenne, F. (2010). Framework for m&s with agents in regard to agent simulations in social sciences. *Activity-Based Modeling and Simulation*, pages 53–84.

[Wolfram, 2002] Wolfram, S. (2002). *A new kind of science*, volume 5. Wolfram media Champaign.