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From statistical physics to social sciences / *De la physique statistique aux sciences sociales*

The politics of physicists' social models

La politique des modèles sociaux des physiciens

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ABSTRACT

I give an overview of the topic of this dossier, the "applications of (statistical) physics to social sciences at large." I discuss several examples of simple social models put forward by physicists and examine their interest. I argue that while they may be conceptually useful to correct our intuitive models of social mechanisms, their relevance for real social systems is moot. What is more, since physicists have always needed to 'tame' the world inside laboratories to make their models relevant, I suggest that social modeling might be linked to human taming, a smashing political project.

RÉSUMÉ

Je donne un aperçu du sujet de ce dossier, les « applications de la physique (statistique) aux sciences sociales en général ». Je présente plusieurs exemples de modèles sociaux simples mis en avant par les physiciens et je discute leur intérêt. Je soutiens que, bien qu'ils puissent être conceptuellement utiles pour corriger nos modèles intuitifs de mécanismes sociaux, leur pertinence pour les systèmes sociaux réels n'est pas évidente. Qui plus est, puisque les physiciens ont toujours eu besoin de « dompter » le monde à l'intérieur des laboratoires pour rendre leurs modèles pertinents, je suggère que la modélisation sociale pourrait être liée au dressage des humains, un projet politique inquiétant.

1. Introduction

Why would physicists study social systems? Can they add anything to the knowledge of social scientists, economists, or all of us, who practice social systems every single day? One possible answer is given by the physicist Rémi Louf, who recently was awarded a prestigious price for his PhD on the physics of cities: physics represents "a way of questioning the world and understanding it," starting from observations to find the "simple mechanisms that govern each phenomenon."

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Thanks to the avalanche of social data, the digital traces left by everyone, physicists can now confront their simple models to social reality and go beyond their "impressions," to found a new "science of cities [...] that would provide a sufficiently precise image to guide political choices." We can understand the enthusiasm of the young physicist to found a true science of society, at once empirical and rigorous, that is, mathematical.

Before getting too enthusiastic, however, it may be useful to read a text published nearly two centuries ago by the Belgian astronomer Adolphe Quételet [1]. He proclaimed the birth of a new science of crime: "If we want to acquire knowledge of the general laws of [human criminal inclinations], we must gather enough observations to ensure that everything that is not purely accidental is eliminated. [Thanks to this knowledge, we will have] the possibility to improve men, by modifying their institutions and their habits." The reasoning is similar: from data to social laws, from laws to the improvement of society. And the parallel is even more striking given the title of Quételet's book: *Sur l'homme et le développement de ses facultés, ou Essai de physique sociale* (on the development of human faculties or Essay on social physics). This book was part of a vast economic, political, and scientific transformation of European societies. Increasingly, strong states transformed their territories and their inhabitants to make them governable from a center. They counted populations and wealth to better enlist soldiers or collect taxes. This control required the setting up of a legal and material infrastructure, an investment similar to that of a road or rail network. Concretely, the States generalized supervision tools that we take for granted today, like the maps, the cadastre, the homogenization of the units of measurement or the stabilization of the surnames.

The science of "statistics" is a direct consequence of this transformation [2,3]. At first, this word – derived from the Italian *stato*, state – meant all the knowledge useful for governing a country, and did not include mathematics. But in the 19th century, the scientific elite invented computing tools capable of exploiting social data to help this centralized government of populations. Pierre-Simon de Laplace, the great astronomer and mathematician, minister of Bonaparte in 1799, developed different approaches to estimate the French population from parcel data, because it was difficult – and expensive – to carry out a comprehensive census. He assumed that the number of births per inhabitant was more or less constant in the country, an assumption that he tested in some thirty carefully selected regions to be representative of the whole territory. It was then sufficient to count the number of births, which were well known from parish registers, to obtain an estimate of the total population.

James Clerk Maxwell exported the statistical approach from social to physical systems. In 1859, he published the founding article of a new branch of physics, aptly called "statistical." He showed how to compute the properties of a gas using those of its constituents, the atoms. Inspired by Quételet's approach, he renounced the Newtonian approach – which dictated calculating the trajectories of each particle – to switch to "statistical" properties, hoping that individual unpredictability would be compensated for at the macroscopic level. This allowed him to build the first rigorous bridge between the micro and macro worlds, by deducing certain properties of the gas, such as viscosity, from the statistical distribution of atomic velocities. Today, physicists complete the circle, drawing inspiration from the well-supplied toolbox of statistical physics to analyze social systems.

2. Social physics today

What are we talking about when we deal with the topic of this dossier: "applications of (statistical) physics to social sciences at large"? A cursory bibliometric search for articles published in Web of Knowledge physics journals using the terms "social," "economics," or "econophysics" in either the title or the abstract leads to roughly 9000 records. Their analysis using BiblioTools [4] reveals seven main research directions (a detailed description is given as Supplementary Information): complex networks [5,6], econophysics [7,8], opinion dynamics [9], evolutionary games [10], community detection [11,12], collective motion [13] and human dynamics [14]. Overall, the domain is steadily growing, as the number of papers has been multiplied by 10 since year 2000, reaching nowadays 800 articles per year.

Most of these articles deal with *simple* models. As Castellano et al. [15] recognize in their review: "there is a striking imbalance between empirical evidence and theoretical modeling, in favor of the latter. This [...] is a rather objective reflection of a disproportion in the literature on social dynamics." The imbalance can be understood easily: simple models are attractive for physicists because they are both elegant and relevant. They capture the essential mechanisms at work in a quantitative way, stripping away unimportant details, as exemplified by the archetypical Ising model for magnetic phase transitions. This simple model extracts with surgical precision the core mechanism of phase transitions, namely the collective, avalanche-like effects provoked by particle interactions, leaving aside all the obscuring "details." Yet, simple models are relevant for real systems, because physical systems are simplified in the laboratories [16] and thanks to the idea of universality: "statistical physics brings an important added value. In most situations, qualitative (and even some quantitative) properties of large-scale phenomena do not depend on the microscopic details of the process. Only higher level features, such as symmetries, dimensionality, or conservation laws, are relevant for the global behavior" [15].

The basic idea behind "applications of (statistical) physics to social sciences" is also summarized very clearly in the review Castellano et al. [15]: "In social phenomena, the basic constituents are not particles, but humans." Then, "statistical physics approach to social behavior" means trying to "understand regularities at large scale as collective effects of the interaction among single individuals, considered as relatively simple entities." In the "initial state," "heterogeneity dominates": "left alone, each agent would choose a personal response to a political question, a unique set of cultural features, his own special correspondence between objects and words." When "interactions between social agents" are added to this initial picture, one finds the "stunning global regularities" "denoted in social sciences as consensus, agreement, uniformity." They add that universality gives hope that simple models will be relevant: "With this concept of universality in mind, one can approach the modeling of social systems, trying to include only the simplest and most important properties of single individuals and looking for qualitative features exhibited by models." In this paper, I will argue that, while simple models are a good tool for physical systems, their usefulness is more limited for social systems. In short, they might be useful to improve our *thinking*, to invalidate intuitive models, but they do not allow us to learn much about real social systems.

3. A useful conceptual model

Let us give an example of how simple models can be useful to improve our conceptualizations of social processes [17,18]. I focus on Schelling's segregation model [19], which became one of the most studied models in social physics, as it helps understanding why the collective state reached by agents may be different from what each of them seeks individually.

I present here a simplified version of Schelling's model, which lends itself to an analytical solution [20]. It represents the movement of a population of agents in a "city," which consists of $Q \gg 1$ non-overlapping blocks, also called neighborhoods. Each block has the capacity to accommodate H agents. Initially, a number of agents $N = QH\rho_0$ are distributed randomly over the blocks, leading to an average density ρ_0. All agents share the same utility function $u(\rho)$ that translates their preference for the density of the block where they are located. The collective utility U is defined as the sum of all agents' utilities, $U = H\sum_{q=1}^{Q} \rho_q u(\rho_q)$ and the average utility $\tilde{u}$ per agent is $\tilde{u} = U/N$. The dynamics is the following: at each time step, an agent and a free site in another block are selected at random. The agent accepts to move to this new site only if its utility is higher in this new location. Otherwise, it stays in its present block. Then, another agent and another empty site are chosen at random, and the same process is repeated until a stationary state is reached, i.e. until there are no possible moves for any agent.

In [20], we have computed analytically the stationary states of such a system for any utility function. They confirm previous results obtained by numerical simulations showing that agents 'segregate' into crowded neighborhoods of low utility. Specifically, for $\rho_0 = 0.4$, a utility given by $u(\rho) = 2\rho$ for $\rho \leq 0.5$ and $u(\rho) = 2(1-\rho)$ for $\rho > 0.5$, the stationary density is given by a phase separation between blocks that remain empty and blocks at a density $\rho = 1/\sqrt{2}$, leading to an average utility $\tilde{u} = 2(1-\rho) \simeq 0.586$. This means that agents do not manage to reach the state of maximum average utility ($\tilde{u} = 1$) by gathering in blocks at $\rho = 1/2$.

Our analytical calculations show that the surprising 'segregation' of agents looking for half-filled neighborhoods arises because agents *collectively* maximize not U, but an effective free energy that we have called the *link* L. This state function allows us to generalize free energy to systems driven by *individual* dynamics. Its key property is that, for any move, $\Delta L = \Delta u$. It is given by the sum over all blocks q of a potential l_q: $L = \sum_q l_q$, where $l_q = \sum_{n_q=0}^{N_q} u(n_q/H)$, with $N_q = H\rho_q$ is the total number of agents in block q. In the large H limit,

$$l(\rho_q) \approx H \int_0^{\rho_q} u(\rho)\,\mathrm{d}\rho \tag{1}$$

The link may be interpreted as the cumulative of the individual marginal utilities gained by agents as they progressively enter the blocks from a reservoir of zero utility. Since agents move only when their individual Δu is positive, the stationary state is given by maximizing L over all possible densities $\{\rho_q\}$ of the blocks, from which no further $\Delta u > 0$ can be found.

This analytical solution to Schelling's segregation model is conceptually interesting because it allows a "clear quantitative demonstration [...] that Adam Smith's invisible hand can badly fail at solving simple coordination problems" [21]. And this unwanted segregation is robust to changes in the model's ingredients: addition of noise, shape of utility functions ... [22]. However, we have recently shown that it is fragile with respect to the introduction of a vanishingly small concentration of altruist agents [23], a kind of "compositional chaos."

The relevance of Schelling's model for real systems is less clear, because the reasons behind urban segregation are far more complex than those that any simple model can come up with [24,18]. While the model shows that one cannot logically deduce individual racism from global segregation, it says nothing about the actual urban segregation. And the idea of "universality" put forward by Castellano et al. [15] has not proved very fruitful in practice. There are some intriguing regularities in social data, such as Zipf's power law, but they are not very useful to understand social systems because they are too easy to obtain [25].

4. Finding the essential mechanisms

To avoid the criticism of irrelevance while keeping the conceptual advantages of simplicity, one interesting proposition is to link the models to real data, hoping that these are produced by a single "essential" mechanism. The elegant model of cities proposed by Louf & Barthélémy represents an exemplary case of this strategy [26]. It explains the increase in the number of urban centers – areas of high employment density – when the number of inhabitants increases by a single "essential" mechanism: congestion. A small city has only one center, bringing together most companies and administrations, while larger cities will have many, like the Parisian hubs La Défense, Les Halles, and many others. To quantitatively link the population and the number of centers, the model creates a virtual city in which there are several potential employment centers, each offering a different salary. Each inhabitant is a social atom preoccupied by one thing: choosing the employment center that offers the best compromise between (high) salary and (low) transportation cost. Clearly, when the city is small, the traffic is low and all residents can go to the job center that offers the best salary: there is therefore only one active center. But as the population grows, traffic and congestion increase. As a result, centers offering slightly lower salaries become active, because their proximity compensates for lost wages. This model is attractive because it combines three advantages, which are difficult to tie together: a mathematical link between ingredients and consequences, a quantitative fit to data for 9000 U.S. cities and an intuitive understanding of the phenomenon.

However, its relevance for real cities is moot. First, a rigorous mathematical link between assumptions and consequences does not guarantee the interest of the result: the global rigor of a chain of reasonings is that of its weakest link! And the choice of variables or the simplifications that led to the model is (are) more fragile. As the authors acknowledge, the definition of an employment center is rather vague: should a minimum number of jobs be required to declare that such a zone is a center? At which value to set the threshold? Should two neighboring areas be considered as one or two distinct centers? Moreover, bold assumptions are needed to build such a simple model: residents and businesses are identical, choose their residence at random, all firms in each center offer the same salary, there is no public transportation... In short, using mathematics to produce explanations by linking these elements is like trying to supply your home with water by using a very solid pipe to a tank... that is almost empty.

All things considered, the idea of “essential mechanisms” governing social systems is as seductive as it is reckless. It postulates the existence of a hierarchy among the many imaginable causes, which would allow one to extract a single one, which dominates all cases. In the city model, it is well known that other factors lead to the creation of centers: companies want to be close to each other to facilitate the exchange of goods or information; retail stores to attract a larger clientele.... We can therefore imagine several simple models, with very different “essential” ingredients, leading to satisfactory empirical predictions, because the data are always noisy and do not allow one to discriminate among them.

Social sciences have created tools that may be more adapted to the complexity of social systems, where several causes have to be combined to produce an effect. When causes can simply be added, as physicists' forces, old tools such as multiple regressions can do the job. But in real systems, the combination is often trickier. For example, a strike may start when either (1) a new technology is introduced and wages stagnate or when (2) the suppression of overtime is combined with outsourcing. Each of the four possible causes is neither sufficient nor necessary to start a strike: for example, wage stagnation will not cause it if no new technology is introduced, and a strike may start even when wages are increased, through the second causal path. More complex causal tools are needed than “finding the essential mechanism” or even multiple regression [27]. The point is that if one assumes from the start that there is a single mechanism at play, noisy data may confirm this idea, even when it is too simple. Respecting the complexity of our object is essential for good science, and this may well mean giving up our fascination for elegant models.

5. More realistic models?

Physicists may draw comfort from the fact that more complex models, that try to include all the relevant variables, fare no better in practice. For example, large teams of economists build complicated models with hundreds of variables to predict economic growth. Alas, these predictions are not much better than those of a much simpler model: economic growth next year will be the same as it is this year [28]. In [18], I discuss at length why complex social models fail. One important point is the absence of conservation laws, which are a major provider of reliable equations for physical systems. For example, climate science models take advantage of energy and momentum conservation laws to build a kind of framework, which grants them robust predictions even for long times and variable conditions. In chemistry, the nature of atoms is conserved, whatever the complexity of the transformations. There is no similar stability in social systems, hampering any credible prediction beyond the simple “tomorrow will be as today.” In other words, social science lacks a *dynamical* theory, based not on simple regularities but on the *reproducibility of change*, as in Newton's second law: $\mathrm{d}v/\mathrm{d}t = F/m$.

6. We are not social atoms!

Let us examine this idea of “conservation laws” and analyze in more detail the example of “social atoms,” a pervasive analogy in economists' (and physicists') models [29]. As summarized above by Castellano et al. [15], the models of the physicists start with isolated “simple entities,” endowed with stable characteristics, and try to “understand the regularities at large scale” that arise when one adds “interactions” between them.

This approach has turned out to be fruitful to analyze physical systems, because the atoms of the physicists can be characterized by stable characteristics. These arise from the strong difference between the typical energy of a chemical reaction and that needed to change the chemical atomic identity, guaranteed by the much more strongly bonded atomic nucleus. The problem is that there seems to be no such energy scale separation for the so-called “social atoms,” i.e. humans. Therefore, the whole idea of starting with isolated individuals endowed with stable characteristics and then adding interactions is unfounded. As argued long ago by John Dewey [30]: “Each human is born an infant [...] immature, helpless, dependent upon the activities of others. There is no sense in asking how individuals come to be associated. They exist and operate in association.” Moreover, human characteristics originate in these interactions: “What [a person] believes, hopes for and aims at is the outcome of association and intercourse.” Unlike atoms, we are constantly remade by who and what we meet. There

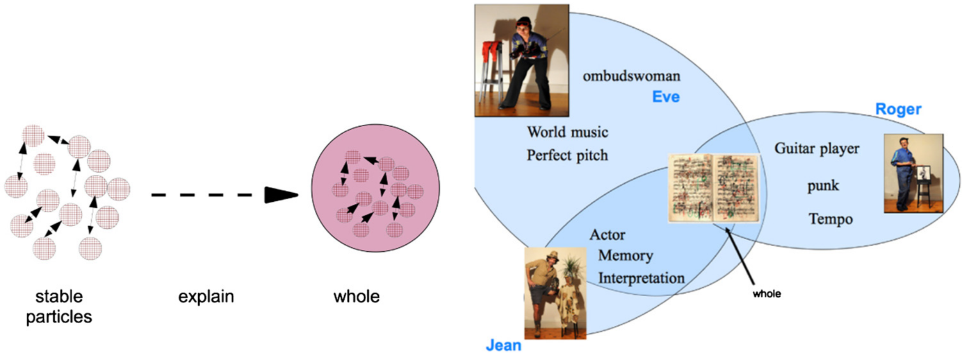

Fig. 1. (Left) In the usual 'atomic' modeling, each individual is simple, stable, and their interactions 'explain' the whole, which is large as it aggregates the 'atoms'. (Right) In our vision, each individual, represented here as an ellipse with several characteristics, is complex. The whole is represented as their intersection – here, the annotated score – and is smaller than the individuals. There is no guarantee of stability in neither the individuals nor the whole.

is no stable nucleus that would characterize us deeply, lending stability to our actions. This sheds doubts on the reliability of approaches that try to predict collective outcomes based on utility functions taken to be stable across individuals, situations or in time [18]. Of course, it is always possible to build an abstract model where any macro-structure is conveniently "explained" by some arbitrarily posited stable microstructure (Fig. 1). Three centuries ago, Descartes' followers 'explained' the acidity of lemons by the tiny 'needles' of 'lemon atoms'…

The failure of simple models does not mean that the relation between individuals and collectives cannot be conceptualized (if not quantified). But the scope is not necessarily to stick with general models, but rather to find conceptualizations that are relevant for social systems. The interesting question becomes how humans "come to be connected in just those ways that give human communities traits so different from those which mark assemblies of electrons, unions of trees in forests, swarms of insects, herds of sheep" [30]. In recent work with sociologists [31], we have discussed an alternative vision of the entire parts/whole perspective, showing that the standard micro/macro approach oversimplifies both the individual and global levels. For example, in Schelling's model, individuals are defined by their color and their utility function, which do not change during the entire process. The whole is defined by the segregation at the (large) scale of the city, which emerges from the interactions between individuals. However, if we cared to survey real people, we would of course learn that each individual is more complex than her utility function, and also that she has specific visions of both the neighborhood and the segregation. Adolescents attending local high schools will likely have segregation experiences that differ from adults that work abroad or retirees who stay on the neighborhood all day. And the researcher adds her own point of view, which is not politically neutral as we will discuss below.

We can understand these different visions of the whole with a simpler example, that of the vocal ensemble in which I sing, Ginga, which has no leader. In the classical vision, the parts would be the twelve singers seen as small atoms, whose interactions would lead to the whole, the vocal group. In our approach, each singer lends a tiny fraction of his own complexity, which he agrees to standardize, in order to create a temporary collective, a whole much smaller than its parts. The whole is "smaller" because it obviously represents only a small part of each of our lives. And, more important, because the creation of a coherent group filters out the many latent possibilities of each person. These possibilities are manyfold because we all have a different story, in which singing takes a more or less important place. Our musical cultures are also disparate, rather classical for some, eclectic for others, from punk to world music. Finally, our technical skills are very diverse, for harmony, rhythm, interpretation, pronunciation or vocal technique. No wonder everyone has different ideas about what Ginga is, or should be. Should we spend time recording in a studio, or focus on public concerts? Does it really matter if we do not strictly follow the score, since few people in the public will notice it? All these differences must, in the end, lead to a common interpretation of each piece. A concrete trace of the "whole" would be the annotated score (Fig. 1), summarizing all the musical choices made collectively, following the more or less lively discussions that allowed us to master the original piece. Singers are thus coordinated, partly simplified by this standard form, the annotated score, which everyone must respect to sing together. The whole is smaller than the parts. But it enriches them, because none of us would have been able, individually, to produce it.

7. The politics of simple models

Let us start with a naive question: why do physicists start by stripping individual entities of their attributes, before adding simple interaction rules to obtain the "whole" that was there from the beginning? Clearly, simplifications are needed if we are to model anything. But the point is that different simplifications lead to different explanations, and in the case of social systems, to different politics [18,32]. Simple models assume that agents are unable to understand and control collective phenomena. Implicitly, only researchers are able to analyze the situation, determine the factors leading to the results, and find the ways to change them. To use an apt image by James Scott, the modeled individuals are, as in Taylor's factory, "the molecules of an organism whose brain is elsewhere" [33]. In other words, modeling takes an external point of view on social systems, assuming that the dynamics of change must come from outside the situation, rather than from the reflections and creativity of the actors [24,34]. This is their implicit political vision, adapted to the control of a periphery by a center, which needs standardized entities and relatively simple interaction mechanisms to guide its actions. Ironically, a supposedly "bottom-up" approach [35] leads to "top–down" social politics! Maybe it is time, as Phil Mirowski suggests, [36] to "abjure the physics" for modeling social systems. For him, the "various attempts to directly appropriate models from physics, and then bend them to the description of economic variables" have not proved successful, even if they constitute "a major source of continuity in the history of neoclassical economics." The alternative conceptualization sketched above, inspired by sociology, keeps the complexity of individuals and their specific visions of the situation, giving more power to the actors than to the center for analyzing and changing the collective state.

Finally, if we analyze empirically how physics has managed to get a grip on the world [37], we find that it has always *transformed* its objects in the laboratory, as tigers are tamed before participating in a circus show. The analogy is interesting [16], as it shows the hard and creative work needed to adjust the theory and the world. It also stresses that there exists, at the same time, some discontinuity between nature and scientific objects (we cannot know much about the untransformed world, as we cannot use a wild tiger in a circus), *and* some continuity (it is a real tiger, and it will not accept to do anything). To become relevant, social models will have to 'tame' humans, for example by using the "social credit" system currently being developed in China [38]. It aims to track people and reward "good social behavior" while punishing bad behavior, using monetary rewards and penalties. This may achieve better predictions, but I am not sure that I want to contribute to the taming of humans.

8. Conclusion

In this personal review of social physics, I focused on the fondness of the physicist for simple models, emphasizing their lack of relevance and political implications. However, it is fair to acknowledge that the distinctive approach of the physicists can help social sciences. For example, econophysics stresses direct interactions between agents and non-equilibrium dynamics, enriching the range of models available to interpret reality, beyond standard economic approaches. Moreover, some social sciences also create simple models: after all, Thomas Schelling, the author of the simple segregation model discussed above, was a political scientist! To me, the bottom line is: what are the consequences of our work on social systems? Are we just playing with mathematical toys? Are we contributing to understanding real social systems? Are we creating the mathematical tools that will help those that own the data – Google, Facebook & Co. – to control the world?

Appendix A. Supplementary material

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.crhy.2019.05.016.

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