Model Assisted Statistics and Applications 4 (2009) 39–62
DOI 10.3233/MAS-2009-0106
IOS Press

Statistical and physical paradigms in the social sciences

Igor Mandel[a] and Dmitri V. Kuznetsov[b]
[a]*Telmar Group Inc., 470 Park Avenue South, New York, NY 10016, USA*
E-mail: igor.mandel@gmail.com
[b]*Intellidyn, 175 Derby St., Suite 40, Hingham, MA 02043, USA*
E-mail: dmitrikuznetsov@yahoo.com

Abstract. Relations between traditional statistical and recently emerging sociophysics paradigms in the social sciences are considered. Similarities and differences between them are analyzed, resulting in a list of the qualitative differences to modeling approaches of reality. Historical review of sociophysics ideas provided, which shows that sociophysics has old and deep, yet often forgotten traces in social and systemic heritage. Importance of complimentary development of two directions in social field is emphasized. Mediaphysics, a branch of sociophysics proposed by the authors, is briefly described as a possible way to use advantages of these two approaches in an organic integrity. It applies general physical models to usual statistical data sets of mass phenomena, which makes it usable for a very wide class of problems, unlike typical physical models, oriented on specific systems. The keystone of the proposed approach is an analysis of population distributions between several alternatives (brands, political affiliations, or opinions) under the influence of internal and external fields.

Keywords: Sociophysics, econophysics, statistics, general system theory, field theory, influence, mediaphysics, word of mouth, media

1. Introduction

The intersection of physical and statistical paradigms has become an actual problem during the last two decades since the introduction of such branches as econophysics and sociophysics. Physics has been successfully applied to many scientific fields as a very important tool to understand complex systems of any nature. But earlier interdisciplinary applications (like biophysics) did not lead to an opposition between physics and statistics, at least for the simple reason that statistics was not considered a tool in the respective fields (say, in biology 150 years ago), while physics very early was. Biologists or geologists, armed with “microscope or/and a hammer”, could do without statistics very well (and they did), but it did not take long to admit that understanding of physical processes in cells or in minerals is mandatory for the progress in “pure” biology or geology. So the need of biophysics or geophysics had been very naturally demanding, while the same type of natural demand for statistics appeared later, for other reasons. In other words, statistics and physics in these areas cohabit peacefully and solve mainly non-overlapping problems (and just recently some universal physical and general system theory applications in biology, analogously to these in sociology, started to extend the already build premise of biophysics, making this branch of it very close to modern sociophysics).

The situation in the social sphere, however, is very different. On the one hand, there are no direct physical processes involved in the investigation of, say, ethnic or class relations, or in the analysis of market crashes. Sociologists lived just as well without physics until recently, as biologists and geologists had done without statistics a long time ago. The natural demand for sociophysics, seemingly, could not appear (though in one crucial period this tie was amazingly strongly established, just to be lost later – see section 2 below). On the other hand, statistics has been an inseparable part of social science since its inception in ancient times, and actually was understood **only** in social

ISSN 1574-1699/09/$17.00 © 2009 – IOS Press and the authors. All rights reserved

context for centuries (from the evangelical census in Bethlehem to the "modern" term "statistics" as "quantitative description of state affairs" in the 1600s). In that broad sense, statistics was and remains the only available legitimate quantitative descriptive tool in the social sciences. It provides all necessary methodology, from hypotheses about mechanisms of data generation through data collection and modeling to interpretation of results. In what sense is physics helpful in this area densely populated by statistics (and statisticians), taking into account a boom in sociophysics in the last decade? What kind of relations between those sciences – cooperative or competitive – would prevail? Discussion of those and related questions is the first objective of this paper.

The second is a description of the core features of the mediaphysics approach [36] as one of possible ways to bridge the two methodologies. Mediaphysics was determined as *a part of sociophysics, studying processes of mass communications in social and sociobiological systems.* These phenomena, considered broadly, take place practically everywhere in society. We demonstrate that mediaphysics may be an approach, which links physical and statistical ways of thinking about social matters. "Media" there is associated mainly with media as an environment in which communicative processes are taking place, but has also some resemblance with media as a medium for motivation fields (described below) and "mass-media", as marketing, economical, political and cultural influences spreading through mass communication channels. This last association has quite a practical value – we started implementation of the approach solving concrete media (in marketing sense) problems. The whole formalism was described in the cited paper, but could be understood from the short version in Appendix; here we pay attention mainly to the main assumptions and illustrative examples.

The third objective is to attract the attention of a wide statistical audience to a fast growing field of sociophysics, which so far remains not well recognizable in the statistical literature. In our opinion, such a gap should definitely be narrowed quickly, because, as it often happens, the merging of the two camps may create new important and unexpected results. Mediaphysics, in fact, is one of such attempts to aggregate approaches that originated from physics, statistics, and sociology.

The paper is organized in the following way. Section 2 gives a brief historical review of sociophysics ideas; Section 3 points out methodological differences between physical and statistical models, Section 4 contains an informal mediaphysics discussion; Appendix has a short formal description of mediaphysics and the conclusion summarizes the results.

2. Physics in social fields

2.1. Prehistory

We cannot pretend here to write the complete history of the relations between two huge areas of science – physics and statistics – when they both were used as tools to understand society. Our purpose is much more modest: just to outline several important knots of the yet unwritten complete history of sociophysics to stress the point that these branches of science, seeming quite departed from each other now, had not always been in such disposition. Possibly, this short survey would contribute to the notion that the next circle of courtship between physics, statistics and the social sciences, which has started recently, will ultimately emerge in a new synthesis – "*socio-statistical physics*" or "*socio-physical statistics*".

In the triad "physics – statistics – sociology" (where the last term for simplicity is understood as a synonym of all social sciences, so includes economics, socio-psychology, etc.), relations within each pair are very rich but are comprehended unevenly in the scientific community. The most studied is, of course, "**statistics – sociology**". The very term statistics came from merely practical social (mainly fiscal) considerations, as a tool to collect data about state affairs. Statistics does remain the most important, if not the only instrument for quantitative analysis of society. Thus, we would touch this pair only when necessary to emphasize something else. The pair "**physics – statistics**" also provides a significant area of interactions, which resulted in the creation of statistical physics in the middle of the 19th century. Again, we cannot go into that area with appropriate depth, one important exception being the role that social statistics played in the creation of statistical physics (a fact rather obscure for both statisticians and physicists). Our main subject is the pair "**physics – sociology**", which has been much less studied than the two others. It demonstrates a fascinating picture of intellectual adventures, which in combination with the statistical way of thinking created a complicated history of interactions within the basic triad.

In a philosophical sense the deep relationship between physics and sociology has been felt and expressed since ancient times. It is hardly a mere coincidence that one of the greatest minds, Epicurus (341–270 BC), providentially merged these two things in the following way: "*. . . in order to keep our freedom, it would have been better to remain attached to the belief in gods rather than being slaves to the fate of the physicists: the former gives us the hope. . . ; the latter, on the contrary, brings with it an inviolable necessity*" [59, p. 10]. If we recall that in fact Epicurus was a devoted materialist and considered gods as immortal but indifferent to human beings (he formulated the famous Epicurus paradox about nature of God, for which he was put into hell by Dante and condemned in the Talmud), the above sentence could be interpreted as the first clearly stated deep *controversy between free will and physical determinism*, which in many aspects shaped Western philosophy for millennia to come. It was culminated in the celebrated "Laplace's determinism" (which in fact was founded very clearly by R. Boscovich in 1758, 56 years earlier than by P.S. Laplace) and has been fascinating physicists and philosophers until now (see a brilliant discussion in [59] and recent results, like "Free Will Theorem" by J. Conway and S. Kochen, cs.auckland.ac.nz/∼jas/one/freewill-theorem.html.). If to add that namely Epicurus created the idea of random atoms' deviation from their straight trajectories (as Democritus earlier assumed), *clinamen*, which was both one of the first notions of random (statistical) process and indeterminism, then one may see that in that earliest account all components of the triad of interest have already been thought out within one conceptual frame.

The first European great social-political oeuvre, which could be called "scientific", *Leviathan* by Thomas Hobbes, was written under the strongest influence of physical ideas and spirit. It is not a coincidence, again, that its author specially traveled to Italy to meet Galileo, one of the greatest contributors to experimental physics. The key Hobbes' ideas – the analogy between a mechanical machine, human body and society; the logical way of deduction of political conclusions from the prime principles (the necessity of the democratically elected super-leader); a presence of the iron forces of laws dictating the social behavior – all make him ". . . the first to seek a physics of society" [4, p. 15]. And if "Hobbes discovered society" (as F. Nussbaum puts it), we should admit that since this discovery modern sociology owns physics much more than it is usually presumed.

However, Hobbes did not make any statistical associations (and could not have them at that time). It took almost a century and a half, and needed the first mortality tables and "laws" by the mathematician-politician (!) de Witt and astronomer Halley, modeled by de Moivre, the founders of the probability theory and a giant figure of Newton, among others, for M. J. de Condorcet to write the following in 1785: for the science of human affairs, "*All that is necessary to reduce the whole of nature to laws similar to those which Newton discovered with the aid of calculus, is to have a sufficient number of observations and a mathematics that is complex enough*" [4, p. 54]. This remarkable phrase, merging physics, statistics, sociology, mathematics and "laws", is most likely the first of countless similar statements, which we will partly witness below. And, again, one of the Enlightenment's brightest minds, not only the contemporary of the great national turmoil, like Hobbes, but one of the luminaries of the French Revolution, links physics and social life together. It goes beyond just metaphorical value for its author; de Condorcet, in his famous *Esquisse*, written in hiding just before his fatal imprisonment in 1794, creates the very optimistic image of future society in accord with these "natural physical laws".

His words and his notion have been aligned with the new world of rationalism. In the 1830s the very term "*physique sociale*" was for the first time proposed by the "pope of positivism" August Comte, another visionary of great scale. But it was not that well known until the publication of a book [55] with this term in its title. Comte, being sure that Quetelet "has stolen" his term (http://en.wikipedia.org/wiki/Auguste_Comte), coined a new one, **sociology, for the same subject (!).** Ironically, the science that Adolphe Quetelet called by the (borrowed? stolen?) term *social physics* and ardently defended all his life, later turned out to be modern **statistics**, of which Quetelet is counted as one of founders.

This interplay between the three sciences and titles in the early period of their development seems very emblematic. At that Newtonian time it was a deep notion that the new social physics would establish laws in the social sphere as solid as those in physics, which looked unshakable. Amazingly, Quetelet's reasoning for social physics remains almost the same as it stands for sociophysics for many scientists today.

A. Quetelet [55, p. 6]: "*. . . the greater the number of individuals observed, the more do individual peculiarities, whether physical or moral, become effaced, and leave in a prominent point of view the general facts, by virtue of which society exists and is preserved*"

D. Stauffer [68]: *"The law of large numbers averages out over individual fluctuations and makes general trends more clearly visible. Thus what we call today statistical physics plays a useful rule, and social scientists . . . have applied it, without knowing then that they dealt with an Ising model of ferromagnets"*

In [36], we cite some other examples of that kind. But arguments like this in fact do not make any distinction between physics and statistics, and if in the first half of the 19th century it was still possible, now it sounds like an oversimplification. One of the purposes of this article is to show that the difference between physics and statistics is deeper than it may seem from the quoted and other statements.

Quetelet's interpretation of social physics as a science about finding solid rules in an ocean of random individual social fluctuations was of enormous importance, directly affecting such thinkers as Galton, Marx, Durkheim, and, probably, Darwin, among others [12], i.e., the originators of the main intellectual achievements of the 19th century (statistics, sociology and evolution theory). But, besides that, there is strong evidence that Quetelet's works inspired J.C. Maxwell to create his kinetic gas theory, the first chapter of statistical mechanics [58], i.e., a social study inspired the physical one, not the other way around. It is quite educating now to read, say, the following paragraph by Maxwell in his presentation of the new ideas to physicists of the British Association in 1873: "The modern atomists have therefore adapted a method which is, I believe, new in a department of mathematical physics, though it has long been in use in department of Statistics" [58, p. 111]. A period 1830–1870 is a turning point, where two key ideas – stability of social statistical distributions and stability of natural laws – after being considered in their integrity, started to split apart. Since then, physics has continued to find fundamental rules yet in statistically solid format, while sociology has gone into the embraces of statistical methodology, but without that physical "fundamentality". The short period of happy marriage was over, and the primary integrated notion of physics, statistics and social science was in fact lost. We now observe the new signs of flirting – but from physical side only.

During the next 130 years, works used physics or physical ideas in the social realm (sometimes without even recognition of it) appeared without noticeable influence on mainstream thinking. In geography a remarkable direct association between population in cities interactions and gravity low was made by H. Carey as early as in end of 1850th (see other interesting historic references to that gravity ideas in Fa íñaa, López-Rodríguez [18]), which was a precursor of important class of models in a next century (see below). Another very important link could easily be traced from Victor Pareto's famous book about income distribution (1897) to modern sociophysics, where Pareto distribution plays a major role (see 3.1). However, Pareto himself did not make any associations with physics.

It was done by Louis Bachelier [2] where, in modern terms, a concept of random walk was first introduced and used to understand the financial speculations (before Einstein's Brownian motion theory and Markov's chain theory). Now Bachelier is widely regarded as a founder of "financial mathematics", but for decades his work did not inspire any development in economics or sociology, in contrast to mathematics, where he always was very highly regarded (say, by A. Kolmogorov in his famous article establishing a modern probability theory in 1931). In his dissertation, the physics theory of heat flow was applied to area of finance – the first formal work of that type in history. It was noticed and praised by his advisor, a great A. Poincare – but did not ignite any development.

In completely different area a book by W. Reilly [62] originated the whole branch of research in "geographical marketing", which is very vivid up to now. His "law of retail gravitation" was a pure sociophysical construction, where Newton's formulas applied to geography yielded wonderfully good results, which many studies validated since then. And even if Reilly didn't do wide statements about marketing and physics in general, his breakthrough work demonstrated much more clear than Bachelier's one the strait benefit of physics in such a practical area as marketing. In spite of the fact that this concept was actively used by many marketers since its inception, the "sociophysical notion" of it did not go outside this comparatively small community.

Maybe the first person who consciously revitalized the "forgotten" relation between social life, physics and statistics in the 20th century was Ettore Majorana (a "genius", in Fermi's words). It was in his work "*A value of the statistical law for physics and social science"* [41], written at the latest in 1938 and published after author's death. The three sciences are considered there from the points of view of quantum mechanics and indeterminism principles. For the very first time, a deep similarity between the fields is shown, together with an awareness of the difficulties on the way. Majorana did not directly apply physics to solving any social problem, as Bachelier has already done, but emphasized the common nature of underlying statistical laws in both spheres, which might open the door for mutual penetration of sciences. In his words, "*. . . our final objective is to illustrate how traditional statistical laws must be improved as a result of the new direction taken by contemporary physics*" [44]. Again, it did not attract interest in the subject at that time, maybe because it was published in Italy during the war.

Soon after the war, the entire notion of social physics was reinvented (it seems, without awareness about Quetelet and Compte) by prominent astrophysicist J. Stewart [72]. His article's title in "Science" speaks for itself: *Suggested Principles of "Social Physics"*. In this and following works (in both physics and sociological journals), not only he advanced models of Reilly's type, but also clearly stated the need of interdisciplinary social physics. Surprisingly enough, in spite of "heavy weight" of the author and journals, Stewart's appeal remained unanswered at his time and not in fact recognized even now.

The concept of Brownian motion was again applied to finance (it seems for the first time after [8]) by M. Osborne at the end of the fifties [53]. His work [54] is in fact the first book on econophysics in the narrow sense, as treated by many, including founders of the term (a science about physics applications in finance), before the establishing work [43], but about the same topic. Quantum physics and theory of chemical kinetics were applied to macroeconomic modeling at that time as well, but it was a rather scholastic exercise [30]. One of the most influential in marketing and management articles was published in sixties, where author proposed to use physics concept of diffusion to analyze innovations and imitations on a market place [5]. This work was widely accepted and developed, but its physics content was lost in a typical perception. A book by Georgescu-Roegen [28], the first attempt to link the fundamental laws of economics and thermodynamics in a systematic way, did not inspire future research, though it did anticipate some ideas developed much later [47]. An article by Schelling [66] about racial segregation in neighborhoods was in fact very "physical" by its content, although the author did not put it this way. As was shown later, situations like that are perfectly described by Ising models from physics (see analysis from this point of view in [68]). However, the importance of this work, very influential in economics (T. Schelling became a Nobel Prize winner in 2005), is that it demonstrates the use of physical concepts in the social sphere, even without naming them as such. Several other isolated works have also appeared in the 1970s (see some references in [26]), with outstanding studies of conflicts and wars by Rummel (1975–1982) among them, who used a theory of catastrophes. But the most notable work of that time was, undoubtedly, the Black-Scholes option pricing model [6], where the old idea of random walk in finance has ultimately brought a result, proven to be, maybe, the best ever known financial applied model (M. Scholes received a Nobel prize for this in 1997). These authors explicitly used the heat-transfer equation, but due to the importance of their result per se, nobody paid attention to that physical aspect (quite unsought though), until modern econophysics took off.

In the book "Laws of Chaos. A Probabilistic Approach to Political Economy" [19], the authors systematically and ambitiously used statistical mechanics for very general theoretical economic purposes and applied it for empirical studies. It was a great novelty, especially because they critically referred to the only real predecessor [28]. Today some economists and econophysicists call this book groundbreaking, and a special conference was held on the 25th anniversary of its publication (http://iwright.googlepages.com/probabilisticpoliticaleconomy); however, it seems to have left no deep traces in mainstream economics. Even more interesting was the fate of the book "More Heat than Light: Economics as Social Physics, Physics as Nature's Economics" [47], with a more than attractive title and no less important content. The author there made very serious claims that all main ideas of neoclassical economics were in fact borrowed from "pre-quant" physics, made a deep analogy between concepts of energy and utility (referring, in particular, to [28]), etc. (some of his ideas were criticized later). P. Mirowski could have lit the fire of the current econophysics, but, again, it did not happen at that time.

The evolution of social physics ideas after these brief historic remarks could be summarized as follows:

Newtonian physics' notion of natural law (no statistics yet)→idea of similarity between physical and social laws (de Condorcet, Comte)→empirically found statistical stability of averages and distributions (Quetelet)→validation of the idea of laws in the statistical sense in society, and hence the notion of social physics (Quetelet)→embedding social statistical ideas back into physics (Maxwell)→specialized and divergent development of statistical physics and social statistics (or just statistics)→sporadic works→modern signs of the new reconciliation.

As we can see from this short and not complete survey of the early development, three types of works have been mainly published:

- these where concept of social physics was announced loudly, but no specific models from physics were presented (Compte, Quetelet, Majorana, and others);
- these where models from physics have been applied for concrete problems, without special accentuation of this fact (Bachelier, Reilly, Osborn, Bass, Black and Choles, Shelling and others);

- generalizing studies, notably Stewart, Georgescu-Roegen, Farjoun and Machover, Mirowski, who demonstrated both full understanding of the deep analogy between two realms and innovative modeling approaches.

Characteristically, many models proposed in works of second type passed the best test – validation by time – and actively used in respective areas, being almost devoid of "physics scant" there. It indirectly tells us, that physics, correctly applied to social problems, does not need a special declaration of its usefulness, it just works.

2.2. *Modern view: A new reconciliation*

The new field did not take off until the 1990s, when the number of published articles started to be counted in tens, hundreds, and thousands. The reconciliation of the new branch in the modern form, as we may see it now, came up from two almost independent sources.

One was an extended implementation of **physical models** for studying social and economic problems, made by professional physicists, who also invented terms for this new occupation – the line we tried to trace in 2.1. In reality, of course, the fragile relations between the works mentioned in 2.1 did not practically affect the new thinkers. The old (renamed by Stewart and recalled by Mirowski) *social physics* was reinvented as "*sociophysics*" in Galam et al. [26]; "*econophysics*" was coined on a conference by H. Stanley in 1995 (http://en.wikipedia.org/wiki/Econophysics) and received wide popularity only in the 2000s, after the book by Mantegna and Stanley [43] (see comments about Osborne [54] in 2.1). In both cases, it was perceived as a completely new endeavor (without comprehension of the many precursors mentioned above and other ones). This perception could be quite misleading.

Particularly, S. Galam even published a self-testimony about his paternity of sociophysics and a review of his own contribution to the field [27], under the eloquent title "Sociophysics: a review of Galam models". There he established the "unbroken link" between the science and Galam's models. Retaining a good sense of humor, he admits that DNA tests may reveal some unexpected things about any paternity (we hope that our article has contributed to the test a bit). But this joke does not hide the seriousness of his self-claim (leaving aside a fact that even adopting Galam's view, there should be three fathers, by number of authors in a cited article of 1982, where the term "Sociophysics", without a reference to "social physics", has first appeared).

Another example of terminological and, possibly, substantial confusion, is a title of the book: *New Directions in Statistical Physics: Econophysics, Bioinformatics, and Pattern Recognition [77].* It could be easily understood that econophysics is considered as a part of statistical physics, what is very questionable (at least because econophysics uses not only statistical models from physics).

In 21st century, more and more physicists started using these terms to address the respective topics, yet meaning some times different things. In our view, sociophysics and econophysics related to each other approximately as sociology to economics, i.e. sociophysics should include econophysics in the same fashion as the social sciences include economics, and might be considered, in a broad sense, as *a science about the application of physics in the social sphere.*

The second source was the **general system theory**. This vast and somehow vague area always had a strong physics component. It is enough to recall just some classical names and theories, which it actively exploits: N. Wiener's cybernetic; I. Prigogine's theory of dissipation; A. Poincaré's earlier studies of instable systems; A. Bogdanov's "Universal Organization Science"; A. Lotka's "energetic evolution theory", Zipf's law, etc. See, for example, the historic survey in [24] or the list of speakers at the European Conference on Complex Systems in 2007 http://www.unifr.ch/econophysics/) – percent of pure physicists is very high. Those works usually did not apply concrete physical models to social situations, but rather put physical concepts to general systemic principles, to be applied, in turn, everywhere. For that reason we did not count them in the "physical line of thinking", although the boundary is rather fragile. For example, both N. Wiener and I. Prigogine had a notion of the relation of cybernetics and theory of dissipation with social systems in the fortieths. However, again, it was not picked up as a specific direction. The system theory was already an extremely large and diversified area in the 1980s and 1990s, and it is hard to say now when and how the penetration of its ideas entered sociophysics, but it did definitely happen.

For the last decade the number of works in the area had been growing exponentially and now counts thousands of articles and several books (Mantegna and Stanley 2000, Weidlich 2000, Bouchaud and Potters 2004 [1,8,11,43, 45,63,76]. At the end of 2007 there were 190,000 references to econophysics, 48,000 to sociophysics and 42,000 to social physics on the web (the maximal results from Google, Yahoo, and MSN), while in September 11, 2008 – 445,000, 100,000, and 90,000 respectively (!); about 4,000, 600 and 2800 articles are registered by Google Scholar. These figures show, by the way, that terms "social physics" and sociophysics" are quite competing, and it is not clear, which will be dominating, if any. An excellent survey of many sociophysical models and ideas for non-physicists is given by Ball [4]. No less available for non-physicists, but much more closer to the traditional statistical problems (especially these of measurements) is a deep book [63]. It looks like sociophysics is a booming area indeed – but not for statisticians yet. . .

The current scope of works in sociophysics could be tentatively broken into several categories (citing is done just for illustrative purposes; we do not pursue the goals of "historical completeness" or selection of the most significant works).

- *Conceptual* – no exact models are proposed, but commonalities between two worlds are traced, like expansion of general laws of nature and general principles of learning to the social realm ([1]; partly [63]).
- *Empirical* – demonstration of the existence of some, supposedly physical-like, phenomena in social life, mainly distributions of different types [31,69].
- *Explanatory* – building physical models, possibly explaining empirical facts, most often mechanisms of generation of observed distributions [33,49].
- *Analytical* – different models from physics receive social interpretation and new analytical results, mostly without direct link to real-life data [70,79].
- *Simulation* – some physics concepts are used as first principles to build a social model (like Ising model of getting opinions-exchange interpretation) and then it is simulated in order to understand the convergence process [22, 68,74].
- *Aggregated* – analytical and/or simulation physics, merged with the idea of solving specific real-data problems, like in statistics [36].

  Separately, we would like to mention one more category:
- **Quasi-physical** – mathematical or econometrical analytical models or simulations without links to physics, published under the "sociophysical roof", very close to those published on simulation and artificial societies in special journals, like *Journal of Artificial Societies and Social Simulation* – see discussion of that direction in Deffuant et al. [14] and Fontana [21].

From this brief list, one can see a big variety of physical approaches to social phenomena. The fundamental question is, how useful are these methods in comparison with more traditional (statistically based) ones? Sociophysicists publish their articles mainly in physics journals, so specialists in respective subject fields hardly read them. Mainstream sciences (economics and sociology) have typically negative or neutral reactions to this type of innovation (though this is slowly starting to change). Yet claims in the new area are very high. "*There is little or nothing in existing micro- or macroeconomics texts . . . that is of value for understanding real markets. . . The reigning economic theory . . . will be displaced by econophysics . . . meaning empirically based modeling where one asks not what we can do for the data* (*give it a massage*)*, but instead asks what can we learn from the data. . .*" [46, p. 4]. If we add that under the "massage of data" McCauley in fact means statistics or data mining, this passage is directly addressed not only to economics, but to statistics as well. Some titles speak for themselves: "The Depth of Economics" [52]; "Economics: the next physical science?" [19]. How seriously grounded are statements of this kind? What are those principally new ideas physics may bring into such developed disciplines as economics and sociology, which statistics has missed? Below we try to address these issues.

3. Physical and statistical methodologies

3.1. *Examples of sociophysical models*

Before we consider the difference between those two approaches, let us discuss several examples of sociophysical problems.

Example 1. Power law distributions (when probability of occurrence of x is the inverse of size of x, $P(x) \propto x^{-\gamma}, \gamma > 0$) of various things (wealth, earthquakes, lengths of words, number of publications and so on) have been known in statistics and econometrics for more than a century under the names of Pareto distribution, Zipf and Lotka curves, hyperbolic laws and others. But for statisticians they all were just specific kinds of popular distributions (like normal, Student and others), until the models of mechanisms explaining occurrences on an individual level were constructed. Those models have a physical nature in the sense that the logic of individual interactions is translated into the logic of statistical distribution. Several most popular models of that type are described in Newman [49] (by the way, one of them is rooted to genetic works of G. Yule, one of the most prominent statisticians – another lost and found link between physics and statistics). Another, very simple model (not described in Newman's survey) proposed in Kawamura and Hatano [33]; we describe here its simplified version for illustrative purposes. There are N agents, having some equal quantity x_i each ($i = 1, N$ in time $t = 1,\ t = 1, T$). Then the process runs:

1. Select random i, $1 < i \leqslant N$;
2. Move the amount αx_{i-1} from agent (i– 1) to agent i, where $0 < \alpha < 1$.
3. Rearrange the entities in the descending order of the values x_i and repeat the process, assigning $t := t + 1$ until $t = T$.

It is proven that this process generates the Zipf law when $T \to \infty$, i.e., $\gamma = 1$ regardless of α or even when α is not constant over the process. Since the process may be interpreted as an exchange of people between cities or exchange of money between companies, it could be a plausible mechanism, explaining the appearance of power law in some situations (in fact, however, $1 < \gamma \leqslant 2.5$ for the majority of the observed data). In this model the physical process of interaction between objects ("particles") ultimately demonstrates the observed statistical distribution, i.e., the model takes one step further than statistics usually does.

Example 2. Causalities of terrorism or insurgency. In Johnson et al. [32], a special model based on some mechanism of terrorist group behavior over time was constructed. It shows deep similarity in patterns of causalities in Columbia and Iraq and even finds the theoretical equilibrium limit of power law $\gamma = 2.5$, to which causalities in Iraq will eventually converge (and which Columbian ones have already achieved). It goes far beyond the typical statistical parameters of estimation and prediction, because it offers a (still discussable) model of individual behavior in its further relation with observed distribution. It is interesting to note that the well-known model of conflict and war by R.J. Rummel [64] – one of earliest and brightest uses of physics in social life – may not be treated (as far as we know) as a basis for statistical conclusions about **many** wars, whereas Johnson's and others may. Rummel's model is built on the idea of the accumulation of tensions between parties and their relaxation through the war; it heavily uses chaos theory and may explain the intensity and even periodicity of conflicts (checked on India-Pakistan's), thus considering conflict between two parties as a result of some concrete individual dynamic process. Johnson's model, in turn, considers conflict on a level of all individual incidents (which makes it much closer to the general statistical approach) and collects data about thousands of them; however, unlike in statistics, it is based on some physical mechanism of grouping-regrouping of insurgents, which ultimately yields the power law distribution of causalities. This comparison emphasizes the difference between **just** individual models, yet having a physical nature (Rummel), and the structure "individual model – statistical collective", which is of special interest for statistics (and for us in this article).

Example 3. Opinion propagation is a very popular topic in sociophysics. There are a number of models of that type – see analytical results in Slanina and Lavicka [70] and Wu and Huberman [79], reviews and simulations results in Stauffer [68] and Sznajd–Weron [74], and a model generalizing many of the proposed ones in Galam [27]. Some other models of opinion formation and selection of alternatives, without direct links to physics, in fact use a similar methodology [65]. The common part of all those models is that they fix a mechanism of how individuals share these opinions (as a group of people convinces one neighbor, or they adapt their opinion to his/her opinion, and so on), and then computationally or analytically follow the dynamics of the process. When process converges, specific types of distributions appear: either two main opinions are shared by the whole society ("stable democracy"), or one becomes dominant ("totalitarianism"); under some conditions a minority may become a majority, etc. Mediaphysics naturally grasps many aspects of those models, too (see Section 4). The recent study empirically confirms that at least one important type of opinion propagation – political voting – obeys power law distribution and thus, very likely, has a "physical" nature indeed [23].

Example 4. Social behavior of insects. It seems that an old puzzle – how such primitive creatures as ants, termites, and bees are able to construct their amazing castles and so on without any centralized managing unit – has found a very convincing solution (see an excellent study in [7]). It is based entirely on a concept of communication between individuals, each of which just follows the simplest rules. For example, an ant is attracted by a pheromone emitted by all individuals when they travel to mark a route. If, traveling randomly, one finds food and brings it back to the anthill, returning by its own traces, the volume of pheromone it has emitted doubles, and other ants will follow this route with higher probabilities. As a result of such positive feedback, the famous ant chain, carrying the food, forms very fast. Physical models of processes like that, which are in nice correspondence with reality, have been proposed. Importantly, this job is in strong relation with one of the most influential interdisciplinary works of the last decades, E. Wilson's "Sociobiology" [78], where for the first time significant material about "pre-determinism" of animal's (and partly human's) behavior by genetics was structured and theorized. Wilson's ideas play a very important role in modern biology, and the term he has coined speaks for itself. Together with perhaps no less famous R. Dawkins's "The Selfish Gene" [13], where the models of animal behavior are very close to later developed sociophysical ones [13], it makes a natural foundation for considering living creatures as obeying general simple principles on individual level, which is so characteristic for sociophysics.

Example 5. Theory of networks. Starting back in the thirties, when the first modern works on graphs theory (D. Konig) appeared (the famous L. Euler's "Konigsberg's bridges" problem (1736) being a very early precursor), the theory of networks is definitely blooming now. From the first empirical findings in S. Milgram's mailing experiments about "six degrees of separation" (1967) between anyone, i.e., a network linking personally unacquainted people, to the huge net of the modern WWW; from concepts of the random graphs by P. Erdos and A. Renyi to "small world networks" by D. Watts and S. Strogatz and "scale-free" networks by R. Albert and A. Barabasi; from the first ideas of perceptron by F. Rosenblatt to modern powerful neural network learning algorithms, it presents now, in fact, a new picture of the world, where everything could be considered from the point of view of mutual connectivity of different types. Physics plays a key role there, even, maybe, usurping it from system theory, mathematics and biology (see the thorough survey in [17] and more recent developments in [50] and in Roehner 2007). In fact, it is impossible to ignore the fact that practically everywhere there is some kind of relationship between components, which in statistics has an extremely universal and all too often oversimplified reflection in the form of correlation of variables or distance between objects. However, network effects are much more complicated, and thus cannot be reduced to this type of metrics. This example alone demonstrates the necessity of a sociophysical approach at least as complimentarily to statistics, because otherwise such an important underlying feature as connectivity, taking place in any complicated system analyzed by statistical tools, will be missed.

Example 6. Self-organized criticality is an extremely powerful theory applied contemporaneously to any processes, if it lasts sufficient time. The key idea is that some tensions are accumulated and then find their resolution through a critical (catastrophic) event, just to clear the ground for new problem accumulation ("self" goes from this). For example, adding new sand grains to the tip of a sand pile will eventually result (after one more grain) in a sudden avalanche, after which a new, flatter pile will start forming a new avalanche situation. Processes like that are so typical (like wars in Rummel's sense, or family conflicts, etc.) that the "decent" title of the seminal book "*How Nature Works*" [3] does not seem an exaggeration. In particular, many power law distributions could be explained by that phenomenon.

Example 7. Mindsets space concept as an approach to model social processes – **mediaphysics** [36]. In there connectivity is also one of the key concepts, as is in networks. The difference, however, is that it is one of the mean fields, without specification of concrete nodes and vertexes (Section 4).

This short set of examples is sufficient to demonstrate that the modern view of the world, whatever problem is considered, from evolution to causes of wars or stock market crashes, cannot be described without models having some physical aspect. Thus **statistical modeling should definitely not ignore this message.**

3.2. Statistical and physical models: Different paradigms

In order to consider a **typical statistical formalization** and not to be debunked for not going into complicated generalizations about problems and counter-arguments (because it is impossible to say what a "typical" model out of hundreds of types is), we decided to take someone's writing and extract from there the only methodological aspects, which, we believe, are indeed typical. Let us consider an example from a modern statistical book, the very authoritative in a field of mixed models. It deals with an important class of statistical machinery, where classical regression models (by far the most popular in statistics) are included as a particular case, thus the text below is concerned with a very wide class of statistical phenomena and represents in a sense a general view of statistical modeling

"*In general, the linear mixed effect* (*LME*) *model is written as*

$$y_i = X_i\beta + Z_i b_i + \varepsilon_i, \quad i = 1, \ldots, N, \tag{1}$$

where b_i *is a vector of random effects such that*$cov(b_i) = \sigma^2 D$ *and* Z_i *is the design matrix.*

. . . Usually we assume that the random effects and the error term have a normal distribution, so that model Eq. (*1*) *can be written more compactly as. . . , meaning that* y_i *has a multivariate normal distribution with mean* $X_i\beta$ *and covariance matrix* $\sigma^2(I + Z_i D Z_i')$*. If D were known, . . . , the generalized least square estimator would be efficient. But the variance-covariance matrix of the random effects is unknown, and its estimation becomes a central theme in the framework of the mixed effects models*" [15, pp. 6–7]. After that, different problems of estimation are discussed for about 200 pages. This formulation has several distinctive features (of course, we do not concern here with concrete meaning of 1.10 and its components).

a) It is assumed that a functional form, linking an outcome and factors, is predetermined by the analyst. It is not discussed why the Eq. (1) has such a form – it derived directly from the mere facts that data are grouped in N clusters, each cluster has its own random effects, and so on. And it is not principal that an equation like that could be, say, quadratic or multiplicative (actually, a lot of statistical works consider this kind of complication); it still remains predetermined. In physics, the whole job of the theorist is to understand what type of relations exists between variables.
b) This universalism of equation is to be explained by the fact that the type of relations is irrelevant to the nature of the "factors" X – they could be any, from sociology to biology. In physics, the nature of the factors is inseparable from the character of the linking equation, and, respectively, there are no universal models like Eq. (1); the meaning of all "factors" is exactly specified.
c) An equation has an error term ε. It means that the model is an approximation, and if it is bad, errors will be very high. Yet the nature of model will not be shaken by this fact (it will be explained by the absence of factors not included). But even if errors are low, it is still an approximation, not an "explanation", keeping aside a "causal explanation" (see detailed discussion in [42]). What seems at first glance to be a "usual equation" in a physical sense, in fact is not that at all. Coefficients of regression are not "transmitters" of force, or pressure, or temperature, as in physical formulas, but just functions of the slopes in clouds of points. Replace one factor with another, a different slope will appear with the same level of approximation; nothing crucial has happened. But take off one parameter from any physical model, and the model will fall apart. As cited above, "a central theme is . . . estimation," and indeed this is a main statistical concern – not to understand what exactly happened, but to estimate parameters of general models. Here is, in our opinion, the **main separating line** between physics and statistics.
d) Character of distribution of errors and variables is usually assumed to be a given type (normal as a rule); this is one of the key assumptions in order to make estimation algorithms valid. Of course, this assumption was relaxed in many occasions on behalf of non-parametrical models and so on, but in essence it does remain the same: in statistics it is assumed that there is some concrete mechanism of data generation **en mass**, without **individualized mechanisms, typical for physics.**

This short consideration of a typical statistical model helps to summarize the main methodological differences in the two sciences, partly being just touched.

1. **Physics postulates behavior of the individual objects of given type and offers the mechanism of the mass process, while statistics usually postulates mass hypothesis directly.** Example 1, with the mechanism of power law generation, clearly illustrates this (M. Newman [50] provides several other possible mechanisms for power law). Statistics usually just states the fact of some distribution and consequences of it (like those done in the Bayesian sense), but does not touch the origination issues – see also d) above and 2 below. Look, for example, at the one of recent very comprehensive handbook about statistical distributions. Each distribution is

described with exhaustive details but just one – from where it appeared, what was the origination mechanism (or at least the hypothesis about it). The typical phrases about applications are not that "it happened, because it went this or that way", but rather "... extreme value distribution ... fits the flood flow data... best among seven distributions considered" [34, p. 33]. This is not to say that statistics does not consider individual objects (it constantly does, say, in classification, multidimensional scaling and so on), but to emphasize the difference in paradigms.

2. **Physics typically considers outlying dynamics** of the process in order to understand its final stage (i.e., observed static disposition), **while statistics** does not. In Examples 1 and 4 it is quite clear (no dynamic data is used, but a final distribution is explained by the model). Example 2 not only offers a simple mechanism, supposedly explaining observed similarities in causalities data in Columbia, Iraq and Afghanistan, but also shows how the dynamic component of the model changes the pattern in Iraq, making it closer to the older conflict in Columbia.
3. **Coefficients** in physical models are either absent ($F = ma$, the second law of Newton), or have the character of a permanent constant ($E = mc^2$, Einstein's most famous equation), or have an adjusted meaning, derived from general formulas to a specific subclass of phenomena. In that last case it makes them similar to statistical ones, but still they are different not for each data set, but for qualitatively different classes of situations. For example, the equation for heat flow (Fourier's equation) is

$$Q = kA\frac{\Delta T}{d},$$

where Q is the rate of heat flow (watts), k is the thermal conductivity, A is the contact area (sq. m), d is the distance of heat flow (m), and ΔT is the temperature difference (Kelvin degrees). The thermal conductivity k has a specific measurement unit (watts/(m*Kelvin_degrees)) and differs for different materials: from 0.025 for the air to 2500 for the diamond. Such a huge difference in five levels of magnitude reflects very different matter structure. Note, then, that k is an intrinsic matter feature, not just a "regression coefficient" of the equation for Q. However, could k be estimated in a statistical way, through regression? Of course, but only under several conditions:

a) someone provides the statistician with all influencing variables and the exact form of relations between them, as above;
b) someone would prevent the statistician from interpreting the equation in the following form: $Q = a_{\ 1}A\frac{a_2\Delta T}{a_3 d}$, the typical way of representation for statistical models;
c) many samples of the same material (say, copper) should be submitted for the analysis; and
d) the statistician should vary A, d, and ΔT in a very large range, making sure that k does not practically change (within measurement errors).

In reality for social problems:

a) nobody knows the way the equation is to be constructed (neither what the composing variables are, nor the form of the equation);
b) from a statistical point of view, each variable entered into the equation should find its own coefficient, as shown in b) above. The notion that just one coefficient k should serve all three variables is alien to statistics. The best the statistician can do is to make a new variable $P = A\frac{\Delta T}{d}$, give it an exact meaning and estimate the equation $Q = kP$. But for that he or she should be indeed very knowledgeable, exactly like a physicist, i.e., should precisely understand the process;
c) nobody knows what "copper" vs. "lead" is, e.g., how to guarantee that all samples are drawn from one homogeneous population; and
d) changing factors in a wide range is usually empirically prohibitive in all observational studies and limited even in experimental ones.

Conditions a) and d) are not completely independent: if one is sure that the equation is correct (as physicists usually do based on considerations other than statistical), one will not be bothered with very wide range of factors in the experiment. It seems that the biggest challenge for statistics is condition c): there is no strong classification of the social situations to classes similar to “copper”, “lead”, etc., in physics; the coefficients are always adjusted for concrete datasets, which mixes many classes. It is like if a physicist made an estimation of k for alloys having no idea about their composition; while all alloys are “metals” (i.e., seemingly similar to each other), k for ingredients varies from 35 (lead) to 429 (silver), and so do the results of the “statistical models”.

4. Sociophysics actively uses such **concepts** as thermodynamic equilibrium, dissipation, diffusion, chaos and catastrophes, fractals, phase transition, criticality phenomena, percolation and others **that have universal value**, but are mainly neglected in statistical models of the same processes (Examples 3 and 5). It makes the physical approach much closer to the theory of complex systems, which all social systems undoubtedly are. For example, sudden jumps in public opinion, lead to weird election results, may not be explained by traditional statistical models, but supposedly may by physical one (4.4).
5. The two sciences have different views of the problem of **causality**. The statistical theory of causality [56] is still in its inception; thousands of routine statistical models do not use this concept at all. Physics, on the contrary, deals only with causal situations in which model assumptions are transparent; correct models are considered causal by design – see a)-c). Of course, physics also periodically experiences problems with conflicting causal models. The latest example is “An Exceptionally Simple Theory of Everything” [40]. In fact it goes against established string theory (and thus challenges the key causal paradigm in physics of the last decades) and unifies quantum mechanics and gravity theory. It also predicts the existence of 20 new elementary particles. If this prediction is true (to be possibly checked on the new CERN collider), a new causal model of the universe will be born. In that case the classical scenario is to be repeated: the theory predicts, the experiment confirms, and if so, the model becomes a causal one. In statistics the situation is much less clear simply because all causal models have deep conceptual drawbacks (see discussion for economics models in [42]).
6. **Prediction** (**forecasting**) can be done in both sciences if only some conditions of the past hold true in the future. However, there is a big difference. In statistics, forecast accuracy usually does not depend on the model quality, but rather on the stability of the observations on which the forecast was based and on the researcher’s luck (look at thousands of “financial guru” forecasts in the current media or examples of economics forecast failures in [52]). It is known, for example, that a good dynamic regression model can make decent forecasts without being causal. In physics, forecast accuracy usually depends on the model quality, i.e., on how the model captures the most relevant leading factors of the phenomenon. It is also possible for an incorrect model to be a good forecaster (the famous example is that the geocentric model worked very well in astronomy before Copernicus), but eventually the forecasting errors are accumulated and inconsistency with other models becomes clear – and a new, better model is built. Statistics does not have such a luxury: forecasting errors may or may not be the indicators of the bad model’s quality; too many other factors can always be put forward to explain why the model did not work well. In that sense statistical models are always not falsifiable, in the K. Popper sense: one does not have criteria to conclude what exactly happened (the model is wrong or “circumstances” are changed).
7. Physics is intended to find **stable laws**, not oriented on particular “data sets”. This is opposed to statistics, which has actually never claimed that obtained regularities are “eternal” because even a few extra data points or a slight change in a model setting can often turn the statistical conclusions upside down (see also 2 above).
8. Two sciences use in fact very different notions of the **measurement**, the basic procedure linking the reality and knowledge. The difference lies mainly in *definition of the measurable procedures*, i.e., what and how to measure. In physics, it is very precise and meets no subjective disputes: “temperature” means practically the same thing for all physicists, regardless on scale (Celsius, Kelvin) or way of measuring (with mercury or spirits devices). A need for strong definitions was culminated in creation of SI for metrical units, where all procedures are determined in all smallest details. In statistics, definitions may vary very much. If one says “revenue”, or “sale”, or “unemployment” – it could be understood and measured differently (with different numerical values) not only in different countries, but by different companies, scholars, schools of thought and the like. In one company revenue will include some taxable items, in other it will not; in one country unemployment counts for home occupied women, in another it does not; etc. A huge work is regularly done by national statistical agencies, Eurostat, UN, etc. about unification of such things, but the difference, sometimes crucial, always remains. Another difficulty is that in the social sciences usually not only the definitions may be different, but

types of scales used, too. The same process may be considered in one study as measured in interval scale, in other in ordinal, and so on (see discussion in [25]). But measurement is very fundamental for any quantitative science; in fact, different way to measure things is almost the same as to speak different language – and this is exactly what often is going on. As it was said once about the motivations for precise measurement and "discovering the laws" in sociology in general: "Why should one bother to improve the accuracy of a law if one knows in advance that its validity will not outlast a couple of decades?" ([63, p. XIV]; "decades" look too optimistic – see also 5–7 above). Implementing models to real data, sociophysics immediately faces these problems, familiar to statisticians, but remote from professional physicists. This fact alone may be a good argument on behalf of collaboration of the sciences. A very good account for bridging of two approaches to measurement could be found in [63], where old physical ideas about isolating the individual factors, breaking complex process into more elementary ones, observing extreme values for revealing the real forces and others are masterly applied to social phenomena.

Recently, after submission of this article, we unexpectedly witnessed the event, what confirms many of these differences in paradigms in very vivid form. At Joint Statistical Meeting in Denver, in August 2008, a New York Times bestselling book, *The Black Swan: The Impact of the Highly Improbable* [75] was actively discussed on a special session. As title suggests, a book is about very rare, but very important events, like market crashes, economic bubbles, and so on. The big success of this indeed very nice book lies, we guess, in a fact, that author, a statistician and financial specialist, emphasizes (with sharp language and bright sense of humor) the failure of sacred cows of traditional statistics ("typical distribution", "average level", "business as usual") and traditional "expertise" and "business knowledge" when facing such unpredictable and disastrous situations. And he is absolutely right, we both agree (many other arguments could be found in [42] or in this article). What one may expect from discussion of such a concept (which, in fact, goes back at least to Greek mythology about complete unpredictability of most important things, without scientific fleur at that time though) from several prominent statisticians gathered in a discussion panel, unlike from general public? Presumably, some scientific light to the problem – for instance, some methods of prediction of these "unpredictable" events.

However, what really happened – all discussants talked exclusively about one thing: that statistics *does* work with rare events, that there *is* a big literature about that, that statistics *is* aware of the problem and so on, i.e. writer's claims to statistics as meaningless in that respect are ungrounded. Physiologically, it looked as an entrenched defense of the own territory; statistically, all discussants considered rare events as low frequent data points *among all others*, needed some special treatment (which is indeed a statistical point of view); scientifically, *no one* (N. Taleb included) even tried to attract any model, explaining *why* these event happen and why they are special. When I. Mandel tried to say that there is a big literature about very mechanisms of these crashes, based on physical and general system type models [3,71] – it received seemingly very cold reception. So, statisticians indeed think not like physicists, for good or for bad...

All listed differences bear seeds of deep conflicts and contradictions. Tending to universality, sociophysics models are very often not supported by real-life data, while offering beautiful plausible mechanisms (although, paradoxically enough, some econophysisists claim that "real data check" is a cornerstone of their approach – see [46] and others). Statistics, in turn, often fails to separate different factors in multicollinear situations, accounting for synergy effects (which are very organic for physics), struggling with non-linear phenomena (or ignoring them), etc. Careful balance and open minds are needed, which should be, in our opinion, very fruitful.

Mediaphysics is aimed to offer a kind of intermediate or "aggregated" approach, without claiming for its uniqueness and universal applicability. It makes first-principle assumptions and puts them in a dynamic frame. It does many derivations analytically but adopts numeric analyses and/or simulations if necessary. It uses universal tools of the field theory. What makes it different from typical sociophysics models is that it allows a general model to be applied to any specific data set. This is the main reason why an approach like that may be useful in statistics: it works with traditional data, but interprets it differently.

4. Mediaphysics: Conceptual background

In this article we give just a short (but sufficient) formal description of the mediaphysics model in Appendix (see all details in [33]) and explain the basic constructions used there. A brief discussion of some preceding physiological and behavioral theories we directly or not used is presented in 4.3.

There are many **institutions** (firms, brands, political parties, hobbies, etc.), who compete for some kind of absorption of **people** (as workers, customers, members, etc.). The whole sense of the concept is to understand how people become attracted to one or another institution. This formulation has very broad meaning and could be applied to many situations where usually inference statistical models are used – for example, all widely used economic models of sales of several brands fall there. It could be considered as some generalization of the opinion propagation models mentioned in Example 3 in 3.2, and, indeed, it could be shown that some class of Galam's models [27] is covered by mediaphysics [37]. Metaphorically, yet quite reasonably, the idea can be illustrated by *competitive fishing*, which we elaborated in depth in a preprint version of the main article (see on a reference page), where fish are attracted to one or another fisherman by different fields in the *physical space* of the water. But for people, quite logically, these mechanisms should work in *mental,* not in physical space. In that case the "fishing" metaphor should be modified and enriched.

4.1. Mindset space of the individual

Let us postulate that there is such a small period of time that only "one elementary thought" may exist in it (the closest analogy is *dharma* in Buddhism, which lasts one *kshana*, about 0.103 second; modern concepts are discussed in 4.3). For future purposes we do not need more specific determination of lasting time, measurement procedures and so on. The only thing we need is the notion of what thoughts are about, what their subject is. Let us say that there is a big but still countable set of possible subjects of thinking for a given person – "work", "home", "food", etc. Out of it, we are interested in thoughts only about something we are going to model – for example, the situation "buying a car".

Obviously, the thought process is not something we can model directly (we are not talking here about special experiments with excitement of different brain zones, etc.), at least for one simple reason – this process does not reveal itself per se. There are just two ways to understand something about it (with some uncertainty though): asking people about what they are thinking and observing their behavior, assuming it results from a previous thought process. Needless to say these two ways have been explored far too much (the whole of psychology and sociology and the full spectrum of the behavioral sciences, including operational research). In that sense, we are not original. Let us, however, look at the elementary process of thinking and doing closer, in order to offer the plausible formalization. Several earlier ideas in that direction are discussed in more details in 4.5.

Willingness to act (W) for an individual is a readiness to make a particular exclusive choice between options at this time. Options may represent buying brands of goods, voting for political parties, dating with mates and so on. It is a complicated function of the real need and different forces affecting the individual's behavior, including advertising, price change, influence of relatives, to name just a few. In the case of buying, it perhaps could be called *non-materialized demand.* Let us consider this the selected example of the "buying a car" situation.

Obviously, a man does not think about buying a car most of the time. But as his old car is getting worse and worse, thoughts belonging to that category appear more and more often in his head. An example of mental trajectory is presented in Fig. 1. The chart depicts one of the possible ways to formalize willingness to act: it varies from -1 (to buy any Competitor's car) to 1 (to buy, say, Volvo). To simplify a picture, just two options are put there; generalizations with many options are also possible, but not considered here (we may just mention that almost any real situation could be ultimately reduced to a binary choice). The horizontal axis represents willingness to buy; 0 corresponds to complete indifference to the topic (he does not want to buy **any** car), while edge points (-1 and 1) represent not only the maximal possible "willingness", but something qualitatively different, a transformation of this **willingness into action**, i.e., they are obtained only when car is bought – a person has acted. The vertical axis is time, but in a "big scale", like months, not in that micro level we considered above. Events determine the trajectory the mindset traveled to make a decision. The small density curves on turning points are symbols of "thought distributions" at these occasions and will be explained below.

$t = 0$. Person is indifferent – his mindset is equally remote from two car options.

$t = 1$. After talk with a friend, some impulse for Volvo appears for the first time.

$t = 2$. An intense Mercedes campaign shifts the person's opinion to this model.

$t = 3$. Shortly after that, the person reads a big insert that claims that Volvo is the safest car ever; the intention to buy a Volvo becomes definitive, much stronger than before.

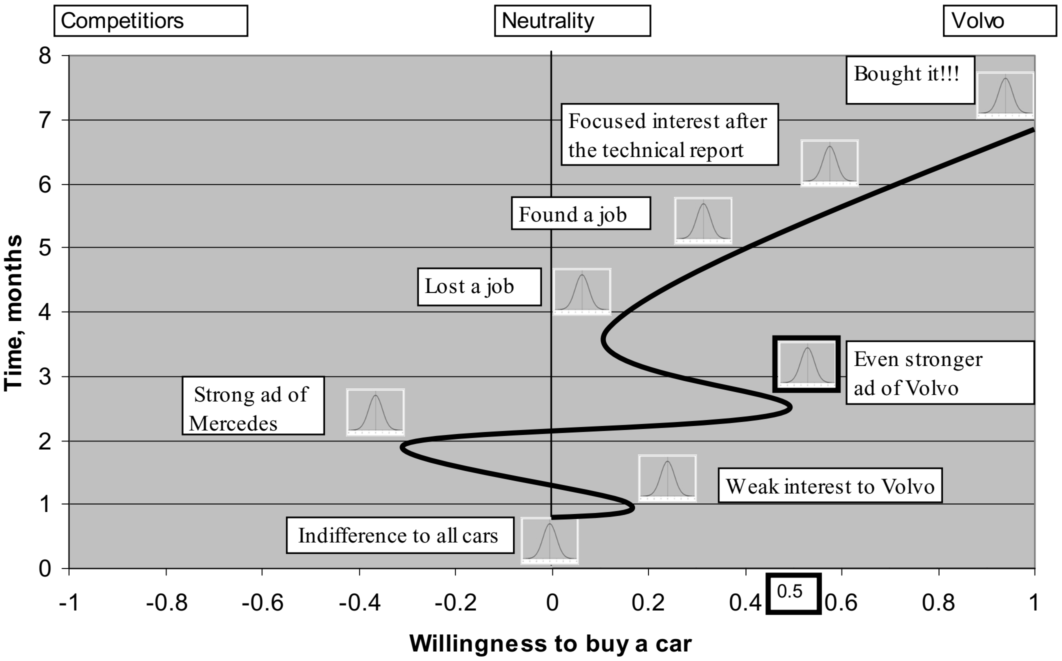

Fig. 1. Mental space and trajectory for an action "Buying a car".

$t = 4$. A week later, the person loses his job and immediately puts all ideas about a car on hold, yet keeping the notion that Volvo is the best (the curve is a bit on to the right of the zero line).

$t = 5$. In a month, the person finds an even better job; the previous preferences and thoughts resume – as a result, the curve shifts strongly to the right.

$t = 6$. The person ultimately reads a technical report, talks to several friends, and prepares money – she is practically sure that she will buy only a Volvo.

$t = 7$. The person buys a Volvo, so the process of thinking is stopped, and a decision is made.

The squared area on the horizontal axis on the chart shows that after Volvo's strong ad, the willingness to buy is 0.5. This point is "zoomed" in Fig. 2 as an example of the process taking place in each point of the trajectory curve. A curve there shows that the probability to change his mind in the next fraction of a second from the already obtained level of W = 0.5 is normally distributed if nothing else affects the mental process. It means practically that no decision will be ever made if no force moves the person from this position. However, if one more ad appears at this time, the curve may shift a bit to the right (a dotted line). Or, if the person has internal permanent desire toward a Volvo, the distribution will be skewed (a broken line). The whole trajectory in Fig. 1 is a result of such small or big shifts and skewnesses due to influence of different forces like that (**fields** – see 4.2). Therefore, the trajectory shows a macro result of micro processes, like visual magnetism is a manifestation of myriads of domains orientation. This is exactly what statistical physics is about. In this case, the theory of Brownian motion should be applied.

4.2. Brownian motion in physical and mental spaces

Brownian motion could be considered both as a physical process of erratic movement of a particle in a liquid, or as a stochastic process of a certain type, also called the Wiener (or Levy-Wiener) process. Also, it is a limit for random walk process with very small step. All those processes have Markovian nature, i.e., the state of the process in the next step depends on the previous state. Respectively, different equally correct formalizations are possible, though sometimes it becomes terminologically confusing. The concept of *random walk* is the best fit for our purposes. That is, a particle (or, as often used in illustrations, a drunkard) travels on a lattice (city) with fixed length of the cell (block), and on each corner changes direction randomly with the same probability. If the length is very small in some sense, it becomes a Wiener (Brownian) process for random variable W_t. Its feature is that W_t has independent

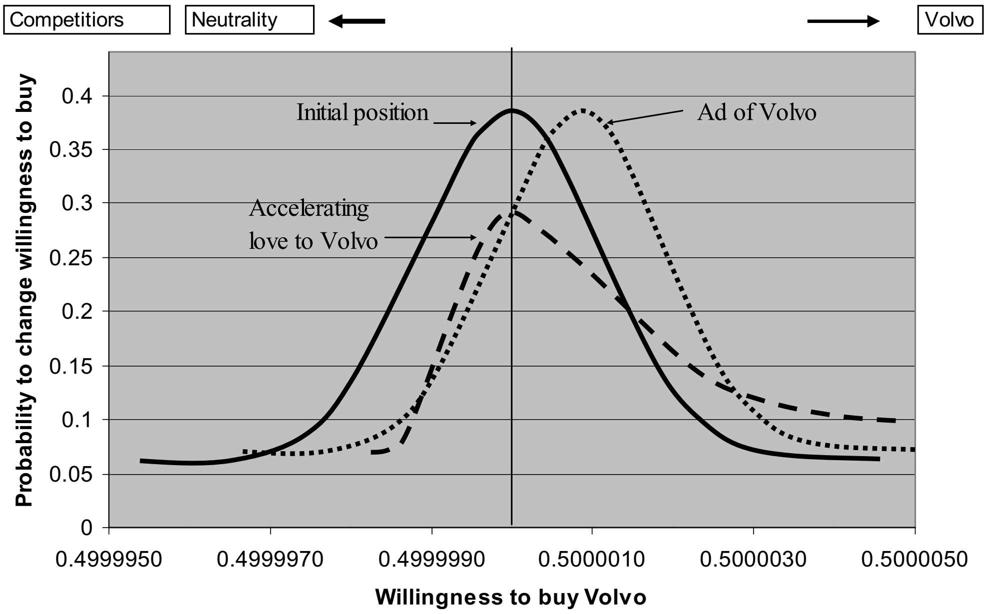

Fig. 2. Mental space in a given point of time for an action "Buying a car".

increments $W_t - Ws \sim N(0, t-s), 0 <= s < t$,where $t-s$ is time passed between steps; a standard deviation of normal distribution $a = t - s$ is a root square **displacement**. It means that average remoteness of the Brownian particle location from any given initial state depends on square root of time passed, and that probability of increments is a normally distributed value.

It explains the normal-like curves in Fig. 2. Indeed, analogously to particle motion, intentions about buying a car in the **absence of any forces** are completely random, they can move here and there, but most likely without any definitive shift on behalf of any option – so, the mean for this normal distribution remained the obtained level of W. However, variance could be different depending on environment. For particles it is a function of such factors as temperature and viscosity, for mental processes it is a function of two features: *agility*, which is an ability to move fast in one direction (like making a fast decision about buying a car), and *flexibility* (an ability to change directions fast).

In reality people's thoughts are always subject to different forces. Originators of those forces could be called **fields**, as is common in physics, but here we use the term in its psychological interpretation. Figure 2 gives examples of fields influence on individual level – external (advertising, the dotted line) and internal (attitude of the person, the broken line).

4.3. Dynamics of population density distribution

Fields could be better understood if we go from one person's mental process to those for many people, i.e., from "particle" to "matter". The sum of individual next-time position distributions for all people, constructed around their previous positions is a new (next-step) population distribution. In a continuous limit, the sum has to be replaced by integral over available space. This procedure can be repeated many times to describe the dynamics of the population and accumulating all available factors mentioned earlier. The accumulated curves for the population are presented in Fig. 3.

The technique for this is based on Green functions and described shortly in Appendix. We will continue to use an example of marketing activity, keeping obvious links with voting, religious or political affiliations, etc. Two key concepts here are a) the transition from thinking into acting, and b) the transition from individual action into mass action.

The sales are considered as only **observable** values, which for each point of time reflect the corresponding number of "ready to buy a brand" mindsets, as in Fig. 3. It is a function of states of individual mindsets under the influence

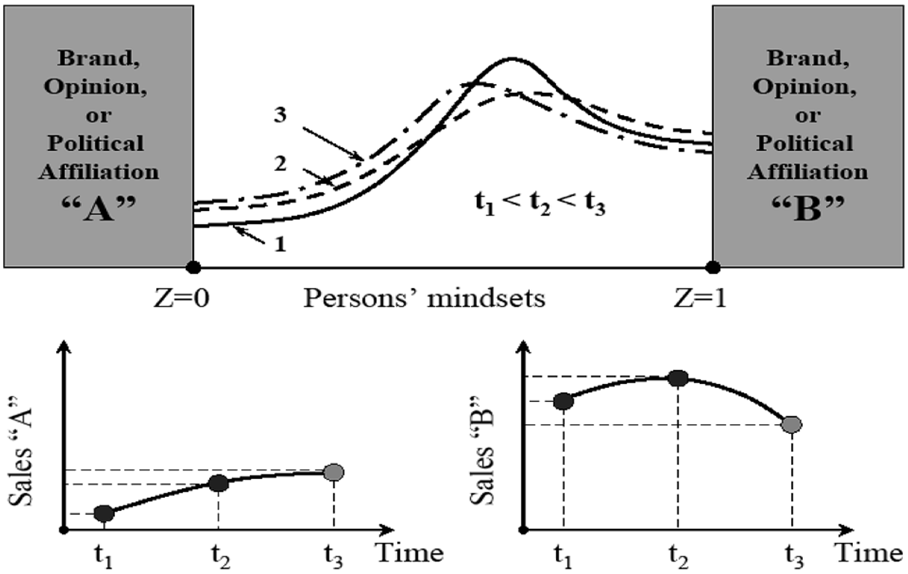

Fig. 3. Population-distribution dynamics and sales.

of different factors (**fields**), similar to those in Fig. 2, and a structure of the population itself. This means that not necessarily one level of displacement (a function of agility and flexibility of people) would govern a behavior of the population, but many of them, because people are different. It also means that very specific fields should be considered which are not presented in the individual scheme: they reflect a fact of mutual connectivity of the system, relations between individuals through word of mouth, common culture, friendship, etc. This creates a possibility to model **mass** processes, which by definition are the subject of statistics.

However, statistics usually **does not distinguish two types of data** – those concerning mass and individual processes. If, for example, macroeconomic data for one country are presented in a table, they will be analyzed as a table, without the notion that each number there represents a million hidden individual actions. Mediaphysics would consider such data differently, trying to understand the underlying structure that resulted in "absorption" of parts of the population on the only observed edges of distributions (Fig. 3). But if extra measurements (e.g., surveys concerning people's intentions or direct brain activity observing techniques – see [80]) are available, some parts of a distribution can also be observed, providing additional knowledge about the distribution shape. It is briefly summarized in the Table 1, which shows that for the same input and output, mediaphysics adds a new dimension, revealing the hidden mass processes.

4.4. Mediaphysics vs. statistical modeling

A deep non-linearity of sociophysical models allows to explain many complicated phenomena in a much more plausible way than any statistical model does; we tried giving some notion of this in 3.1. Mediaphysics is not an exception. In Kuznetsov and Mandel [36] we have shown how mediaphysics was applied to a marketing problem, which statistically was a typical regression. The specific features of the mediaphysical solution distinguishing it from statistical model were as follows:

a) the presence of a "system connectivity" term gives non-zero time varying outcome when all factors (fields) are zeroes;
b) effects of factors changes stay in a model forever (unlike in lag-structured statistical models);
c) all individual effects of factors are interconnected among themselves (the synergistic effect), thus it is unrealistic to separate many of them (as statistics rashly often claims to have done).

Table 1
Comparison of statistical and mediaphysical views at the data's nature

	Input	Mechanism of transmission of individual intentions into actions and then in mass behavior	Internal unobserved people's interactions in population	Output
Statistics	Measurable variables	Ignored	Ignored	Measurable behavior
Mediaphysics	Measurable variables, transformed to attractive or repulsive fields	Formalized	Modeled	Measurable behavior

What is more, it was also shown that mediaphysics organically adopts the ideas of dynamic regression and regression with random coefficients (*yield analysis* [16]). This means that both approaches are somehow able to talk to each other. In addition to these attractive and quite natural similarities, however, another class of effects demonstrated in the later mediaphysical model [37], which has a deep physical meaning and cannot be paralleled in statistical modeling.

As a simplified example, let us consider one phase diagram from Kuznetsov [37]; see Fig. 4. The vertical axes (with opposite directions) represent percentage of population supporting opinions "0" and "1". This is a model of a black-and-white world, where two opinions represent 100% of the population. Figure 4 shows equilibrium-state dependencies of the opinion percentages on advertising activities and other external factors (economic, natural, etc.), included in C_X factor, for three different values of the world-of-mouth (WOM) factor C_{WOM}: (a) in the absence of WOM; (b) with WOM critical value and (c) C_{WOM} stronger than that critical one. Negative values of C_X mean action of the external factor in favor of the opinion "0", and positive values, of the opinion "1". The stronger the absolute value of C_X, the stronger the action in favor of the corresponding opinion.

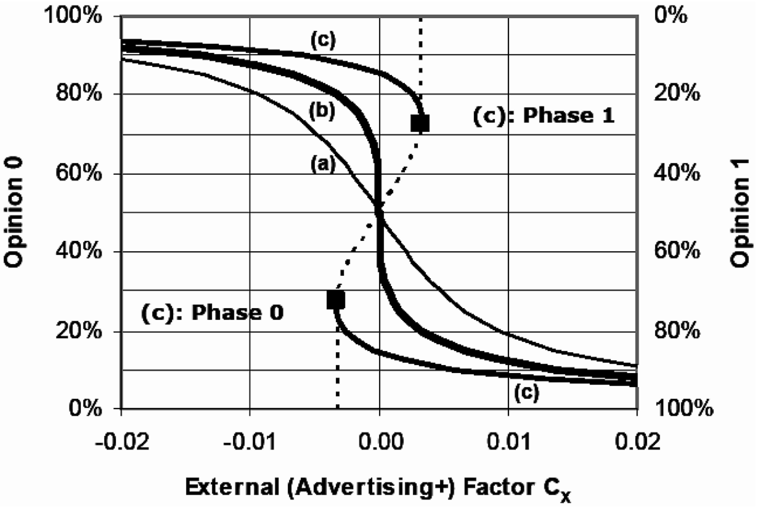

Fig. 4. Effect of advertising and other external (economic, natural, etc.) factors C_X on equilibrium states of opinion distributions for black-and-white world: (a) in the absence of word of mouth (WOM), (b) with critical value of WOM, and (c) WOM stronger than the critical one. There are two phases for case (c) separated by dashed line.

There are two phases where the WOM factor is stronger than the critical value, and only one phase otherwise. Following changes of C_X, there is the phase transition (of the first order in physics interpretation) for strong word of mouth with hysteresis type effects for the transition. For example, if about 85% of the population prefers opinion "0" on curve (c) and the "opinion 0 manager" is going to save money on advertising (i.e., to move to the right) and passes the critical point (black square in Fig. 4), the effect will be unexpected and catastrophic. One may lose dominance and jump from about 75% of preference to 10%. If the "opinion 0 manager" observing that would try to restore the initial status quo and increase spending, it could be too late or would take much more money to achieve the back transition to opinion-0 majority: it is necessary to pass the critical point on the bottom part of the curve (c), moving now from right to the left far behind the C_X. In physical terms it means that the system underwent a phase transition. Naturally, this jump will take a certain period of time. If a political voting is occurring during this transitional process, then selection of a voting time (before or after the society will pass the 50/50 distribution) is crucial for its results. It may have happened at the French referendum with 55% voters against the European Constitution in May 2005. This "critical time related" explanation may be an alternative to one proposed by Galam [27], which is accounted for the duration of the advertising campaign, not on a moment when it performs.

The situation of strong word-of-mouth (case c) describes a dramatic struggle between two opposite forces – advertising for opinions 0 and 1. If opinion 1 advertising increases, it leads to increasing number of opinion 1 proponents. At the same time WOM becomes less supportive for opinion 0 and more supportive for opinion 1. The reason for this is that share 1 is increasing and strength of WOM is increasing with the increase of share of the opinion 1 proponents. If the system has passed a critical point, the process is going as an avalanche due to this positive feedback: the higher the share because of advertising, the higher the WOM due to increased share. If WOM is not that strong (curves (a) and (b)), the same type of sharp changes in shares are observed, but not in the described catastrophic form. No statistical model can analyze processes like this.

4.5. Thinking and doing – psychological concepts

The model we consider is based on assumptions about processes going in human mind for decision making. We used several concepts there, such as *discrete thoughts*, *mind space*, *willingness to act*, *psychological fields*, which may need some clarification in terms of their relations with modern psychology and behavioral science. Here we give such a short review, very far from a complete one, just to show that these concepts in a different form have already been discussed separately, sometimes intensively, in the respective literature.

The oldest (without counting for *dharma* – 4.1) seems an idea of "*psychological fields*" – a famous psychologist Kurt Levine (some times Lewine) has offered it in 1930th and developed since then [48]. It was not a formalized concept, but rather metaphorical association (which may be considered in a frame of yearly sociophysics). His ideas generated intensive discussions in psychology (see, for example [72]). The most specific and closest to our approach are works by K. Rainio ([60,61] and others), who started them as early as in the 1960s. Not only has he formalized the notion of these fields, vaguely determined by Levine, but also introduced the concept of discrete thinking process with certain probabilities for transitions from one state to another (of Markovian type), which lies in a core of his theory. Rainio gave references to many other authors, either preceding his own works or making similar constructions [61, pp. 12 and on]. His own contribution is very well described in the author's words as follows.

"I made in 1960–1980 radical corrections to the Lewinian system by 1) defining psychological force a probability of transition from one state (region) to another during a step in discrete time, 2) giving up the concept "resultant force" (the key one for Levine – I. M., D. K.) *and, instead of that, assuming the forces acting as a Markov vector, the "resultant" being an outcome when Monte Carlo method was applied to it, 3) taking into account the concept "success of trial", instead of Lewin's "boundary force", and 4) making a clear distinction between cognition and the observable behavior. In one word: I developed in psychology principally the same model which is now called the discrete process model, DPM" [61, pp. 77–78].*

As one can see, even terminology used by Rainio [61] is quite similar to that which we described above. Although we developed mediaphysics independently, it shows that basic ideas are quite natural, such as discreteness of thoughts, Markovian character of the thinking process (a requirement which in our opinion could be relaxed), and difference between thinking and doing. The problem though is what to do with these ideas. K. Rainio (keeping aside Levine) does not go further than basic definitions and illustrative models; what is most important, he does not go from cognition analysis on an individual level to behavior of the whole population. In fact, his main contribution (under the angle of our approach) is in theoretical and experimental foundation of these core concepts (see the quotation above) with emphasis on discrete (quantum, in his words) character of thinking: *"... if any change occurs, it needs to occur as a "jump"* [61, p. 46]. By the way, we deliberately did not develop further the quantum ideas in derivation of the key equation A2 in Appendix, which may also contain Schr ödinger's wave function, because on a level of population it does not seem necessarily.

The interesting aspect of Rainio's approach is adding a concept of "success of trial" into the cognition process. We did not explore that specifically in mediaphysical model, although it looks worth trying. The importance of it is indirectly strengthened in a recent model of cognition, which sharply departs from many traditional notions (in particular, it rejects Aristotle's logic as a basis for cognition) and provides very fruitful and promising views to the problem [57]. Not only trials are organically imbedded there, but cognition is considered as a process of mutual adjustment of two vague systems – sensorial and analytical – in such a way, that the set of originally fuzzy concepts in the process of learning makes one set of concepts sharper than others. A special recognition formalism is proposed there; it helped to solve successfully complex problems (like detection of three images by 18 realizations among 3000 noisy signals), which traditional algorithms do not seem to handle. This approach seems logical for inclusion into mediaphysics as an individual model of cognition and decision making with further generalization for the population.

Terms "*willingness to act, to buy, to pay*" have been actively used in many studies of marketing psychology for the long time (see intensive references in [51]). All that way of thinking is actually the attempt to overcome the traditional neo-classical economical theories oriented to "rational" behavior and profit-maximization practices – as these studies show, it is not the case in real life. In On and Dan [51], for example, it was evidently (experimentally) demonstrated that in many situations direct monetary benefit is to be "overridden" by different rules and settings, from hedonic motivations to moral principles. That is why "willingness to act" is considered there as a complicated function of several, often conflicting, impulses, where "real" preferences have no guarantee to win – which agrees with our understanding of this term. Of course, we treat it in a more formal way, but in essence it is the same. Interestingly, that whole bunch of these works undermines the classical economical theory from another angle than sociophysisists, which is another call for reconsidering many basic principles.

We do not know very direct references in a literature to the "*mind space*" concept we use (as a "space" where individual thoughts are "located" and have "distances" between themselves), and in that sense we can consider this concept as a new one. However, logically speaking, authors we mentioned (especially K. Rainio and L. Perlovsky) should not deny the concept of such a space and metric in it – we just transparently talk about it. New may be a fact that in mediaphysics construction the same metric measures similarity between different thoughts and final decisions (which are not thoughts anymore). We consider it as a convenient way to say that at extreme points our thinking process are to be either materialized (in acting) or not – there is no need for different formalisms for these two things, if considered from inside out.

This short review demonstrates that the main concepts used in mediaphysics are quite popular or at least known in science, although they have not been combined to form one integrated approach.

5. Conclusion

The involvement of physical principles and models in social areas, where traditionally statistics was the only tool, is rapidly increasing. On the one hand, sociophysics offers a very fresh and innovative view to forming mechanisms of social processes, which definitely should be important for statistics to comprehend. On the other hand, serious possible conflicts could be raised between statistical and physical paradigms: if statistics enjoys swimming in the messy and transient sea of social life, then physics relies on solid laws there, while they, maybe, do not exist.

In this article we tried to show that there is no real gap between the two sciences, but rather a lack of studies filling the problems on the boundaries. Historically very similar concepts drove development in statistics, sociology, and physics. The modern development has also confirmed that ideas are migrated from one area to another, often without recognition. It gives a hope that an increase in the mutual interest of scientists from the three camps to the intriguing field of social statistical physics will be very important for developing new classes of models, located closer to reality than these isolated parents. Since sociophysics is not supported by current educational system (physics is not included in typical statistical curriculum and visa versa and sociology is usually separated from both as a well), we expect progress from small groups of specialists from respective fields. The proposed mediaphysical approach could be considered as an attempt in that direction – as a merging of different ideas and as a collaboration of people with different backgrounds. The Hegelian concept of synthesis of two antitheses on the new level may work here as well as it has worked many times in history of knowledge.

Acknowledgments

The authors are very grateful to two unknown reviewers and to the Associate Editor Marcin Kozak for their comments, which were extremely helpful and added a lot to the current form of the article. I. Mandel expresses his deep gratitude to Stanley Federman for his support and stimulation of the research.

Appendix

Mediaphysics: Overview of the approach

For more detailed description of mediaphysics see [36].

The mediaphysics methodology is based on the concept of *a metric space of personal mindsets* between two or many choices. Any metric space requires defining a notion of distance (a metric) between its elements. We define *distance* between a mindset position and a choice as a measure of relative propensity to accept the choice with respect to other available choices. In general, this space can be non-Euclidean with a complicated *topology*.

Mindsets for a large number of people (a population selected for an analysis) can be characterized by dynamics of mindsets density distribution in the introduced space. Just *population mindsets distributions* (not mindset of a single person) are subject of the analysis. The fundamental Markovian character of the considered system makes possible to model it using well-developed techniques of the Brownian motion under action of different *fields that represent motivations* applied to population mindsets.

Green's function $G_t(\vec{q}_t, \vec{q}_0)$ is the conditional probability that the Brownian particle at time t is placed at the point $\vec{q}_t$ provided the initial state was $\vec{q}_0$. The $\vec{q}_t$ can be multi-dimensional generalized coordinate of the state. In particular, it can include not only location, but also, for instance, velocity. Green's function $G_{t+1}(\vec{q}_{t+1}, \vec{q}_0)$ follows the recurrent relation

$$G_{t+1}(\vec{q}_{t+1}, \vec{q}_0) = \int G_1(\vec{q}_{t+1}, \vec{q}_t) \cdot G_t(\vec{q}_t, \vec{q}_0) d\vec{q}_t$$

or $G_{t+1} = \hat{Q} G_t$, where $\hat{Q}$ is the transfer operator written as $\hat{Q} = \exp\left[-W_{t+1}(\vec{q})\right] \cdot \hat{g}$:

$$G_{t+1} = \exp\left[-W_{t+1}(\vec{q})\right] \cdot \hat{g} G_t. \tag{A1}$$

In Eq. (A1), $W_t(\vec{q})$ stands for a field applied to units in position $\vec{q}$ at time t, and $\hat{g}$ is the connectivity operator, which for the simplest Gaussian model in the D-dimensional location space $\vec{z}$ (assuming $\vec{q} \equiv \vec{z}$) in leading terms is $\hat{g} \approx 1 + (a^2/2D) \cdot \Delta_{\vec{z}}$. Here $\Delta_{\vec{z}}$ is the Laplacian operator in the position space $\vec{z}$, and a^2 is the mean-square distance (displacement) between two neighboring states during time in the absence of other fields. Equation (A1) is valid for a smooth variation of the field $W_t(\vec{q})$ on the time scale, because for these cases we can consider the interval between two neighboring states as unperturbed by external fields and identify (A1) as the Chapman–Kolmogorov equation for transitional probabilities.

For the Gaussian model, Eq. (A1) can be reduced to the Schrödinger-type diffusion equation

$$\frac{\partial G_t}{\partial t} = -W_t \cdot G_t + \frac{a^2}{2D} \cdot \Delta_{\vec{z}} G_t. \tag{A2}$$

Dynamics of the total population number $N(t)$ is incorporated through the following normalization:

$$\int G_t(\vec{q}_t, \vec{q}_0) d\vec{q}_t = N(t). \tag{A3}$$

To calculate G_t, we have to apply boundary conditions, which depend on character of observations. For instance, for non-adsorption case (the one store is closed): $G_t(0) = 0$; for sales with in-stock daily limits lower than demand: $\partial G_t(0)/\partial t = 0$; etc.

Then, the observed outcomes (e.g., sales for the choices "0" and "C") at the moment t can be derived from unobserved Green's function at the corresponding adsorption points ($z = Z_0$ and $z = Z_C$, respectively):

$$S_0(t) = \lambda \cdot G_t(Z_0) \text{ and } S_C(t) = \lambda \cdot G_t(Z_C), \tag{A4}$$

where λ is the scaling factor.

In social life, the total motivation field

$$W(\vec{z},t) = f\left[W_0(\vec{z},t), W_C(\vec{z},t), W_F(\vec{z},t), W_I(\vec{z},t)\right] - \bar{W}(t) \tag{A5}$$

is a function of the following basic components: $W_0(\vec{z},t)$ and $W_C(\vec{z},t)$ are the field contributions arising from marketing and political efforts to attract opinions to choice "0" and to all other competitive choices "C", respectively; $W_F(\vec{z},t)$ stands for the contributions from general economic, natural and social factors. $W_0(\vec{z},t)$, $W_C(\vec{z},t)$ and $W_F(\vec{z},t)$ are external fields. $W_I(\vec{z},t)$ is the internal field, arising from within-system connectivity (i.e., interpersonal relations, like word of mouth, stable traditions, etc.). In a *self-consistent form* (i.e., where a field that affects density distributions in its turn is determined by the distributions themselves), $W_I(\vec{z},t)$ is a function of $G(\vec{z},t)$. The last uniform term in Eq. (A4)

$$\bar{W}(t) = \frac{1}{V}\int\limits_V f\left[W_0(\vec{z},t), W_C(\vec{z},t), W_F(\vec{z},t), W_I(\vec{z},t)\right] d\vec{z} \quad , \tag{A6}$$

where $V = \int\limits_V d\vec{z}$ is the considered space volume. Thus, $\int\limits_V W(\vec{z},t)d\vec{z} = 0$.

To understand what kind of the extra information we can obtain using this approach compared to the traditional statistics, we can expend the sales value Eq. (A4) in leading terms:

$$S_t = \theta(t) + \sum_{i=0}^{i_0}\left\{\left[\vec{C}_i^0 + \delta\vec{C}_i(t)\right]\cdot\vec{b}(t-i)\right\} + \frac{a^2}{2D}\lambda\cdot\sum_{i=0}^{i_0}(\Delta_{\vec{z}}G_{t-1-i})_0. \tag{A7}$$

Here, all the terms are derived from the above-described equations for Green's function and acting external and internal fields. The derived time-dependent base line $\theta(t)$ and the second term in the last equation represent typical statistical contributions to the target (sales) value from the factor vector $\vec{b}(t) \equiv \{b_1(t), b_2(t), \ldots, b_m(t)\}$ including the sum of i_0 lags (prolonged affect of advertising). Apart from the regular regression with lags (where $\delta\,\vec{C}_i(t) \equiv 0$ and all the factor coefficients are constant over time for each lag), these two terms represent a generalized regression with fluctuating (random) coefficients, called *yield analysis* ([36]; it was later reduced to redistribution of regression residuals in [39]). These two first terms in mediaphysics are calculated in a much more consistent manner and with clearer causality than in traditional techniques. But the most powerful extra information from the hidden distributions and interactions is contained in the last term of Eq. (A7), which is absent in statistical models.

One may say that this last term is basically what mediaphysics approach is about, since it bears no similarity to factors in a statistical sense. It can be interpreted as the *system connectivity* or *diffusion disorganizing entropic term* and its value indirectly contributes to the base line and factor coefficients of the first two terms through word-of-mouth and other internal self-consistent fields. This means that observed outcomes are not only direct responses to some external factors, but also consequences of hidden time-dependent structures of the complex organized systems.

The lower displacement a (the more inertial system) is, the smaller value of the last term is and the harder any changes take place. However, the total effect of the a value is more complicated: the term in last brackets depends on Green's function distributions, which, in turn, depend on initial conditions of the system and all fields, both internal and external, where a is also included. The term can be equal zero (i.e., the model will be as close to a statistical one as possible) only either system is completely motionless ($a = 0$), or completely uniform $\left(\sum\limits_{i=0}^{i_0}(\Delta_{\vec{z}}G_{t-1-i})_0 = 0\right)$. Each such condition is practically implausible, thus in all real systems this term is not equal zero and it is very important. If the system does not have external factors or fields, then the model still can be developed due to only internal forces (such as consumption experience and word of mouth).

We have to emphasize again, as it follows from the above, that in mass systems it is impossible in principle to make an exact decomposition of different effects as separated ones. Indeed, if, for example, in regression models such decomposition plays an important role in interpretation (like coefficient of determination might be presented as a sum of partial contributions of factors – see throughout analysis in [38]), mediaphysics demonstrates that there is always an effect of internal connectivity in a system, spread all over the fields in an inseparable way. The only way to get an impression about the comparative importance of different factors, including internal fields, is to make models with and without these factors.

The mediaphysics is a powerful tool for many real life situations. In the example with advertising and WOM (Fig. 4) we simplified the above methodology from "color" to "black-and-white" world, where the mindset space is reduced to just two points of choices ("0" and "1") without opinions between choices. Thus, each person in the whole population has selected one of two choices. Normalized Green's functions can be formalized as

$$G_0(t) + G_1(t) = 1. \tag{A8}$$

For this case Eq. (A2) can be transformed in two equations:

$$\begin{aligned} G_0^*(t+1) &= e^{-W_0}\left\{G_0(t) + \frac{a^2}{2Dh^2}\left[G_1(t) - G_0(t)\right]\right\} \\ G_1^*(t+1) &= e^{-W_1}\left\{G_1(t) + \frac{a^2}{2Dh^2}\left[G_0(t) - G_1(t)\right]\right\}. \end{aligned} \tag{A9}$$

Results and phase diagrams for this bipolar world are discussed in the text of this paper.

References

[1] P. Arnopoulos, *Sociophysics: Cosmos and Chaos in Nature and Culture*, Nova Science Publishers, 2005.
[2] L. Bachelier, *Theorie de la speculation*, Gauthier-Villars, Paris, 1900.
[3] P. Bak, *How Nature Works: The Science of Self-Organized Criticality*, Copernicus, New York, 1996.
[4] P. Ball, *Critical Mass: How One Thing Leads to Another*, Arrow Books: London, 2006.
[5] F. Bass, A new product growth model for consumer durables, *Management Science* **15**(5) (1969). 215–227.
[6] F. Black and M. Scholes, The pricing of options and corporate liabilities, *Journal of Political Economy* **81** (1973), 637–654.
[7] E. Bonabeau, M. Dorigo and G. Theraulaz, *Swarm Intelligence: From Natural to Artificial Systems,* Oxford University Press, 1999.
[8] J.-P. Bouchaud and M. Potters, *Theory of Financial Risks and Derivative Pricing* (2nd Edition), Cambridge University Press, Cambridge, 2004; 1st Edition on French, 1997.
[9] S. Broadbent, *Accountable Advertisement*, Admap Publications, London, 1997.
[10] C. Castellano, S. Fortunato and V. Loreto, Statistical physics of social dynamics arXiv:0710.3256, *Accepted in Review of Modern Physics*, (October 2007).
[11] B. Chakrabarti, A. Chakraborti and A. Chatterjee, (editors) *Econophysics and Sociophysics: Trends and Perspectives*, Wiley-Verlag, 2006.
[12] V. Coven, A History of Statistics in the Social Sciences, *Gateway* (*An Academic Journal on the Web: Spring 2003*).
[13] R. Dawkins, *The Selfish Gene*, Oxford University Press, 2006.
[14] G. Deffuant, S. Moss and W. Jager, Dialogues Concerning a (Possibly) New Science, *Journal of Artificial Societies and Social Simulation* **9** (2006), 1.
[15] E. Demidenko, Mixed Models, *Theory and Applications*, John Wiley & Sons, 2004.
[16] E. Demidenko and I. Mandel, Yield analysis and mixed model, *JSM Proceedings: ASA Section on Nonparametric Statistics* (2005), 1636.
[17] S. Dorogovtsev and J. Mendes, *Evolution of Networks: From Biological Nets to the Internet and WWW*, Oxford University Press, 2003.
[18] J.A. Faíñaa and J. López-Rodrı́guez, *Population Potentials and Development Levels: Empirical Findings in the European Union*, http://www.ersa.org/ersaconfs/ersa03/cdrom/papers/30.pdf, 2003.
[19] E. Farjoun and M. Machover, Laws of Chaos, *A Probabilistic Approach to Political Economy*, Verso, 1983.
[20] J. Farmer, M. Shubik and E. Smith, *Economics: The Next Physical Science?* arXiv:physics/0506086, 2005.
[21] M. Fontana, Simulation in Economics: Evidence on Diffusion and Communication, *Journal of Artificial Societies and Social Simulation* **9**(2) (2006).
[22] S. Fortunato, *Monte Carlo Simulations of Opinion Dynamics*, Cond-Mat/0501105, 2005.
[23] S. Fortunato and C. Castellano, Scaling and Universality in Proportional Elections, *Phys Rev Lett* **99** (2007), 138701.
[24] C. François, Systemics and Cybernetics in a Historical Perspective, *Systems Research and Behavioral Science* **16** (1999), 203–219.
[25] D.J Hand, Statistics and the theory of measurement, with discussion, *J of the Royal Statistical Society* (1996), Series A, 159, 445–492.
[26] S. Galam, Y. Gefen and Y. Shapir, Sociophysics: A mean behavior model for the process of strike, *Journal of Mathematical Sociology* **9** (1982), 1.
[27] S. Galam, Sociophysics: a review of Galam models, *International Journal of Modern Physics C* **19**(3) (2008), 409–440.
[28] Georgescu-Roegen, *The Entropy Law and the Economic Progress*, Harvard University Press, 1971.
[29] A.Y. Grosberg and A.R. Khokhlov, *Statistical Physics of Macromolecules*, AIP, New York, 1994.
[30] B.I. Iskakov-Plyuchin Concerning the Chain Model of Expended Reproduction, *A Journal of Translations Mathematical Studies in Economics and Statistics in USSR and Eastern Europe* **II**(2) (1965–1966), (In Russian – 1959).
[31] A. Ishikawa, *Pareto Law and Pareto Iin the Income Distribution of Japanese Companies* (2004), arXiv:cond-mat/0409145v3.
[32] N. Johnson, M. Spagat, J. Restrepo, O. Bestero, J. Bohorquez, N. Suarez, E. Restrepo and R. Zarama, *Universal Patters Underlying Ongoing Wars and Terrorism*, 2006, www.unifr.ch/econophysics/physics/0605035.

[33] K. Kawamura and N. Hatano, *Universality of Zipf's Law*, 2002 arXiv:cond-mat/0203455.

[34] K. Krishnamoorthy, *Handbook of Statistical Distributions with Applications*, Chapman and Hall, 2006.

[35] D.V. Kuznetsov and W. Sung, A Green's-function perturbation theory for nonuniform semiflexible polymers: Phases and their transitions near attracting surfaces, *Journal of Chemical Physics* **107** (1997), 4729–4740.

[36] D.V. Kuznetsov and I. Mandel, Statistical physics of media processes: Mediaphysics, Physica A, *Statistical and Theoretical Physics* (Vol. 377), 2007, *Issue 1*, 1, 253–268, preprint: http://xxx.lanl.gov/ftp/physics/papers/0506/0506217.pdf, (June 2005).

[37] D.V. Kuznetsov, *Dynamics of Opinion Spreading in Marketing, 2007 Proceedings of the American Statistical Association, Section on Statistics and Marketing [CD-ROM]*, Alexandria, VA: American Statistical Association: 2321–2327.

[38] S. Lipovetsky and M. Conklin, Incremental net effects in multiple regression, *International Journal of Mathematical Education in Science and Technology* **36**(4) (2005).

[39] S. Lipovetsky, Iteratively Re-weighted Random-Coefficient Models and Shapley Regression, *Model Assisted Statistics and Applications* **2** (2007), 201–212.

[40] G. Lisi, *An Exceptionally Simple Theory of Everything*, arxiv.org/abs/0711.0770, 2007.

[41] E. Majorana, Il valore delle leggi statistiche nella fisica e nelle scienze sociali, *Scientia* **36** (1942).

[42] I. Mandel, Statistical modeling and business expertise, or where is the truth? *Model Assisted Statistical Applications* **3** (2008), 3–20.

[43] R.N. Mantegna and H.E. Stanley, *An Introduction to Econophysics: Correlations and Complexity in Finance*, Cambridge University Press, 2000.

[44] A. Mastroianni, Science Communication and the via Panisperna boys: the role of Ettore Majorana, *Journal of Science Communication* **1** (2002), 3.

[45] J. McCauley, *Dynamics of Markets: Econophysics and Finance*, Cambridge University Press, 2004.

[46] J. McCauley, *Response to Worrying Trends in Econophysics*, 2006, www.unifr.ch/econophysics/(June 2006, 0606002).

[47] P. Mirowski, *More Heat than Light: Economics as Social Physics, Physics as Nature's Economics* (*Historical Perspectives on Modern Economics*), Cambridge University Press, 1989.

[48] A. Morrow, *The Practical Theorist: The Life and Work of Kurt Levine*, Basic Books, New York, 1969.

[49] M. Newman, Power laws, Pareto distributions and Zipf's law, *Contemporary Physics* **46** (2005), 323–351.

[50] M. Newman, A. Barabási and J. Watts, *The Structure and Dynamics of Networks*, Princeton University Press, 2006.

[51] A. On and A. Dan, Decisions by Rules: The Case of Unwillingness to Pay for Beneficial Delays, *Journal of Marketing Research* **142**(XLIV) (2007), 142–152.

[52] P. Ormerod, *The Death of Economics*, John Wiley & Sons, 1997.

[53] M.F. Osborne, Brownian motion in the stock market, *Operations Research* **7**(2) (1959), 145–173.

[54] M.F. Osborne, *The Stock Market and Finance From a Physicist's Viewpoint*, Crossgar Press, 1996.

[55] A. Quetelet, Sur l'homme et le developpement de ses facult'es, essai d'une physique sociale, 1835; A facsimile reproduction of the English translation A treatise of man, 1842 (Gainesville, Fl: Scholars Facsimiles and Reprints; 1969).

[56] J. Pearl, *Causality*, Cambridge University Press, 2000.

[57] L.I. Perlovsky, Toward Physics of the Mind: Concepts, Emotions, Consciousness, and Symbols, *Phys Life Rev* **3**(1) (2006), 22–55.

[58] T. Porter, *The Rise of Statistical Thinking*, 1820–1900. Princeton University Press, 1988.

[59] I. Prigogine, *The end of Certainty*, Time, Chaos and the New Laws of Nature, The Free Press, New York, 1997.

[60] K. Rainio, Corrected Lewinian system in terms of probabilistic theory, in: *Formalization of Psychological Theories*, Micko and Schultz, eds, University of Bielefeld, 1983.

[61] K. Rainio, *Discrete Process Model for Quantum and Mind Systems*, University of Helsinki, 2007, http://ethesis.helsinki.fi/julkaisut/val/sosps/muut/rainio2/discrete.pdf.

[62] W.J. Reilly, *The Law of Retail Gravitation*, Knickerbocker Press, New York, 1931.

[63] B.M. Roehner, Driving Forces in Physical, Biological and Socio-economic Phenomena, *A Network Science Investigation of Social Bonds and Interactions*, Cambridge University Press, 2007.

[64] R.J. Rummel, *Understanding Conflict and War* (Vol. 1–5), Sage Publications, 1975–1981.

[65] M. San Miguel, V.M. Eguiluz and R. Toral, Binary and Multivariate Stochastic Models of Consensus Formation, *Computing in Science and Engineering* **7**(6) (2005), 67–73, physics/0507201.

[66] T.S. Schelling, Dynamic Models of Segregation, *Journal of Mathematical Sociology* **1** (1971), 143–186.

[67] F. Schweitzer, *Brownian Agents and Active Particles: Collective Dynamics in the Natural and Social Sciences*, Springer, 2003.

[68] D. Stauffer, *Opinion Dynamics and Sociophysics*, 2007, http://arxiv.org/abs/0705.0891v1.

[69] S. Sinha and R. Pan, Blockbusters, *Bombs and Sleepers: The Income Distribution of Movies*, 2005, arXiv:physics/0504198.

[70] F. Slanina and H. Lavicka, *Analytical Results for the Sznajd Model of Opinion Formation*, 2004, arXiv:Cond-Mat/0305102.

[71] D. Sornette, *Why Stock Markets Crash: Critical Events in Complex Financial Systems*, Princeton University Press, Princeton, 2003

[72] R. Sternberg, *Cognitive Psychology*, Wadsworth Publishing, 2006.

[73] J.Q. Stewart, Suggested Principles of Social Physics, *Science* **29**(106) N. 2748 (1947), 179–180.

[74] K. Sznajd-Weron, Sznajd Model and Its Applications, *Acta Physica Polonica B* **36**(8) (2005), 2537

[75] N.N. Taleb, *The Black Swan: The Impact of the Highly Improbable*, Random House, 2007.

[76] W. Weidlich, *Sociodynamics: A Systematic Approach to Mathematical Modeling in the Social Sciences*, CRC Press, Boca Raton, 2000.

[77] L.T. Wille, (editor), *New Directions in Statistical Physics: Econophysics*, Bioinformatics, and Pattern Recognition, Springer, 2004.

[78] E. Wilson, (1975) Sociobiology: The New Synthesis. Belknap Press, USA, 2000.

[79] F. Wu and B.A. Huberman, *Social Structure and Opinion Formation*, 2004, arXiv:Cond-Mat/0407252.

[80] G. Zaltman, How customers think. Harvard Business School Press, 2003.