On the collective behavior of inanimate and living systems

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Abstract

The clustering phenomenon for inanimate and living systems and the herding effect for living systems are analyzed under the light of physical sciences. The suggested approach derives from the classical mechanics, the variational principle of least action and fluid dynamics theory is used, qualitatively, to enlighten some irrational behavior of financial systems.

Introduction

Open systems consisting of mutually interacting objects have a clustering tendency and all they, under certain conditions, show definite “shapes” or aggregate patterns, known by emergence phenomena. This occurs, according to Baas, “(…)*when something happens in the course of the interaction among a system’s parts that produce a feature of the system that wasn’t present when the individual parts were considered separately*”.

These systems may be constituted, *inter alia*, by a bunch of nucleons in an atomic nucleus, a cloud of electrons around an atom, molecules of a substance, planets, stars, galaxies, a cluster of bacteria, a school of fish, a herd of cattle and human society. Natural phenomena must obey two basic principles: the second law of thermodynamics and the law concerning energy constraints. It will be shown several examples of systems involving inanimate and living objects in which the system “looks for paths” related to Hamilton’s variational principle or usually known by the principle of least action[13]:228, which leads the system, to minimal state of energy expenditure. Recently[33] showed that data processing networks minimizes energy expenditure through clustering process. It will be shown that clustering phenomena and the well-known “herding effects” in a collection of living objects is derived from this variational principle. For this kind of phenomenon it will be shown that this energy saving principle comes before any other tenet commanding living beings, or in other words, the clustering and the*herding* effects can be explained by the action of least energy consumption principle. In other words, living aggregations that have been viewed, classically, as an evolutionary advantageous process, in which participants share the benefits of protection, information and mate choice, comes as a fortuitous consequence and cannot be considered the key factor or reason of these effects, being preceded before by energy constraints. A question raised by[29]: are all emergent properties of animal aggregations functional or are some simple patterns? Could certain class of human behavior dynamics be described by physics concepts like the Reynolds number of hydrodynamics? To what extent the emerging results of complex systems are universal and could be extended ubiquitously to all? There are some succeed results in this sense: the conceptual framework provided by*scaling* and *universality* in animate and inanimate systems, for example, explain the aggregation phenomenon described by a simple physical model[6,40,41] and seems to be applicable on DNA sequences, heartbeat intervals, avalanche-like lung inflation, urban growth and company growth.

The purpose of this paper is:

- Offers an explanation of physical clustering behavior, driven by fundamental principles, common to all open systems, based on system composed by mutually interacting inanimate or living members.
- Analyze some elected behavior of living systems associated with a non-rational behavior, commonly known as “herding effect”.
- Discussing also the possibility of addressing part of social dynamics from the exact sciences viewpoint, given its resemblance with the behavior of fluids and thereafter, subject to formal description through mathematical equations.

Collective ubiquitous behavior

Starting with a microscope world, the “shape” of the nucleus is nothing but the density distribution of the particles—protons, neutrons, hadrons, quarks and others—governed by a variational principle, through “paths” which follows the Hamilton’s principle of least action and minimize the energy state of the system.

One of most successful model to describe the atomic and nuclear "shapes" on all except the lightest atoms and nuclei, has over 85 years of age, known by Hartree central-field approximation[15]. It was originally conceived for atomic systems and assumes that each of the atomic electrons moves in a "mean" spherically (for isotropic property of space) attractive potential field due to the nucleus (positive charge) and all the other electrons (negative charge). Owing to the analytical impossibility of treating the "three or more body problem", the Schrödinger equation is solved for each electron in its own central field, neglecting the presence of the other electrons, and the resulting wave functions made consistent with the fields from which they are calculated. The important fact is that the Hartree method is in complete agreement with the Hamilton's variational principle of least action or, in other words, it minimizes the energy state of the system[35:284].

Nuclear aggregation can also be described successfully through central Hartree "mean potential" generated by attractive nuclear force acting mutually between the nucleons, coming out the "shell model" nuclear theory.

Some living objects have mutual attraction force acting between them, so the "mean potential" concept can be applied to describe the tendency of a given kind of animals to the aggregation phenomenon. In particular the human being has the known "bio-social attraction"[5,36], giving rise to the equivalent aggregative "mean potential", leading to human tendency to clustering, driven by physical reasons: the Hamilton's variational principle of least action. This enlightens the issue raised by Parrish in the introduction in the sense that, although clustering members share the benefits of protection, mate choice, and centralized information against the costs of limiting resources, it cannot be seen as a selective evolutionary criterion, since aggregation phenomenon happens regardless of these advantages. Furthermore, in human societies optimal group size is often exceeded, with regrettable environmental consequence: pollution, epidemics and social degradation[27,29].

The problem of animal clustering was also treated by Flierl *et al.*[10], using the "individual-based model" computer simulation (cellular automata model) to study the environmental and social forces leading to grouping. They describe social behavior at the level of the individual animal in the Lagrangian framework in terms of their position, velocity, acceleration, internal states and environmental variables (see [14] for a review).

Therefore, the aggregation phenomenon in living and inanimate systems is explained by variational principle of least action and is usually followed by another "non-thinking" or irrational behavior driven by energy saving laws, the *herding* effect.

The herding effect

> *"Let them alone: they are blind leaders of the blind. And if the blind lead the blind, both shall fall into the ditch." [Matthew 15:14]*

In [4].

> *"Unanimity is always stupid"*

(Rodrigues[31], Brazilian journalist and novelist)

> *"Think, really think, it was so laborious, as hard as carrying heavy chests to the attic."*

(Yalon[42], writer and psychiatrist professor at Stanford University)

1. It's known fact that when a large numbers of lemmings migrate, a lot of them inevitably drown while crossing rivers and lakes.
2. In the town of Gevas, Turkey, 450 sheep jump to their deaths (USATODAY.com, 7/8/2005).
3. In Falmouth, Cornwall, England, 26 dolphins died after beaching (theguardian.com, June 11, 2008).
4. Thousands of jumb squid have beached themselves on central California shores this week (livescience.com, December 15, 2012).
5. "…*Touched by the wand of speculation, frenzy runs through the entire nation*…" (The Gazette of August 13, 1791, on the financial crash of 1791, in [38]).

Imitative behavior transmission among animals is relatively common in primate, vertebrate and invertebrate organisms. All the facts mentioned above have in common possibly the same explanation known by *herding effect*, based on *allelomimesis* phenomenon, or in other words, “doing what your neighbors do”[29]. One of underlying cause of this phenomenon may be a mere extension of the non-rational principle which drives the clustering behavior, i.e., the variational principle of least action or energy expenditure. Saving energy is one of the driving forces which may explain these natural phenomena of living systems, which submitted to internal/external changes will adapt to a new situation with minimum energy expenditure, looking for a most “comfortable” state, i.e., a state of least effort[44]. Considering specifically the human beings the neural processing of information is metabolically expensive. The metabolism of the brain consumes about 20% of the total metabolic energy consumption, although the brain is only 2% of whole body weight[1,23,32]. The number of decisions that an individual makes on a daily since his awakening is immense[2,4]: choice of stores, products, schools, political candidates, technologies, how many children to have, drug, alcohol and cigarette use, religions, fads, fashion and custom – your brain is continuously requested from small tasks till presumed sophisticated decisions needed, for example, the investment decisions in the capital market. A traditional paradigm on this market is one of rational utility maximizing agents: investment decisions reflect agent’s rationally formed and decisions are made under all available information in an efficient way. However, what happens is that managers simply mimic the investment decisions of other managers, ignoring substantial private information, which may lead the market to catastrophic situations. There is a huge bibliography on this subject: see for example[3,8,11,34,37]. On the modern influence of the WEB sites in the *herding* effect see [26].

There is no doubt about the importance of *herding* effect on the mass psychology and its significance for political leaders and product marketing. From a simple choice of a toothbrush till to convince people about a political ideology are issues deeply driven by this effect.

Fluid dynamic approach

Nuclei in the fundamental state have in general “spherical” shape, for isotropic symmetry of space, mentioned above. However, when the matter density reaches about 10^{14}g.cm^{-3}, case the inner crust of a neutron star, the nucleus “looks” for a more “comfortable” state or energetically most favorable nucleus shape and changes from spherical to cylinder, slab, cylindrical hole and spherical hole[28]. One of the most successful models to describe the nuclear binding energy and a class of collective phenomena like the nuclear fission, nuclear vibration and nuclear rotation have been derived from the hydrodynamic theory, the Liquid-Drop Model, for almost 80 years[30,39,43]. In this model, the core is treated as a deformable drop of nuclear “liquid”, in interaction with few extra nucleons in an unfilled shell, in order to obtain other nuclear nonspherical emergent shapes, through dynamical “paths” which minimize the energy of the system. In the same way, that is, obeying the energy constraints, groups of atoms, through covalent or ionic coupling, can develop from simple bounded atoms to complex chain of molecules.

One theory sustained by most scientists about the emergence of life on earth considers the origin of cells from inanimate matter through a spontaneous and gradual increase of molecular complexity. This process starts with a closed spherical molecular aggregation (micelles), like the microscope process described before. Micelles formation is an example of self-organization which is obtained by addition of some liquid soap in water at a concentration higher than the critical micelle concentration. In this soap a spherical micelle aggregates spontaneously appears. This process takes place with a negative free energy change, or looking for a more “comfortable” energy state and by an increase of entropy. This occurs by the fact that *amphiphilic* molecules tend to aggregate in order to decrease the unfavorable contacts with water molecules—thus, upon aggregation, water molecules are set “free”.

> *“Micelles are the spontaneous self-aggregation of membranogenic surfactants into a vesicle, with an interior water pool that can host water-soluble molecules. If this self-aggregation takes place also in the presence of hydrophobic molecules, and/or ionic molecules, these can organize themselves into the bilayer or on the surface of the vesicle.”*[24]

The remarkable fact on this self-organizing phenomenon is that, despite the apparent second thermodynamic law violation—the system going spontaneously from a less ordered to a more ordered state, it occurs with an increase of total entropy[24].

Analogously, another phenomenon which apparently violates the entropy principle is one that a pot of water is placed on the stove flame, an emergence occurs before the water reaches a turbulent or boiling state—a toroidal conformation of the fluid, provided by the convection water flowing, showing a “doughnut” pattern shape.

The most of natural phenomena cannot be described mathematically due to a non-linearity coming from the mutually many bodies interaction, even for the so called *Newtonian* problems. A paradigmatic approach for analyze complex systems is through the fluid dynamics theory, since it contains the main ubiquitous aspects of emergent phenomena concerning these systems. According to Hofstadter:

> *“Fluid concepts are necessarily, I believe, to understand emergent aspects of a complex system. I suspect that conceptual fluidity can only come out of a seething mass of subcognitive activities, just as the less abstract fluidity of real physical liquids is necessarily an emergent phenomenon, a statistical outcome of vast swarms of molecules jouncing incoherently one against another.”*

Concerning human beings, the behavior of pedestrian crowds is similar to that of gases or fluids[16,17,18], and footsteps of pedestrians in snow look similar to streamlines of fluids. At borderlines between opposite directions of walking one can observe “viscous fingering”[19]. The process by which organisms form groups and how social forces interact with environmental variability was studied by Flierl[10], utilizing a model derived from fluid dynamics specifically considering a system embedded in a turbulent flow fields. The origin of the word *turbulence* is generally believed to have been coined by Leonardo da Vinci which conceived the chaotic flow of a waterfall, as analogous to a crowd of agitated people (*turba*), which derives *turbolentia*, the Latin origin of *turbulence*[25].

According to Kauffman[20,21,22]; in [12], the two key variables that drives the dynamics of a complex system are the number of agents (**N**) and the density of their connection (**?**). The behavior of the system will change through a sequence of critical thresholds, from stable (lamellar) to turbulent behavior by increasing N and/or **?**. However, if the complex system is seen from the perspective of fluid dynamics, two other variables become important to account the dynamic stability: the velocity (**v**) of the agents (**N**) and the “viscosity” (**µ**) pervading them, through the *Reynolds* number **R**[9]:

R = ?.v.L/µ

For an ordinary fluid, **v** means the velocity, **?** the density, **µ** the viscosity and **L** a parameter concerning some kind of size measure of the system. Thus, the numerator represents the inertial properties, while the denominator is connected to the fluid viscosity or motion braking. The R number therefore measures the relationship between these two forces in the fluid whose flow is laminar if **R** is small, in which case the numerator is small (low speed, density or size) or large denominator (large viscosity **µ**). Otherwise, if **R** is large the fluid can flow in chaotic or turbulent regime. This concept may be transferred qualitatively to other complex systems, for example, the financial system. Globalization has led to a sharp increase of participants thus increasing the “density” of transactions in these interconnected systems. On the other hand, information processing technology has also made possible the considerably increase in the “speed” **v** of these transactions without any increase in the “viscosity” in that environment. Viscosity **µ** means, in this case, a set of restrictions and regulations which “put the brakes on” the financial “flows”. The USA is confessedly a country in which this variable is lower than other countries for historical reasons, since they are the emblematic “proxy” of the liberal economic system. As a consequence, turbulent episodes have occurred with increasing frequency triggered by disproportionate facts showing a strong non-linearity and instability in these systems.

Conclusion

Saving energy seems to be a fundamental principle that drives much of the dynamic behavior of living and inanimate systems. Clustering effect for both living and inanimate systems and *herding* behavior for living systems may be understand as a consequence of physical sciences: the variational principle of least action. Some non-living concepts due to fluid dynamics may be employed, at least in a qualitatively way, to understand the turbulence behavior of financial systems crash.

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