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# Thermodynamics of relation-based systems with applications in econophysics, sociophysics, and music

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ABSTRACT

A methodology was developed to analyze relation-based systems evolving in time by using the fundamental concepts of thermodynamics. The behavior of such systems can be tracked from the scattering matrix which is actually a network of directed vectors (or pathways) connecting subsequent values, which characterize an event, such as the index values in stock markets. A system behaves in a rigid (elastic) way to an external effect and resists permanent deformation, or it behaves in a viscous (or soft) way and deforms in an irreversible way. It was shown in the past that a formula derived using the slope of paths gives a measure about the extent of viscoelastic behavior of relation-based systems Gündüz (2009) [5] Gündüz and Gündüz (2010) [6]. In this research the 'work' associated with 'elastic' component, and 'heat' associated with 'viscous' component were discussed and elaborated. In a simple two *subsequent* pathway system in a scattering diagram the first vector represents 'the cause' and the second 'the effect'. By using work and heat energy relations that involve force and also storage and loss modulus terms, respectively, one can calculate the energy involved in relation-based systems. The modulus values can be found from the parallel and vertical components of the second vector with respect to the first vector. Once work-like and heat-like terms were determined the internal energy is also easily found from their summation. The parallel and vertical components can also be used to calculate the magnitude of torque and torque energy in the system. Three cases, (i) the behavior of the NASDAQ-100 index, (ii) a social revolt, and (iii) the structure of a melody were analyzed for their 'work-like', 'heat-like', and 'torque-like' energies in the course of their evolution. NASDAQ-100 exhibits highly dissipative behavior, and its work terms are very small but heat terms are of large magnitude. Its internal energy highly fluctuates in time. In the social revolt studied work and heat terms are of comparable magnitude. The melody depicts highly organized structure, and usually has larger work terms than heat terms, but at some intervals heat terms burst out and attain very large magnitudes. Torque terms reach high values when the system is recovering from a minimum value.

## 1. Introduction

A human being is in continuous interaction with his natural and social environment, and his activities are usually directed by these interactions. The sum of activities when evolved in time on a special issue forms a 'relation-based' system; a stock market is a good example for a relation-based system. Although every step in an evolving system naturally involves the 'cause and effect' principle in the classical sense, it is not possible to express the entire processes in terms of the laws of thermodynamics. For instance, the energy change due to the change of the value of stock indices, or energy involved in

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human relations cannot be defined. It is somehow impossible to attribute a kind of energy to these systems and apply the first law of thermodynamics. However we are somehow lucky with the second law, which can be applied to all systems whether its energy can or cannot be defined. In simple diffusive mixing where there is no energy involved the entropy of mixing can be easily calculated using the basic equations. This is because, it is sufficient to know or define phase space to calculate entropy. Degradation of phase increases entropy; meanwhile it also drives the system into chaos. Besides entropy 'fractal dimension' is also a powerful tool to analyze an evolving system; the former is a measure of increase of randomness whereas the second is a measure of nonlinearity. The increase of nonlinearity naturally decreases the correlations between the components or variables of a system. So the increase of nonlinearity can both increase entropy and fractal dimension. The increase of randomness in a system increases the heat term in the first law at the expense of the work term.

The 'relation-based system' in this research work means a system for which it is difficult or impossible to define an energy conservation equation, because, the system evolves due to 'relations or mutual interactions' between many components or variables. For instance human relations, economic relations, social strike or war, stock markets, or many such events or phenomena can be defined as 'relation-based' systems. Systems such as stock markets, international terror, war in Iraq, the rise of empires, melodies, etc. can be characterized by their entropy content and their fractal dimension [1–6]. There have been some attempts in recent years to assign a force (or energy) which drives such systems [7–12]. These encouraging attempts try to understand the driving forces and energy behind the cases they studied.

In this work such systems will be examined from a thermodynamical point of view, and a general framework will be described to analyze the components of energy as work-like energy and heat-like energy of the system. As case studies three different phenomena will be presented. These are, (i) the NASDAQ-100 index between January and June 2011, an example from econophysics, (ii) a car burning revolt in France in 2005, an example from sociophysics, and (iii) a folk song, an example from music. Their dynamics will be analyzed by developing a kind of formalism which involves terms of first law of thermodynamics.

## 2. General features of relation-based phenomena

The properties of a system are associated with the interrelations and correlations existing between its components. The dynamical changes naturally depend on both the dynamic parameters like velocity, momentum, and energy, or on the structural properties like mass, charge, and chemical potential. Whatever is measured experimentally is interpreted as a property or an attribute. The preferential absorption of certain wavelengths of visible light by a substance is its property but the color thus owned is its attribute. In relation-based phenomena the property and the attribute are so fused with each that we may not be able to differentiate them. In fact the differentiation of quantitative and qualitative properties was a fundamental issue of Ancient philosophers.

The change in a system within time is measurable by some means and it should be possible to analyze it whether it denotes a change in property or in attribute. In physically expressible changes only the property changes are considered. For instance, in a chemical reaction like $A \to B$, the Gibbs free energy change ($\Delta G$) can be written in terms of the number of moles ($n_A$, $n_B$) and the chemical potential ($\mu_A$, $\mu_B$) like, $\Delta G = n_B\mu_B - n_A\mu_A$. Note that $\Delta G = 0$ denotes the equilibrium condition. The structural change of $A$ into $B$ changes the chemical potential from $\mu_A$ to $\mu_B$. The structural change actually changes the electronic configuration and thus the internal energy content. A chemical system can be well defined with its properties (i.e. chemical potentials), and it does not have qualitative descriptions or attributes. However under an external effect such as strong electrical or magnetic force the electronic configuration changes (i.e. Stark and Zeeman effects) and the change in the number density distribution of electrons can be described by the Boltzmann factor. The chemical potentials also change accordingly and the system achieves a new $\Delta G$. In complex systems with too many parameters involved, the equilibrium condition is achieved when a balance of opposing forces is attained. However, the time dependent change of all those parameters may usually be impossible to estimate, and what is measured at present may not mean the same thing with what is measured in the past; the past and the present states may not have a one to one correspondence or property. So the attributes that we assign for the past and the present states becomes different. In economics many parameters change in time, and these parameters usually cannot be well defined. The past and the present states are different, and they may involve a different number of parameters, and in addition their weighted effects might have been changed. So the economists define 'nominal value' and 'real value' to take into account time dependent changes of economic parameters. This definition is quite relative and is of importance only from the evolution point of view of economic relations. In biological, social, cultural or technological evolution 'nominal value' and 'real value' do not correspond to anything meaningful. However, if we have information about the parameters of two states in sequence they can be analyzed to characterize the change from one state to the next one. In physics there is a powerful tool to do this; it is the scattering matrix which transforms the former state to the final state. In the language of natural philosophy the scattering matrix relates 'now' to 'next', or 'cause' to 'effect'.

In multi parameter systems the arrow of growth depends on how the forces involved act or counteract. If external forces contribute to the growth of the system, and if the system meanwhile sustains stability, it keeps growing. If external forces put a negative effect on the system or strip out something from the system, then it shrinks. Even if the external forces remain unchanged the system may grow or shrink if internal parameters may shift it in that direction. So a system can be considered to be embedded in the sea of parameters or variables which contribute to growth or to shrinkage.