My research activity is on the application of statistical physics in complex systems. For my PhD thesis I worked on conformal field theory which illustrates the mathematical framework of the universality class of the two dimensional critical phenomena. I basically, worked on non-relativistic conformal algebra. I worked out a new class of Algebra which might represents symmetries of dynamical critical phenomena in two dimensions [1]. I as well worked on central extensions [2]. Besides, I worked out all possible fractional extensions of the non-relativistic conformal algebras [3]. Later, I switched towards agents based models in socio-economic systems. I as well worked on the time series analysis.

Agent-Based models in economics:

In 2009 when the Obama administration was going to stimulate economy via a stimulus bill named "The American Recovery and Reinvestment Act of 2009", some economist such as the Nobel laureates: Joseph Stiglitz and Paul Krugman claimed that the bill was not big enough to successfully help economy to recover. In a number of works through the agent based simulation, I and colleagues showed that correlation of activities of economic firms results in a dynamical hysteresis in the system Ref. [4-6]. We showed that a minimum of bill was needed to overcome hysteresis of the depression. In other words, we showed that stimulation with a budget below such a minimum would not be able to successfully recover economy from recession. We as well showed that such minimum is universal and does not depend on the characteristic of the network of firms. As far that the networks of firms are homogenous (rather than scale-free), the minimum bond for a successful stimulation is

$$Bill_{min} = 0.44\,\Delta GDP,$$

in which ΔGDP is the gap of the gross domestic product (GDP) before and over the crisis. Interestingly our model provided true prediction for the outcome of stimulations of the US and the EU. While stimulation of the US was above the dynamical hysteresis and successful [4]. The European Union stimulation was below the dynamical hysteresis and unsuccessful. Besides, we proved that in scale-free networks stimulation of economy has less cost if large companies are stimulated.

Currently, we are interested in developing our simulation to grab heterogeneities of the real networks of firms and provide more solid results. To this aim we are working on communities of the Leontief input output network. In economy each sector is connected to the other sectors via intermediate outputs.

It has been shown that countries such as Germany which have more interdependent sectors, are more vulnerable to the economic shocks. In our research however we are interested in identifying the role of community in shaping recessions.

- **Agent Based models in economics:**

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I and colleagues showed that correlation of activities of economic firms results in a dynamical hysteresis in the system [4-6]. The point is that firms and corporations are customers of each other's products. So, if a firm increase or reduce its production it will affect its trade partners. As a result of such interaction, when policy makers aim to stimulate the network of firms for recovery, economic crisis faces dynamical hysteresis.

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- **Aggregation of time series of economic indices, invariant measures, and the role of geometry:**

Why China may pass the sum of economy of the United States and the European Union much sooner than what we expect? What physics can say about the systematic error in econometrics?

In econometrics we face time series of prices and services which are subject to heterogeneous evolution over time. Economists need to extract aggregate values such as inflation and growth rate form these time series. However, it has been shown that extracting a correct measure from such series is impossible. Let us explain the problem in more details.

Consider economy of a country which consists of N sectors to produce N final goods or services. So, gross domestic product (GDP) in a given year "i" can be measured if we have the quantity of products or services in all sectors: i.e. $\{Q_1^i, Q_2^i, \dots, Q_N^i\}$, in which Q_a^i indicates quantity of product "a". Now, the point is that price of different products are not the same. So, to measure GDP we need the time series of prices, i.e. $\{P_1^i, \dots, P_N^i\}$. Now, if for two sequential year quantity of products do not change and all prices grow by a rate "r", we call such it an inflation. As well, if prices sustain their values, and all products grow by a rate "g", we call this rate the "real growth

rate". The problem however arises in real world where time series of quantities and prices experience heterogeneous evolution. In such case, it is impossible to measure inflation and growth rate correctly. Actually, all possible definitions of inflation and growth rates fail circularity test. Let, us explain what is the circularity test.

Circularity test means that if for a country the quantity and prices of all products are the same at the beginning and the end of a period of M years, (i.e.$P_a^1 = P_a^M, Q_a^1 = Q_a^M\ a = 1{:}N$), then we expect our measurements show an average of zero growth and zero inflation. But surprisingly, you can produce time series with periodic boundary condition with a non-zero value for growth and inflation.

The consequence of failure in circularity test is that you can have economies which start at the same point in the beginning of a period and end with the same values for products and prices, but surprisingly, the average growth for two economies could be quite different.

The failure of circularity test of economic aggregate indices, first was noticed by Irving Fischer. Through that time the subject has been of interest for experts in econometrics. Different approaches such as power purchasing parity (PPP) method fail to overcome the circularity test.

In my work I showed that there is a nice geometrical interpretation for the matter and we have an interesting correspondence between this problem in econometrics and the general theory of relativity. The geometrical impression of my work makes it clear that China will pass the economy of the US and the EU, (even the sum of them) much faster than economic indices predict [7]. I am interested in studying structural changes in economies of the US and the EU and try to evaluate when the size of economy of China may pass the sum of economy of the US and the EU. Analyzing time series of economies of the US, EU, and China can help us to provide a more reliable evaluation.

Another problem I have been interested is the impact of transfer of a manufacture economics to a service based economics. The point is that manufacturing products are tradable and have relatively equal price worldwide. Services however are non-tradable. Relative prices of services and products however can be addressed through the production function. In a work we showed that similar to physical systems, in economy we have extensive and intensive indices [8]. My future interest is to analyze, the impact of transformation to service economy in the US, the EU and China, where the average of age is growing and service have more important role in the future. Based on the proposal of my method, such transfer have important role on exchange rates. So, policy maker may need to have more attention to the role of measurements and targeted inflation.

- **Agent based models of the social systems:**

Our group has a wide range of works in social systems. One of the interesting models in social systems is the Heider balance model. This model states that pairwise relation between agents are influenced by the third-parties relations. In the interstate level, for example, countries are more interests to unite if they have common enemy in the world. The Hamiltonian is expressed as:

$$H = -J\Sigma_{<ijk>}S_{ij}S_{jk}S_{kl},$$

in which S_{ij} indicates the state of relation between nodes "I" and "j". The model has been utilized to explain coalitions in the first world war.

Recently, people have tried to extend the model to grab heterogeneities of the real world. In our group we have been interested in conflict of interests in real world. The fact is that friendship and enmity in real worlds might have different aspects and origins. In the Middle East for example, friendship and enmity, besides the political or geographical interest might have religious origin. In such cases reduction of tensions might be more complicated than what the original Heider balance model predict. We have a number of publications in this regard [9-11] . So far we have analyzed the matter on the homogenous networks. Currently, we have ongoing project on heterogeneous and real data-based networks.

Collective behavior in biology:

We have been trying to study collective behavior in biology through the apparatuses developed in the complex network sciences. In an analysis we showed that if we consider the global structure of genes we can extend the list of important genes. We first noticed that the landscape of the eigenvalues of genes have a tail with large number eigenvalues. We then through a new indicator in the random matrix theory identified genes which had played important role in shaping the eigenvectors of the large eigenvalues. Since in the dynamical systems, large eigenvalues address leading effects, we proposed that the selected genes play important role in the network [12,13]. The interesting point is that a noticeable number of such genes where not in the proposed list of essential genes in the literature.

Selected publications:

[1] Affine extension of Galilean conformal algebra in dimensions, A Hosseiny, S Rouhani

Journal of mathematical physics 51 (5), 052307 9 (2010)

[2] Possible Central Extensions of Non-Relativistic Conformal Algebras in 1+ 1, A Hosseiny

JMP 55 (6), 061704

[3] Fractional Galilean Symmetries, A Hosseiny, S Rouhani, Nuclear Physics B (2016) pp. 336-345

[4] Metastable features of economic networks and responses to exogenous shocks

A Hosseiny, M Bahrami, A Palestrini, M Gallegati, PloS one 11 (10), e0160363

[5] Hysteresis of economic networks in an XY model, A Hosseiny, M Absalan, M Sherafati, M Gallegati, Physica A 513, 644-652

[6] M Bahrami, N Chinichian, A Hosseiny, G Jafari, M Ausloos," Optimization of the post-crisis recovery plans in scale-free networks" Physica A, 540, 123203

[7] A. Hosseiny, “A geometrical imaging of the real gap between economies of China and the United States”, Physica A, 479, 151-161, (2017)

[8] A Hosseiny, M Gallegati “Role of intensive and extensive variables in a soup of firms in economy to address long run prices and aggregate data” Physica A, 470, 51-59 (2017)

[9] F Oloomi, R Masoumi, K Karimipour, A Hosseiny, GR Jafari, “Competitive balance theory: Modeling conflict of interest in a heterogeneous network” Physical Review E 103 (2), 022307

[10] R Masoumi, F Oloomi, A Kargaran, A Hosseiny, GR Jafari, “Mean-field solution for critical behavior of signed networks in competitive balance theory” Physical Review E 103 (5), 052301

[11] A Kargaran, M Ebrahimi, M Riazi, A Hosseiny, GR Jafari, “Quartic balance theory: Global minimum with imbalanced triangles” Physical Review E 102 (1), 012310

[12] N Allahyari, A Hosseiny, N Abedpour, GR Jafari, “Analyzing the heterogeneous structure of the genes interaction network through the random matrix theory” arXiv preprint arXiv:2107.13300 (under review)

[13] N Allahyari, A Kargaran, A Hosseiny, GR Jafari, “The structure balance of gene-gene networks beyond pairwise interactions” PloS one 17 (3), e0258596 (2022)