**Summary of activities**

**for the UEFISCDI Exploratory Research Project PN-III-P4-ID-PCE2020-0647**
Statistical Thermodynamics Approach to Complex Systems
proiect webpage: https://atom.ubbcluj.ro/stacos

The objectives of the project have been achieved, as follows: Specific complex systems for bottom-up modeling have been identified. In accordance with the implementation plan, databases have been built, which stands at the base of theoretical modeling studies. These databases can be consulted on the project web page: https://atom.ubbcluj.ro/stacos/. The study of 11 specific problems have been carried out, through which the objectives and specific tasks have been reached.

Bottom-up and top-down approaches targeting the generalization of statistical thermodynamics methods for complex phenomena have been addressed. Gintropy was thus generalized, combining elements from classical entropy with the Gini inequality index, introducing the f-Gintropy measure and arguing its applicability to specific problems. It was shown how concepts from thermodynamics can be generalized to problems of hadronizations following relativistic collisions, a deeply non-stationary phenomena. Using the classical methods of statistical physics, a new method has been developed for determining the Gini index in socio-economic phenomena from coarse data. Here we have focused on the modeling of the cerebral neural network. Data processing and visualization have been performed for abundance studies in biological systems. Bottom-up and top-down approaches to the generalization of statistical thermodynamics methods for socio-economic systems, analysis of earthquake data and atmospheric noise were carried out. All deliverables have been realized as listed below by categories.

**The topics covered in the project**
I. Construction of databases.
II. Modeling data obtained on complex systems. Wealth distribution in modern and communist societies using the Local Growth and Global Reset model.
III. Studying cross-country income inequalities using entropy-related measures of complexity and linking it to socio-economic indicators of inequality.
IV. Collective behaviors in fluid dynamics.
V. A new methodology inspired by mean-field theories for determining the Gini coefficient using coarse-grained data.
VI. f-Gintropy – generalization of Gintropy.
VII. The use of thermodynamics methods to describe the hadronization phenomenon.
VIII. Statistical approach to some limits and scalings of the Hirsch index with the total number of citations.
IX. Brain neural network study by a simple statistical model.
X. Collective behavior in oscillating fluid columns. Computational simulations.
XI. Data analysis and experimental modeling of seismic activities.
XII. Experimental study of atmospheric noise. Statistics of intervals between lightning
XIII. The study of dynamics in biological systems through the Local Growth and Global Reset model
XIV. Thermodynamics of state-transition networks

**WOS publications with acknowledgment to the project**:
1. I. Gere, S. Kelemen, G. Toth. TS Biro and Z. Neda, *Wealth distribution in modern societies: Collected data and a master equation approach*, **Physica A - Statistical Mechanics and its Applications,** vol. 581, art. nr. 126194 (2021) (IF: 3.26), https://doi.org/10.1016/j.physa.2021.126194
2. A. Gergely, Cs. Paizs, R. Tötös and Z. Néda, *Oscillations and collective behavior in convective flows*, **Physics of Fluids**, vol. 33, 124104 (2021) (IF: 4.98) https://doi.org/10.1063/5.0073347
3. T.S. Biró, A. Telcs, M. Józsa and Z. Néda , *f-Gintropy: An Entropic Distance Ranking Based on the Gini Index*, **Entropy**, vol. 24, 407 (2022) (IF: 2.524), https://doi.org/10.3390/e24030407

4. T.S. Biró and Z. Néda, *Thermodynamical aspects of the LGGR approach for Hadron Energy Spectra*, **Symmetry,** vol. 14, 1807 (2022) (IF: 2.94), https://doi.org/10.3390/sym14091807
5. A. Gergely and Z. Néda, *Computational Fluid Dynamics Approach for Oscillating and Interacting Convective Flows*, **Fluids,** vol. 7, 339 (2022) (IS: 1.93) https://doi.org/10.3390/fluids7110339
6. T. S. Biró, *Kaniadakis' Entropy Leads to Particle-Hole Symmetric Distribution*, **Entropy** 24, 9, 1217 (IF: 2.7) (2022) https://doi.org/10.3390/e24091217
7. T. S. Biró, *Jean Cleymans, Stringy Thermal Model, Tsallis Quantum Statistics*, **Physics** 4, 873-879 (IF: 1.6) (2022) https://doi.org/10.3390/physics4030056
8. A. Kuki, F. Járai-Szabó, A. Gergely, I. Gere, Z. Néda, S. Lipcsei, P. Dusan-Ispanovity, Z. Dankházi and I. Groma; *Statistical analogies between earthquakes, micro-quakes and avalanches in the 1D Burridge-Knopoff model*, **Geofizika** 40, 1-27 (2023) (IF: 1.0) https://doi.org/10.15233/gfz.2023.40.4
9. T. S. Biró, A. Telcs, M. Józsa, Z. Néda, *Gintropic scaling of scientometric indexes*, **Physica A**, 618, 128717 (2023) (IF: 3.3) https://doi.org/10.1016/j.physa.2023.128717

**Publicație BDI (anul 2023)**:
1. Antal Dávid, Gergely Attila, Néda Zoltán, *Földrengésmodell a futószalagon*, **Fizikai Szemle**, 10, 353-356 (2023) https://epss.hun-ren.hu/research/legujabb-publikaciok/fizikai-szemle-2023-10/

**Prepared manuscript:**
1. Sz. Kelemen, M. Jozsa, T. Hartel, Gy. Csoka, Z. Neda, *Tree size distribution as the stationary limit in an evolutionary master equation*, submitted to **Scientific Reports** (2023), (IF: 4.6) https://arxiv.org/pdf/2310.09595
2. I. Gere, *Atmospheric Noise Measurements in the Garden: Detecting Universalities in Inter-spheric Waiting Time Statistics*, submitted to **Romanian Journal of Physics** (2023)
3. Máté Józsa, Zsolt I. Lázár, Mária Ercsey-Ravasz, *Coarse-graining effect in axonal wiring databases confirms the exponential distance rule*, https://arxiv.org/abs/2307.06061

**Presentations at international conferences:**
1. Z. Neda, T.S. Biro, G. Toth, I. Gere, Sz. Kelemen, *The growth and reset model for social inequalities,* **11-th Polish Symposium on Physics in Economy and Social Sciences**, 01.07-03.07 2021, online webpage: https://indico.fis.agh.edu.pl/event/69/
2. Z. Néda**, MECO47** (Middle European Cooperation in Statistical Physics, 12-14 June 2022, Erice, Italy) *A unified approach to wealth and income inequalities in modern societies* https://meco47.sciencesconf.org/resource/page/id/9
3. S. Kelemen, I. Gere, T. Biro and Z. Néda, **MECO 47** (Middle European Cooperation in Statistical Physics, 12-14 June 2022, Erice, Italy) *Wealth inequalities in different socio-economic situations, Exhaustive data and a general modelling framework* https://meco47.sciencesconf.org/resource/page/id/10
4. Mate Jozsa, Maria Ercsey-Ravasz, Zsolt I. Lazar, *Investigating brain wiring by simple statistical models*, **MECO 47** (Middle European Cooperation in Statistical Physics, 12-14 June 2022, Erice, Italy) https://meco47.sciencesconf.org/resource/page/id/10
5. Z. Néda**, BIODYNAMICS**, A transdisciplinary approach -invited talk (Academia Romana si Institutul de Biodinamica, Bucuresti, 19-21 May, 2022) *The growth and reset dynamics in Complex Systems* *https://sites.google.com/view/biodynamics2022/home*
6.I. Gere, Sz. Kelemen, T.S. Biro and Z. Néda; **Econophysics Colloqium** 2022 **(**August 24-26, 2022, Thessaloniki, online) *Wealth inequality patterns based on exhaustive sampling. Data mining and modelling* https://ec2022.auth.gr/
7. Sz. Kelemen, M. Jozsa and Z. Néda; **Econophysics Colloqium** 2022 **(**August 24-26, 2022, Thessaloniki, online) *Estimation of the Gini coefficient from incomplete datasets;* https://ec2022.auth.gr/
8. T. S. Biró, M. Józsa, S. Kelemen, I. Gere, and Z. Néda, **MECO48** (Middle European Cooperation in Statistical Physics, May 22-26, 2023, Stara Lesna, Slovakia) *The Local Growth and Global Reset (LGGR) model and its applicability for complex systems;* https://meco48.science.upjs.sk/abstract/
9. S. Kelemen, M. Józsa and Z. Néda, **MECO48** (Middle European Cooperation in Statistical Physics, May 22-26, 2023, Stara Lesna, Slovakia) *The Gini coeficient from incomplete data*; https://meco48.science.upjs.sk/abstract/

10. S. Kelemen, M. Józsa, T. Hartel, C. György, and Z. Néda, **MECO48** (Middle European Cooperation in Statistical Physics, May 22-26, 2023, Stara Lesna, Slovakia) *Tree size distribution in the perspective of the Local Growth and Global Reset (LGGR) model*; https://meco48.science.upjs.sk/abstract/ -poster
11. A. Gergely, A. Kuki, S. Lipcsei, Z. Néda, **MECO48** (Middle European Cooperation in Statistical Physics, May 22-26, 2023, Stara Lesna, Slovakia) *Stick-slip dynamics of a 1D Burridge-Knopoff type spring-block system on a treadmill*; https://meco48.science.upjs.sk/abstract/ -poster
12. B. Sandor, A. Rusu, K. Denes, Z.I. Lazar and M. Ercsey-Ravasz, **MECO48** (Middle European Cooperation in Statistical Physics, May 22-26, 2023, Stara Lesna, Slovakia) *Novel measures for state-transition networks;* https://meco48.science.upjs.sk/abstract/
13. Attila Gergely, Sándor Szakács, Ágnes Gál, Mihai Ciocîrlan, Zoltán Néda, **SigmaPhi2023** (International Conference on Statistical Physics, July 10-14, 2023, Chania-Crete, Greece) *Fluctuations of CO2 concentration inside a mofette long-term, high-frequency monitoring and a simple model*; http://www.sigmaphi.polito.it/ - poster
14. Szabolcs Kelemen, Máté Józsa, Zoltán Néda, **SigmaPhi2023** (International Conference on Statistical Physics, July 10-14, 2023, Chania-Crete, Greece) *Handling incomplete information: Gini coefficient from coarse-grained data*; http://www.sigmaphi.polito.it/ - poster
15. Tamas Biro, Andras Telcs, Mate Jozsa, Zoltan Neda, **SigmaPhi2023** (International Conference on Statistical Physics, July 10-14, 2023, Chania-Crete, Greece) *Gintropic limits and scaling for the Hirsch index*; http://www.sigmaphi.polito.it/
16. Z. Néda, **Econophysics Colloqium** 2023 (July 30 **-** August 5, 2023, Lipari, Italy) *Wealth and income inequalities in the perspective of the LGGR model; https://ec2023.liparischool.it/* (abstract book p. 17)
17. T. S. Biró, **TTK23** (XVI. Tudomány- és Technikatörténeti Konferencia 2023, July 29 **-** August 2, 2023, Salonta, Romania) *Az entrópia története - Clausiustól a mesterséges intelligenciáig/ The History of Entropy - from Clausius to AI; https://ojs.emt.ro/TTK/issue/view/57* (proceedings book p. 1-10)
18. B. Sandor, A. Rusu, K. Denes, Z.I. Lazar and M. Ercsey-Ravasz, **DDE2023** (XLIII Dynamics Days Europe, September 3-8, 2023, Napoli, Italy) *Measuring the dynamical variability of state-transition networks*; https://sites.google.com/view/dynamicsdayseurope2023/book-of-abstracts (abstract book p. 313)
19. Z. Néda, **DDE2023** (XLIII Dynamics Days Europe, September 3-8, 2023, Napoli, Italy) *Oscillation and Synchronization in Convective Flows*; https://sites.google.com/view/dynamicsdayseurope2023/program?authuser=0

**Video-abstract:**
1. D. Antal, F. Járai-Szabó, A. Gergely, Z. Néda, S. Sárközi: Earthquake model on the conveyor belt, 2023 https://youtu.be/IRjoSaNPER8

**Media appearances and popularization of science:**
1. Presentations on the Web:
*Social inequalities in the perspective of a physicist* (in Hungarian)
https://www.youtube.com/watch?v=BzoTP8pSyzg
https://www.youtube.com/watch?v=nHLxJxSryy0
2. Z. Néda: Rend a rendezetlenségben, DeepDive2023 (23.09.2023, Târgu Mureș, România) - talk
**PhD and master theses on the subject of the project:**
1. I. Gere: Statistical universalities in socio-economic systems, PhD, an finalizare 2022
2. A. Gergely: Oscillation and collective behaviour in convective flows, MSc, an finalizare 2021
3. A. Kuki: Statistical analogies between earthquakes, micro-quakes and avalanches in the 1D Burridge-Knopoff model, MSc, an finalizare 2022
4. Sz. Kelemen, Applications of the Local Growth and Global Reset (LGGR) model for socio-economic and biological problems; PhD, în derulare din 2020