

Tallinn University of Technology
Department of Cybernetics, School of Science

Research Report 331/24

Annual Report 2023
on Nonlinear Dynamics and Biophysics

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1. Introduction

This Report continues the series of Annual Reports on nonlinear dynamics started in 1999 within the Institute of Cybernetics. After restructuring of the Tallinn University of Technology, the studies on nonlinear waves are carried on in the Department of Cybernetics, the School of Science. What follows, is the description of the results of the subgroup of biophysical modelling in the Laboratory of Solid Mechanics during 2023. The attention is focused on dynamical processes and waves in nerve fibres which means working at the interface of physics, mathematics and physiology.

2. Research results

Waves in nerve fibres

Papers

1. J.Engelbrecht, K.Tamm, T.Peets. Axons' Signals. In: A. Costa, E.Villalba (Eds), Horizons in Neuroscience Research, Nova Science Publishers, 2023, vol. 49, 33-73.

Abstract. The modelling of biological systems means actually the modelling of complexity. In this paper, our inquiry is focused on signals in axons. The complexity of the axonal structure and processes accompanying the electrical signals need functional integration of many disciplines for the full description of signalling in axons. The modelling involves not only biology or more definitely electrophysiology, but it also involves physics including thermodynamics and theory of continua, the mathematics used for deriving the governing equations of processes, and also a philosophy for embedding the results into the general understanding. Consequently, one must deal with interdisciplinary studies. The ideas of modelling, paying attention to the structure of an axon and the possible physical mechanisms responsible for a signal generation as an ensemble of several effects, are analysed step-by-step. The concrete integrated general models are presented. It is shown how the knowledge from physics, chemistry, mathematics, and philosophy has helped to build up a mathematical model that helps understand the process of formation and propagation of action potential with accompanying effects. The possible modifications of models are also briefly discussed.

2. T. Peets, K. Tamm, J. Engelbrecht. Comment on "Solitons in the Heimburg-Jackson model of sound propagation in lipid bilayers are enabled by dispersion of a stiff membrane" by M. Drab et al. Eur. J. Phys. E, 46, 34

Abstract. In this short comment, attention is drawn to the shortcomings of the study of Drab et al. that could lead to a distorted interpretation of the described phenomenon.

3. T. Peets, K. Tamm, J. Engelbrecht. On concepts of mathematical physics for modelling signals in nerves. arXiv: 2306.04229v1 [physics.bio-ph] 7 jun 2023

Abstract. In this short paper, the results of the paper by Drab et al. (Eur. Phys. J. E (2022) 45:79) are described in the framework of wave mechanics and mathematical physics based on common understandings. The attention is focused on properties of Boussinesq-type equations, solitons, and peakons. These concepts are supported by several experimental observations.

4. T. Peets, K. Tamm, J. Engelbrecht. On mathematical modeling of the propagation of a wave ensemble within an individual axon. Frontiers Cell. Neurosci. 2023, vol. 17. online: 27 July 2023, doi.org/10.3389/fn-cel.2023.122785

Abstract. The long history of studying the propagation of an action potential has revealed that an electrical signal is accompanied by mechanical and thermal effects. All these effects together generate an ensemble of waves. The consistent models of such a complex phenomenon can be derived by using properly the fundamental physical principles. In this paper, attention is paid to the analysis of concepts of continuum physics that constitute a basis for deriving the mathematical models which describe the emergence and propagation of a wave ensemble in an axon. Such studies are interdisciplinary and based on biology, physics, mathematics, and chemistry. The governing equations for the action potential together with mechanical and thermal effects are derived starting from basics: Maxwell equations, conservation of momentum, Fourier's law, etc., but modified following experimental studies in electrophysiology. Several ideas from continuum physics like external forces and internal variables can also be used in deriving the corresponding models. Some mathematical concepts used in modeling are also briefly described. A brief overview of several mathematical models is presented that allows us to analyze the present ideas of modeling. Most mathematical models deal with the propagation of signals in a healthy axon. Further analysis is needed for better modeling the pathological situations and the explanation of the influence of the structural details like the myelin sheath or the cytoskeleton in the axoplasm. The future possible trends in improving the models are envisaged.

Papers submitted.

1. J. Engelbrecht, K. Tamm, T. Peets. On the phenomenological modelling of physical phenomena. Proc. Estonian Acad. Sci. (submitted)

Abstract. Mathematical modelling of physical phenomena is based on laws of physics but for complicated processes phenomenological models could enhance the descriptive and prescriptive power of the analysis. This paper describes some hybrid models where in addition to the physics-driven part some phenomenological variables (based on observations) are added. The internal variables widely used in continuum mechanics for the modelling of the dissipative processes and phenomenological variables used in the modelling of neural impulses are described and compared. The appendices describe two models of neural

impulses and test problems for two classical cases: the wave equation and the diffusion equation. These test problems demonstrate the usage of phenomenological variables for describing dissipation as well as amplification.

Books

1. G. Jacobs, I. Šlaus, J. Engelbrecht, A. Zucconi (Eds). *Catalytic Strategies for Conscious Social Transformation: Leadership in Thought*. Cambridge Scholars Publishing, Newcastle, 2023. (ISBN 978-1-5275-1081-6)

Abstract. This collection of essays examines the unprecedented reach, magnitude and complexity of global challenges—political, economic, technological, social and environmental. It advocates fundamental changes in theory, research, public policy, and institutions, and advances new thinking on global leadership, human security, human-centered economics, and human rights. The book also proposes measures to break down the barriers between academic disciplines and between research and policy-making, and reconciles the objective facts of science with the subjective truths of the arts and human values. It replaces mechanistic analytic thinking with integrated knowledge, bridging the divide between abstract theory and the living complexity of social reality.

Esseede kogumik hõlmab Maailma Kunsti ja Teaduse Akadeemia (World Academy of Art and Science - WAAS) egiidi all ilmunud uuringuid ja katab suure osa globaalsete väljakutsete probleemidest. Rohkem kui 20 autorit käsitlevad oma esseedes poliitilisi, majanduslikke, tehnoloogilisi, sotsiaalseid ja ökoloogilisi probleeme. Siduvaks ideeks on vajadus muuta mitmeid paradigmasid avalikus poliitikas ja selle institutsioonides tuginedes teadusuuringutele. Fookuses on globaalsed reeglid, julgeolek, heaolu printsiipe järgiv majandus ja inimõigused. Mitmes essees on rõhutatud vajadus ületada poliitiliste otsuste ja teadusuuringute vahelised barjäärid, samuti on pööratud tähelepanu teadusuuringute objektiivsete tulemuste ja väärtuste seostamisele. See aga tähendab teoreetiliste teadmiste ühendamist reaalsuse kui kompleksüsteemiga.

2. J.Engelbrecht. *Peegeldusi teadusmaastikult (Reflections from Science)*. Ilmamaa, Tartu 2023 (ISBN 978-9985-77-528-8).

Käesoleva kogumiku kaante vahele on kogutud kirjutised, mis on enamjaolt varem ilmunud erinevates ajakirjades või väljaannetes. Kogumik algab esseede kujul korrastatud mõtetega kultuurist, haridusest, ühiskonnast, väärtustest ja tulevikust. Järgnev osa haarab lühemaid artikleid ja arvamusi. Pilk ajaloo radadele kolmandas osas aitab mõista nii omaaegset maailmapilti kui ka selle mõju olevikule ning tuleviku suundumustele. Nende põhjal on kirja pandud kokkuvõtted traktaatide kujul olulistel üldistel teemadel, nagu teadus, ühiskond ja tulevik,

3.J. Engelbrecht. *Complexity of Social Systems and Academies*. Cambridge Scholars Publishing, Newcastle. Paperback 2023 (ISBN 1-5275-9489-0).

Earlier: Hardback 2021 (ISBN 1-5275-7309-5).

Kogumik on pehmete kaantega kordustrükk varasemast väljaandest (vt RR 2021).

Biography

1. J.Engelbrecht. *Sirvilauad (The Life Story)*. Tallinn, Grano Digital OÜ, 2023. (ISBN 978-9916-4-1741-6)

Conferences and abstracts

1. K. Tamm, T. Peets, J. Engelbrecht. The modelling of signals in nerves needs interdisciplinarity. Conf. Physiology in Focus, Tallinn, 2023, Book of Abstracts, p 86.

Seminars

Modelling of complex signals in nerves, Jüri Engelbrecht, Kert Tamm and Tanel Peets, St Hugh's College, University of Oxford, January 9, 2023, Oxford, United Kingdom

Research Reports

1. J. Engelbrecht, K. Tamm, T. Peets. Annual Report 2022 on Nonlinear Dynamics and Biophysics. RR Mech 330/23, Tallinn University of Technology, School of Science, Dept. of Cybernetics.

General publications

1. J. Engelbrecht. Lugesin üht raamatut: Sonia Contera, Nano Comes to Life. How Nanotechnology is Transforming Medicine and the Future of Biology. Princeton University Press, 2021. Horisont, 2023, No 2, lk 58.

2. M. Djurovic, J. Engelbrecht. Is the Future Known? Proc. Montenegrin Academy of Sciences and Arts, Section of Natural Sciences, 2023, 25, 5-17.

3. J. Engelbrecht, R. Kitt. Knowledge Generation and Interdisciplinarity. In: G. Jacobs, I. Šlaus, J. Engelbrecht, A. Zucconi (Eds) Catalytic Strategies for Conscious Social Transformation: Leadership in Thought. Cambridge Scholars Publishing, Newcastle, 2023, 390-404.

4. J. Engelbrecht. Mõtlemine kaugemale tänasest päevast. Postimees, 28. 10.2023

5. J. Engelbrecht. Muudame maailma. Kastidest võrgustikuteni. Postimees, 20.11.2023

General articles submitted

1. J. Engelbrecht. Sõnade vägi mõtteloos. Artiklite kogumik, Ilmamaa, Tartu.

Teaching

K. Tamm - Courses in Tallinn University of Technology:

BSc level: Fundamentals of Analytical Mechanics and Elasticity (YFX0590),
Analytical Mechanics (YFX0591)

T. Peets - Courses in Tallinn University of Technology:

BSc level: Writing Academic Papers and Thesis (YFX0540), Mechanics (YFX0552)

MSc level: Mathematical Modelling and Nonlinear Dynamics (YFX1520),
Seminar of Applied Mechanics (YFX1530)

Reviewing

T. Peets: reviews for Israel Science Foundation, Communications Physics

K. Tamm: [1] TalTech BSc thesis review Janek Käsper, Mitokondriaalsete protsesside modelleermine; [2] TalTech BSc thesis review Kaarel Beljaev Difusioon fikseeritud südamelihaskudede; [3] German Research Foundation, review for a project proposal

Membership in Editorial Boards:

Applied and Computational Mechanics (Czech Republic): J. Engelbrecht

Proc. Estonian Acad Sci.: J. Engelbrecht

Applied Mechanics (Kiev): J. Engelbrecht

J. Theor. and Appl. Mech. (Warsaw): J. Engelbrecht

Trames (Estonia): J.Engelbrecht
Akadeemia (Estonia): J.Engelbrecht

Professional organizations

Euromech: J.Engelbrecht, K.Tamm, T.Peets

ISIMM: J.Engelbrecht

Nordic Association for Computational Mechanics: T.Peets (member of the Executive Committee)

Estonian Academy of Sciences: J.Engelbrecht (Adviser)

WAAS – World Academy of Art and Science: J.Engelbrecht (Fellow)

Estonian National Committee for Mechanics: T.Peets (secretary), J.Engelbrecht (member)

4. Grants and cooperation

4.1 Estonian grants

K.Tamm, funded by PRG1227 (ETAg)

T.Peets, funded by PRG1227 (ETAg)

J.Engelbrecht (consultant), funded by PRG1227 (ETAg)

5. Varia: publications reflecting previous work

1. T.Tiivel. Raamat "Peegeldused teadusmaastikult". Horisont, 6, 2023, 58.

5. Conclusions

The research on modification of the model (described in a book by Springer in 2021) is continued with the main attention to the refining of the model by taking the structural details of nerve fibres into account..

Concerning the previous results:

- papers by J .Engelbrecht have more than 18 000 “reads” in Research Gate;
- the book "Microstructured Materials: Inverse Problems" (Springer, 2011) - has ca 7900 chapter downloads;
- the book "Questions About Elastic Waves" (Springer, 2015) - has ca 8000 chapter downloads;
- the book "Modelling of Complex Signals in Nerves" (Springer, 2021) has ca 2700 chapter downloads,
- the book "Applied Wave Mathematics II" (Springer 2019) has ca 10k chapter downloads and the chapter "Mathematics of nerve signals" - over 600 downloads.

The recent results are widely known according to SciVal lists on topics by authors over the world (in brackets the place in the list):

- Action Potentials; Liquid Membranes; Nerve:
J.Engelbrecht (1), T.Peets (2), K.Tamm (3);

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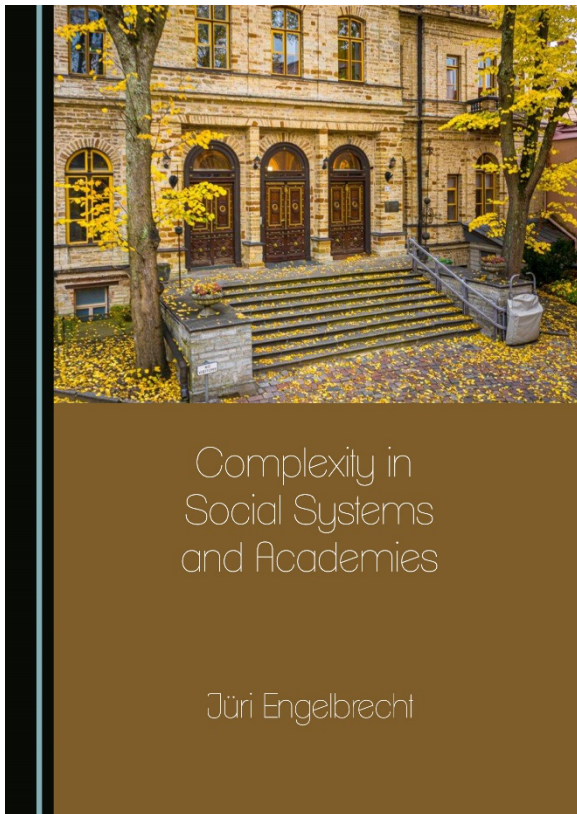
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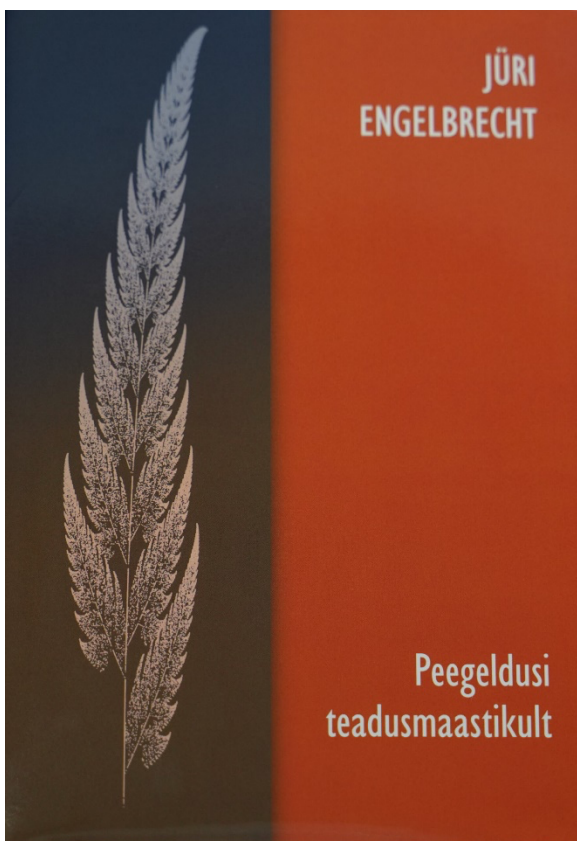
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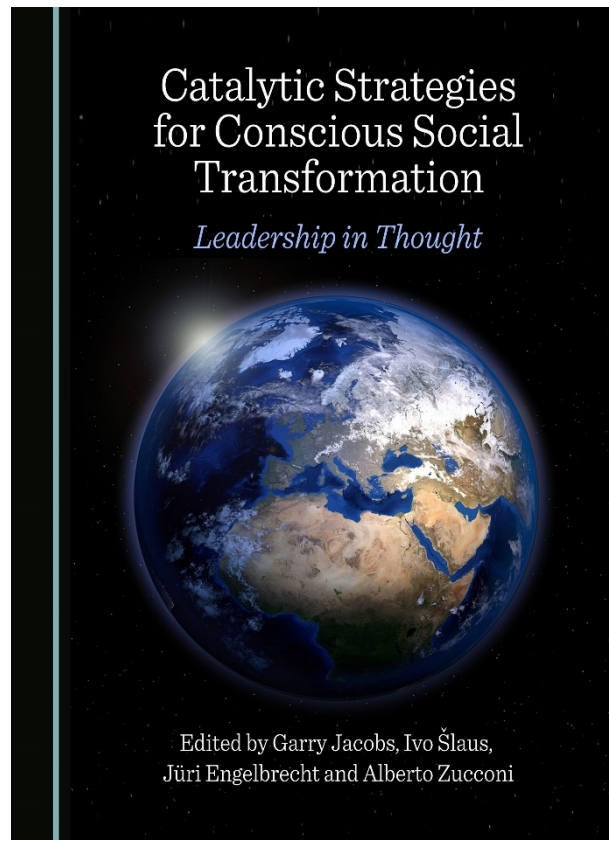
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