The first  10 years of the Department of Biological Physics

at the Institute of Physics, Eötvös University

UNIVERSITAS BUDAPESTINENSIS DE ROLANDO EÖTVÖS NOMINATA

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1998 - 2008

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Front cover:	The Department working day and night …
Back cover:	The community graph for the co-authorship network of the Department found by the k-clique percolation method at $k = 4$ (Palla *et al* [94]). Each article of the Department contributes the value $1/(n-1)$ to the weight of the link between every pair of its n authors. Links connecting to co-authors not belonging to the Department are shown in light grey. The size of each node is proportional to the total number of papers of the author in the publication list (inside). The network is surrounded by pictograms of the groups' research interests.

FOREWORD

The Department of Biological Physics was created in January 1998. By doing so, the physics community and the leadership of the Faculty of Science at Eötvös University have recognized the increasing importance of providing specific education in the quickly growing field of biologically motivated physics.

Our department grew out of a seed in the Department of Atomic Physics, where a Biophysics Group with the leadership of Elemér Papp, and with the strong support of Professor György Marx, the long time head of the Department of Atomic Physics, had existed for about 25 years. Over the years the spectrum of research and teaching activities of this group has expanded as the need in biologically oriented projects and courses has been steadily increasing.

The foundation of the Department of Biological Physics was initiated by Professor Tamás Vicsek, who then became the first head of the new Department and also the head of the Biological Physics Research Group of the Hungarian Academy of Sciences. There is a continuous strong connection between the Department and the Research Group.

The establishment of the new Department practically coincided with the movement of the whole Institute of Physics from the old building at Puskin utca to the new building of the Faculty of Science near the Danube. At that time associate professor Noémi Rozlosnik played an active role not only in planning the infrastructure in the new building, but also in developing the new teaching and research profile of the Department.

In the past the main teaching activity of the Department was exerted within two undergraduate specialties of physics education: Physics of Atoms and Molecules and Biological Physics. An important part of the teaching was and still is the organization and leading of the Modern Physics Laboratory course. One of the physics PhD programs (Statistical Physics, Biological Physics and Physics of Quantum Systems) is supervised by our Department. After introducing the new BSc-MSc system the role of our Department in the education at the interdisciplinary field of biology and physics has been increased. The biophysics specialty in both the physics BSc and physics MSc training has been accredited. In addition to this the accreditation of a new biophysics MSc is under way.

Many of the research activities at our Department are internationally well recognized. Originally, still within the Department of Atomic Physics, the central research topic in biophysics was photosynthesis and other energy converting mechanisms, but during the 90s several new directions of research have been launched: biooptics, biomechanics, theoretical ecology and evolution, cell motility, modeling and theoretical investigation of collective behavior of humans and animals. Later, after the creation of the new Department of Biological Physics these research areas developed further and some new topics emerged: complex networks, protein dynamics, motor proteins, membrane dynamics, vasculogenesis, flocking, soaring. There are also some other types of researches at our department, with only loose potential connections with biological physics: theoretical investigation of carbon nanostructures and experimental investigation of turbulences in two dimensions.

The success of the research at our Department can be measured by bibliometrics data for the last 10 years: the number of books and book chapters is 20, the number of peer-reviewed journal articles is 246. The number of SCI citations to the latter is larger than 3000, the h-index to these publications is 30. The members of the Department and the Research Group of the H.A.S. obtained $\approx$ 2 million Euros as financial support from various Hungarian, EU and US sources.

The present staff of the Department of Biological Physics consists of 18 people academic staff (2 of them are retired, 2 of them are part-time research fellows), 6 people non-academic staff and 8 PhD students.

Head of the Department of Biological Physics at Eötvös Loránd University, Budapest:

VICSEK Tamás	1998-2006
KÜRTI Jenő	2006-

Website: http://biolphys.elte.hu

PEOPLE AT THE DEPARTMENT

People at the Department in 2008

Academic staff

KÜRTI Jenő, DSc, Professor, Head of Department
VICSEK Tamás, MHAS, Professor, Head of HAS Research Group
ÁKOS Zsuzsa, MSc, Research Assistant
CZIRÓK András, PhD, Assistant Professor
DERÉNYI Imre, DSc, Associate Professor
FARKAS Illés, PhD, Research Associate Professor
HAIMAN Ottó, Univ.Dr., Retired Research Advisor
HÁMORI Jenő, PhD, Visiting Researcher
HORVÁTH Gábor, DSc, Associate Professor
HORVÁTH Viktor, PhD, Associate Professor
KOLTAI János, PhD, Assistant
MÉHES Előd, PhD, Research Assistant Professor
MESZÉNA Géza, DSc, Associate Professor
ORMOS Pál, MHAS, Part-time Professor
PALLA Gergely, PhD, Research Associate Professor
PAPP Elemér, CSc, Retired Associate Professor
POLLNER Péter, PhD, Research Associate Professor
SZABÓ Bálint, PhD, Assistant Professor
ZÁVODSZKY Péter, MHAS, Part-time Professor
ZWEIG, Katharina, PhD, Visiting Researcher

Former academic staff

DARUKA István, PhD, Research Associate Professor
FRICSOVSZKY György, CSc, Associate Professor
GARAB Győző, DSc, Széchenyi Professor Fellow
RAJCZY Péter, Univ.Dr., Assistant
ROZLOSNIK Noémi, PhD, Associate Professor
SIMON István, DSc, Széchenyi Professor Fellow
SZABÓ Péter, PhD, Research Assistant Professor
SZILÁGYI András, PhD, Postdoctoral Fellow
ZÓLYOMI Viktor, PhD, Research Assistant Professor

Non-academic staff

BOTOS Krisztina, Departmental Finance Officer
CSISZÉR Miklós, Technician
FARKAS Anikó, Acquisition Officer
FOGL László, Departmental Engineer
KOLLÁRNÉ RUFF Mariann, Lab Technician
VASS Rita, Lab Technician

Former non-academic staff

BENEDEK Zsuzsanna, Acquisition Officer
CZAPÁRI Katalin, Acquisition Officer
ZAVACZKI Csilla, Lab Technician

PhD students

ÁBEL Dániel
CZÖVEK András
GÖNCI Balázs
HEGEDÜS Ramón
NAGY Máté
RUSZNYÁK Ádám
SZABÓ András
SZÖLLŐSI Gergely

Former PhD students

ABLONCZY Zsolt
ADAMCSEK Balázs
BARTA András
BERNÁTH Balázs
BÓTA Attila
CSEH Zoltán
CZIRÓK András
FARKAS Illés
FARKAS Zénó
GÁL József
HEGEDŰS Balázs
HORVÁTH Róbert
KOVÁCS Baldvin
KOVÁCS János
LUKÁCS András
MÁGORI Krisztián
MIZERA Ferenc
NEMES Csilla
POMOZI István
SELMECZI Dávid
SZABÓ Bálint
SZABÓ Péter
SZILÁGYI András
TEGZES Pál
VÖRÖS János
VUKOV Jeromos
ZÓLYOMI Viktor

AWARDS & SCHOLARSHIPS

HORVÁTH Gábor	International Paleobiological Award, Spanish Palaeontological Society (2008)
FARKAS Illés	Prima Junior Award (2007)
HORVÁTH Gábor	Best Paper Award, Hungarian Science Foundation (2007)
ZÓLYOMI Viktor	Bolyai Research Scholarship of H.A.S. (2007)
ZÓLYOMI Viktor	Young Scientist Prize of the H.A.S. (2007)
CZIRÓK András	International Dennis Gabor Award (2006)
DERÉNYI Imre	Burgen Scholarship of the Academia Europaea (2006)
DERÉNYI Imre	Physics Prize of the H.A.S. (2006)
FARKAS Illés	Young Scientist Prize of the H.A.S. (2006)
PALLA Gergely	Young Scientist Prize of the H.A.S. (2006)
DERÉNYI Imre	Bolyai Research Fellowship (2005-2008)
FARKAS Illés	Bolyai Research Scholarship of H.A.S. (2005)
HORVÁTH Gábor	Young Bolyai Prize, Ministry of Education (2005)
FARKAS Illés	German Physical Society, AKSOE Group: Young Scientist Award (2004)
HORVÁTH Gábor	Budó Prize of the Eötvös Physical Society (2004)
DERÉNYI Imre	Bródy Prize of the Eötvös Physical Society (2003)
MESZÉNA Géza,	Széchenyi Research Fellowship (2003-2006)
VICSEK Tamás	Leó Szilárd Award (2003)
CZIRÓK András	Selényi Prize of the Eötvös Physical Society (2002)
DERÉNYI Imre	Békésy Post-doc Fellowship (2002-2005)
FARKAS Illés	Pro Scientia Medal (2001)
HORVÁTH Gábor	Széchenyi Research Fellowship (2001-2004)
HORVÁTH Gábor	Humboldt Research Fellowship (2001-2003)
MESZÉNA Géza,	Széchenyi Professorship (1999-2002)
KÜRTI Jenő,	Széchenyi Professorship (1998-2001)
VICSEK Tamás	Széchenyi Award (1999)
HORVÁTH Gábor	Bolyai Research Fellowship of H.A.S. (1998-2001)
HORVÁTH Gábor	Magyary Postdoctoral Fellowship of Ministry of Education (1997-1998)

Habilitation

CZIRÓK András (2008)
MESZÉNA Géza (2006)
DERÉNYI Imre (2005)
HORVÁTH Gábor (2002)
KÜRTI Jenő (1999)

DSc

MESZÉNA Géza (2007)
DERÉNYI Imre (2006)
HORVÁTH Gábor (2005)
KÜRTI Jenő (1999)

RECENT TEACHING ACTIVITIES *Selection*

Laboratory works

Modern Physics / 4 hours/week /	Physics BSc
Physics of Atoms and Molecules – Biophysics / 5 hours/week /	Physics MSc

Present courses

Applications of computer-based image processing in the natural sciences*	Physics MSc
Bioinspired materials	Biology, Physics BSc, MSc
Biological physics / 4 hours/week /	Biology BSc
Biomechanics and biooptics / 3 hours/week /	Physics BSc
Biophysics I-II / 2-2 hours/week /	Physics BSc, MSc
Biophysics (for Biology students) / 4 hours/week /	Biology 3-5
Biophysics of polimers and membranes	Physics MSc, PhD
Carbon nanostructures	Physics, Chemistry MSc, PhD
Cellular signaling networks	Biology 3-5, Physics 3-5
Experimental methods for structural analysis in biophysics	Physics BSc, MSc
Fractal growth	Physics MSc, PhD
Graphs in bioinformatics I-II	Physics, Biology MSc, PhD
Introduction to Biophysics	Physics 3-4
Macromolecules	Physics, Chemistry MSc, PhD
Optical devices and methods	Physics 3-5, Chemistry 3-5
Optical waveguides and laser tweezers	Physics 4-5, PhD
Optics and quasi-optics	Physics 3-5, Chemistry 3-5
Physical biochemistry	Physics PhD
Physics I-II / 4-2 hours/week /	Chemistry BSc
Physics and experimental methods of turbulent flow	Physics 3-5, Meteorology 3-5
Quantitative models of developmental mechanisms	Biology, Physics MSc
Selected chapters of physics	Chemistry MSc, Chemistry 2-5
Selected problems in biophysics	Physics 5
Sensory biophysics	Biology , Physics MSc
Statistical physics of biological systems	Physics MSc
Theoretical ecology	Biology 2-5, Physics 2-5, (PhD)
Theoretical evolutionary biology / 3 hours/week /	Physics BSc
Thermodynamics	Biology 4, Physics 4

New courses

Bioenergetics	Physics MSc
Environmental biophysics	Physics MSc
Modern imaging techniques in biology	Physics MSc
Molecular physics	Physics BSc
Physical simulations	Physics BSc

*Courses are on a 2 hours/week basis, if not stated otherwise.

PHD THESES

Name	Supervisor	Title of thesis, Year of degree
VUKOV Jeromos	MESZÉNA Géza SZABÓ György	”Evolutionary prisoner's dilemma game on different networks” (2008)
BARTA András	HORVÁTH Gábor	”Study of biooptical and atmospheric optical phenomena with geometric optical and imaging polarimetrical methods” (2007)
BERNÁTH Balázs	HORVÁTH Gábor	”Light-polarizational phenomena in the optical environment of water-associated animals examined by imaging polarimetry” (2006)
SELMECZI Dávid	CZIRÓK András	”Cell motility as persistent random motion: Theories from experiments” (2006)
SZABÓ Péter	MESZÉNA Géza	”Scale dependent aspects of coexistence mechansims in ecological communities” (2006)
ZÓLYOMI Viktor	KÜRTI Jenő	”Theoretical investigation of small diameter carbon nanotubes” (2005)
MÁGORI Krisztián	MESZÉNA Géza	”Adaptive dynamics on lattice” (2004)
BÓTA Attila	ROZLOSNIK Noémi	”Structural behaviours of DPPC/water liposomes” (2003)
CSEH Zoltán	PAPP Elemér GARAB Győző	”Thermo-optical structure changes in lamellar LHCII aggregates” (2003)
FARKAS Illés	VICSEK Tamás	”Random graphs in life” (2003)
SZABÓ Bálint	VICSEK Tamás	”Nanometer scale fluctuations of cells, nuclear migration in cells on micropatterned surfaces” (2003)
FARKAS Zénó	VICSEK Tamás	”Transport by ratchet mechanisms: application for granules and DNA” (2002)
GÁL József	HORVÁTH Gábor	”Biooptical and atmospheric optical applications of geometric optics and imaging polarimetry” (2002)
HEGEDŰS Balázs	VICSEK Tamás	”Long term videomicroscopic study of cell motility and proliferation” (2002)
NEMES Csilla	ROZLOSNIK Noémi	”Measurement of nanomechanical properties of proteins with Atomic Force Microscopy” (2002)
POMOZI István	HORVÁTH Gábor	”Wide and narrow field-of-view imaging polarimetry of polarization patterns with atmospheric optical and biological implications” (2002)
TEGZES Pál	VICSEK, Tamás	”Stability, avalanches and flow in dry and wet granular materials” (2002)
HORVÁTH Róbert	PAPP Elemér	”Biological applications of optical waveguide sensors” (2001)
ABLONCZY Zsolt	PAPP Elemér CROUCH, Rosalie	”Structural and functional studies of light sensitive integral membraneproteins” (2000)
CZIRÓK András	VICSEK Tamás	”Models of collective behaviour in biology” (2000)

MSC THESES

Name	Supervisor	Title of thesis, Year of degree
VÖLGYES Dávid	MESZÉNA Géza	”Fajgyakorisági modellek” (2008)
ÁBEL Dániel	VICSEK Tamás	”Komplex hálózatok átfedő moduljainak keresése” (2007)
CSAPÓ Adelinda	HORVÁTH Gábor	”Négylábú járásábrázolások biomechanikai elemzése, különös tekintettel a múzeumi preparátumokra és az anatómiai tankönyvek illusztrációira” (2007)
CZÖVEK András	DERÉNYI Imre	”Nanopórusok” (2006)

Name	Supervisor	Title of thesis, Year of degree
JURÁNYI Zsófia	SZABÓ Bálint	"Sejt-hordozó és sejt-sejt adhézió hatása a sejtmozgásra: videomikroszkópos vizsgálat" (2006)
MALIK Péter	HORVÁTH Gábor	"Környezetünk antropogén fénypolarizáló felületeinek polarimetriai vizsgálata biológiai vonatkozásokkal" (2006)
NAGY Gergely	CZIRÓK András	"Sejtmozgás és sejtmagmozgás során fellépő erők analízise" (2006)
SZABÓ András	CZIRÓK András	"Szöveti sejtek térbeli hálózatképzésének modellezése" (2006)
GÖNCI Balázs	SZABÓ Bálint	"Keratocita sejtek mozgásának vizsgálata videomikroszkópiával mikromintázatokon" (2005)
HEGEDÜS Ramón	HORVÁTH Gábor	"A rovarok polarizáció-érzékelésének spektrális tulajdonságai, avagy polarizációs hamis színek és polarizáció-látás a spektrum zöld tartományában" (2005)
KOVÁCS Baldvin	VICSEK Tamás	"Biológiai hálózatok modellezése" (2005)
NAGY Zoltán	VICSEK Tamás	"Rendezett mozgás kialakulása önhajtott részecskékből álló rendszerekben" (2005)
OROSZLÁNY László	KOLTAI János CSERTI József	"Mágneses kvantumdotok transzporttulajdonságai" (2005)
SZÖLLŐSI Gergely	DERÉNYI Imre	"Fehérjeadszorpció: egy reverzíbilis mezoszkopikus modell" (2005)
FAZEKAS Ferenc	KÜRTI Jenő	"Fizikai alapok a kémiában" (2004)
TÓTH Csaba	MESZÉNA Géza	"Evolúcióbiológiai modellezés sejtautomatákon" (2004)
ZÁCH Júlia	HEGEDŰS Balázs VICSEK Tamás	"Radiokemoterápia hatása tumorsejtek in vitro proliferációjára és migrációjára" (2003)
ZÓLYOMI Viktor	KÜRTI Jenő	"Többszörös rezonancia Raman jelenségek szén nanocsövekben" (2002)
BARTA András	HORVÁTH Gábor	"Felhőészlelés a földről 180° látószögű képalkotó polarimetriával" (2001)
LANTOS Diána	MESZÉNA Géza	"Fluktuáló környezetben élő populációk vizsgálata adaptív dinamikai módszerekkel" (2001)
VASSY Attila	VICSEK Tamás	"A vastaps statisztikus fizikai analizise" (2001)
ANTOS József	KÜRTI Jenő	"Szén nanocsövek Raman-spektrumának elméleti vizsgálata" (2000)
FARKAS Illés	VICSEK Tamás	"Gyalogosokból álló rendszerek statisztikus fizikai leirása" (2000)
ILLYÉS Péter	PAPP Elemér	"Biological application of optical waveguides" (2000)
KATONA Csaba	FOGL László	"Számítógép felhasználása a középiskolai fizika tanításában" (2000)
LUKÁCS András	PAPP Elemér	"Investigation of bacteriorhodopsins photocycle with Maximum Entropy Method" (2000)
MARÓDI Máté	VICSEK Tamás	"Emberi viselkedés szinkronizációjának vizsgálata statisztikus fizikai módszerekkel" (2000)
SZEDENICS Gábor	HORVÁTH Gábor	"Vízfelületek és a budapesti pakurató tükröződési-polarizációs sajátságainak videopolarimetriás vizsgálata" (2000)
BERNÁTH Balázs	HORVÁTH Gábor	"A polarizáció-látás szerepének vizsgálata rovarok és madarak vízkeresésében" (1999)
MIZERA Ferenc	HORVÁTH Gábor	"Dobósportok a forgó Földön. Hogyan befolyásolja a dobótávot a Coriolis- és a centrifugális erő?" (1999)
MÁGORI Krisztián	MESZÉNA Géza	"Kooperáció és kompetició térben és időben heterogén környezetben: erőforrás-integrációs stratégiák evolúciója klonális növényekben" (1999)
SZABÓ Bálint	KÜRTI Jenő BIRÓ László Péter	"Szén nanocsövek vizsgálata pásztázó alagútmikroszkóppal" (1999)
TÖRŐCSIK Zoltán	HORVÁTH Gábor	"Egyszerű demonstrációs eszközök az összetett szem alkotta mozaikkép szemléltetésére" (1999)
NÉVERI Gábor	KÜRTI Jenő	"Szén nanocsövek lélegző módusú rezgési frekvenciájának és elektronszerkezetének kvantumkémiai számítása (1998)
DUBAY, Orest	KÜRTI Jenő KUZMANY, Hans	"Dynamic Stability of the Neutral Fullerene Dimer C_{120}" (1998)

Grants at the Department

Started in the year 2008

Title of project	Supervisor	Period	Sum [a]	Supporter
Collective tissue formation	CZIRÓK András	2008-2012	11,670	OTKA K72664
Functional assays for membrane protein on nanostructured supports	DERÉNYI Imre	2008-2011	€98,160	CP-FP 214666-2 ASMENA
Development of a fluorescence activated scanning cell sorter micropipette	SZABÓ Bálint [b]	2008-2009	24,160	Innocsekk KM_CSEKK 2006-00282
TEXTREND: 2. Competitive Industry	VICSEK Tamás	2008-2010	42,000	NKTH - Jedlik OM-00006/2008

Started in the year 2007

CellKom RET	VICSEK Tamás	2007-2010	23,000	RET 06/2006
CellKom RET	VICSEK Tamás [c]	2007-2010	19,000	RET 06/2006
Modular Structure of Complex Networks	PALLA Gergely	2007-2010	7,866	OTKA K68669

Started in the year 2006

Kinesin motors under load applied by ”nano-springs”	DERÉNYI Imre	2006-2009	$240,000	HSFP RGY62/2006
Statistical physical modeling of the dynamics of subcellular structures	DERÉNYI Imre	2006-2009	6,764	OTKA K60665
Theoretical investigation of novel carbon nanosystems	KÜRTI Jenő	2006-2009	13,900	OTKA K60576
MTA Resarch Group - Collective phenomena in physical and biological systems	VICSEK Tamás	2006-2009	31,000	MTA 01 147

Started in the year 2005

Statistical physics of the collective behaviour of organisms	VICSEK Tamás	2005-2008	16,700	OTKA T049674
Starlings in flight: understanding patterns of animal group movements	VICSEK Tamás	2005-2007	€165,000	EU6 NEST-STREP 012682
Adaptive ecology in variable environment	MESZÉNA Géza	2005-2007	7,997	OTKA K49689
A smart microscope stage incubator prototype	SZABÓ Bálint [d]	2005-2007	23,610	GVOP-3.3.1-05 / 1.-2005-07-0003/3.0
Investigation of cell motility and proliferation on micropatterned surfaces	SZABÓ Bálint	2005-2007	2,400	OTKA F49795

Started in the year 2004

Theoretical and experimental studies of biologically relevant processes: particle separation, polymer and membrane dynamics, molecular adhesion	DERÉNYI Imre	2004	€20,000	EU6 MERG-CT-2004-505969
Self organization of embryonic vasculature	CZIRÓK András	2004-2006	6,455	OTKA T047055
Studies of complex networks using methods of statictical physics	FARKAS Illés	2004-2007	21,075	OTKA PD48422
Studies of complex networks	PALLA Gergely	2004-2006	2,324	OTKA F047203
Imaging polarimetry, equipment grant	HORVÁTH Gábor	2004	€20,000	Humboldt Foundation

[a] in units of thousand HUF, if not stated oherwise
[b] This project is connected to the CellSorter Ltd.
[c] This project is allocated to the Statistical and Biological Physics Research Group of the H. A. S.
[d] This project is connected to the CellMovie Ltd.

Started in the year 2003

Title of project	Supervisor	Period	Sum [a]	Supporter
Studies of biological processes of the cell using the methods of statistical physics	DERÉNYI Imre	2003-2006	2,400	OTKA F43756
OM Post-doc	VICSEK Tamás	2003-2006	14,976	OM 124/2003
MTA Resarch Group – Collective behaviour in biology	VICSEK Tamás	2003-2006	24,000	MTA 01 147
Experimental investigation of turbulent flow	HORVÁTH Viktor	2003-2005	3,000	OTKA T43122

Started in the year 2002

Developing nano-biotechnological devices	VICSEK Tamás	2002-2005	26,324	OM-00245/2002
Renewal of the Nd-YAG pulse laser equipment	KÜRTI Jenő	2002	4,198	OMFB-00312/2002
Theoretical investigation of fullerenes and carbon nanotubes	KÜRTI Jenő	2002-2005	4,000	OTKA T038014

Started in the year 2001

Physical properties of biological systems of many organism	VICSEK Tamás	2001-2004	12,000	OTKA T034995
Biomechanical study of the optimal wall thickness of tubular bones	HORVÁTH Gábor	2001-2004	3,720	OTKA T034982
Adaptive Dynamics: the mathematical link between population dynamics and evolution	MESZÉNA Géza	2001-2003	€ 32,000	OTKA ,NSF, Magyar-Holland N34028
Instrument acquisition: incubator	VICSEK Tamás	2001	1,400	OTKA

Started in the year 2000

Collective motion in driven systems	VICSEK Tamás	2000-2003	6,950	OTKA T033104
Theoretical investigation of novel carbon nanostructures	KÜRTI Jenő	2000-2002	3,000	FKFP 0144/2000

Started in the year 1999

Population genetics of adaptive speciation	MESZÉNA Géza	1999-2001	1,900	OTKA T033097
Ecological basis of adaptive dynamics	MESZÉNA Géza	1999-2000	1,700	FKFP 0187/1999

Started before the year 1998

A survey on the animals trapped in the waste oil reservoir in Budapest.	HORVÁTH Gábor	1998-2000	3,000	OTKA F025826
Quantum chemical investigation of vibrational spectra and electronic structure of carbon clusters	KÜRTI Jenő	1997-2000	2,100	OTKA T022980
Statistical physics of complex biological and granular systems	VICSEK Tamás	1997-2000	10,000	FKFP 0203/1997
Examination on the water detection and polarization vision of aquatic birds and insects	HORVÁTH Gábor	1996-1999	3,000	OTKA T020931
Cooperative phenomena in non-equilibrium sytems of complex particles	VICSEK Tamás	1996-1999	2,516	OTKA T019299
Natural polarization patterns and the polarization vision of animals	HORVÁTH Gábor	1995-1998	2,000	OTKA F014923

RECENT RESEARCH TOPICS

Statistical and Biological Physics Research Group
Group leader: Tamás Vicsek

Our topics represent biological applications of statistical physics. They involve experimental observations, computer modelling and development of theoretical concepts. Techniques applied in statistical physics have proven to be fruitful in other fields of research as well. Networks map the investigated phenomenon to a list of pairwise connections (links) among its subunits (nodes), while models of collective motion treat the participating moving subunits (bacteria in a colony, fish in a flock or even humans in a stadium) as interacting physical particles. Correspondingly, the biological organisms we consider range from cultures of tissue cells to groups of humans. The two directions we do research in are about the *essential features of collective motion and the internal organization of large networks.*

Collective motion: The actions of moving individual animals or robots add together creating patterns of motion, so complex that they seem to have been choreographed from above. Flocks and schools have a distinctive style of behavior – with fluidity and a seeming intelligence that far transcends the abilities of their members. Vast congregations of birds, for example, are capable of turning sharply and suddenly *en masse*, always avoiding collisions within the flock.

In 1995 we introduced a statistical physics type approach to flocking [1] in order to establish a quantitative interpretation of the behavior of huge flocks in the presence of perturbations, where perturbations are considered as a natural consequence of the many stochastic and deterministic factors affecting the motion of the flocking organisms. In this approach of self-propelled particles (SPP-s) the units move with a fixed absolute velocity and taken on the average direction of others within a given distance. Perturbations are taken into account by adding a random angle to the average direction. This extremely simple model already showed continuous ordering in the limit of very large systems. It also displays a new type of transition as a function of one of its parameters which corresponds to velocity. Recently we have found [2] that for large velocities ($v > 0.3$) the interplay between the anisotropic diffusion and the periodic boundary conditions leads to an artificial symmetry breaking of the solutions (directionally quantized density waves) and a consequent first order transition like behavior.

We have developed a visualization software [3], which is required by both the empirical and theoretical investigations of collective motion. This application tool enables the visual observation of the three-dimensional positional data of large flocks. The main features of this software are platform independency, user-friendliness and usefulness for generic visualization purposes, and stereo mode also supported. The source code of the software is openly available, and the program can be downloaded from http://angel.elte.hu/starling/Demos.html.

The get experimental data of collective motion we have recorded the swarming-like collective migration of a large number of keratocytes (tissue cells obtained from the scales of goldfish) using long-term videomicroscopy [4]. By increasing the overall density of the migrating cells, we have been able to demonstrate experimentally a kinetic phase transition from a disordered into an ordered state. Near the critical density a complex picture emerges with interacting clusters of cells moving in groups. Motivated by these experiments we have constructed a flocking model that exhibits a continuous transition to the ordered phase, while assuming only short-range interactions and no explicit information about the knowledge of the directions of motion of neighbors. Placing cells in microfabricated arenas we found spectacular whirling behavior which we could also reproduce in simulations.

We have also carried out a research [5] inspired by and being closely related to understanding the group flight of birds. In this project, we used lightweight, high resolution GPS devices (attached to the back of the birds) in order to obtain the detailed temporal dependence of the trajectories of Peregrine falcons and White storks. The GPS device we developed, was capable of logging $24,500$ log points (latitude, longitude, and altitude coordinates and time) and had the size of $4.5 - 6.2\,\mathrm{cm}$, weighing only $34\,\mathrm{g}$. We have found that falcons and leading human paraglider pilots adopt the same optimal soaring strategy while calculating the best slope to take before an upcoming thermal (MacCready theory) and they follow a similar flight pattern.

Increased possibilities for travel and the high number of mass events (music, religious, sports, etc.) often lead to large densities of humans over extended areas. In all of these cases, people need to enter and leave on foot the common

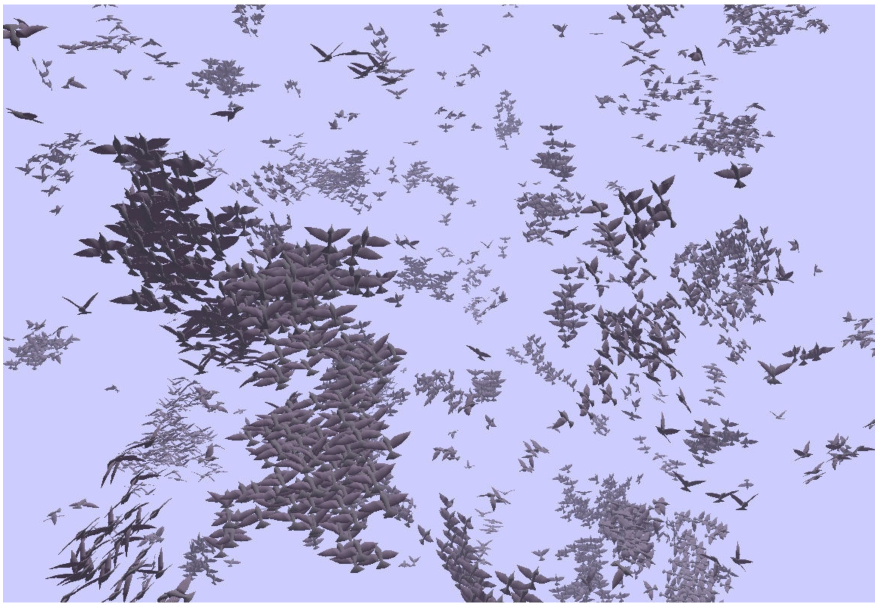

Figure 1: Snapshot of our three dimensional flocking model simulation as displayed by our visualization software

area and often they use that common space for motion, *e.g.*, in Mecca tens of thousands of pilgrims may circle at the same time around the Black Stone. The avoidance of casualties and the facilitation of the efficient collective motion of pedestrians at mass events are of key importance. Triggered by the high need for the modeling and improvement of the collective motion of pedestrians, we have constructed a model of pedestrian motion [6]. In the model each pedestrian is represented by a particle with an internal self-propelling force and simple collision avoidance forces similar to physical forces. With realistic parameters our simulations of the model suggested practical ways to prevent dangerous crowd pressures. In addition, we found an optimal strategy for escape from a smoke-filled room, involving a mixture of individualistic behavior and collective "herding" instinct. A further phenomenon involving the collective motion of humans is the Mexican wave when on the tribune of a stadium neighboring groups of spectators subsequently leap to their feet and give rise to a propagating human wave. With a lattice gas-based model of this motion we found that triggering a Mexican wave requires a critical mass of initiating spectators [7].

Figure 2: Photo of a Mexican wave

Networks: provide a ubiquitous tool for describing complex systems in nature and society. Whenever many similar objects in mutual interactions are encountered, these objects can be represented as *nodes* and the interactions as *links* between the nodes, defining a network. The world-wide-web, the science citation index, and biochemical reaction pathways in living cells are all good examples of complex systems widely modeled with networks.

A collection of important problems in complex network theory is related to the description of the change in the topology with the help of *equilibrium graph ensembles*. In this approach the rewiring of the links is governed by a Hamilton-function depending on the structure of the network, whereas the temperature corresponds to the degree of noise in the restructuring. According to our results, (with appropriate choice of the Hamiltonian), the structure of the network can undergo a *topological phase transition* when the temperature (the level of noise) is varied [8].

Another important field in complex network theory is devoted to the study of *communities* (also called as modules, clusters or cohesive groups). These structural sub-units (with no widely accepted unique definition) in most cases correspond to dense subgraphs in which the group members are more tightly connected to the group than to other parts of the network. A friendship circle, a family or a work group in a social network provide simple examples, similarly to a group of densely interlinked web-pages of the same topic in the WWW, or a module of functionally related proteins in a protein interaction network. The communities in a typical complex system are not isolated from each other, instead, they have *overlaps*, *e.g.* a protein can be part of more than one functional unit, and people can be members in different social groups at the same time. We have developed a community finding algorithm based on the concept of *k-clique percolation* [9]. The overlaps between the communities naturally lead to the definition of the *community graph* [10]: a network in which the nodes refer to communities and links correspond to the shared members between the communities. The community graph can be treated as a ”coarse-grained” view of the original network, and can be used to study the organization of the system at a higher level. To illustrate this point, in Fig.3. we show the community graph of the protein-protein interaction (PPI) network of the yeast, *S. cerevisiae*.

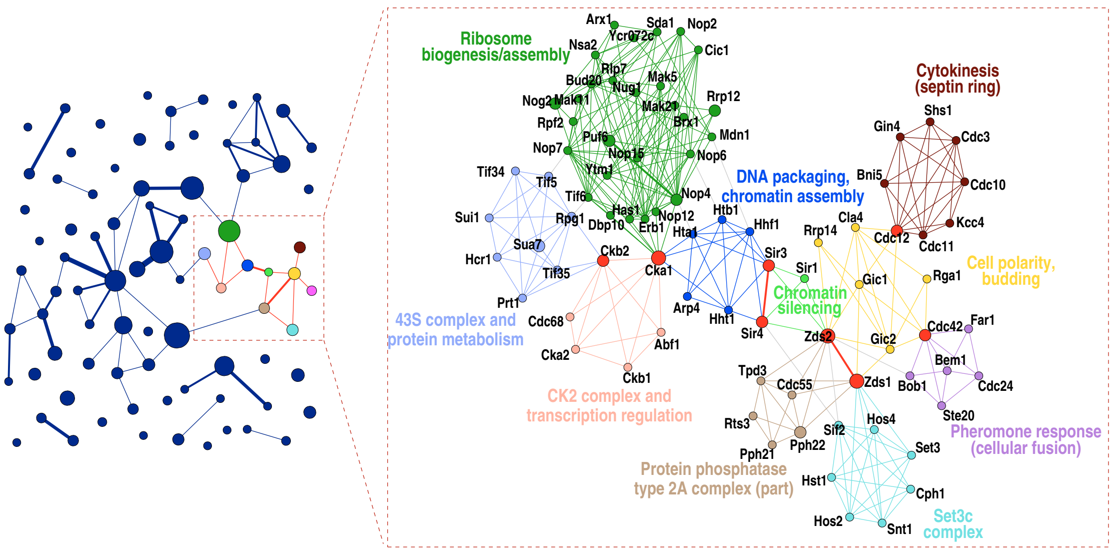

Figure 3: The community graph at $k = 4$ for the PPI network of *S. cerevisiae* obtained from the DIP core list.

Many networks are not static in time; instead their topology is under constant restructuring. Naturally, these processes induce changes in the modular structure as well: the size of an individual community can grow or decay, communities can merge or split, new communities can be born and old ones may disappear. We analyzed the statistical features of community evolution in two large social networks, capturing the collaboration between scientists and the calls between mobile phone users [11]. We found that large groups persist longer if they are capable of dynamically altering their membership, allowing for the possibility that after some time practically all members are exchanged.

Such loose, rapidly changing communities are reminiscent of institutions, that can continue to exist even after all members have been replaced by new members. Remarkably, the behaviour of small groups displayed the opposite tendency, the condition for stability being that their composition remains unchanged. We have also shown that the knowledge of the time commitment of the members to a given community can be used for predicting the communitys lifetime.

Web page: http://angel.elte.hu/~vicsek

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Bioenergetics Laboratory
Group leader: Elemér Papp

Application of Maximum Entropy Method (MEM) to absorption kinetic data processing: The MEM was originally developed for astronomical image restoration. We applied this method to analyze the bacteriorhodopsin photocycle kinetics using experimental absorption kinetic data. Though the MEM does not give direct photocycle kinetics, it can determine (without any assumption) the number of possible intermediate states in the photocycle. Many possible photocycle kinetic models were studied and compared with the MEM result. The best agreement was found with a branching photocycle model of eight intermediate states.
Participants: Zsolt Ablonczy, András Lukács and Elemér Papp.

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Biophysical application of the Optical Waveguide Lightmode Spectroscopy (OWLS): An equipment was developed and built for OWLS measurements at different wavelengths and temperatures. By this method the optical parameters (index of refraction, thickness) of the molecular adlayer on the waveguide sensor can be measured with high precision. The following problems were studied. The main phase transition of the DMPC lipid bilayer around the critical temperature, optical anisotropy of the bilayer. The effect of ultraviolet (UV) irradiation on uracil thin layer, the possibility of application as a sensitive UV dose-sensor. It was shown that patterns and inhomogeneities in the adlayer on the optical waveguide lead to broadening and fine structure of the OWLS spectra, which can give valuable information about the structure of the adlayer. Light-induced changes in the optical parameters of purple membrane and photosynthetic LHCII films were also studied. A numerical method was developed for the 4-layer mode equation to obtain reliable results from the experiment.
Participants: György Fricsovszky, Győző Garab, Róbert Horváth, András Lukács and Elemér Papp

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Biological thermo-optic effect. A novel mechanism driving elementary structural changes in chloroplats thylakoid membranes by dissipated photon-energy: Thylakoid membranes of green plants – a unique assembly of protein, pigment and lipid molecules – accommodate all light-harvesting and energy transducing functions. They are self-assembled structures of high complexity and high order at all levels of the hierarchically organized structure. The membranes are differentiated into stacked and unstacked regions (granum and stroma membranes, respectively). In the stacked regions the constituent proteins and supercomplexes, photosystem II (PSII) and its main light harvesting complexes (LHCII), are assembled into quasi-crystalline chirally organized macrodomains. A basic feature of all photosynthetic systems is their ability to be regulated by short-term variations in the external environmental conditions, which is achieved by multilevel regulatory mechanisms. These involve significant reorganizations in the membranes, which is allowed by a remarkable structural flexibility, combined with an overall structural stability. Our interest has been focused on the mechanism of reorganizations in excess light that cannot be utilized in photosynthesis. In the absence of regulation they would damage the photosynthetic apparatus. Granal thylakoid membranes and, surprisingly, lamellar aggregates of LHCII have been shown to be capable of undergoing light-induced reversible reorganizations. Our studies have shown that these reorganizations can include the following consecutive steps: (i) unstacking of membranes, (ii) a lateral desorganization of the chiral macrodomains, and (iii) monomerization of the LHCII trimers. These structural transitions are accounted for by a novel, biological thermo-optic mechanism: fast thermal transients, arising from dissipated excitation energy, which can lead to elementary structural transitions in the close vicinity of the site of dissipation due to the presence of 'built-in' thermal structure-instabilities. In recent years, thermo-optically induced reorganizations have been shown to be involved in important enzymatic reactions, in the regulation of phosphorylation of LHCII and in their proteolytic removal from the thylakoid membranes.
Participants: Zoltán Cseh, Győző Garab, András Lukács, Elemér Papp.

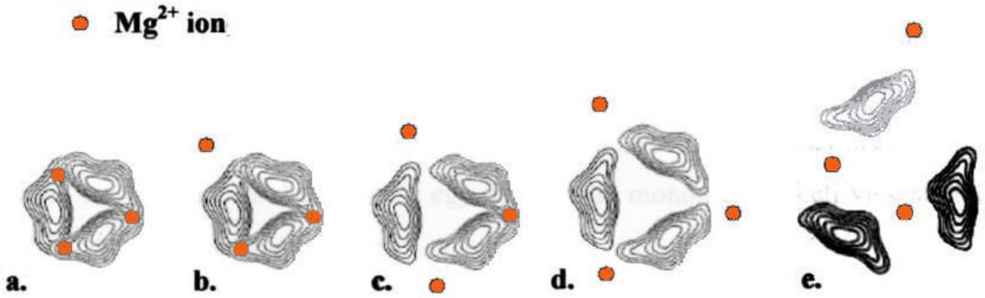

Figure 4: Possible states of monomerization of LHCII trimer based on the model of thermo-optical effect.

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Biooptics and Biomechanics Laboratory
Group leader: Gábor Horváth

Biooptics

Optics of trilobite eyes: Trilobites extincted a few hundred million years ago. They possessed the oldest known preserved visual system. Their compound eyes contained lenses composed of calcite, which preserved the lens shape, on the basis of which the optics of the eye can be reconstructed. With microscopical study of thin sections of trilobite eyes, and using computer ray tracing through trilobite lenses, we reconstructed the major optical characteristics of different kinds of trilobite eye. We discovered that certain trilobites had bifocal lenses, which enabled them to see simultaneously both far and near in spite of the fact that the calcite lenses were rigid, and thus could not accommodate.

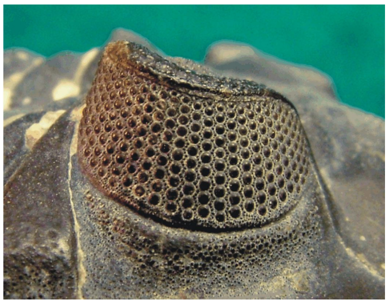



Figure 5: A fossilized *Hollardops* trilobite (left) and its right compound eye with numerous calcite lenses (right) /photograph of Riccardo Levi-Setti/

Refraction-distorted binocular visual field of animals living at the air-water interface: If we look through the air-water interface with two aerial / underwater eyes, the apparent position, size and shape of underwater / aerial objects differ from the real ones due to refraction of light. We improved the theory of aerial / underwater binocular imaging of underwater / aerial objects: We calculated the position of the binocular image point of an underwater / aerial object point viewed by two arbitrarily positioned aerial / underwater eyes. Assuming that binocular image fusion is performed by appropriate vergent eye movements to bring the image onto the foveae, the fine structure of the underwater / aerial binocular visual field was computed and visualized as functions of the eye positions. We revised several earlier treatments, and corrected many widespread erroneous or incomplete representations of this optical problem occurring in the literature. We showed that the structure of the underwater / aerial binocular visual field of aerial / underwater observers distorted by refraction is more complex than it has been thought previously.

Imaging polarimetry: We developed different portable imaging polarimeters by which the spatial distribution of the radiance, degree and direction of linear polarization, furthermore the degree of circular polarization of light from the optical environment can be measured in the visible $(400 - 700\,\mathrm{nm})$ or the ultraviolet $(< 400\,\mathrm{nm})$ part of the spectrum up to $180°$ field of view. Using these polarimeters, we achieved numerous discoveries in atmospheric optics, animal vision and behavioural ecology in different expeditions and measuring campaigns in Alaska, Finnish Lapland, Hungary, Switzerland, in the Tunisian desert, on the Arctic Ocean, and at the North Pole.

Polarization vision: (1) We improved the theory of polarization-induced false colours. We demonstrated that in colour- and polarization-sensitive visual systems polarizational false colours occur, which disturbe the perception of real colours. (2) We showed that it is advantageous for animals to detect celestial polarization in the ultraviolet part of the spectrum, because skylight polarization under clouds and canopies is strongest in the UV. (3) We explained that dusk-active cockchafers detect polarization in the green, because their polarization vision is tuned to the high polarized intensity of downwelling light under canopies during sunset. (4) We measured as first the circular polarization patterns of metallic shiny scarab beetles. (5) In laboratory choice experiments we discovered that yellow fever mosquitoes (*Aedes aegypti*) do not possess positive polarotaxis, although their larvae develop in water. *Aedes aegypti* is the first

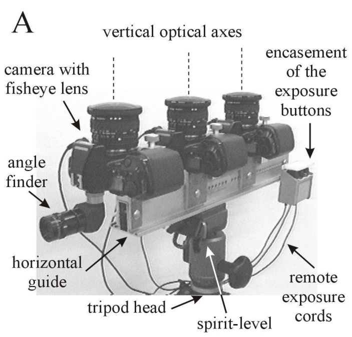
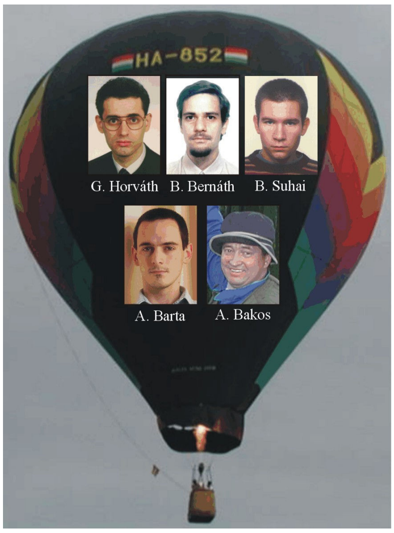


Figure 6: (A) A portable 3-lens 3-camera 180° field-of-view simultaneous imaging polarimeter. (B) Imaging polarimetry of the sky at the North Pole on 12 September 2005 during the Beringia 2005 polar research expedition /photograph of Susanne Åkesson/.

aquatic insect species which does not detect water by the horizontally polarized light reflected from the water surface. Thus, unfortunately, these dangerous mosquitoes cannot be exterminated by polarized light traps.

Celestial polarization patterns: We measured the celestial polarization patterns under various normal (clear, partly cloudy, total overcast, foggy) sky conditions and in extreme meteorological situations (polluted by forest fire smoke, during total solar eclipses, at full moon in the night, skylight transmitted through the Snells window of the water surface, on the ice-cover of the Arctic Ocean) in Alaska, Arctis, Finland, Hungary, Switzerland, Tunisia and Turkey. We performed numerous pioneering achievements in atmospheric optics: (1) In 2001 we observed as first the fourth neutral polarization point in the atmosphere from a hot air balloon at a height of $3.5\,\mathrm{km}$. The other three neutral points of the sky have been discovered in 1810, 1840 and 1842 by Arago, Babinet and Brewster. (2) We measured the fine structure of the sky polarization pattern and its temporal change during total solar eclipses. We showed that these patterns differ considerably from those of the normal sky, and dicovered some new neutral points in the eclipse sky. (3) We proved that the polarization patterns of the moonlit night sky are the same as those of the sunlit sky. This is important for some night-active polarization-sensitive animals in their orientation. (4) We determined also the polarization characteristics of rainbows and Arctic fogbows. (5) We proved that the pattern of the direction of polarization of the celestial hemisphere is practically the same under almost all (clear, partly cloudy, overcast, foggy, smoky) sky conditions and under sunlit tree canopies. This robust feature of the sky polarization plays an important role in the polarization-based orientation of many animals.



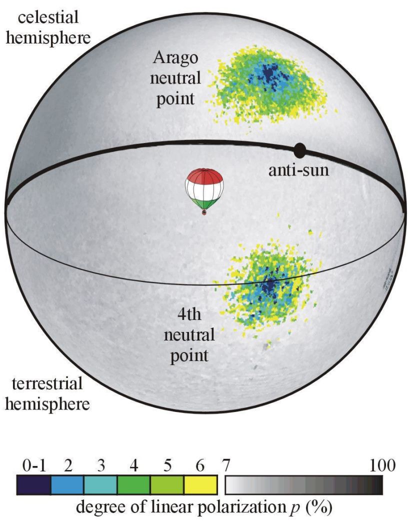


Figure 7: Members of the hot air balloon flight, who observed on 28 June 2001 as first the fourth neutral point of atmospheric polarization (left), and spatial distribution of the degree of linear polarization p at a height of $3500\,\mathrm{m}$ showing the Arago and the 4th neutral point (right).

Polarimetric Viking navigation: In sunshine the Vikings navigated on the open sea by sun-dials. According to a widespread hypothesis, when the sun was occluded by fog or clouds the Vikings might have navigated by the skylight polarization detected with an enigmatic birefringent crystal, the sunstone. There are two atmospheric optical prerequisites for this alleged polarimetric Viking navigation under foggy/cloudy skies: (1) the degree of linear polarization p of skylight should be high enough, and (2) at a given sun position the pattern of the angle of polarization α of the foggy/cloudy sky should be similar to that of the clear sky. Earlier these prerequisites have not been investigated. Using full-sky imaging polarimetry, we measured the p- and α-patterns of Arctic foggy and cloudy skies when the sun was invisible. These patterns were compared with the polarization patterns of clear Arctic skies. We showed that although prerequisite 2 is always fulfilled under both foggy and cloudy conditions if the fog layer is sunlit, prerequisite 1 is usually satisfied only for cloudy skies. In sunlit fog the Vikings could have navigated by polarization only, if p of light from the foggy sky was sufficiently high. One of the counter-arguments of polarimetric Viking navigation is the belief that solar positions can be estimated quite accurately by the naked eye, even if the sun is behind clouds or below the horizon, thus under cloudy/twilight conditions Vikings might have been no need for a sky-polarimetric method to determine the solar position. In psychophysical laboratory experiments we tested quantitatively the validity of this qualitative counter-argument. Our results did not support the common belief that the invisible sun can be located quite accurately from the celestial brightness and/or colour patterns under cloudy/twilight conditions. Thus the mentioned counter-argument of the theory of polarimetric Viking navigation cannot be taken seriously.

Polarization tabanid traps - TabaNOid technology: To know how tabanid flies locate their host animals, terrestrial rendezvous sites and egg-laying places would be very useful for control measures against them, because the haematophagous tabanid females are vectors of some severe animal / human diseases / parasites. In choice experiments we discovered that both males and females of several tabanid species have positive polarotaxis, *i.e.* they are attracted to horizontally polarized light stimulating their ventral eye region. The novelty of this is that polarotaxis has been described earlier only in connection with the water detection of aquatic insects ovipositing directly into water. A further particularity of our findings is that in the order Diptera and among blood-sucking insects the studied tabanids are the first known species possessing ventral polarization vision and definite polarization-sensitive behaviour with known functions. The polarotaxis in tabanids makes it possible to develop new optically luring traps being more efficient than the existing ones. The development of our patented protective system, called TabaNOid, against tabanids for eco-farms, graziers and race-horse breeders is in progress.

Polarized light pollution and polarization ecological traps: Ecological photopollution (EPP) has been defined as the degradation of the photic habitat by artificial light. We introduced a new term, the polarized light pollution (PLP), meaning all adverse effects on polarotactic aquatic insects attracted by horizontally polarized light reflected from artificial surfaces. PLP is a new kind of EPP, it is global and novel in an evolutionary sense. In numerous choice experiments with polarotactic insects and using imaging polarimetry we gave experimental evidence of PLP, such as (1) trapping of aquatic insects by dark oil surfaces; (2) dehydration of polarotactic insects attracted to black plastic sheets used in agriculture; (3) egg-laying of polarotactic mayflies onto dry asphalt roads; (4) attraction of aquatic insects to black, red or dark-coloured car paintwork; (5) deception of polarotactic dragonflies by shiny black gravestones; (6) attraction of mass-swarming polarotactic caddis flies to glass surfaces. All such highly and horizontally polarizing artificial surfaces can act as polarized ecological traps for polarotactic insects, because these surfaces are inappropriate for the development of eggs laid by the deceived insects. The mortality associated with PLP may threaten populations of endangered aquatic insect species. We pointed onto some possible benefits and/or disadvantages of predators (spiders, birds, bats) feeding on the polarotactic insects attracted to different sources of PLP. We also suggested several remedies of PLP, which is a byproduct of the human architectural, building, industrial and agricultural technology, and it may allow to function feeding webs composed of polarotactic insects and their predators. We emphasized that conservation planners should pay much more attention to aquatic insects because of their positive polarotaxis and their demonstrated vulnerability due to PLP.

Participants: József Gál, István Pomozi, Balázs Bernáth, András Barta, Ramón Hegedüs, Ildikó Szivák, Bence Suhai, Krisztián Buchta, Brigitta Sipőcz, Dezső Varjú, György Kriska, Gábor Szedenics, Ottó Haiman, Péter Malik and Gábor Horváth.

Biomechanics

Sports biomechanics: On the rotating Earth, in addition to the Newtonian gravitational force, two relevant inertial forces are induced: the centrifugal force and the Coriolis force. Using computer modelling for typical release heights and optimal release angles, we compared the influence of Earth rotation on the range of the male hammer throw and shot put with that of air resistance, wind, air pressure and temperature, altitude and ground obliquity. Practical correction maps were determined, by which the ranges achieved at different latitudes and/or with different release directions can be corrected by a term involving the effect of Earth rotation. We concluded and suggested that the normal variations of certain environemtal factors can be substantially larger than the smallest increases in the world records, and therefore these should be accounted for in a normalization and adjustment of the world records to some reference conditions. Our numerical calculations contributed to the comprehensive understanding and tabulation of these effects, which is largely lacking today.

Bone biomechanics: We studied experimentally how the ratio K of the internal to external diameter of long bones in foxes, birds and human mummies follows the biomechanical optima derived for marrow- and gas-filled tubular bones with minimum mass designed to withstand yield and fatigue, stiffness, bending fracture, or impact strengths. With evaluation of radiographs of numerous femora from red foxes (*Vulpes vulpes*) and mummies, furthermore of many humeri, femora and tibiotarsi from crows (*Corvus corone cornix*) and magpies (*Pica pica*) the values of K were measured. We found that fox femurs are optimized to withstand yield, fatigue or stiffness strengths. Human femora are optimised to withstand bending fracture, or yield and fatigue strengths; there are no sex-, age- and length-specific differences in K, and the means of K of the right and left femora of individuals are the same. The biomechanical optimization for K of human femora is not finely tuned. Compared with fox femora, K of human femora follows the biomechanical optimum to a much lesser extent. Although the relative wall thickness $W = 1 - K$ of human femora are optimised, the very low relative mass increment due to deviation of K from the optimum and the considerable intraspecific variance of K make it probable that an accurate optimization of W is irrelevant in humans. On the other hand, the marrow-filled tibiotarsi of *Corvus* and *Pica* are optimized for stiffness, while the marrow-filled femora are far from any optimum. The relative wall thickness of gas-filled avian humeri studied is much larger than the theoretical optimum, and thus these bones are thicker-walled than the optimal gas-filled tubular bone with minimum mass.

Participants: Balázs Bernáth, Sándor Évinger, Ferenc Mizera, Bence Suhai and Gábor Horváth.

Web page: http://arago.elte.hu

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Nanoscale Biological Physics Group
Group leader: Imre Derényi

Over the past decade molecular biology has made an extraordinary progress and become one of the most influential scientific disciplines. The new results, however, raise increasingly more questions that point beyond the realm of biology and require the tools of statistical physics and soft condensed matter to be answered. Our theoretical research along this border line between nanoscale biology and physics can be grouped into the following four topics.

Protein dynamics: The last decade has witnessed a remarkable development of physical investigation methods to probe single molecules or complexes by various micromanipulation means. One of these methods that we have focused on is the so called dynamic force spectroscopy, in which an increasing load is applied on an adhesion complex to probe its strength. In the simplest case, when the bound and unbound states of a molecular pair are separated by a single sharp energy barrier, the typical unbinding force is linearly proportional to the logarithm of the loading rate. We have determined how the response of the complex changes if unbinding can occur either along alternative pathways or multiple energy barriers [1].

Protein adsorption at liquid-solid interfaces is a fundamental problem of diverse areas of biotechnology. We have developed a reversible mesoscopic model of this process, which is based on the fact that adsorbed proteins can undergo transitions between several different conformational states that are characterized by different surface (or footprint) sizes and binding energies. This model qualitatively reproduces known experimental phenomena and offers a promising way of studying the exchange of the adsorbed proteins by the proteins of the solution [2].

Motor proteins: How motor proteins convert chemical energy into mechanical work is a longstanding question in biology. We are currently trying to understand the details of the stepping motion of conventional kinesin. The protein itself is a dimer and is believed to use its two identical motor domains (heads) alternatively to move along a microtubule, reminiscent of "walking". Although over the past decade much has been learned about the structure and kinetics of the individual kinesin heads, how two of such heads coordinate their motion during walking is still poorly understood. The most plausible explanation is that the heads communicate through a mechanical force mediated by the neck linkers that connect the two heads. By considering the neck linkers as entropic springs and incorporating the most relevant kinetic and structural properties of the individual heads, we have assembled a thermodynamically consistent model of the kinesin dimer, which can explain the cooperative motion of the heads during walking and reproduce much of the experimental results under various conditions (e.g. under different loads). We have also found very strict constraints for the way the neck linkers dock to the heads. Apart from understanding the operation of the motor, our model also allows us to look into the details of the motion, to see when and how unsuccessful steps occur, and to predict how certain changes in the protein can affect its motion [3].

Membrane dynamics: There is a growing pool of evidence showing the biological importance of membrane nanotubes (with diameter of a few tens of nanometers and length upto tens of microns) in various intra- and intercellular transport processes. These ubiquitous structures are often formed from flat membranes by highly localized forces generated by either the pulling of motor proteins or the pushing of polymerizing cytoskeletal filaments. Recently we have investigated (i) how two nanotubes coalesce [4], (ii) why the elongation and retraction of nanotubes is accompanied by a pronounced first order shape transition when the membrane is grabbed at a large area, and (iii) how the presence of curvature sensitive lipids or membrane proteins affects tube formation [5].

Evolutionary theories: Why sex is maintained in nature is a fundamental question in biology. Natural genetic transformation (NGT) is a sexual process by which bacteria actively take up exogenous DNA and use it to replace homologous chromosomal sequences. We have developed a novel simulation approach for the long-term dynamics of genome organization (involving the loss and acquisition of genes) in a bacterial species consisting of a large number of spatially distinct populations subject to independently fluctuating ecological conditions. Our results show that in the presence of weak interpopulation migration NGT is able to subsist as a mechanism to reload locally lost, intermittently selected genes from the collective gene pool of the species through DNA uptake from migrants. Reloading genes and combining them with those in locally adapted genomes allow individual cells to readapt faster to environmental changes. The machinery of transformation survives under a wide range of model parameters readily encompassing real-world biological conditions [6].

We are also investigating (i) the effects of the above metapopulation structure on evolutionary games, and (ii) various aspects of the neutral evolution of genetic robustness [7].

Participants: Gergely Szöllősi, András Czövek and Imre Derényi.

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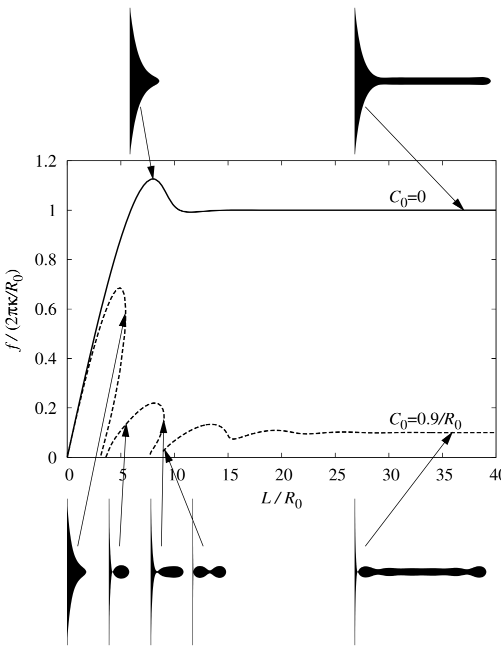

Figure 8: Force vs. length curves for the formation of a membrane nanotube pulled out of a flat membrane for two different values of the spontaneous curvature (induced by curvature sensitive lipids or proteins). The shape of the emerging tube is also depicted at certain stages.

Carbon Nanostructures Group
Group leader: Jenő Kürti

Carbon nanostructures (nanotubes, linear chains and cage like fullerene molecules) are in the forefront of material science. Beside the intellectual challenge, the many possible and already existing physical, chemical and biological applications attract great interest for these materials. Our group carried out many theoretical investigations in the field of carbon nanostructures, mostly single walled carbon nanotubes – always in close collaboration with experimental groups. The main results can be grouped in the following topics:

Radial breathing mode in the Raman spectra of carbon nanotubes: Single-walled carbon nanotubes (SWCNTs) are cylinders made of carbon atoms, having a diameter in the nanometer range, whereas their length can even be much larger than $1\,\mu\mathrm{m}$. An infinitely long SWCNT can be imagined as a rolled up piece of a hexagonal graphene sheet (two-dimensional graphite plane). Each SWCNT is uniquely given by two integer numbers, the (n, m) chiral indices, which characterize the direction of wrapping up a regular hexagonal lattice.

Any preparation method so far results in a mixture of tubes with many different (n, m) indices. The experimental identification of the different tubes is based primarily on the measured frequencies of the Raman active radial breathing mode (RBM) of the individual tubes. The RBM is a totally symmetric radial motion of the carbon atoms, the most characteristic vibrational mode of carbon nanotubes, and the only one which cannot be traced back to the vibrational modes of the graphene sheet. Therefore, it is crucial to compare the measured frequencies with the calculated ones. We were the first who carried out the calculation of the RBM frequencies on the density functional theory (DFT) level for SWCNTs [1]. We showed that for large enough diameters the RBM frequency is inversely proportional to the diameter, but for diameters less than $1\,\mathrm{nm}$, there is a softening of the RBM frequency, where the softening is chirality dependent. We have also shown that there is a mixing of the RBM and the tangential totally symmetric vibrational modes.

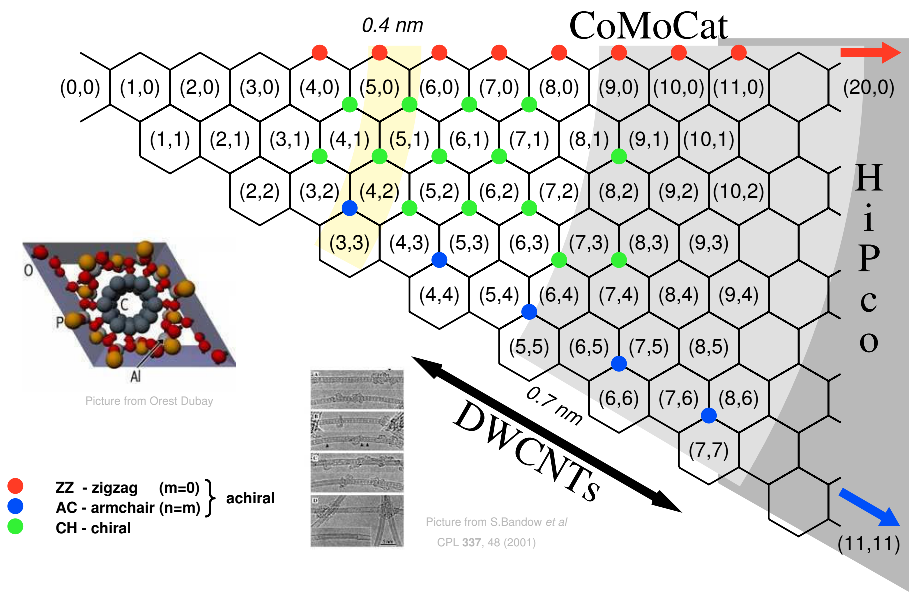

Figure 9: Chirality map for small diameter SWCNTs. The tubes studied by the DFT method are marked by red, blue and green circles for the zigzag, armchair and chiral tubes, respectively.

By calculating the isotope broadening effect on the RBM for ^{13}C enriched inner tubes in double walled carbon nanotubes we were able to draw important conclusions about the growth mechanism of the inner tubes [2].

Disorder induced band in the Raman spectra of carbon nanotubes: Usually the Raman active modes are Γ-point modes, for which the phonon wave number is zero. There is one important exception in graphitic materials: the so called disorder induced band (D band). The D band can be observed not only in disordered graphite (graphene) but also in SWCNTs. We have compared these two cases by calculating the necessary integrations within the double resonant perturbation approximation. After a debate in the literature, we have shown that the effect of Van Hove singularities in the one dimensional electronic band structure of the SWCNTs plays an important role in the interpretation of the experimental observations. We called this 'triple resonant effect' [3].

Change of the geometry with electric charge – 'artificial muscle': We investigated by DFT method the effect of charging on the geometry, in particular the length of SWCNTs. We have shown that the length of the unit cell changes asymmetrically as a function of the electric charge: negative charge results in elongation but positive charge results in shrinking [4]. The change is more or less linear up to 0.05 electrons per carbon atom. Because the theoretical predictions for the performance was much better than that of the human muscle, these theoretical results gave an important motivation for the experimental colleagues in the USA for doing their actuator project.

Charge transfer effects: We investigated by DFT method several different composite systems of carbon nanostructures: linear carbon chain inside a SWCNT [5], DWCNTs [6], and fullerene-cubane systems [7]. They have one thing in common: there is always an interaction between the subsystems which leads to a small charge transfer. This effect should be taken into account during doping experiments on these systems.

Curvature effects: In many cases the properties of a SWCNT can be described simply by using the 'zone folding approximation'. In a general sense it means, that the properties of the graphene sheet (geometry, electronic band structure, phonon dispersion) can be used for the tube with the restriction that the perpendicular wave number is quantized. This approximation loses its validity if the diameter of the tube is less than 1 nm. We carried out DFT calculations to take the curvature effects explicitly into account [8]. The geometrical parameters deviate from the values obtained from simple wrapping of a perfect hexagonal sheet. The deviation from the ideal behaviour increases with increasing curvature. The most prominent change is the increase of the diameter with respect to its ideal value. The lattice constant along the tube axis exhibits a slight shrinking. The electronic band structure changes significantly. There are two different reasons for this: the $\sigma - \pi$ mixing, and the opening of a secondary gap [9]. The treatment of the phonons deserves special attention. For the first time in the literature we were able to calculate the phonon dispersion of many chiral SWCNTs by making use of the helical symmetry of the tubes. This allowed us to explain the experimentally observed softening of the D band and its overtone, the D* band [10].

Participants: János Koltai, Ádám Rusznyák, Viktor Zólyomi and Jenő Kürti. Web page: http://virag.elte.hu/kurti

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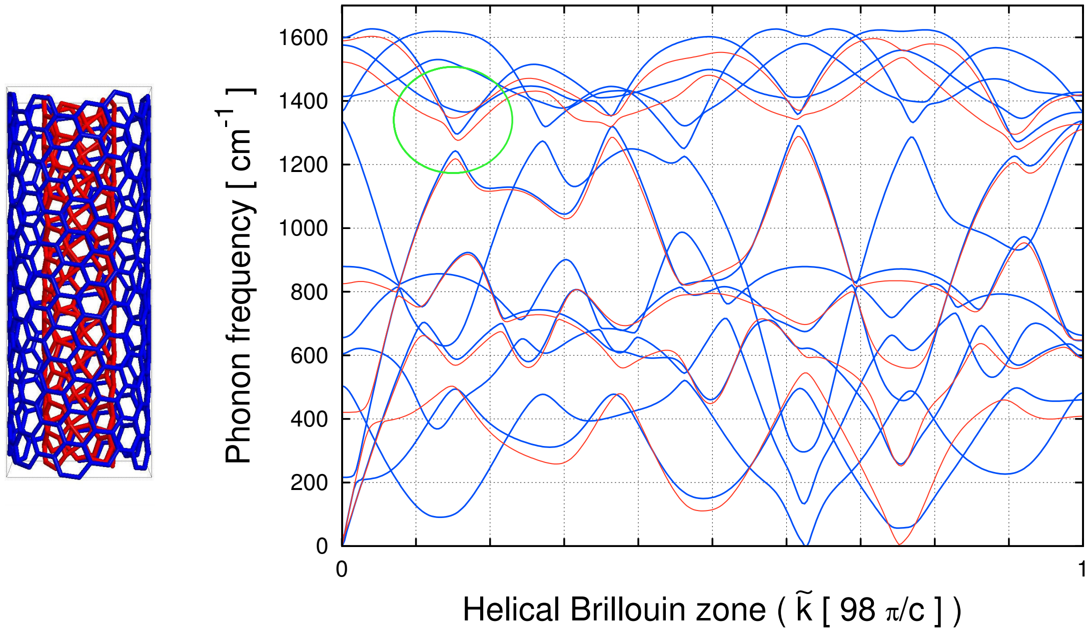

Figure 10: Schematic depiction of a double walled carbon nanotube (left), the phonon dispersion of the (5,3) and (10,6) chiral nanotubes (right). The comparision clearly shows a twofold softening of the D* band.

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Theoretical Ecology and Evolution Group
Group leader: Géza Meszéna

The science of ecology and evolution is experiencing a gradual transition from diverging, and often conflicting, pictures to a unified mathematical theory. The group is seeking to play a role in this process.

Our central issue is the question of biological diversity. How can we reconcile the theory of natural selection with the existence of millions of species on Earth? Why species coexist rather than outcompete each other? Starting from a given point in the evolutionary space, how does evolution reach a multitude of fitness peaks, instead of getting stuck at the top of the nearest peak, as if it were just an uphill process?

Darwin understood clearly that these issues were deeply inherent in his theory. Also, he had the intuitive answer: Similar kinds of organisms are in competition, while increasing difference between variants allows their coexistence via reduced competition. In ecology, this simple idea was developed into the theory of niche.

Unfortunately, further empirical and theoretical developments lost the forest between the trees. Most of the (many) evolutionary theories considred the process as just an uphill one, as it was complicated enough this way. The diversifying viewpoints in ecology lead to scepticism towards the possibility of general theories and, in particular, towards the usefulness of the concept of niche. However, as physicists know, the arrow of time points towards unification of science.

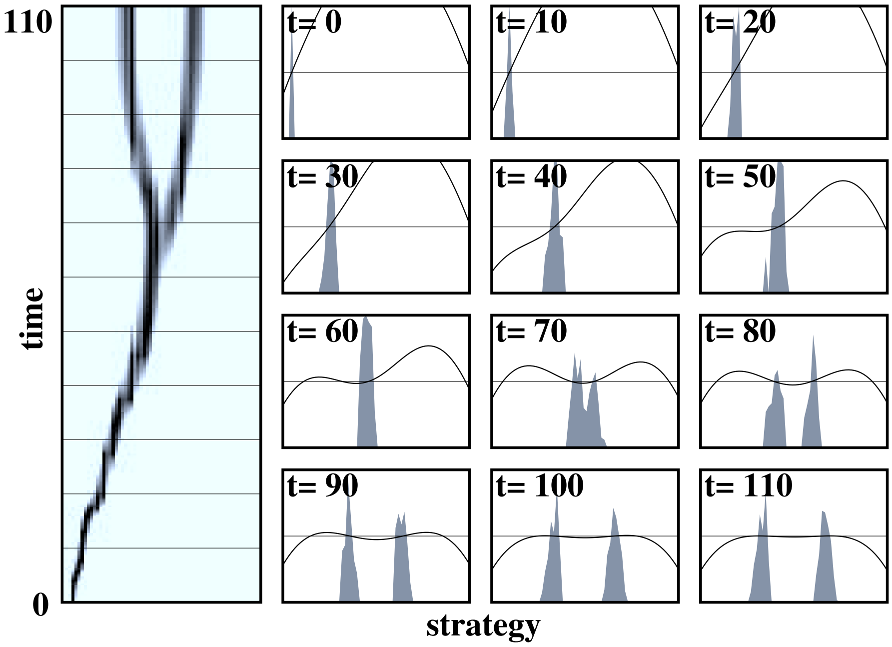

Figure 11: Evolutionary branching in competitive Lotka-Volterra model

Adaptive dynamics: Our main international background is the adaptive dynamics "movement". Adaptive dynamics is a mathematical framework to consider the evolutionary consequences of arbitrary ecological situations. Ten years ago we contributed to the basic papers of the theory [1]. They were about the fixed point analysis of the dynamics of evolution when it feeds back to the fitness landscape. More recently a "first principles" derivation from popultion dynamics was provided [2].

The most important conclusion of adaptive dynamics is that the population-environment interaction may force evolution to converge to a fitness minimum. The reason is that being different from the rest of the population may become advantageous enough via of the population's environmental impact. The disruptive selection emerging at this "branching" point attempts to split the population (Fig. 11). We investigated the phenomenon in several models with emphasis on the effect of spatial heterogeneity [3, 4]. Evolution in multidimensional trait space was studied also.

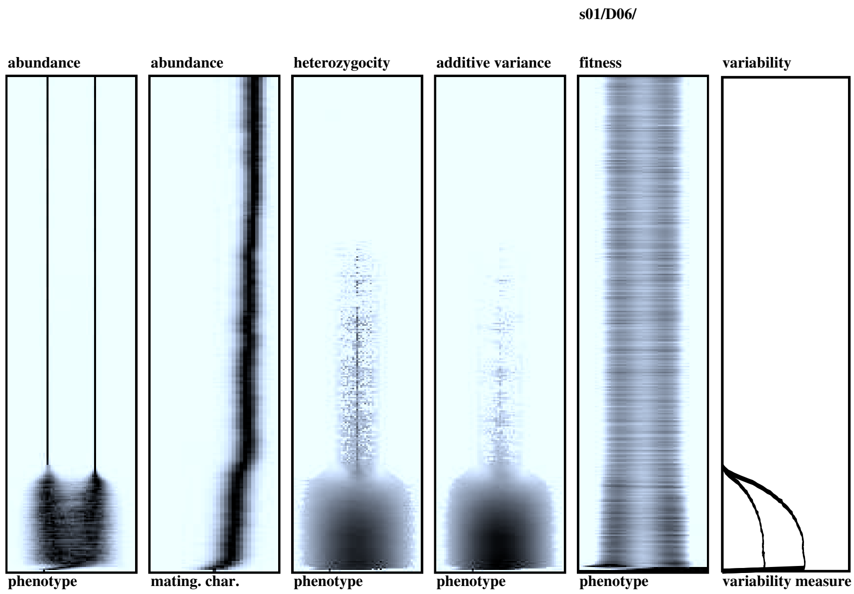

Figure 12: Simulation of adaptive speciation in a Lotka-Volterra ecology. Note the gradual emergence of reproductive isolation between the emerging species.

Adaptive speciation: The classical theory of speciation assumes that emergence of a new species is initiated by an externally imposed barrier to migration between two subpopulations. If divergent evolution at the different locations leads to reproductive isolation as a by-product, then secondary contact between the two populations will not destroy the acquired difference. This way of thinking avoids the consideration of the niche aspect. One wonders why not competitive exclusion is the typical outcome of secondary contact between the already isolated species? Moreover, while the presence of spatial segregation is beyond doubt in many speciation processes, the possibility of speciation without a barrier is also considered to be empirically established by now. We are observing an empirically-driven paradigm shift in understanding speciation from the purely genetic approaches towards considering the ecological background of diversity as in integral (maybe, dominant) aspect of the process.

On the basis of adaptive dynamics theory, we are working on the ecology-based theory of speciation. Population genetics of the possibly emerging reproductive isolation between the daugther populations was modelled recently [5]. We are studying a multitude of models to understand the common and different elements of adaptive speciation under different circumstances. The gradual buildup of reproductive isolation (Fig. 12) is of special interest because it may interpret the (often observed) cases of partial isolation.

Niche theory: The most important direction of the group's work is to develop a general ecological theory of species coexistence, as a basis of evolutonary emergence of biological diversity. We proved in a model-independent way that robustness of coexistence depends on the sufficient difference in the mode of population regulation (Fig. 13) [6]. Relatedly, coexistence of infinitely many species is structurally unstable [7, 8]. This work provides a solid mathematical basis for the concept of niche.

Spatiotemporal heterogeneity of the environment is considered as a central fact of ecology. We have been analysing the role of spatiality and heterogeneity in several kinds of metapopulation and lattice models [9]. We demonstrated applicability of both adaptive dynamics and the coexistence theory on the large-scale description of the processes that can be very complex on the local scale [4].

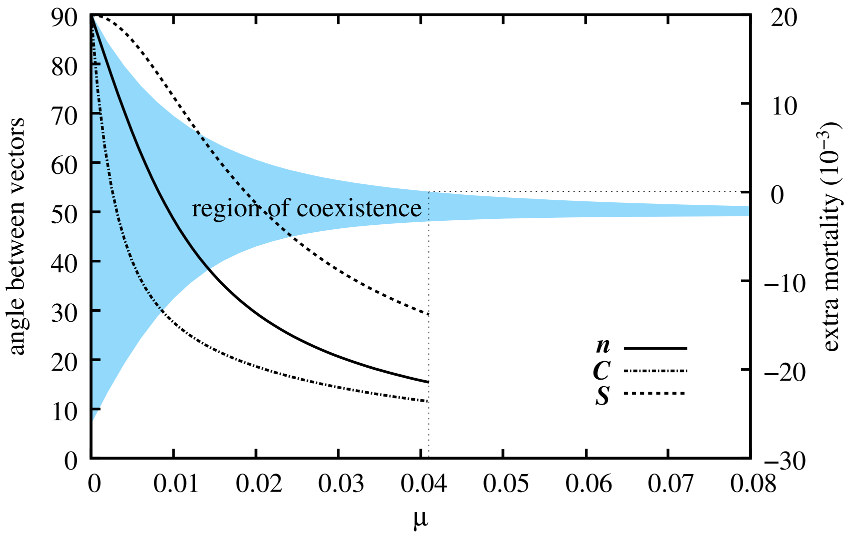

Figure 13: Robustness of coexistence of two species in a two-patch environment. The colored region is the range of the extra mortality that the system can tolarate. It diminises with increasing migration rate, because migration decreases the niche-segregation, as shown by the lines.

Activity: In the framework of our international collaboration a series of adaptive dynamics workshops were organized in Hungary. We participate in a new ESF research network on empirical and theoretical studies of speciation. Four master thesis and two PhDs has been defended in the group; two more PhDs are coming.

Participants: János Asbóth, István Czibula, György Barabás, Diána Lantos, Krisztián Mágori, Ferenc Mizera, Péter Szabó, András Szilágyi, Dávid Völgyes, András Vukics, Jeromos Vukov, Zoltán Zimborás and Géza Meszéna.

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Tissue Mechanics Laboratory
Group leader: András Czirók

In the current era of biology, a major question we still face is how does form and function arise at each organizational level (*i.e.*, molecular, cellular, tissue, organ, system). For example, how is a protein folded into its native structure and how does the protein work as a nano-machine? How are the various molecular components of a cell integrated to perform highly specific functions? And most mysteriously ... how are cells and extracellular matrix (ECM) assembled into functional tissues and organs? During these assembly processes information on individual cell position is not directly specified, and genetic information does not encode cell behavior or organ anatomy as a blueprint. Rather, in many cases we are compelled to study emergent phenomena, where the system-level behavior is a ”byproduct” of the interaction among the components.

Living organisms, from bacteria to vertebrates, are well known to generate sophisticated multicellular patterns. It is widely assumed that adhesion-based activities such as exertion of traction and compressional forces, shape-change and motility are the physical means by which tissues and organs are formed. However, our knowledge is limited about how collective cell behavior creates a specific physical tissue or organ. With the advent of tissue engineering, the problem of how cells assemble and maintain a certain functional structure is now in the front line of research. Understanding emergent phenomena in cell and developmental biology requires an interdisciplinary approach: One has to deal with physical objects and the laws that govern their behavior, which requires the use of statistical methods and computationally intensive measurement techniques to follow and analyze a large number of disparate components. Our research is focused on the following problems:

Vasculogenesis, the de novo assembly of vessels from endothelial precursors, is a fundamental process common to both embryonic development and certain pathophysiologies. Recent advances in imaging technology [1] allowed the *in vivo* visualization of endothelial cell dynamics during vasculogenesis in avian embryos. We showed that the formation of vascular cords from isolated clusters of angioblasts involves extensive invasive activity [2]. During this process, vasculogenic sprouting, a group of endothelial cells invades hundreds of micrometers into avascular areas, and thereby lays down the structure of the primordial vascular plexus. In a synergestic effort with researchers at the University of Kansas Medical Center, we aim to determine the specific roles of cell-cell connections [3] of growth factor signaling and extracellular matrix components, primarily fibronectin, in the patterning mechanism.

Collective Cell Motility: Based on new theoretical understanding on the collective behavior of motile, autonomous agents [4], we study collective cell motility. We investigate micromechanical aspects of cell-cell and cell-ECM connections, and how they interact with cytoskeletal changes underlying cell motility. We study the multicellular coordination during ECM organization [5] and also estimate the material properties, intrinsic stresses and stress relaxation parameters of the emerging structures, *in vitro*, *in vivo*, and in electrospun biodegradable artificial tissue scaffolds. A successful research project would contribute to the understanding of one of the oldest problems of science, namely, how multicellular tissues form. It would also lay the foundations for advanced tissue engineering designing and building artificial tissues which are not only bio-compatible, but are actively maintained by a cell population.

Participants: Előd Méhes, András Szabó, Edina Kósa, József Harangozó, Gergely Nagy, Bálint Szabó and András Czirók.

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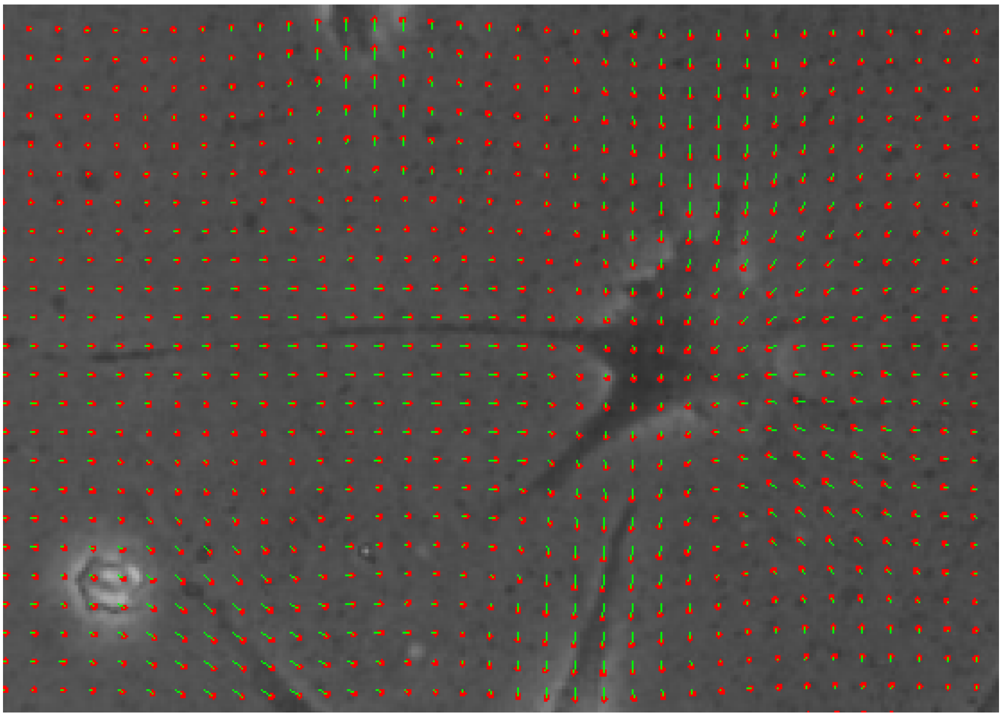

Figure 14: Cell traction forces generate substantial mechanical deformations in the attachment substrate.

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Time-lapse Imaging Laboratory
Group leader: Bálint Szabó

Our live cell imaging stations consists automated microscopes, capable for parallel monitoring of a number of specimens for an extended period of time. These long-term observations form the basis of obtaining cell motion and cell division statistics from a large number of cells, or to trace developmental processes such as neuronal differentiation. We keep improving the culturing techniques and also devote efforts to develop new ways of statistical data extraction from time-lapse image sequences.

Research: We are investigating cellular behavior in tissue cultures in cooperation with András Czirók's lab and Zsuzsanna Környei (Institute of Experimental Medicine of the H.A.S.) Lately, we studied nuclear migration (Fig. 15), collective cell motility (Fig. 16) and *in vitro* neurogenesis.

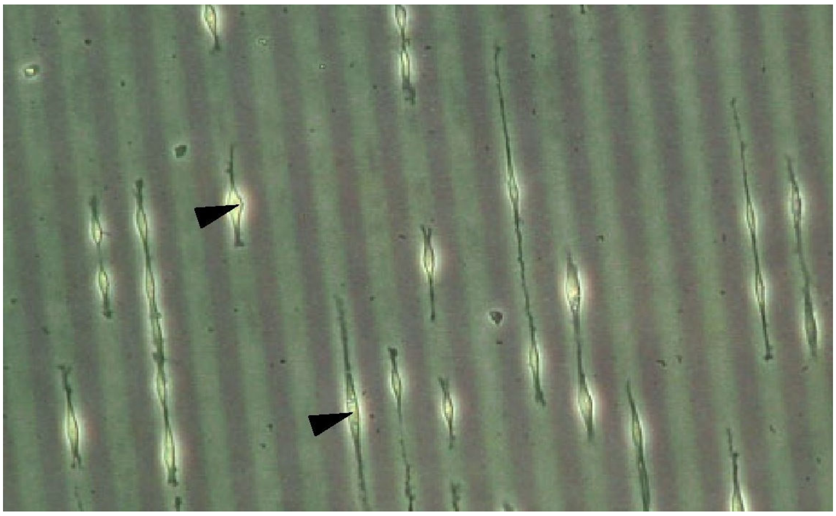

Figure 15: C6 cells on micropatterned surfaces. A phase contrast image is superimposed upon a background showing epifluorescence from 20-μm-wide FITC-poly-l-lysine stripes (green). Due to the constrained cell attachments, cells assume elongated, bipolar morphology. The positions of cell nuclei (arrowheads) are clearly recognizable [3].

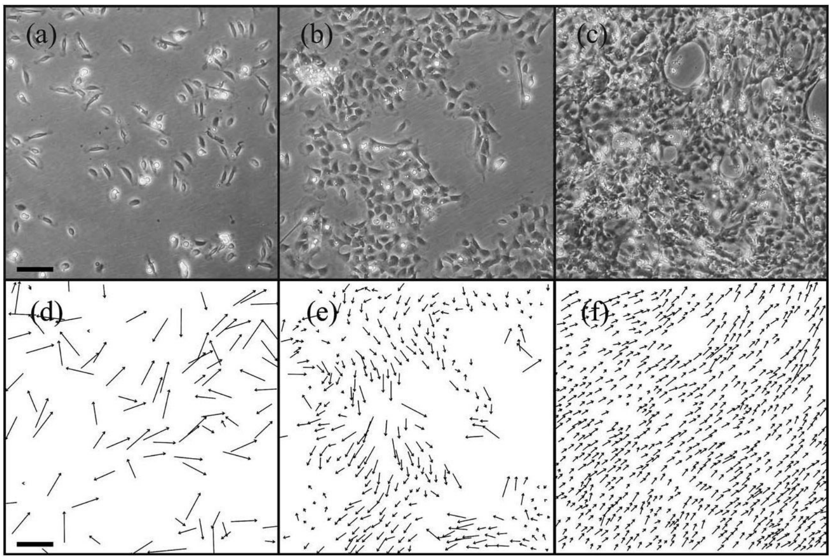

Figure 16: Phase contrast images showing the typical behavior of cells for three different densities. (a) 1.8, (b) 5.3, (c) 14.7 $\text{cells}/100 \times 100\,\mu\text{m}^2$. We observed that as cell density increases cell motility undergoes collective ordering. The speed of single cells is higher than that of cells moving in coherent groups. Scale bar $200\,\mu\text{m}$. (d)–(f) Velocity of cells. Scale bar $50\,\mu\text{m/min}$.

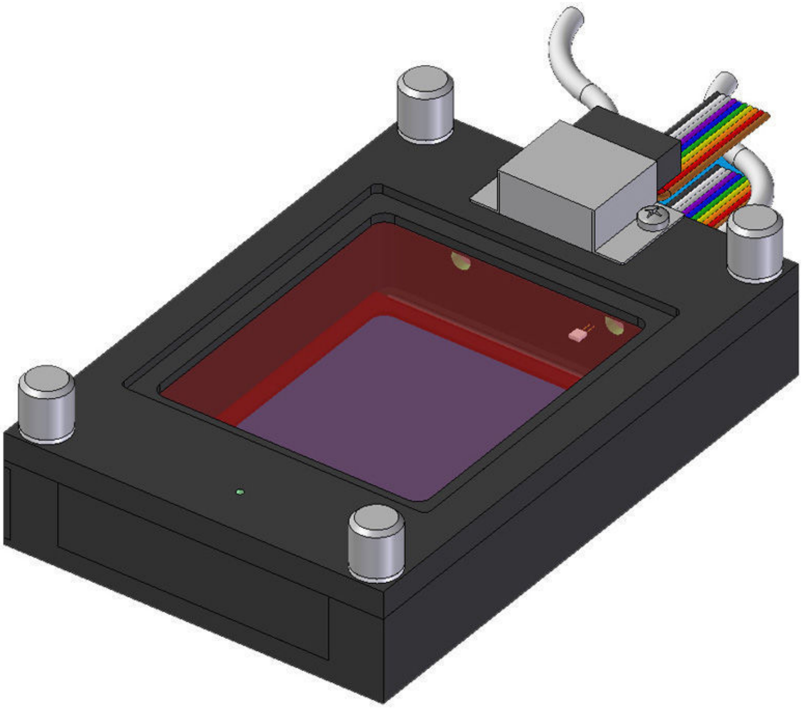

Figure 17: CellMovie wide-screen microscope stage incubator.

Development: We have been developing devices and control software for fluorescent time-lapse microscopy of *in vitro* cell cultures in the last decade. People involved in these projects:

We also launched a spin-off company called CellMovie that develops and sells microscope stage incubators. Our Linux videomicroscope control software (VMC) was written by Dávid Selmeczi. Now it is being further developed and implemented in Windows XP environment. Our new integrated software can control a 2 or 3D motorized microscope stage, micromanipulator, fluorescent shutter and synchronized camera, microscope stage incubator, syringe pump for injecting drugs or changing culture medium, and a CO_2 valve.

We develop a selective plane illumination microscope (SPIM) for the 3D time-lapse imaging of mouse brain slices. Our new project will be the development of the ”Scanning cell sorter micropipette”.

Participants: András Czirók, Miklós Csiszér, Dávid Selmeczi, Tamás Vicsek and Bálint Szabó.

Web page: http://www.cellmovie.eu

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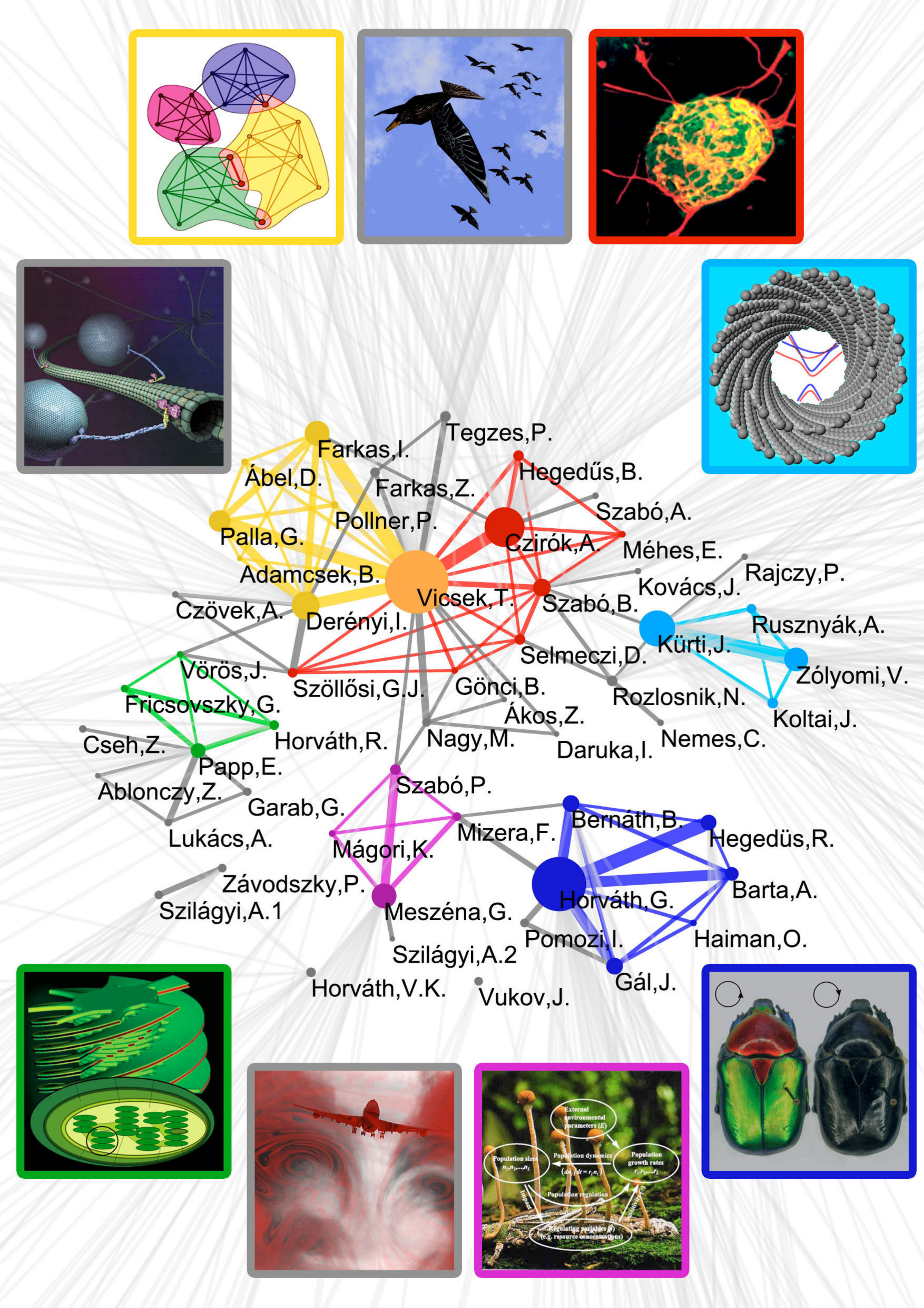

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Farkas,I.
Ábel,D.
Hegedűs,B.
Farkas,Z.
Szabó,A.
Pollner,P.
Palla,G.
Czirók,A.
Méhes,E.
Adamcsek,B.
Rajczy,P.
Kovács,J.
Vicsek,T.
Szabó,B.
Czövek,A.
Derényi,I.
Rusznyák,A.
Kürti,J.
Selmeczi,D.
Zólyomi,V.
Vörös,J.
Szöllősi,G.J.
Gönci,B.
Rozlosnik,N.
Fricsovszky,G.
Ákos,Z.
Koltai,J.
Horváth,R.
Nagy,M.
Nemes,C.
Cseh,Z.
Daruka,I.
Papp,E.
Szabó,P.
Ablonczy,Z.
Garab,G.
Bernáth,B.
Hegedüs,R.
Lukács,A.
Mizera,F.
Mágori,K.
Závodszky,P.
Barta,A.
Horváth,G.
Szilágyi,A.1
Meszéna,G.
Pomozi,I.
Haiman,O.
Szilágyi,A.2
Gál,J.
Horváth,V.K.
Vukov,J.
External environmental parameters (E)
Population sizes
Population dynamics
Population growth rates
Population regulation
Regulating variables (I)
(e.g. resource concentrations)