Curriculum Vitae: Nicola Bellomo - June 2024

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*This report is dedicated to **Abdelghani Belloquid** who passed in 2016. He had enough time to show his outstanding ability to deal with functional inequalities towards the qualitative analysis of nonlinear differential systems as well as with the sixth Hilbert problem. But not sufficient time to fully enjoy his own life.*

1 Who I am

I was born in Amalfi (actually in the fraction Atrani) in the house to the left of the church, on September 8, 1943. That same day the Italian government signed the armistice to end the war, but the partisan resistance continued for several months, as it did in France, where I now live.

In the same days, my grandfather, General Nicola Bellomo, organized in the city of Bari, together with the citizens and some soldiers an action of resistance action against the German troops in order to liberate Bari from the invading (occupying) army. This action developed in the old city center, closed to the port was successful, as the German occupying army was forced to leave the town and, in particular, the port of Bari. The general is buried in the "Sacrario Militare dei Caduti d'Oltremare di Bari".

The story is reported in various books from

Ruggero Zangrandi, *Il Lungo Viaggio Attraverso il Fascismo*, Feltrinelli, (1963).
to
Fiorella Bianco, *Il Caso Bellomo*, Mursia, Editore, (1995).

Figure 1: Fiorella Bianco, **Il Caso Bellomo**, Mursia, (1995) and Sacrario Caduti di Oltemare di Bari, where General Nicola Bellomo, silver medal for his defense of the port of Bari, is buried, after a funeral with honors of his rank.

My academic career began in 1980 when I was appointed to the Chair of Mathematical Physics and Applied Mathematics, at the Politecnico di Torino, Italy.

At present, I am Professor Emeritus at the **Polytechnic University of Torino**.

My recent research activity is mainly developed at the **University of Granada**, where I act as **Distinguished Professor** in the project "Modelling in Nature", https://www.modelingnature.org/.

2 A Journal of Applied Mathematics

The main editorial initiative of NB is the journal *M3AS* which he directs together with **Franco Brezzi**, thanks also to the precious editorial management of **Fiorella Bianco**. M3AS is one of the leading journals open to new research frontiers in mathematics. The journal deals with applications of mathematics, but also on the basis of advanced mathematical tools, both analytical and computational.

M3AS: Mathematical Models and Methods in the Applied Sciences

Some of the articles published in this journal show that in some cases the treatment of complex systems requires the invention of new mathematical methods. In a few cases, a new mathematical theory.

Figure 2: Editors-in-Chief of M3AS

3 Awards

- Award appointed by the **President of the Italian Republic** by the third level "honorifics" for scientific merits.
- **Highly Cited Scientists in the field of mathematics** by *Clarivate Web of Science*, for all years from 2013 to 2022. This ranking reported in a List of 52, worldwide Highly Cited Mathematicians, Clarivate decided not to publish the list of 2023 HiCi Mathematicians.
- **Highly Cited papers:** in this 2023 NB has 16 HiCi papers, while 20 papers have been HiCi the period 2012-2022.
- **Hirsch Index: WEB of Science: HI=42, SCOPUS: HI=45**.
- **International Boards:** *President of the Italian Society of Applied and Industrial Mathematics*, *President Of the Society: Gruppo 2003 per la Ricerca Scientifica* (July 2017 to2020), *Board of Trusties of the European Mathematical Society.*
- Two events organized by *Gruppo 2003 per la Ricerca Scientifica*, with NB President, have received, each of them, the **Medal of the President of the Italian Republic**. The events were held in Roma, in May 2021 at the CNR "Research in Europe", and May 2022, in the "Accademia dei Lincei" on "Scientific Research and Safety Problems in the Society".

Figure 3: Gruppo 2003, CNR-Roma, with the Medal of the President of the Italian Republic

4 Direction of EU Research Networks

A "selection" of EU projects where NB had a role of EU or WP Coordinator:

• TEMPUS: ERB CIPACT 92/2245 (1992); TEMPUS: ERB CIPACT 93/2373 (1993); TMR: ERB4001GT 96/5276 (1996); Human Potential and Mobility: HPRN - CT - 2000 - 00105; (**European Coordinator**).

• **Project A:** FP6 - 2000-2004 - Research Training Network - Using mathematical modelling and computer simulation to improve cancer therapy (**EU Coordinator**).

• **Project B:** FP6 - 2004-2008 - Marie Curie Research Training Network - 5, No 500923 - Modeling, mathematical methods and computer simulation of tumor growth and therapy (**EU Coordinator**).

• **Project C:** FP7, No 202047. - 2008-2012 - RESOLVE, Chronic Inflammation and achieve healthy ageing by understanding non-regenerative repair (**WP Coordinator**).

• **Project F:** ERASMUS MUNDUS ACTION 2 (EMA2). Eurotango Project: D. Knopoff's and J. Agnelli's mobility from Cordoba University (Argentina) to Politecnico di Torino. (**EU Coordinator**).

• **Project D:** FP7 (Safety Call) (2013-2017) - eVACUATE - An end-to-end situational awareness, guidance and evacuation system for large crowds (**WP Coordinator**).

• **Project E:** FP7 (Safety Call) (2015-2017) - SAFECITI - Simulation Platform for the Analysis of Crowds Behaviour in Urban Environments with Training and Predictive Capabilities, (**WP Coordinator**).

Figure 4: The "Tumor" project was designed and planned in Oberwolfach, Germany - from the right: Miroslaw Lachowics, Mark Chaplain, Walter Schubert, Andreas Deutsch, Zvia Agur, John Adam, Philip Maini, Luigi Preziosi, NB, Urzula Foris, Helen Byrne, and Sabine Stocker.

Dealing with projects of the European Council promotes interdisciplinary collaborations that, on one hand, enriches and opens the culture of mathematicians and, on the other hand, opens a dialog that contributes to scientific developments. This type of studies was considered in Covid time to understand more about the fragility of the lung.

This is the case of a study on the propagation of stress to fracture in the lung due to tissue degeneration. The collaboration involved A. Carloni, Dep. of Radiology, Ospedale Santa Maria, Terni; V. Poletti, Dep. of Diseases of the Thorax, Ospedale Morgagni, Forli'; M. Chilosi, Dep. of Pathology and Diagnostics, University of Verona, Italy; and two mathematicians NB and Luisa Fermo, University of Cagliari.

• **A.Carloni, V.Poletti, L.Fermo, N.Bellomo, M.Chilosi**, Heterogeneous distribution of mechanical stress in human lung: A mathematical approach to evaluate abnormal remodeling in IPF, *J. Theoretical Biology*, **332**, 136–140, (2013).

Figure 5: NB and Marco Chilosi

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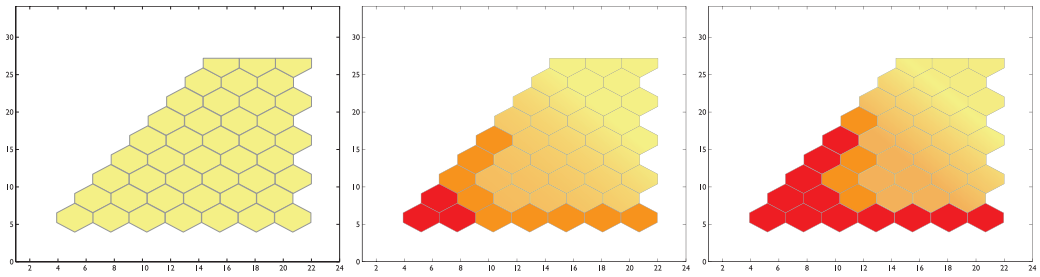

Figure 6: Dynamics of stress propagation in a lung

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5 Selection of Distinguished Lectures

NB has delivered several keynote lectures. Seven lectures selected out of about thirty:

- "Shanks Lectur" at Vanderbilt University, May 2009.
- "Luis Santaló" 2013, Santander, SPAIN: Mathematics of Planet Earth Scientific Challenges in a Sustainable Planet.
- Keynote Opening Lecture at Meijei University (Conference of Crowd Dynamics) Tokio, Japan (2014).
- Special Lecture at Oberwolfach Workshop "Mathematical Models for Cancer Cell Migrations", (2014).
- Keynote Opening Lectures on Crowd Dynamics Academy of Sciences and Technology Rabat, Morocco. (2015).
- Newton Institute, Cambridge *Understanding the Generation Time for COVID–19*, Newton Gateway to Mathematics, (2021).
- New York University Abu Dhabi "Research Center on Stability, Instability, and Turbulence", May 11, (2023).

Figure 7: Special Lecture in Oberwolfach, NB with Andreas Deutsch, Christina Surulescu, Thomas Hillen, and Michael Winkler

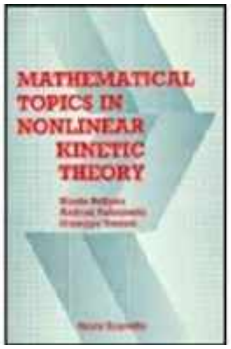
This meeting was followed by a fruitful scientific collaboration and friendship with Michael Winkler, NB, Abdelghani Bellouquid and the team of the University of Grana were already working on nonlinear diffusion problems. Then, we joined, towards deeper analytical problems, with Michael and Youshan Tao as reviewed in Section 12.

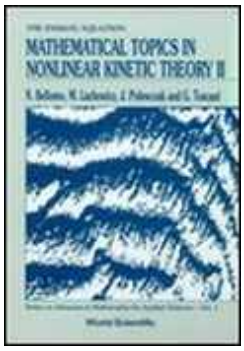
6 Studies in Mathematical Physics

Most of the activity was focused on the *Boltzmann and Enskog equations*. For both classical models, the activity was mainly devoted to the qualitative analysis of initial and initial-boundary value problems. The main results, which include one of the few global existence theorems for the two equations, are reported in:

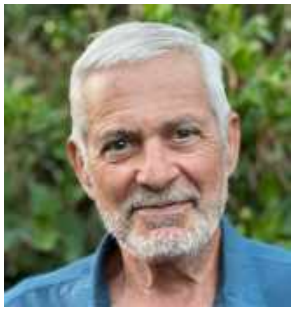
• **N. Bellomo, A. Palczewski, and G. Toscani**, *Mathematical Topics in Nonlinear Kinetic Theory*, World Scientific, (1988).

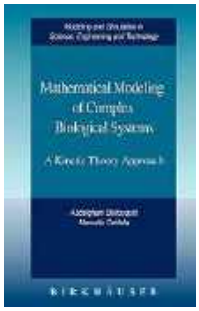
• **N. Bellomo, M. Lachowicz, J. Polewczak and G. Toscani**, *Mathematical Topics in Nonlinear Kinetic Theory II: The Enskog Equation*, World Scientific, (1991).





Classical kinetic theory, albeit in a different conceptual framework, contributes to the study of immune competition, which has been the key study as a first step towards a mathematical theory of living systems. This was made possible by combining the theory of immune competition, as known from biology, with mathematical tools inspired by statistical physics. The bridge was built by immunologist Guido Forni. He is pictured in the middle of the two books below.





7 Towards Applied Mathematics

NB's attention moved from mathematical physics to applied mathematics after the publication of this book:

• **N. Bellomo and L. Preziosi**, *Modelling Mathematical Methods and Scientific Computation*, CRC Press, (1994).

This book shows how modeling, qualitative analysis, and computational analysis should march together. This philosophical concept guides all the research activities presented in the following sections. This vision also guides the following book, where the study of classical mechanics is also developed with the aid of simulations.

• **N. Bellomo, L. Preziosi, and A. Romano**, *Mechanics and Dynamical Systems With Mathematica*, *Modeling and Simulation in Science, Engineering and Technology*, Birkhauser-Springer, (1999).

This book promotes the idea that university courses in mathematics should not be limited to a single discipline, but they should combine in a unified presentation the interaction of several tools that mathematics can offer. *The master of the scientific software "Mathematica" is NB's colleague and friend Antonio Romano.*

A step towards applied mathematics is the IUTAM Conference held in Torino 1991.

8 Towards a science of living systems

NB initiated the study of living systems when he understood that several behavioral (living) systems could be described by appropriate developments of the classical kinetic theory. This method is now known as the *Kinetic Theory of Active Particles*. The mathematical approach combines ideas from the kinetic theory with those of stochastic game theory. This mathematical theory consists in a new mathematical-physical science, i.e. the *Science of Living Systems* and chases the objective of developing a strategy to tackle the difficulty that the support of field theories is not available for living matter.

> *The strategy consists in replacing the field theory by a mathematical structure (e.g., a mathematical theory) that is able to capture as much as possible the complexity features of living systems. This structure defines the conceptual framework for the derivation of models in different fields of soft sciences.*

Five complexity features have been selected:

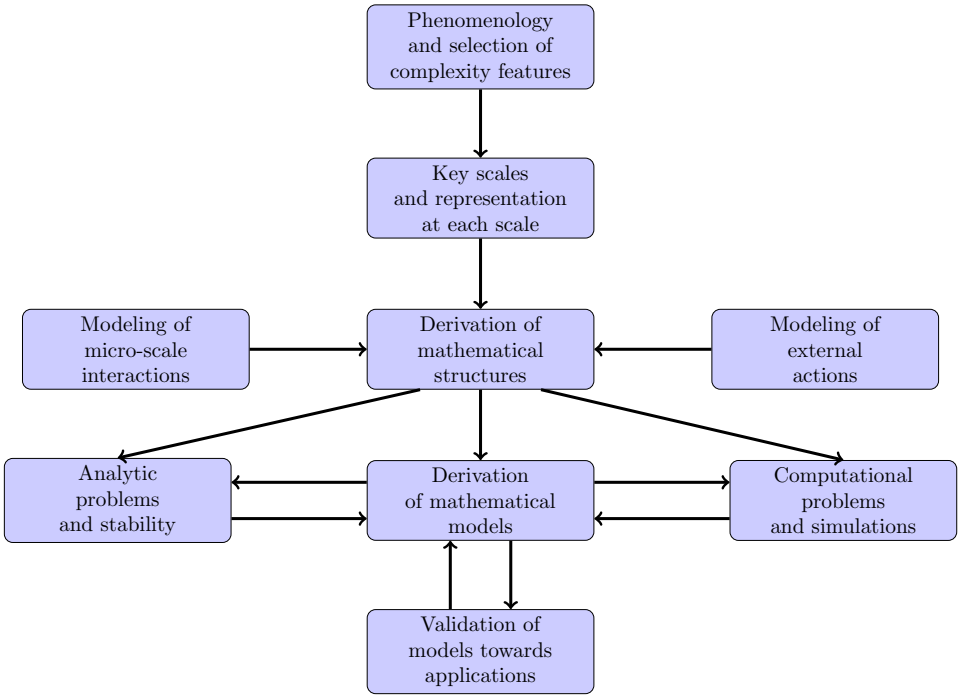
1. **Ability to express a strategy:** Living entities are capable of developing specific *strategies* and *organizational abilities* that depend on the overall state of the surrounding environment.
2. **Heterogeneity:** The ability to express a strategy is not the same for all entities. Indeed, the *expression of heterogeneous behaviors* is a common feature of a great part of living systems.
3. **Nonlinear interactions:** Interactions are nonlinearly additive and involve immediate neighbors, but in some cases also distant entities.
4. **Learning capability:** Living systems receive inputs from their environment and have the ability to learn from past experience.
5. **Darwinian mutations and selection:** Birth processes can generate entities better adapted to the environment which, in turn, generate new entities again better adapted to the external environment.

The first results were published in the book:

• **N. Bellomo**, *Modeling Complex Living Systems - Kinetic Theory and Stochastic Game Approach*, Birkhauser-Springer, (2008).

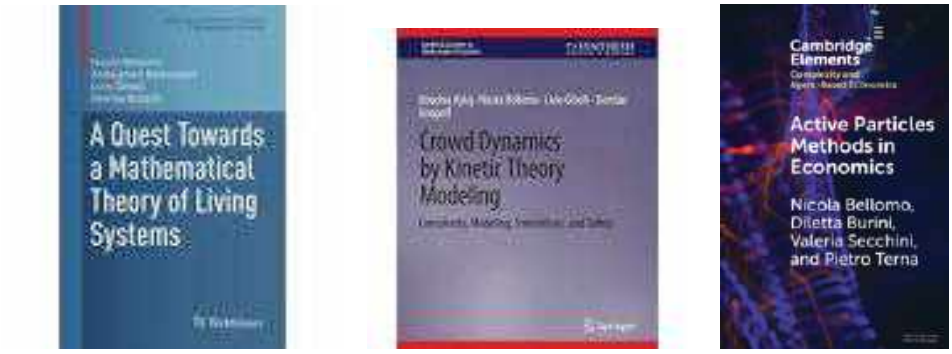
This book was followed by an intense research activity by several mathematicians not only in biology, but also in the field of collective learning, social sciences, economics, epidemiology, and vehicular traffic. Applications have suggested various developments of the method which has been later evolved towards a mathematical theory of living systems. Indeed, this is a new frontier of mathematics. The study is based on the concept that the method should first look for mathematical structures suitable to capture the complexity features of living systems and then derive specific systems by inserting into these structures a mathematical description at the micro scale.

• **N. Bellomo, A. Bellouquid, L. Gibelli, and N. Outada**, *A Quest Towards a Mathematical Theory of Living Systems*, Brihkauser-Springer, (2017).



The last developments are in the review article:

• **N. Bellomo, D. Burini, G. Dosi, L. Gibelli, D.A. Knopoff, N. Outada, P. Terna, and M.E. Virgillito**, What is life? A perspective of the mathematical kinetic theory of active particles, *M3AS*, **31**, 1821–1866, (2021).



9 Mathematical theory of human crowds

• **N. Bellomo, A. Bellouquid, and D. Knopoff**, From the micro-scale to collective crowd dynamics, *Multiscale Modelling and Simulations*, **11**, 943–963, (2013).

• **N. Bellomo, L. Gibelli**, Toward a mathematical theory of behavioral-social dynamics for pedestrian crowds, *M3AS*, **25(13)**, 2417–2437, (2015).

• **B. Aylaj, N. Bellomo, L. Gibelli, and D.A. Knopoff**, *Crowd Dynamics by Kinetic Theory Approach*, *Synthesis Lectures on Mathematics and Statistics*, Springer, (2021).

• **G. Albi, N. Bellomo, L. Fermo, S.-Y. Ha, J. Kim, L. Pareschi, D. Poyato, and J. Soler**, Traffic, crowds, and swarms. From kinetic theory and multiscale methods to applications and research perspectives *M3AS*, **29**, (2019), 1901–2005.

Figure 8: NB with Livio Gibelli and Alessandro Reali

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The design of the mathematical approach to crowd modeling is the result of several meetings at the University of Pavia with ***Livio Gibelli*** *(Edinburgh) and* ***Alessandro Reali*** *(Pavia) in the photo. Skype meetings were organized, before COVID time, with* ***Annalisa Quaini*** *(Houston and Harward), and* ***Damian Knopoff****, Deusto University in Bilbao, and* ***Jie Liao*** *Shanghai. The results of these meetings are presented in the two papers below.*

• **N. Bellomo, L. Gibelli, A. Quaini, A. Reali**, Towards a mathematical theory of behavioral human crowds, *M3AS*, **32(2)**, (2022) 321–358.

• **N. Bellomo, Jie Liao, A. Quaini, L. Russo, and C. Siettos**, Human behavioral crowds review, critical analysis and research perspectives, *M3AS*, **33**, (2023), 1611–1659.

10 Cancer Modeling: The immune competition

This research has produced various results on modeling, within a multiscale view. The research has also been developed within the European Research Training Networks (see projects A and B in section 4) coordinated by NB.

This research activity started thanks to a lucky circumstance. The collaboration with Guido Forni, immunologist. Thanks to a colleague of mine Davide Lovisolo, biophysicist, who introduced NB to Guido.

An important contribution to this research topic is the book:

• **A. Bellouquid and M. Delitala**, *Modelling Complex Biological Systems - A Kinetic Theory Approach*, Series, *Modeling and Simulation in Science, Engineering and Technology*, Birkhäuser, Boston, (2006).

The main results of various authors are presented in

• **N. Bellomo, P. Maini, N. Kaleta Li**, On the foundation of cancer modeling: Selected topics, speculations and perspectives, *M3AS*, **18**, (2008), 593–646.

Figure 9: NB and Philip Maini in Bloomington, USA

This topic remains a challenging research perspective, where the high challenge is the modeling of the immune competition including the role of vaccines. The project of the European Council has promoted the scientific involvement of several European scientists.

Figure 10: Annual school in Propriano, Corsica, FR

The BIOMAT School organized in Granada was launched in June 2005 by Antonio Campillo, Miguel A. Herrero, and Juan Soler. It rapidly become an excellent forum for complex systems in general and cancer modeling in particular, within an interdisciplinary framework, where advanced mathematical tools are engaged to describe the complex dynamics of biological and social systems.

Figure 11: Biomat2014, Granada: NB with From the left Juan Soler, Eitan Tadmor, Miguel A. Herrero, Jorge M. Pacheco on the first row. Philip Maini on the second row.

11 Multiscale theory of SARS-CoV-2 epidemics

The SARS-CoV-2 pandemic has engaged applied mathematicians in new and challenging problems. NB has been one of the pioneers in this new frontier, developing studies on a new view of epidemics based on a multiscale description of both the in-host dynamics and the transport of epidemics in the territory, somehow related to transportation networks.

• **N. Bellomo, R. Bingham, M. A. J. Chaplain, G. Dosi, G. Forni, J. Lowengrub, D. Knopoff, R. Twarock, M.E. Virgillito**, A multi-scale model of virus pandemic: Heterogeneous interactive entities in a globally connected world, *M3AS*, 30, 1591–1651, (2020).

Then this paper was followed by more specific topics, i.e., the study of the dynamics of variants and of vaccination programs:

• **N. Bellomo, D. Burini, and N. Outada**, Multiscale models of Covid-19 with mutations and variants, *Networks Heter. Media*, **17(3)**, (2022), 293–310.

• **N. Bellomo, D. Burini, and N. Outada**, Pandemics of Mutating Virus and Society: A multi-scale active particles approach, *Phil. Trans. A, Royal Society*, 380: 20210161, (2022).

A recent result considers the activation of the adaptive immunity:

• **N. Bellomo, R. Eftimie, and G. Forni**, What is the in-host dynamics of SARS-CoV-2 virus? A challenge within a multiscale vision of living systems, *Work in progress*, (2023).

A key feature that guided this line of research was the interdisciplinary vision proposed in the first paper, where mathematicians interacted with virologists, immunologists, and economists.

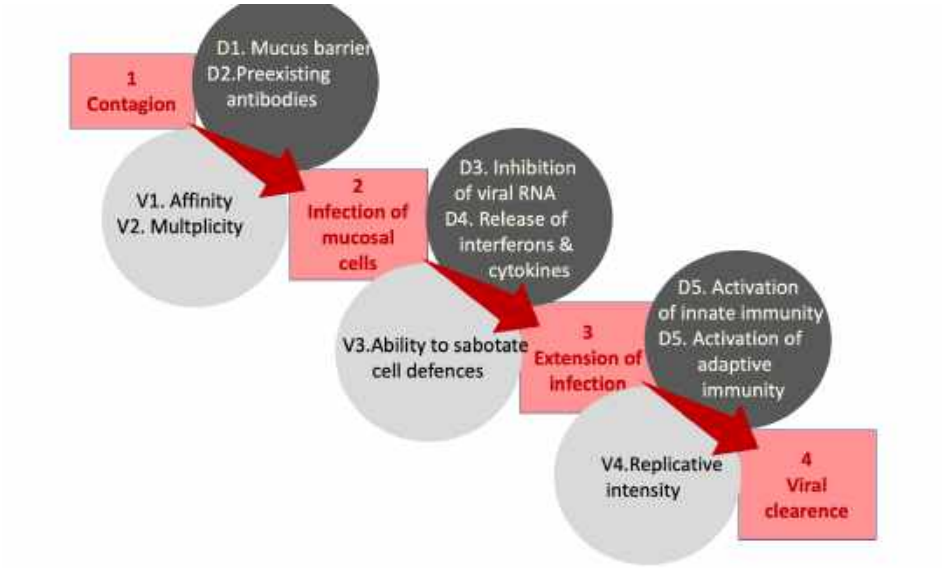

Figure 12: In-host picture, gift by Guido Forni)

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12 Cross diffusion: Analytical problems

Analytical problems have been developed on the qualitative analysis of cross-diffusion systems.

• **N. Bellomo, A. Bellouquid, J. Nieto, and J. Soler**, Multiscale biological tissue models and flux-limited chemotaxis, *M3AS*, **26** (2010), 2041–2069.

• **N. Bellomo, A. Bellouquid, and N. Chouhad**, From a multiscale derivation of nonlinear cross-diffusion models to Keller–Segel models in a Navier-Stokes fluid, *M3AS*, **26** (2016), 2041–2069.

• **N. Bellomo, A. Bellouquid, Y. Tao, and M. Winkler**, Toward a mathematical theory of Keller–Segel models of pattern formation in biological tissues, *M3AS*, **25**, (2015), 1663–1763.

• **N. Bellomo and M. Winkler**, A degenerate chemotaxis system with flux limitation: Maximally extended solutions and absence of gradient blow-up, *Comm. Part. Diff. Eq.*, **41**, (2017), 436-473.

• **N. Bellomo, N. Outada, J. Soler, Y. Tao, and M. Winkler**, Chemotaxis and cross–diffusion models in complex environments: Models and analytic problems toward a multiscale vision, *M3AS*, **32**, (2022), 713–792.

Figure 13: Torino: Michael Winkler, Youshan Tao, Christina Surulescu, Fiorella Bellomo, and Nisrine Outada. (Standing) NB and Stella Vernier-Piro)

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The micro-macro derivation (somewhat inspired by Hilbert's sixth problem) was initiated by A. Bellouquid with NB. At present D. Burini and N. Chouhad are in charge of continuing this research project.

13 Mathematical theory of behavioral swarms

The **Mathematical Theory of Behavioral Swarms** which goes beyond the mechanical theory by Cucker and Smale and provides a mathematical interpretation of the so-called topological interactions proposed by Giorgio Parisi's team. This theory was introduced in

• **N. Bellomo and J. Soler**, On the mathematical theory of swarms viewed as complex systems, *M3AS*, **22**, (2012), paper n. 1140006 (29 pages).

Up to

• **N. Bellomo, S.Y. Ha, N. Outada**, Towards a Mathematical Theory of Behavioral Swarms, *ESAIM: Control, Optimization and Variational Calculus*, (2020), **26**, paper 125.

and

• **N. Bellomo, S.Y. Ha, N. Outada, and J. Yoon**, On the mathematical theory of behavioral swarms emerging collective dynamics, *M3AS*, **32**, (2022), 1901–2005.

The main feature of this theory is that the dynamics of the swarm includes a behavioral dynamic variable that evolves with the system. The first applications have been developed in the field of economics. In particular, it has been used to model the dynamics of prices in open markets.

Figure 14: Seung-Y Ha's Team

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14 On a quest towards mathematical theories of economics

This topic is the latest challenge tackled for NB, where an interdisciplinary approach to modeling behavioral systems and economics, is being developed in collaboration with economists. NB starts from a literature where developments kinetic theory methods for applied mathematic have been developed. Some selected titles are in the following:

Mathematical Foundations: **Applications to economics and social problems have required further developments of a mathematics for living systems and have generated interesting mathematical problems**

• **M.L. Bertotti and M. Delitala**, On the existence of limit cycles in opinion formation processes under time periodic influence of persuaders, *M3AS*, **18**, 913-934, (2008).

• **V. Coscia**, On the mathematical theory of living systems, I: Complexity analysis and representation, *Math. Comp. Modelling*, *54*, 1919–1929, (2011).

• **B. Carbonaro**, The role of the principle of inertia in KTAP models, *J. of Math. Phys.*, **63(11)** Article number 013302, (2022).

New mathematical structures in multi-physics (economics) social dynamics:

• **M. Dolfin, D. Knopoff, L. Leonida, and D. Patti**, Escaping the trap of "blocking": a kinetic model linking economic development and political competition, *Kinetic and Related Models*, **10**, 423–443, (2017).

• **M. Dolfin and M. Lachowicz**, Modeling altruism and selfishness in welfare dynamics: the role of nonlinear interactions *M3AS*, **24**, 2361–2381, (2014).

• **G. Ajmone Marsan, N. Bellomo, and L. Gibelli**, Stochastic evolutionary differential games toward a systems theory of behavioral social dynamics, *M3AS*, **26**, 1051–1093, (2016).

• **N. Bellomo, M.A. Herrero, and A. Tosin**, On the dynamics of social conflicts looking for the Black Swan, *Kinetic Related Models*, **6(3)** 459–479, (2013).

A systematic collaboration with economists has been recently developed:

• **N. Bellomo, G. Dosi, D. Knopoff, and M.E. Virgillito**, From particles to firms: on the kinetic theory of climbing up evolutionary landscapes, *M3AS*, **30(7)**, (2020), 1441–1460.

• **N. Bellomo, S. De Nigris, D. Knopoff, M. Morini, and P. Terna**, Swarms dynamics approach to behavioral economy: Theoretical tools and price sequences, *Networks Heter. Media*, **15(3)**, (2020), 353–368.

• **N. Bellomo and M. Egidi**, From Herbert A. Simon's Legacy to the Evolutionary Artificial World with Heterogeneous Collective Behaviors, *M3AS*, **34(1)**, (2024).

15 Perspectives

The study of living systems can have a strong impact on the well-being of our society. This implies that their study involves different types of dynamics, such as social dynamics and economics, epidemiology and the politics of governments. The further development of the theory should consider multi-physics, multi-economic dynamical systems

The perspectives look ahead to further developments of a mathematics for living systems and to applications to the study complex systems of interest for our society. This legacy, from myself and Abdelghani Bellouquid, is addressed to a young generation.

Figure 15: Damian A. Knopoff, NB, Jie Liao, Marina Dolfin, Abdelghani Bellouquid

The stone-guest of all the above topics is the development of "artificial intelligence methods" capable of taking into account the complexity of the dynamics of living systems. Indeed, this will be a challenging research frontier in the next decades.

Philosopher George Santayana, in its original form, said, "Those who cannot remember the past are condemned to repeat it." This phrase evolved into: Those who do not learn history are condemned to repeat it. Arguably, this phrase can also be applied to artificial intelligence, which, if not fully understood, could have a negative impact on human and planetary life.

Figure 16: Herbert Simon's Lecture