# 2023 Research Activities Plan

## Department of Mathematics and Computer Science

## University of Palermo

The research activities of our department encompass all areas MAT/01 through MAT/08, INF/01 as well as SSD SECS-P/01-Political Economy and ING-INF/05- Systems for the Elaboration of Information. In what follows, we report the main activities for each SSD.

### MAT/01 - Logic

Researchers: Marco Elio Tabacchi (Tenure Track Assistant Professor RTD/B), Settimo Termini (Collaborator, CE)

Research Projects

History and Philosophy of Soft Computing: research into the origins of the treatment of vagueness, uncertainty and fuzzy concepts prior to the formal definition of fuzzy logic and its algorithmic implementation tools.
Applications of Fuzzy Logic: use of fuzzy classification algorithms to support the construction of introspective systems for Artificial Intelligence (AI) and computational learning; development of fuzzy algorithms for the classification of geo-economic data for use in expert decision support systems (DSS).

Research Funds

- University Research Funds
- GNSAGA-INDAM
- MISE Sustainable Growth Fund (FCS)
- As a main research unit, we intend to apply, together with other researchers from the Department and the University, to PRIN calls, as well as to other projects funded by the PNRR.

National and international collaborations

Joint research projects on related topics are currently in progress with the University of Santiago de Compostela (ES), with the Research Institute for the History of Science and Technology of the Deutsches Museum in Munich (DE) and with researchers from the University of Oviedo (ES). Publications with EU (Germany, Spain) are in preparation. LISP language experts from France will be invited as part of the Computational Logic lectures plan.

### MAT/02 - Algebra

A. Polynomial identities theory.

Researchers: Francesca Saviella Benanti (Assistant Professor, RU), Daniela La Mattina (Full Professor, PO), Fabrizio Martino (Tenure Track Assistant Professor, RTDB), Carla Rizzo (Post-Doc, AdR), Sara Accomando (Ph. D. Student D), Antonio Giambruno (collaborator, CE).

B. Categorical algebra.
Involved researchers: Giuseppe Metere (Associate Professor, PA), Manuel Mancini (Ph. D. Student, D).

Research projects

A. Algebras with polynomial identities over a field of characteristic zero.

The investigation focuses on the study of the polynomial identities satisfied by an algebra over a field of characteristic zero and the T-ideals of the free algebra by means of combinatorial methods involving the representations of the symmetric and the general linear groups. In particular, the degrees of the irreducible representations of the symmetric group are well-known and they allow to compute the asymptotic behavior of some invariants of the corresponding varieties of algebras. In the last years, a similar study has begun concerning central polynomials of an associative algebra. In such a setting, two more invariants connected to the corresponding T-space of the free associative algebra were defined and one of the main task is to analyze such invariants trying to relate them with the well-known invariants of the T-ideals. For non-associative algebras, it will be studied the Specht problem for graded Jordan algebras. Moreover, polynomial identities with trace were defined and studied for algebras with trace. In this setting, the varieties of algebras with trace of almost polynomial growth were classified.

In more detail, the following are the expected results:

1. Prove that for Jordan algebras the corresponding T-ideals are finitely generated. In particular, on one hand we try to prove such property for finitely generated graded Jordan algebras, on the other a same result shall be obtained for any Jordan algebras without additional structures.
2. Classify the color involutions for matrix algebras and study the corresponding simple algebras. Right after, analyze the codimension growth of a graded algebra with color involution.
3. Study the relation between the polynomial identities of any graded algebra with color involution with the Grassmann envelope of a suitable finite dimensional graded algebra with color involution.
4. Study of the T-ideals generated by the standard polynomials and the Capelli polynomials with involution in order to get a new classification of the T-ideal of identities of any simple algebra with involution. A similar study will be carried out concerning algebras with superinvolution and graded involution.
5. Determine the asymptotic behavior of the codimension growth of the so-called differential identities of an algebra with a Lie algebra action.
6. Study the exponential growth of the central polynomials of algebras with additional structures, relating it with the exponential growth of the polynomial identities of the same algebra.

7. Determine the exact growth of the codimension sequence of a fundamental algebra. To this end, a theory about fundamental algebras will be developed and it will be connected to the Kemer index.
8. Study the codimension growth of algebras with trace.

B. Category theory and categorical algebra.

Intrinsic categorical algebra is (intended here as) the formalization and study of systems of axioms for which certain properties of algebraic structures are reflected in properties of their categories. If for commutative algebra the notion of abelian category has been present since the 1950s, in the non-abelian field a satisfactory setting to deal effectively with groups, Lie algebras and other non-commutative structures was proposed only in 2002 with the notion of semi-Abelian category. Our research is now following two lines of development.

1. Fibrational aspects of non-abelian cohomology. The investigation origins from the study of "internal categories" inside algebraic varieties (in the sense of universal algebra). Indeed, the idea of internal category is pervasive in abstract algebra, but it is not always made explicit. For example, the "congruences" are internal categories, whose relevance in the study of the properties of some algebraic structures is undoubted. In fact, by using internal categories, or their normalized version (crossed extensions) it is possible to give a description of the cohomological theories in several non abelian categories. In a recent work, we proposed a theory based on the notion of fiberwise opfibration, which extends the notion of regular span elaborated by N. Yoneda in the 60's. With the help of this tool, we intend to study low-dimensional cohomology through the use of higher-dimensional categorical structures, i.e. define cohomology 2-groups and study their related properties [5].
2. Weakly representable actions in semi-abelian categories. The notion of representation is central to many sectors of abstract algebra. From an intrinsic categorical point of view, this notion can be interpreted in the context of so-called internal actions. However, a drawback of this approach is that internal actions are rarely representable. A possible solution, is the weakening of the notion of representable action, as recently proposed by George Janelidze. In 2022 we started to study the weak representability of the actions of Leibniz and Poisson algebras. Next year, we intend to turn our attention to non-associative algebras and other semi-abelian algebraic varieties.

We organize the 108$^{th}$ Peripatetic Seminar on Sheaves and Logic, Terrasini (Pa), September 2023.

<u>Research funds.</u>

A. Visits abroad and participation to conferences will be supported by National and University funds, by GNSAGA-INDAM funds and by Brazilian research institutions such as FAPEMIG and CAPES.
B. Visits abroad and participation to conferences will be supported by National and University funds and by GNSAGA-INDAM.

<u>National and international collaborations.</u>

A. Periods of permanence are foreseen for collaborations at the University of Sao Paulo, at the Federal University of Minas Gerais and at the University of Campinas, Brazil. Moreover, research visits in Palermo are planned by professors R. Bezzerra dos Santos and A.C. Vieira (Federal University of Minas Gerais, Brazil), E. Aljadeff (Technion, Haifa, Israel).
B. We plan to visit our collaborators and coauthors in Belgium (UCLouvain), Milano, Torino and Salerno.

**MAT/03 - Geometry**

A. Foundations of Geometry and Lie Theory.

Researchers:
Giovanni Falcone (Associate Professor, PA), Alfonso Di Bartolo (Assistant Professor, RU), Alessandro Dioguardi Burgio (Ph. D. Student, D), Giuseppe Filippone (Ph. D. Student, D), M. Galici (Ph. D. Student, D), G. La Rosa (Ph. D. Student, D), Manuel Mancini (Ph. D. Student, D).

Research projects
A1. As planned last year, Dr. G. La Rosa and Dr. M. Mancini have produced the following articles:
M. Mancini, "Biderivations of low-dimensional Leibniz algebras", on Non-associative algebras and related topics II, Springer Proceedings in Mathematics and Statistics;
G. La Rosa, M. Mancini "Derivations of two-step nilpotent Leibniz algebras", ArXiV pre-print;
G. La Rosa, M. Mancini, G. P. Nagy "Isotopisms of nilpotent Leibniz algebras and Lie racks", ArXiV pre-print.

For the next future, together with A. Di Bartolo, they plan to classify non-nilpotent with a 1-dimensional commutator ideal; and together with Xabier García Martínez, from the university of Vigo, Tim Van der Linden and Corentin Vienne, from the university of Louvain-la-Neuve, the weak representability of non-associative structures.

A2. The study of Goppa codes on hyperelliptic curve has produced the paper
G. Falcone, A. Figula, C. Hannusch
"On the generating matrices of Goppa codes over hyperelliptic curves", J. Ramanujan Math. Soc. 37, 273-279 (2022).
This paper was inspiring for G. Falcone and G. Filippone for planning to study the Riemann Roch space of a divisor on a hyperelliptic curve, given in its Mumford representation. Moreover, we report on the article
G. Filippone "Exp function for Edwards curves over local fields" which is submitted for publication. G. Filippone is also going to finish his research on the Riemann Roch space of a divisor on an Edwards curve, thus we foresee to report on this work next year. G. Falcone and G. Filippone are also studying the representation of an elliptic curve defined over the field of rational numbers as a group extension of the additive group of p-adic integers by its reduction mod p, and its possible applications to Cryptography.

A3. The planned study of Steiner triple systems, together with M. Galici and A. Figula turned out to be more involved than foreseen, thus it will take at least one more year to be finished.

A4. The connection between periodic bi-variate functions, non totally real cubic number fields, and torsion points on the generalized Jacobian of elliptic curves has been the subject of the paper A. Dioguardi Burgio, G. Falcone, M. Galici "Non-totally real number fields and toroidal groups" appearing on the J. Th. nombres Bordeaux. The authors plan to carry this research to higher degree extensions.

**B. Algebraic Geometry**

Researchers: Gilberto Bini (Full Professor, PO), Vassil Kanev (Full professor, PO), Luca Ugaglia (Associate professor, PA).

Research projects

B1. Grassmann tensors.
B2. Birational geometry.
B3. Hurwitz moduli varieties and Siegel modular varieties
A manuscript on the Hurwitz moduli varieties, which parameterize coverings of degree d of a given curve with n branch points and fixed monodromy subgroup of the symmetric group S_d, is to be completed soon and presented for publication. The study of the Prym-Tyurin morphism from Hurwitz spaces to Siegel modular varietes, which was begun some years ago will be continued.
B4. Effective cones of blown up surfaces.
Given a projective toric surface S associated to a lattice polygon P, we consider the blow-up X of S at a general point. A first goal is to relate the geometry of the polygon P with the non-polyhedrality of the pseudo-effective cone of the blown-up surface X. A second goal is to characterise lattice polygons P such that the Cox ring of the surface X is generated by classes of curves having multiplicity at most 1 at the blown up point. Finally we intend to study the pseudo-effective cone of the blow-up of other interesting classes of algebraic surfaces, such as the second symmetric product Sym^2(C) of an algebraic curve C of positive genus.

Research Funds
- FFO 2021 of the University of Palermo
- FFR funds;
- GNSAGA-INDAM;
- the mobility of PhD students is supported by both the University of Palermo and by INDAM;
- A. Di Bartolo is supported by the University of Palermo “FFR2022” fund. G. Falcone is supported by INDAM GNSAGA, and by the University of Palermo “FFR2022” fund.

National and international collaborations

A. Gabor Nagy, University of Szeged (Hungary), Xabier García Martínez, University of Vigo (Spain), Tim Van der Linden and Coronation Vienne, University of Louvain-la-Neuve (Belgium), Agota Figula and Carolin Hannusch, University of Debrecen (Hungary).
B. Antonio Laface, Universidad de Concepción (Chile), Robert Laterveer (France), Nick Vannieuwenhoven (Belgium), Gian Mario Besana (USA), Marina Bertolini and Cristina Turrini (Italy).

**MAT/04 - Mathematics Education and History of Mathematics**

**A.** *History of Mathematics*
*R*esearchers: Cinzia Cerroni (Full Professor, PO), Maria Alessandra Vaccaro (Associate Professor, PA), Pietro Milici (Nontenured Assistant Professor, RTD/A), Aldo Brigaglia (Collaborator, CE), Giovanna Rinchiusa (Ph.D student, D).
**B.** *Mathematics Education*
Researchers: Benedetto Di Paola (Associate Professor, PA), Pietro Milici (Nontenured Assistant Professor, RTD/A), Giulia Buttitta (Post-Doc, AdR), Giuseppe Bianco (Ph. D. Student, D)

1. <u>Research projects</u>

**A.** *History of Mathematics:*

1. History of Algebraic Geometry with particular reference to Luigi Cremona and Corrado Segre.
2. History of quadratic transformations and their role in the first formulation of the concept of birational transformation.
3. Historical origins of elliptical cubics related to the so-called “Geometry of the triangle”.
4. Historical origins of chains of theorems related to the Geometry of the triangle, such as Clifford's configurations and de Longchamps’ “recurrent geometry”.
5. The history of the development of non-Desarguesian and non-Archimedean geometries and the one related to them, the Algebras (Octhonions, etc.).
6. Research related to the Circolo Matematico di Palermo, in particular to the correspondences between G.B. Guccia, H. Poincaré and G. Mittag Leffler.
7. The publication of correspondence of Luigi Cremona, E. Beltrami, G. Battista Guccia, Placido Tardy and the Neapolitan mathematicians.
8. The origins and subsequent mathematical formalisation of star geometric figures from their use in art to their final mathematization by Kepler, via the lesser-known mathematicians of the Middle Ages who contributed to their theoretical systematisation.
9. The unexpected role of mathematics in literature (joint work with Elena Toscano RU MAT/08).
10. Historical aspects related to the influence of Bourbakist ideas and methodologies on disciplines that transcend the mathematical realm (joint work with Elena Toscano RU MAT/08).

**B.** *Mathematics Education:*

1. Mathematics and Language: Theoretical-experimental research aimed to frame the discipline as Language.

2. Mathematics, Science and reality: interdisciplinary approaches between Mathematics, Physics, Science, Statistics, Literature, Music, etc. with particular reference to the teaching/learning models and the related cognitive processes in all Education levels.
3. Mathematics and culture: researches aimed to comparing the cognitive processes currently underway by students of different cultures included in Italian classes and beyond. The investigated frame is used to define/re-define different theoretical frameworks (as the "cultural transposition" or the "Etnomathematics") useful for teacher PD courses.
4. Psycho-pedagogical, didactic and neuro-scientific references aimed to the study of Teaching/Learning processes in Mathematics. In this sense, an example is to study the didactical aspects related to errors, obstacles and misconceptions in mathematical problem solving (in collaboration with Prof. G. Cappuccio (PO) of the Department of Psychological, Pedagogical, Physical Exercise and Training Sciences, UniPa).
5. Theoretical-experimental researches about quantitative (hierarchical/non-hierarchical clustering and implicative analysis) and qualitative methods (audio-video analysis; interviews; protocols, etc.) in Mathematics Education (in collaboration with Prof. Claudio Fazio (PA) of the Dept. of Physics and Chemistry - Emilio Segrè, UniPa and dr. Onofrio Rodario Battaglia (RTDb) of the Department of Physics and Chemistry - Emilio Segrè, UniPa).
6. Relations between History of Mathematics and Mathematics education in teaching mathematics.

2. Research funds

**A.** GNSAGA-INDAM;
**B.1.** ERASMUS+ *Developing Bridging Courses for Mathematics and Science Teacher Students* (Bridge2Teach);
**B.2.** HORIZON 2020 *Enhancement of research excellence in Mathematics Teacher Knowledge* (MaTek);
**B.3.** GIMAT - Teachers training local fund.

3. National and international collaborations

**A.** There are many collaborations with other national and international research groups. In particular, as regards the archive material, there are collaborations with the Universities of Milan and Turin, the University of Perugia and the University of Basilicata. For the other research, there are collaborations with the Universities of Lille and Nancy. We also note the participation into the Italian-French CIRMATH project.

**B.** There are many collaborations with other national and international research groups in Mathematics Education working on the same research topics. Among these: the research groups of Bari, Bologna, Bolzano, Catania, Ferrara, Insubria, Modena-Reggio Emilia, Naples, Rome, Salerno etc. for the national context. The research groups of San Diego (USA), the research group of Beijing (China), the one working in Melilla (Spain) and the Swiss one (Locarno), as regards the international context. Added to these are research collaborations and dissemination of teaching practices with international partners (AT, CY, CZ, LT, UK, SK); research collaborations in MAT/04, also defined thanks to several European Mathematics Education projects with Benedetto Di Paola local coordinator in UniPa.

**MAT/05 - Mathematical Analysis**

*A. Frames and applications to biomedical systems, locally convex quasi *- algebras.*
Researchers: Camillo Trapani (Full Professor, PO), Francesco Tschinke (Assistant Professor, RU), Giorgia Bellomonte (Tenure Track Assistant Professor, RTD/B), Rosario Corso (Nontenured Assistant Professor, RTD/A).
*B. Integration, functional spaces, convergence problems and applications.*
Researchers: Diana Caponetti (Associate professor, PA), Valeria Marraffa (Associate Professor, PA), Luisa Di Piazza (collaborator, CE).
*C. Variational, topological and dynamical methods for nonlinear differential problems.*
Researchers: Barbara Brandolini (Full Professor, PO), Roberto Livrea (Full Professor, PO), Elisabetta Tornatore (Associate Professor, PA), Calogero Vetro (Associate Professor, PA), Francesca Dalbono (Assistant Professor, RU), Angela Sciammetta (Tenure Track Assistant Professor, RTD/B), Giuseppe Failla (Ph. D. Student ), Diego Averna (Collaborator, CE).
*D. Shape optimization.*
Researchers: Barbara Brandolini (Full Professor, PO), Antonella Nastasi (Nontenured Assistant Professor, RTDA-Unipa)
*Non-absolutely convergent integrals and applications, elliptic problems.*
*E.* Researcher: Francesco Tulone (Assistant professor RU).
*F. Numerical methods for PDEs and applications.*
Researchers: Calogero Vetro (Assistant Professor, PA), Syed Ibrar Hussain (Ph. D. Student D), jointly with Elena Toscano (Assistant Professor in Numerical Analysis).

1. Research Projects
A. *Frames and applications to biomedical systems, locally convex quasi *- algebras.*
The activity is divided basically into two main lines:
1. *Frames and applications to biomedical systems.* Generalizations of the concept of basis in a Hilbertian framework have been studied so far: generalized Riesz bases, distribution bases, frames, "reproducing pairs," weak A-frames. The latter notion, recently introduced, could be further generalized in the sense of semi-frames. The generalization of the concept of frames to the case of rigged Hilbert spaces leads to the study of conditions for which generalized eigenvectors in the sense of Gel'fand of certain classes of operators constitute distributional frames. It is intended to examine the case where these are Riesz bases or simply Bessel frames. Operators acting in rigged Hilbert spaces that transform weakly measurable applications with values in spaces of distributions, into frames, Riesz bases, or Gel'fand distribution bases will be studied. In addition, results of frames theory and generalized sampling operators are intended to be applied to the analysis of biomedical images, in particular to problems of segmentation and extraction of radiomic features. This biomedical image study, which takes place under the PON 2014/2020-Innovazione project, will be supported by UPMC Italy and its partners (Fondazione Ri.MED and IBFM-CNR).
2. *Locally convex quasi *-algebras.* It is intended to continue the study undertaken on locally convex quasi *-algebras that admit a sufficiently ''rich'' family of invariant positive sesquilinear forms. In particular, one wants to study the topologies originating from such a family of forms.
Funds with which the research activity is to be implemented:
INdAM-GNAMPA, University FFR and PON 2014/2020-Innovazione

Keywords: Frames and Hilbertian bases, biomedical image analysis, topological quasi *-algebras.

*B. Integration, functional spaces, convergence problems and applications.*
We distinguish the following topics.
1.Integral representations of measures and multimeasures. Aim is the study of the integrability of a scalar function with respect to a multimeasure, in order to obtain Radon-Nikodym typre theorems for integrals of Bartle-Dunford-Schwartz type with respect to multimeasures. The theory of scalar functions integrable with respect to vector measures is quite rich and interesting, and not as simple as that of scalar functions integrable with respect to positive measures. The Bartle-Dunford-Schwarz integral is a classical integral of scalar functions with respect to vector measures. Few results are known about the theory of integration of scalar functions with respect to multimeasures. Fatou's lemma and convergence theorems are fundamental theorems of probability theory. Results of convergence with respect to sequences of measures have important applications in statistics, stochastic processes and game theory. Interesting results are known in the case of scalar functions, but at the moment few results are known in the case of vector-valued functions; therefore our aim is to study convergence results for functions or multifunctions with values in Banach spaces.
2. Differential inclusions driven by measures. Studying the evolution of a large number of processes in real life, it is observed that the measured quantities often have discontinuities. For example, this characteristic is found whenever discrete perturbations occur in a continuous evolution of a phenomenon. This leads to the study of the properties of the solution set of a very general problem: differential inclusions driven by Borel measures. This is a very comprehensive class, covering a large number of classical problems such as: differential inclusions, difference inclusions, impulsive problems, dynamical problems on time scales or generalized differential equations. The Filippov-Wazewski relaxation theorem is of considerable importance in the theory of multivalued differential problems. It has been generalized in various directions, for example for impulsive semilinear differential inclusions and for unbounded differential inclusions. Applying a recent Filippov, we want to study a Filippov-Wazewski type theorem in the case of differential inclusions involving the Stieltjes derivative with respect to a non-decreasing and left-continuous function g, assuming that the multifunction on the right is uniformly continuous in both variables in the product topology of $\tau_g$ with the topology of $R^d$.
3. Measures of noncompactness. We will study measures of noncompactness and fixed point theorems in complete non-locally convex spaces with respect to an F-norm. We intend to provide an axiomatic approach to a measure of noncompactness with respect to a topology weaker than the one induced by the F-norm.
Keywords: Integral, multifunction, multimeasure, differential inclusion, measure of noncompactness, fixed points.

*C. Variational, topological and dynamical methods for nonlinear differential problems.*
We distinguish the following topics.
a. We consider certain classes of equations involving non-homogeneous differential operators, in divergence form, under different boundary conditions. We study existence,

multiplicity, regularity and uniqueness of solutions to differential problems with nonlinear singularities. We also investigate existence and multiplicity of solutions to some classes of ordinary differential equations and asymptotically linear systems of second order ODEs. The adopted strategy combines variational tools together with topological methods. Further theoretical efforts are focused on non-regular counterparts of a recently obtained version of mountain pass theorem. We intend to establish a non-standard Ekeland variational principle. Lastly, we study the properties of solutions to Schrödinger evolution problems, using suitable test functions together with truncation methods.
b. We study existence and multiplicity of radial solutions to elliptic equations driven by the Laplacian and p-Laplacian, using the theory of invariant varieties and Fowler type transformations. Special attention is paid to establish both the existence and non-existence of positive solutions to a Dirichlet problem for the curvature equation in a ball. We also investigate asymptotic behavior and nodal properties of radial solutions to nonlinear Laplace equations.
c. We analyze the existence and regularity of solutions to elliptic equations whose principal part is anisotropic, fractional, degenerate p-Laplacian. We also investigate Hardy type anisotropic inequalities, or more generally Caffarelli-Kohn-Nirenberg type inequalities.
Keywords: Variational methods, topological methods, dynamical methods, elliptic equations, p-Laplacian, existence, uniqueness, multiplicity and regularity of solutions.

*D. Shape optimization.*
Shape optimization consists into finding the optimal shape of a domain under some constraints. We consider cases when these constraints are given in terms of elliptic, linear or nonlinear, PDEs. In particular, we face optimization problems for functionals involving geometric quantities related to the domain and eigenvalues and/or torsional rigidity of nonlinear elliptic operators.
Keywords: Shape optimization, elliptic equations, eigenvalues, geometric constraints.

*E. Non-absolutely convergent integrals and applications, elliptic problems*
The lines of research will be as follows:
1. Abstract integration: in L^r spaces we can define a type of derivation which generalizes the usual derivation and two types of "antiderivative", the first one by Henstock-Kurzweil method and the second one using the Perron method. Contrary to the known theory, the first way is more general than the second one elaborated by Perron. We propose to compare the Perron type integral with the trigonometric integrals introduced by Burkill, while as regards the Henstock-Kurzweil-type integral on the spaces L^r we hope to give a totally descriptive characterization of the integral as Lusin has done for classical Denjoy integral.
2. Elliptic problems: with variational techniques we will study the existence and multiplicity of solutions for some elliptic problems.
Keywords: Henstock-Kurzweil-type integral, Perron type integral, Denjoy-type integral, ACG-type functions, elliptic problems, variational methods.

*F. Numerical methods for PDEs and applications*
We investigate numerical methods for solving space- and time-dependent partial differential equations.

2. Research Funds

A. FFR 2023, INdAM-GNAMPA, PON 2014/2020-Innovazione.
B. FFR 2023, INdAM-GNAMPA 2022.
C. FFR 2023, INdAM-GNAMPA, PRIN 2017: Nonlinear Differential Problems via Variational, Topological and Set-valued Methods (grant no: 2017AYM8XW), PRIN 2017: Qualitative and quantitative aspects of nonlinear PDEs (grant no: 2017JPCAPN).
D. FFR 2023, INdAM-GNAMPA.
E. FFR 2023.
F. FFR 2023.

3. National and International collaborations

A. On these lines of research there are ongoing collaborations with scholars from Italy (Professors F. Bagarello, S.Triolo, D. Tegolo of the University of Palermo and Albert Comelli of UPMC Italy), from different European countries (P. Balazs Austria, J-P. Antoine Belgium, M. Fragoulopoulou Greece, M. Ptak Poland, S. Ivkovic Serbia) and Japanese (A. Inoue and H. Inoue).
B. National (A.Sambucini, A. Trombetta, G. Trombetta) and international cooperation (M. Chicon, K. Musial, Poland; B. Satco, Romania).
C. Foreigner countries involved in the planned research: Australia, Belgium, Bulgaria, France, Germany, Greece, Poland, Portugal, Romania, Saudi Arabia, Slovenia, USA.
D. Foreigner countries involved in the planned research: France, USA.
E. Italian and international cooperation (Russia, India, Kazakhstan, USA).

MAT/06-Probability Theory

Researchers: Giuseppe Sanfilippo (Associate Professor, PA), Lydia Castronovo (Ph. D. Student, D)

Research Projects

A. On conditional probabilities and their canonical extensions to Boolean algebras of compound conditionals: we investigate canonical extensions of conditional probabilities to Boolean algebras of conditionals. We study how the canonical extensions behave well with respect to conditional subalgebras. We also study if a canonical extension and its original conditional probability agree on basic conditionals. Moreover, we compute the probability of conjunctions and disjunctions of conditionals in a recently introduced framework of Boolean algebras of conditionals and we check if they are in agreement with the corresponding operations of conditionals as defined in the approach of conditional random quantities. We also discuss relations of our approach with nonmonotonic reasoning based on an entailment relation among conditionals.

B. Probabilistic properties for a generalized notion of conjunction of two conditional events and iterated conditionals in trivalent logics: traditionally the conjunction of conditional

events has been defined as a three-valued object. However, in this way classical logical and probabilistic properties are not preserved. In recent literature, a notion of conjunction of two conditional events as a suitable conditional random quantity, which satisfies classical probabilistic properties, has been deepened in the setting of coherence. We propose a generalization of this object and we study some probabilistic aspects.
We also consider de Finetti's notion of conditional as a three-valued object and as a conditional random quantity in the betting framework. In the framework of specific three-valued logics we analyze the notions of iterated conditional introduced by Cooper-Calabrese, de Finetti and Farrell, respectively. We study the compound probability theorem and other basic properties and we check if they are preserved by these objects. We also compute some probability propagation rules. For each trivalent logic we study iterated conditionals as a suitable random quantity which satisfies the compound prevision theorem and we check the validity of some of the desirable probabilistic properties. We consider generalized version of Bayes' Theorem and a generalized compound probability theorem.

C. Coherence-based probability semantics and probability propagation rules for (categorical) Aristotelian syllogisms and for connexive logics: we present two approaches to investigate the validity of connexive principles and related formulas and properties within coherence-based probability logic. Connexive logic emerged from the intuition that conditionals of the form "if not-A, then A", should not hold, since the conditional's antecedent not-A contradicts its consequent A. Our approaches cover this intuition by observing that the only coherent probability assessment on the conditional event A|not-A is 0. In the first approach we investigate connexive principles within coherence-based probabilistic default reasoning, by interpreting defaults and negated defaults in terms of suitable probabilistic constraints on conditional events. In the second approach we study connexivity within the coherence framework of compound conditionals, by interpreting connexive principles in terms of suitable conditional random quantities. We compare both approaches conceptually.
We present a coherence-based probability semantics and probability propagation rules for (categorical) Aristotelian syllogisms. For framing the Aristotelian syllogisms as probabilistic inferences, we interpret basic syllogistic sentence types A, E, I, O by suitable precise and imprecise conditional probability assessments. Then, we define validity of probabilistic inferences and probabilistic notions of the existential import which is required, for the validity of the syllogisms. Based on a generalization of de Finetti's fundamental theorem to conditional probability, we investigate the coherent probability propagation rules of argument forms of the syllogistic Figures I, II, and III, respectively. These results allow to show, for all three figures, that each traditionally valid syllogism is also valid in our coherence-based probability semantics. Moreover, we interpret the basic syllogistic sentence types by suitable defaults and negated defaults. Thereby, we will build a bridge from our probability semantics of Aristotelian syllogisms to nonmonotonic reasoning. We also show how the proposed probability propagation rules can be used to analyze syllogisms involving generalized quantifiers, like Most.

E. On Trivalent Logics, Compound Conditionals, and Probabilistic Deduction Theorems: conditionals are important in human reasoning under uncertainty because they allow individuals to make decisions and inferences based on incomplete or uncertain information.

Thus, the interpretation and evaluation of conditionals is a key challenge for artificial and human reasoning under uncertainty. We study the equivalence between bets on conditionals and conditional bets, by reviewing de Finetti's trivalent analysis of conditionals. Our approach goes beyond de Finetti's early trivalent logical analysis and is based on his later ideas, aiming to take his proposals to a higher level.
We will examine two recent articles that explore trivalent logics for conditionals and their definitions of logical validity and compare them with our approach to compound conditionals. We will consider a Probabilistic Deduction Theorem for conditional events. After that, we study some probabilistic deduction theorems, by presenting several examples. We focus on iterated conditionals and the invalidity of the Import-Export principle in the light of our Probabilistic Deduction Theorem. We will introduce a General Import-Export principle and we will illustrate it by examining some p-valid inference rules of System P.

F. Conditional partial entropy and extropy: we will study possible definitions of entropy and extropy for partial probabilistic assessments on arbitrary family of events and-or of conditional events. We relate them with proper scoring rules by means of the Bregman divergence. We study properties and results.

G. Subjective probability, trivalent logics and compound conditionals: we illustrate the subjective theory of de Finetti. We study the equivalence of the two criteria by giving the geometrical interpretation of coherence. We also consider the notion of coherence based on proper scoring rules. We discuss conditional events in the trivalent logic of de Finetti and the numerical representation of truth-values. We check the validity of selected basic logical and probabilistic properties for some trivalent logics: Kleene-Lukasiewicz-Heyting-de Finetti; Lukasiewicz; Bochvar-Kleene; Sobocinski. We verify that none of these logics satisfies all the properties. Then, we consider our approach to conjunction and disjunction of conditional events in the setting of conditional random quantities. We verify that all the basic logical and probabilistic properties (included the Fréchet-Hoeffding bounds) are preserved in our approach. We also recall the characterization of p-consistency and p-entailment by our notion of conjunction.

Research Funds: FFR University of Palermo and INdam-Gnampa projects

National and international collaborations:
Angelo Gilio (Rome), Tommaso Flaminio (Barcelona, Spain), Lluis Godo (Barcelona, Spain), Frank Lad (Christchurch, New Zealand), David Over (Durham, UK), and Niki Pfeifer (Regensburg, GE).

**MAT/07 - Mathematical Physics**

Two areas of research can be distinguished:
**A.** *Mathematical models and dynamical systems.*

Researchers involved: Marco Maria Luigi Sammartino (Full Professor, PO-UNIPA), Maria Carmela Lombardo (Full Professor), Vincenzo Sciacca (Full Professor, PO), Gaetana Gambino (Associate Professor, PA), Sara Di Ruzza (Nontenured Assistant Professor, RTDA), Francesco Gargano (Tenure Track Assistant Professor, RTDB-UNIPA), Antonio Maria Greco (collaborator), Rossella Rizzo (Nontenured Assistant Professor, RTD/A-Unipa), Giovanni Denaro (Nontenured Assistant Professor, RTD/A-Unipa)

**B.** *Statistical mechanics and the structure of matter.*

Researcher involved: Valeria Ricci (Assistant Professor).

1. Research Projects.

**A.** *Mathematical models and dynamical systems. We distinguish the following seven lines of research:*

**1.** Mathematical modelling using reaction-diffusion systems. In recent years, reaction-diffusion type equations have been widely used to describe the mechanism by which homogeneity breaking and self-organization (in space and time) lead to the emergence of new coherent structures (patterns). Much attention has been given to the generation of Turing-type patterns, structures that are periodic in spatial variables and stationary in time, the formation of which is essentially due to the destabilization, through diffusion, of a stable steady state for the reaction system. In various contexts, from biochemistry to geological systems with heterogeneity, from ecology to industrial processes such as electrodeposition, classical diffusion would be a simplifying and inadmissible hypothesis for describing the occurrence of self-organizing phenomena, which is why we intend to study the key role of non-linear diffusion in this type of field. In particular, taking into account the affiliation of some members of the group to the NBCF- National Biodiversity Future Center, we intend to formulate and analyze models that describe the behaviour of planktonic myxotrophic species through IGP (intraguild predation) dynamics. It is intended to consider multiple trophic interactions and oriented species movements, describing typical predation strategies through cross-spreading. Such models are intended to determine the formation of persistent patchiness, steep density gradients due to parameter variations (such as light intensity, temperature or salinity), the appearance of recurring outbreaks (such as harmful algal blooms), the propagation of fronts, and more complex dynamics (spatio-temporal chaos, spiral waves).

**1.1** Reaction-diffusion type systems with linear cross-diffusion. It is well known that the global existence of solutions in reaction-diffusion systems with complete diffusion matrix (thus in the presence of linear cross-diffusion), can only be demonstrated in the case of kinetics for which balance laws apply. It is proposed to demonstrate the global existence of the solutions in less restrictive cases, e.g. for Schnakenberg-type kinetics, in which the mere cancellation property of the non-linear terms (due to the reversibility of the chemical reaction) should allow a uniform control on the total mass of the components to be determined, thus suggesting the impossibility of blow-up in a finite time. Linear cross diffusion also does not ensure the positivity of solutions. It is therefore proposed to investigate under which conditions such positivity is preserved.

**1.2** Reaction-diffusion systems for modelling inflammatory diseases (Erythema, Multiple Sclerosis, cerebral gliomas). The aim is to develop mathematical models for the description of a class of diseases that share an inflammatory-type pathogenesis; in particular, the mechanisms determining the onset of skin rash phenomena (such as Lyme disease, recurrent erythema multiforme) and Multiple Sclerosis will be described. In the latter case, the focus will be on the demyelination process, which determines the formation of the characteristic plaques in brain matter. The anti-inflammatory effects produced by certain cytokine species will also be taken into account in order to describe certain reparative processes set in motion

by the immune system in response to the disease attack. This immune response determines, in the case of erythema, the (temporary or definitive) resolution of the inflammatory state and, in the case of Multiple Sclerosis, the spontaneous repair of the lesions with the consequent formation of so-called shadow plaques. Reaction-diffusion-chemotaxis type models will be used both with non-linear cross-diffusion, which well reproduce the diffusive processes in non-homogeneous media such as brain matter, and with fractional-type diffusion, in order to reproduce the ability to create long-range metastases, which is a typical feature of brain gliomas.

**1.3** Pattern formation in reaction-diffusion systems with bistability. Some reaction-diffusion systems may admit, for the same set of parameters, several stable steady states from which different diffusive instabilities may arise that interact with each other. In such cases, the patterns formed are structures with very large amplitudes due to the coupling of critical spatial modes with a homogeneous quasi-neutral mode. The problem of pattern selection must, therefore, take into account the coupling of these modes, and the classical weakly nonlinear analysis, which is applied in the monostable cases to predict pattern formation, must be suitably modified. The aim is to analyse the mechanism of pattern formation in a FitzHugh-Nagumo type system, which supports the bistability of its homogeneous stationary states with linear cross-diffusion. In particular, in two-dimensional domains it is intended to show the occurrence of quasi-periodic resonant and superlattice-like structures.

**2.** Oscillating pattern formation: interaction between Turing- Hopf bifurcations and non-linear phenomena in the sub-critical case. It has recently been discovered that some reaction-diffusion systems can give rise not only to the Turing-type patterns described in 1), but also to spatio-temporally oscillating Turing patterns (STOS: spatio-temporally oscillating solutions). These are phenomena quite different from uniform oscillations due to the presence of a Hopf bifurcation in the kinetic term; they are generally due either to the resonance of unstable Turing modes with Hopf-instable sub-harmonics or to the interaction of unstable Turing modes with a subcritical bifurcation. It is therefore intended to investigate the phenomenon of STOS in reaction-diffusion type systems with a nonlinear diffusive term, either using Lengyel-Epstein type kinetics (to investigate the interaction with Hopf-instable modes) or using Lotka-Volterra type kinetics (to investigate the interaction with the subcritical bifurcation. In both cases, it is planned to proceed with a weakly non-linear analysis in the vicinity of the bifurcation as well as with continuation-type numerical techniques.

**3.** Analytical solutions of fluid dynamics equation. It is intended to prove well posedness theorems for certain dissipative equations of fluid dynamics (e.g. primitive equations, or Navier-Stokes equations) with existence times that do not depend on dissipation. It is well known that when the fluid interacts with a boundary, a layer is generated, the thickness of which is of the order of the square root of viscosity, within which there are high gradients of 'vorticity', the so-called boundary layer. In this layer, the dynamics are governed by the Prandtl equations. It is therefore intended to develop an asymptotic procedure in the limit of zero viscosity and to demonstrate its rigorous validity in appropriate spaces of analytical functions.

**4.** *Singularity Formation for the Equations of Fluid Dynamics.*

**4.1.** High Reynolds number fluids interacting with a rigid boundary. It is well known that in fluids interacting with rigid boundaries with high Reynolds numbers, a series of phenomena are triggered that ultimately lead to the phenomenon of non-stationary boundary layer separation, i.e. the formation of vortical structures on the boundary and their subsequent detachment and entry into the fluid outside the boundary layer. It has already been shown recently, by the Palermo group in collaboration with K. W. Cassel of I.I.T. Chicago, how these interactions are closely linked to the presence of complex singularities in the Navier-Stokes

solution. The aim is to investigate how the boundary conditions to be imposed on the boundary can influence the formation of the complex singularities, and the consequent behaviour of the fluid. Specifically, one wants to investigate the role of the Navier boundary conditions. One wants to verify the presence of any new viscous-non-viscous interactions between boundary layer and external fluid, or how the same interactions, already present in the case of no-slip conditions, can be modified.

**4.2.** Vortex-sheets and regularisations of the Birkhoff-Rott equation. Shear-layer flows are characterised by strong velocity field variations concentrated in a region of small thickness, within which high vorticity is present. In the limit where the thickness of the region tends to zero, 'vortex-sheets' are formed, i.e. flows in which vorticity is concentrated on a curve in space. From a mathematical point of view, vortex-sheets are governed by the Birkhoff-Rott equation, for which the solution is known to form a singularity in the curvature of the curve in finite times. It is possible to continue the evolution of the vortex-sheet beyond the time of the singularity by applying some appropriate regularisation to the Birkhoff-Rott equation (vortex-blob type regularisation or Euler-$\alpha$ type regularisation), or by approximating the motion of the vortex-sheet with that of a vortex layer of finite size. It is intended to investigate whether different regularisations admit different solutions in the zero-regularisation limit, showing more generally how it is not possible to prove the uniqueness of weak solutions of the Euler equation for initial data of vortex-sheet type.

**5.** Kolmogorov flow. The research activity will be aimed at studying the stability and transition to turbulence for a Kolmogorov flow stratified in density and under the action of a gravitational field. The aim will be to characterise how, as the Reynolds number increases, the cascade of successive bifurcations leads to the appearance of increasingly complex states (from oscillatory or translatory states, through quasi-periodic solutions to chaotic states); and to understand how this cascade is influenced by the effects of stratification. Continuation and proper orthogonal decomposition techniques will be employed.

**6.** Analysis and Control of Dynamical Systems The study and control of chaotic dynamical systems has received increasing attention over the last few decades. This is due both to the theoretical interest in non-linear dynamics and to the considerable spin-offs in the field of application. The term control generally refers to the application of an external - usually small - signal to a chaotic system in order to obtain a well-determined dynamic (stationary, periodic or even chaotic). An essential characteristic of the applied control must of course be its 'robustness', i.e. how well the results of the study on idealised models remain valid with respect to real systems and conditions. The area in which we intend to work therefore concerns the design of feedback-type controls (linear and non-linear) for chaotic systems. In particular, controls will be studied for the so-called generalised Lorenz family, a family of parameter-dependent chaotic systems containing in itself a number of chaotic systems of relevant interest, such as the Lorenz system, the Chen system and the Lu system. It is planned to study the robustness of the control with respect to possible time delays in signal insertion: this study will be carried out both from an analytical point of view - studying the possibility of Hopf-type bifurcations and determining the corresponding dynamics on the central variety in order to determine the supercritical or subcritical character of the bifurcation - and from a numerical point of view, in order to validate the theoretical results.

**7.** Celestial mechanics and chaotic dynamical systems. One of the most studied issue of Celestial Mechanics is the three-body problem (or n-body problem) where three (or n) bodies interact through the only gravitational force and the problem cannot be solved exactly. Depending on how the model is conceived, motions of different objects in the solar system can be represented, from the motion of the planets, to that of asteroids, to that of artificial satellites orbiting the Earth or in interplanetary missions. The problem aims to find estimates of stability of the motion of these objects in time, and through perturbation theory

methods the existence of regular and chaotic motions is detected. The phase space has different time scales depending on the frequencies of the motions involved and the problem can be studied in its entirety or averaged with respect to the fast frequencies: in this case the number of degrees of freedom of the model decreases and only secular (long time scale) perturbations are analyzed. The research activity develops along different lines. The first sees a modeling of the planetary system, in which the three (or more) interacting bodies have masses that are comparable or in any case non-negligible to each other. The objective is to study the phase space of the associated dynamical system and to characterize for which values of the parameters involved there are regular or chaotic motions, using techniques of Perturbation Theory, KAM (Kolmogorov-Arnold-Moser) Theory and Nekhoroshev estimates. Continuing the line of the last works carried out, the idea is to demonstrate the existence of chaotic motions also through the use of symbolic dynamics. The problem is studied both in the averaged and in the non-averaged cases and we provide estimates of validity and comparisons of the two models. Furthermore, the applicability of the models studied to real celestial systems is sought, such as binary asteroid systems or extrasolar planetary systems. Another line of research involves the study of the restricted three-body problem, where restricted indicates that one of the interacting bodies has a negligible mass compared to the other two bodies and therefore does not influence their motion. Usually, the motion of an asteroid or an artificial satellite is modeled with this system. In this case, orbital resonances are particularly interesting; in particular we intend to continue the study of asteroids that are in co-orbital motion with the planets, i.e. in 1:1 mean motion resonance (asteroids that have the same rotation period of the planet, therefore a comparable semi major axis and rotate in the same space as the planet ), with the aim of characterizing and cataloging asteroids according to their dynamical features. The problem has already been studied in the planar case, and the analysis is extending to the spatial case, i.e. in the more realistic case in which the asteroid has a non-zero inclination with respect to the orbital plane of the planet around the sun. We also intend to continue the study making use of Artificial Intelligence for a more effective and complete cataloging of asteroids.

**B.** *Statistical mechanics and the structure of matter*. The scope of the research is the mathematical study of complex systems out of equilibrium (of interest in applications) through the analysis of the rigorous connection among models describing them at different scales and the formulation and validation of such models. The main research topics, objects of the research, are four: the validation from particle systems of kinetic and hydrodynamic equations of theoretical interest; the study of multi-phase systems of interest in applications (e.g., spray); the modelling and mathematical analysis of thermonuclear and astrophysical plasmas, in a theoretical and applicative context; the mathematical analysis of vision processes at low light intensities.

2. Research Funds

GNFM - INDAM funding is provided for collaborations.

PRIN 2017YBKNCE Multiscale phenomena in Continuum Mechanics: singular limits, off-equilibrium and transitions.

NBCF- National Biodiversity Future Center.

3. National and international collaborations

**A.** - C. Bardos, Laboratoire Jacques-Louis Lions, Paris, (France);

-R. Caflisch, Courant Institute, New York (USA);

- M. Cannone, Laboratoire d'Analyse et de Mathématiques Appliquées, Université Paris-Est, Marne-la-Vallée Cedex 2, (France);

- S. Roy Choudhury, Department of Mathematics , University of Central Florida, Orlando (USA);
- M. Haragus, Laboratoire de Mathématiques, Université de Franche-Comté, Besançon cedex (France);
- I. Kukavica, Department of Mathematics, University of Southern California, Los Angeles (USA) ;
- Lopes-Filho, Milton Da Costa, Universidade Federal do Rio de Janeiro, Rio de Janeiro, Brazil;
- Nussenzveig Lopes, Helena J.N., Universidade Federal do Rio de Janeiro, Rio de Janeiro, Brazil;
- M. Schonbek, Department of Mathematics , University of California, Santa Cruz (USA);
- E. S. Titi, Department of Mathematics, College Station, Texas A and M University (USA).

**B.** - L. Desvillettes, Institut des Mathématiques de Jussieu, Paris Rive Gauche (IMJ-PRG), Université Paris Diderot (Parigi 7) (Francia);
- F. Golse, CMLS Ecole Polytechnique e CNRS Université Paris Saclay (Francia);
- A.J. Pereira Costa Soares, CMAT Universidade do Minho (Portogallo);
- S. Mei, Université Paris Diderot e Observatoire de Paris (Francia) ;
. B.Coppi, Massachusetts Institut of Technology, Boston (USA).

**MAT/08 - Numerical Analysis**

1. Research projects:

**A**. *Numerical methods for time- and space- dependent partial differential equations*. Researchers: E. Toscano (Assistant professor, MAT/08), Syed Ibrar Hussain (Ph. D. Student, D) in collaboration with C. Vetro (Associate Professor in Mathematical Analysis, PA).
Study and implementation of numerical methods concerning discretization in space and time of *time-dependent* PDEs. The most commonly used finite difference methods for the discretization of time derivatives whereas, on the one hand, when they are implicit methods they guarantee robustness and stability, on the other hand they lead to systems of algebraic equations (linear and nonlinear) whose numerical resolution can both be hard to found and require an *a priori* study of the convergence conditions of the matrix system. Meshless (i.e., computational grid-free) techniques have proven to be competitive with respect to traditional difference methods in the case of problems involving discontinuities. Therefore, we plan to investigate the possibility of "combining" difference techniques "in time" and meshless techniques "in space".

**B.** *Three-dimensional discrete tomography*. Researchers: E. Toscano in collaboration with C. Valenti (Associate Professor, PA, ING-INF/05).
The goal of computerized tomography is the three-dimensional reconstruction of objects, slice by slice, from several hundreds of projections. In the particular case of objects with a few density values it is possible to reduce the number of projections, thus defining discrete tomography. We plan to prove that it is possible to extend binary discrete tomography to the three-dimensional case, by setting aside the original assumption that there is a correlation between adjacent slices; indeed this implicitly introduces a model of the volume to be reconstructed. Mathematical morphology, fast convolution and evolutionary approaches are among the main methods we will investigate.

**C.** *Mathematics and Literature*. Involved researchers: E. Toscano in collaboration with M. A. Vaccaro (History of Mathematics and Mathematics Education).
The theme of the influence of Bourbaki's ideas and methodologies on disciplines that transcend the mathematical field and, in particular, the reflection on the relationship between Bourbaki and Oulipo have been frequently addressed has animated a passionate debate within literary criticism.
The purpose of this contribution is to investigate the relations between Bourbaki and Le Lionnais, Queneau, Roubaud and more generally Oulipo. Through a comparative examination between the two groups, the existence of an undeniable charisma of the "polycephalic mathematician" on the artistic-literary movement was highlighted.

2. Research Funds
- FFR funds.
- *SMART WAVE* Project. Project code: 08PA7111000479.
-*BLIND: una libreria crittografica per l'elaborazione cieca di dati sensibili* Project. Project code: FISR2020IP_04958.

3. National and international collaborations
**C.** It is planned a collaboration whit the Prof. Olivier Salon (France).

**SECS01/P-Political Economy**

1. Research projects:
Researcher involved: Salvatore Modica (Full Professor, PO)

Research on the balances in interactions between competing groups is being carried out with the research group involved in the PRIN mentioned below. In particular, attention is being paid to the role of leaders in conflicts between groups. The results that we have so far suggest that through the mediation of leaders you can achieve cooperative equilibria in games where in the absence of a leader this is not possible (for example in the prisoner's dilemma). A decisive role in this is played by leaders whose preferences are an average of the preferences of the groups involved. With only "biased" leaders, that is, who share the preferences of a particular group, one can only replicate the 20 of 31 equilibria of the underlying leaderless game. Another key element is that leaders can be punished if they make promises that don't come true - one would say in English that leaders - especially partisan ones - must be accountable. The models we are studying are in fact models of political parties. So the search continues in the scope of the "Political Economy via Economic Sociology" which gives the title to the book we are about writing to put the results together and make them usable also by PhD students that we've been getting in recent years. The above theoretical results will be put compared with data on the political situation of advanced countries, to understand if actually in the presence of growing polarization in situations where leaders "moderate" have a greater weight a greater degree of cooperation and of consequence of social welfare.

2.Research Funds
MIUR PRIN 2017 n. 2017H5KPLL_01: “Voting, Lobbying and Disrupting: Political Economy via Economic Sociology” (beginning February 6, 2020; ending August 6, 2023)

3.National and international collaborations

The research group includes, professors David Knudsen Levine and Andrea Mattozzi, both professors at the European University Institute (https://www.eui.eu/en/academicunits/department-of-economics), and a few months ago Dr. Junze Sun (PhD, Amsterdam) in as a research fellow. Professor Aldo Rustichini joined the group, of the University of Minneapolis (USA), which is actively collaborating in research on the role of leaders described above.

**INF/01-ING/INF-05**

Research projects:

***A.*** *Combinatorics and algorithms on automata, languages and discrete structures* **(Inf/01)**

Researchers involved: Giuseppa Castiglione (RU), Chiara Epifanio (RU), Gabriele Fici (PA), Manuela Flores (RTD), Sabrina Mantaci (PA), Arianna M. Pavone (RTD), Antonio Restivo (CE), Marinella Sciortino (PO)

These research areas lie at the crossroads between theoretical computer science, mathematics and applications. They mainly use the combinatorics of words, as well as tools from non-commutative algebra, logic and probability calculus. They also include the study and analysis of string algorithms, an important aspect of which is motivated by potential scientific applications that involve, among others, coding, compilation, software verification, data compression, indexing and bioinformatics. The lines of research mainly concern the combinatorial and algorithmic aspects of automata, languages and discrete structures, and also consider several application domains. The specific research topics to be developed in 2023 are listed below:

*A1.Theoretical and algorithmic aspects of deterministic finite-state automata theory (DFA) and formal languages.* One of the principal aims of the formal languages theory is the characterization of various natural subclasses of regular languages, each motivated by particular issues and applications. In many cases, in particular, for subfamilies of star-free languages, such a characterization has involved some structural properties of the minimal automaton that recognizes the language, involving forbidden configurations of the state-graph. This is quite natural since the minimal deterministic automaton captures both the combinatorial and algebraic nature of the language and its complexity. For example, this occurs for piecewise testable, locally testable and reversible languages. Very recently the family of Wheeler languages has been defined as regular languages recognizable by Wheeler automata, whose set of states is equipped with an ordering induced by the co-lexicographic order. Wheeler languages are star-free languages and their minimal automaton can be characterized by means of a forbidden pattern. Even if they have represented a turning point

in both this theoretical and applied context, unfortunately they constitute a small class of regular languages not closed for many regular operations. It is our goal to generalize the concept of ordering of the states of an automaton by detaching it from the co-lexicographic. Define some classes of ordered automata recognizing ordered regular languages and study completion, minimization and closure for the Boolean operations. Furthermore, our goal is to contextualize them in the classification of subregular languages characterized by forbidden patterns in the minimal automata. It would be interesting to find the relationship with the main subclasses of star-free languages, with reversible languages and, furthermore. These results would create a connection between problems of indexing finite automata and the theory about subclasses of regular languages.
Finally, in the context of the theory of free monoids, of fundamental importance for the theory of formal languages, we want to use an automaton/theoretical approach for the study of the intersection of free finitely generated monoids. Just like in regular languages, the intersection of free monoids leads to more complicated situations that we want to deal with through simpler setups. We propose to address all these issues from a theoretical and algorithmic point of view with techniques specific to combinatorics of words. Such research is partially supported by Indam-GNCS project 2023 “Ordered regular languages, indexing and comparing string collections, with applications”

*A2. Combinatorics on words and applications to graph theory* A first research line is devoted to the study and experimentation of the CDAWG average size (number of nodes and number of arcs) of strings generated from i.i.d. sources of variable entropy, even very small. Literature contains analyses made for strings generated by i.i.d. sources of maximum entropy as the alphabet varies. Preliminary experimental results show that the average size of the CDAWG decreases with the reduction of the entropy, even if not in a proportional way. This property suggests the possibility of using this data structure in case of highly repetitive sequences.
A second search line focuses on isometric words and partial cubes. Isometric words, although defined in the framework of graph theory, have been interestingly characterized using combinatorial string properties involving avoided factors and overlaps. A string f is called isometric if, for each pair of words u and v avoiding f, there exists a transformation from u to v of length equal to their distance in which each intermediate word avoids f. In particular, it has been proved that f is non-isometric with respect to the Hamming distance if and only if it has a prefix and a suffix of the same length whose distance is two. Our aim in this setting is to study isometricity with respect to an edit distance that allows not only replacement (Hamming distance) but also swap operation that exchanges two adjacent letters of a word. Furthermore, it is well-known that isometric words allow us to construct isometric subgraphs of the hypercube, where two nodes are linked if they have Hamming distance equal to 1. A very famous example is the Fibonacci cube, which has important applications in designing interconnection networks. We want to generalize such graphs with the new connection rule of swap and mismatches distance.

*A3. Similarity measures for combinatorial discrete structures and applications.* The main combinatorial object of interest for this line consists of sequences of characters, or words. The dual objective is to define new alignment-free similarity measures for the comparison of large collections of words but also to extend some known measures so that they can be applied to large datasets of sequences, especially in biological contexts such as pan genomes.

This question will be investigated making use mainly of combinatorial notions and tools such as minimal absent words, k-mers, Lyndon's words, and the Burrows-Wheeler transform. This line of research will be developed both from a theoretical and an applied point of view.
We are also interested in developing some studies about distances based on alignments. The Edit Distance was introduced by Levenshtein to formalize and quantify the difference between two strings as the minimum number of single-character edits (insertions, deletions or substitutions) required to change one sequence into the other. Edit distance has important applications in linguistics, bioinformatics and Information Retrieval. A special case of Edit distance is the Hamming distance, where the only possible operation is the substitution. We plan to study some extensions of these distances, both by adding some operations or by modifying some existing operations. We will investigate properties and fields of application.
Labelled trees represent the other combinatorial structure under investigation for this line of research. We plan to define new similarity measures inspired by methodologies from combinatorics on discrete structures to compare fully labelled trees. The tree data structure, besides its importance in computer science to represent hierarchy and decisions, has important applications in medical research since it turns out to be the best abstraction to describe cancer phylogeny reconstruction, leading to the consequent need to define solid and efficient methods for comparing the results. Machine learning models will also be used for both sample classification and prediction of patterns identifying specific cancers. Such a research line is partially supported by the project PNRR ITSERR – Italian Strengthening of the ESFRI RI RESILIENCE.

*A4. Combinatorial algorithms on strings and applications to machine learning and data mining problems.* We intend to continue the search for applications of theoretical frameworks (e.g. minimal absent words) to algorithmic problems on textual data, in relation to emerging problems related to machine learning and data mining. This research is supported by a PRIN 2017 youth line project (local unit coordinator: Gabriele Fici).

A5. *Ambiguity in Symbolic Dynamics.* Symbolic Dynamics studies discrete dynamical systems called shift spaces and their classification. There is a considerable overlap between symbolic dynamics and automata theory. Actually, one of the basic objects of symbolic dynamics, the sofic shifts, are essentially the same as finite automata. Coded shifts were introduced as a generalization of irreducible sofic shifts. Recently some interest has appeared in those coded shifts which are unambiguously coded. They can also be defined by automata having the property of strong unambiguity. This, in particular, allows to prove in [3] that every irreducible sofic shift is unambiguously coded by a rational prefix code. We show that the notion of strong unambiguity is connected with that of recognizable morphism, which is central in the study of shifts defined by morphisms. We have investigated several questions related to the notion of recognizable morphism. In particular, we prove new results which allow us to formulate the property of recognizability in terms of finite automata. From this, we derive the decidability of some notions related to recognizability by algorithms of low polynomial complexity. We propose to use the notions and techniques introduced in the previous papers to approach other related questions in shift spaces (in particular decision

problems) and also extend such notions and techniques to more general contexts, as, for instance, S-adic shifts.

*A6. Two-dimensional languages and structures.* The main research direction of the project is the extension to two dimensions of some well-founded notions and combinatorial results in string theory. We will use combinatorial techniques developed in string theory to face and attack problems in two dimensions. Particular attention is given to the notions of code, overlap, avoided factor, and distance between strings. Avoided factors are also referred to as forbidden factors or absent words, depending on the context. One of the directions will be to generalize the definition of MAW (minimal absent word) to pictures. An aim is to develop the two-dimensional concept of minimal absent picture to understand which of the combinatorial properties connected to minimal absent words are preserved for pictures. As previously stated, this kind of extension hopefully brings a definition of a distance between pictures with interesting applications on problems of image comparison. Moreover, we will investigate the corresponding isometric strings and pictures based on this new distance. The *tiling recognizable picture languages*, for short REC*,* are one of the well-known extensions of recognizable languages from one to two dimensions, i.e. from words to digital pictures. The elements of REC are defined as the projection of strictly locally testable (SLT) languages of order 2 over a “local alphabet”. The size of the local alphabet is a measure of the descriptive complexity of the picture language. We have investigated how it is possible to reduce the size of the local alphabet by increasing the order of the SLT language. In particular, we have proved that any element of REC over an alphabet of size n is the projection of an SLT language over an alphabet of size 2n. The proof of the previous result relies on a new family of *comma-free picture codes*, on their numerosity (the number of code-pictures) and on the relation between the language of encoded pictures and SLT languages. Remark that comma-free codes are a classical topic for words, but are less studied for pictures: very few (if any) examples of comma-free 2D code are available in the literature. We propose to investigate more in general the structure of 2D comma-free codes, their numerosity and their relations with families of picture languages. Another line of research is to define *context-free picture languages*, without any explicit use of models of (pictures) grammar. As in the case of recognizable languages, where the family REC is defined without any explicit use of finite automata, we propose to look at some of the characterizations of context-free (word) languages that make use of notions which are suitable to have a “natural” extension in 2D.

A7. *Compression and indexing of highly repetitive string collections.* In several applicative fields such as bioinformatics, new technologies have made available quantities of data (particularly textual data) that are much greater than our ability to handle them, even in compressed form. One of the main characteristics that these rapidly growing data collections have in common is their high repetitiveness. For this reason, great attention is currently developing new compression and indexing techniques that effectively exploit this high repetitiveness. This research line aims to study the efficiency and effectiveness of compression and indexing of large collections of highly repetitive sequences, with

applications, especially to large collections of biological sequences. Our goals are twofold. Firstly, we are interested in the study of repetitiveness measures to assess the compressibility of highly repetitive collections of strings. This is crucial in the design of optimal compressed indexing structures. Indeed, we recall that classical notions of empirical entropy have limited relevance when applied to large collections of highly repetitive data. We intend to pursue the study of repetitiveness measures based on compression algorithms and evaluate the sensitivity of such measures with respect to edit operations on texts but also with respect to the action of morphisms. Secondly, we are interested in defining new compressed indexing structures, based on the sampling of combinatorial structures, that can efficiently support search operations on large and highly repetitive collections of strings. Such a research line is partially supported by the Indam-GNCS project 2022 “Combinatorial methods for indexing and comparing collections of highly repetitive texts”.

A8. *Teaching Informatics at school to develop Computational thinking.* One new research direction is an experimental work on Informatics Teaching, with a particular focus on training teachers to teach fundamental concepts of Computer Science. In fact, digital technology is becoming crucial to ensure the delivery of many essential services to society. The digital economy requires digitally competent citizens and workers, capable of influencing and contributing to the development of the real world and its digital counterpart. Teaching the fundamentals of informatics as an independent subject area would contribute to forming and enriching the cultural, technical and scientific background of each person. Children and youth to become active, responsible and engaged citizens, should be equipped with both digital skills and with knowledge and understanding of informatics science. In order to promote the dissemination of the scientific principles of informatics and the concepts of digital awareness in primary schools among pupils, it is fundamental to make teachers able to teach informatics. We aim to conduct experimentation with different teaching methodologies of new resources for programming designed so that they can be readily adopted by both experienced and inexperienced teachers, to support them in introducing computer programming into their classrooms. Namely, the purpose of this proposal is to compare, in the Italian context, the puzzle-based approach typical of Code.org with the UMC (Use, Manipulate, Create) approach, with respect to specific aspects of teaching coding skills. Remark that learning Informatics, besides equipping young people with a cultural scientific background, which is fundamental in a digital society, gives them the opportunity to develop what is considered a fundamental skill for tomorrow’s citizens: Computational Thinking (CT). In fact, CT includes foundational computing concepts such as abstraction and algorithms, as well as computing practices such as problem decomposition and debugging. All of them develop a way of thinking that is fundamental even to those students that do not aim to become computer scientists. This line of research is also supported by PLS (Piano Lauree Scientifiche) in Informatics.

***B.*** *Algorithms and techniques to extract knowledge from discrete data structures* **(Inf/01)**

Researchers involved: Raffaele Giancarlo (PO), Simona E. Rombo (PO), Domenico Garlisi (RTD)

The research objective concerns the analysis and design of new algorithms and data structures for solving a problem that considers knowledge extraction in different application contexts. In particular, the research will focus on applications in the areas of social networks, biological and medical data, digital images and videos, wireless networks and Internet of things. Mainly, it will be predominantly adopted techniques in the area of data mining, machine learning and big data management. According to the expertise of the team members, the research plan is briefly outlined below.

*B1. Study of the combinatorial and informational properties of strings and sequences in the epigenomic domain.* It is well known that the DNA sequence is the generator of the so-called 'code of life'. It is equally well known that the intrinsic organisation of this sequence plays a key role in various biological processes, such as chromatin organisation and histone modifications. So far, however, there is a lack of fundamental results that clearly establish the role of intrinsic sequence organisation in these processes. The planned work will focus on studies of k-mer (exact sequences) within two fundamental processes in biology: chromatin organisation and histone modifications. Expected results will include: the construction and the analysis of 'epigenomic' dictionaries for 'nucleosome' positioning; methodologies for compression in the sequence space of 'nucleosome' positioning classifiers, and the analysis of k-mer dependency graphs about the acquisition of function stability for 'nucleosome' positioning and histone modifications.

*B2. Performance evaluation of efficient algorithms in the life sciences environment.* It is well known that algorithmics has made fundamental contributions to the life sciences, for instance in the area of human genome sequencing. It is equally clear that the epoch-making changes brought about by new data production technologies in biology require a critical analysis of the role of algorithms in this area. The aim of this line of research is to provide measures of the impact of algorithms on the life sciences and useful recommendations for the future, also in the scope of the BIG DATA field and independently from biology.

*B3. Clustering, Supervised Classification and Algorithm Engineering.* Clustering, classification, and pattern discovery in data have experienced significant advancements in recent years, particularly in the context of microarrays, which are commonly used in biology experiments, and in the analysis of two-dimensional arrays used, for example, in digital images. The goal of this line of research is to facilitate the dissemination of these methods by creating software that can be easily accessed and utilized by researchers and practitioners around the world. This would enable them to apply these techniques to their own data and accelerate the rate of scientific discovery across a variety of fields.

*B4. Techniques and tools for personalised medicine.* In recent years, we have observed exponential growth of biological and medical data from the advanced technologies of sequencing, clinical and imaging data, electronic medical records, etc. The resulting data are complex, heterogeneous and big. This 'big data' offers new opportunities to find new solutions to classical problems, but also new approaches to solve open challenges for data

storage, validation and processing. In this context, a new interesting scenario is represented by precision medicine, whereby medical decisions, treatments, practices and/or recommended products should be tailored to the individual patient. In particular, the selection of appropriate and optimal therapies can be based on the context of a patient's genetic content or other molecular or cellular analyses. The goal of this research line is to investigate and design appropriate data integration and analysis methodologies, with particular reference to the study of the cellular components (e.g., long non-coding RNA) and particular cell types (e.g., stem cells). Furthermore, appropriate models and algorithms on these models will be proposed for the extraction of specific patient characteristics. For example, network-based strategies can combine multiple data sources through graph-based integration methods, including Similarity Network Fusion, Multiple Kernel Learning models, or multi-task Hopfield Networks. A recent alternative approach is Graph Representational Learning (GRL) method. GRL translates the non-Euclidean graph representation of nodes and arcs into a Euclidean space that can be easily used by machine learning algorithms to efficiently perform problems ranging from classification to unsupervised clustering and recommendation systems. Another objective of this research activity will be to develop innovative machine learning methods for the integration of large amounts of heterogeneous data for precision medicine, focusing on: (i) Integration of diverse clinical, biochemical, genetic, imaging and omics data through supervised and semi-supervised machine learning methods to support clinical diagnosis, prognosis and treatment of diseases; (ii) Analysis of biomedical data represented by heterogeneous multi-graphs, including Knowledge Graphs; (iii) Analysis of medical big data through highly parallel machine learning methods and High Performance Computing (HPC) technologies.

*B5. Viral marketing and social advertising.* This line of research topic is focused on the integration and analysis of data from various sources such as social media, online shopping sites, and loyalty cards, to gain insights into and improve corporate marketing processes. To achieve this objective, which is critical due to the large volume of data to be analyzed and the need for real-time processing in some specific applications, the research activities leverage big data technologies. The research investigates several aspects of viral marketing and social advertising, including user profiling and profile matching, analysis of network centrality measures, the study of information dissemination, algorithms for identifying influencers, and interactive advertising systems. One key area of research is user profiling and profile matching, which involves the analysis of user behaviour across various platforms to develop a comprehensive picture of their preferences and interests. Finally, these strategies are essential in gaining a better understanding of the behaviour of potential customers and developing effective marketing strategies.

*B6. Data-driven approach to measuring, analysing and modelling social behaviour.* Online Social Networks platforms represent one of the main 'disruptive innovations' of the last 15 years and are currently used by billions of users to exchange information. The widespread use of these communication platforms and the data generated by their user's interactions constitute an important source of information for understanding, studying and analysing users' behaviours. The research topic aims to use real data from Online Social Networks to measure, analyse and model the characteristics of user behaviour in different contexts, which include: trust, reputation, privacy, communication patterns and information

dissemination. To this end, the following strategies will be adopted: i) data collection methodologies based on profiling, crawling, and monitoring, ii) data modelling techniques for static and dynamic networks, and iii) data mining and machine learning algorithms for the analysis of complex networks.

*B7. Machine learning for data analysis in the IoT and security aspects.* According to the Internet of Things Analytics forecast, there are currently seven billion IoT devices connected, and this number is expected to grow rapidly in the coming years. As the number of devices connected to the IoT increases, so too does the amount of data that needs to be stored and processed, IoT classical approaches cannot lead with this amount of data and big data solutions cannot be applied due to the drastic dissemination of the data sources. These approaches can help to improve the performance of IoT networks by identifying and resolving issues before they cause network faults and service denial. To address these challenges, this research topic aims to apply machine learning techniques to optimize the process operation in future IoT networks. These techniques involve device profiling through clustering, which can help to identify patterns and similarities between devices, as well as the prediction of their behavior using neural networks. In addition to optimizing the performance of the network, the research also focuses on the security aspect of IoT devices. Overall, the research aims to address the challenges associated with the growth of IoT networks by leveraging machine learning and other advanced technologies. By doing so, it seeks to optimize the performance and security of these networks, enabling them to realize their full potential in connecting devices and collecting and analyzing data across a wide range of applications and industries.

*B8. Distributed processing in IoT networks.* Classical Internet of Things architecture presents a centralized system for data collection and processing. In such cases, especially when dealing with a large number of devices distributed over a wide area, the central architecture may cause problems related to response time and service guarantee. The research activity arises to address this issue, mainly it focuses on extending the architecture of an IoT system such as LoRaWAN (Long-Range Wide Area Network) to support data processing at the edge of the network, thus unifying IoT and Big Data architectures. The main goal of this research is to define a new IoT system architecture that automates resource provisioning and dynamic edge-processing management, while also providing programmable interfaces to operators for rapid prototyping and experimentation of resource allocation schemes. By moving the data processing closer to the edge of the network, the system can improve response times, bandwidth reduction and service guarantees, the research is led in conjunction with national Italy operators.

*B9. Data collection and resource optimisation strategies in water distribution networks.* Water is one of the most important natural resources on which humans base their survival. However, in recent years, global water consumption has increased significantly, while the world is facing a global water deficit, mainly due to the effects of climate change. Strategies need to be implemented to conserve water resources in order to optimise distribution and reduce wastage. The research topic involves the use of data-driven models to monitor and evaluate water distribution networks in real-time and detect leaks or waste in the most timely manner possible. The research involves the creation of Internet of Things monitoring

networks (e.g. by LoRaWAN technology). The data collected by the monitoring system is exploited to build a model of the network, which can use measurements (such as pressure and water demand values) to understand possible issues in the distribution. For example, the model can be exploited to identify changes in network topologies due to unexpected events (such as new leakage points) as a function of prediction error. In particular, new approaches are envisaged that combine classification and neural networks to predict losses with a high level of generalisation with respect to the topology of the water distribution network.

C. *Methodologies and algorithms for data analysis in biomedicine, cultural heritage and e-learning* **(Inf/01, Ing/ Inf-05)**

Researchers involved: Fabio Bellavia (RTD), Biagio Lenzitti (RU), Domenico Tegolo (PA), Cesare Valenti (PA)

The research activity will focus on the development of innovative methodologies for the analysis of data structures with multiple dimensions, typical in the biomedical field and cultural heritage. The topics will be addressed with well-established theories of machine learning and evolutionary algorithms and applications of computer vision and image processing.

C1. *Cultural heritage*. This research will investigate new methods for accurate 3D reconstruction from 2D images or videos. The specific applications of this study to cultural heritage are aimed at the virtual preservation of rare and precious objects of interest and to grant wide fruition of these objects to the public. The research will focus on new image-matching methods for 2D images to improve the object localization on the scene so as to increase the precision of the reconstructed models. The research will also explore new approaches to compare recent images with historical photos, drawings and pictures in order to highlight the changes in the scene across time. Moreover, in order to enhance the quality of historical photos, the research will also include the study of novel methods to register and merge images and for colour corrections. Finally, new solutions for the large-scale processing of high-resolution images will be investigated to intrinsically improve the accuracy of the 3D models from the image acquisition process, as well as to increase the allowable scale variation between the objects in the scene and among the input images.

C2. *Multidimensional data analysis*. The research activity in the field of vision, and more generally in multidimensional data analysis, finds its foundations both in the three fundamental areas of computer vision (low, medium and high level) and in the field of genetic algorithms and computational and statistical learning. Classical problems such as segmentation, feature detection and selection, classification and three-dimensional reconstruction will be addressed with traditional algorithms and with the definition and validation of new and more accurate methodologies oriented to specific fields of research such as computational and neurophysiological methods. New control measures will be identified and defined to ensure accurate responses to the proposed methodologies. These approaches will be proposed in the literature and validated on synthetic and real biomedical images, including cellular, automated retinal fundus analysis, videocapillaroscopy, discrete tomography, and magnetic resonance imaging. During the validation phase, we will rely on

experts to provide ground truth and medical annotations. Regarding e-learning, we plan to investigate the design and implementation of tools dedicated to the process of patient awareness. Such tools, placed at the centre of health and social services, will be realized to be inclusive and therefore allow citizens to control their own medical needs.

C3. *BioImages*. In biomedical images, it will be necessary to define new metrics and guarantee a more accurate response to the proposed methods. New methods will be developed on real or synthetic and biomedical images to validate the microscopic and macro aspects. They regard cellular analysis, the automatic analysis of the retinal fundus, the "capillaroscopy" of the mucous membranes and epidermis, and discrete tomography. In the validation phase, experts will be involved to provide ground truth and medical annotations of the real data. An appropriate subset of the data will be available in the "public domain" mode to compare with other innovative techniques and facilitate collaboration with international partners.

C4. *Neural Models*. The computational neurophysiological models will also be of interest: The cellular processes underlying the differences between individuals of the same species in working memory capacity are unknown. Any experiments indicate that subjects with lower working memory capacity than those with greater capacity require longer times for retrieving the items memorized in a list and also appear to be more sensitive to interference during the information retrieval time. However, a more precise link between such experiments and cellular properties still needs to be improved with other complex experiments. The research activity in this area will investigate possible underlying mechanisms at the single neuron level using a computational model of pyramidal CA1 hippocampal neurons, which appear to be deeply involved in recognising specific elements. The results produced by the new models will suggest a plausible explanation of the different performances between individuals.

C5. *Models for patient integration in medical decision-making processes.* The objective of the research lines will be to provide both methods for extracting results from complex data and suggest guidelines for future developments. Moreover, the production of large amounts of data to identify complex correlations between heterogeneous data will obtain a more homogeneous integration in the field of BIG DATA. Another aspect will investigate the context of e-learning to design and implement dedicated tools for patient empowerment. The design and implementation of these tools, placed at the centre of social and health services, will be carried out to be inclusive and also allow citizens to take control of their medical needs.

C6. *Data Technologies in agriculture*. to unlock the potential data and to provide farmers with trusted data. EU projects have addressed the need for data space concepts and technological infrastructures for agriculture and provide infrastructure solutions, an open interoperability network for the entire agri-food chain, or a cloud data hub in a collaborative, initiative-oriented manner for the development and growth of the European IoT Ecosystems. Current research on data-sharing technologies in agriculture focuses on IoT and sensing

devices, associated cloud technologies, software architectures, traceability and AI-driven analytical technologies to improve productivity and efficiencies or to address sustainability aims in crop-, water-, soil-, or livestock management. A coherent data space approach, accounting for the needs of farmers while meeting governance requirements such as trust, transparency or security, still needs to be established. However, underpinned by the data governance act, it is imperative to position farms at the centre of the collection, exchange, and management of data to create and capture value, accounting for adoption barriers for digital technologies and addressing the need for mechanisms ensuring trust, accessibility, interoperability from a technological perspective. Instead, the inferential techniques based on rules or mathematical models that consider the time-space evolution of the data in the different farms seem more appropriate to the problem as defined, which will therefore be the subject of further study. Furthermore, semantic preprocessing techniques, possibly of the fuzzy type, will also be evaluated for textual analysis if, among the data, there is free text obtained from the notes on the processing of the goods.

C7. *3D tissue models*. This task aims to develop Machine Learning (ML) models for cell growth prediction under the action of external agents on its DNA (e.g. drugs, radiation, etc.). ML algorithms will be trained using biological and imaging features extracted from 3D tissue models (i.e. multicellular spheroids). In particular, a mixed cellular 3D model will be studied, with cellular spheroids of normal fibroblasts (3T3 cells) and "pathological" cells. Trained algorithms will predict the action of specific inhibitors of neoplastic growth processes and the "physiopathology" or the reproduction of the single cell of each of the individual tissues or of their whole. Explainable AI (XAI) algorithms will also be used to understand the complex relationships between the input biomarkers discovered by the trained algorithms and the external agent response. A study on the features inhibiting cell growth will also be performed. XAI-enhanced models, able to make correct predictions about a therapy's efficacy, will also explain the main factors affecting the prediction.

**D.** *Multisensory interaction* **(Inf/01)**

Researchers involved: Vincenzo Taormina (RTD), Davide Rocchesso (PO)

Visual, auditory, tactile, and proprioceptive Interactions between people and devices are studied. The main areas of investigation are:

D1. *Methods for interaction design:* Continuous multisensory interaction and design of perception-action coupling mechanisms. Multisensory basic design and protocol analysis of interaction exercises. Methods and tools for sketching in interaction design.

D2. *Sound models.* Sonic interaction design focuses on sound as a carrier of information, meaning, and aesthetic-emotional content in interactive contexts. In interaction between humans and artifacts, sound synthesis should be efficient, versatile, and controllable. Sound synthesis by physical models is proposed both for simulation of existing acoustic systems and to develop structures and methods that support creativity. Primitives for the representation of sound are proposed, on the time-frequency plane, according to a taxonomy of physical

phenomena, or based on articulatory phenomena (voice and gesture). The Quantum Vocal Theory of Sound (QVTS) has been proposed, that describe sound phenomena within a complex Hilbert space, where Pauli operators correspond to the extraction of articulatory vocal primitives. QVTS and quantum computing are applied to the analysis of auditory scenes and to digital audio effects.

D3. *Non-visual interaction.* In virtual and augmented reality, attention is steered toward haptic and auditory displays. Multisensory data exploration of complex information is studied in interactive contexts.

D4. *Perception applied to human-computer interaction.* Experimental psychology methods and tools are applied to the study and evaluation of artifacts and interaction modalities. Predictive models of human-computer interaction are experimentally evaluated in different sensory contexts.

D5. *Rhythmic interaction.* Exploitation of human abilities in detecting, reproducing, and entraining with rhythmic patterns, for the purpose of human-artifact interaction. Integration of the different senses in the action-control loop involving rhythmic cells. Display and segregation of concurrent rhythmic streams to monitor and control multiple interaction points.

D6. *Human interaction with sustainable artificial intelligence.* Definition of new techniques for cooperative human-machine interaction and learning, in individual as well as in social contexts. Integration of sustainable practices in the lifecycle of intelligent systems, in the stages of design, training, development, validation, re-tuning, implementation, and use.

D7. *Explainable artificial intelligence.* Augmentation of machine learning algorithms with procedures aimed at human comprehension of automatic decisions. Experimental evaluation of techniques of explainable artificial intelligence, with the involvement of human experts and a particular focus on diagnostic imaging.

**E.** *Artificial Intelligence for knowledge extraction from data* **(Inf/01).**

Researchers involved: Giosué Lo Bosco (PA), Riccardo Rizzo (CNR), Giovanni Pilato (CNR).

Data-driven artificial intelligence is the discipline adopted by the participants of this group to face several application domains characterized by structured and unstructured data to be processed. Multidimensional signals, digital images, and text are examples of the data related to the applications listed in the following:

E1. *Deep Learning Models for DNA sequence analysis.* Deep Learning Models are machine learning methodologies capable of avoiding the feature engineering phase. They are mainly implemented through artificial neural networks organised on various progressive layers. These models will be adopted for the clustering and classification of DNA sequences. Finally, the automatic extraction of sequence features will be used to study their complexity in relation to the different biological species that will be considered in the study.

E2. *Deep Learning Models for the analysis of seismic events*. We plan to study classification models based on deep neural networks to be employed in the automatic and real-time analysis of signals recorded by seismic networks. The important recent technological development in the field of seismic monitoring has led to the development of distributed networks consisting of thousands of detection sensors. The signals acquired by these networks, due to their number and complexity, today require the use of automatic processing techniques. Deep networks have caught considerable interest from the scientific community involved in the analysis of seismic signals. It is becoming more and more clear that the development of these techniques can support, and over time replace, the expert seismological analyst. As part of this research activity, it is planned to develop automatic analysis techniques able to recognise within a seismic signal, the waveforms generated/associated with earthquakes and to extract from these the most important kinematic and dynamic information. This will allow for a complete automatic characterization of the earthquake phenomenon. It is planned to implement and test the most modern techniques reported and already identified in the scientific bibliography in order to identify the most efficient one, both in terms of robustness of the results and efficiency of implementation.

E3. *Deep Learning for Question Answering in museum virtual tour*. Museums play an essential role in enabling people of all ages to study history, culture and contemporary society. Many museums, in turn, use interactive systems such as chatbots to provide this type of information to visitors. A chatbot that answers a user's question in natural language can be seen as a question-answering system. A modern and effective approach to question-answering concerns the use of deep learning networks that define a so-called language model, which, suitably followed by a fine-tuning phase, can be used to develop unsupervised question-answering methods. An example is the Bert model (BERT (Bidirectional Encoder Representations from Transformers) which is a language model that has been used as the main module for question answering on different types of topics. We intend to use and compare different language models in the museum context, creating virtual agents capable of answering a visitor's questions. The virtual agent will be integrated into the museum via virtual or augmented reality, using the Unity development platform.

E4. *Deep Learning for embeddings*. An embedding is a low-dimensional space where high-dimensional vectors are mapped into. Thanks to embeddings, the application of clustering and classification methods could become easier and in some way interpretable. In recent years, with the increasingly frequent use of deep networks, embedding methods based on deep networks have been proposed. This is the case of the so-called deep metric learning. The objective of this research topic is to study the methods that allow the creation of an embedding with particular attention to those that use deep networks. Graph neural networks are another possible approach to embedding. Researchers of the group have already investigated the application of these methods in the field of medical imaging, in particular histopathology image classification of breast cancer. Atrial fibrillation identification is another application we plan to investigate.

E5. *Natural language processing for legal document analysis*. The purpose of this research is to provide decision-support systems to aid legal investigations. Machine learning, deep learning, and complex networks will be the main components of the system. Deep learning will be adopted to recognize various entities in legal texts, which will be arranged in a complex network that relates these entities. After a statistical validation phase, this network could be used as a graphical tool to make new discoveries or deeper investigations. We plan to investigate different methodologies to extract the identities and different complex network models. This research will be conducted using Italian text provided by the Public Prosecutor's Offices.

E6.*AI for community-based digital primary prevention.* The purpose of this research is to develop an advanced interoperable Advanced Cancer Surveillance System powered by an innovative digital infrastructure integrating administrative, clinical, health, and environmental data sources at both the individual and the population levels. The innovative cancer surveillance system will be based on data-driven models and state-of-the-art ML techniques with advanced functions for a) integrating epidemiological data with data from environmental monitoring and occupational settings, health determinants, and lifestyles profiling to improve cancer primary prevention; b) interoperating population-based registries, specialized clinical registries and biobanks for high-resolution studies; c) developing advanced models to assess the effectiveness of preventive interventions.

<u>Research funds:</u>

**A.** Fundings coming from future calls belonging to PON, POR, PRIN. Actually, fundings from PRIN 2017 ADASCOML, from GNCS-IndAM and National Recovery and Resilience Plan ITSERR – Italian Strengthening of the ESFRI RI RESILIENCE.

**B.** The researcher's team use funds from national and regional research project including FFR, FIRB, PRIN, PON and GNCS-INdAM, both completed and currently active. Moreover, thirty-party contracts are considered. The advised strategy is to track all opportunities available in national and international environments. In terms of procuring funds, the team is part of the Infolife, Artificial Intelligence and Intelligent Systems and Big Data laboratories of CINI, an inter-university consortium. The team is also part of the CNIT consortium (Consorzio Nazionale Interuniversitario per le Telecomunicazioni) and one of the group's members is involved in the H2020 ELEGANT project, which partly covers the research on distributed processing within IoT networks. There are ongoing and/or completed activities related to the submission of proposals for participation in H2020, PRIN, FIS, FISA and national calls under the PNRR plan.

**C.** In addition to the research funds of the individual participants, funding from the following projects will be used: PO FESR Sicilia 2014-2020 - Azione 1.1.5, 3DLab-Sicilia (use-case SIMAM); ENTRUST (Next Generation of Trustworthy Agri-Data Management, GA 101073381) Marie Skłodowska-Curie Doctoral Network (DN); HEAL ITALIA - Health Extended Alliance for Innovative Therapies, Advanced Lab-research, and Integrated Approaches of Precision Medicine, PNRR. Codice identificativo PE0000019 - CUP UNIPA B73C22001250006.

**D.** In the framework of *Programma Operativo Nazionale Ricerca e Innovazione* (PON-RI 2014-2020) a fixed-term research position has been funded for years 2022 and 2023 (23 months x 5,088 euros), filled by a researcher working on human interaction with sustainable artificial intelligence (D11) and explainable artificial intelligence (D12). As part of the call for projects PRIN 2022, the research unit is leading a national consortium for the proposal Visual-Auditory-Tactile Trajectories, aimed at finding consistent representations of trajectories at a variety of scales of the egocentric space, by a variety of technologies in diverse interacting sensory environments.

**E.** In the framework of the *complementary fund of the National Recovery and Resilience Plan* (PNRR PNC 2022), a fixed-term research position will be funded for years 2023–2026 (36 months x 5,088 euros) and will be filled by a researcher working on AI methodology for primary disease prevention. The group can also benefit from third-party funding, FFR and PON. Researchers in the group are involved in several submitted PRIN 2022 proposals in the role of principal investigators.

National and International Collaborations:

**A.** List of international partners who collaborate on the research topics:

- Université du Québec, Montreal, Canada
- Université Gustave Eiffel, Francia
- Université Paris Nord, Francia
- Université Paris Diderot, Francia
- Eötvös Loránd University, Ungheria
- Universidade Nova de Lisboa, Portogallo
- University of Helsinki, Finlandia
- Université Claude Bernard Lyon 1, Francia
- Centrum Wiskunde & Informatica (CWI), Paesi Bassi
- Federal University of Uberlandia, Brasile
- University of South-Florida, USA
- Kyushu University, Japan

**B.** The team engages in active collaborations with both national entities such as the National Research Council (CNR) and Italian Universities, as well as international organizations including IBM T.J Watson Research Center, Harvard University, and the National Institute of Health (NIH) in the USA. These collaborations have been productive and are planned to be continued and potentially expanded, especially within the European region.

**C.** The group has been doing its work for many years already in collaboration with various national and international research organizations, producing contributions to the literature and laying the groundwork for possible future projects. In the international sphere, collaboration with the University of Dundee (UK), Innovation Value Institute, Maymooth University, Dublin (EI). Moreover, ERASMUS+ interchange projects have been activated with Ruse University in Bulgaria and with Vilnius Gediminas Technical University in Lithuania.

**D.** The research unit has established research relations with Delft University of Technology, KTH Stockholm; IRCAM Paris; ZHdK Zurich; Aalborg University Copenhagen; University Diego Portales (UDP-Chile). A researcher from UDP-Chile has been visiting the Department of Mathematics and Computer Science of the University of Palermo for four months in year 2022 and a continued collaboration program is being run in 2023.

**E.** The group has documented national collaborations with the National Research Council of Italy, in particular the Institute for high-performance computing and networking (ICAR-CNR) and the Institute for Educational Technology (CNR-ITD). There is also an active collaboration with the National Institute of Geophysics and Volcanology. The international collaborations are with Massachusetts General Hospital and Harvard Medical School, USA. All these collaborations will be maintained in terms of the production of scientific papers and research proposals.