Projects or Research lines -------------------------

Offer name	Description
Mathematical biology	The understanding of natural phenomena requires the interaction of specialists from different areas of scientific knowledge. In this way, biological phenomena have benefited from the diversity of approaches with which they have been studied. In particular, since the beginning and especially from the mid-20th century onwards, specialists in Mathematics, Physics, and Engineering have directed their research interests toward problems in Biology. Consequently, Biomathematics and Mathematical Biology have emerged as a transdiscipline, the former, and an interdiscipline, the latter, which capture the essential elements for the optimal and rigorous analysis of biological phenomena. Specifically, the study of the mechanisms governing different types of self-organization is of vital importance for phenomena in biology, chemistry, physics, and other scientific fields. An example of this is the morphogenetic processes associated with the growth and development of organs such as roots in plants, where the interactions between families of proteins and hormones, along with the physical structure of the environment in which the roots grow, are crucial. So far, several mechanisms that produce different types of self-organized structures have been identified. These mechanisms involve specific dynamic behaviors, for example, traveling wave types or "wave-pinning" types; similarly, the formation of extended patterns and localized structures. However, a complete theory that includes the consequences that various physical and chemical aspects may have on these mechanisms and on the shapes and structures that organisms acquire during their development is still lacking. For example, most models proposed to study different self-organization phenomena, particularly in biology, fundamentally include the transport of substances through diffusive processes which, usually, due to the size of the participating agents or isotropic characteristics of the medium at a certain scale, are assumed to be local interactions. However, due to the heterogeneities and physical characteristics present in some biological systems, such as the existence of cell membranes and the usual crowding conditions inside living cells, these processes can be anomalous in nature. For example, models describing the propagation of contaminants in aquifers. Because the methods and tools used in the study of biological phenomena are widely diverse—that is, they belong to areas such as dynamical systems, differential equations, numerical and asymptotic analysis, among others—the area of Biomathematics cultivated at the CCM has the potential to connect not only with other areas of mathematics but also with other fields of scientific knowledge.

Mathematical physics	Within mathematical physics, the Morelia group cultivates the areas of nonlinear evolutionary equations and quantum gravity, with some overlap in the study of quantization methods. In the area of quantum gravity, new structures in mathematics and physics are developed, inspired by quantum field theory and particularly by quantum gravity. Topological field theories, lattice field theory, loop quantization, and Wilson's renormalization group collaborate to form rich structures. They generate powerful invariants in the study of knot theory and manifolds; in physics, they help formulate better models for quantum gravity and study the semiclassical limit of existing models. A. Corichi, R. Oeckl, and J. A. Zapata have made contributions in this direction. On the other hand, relativistic physics suggests quantization problems that are addressed using ideas from geometric quantization and symplectic reduction. This leads to concrete problems in symplectic geometry, such as the classification of certain classes of polarizations. J. A. Zapata collaborates in solving these types of problems.
Quantum gravity	The field of gravitational physics has become in the past decades a broad field of physics whose theoretical aspects range from astrophysics and cosmology to quantum gravity, one of the most important frontiers of our current understanding of the nature of matter and spacetime. Research in gravitational and mathematical physics at UNAM-Morelia includes a broad spectrum from mathematical espects of the quantum theory, gauge theories to some numerical applications. Research in Gravitational Physics at UNAM-Morelia covers both classical and quantum aspects of gravitational theories. Among the classical part, of particular interest are mathematical aspects of hairy black hole solutions and the nature of the evolution equations used in realistic simulations of evolving geometries that may undergo gravitational collapse. The quantum aspects are motivated by the current attempts to construct a complete theory of quantum gravity and to understand the geometrical structure of spacetime at the smallest scales. In particular, a strong research efford is being pursued within loop quantum gravity and spin foam models. There is also a strong research efford in quantum field theory and mathematical physics.

Algebraic Topology and Geometric Group Theory	These areas study the interrelations between algebra, topology, and geometry. At the Center for Mathematical Sciences, the branches worked on include topics in geometric group theory, large-scale geometry, global analysis, and applications of algebraic topology. Dr. Jesús Hernández specializes in the study of the Teichmüller modular group and its relationship with the geometry of the curve complex and other simplicial complexes, in the context of rigidity of actions and large-scale geometry of the modular group. Dr. Noé Bárcenas's work includes topics in global analysis, index theory methods, and noncommutative geometry interacting with the Baum-Connes conjecture and the Gromov-Lawson-Rosenberg conjecture, the use of equivariant homotopy theory to study finiteness properties of groups, and applications of algebraic topology in various contexts. Dr. Daniel Juan Pineda has conducted research gathering evidence for the Farrell-Jones conjecture and its geometric consequences, such as the Borel Conjecture. Likewise, he has made important contributions in the area of finiteness conditions for groups, especially in the study of classifying space models for families of groups. Drs. Noé Bárcenas and Daniel Juan are interested in topics of geometric group theory and its application to the Farrell-Jones and Baum-Connes conjectures, as well as in gathering computational evidence for these conjectures. Drs. Jesús Hernández and Ferrán Valdez also conduct research related to the large-scale geometry of the modular group and complexes on which it acts, in the context of infinite-type surfaces.

Algebraic Combinatorics	Algebraic Combinatorics is a young interdisciplinary area of Mathematics with a very broad character, whose essence lies in the interaction between combinatorics and algebra. On one hand, it studies combinatorial aspects of more classical branches of mathematics such as Group Theory, the Representation Theory of Coxeter Groups and Semisimple Lie Algebras, Symmetric Function Theory, and Schubert Calculus. On the other hand, to solve problems of enumeration and about permutations, simplicial complexes, polytopes, graphs, partially ordered sets, and other combinatorial objects, it uses a variety of algebraic ideas and techniques, such as those coming from Group Theory, Linear Algebra, Homological Algebra, Commutative Algebra, Hopf Algebras, and Category Theory. Algebraic Combinatorics and Group Representation Theory constitute the working context of Dr. Ernesto Vallejo, whose recent work is described in the following lines. One of the problems he has worked on over several years is studying ways to calculate the decomposition into irreducibles of the tensor product of two representations and to provide combinatorial or geometric methods to calculate the multiplicity of each irreducible representation in the product. In some cases, it is relatively simple; in others, extremely complicated. A classic and very important example is the study of Littlewood-Richardson coefficients, which give the multiplicity of an irreducible representation of the general linear group in the product of two other irreducible representations. These coefficients are calculated by counting the number of certain combinatorial objects called Littlewood-Richardson tableaux, or the number of integer points in certain convex polytopes. There are other coefficients, the Kronecker coefficients, which give the multiplicity of a complex irreducible representation of the symmetric group in the product of two other irreducible representations. These coefficients generalize the Littlewood-Richardson coefficients. It is an open, difficult, and highly interesting problem in algebra, physics, and more recently in Geometric Complexity Theory, to find a satisfactory method to calculate the Kronecker coefficients and describe them combinatorially or geometrically, in the style of the Littlewood-Richardson coefficients. Over several years, he has developed a method to study these coefficients using two- and three-dimensional matrices, together with two concepts from Discrete Tomography: uniqueness and additivity. In particular, he has obtained several results and characterizations of additive matrices. The method has allowed finding some stability results for the Kronecker coefficients. Dr. Daniel Pellicer is dedicated to the study of symmetries of discrete structures. His work focuses on symmetries of maps on surfaces and certain objects called abstract polytopes. Maps on surfaces have been studied from various aspects including purely combinatorial (for example, the four-color theorem), eminently

Foundations of Quantum Field Theory	The fruitful interplay between mathematics and physics has a long history going back to the very beginnings of both subjects. In recent times quantum field theory has been at the forefront of novel directions in this interplay. In particular, work by Witten, Segal, Atiyah and many others beginning in the 1980s and inspired by quantum field theory has lead to new insights into low dimensional topology, knot theory and their relations to other areas such as category theory, quantum groups and operator algebras. While this development, also known as topological quantum field theory, has lead to a whole new branch of algebraic topology, its impact back on physics has been more limited. While it plays an important role in two-dimensional conformal field theory, its potential for elucidating the mathematical foundations of the type of quantum field theories at the basis of our modern understanding of nature is largely unexplored. This is a main aspect of research in quantum field theory at the CCM. It is well known that quantum field theory in its present form is incompatible with key principles of general relativity. This may be traced back to the prominent role of a non-relativistic conception of spacetime build into the formalism of quantum theory at its very inception. One of the aims of research at the CCM is to seek a formulation of the foundations of quantum theory that does away with any reference to an external classical notion of time, while still embracing the overwhelming empirical success of quantum field theory in fundamental physics as we know it.
Dynamical Systems	Superficially speaking, Dynamical Systems is the area of mathematics that studies phenomena that depend on time. It originated from differential equations (when studying the behavior of solutions for large times), and from the iteration of real and complex variable functions (when applying iterative methods to find roots of algebraic equations). Currently, dynamical systems form a branch of mathematics that includes a wide variety of techniques: differential equations, differential and algebraic geometry, Riemann surfaces, complex variables, singularities, differential topology, and more. This area is closely related to applications, since for many applied mathematics models, it is natural to study their behavior over long time periods.

Topology and Set Theory	Topology is one of the areas of mathematics that has experienced significant development both nationally and internationally in recent years. Increasingly, topological methods are being applied across various scientific fields. The activity of this group within the Unit shares a common topological context, although they conduct research projects in a wide variety of topics including algebraic topology, set-theoretic topology, and set theory, as well as related areas such as mathematical logic and model theory, dynamical systems, and Boolean algebras. M. Hrusak and S. García-Ferreira focus primarily on the interactions between topology and set theory. Using methods from infinite combinatorics, they have solved several important problems in fields such as topological groups, selection theory, ultrafilter theory, pseudocompactness, resolvability, topological games, almost disjoint families, Fréchet spaces, and Boolean algebras. They employ set-theoretic techniques and have also developed them in their work on cardinal invariants, almost disjoint and independent families, guessing principles, and the forcing method. Meanwhile, Daniel Juan has concentrated his work in the area of algebraic topology, whose main objective is the classification of topological spaces emphasizing different geometric aspects of them. For example, the goal is to classify spaces according to homotopy, h-cobordism, or homology. The methods of algebraic topology seek algebraic invariants to study topological or geometric phenomena. Examples include homology groups, homotopy groups, and various types of K-theory. Some of his work involves the computation of these invariants. Notably, he has worked towards gathering evidence for the Farrell-Jones conjecture, which states that the algebraic K-theory of the group ring of a discrete group is determined by the algebraic K-theory of its virtually cyclic subgroups.

Algebraic Combinatorics and Group Theory	Algebraic combinatorics is a broad area of mathematics whose essence lies in the interaction between combinatorics and algebra. On one hand, it studies combinatorial aspects of more classical branches of mathematics such as group theory, representations of Coxeter groups and semisimple Lie algebras, symmetric function theory, and Schubert calculus. On the other hand, it uses algebraic methods to solve combinatorial problems, such as those arising from enumerative combinatorics and the theories of convex polytopes and graphs. Algebraic combinatorics and group theory constitute the research context of this group, whose recent work we describe in the following lines. The Burnside ring of a group is an invariant of the category of groups that has been extensively studied due to its relation to modular representations of groups and group cohomology. This invariant does not determine the group in general, but it is interesting to explore the types of properties that groups sharing the same Burnside ring must have. We have proven that for abelian groups the Burnside ring determines the group, and that for arbitrary groups, the table of marks determines the composition factors of the group. It was also shown that every isomorphism of Burnside rings can be normalized and induces a good correspondence between the conjugacy classes of the lattices of soluble subgroups. 3-transposition groups were introduced by B. Fischer in his search for a class of sporadic groups. In his work, he classified all 3-transposition groups that do not have normal soluble subgroups. In this research line, we study 3-transposition groups, not necessarily finite, from a geometric point of view. We have obtained the classification of 3-transposition groups whose associated Fischer space is symplectic. We introduced the concept of diagram, which gives a minimal generating set of the group, and we have characterized the diagrams in the category of Fischer spaces. One of the classical topics in algebraic combinatorics is the use of Young tableaux for the study of representations of the symmetric group. In this area, there is a classical, complex, and highly interesting problem in algebra and physics, which consists of finding a satisfactory method to calculate the decomposition of a Kronecker product of two irreducible complex characters of the symmetric group into its irreducible components and to combinatorially describe their multiplicities. We have developed a new research line that consists of determining the minimal components with respect to the dominance order of partitions and providing a

Algebraic Geometry	Algebraic geometry studies the sets determined by the solutions of systems of polynomial equations in several variables with coefficients over a field. These sets define what are known as algebraic varieties, which can be affine and/or projective varieties, depending on the space in which the solutions are studied. Algebraic varieties can be points, curves, surfaces, or higher-dimensional varieties. Understanding certain geometric properties of algebraic varieties is an important problem in algebraic geometry, and to understand such properties, it is very useful to study varieties in "families," that is, to study varieties by varying the coefficients (parameters) of the polynomials defining them. One of the central and current problems in algebraic geometry is the description of the properties of such families, and in particular, the description of the properties of their "parameter spaces." This gives rise to the so-called moduli spaces, which are also algebraic varieties. These topics are currently very relevant and active at the international level. Some algebraic geometry problems studied at CCM relate to the study of properties of subvarieties of the moduli space of curves M_g. For example, studying the geometry of subvarieties that parametrize curves with a projective model having nodal singularities and their relation to subvarieties in the Severi variety of plane curves with nodes. Topics related to abelian varieties and Prym varieties obtained from group actions on curves are also studied. Research topics also include vector bundles over curves, in particular the study of (determinantal) varieties called Brill-Noether varieties, which parametrize stable bundles of a given degree and rank with a fixed number of sections. One of the main problems in this direction is the study of the existence of irreducible components that are generically nonsingular and have the expected dimension for certain values of the genus of the curve, the degree, the rank of the bundle, and the number of sections of the bundles. A technique used to establish the existence of new components is the degeneration of curves together with the theory of limit linear series in rank one and higher rank for vector bundles. Another technique used in these problems is the deformation and extension theory of sheaves to understand some properties of the bundles of interest. We have collaborations with academic groups from other national universities where algebraic geometry is applied in other areas. For example, we have collaborated with researchers in dynamical systems at Universidad Juárez Autónoma de Tabasco, with the algebraic geometry and dynamical systems groups at CIMAT and the Department of Mathematics at Universidad de Guanajuato, and also with geometers from the algebraic geometry group at Universidad Autónoma de Zacatecas. This
Number Theory	Since the 17th century, when P. de Fermat stimulated the mathematical community's interest in researching problems in number theory, a large number of tools have been developed to address the solution of such problems. These tools range from clever arguments explicitly designed to tackle particular problems to the development of powerful, general, and deep techniques and theories. Among the latter, one can mention, for example, algebraic number theory, the theory of Diophantine approximations, and analytic number theory. Each of these areas has multiple branches. In their mathematical work, E. Balanzario, M. Garaev, and F. Luca have contributed to solving various problems in number theory while also advancing the development of the methods specific to this theory.

Differential Equations	Evolutionary equations form the basis of mathematical models for various phenomena and processes in physics, biology, engineering, and other scientific domains. One research line in this area is to solve the famous Navier-Stokes problem. Asymptotic methods hold a special place in the theory of nonlinear evolutionary equations, as they allow us to obtain approximate representations of solutions. The goal is to develop new methods to study the asymptotic behavior for large times of solutions to conservative or dissipative nonlinear equations in the case of large initial values. One of the research lines pursued by E. Kaikina and P. Naumkin is related to the development of new analytical methods for studying Cauchy and boundary value problems for a general class of nonlinear evolutionary equations. These equations describe various wave propagation phenomena in different conservative or dissipative media and are of great importance in many areas of physics.
Discrete Geometry	Discrete Geometry is a branch of mathematics that studies properties of discrete geometric objects such as point configurations, tessellations, and polytopes, as well as combinatorial properties of families of geometric objects like convex sets and hyperplane arrangements. Dr. Daniel Pellicer studies highly symmetric objects in Euclidean, projective, or hyperbolic spaces. In particular, he has focused on polytopes from the viewpoint introduced by Grünbaum, where faces of rank greater than 1 are seen as one-dimensional objects (graph embeddings). From this perspective, the faces are not required to lie in a subspace of any given dimension. The most studied polytopes are the so-called regular ones, which have all possible symmetries by combinatorial reflections. In the last two decades, chiral polytopes have attracted particular interest; these are polytopes that have all possible symmetries by combinatorial rotations but none by combinatorial reflections. In 2005, Schulte classified chiral polyhedra in three-dimensional Euclidean space; all of them are infinite. The classification in three-dimensional Euclidean space was completed in 2017 with the full list of rank 4 chiral polytopes (it is proven that there are no chiral polytopes of rank higher than 4 in this space). Some examples of chiral polyhedra and rank 4 chiral polytopes are known in other spaces, but a final classification still seems far away. Even less is known about polyhedra with other interesting types of symmetry, such as those where the symmetry group acts transitively on the edges. This suggests many lines of research to pursue in the coming years. Dr. Edgardo Roldán focuses his work on topics related to convexity. One example is Helly's theorem, and other theorems related to convexity include Radon's and Carathéodory's theorems, which deal with the structure of point sets in Euclidean spaces. It has long been known that there are more general versions of these three theorems. For example, Helly's theorem has a generalization called the "colored Helly theorem."

Representation Theory of Algebras	Over the past 40 years, the representation theory of associative algebras has undergone vigorous development. Its foundations have been reorganized, and its applications and connections with other areas of mathematics have diversified and deepened. Currently, it is a vibrant field marked by numerous publications and frequent international specialist meetings. The Morelia group is part of the Mexican school that emerged in the late 1970s and has played an influential role in the theory's development. Key techniques that have driven the field include almost split sequences, diagrammatic methods, universal covers, and matrix methods. Central achievements include the proof of the Brauer-Thrall conjecture (Bautista), the tame/wild dichotomy theorem (Drozd/Crawley-Boevey), and classification methods for finite type algebras. Current research largely focuses on the study of tame representation type algebras, the application of homological methods and algebraic topology, and the extension of representation theory to areas such as commutative algebra, geometry, and quantum groups. The Morelia group actively contributes to contemporary research trends, including: -Development of bocs theory and its application to tame and wild cases (R. Bautista, L. Salmerón, R. Zuazua). -Study of derived categories (R. Zuazua, R. Bautista, R. Martínez-Villa). -Geometry of representation varieties of bocses (R. Bautista, A.G. Raggi, L. Salmerón). -Application of homological methods to the study of sheaves over projective space (R. Martínez-Villa). This body of work situates the Morelia group at the forefront of algebra representation theory, bridging deep theoretical advances with broad applications.

Nanoestructuras poliméricas y sistemas transdérmicos con aplicación en ingeniería de tejidos y fines terapéuticos	Generate scientific knowledge on the synthesis of new compounds and polymeric hybrids useful in the manufacturing of nanostructured polymeric materials for application in guided tissue engineering, controlled release of therapeutic agents (based on patches and polymeric microneedles), and in cell culture and study.
Environmental Impact Assessment through Life Cycle Analysis	Environmental impacts of processes and/or products are estimated using the Life Cycle Assessment methodology: evaluation from raw material extraction to use.
Ecotechnologies	Development, dissemination, implementation, and monitoring of technologies with lower environmental impact.

UNESCO Global Geoparks	Geoparks are one of UNESCO's most recent and innovative site designations. The result of decades of effort, this new designation is based on extensive discussions and pilot tests focused on a previously recognized need: the valorization and conservation of geological heritage, or The Memory of the Earth. Since they fall under UNESCO, geoparks have a global reach, establishing themselves as a powerful mechanism for international cooperation to promote sustainable development actions based on communities. China is the country with the most geoparks in the world, while Mexico has only achieved two designations since the program began.
Waste valorisation and treatment	Organic fraction of urban and domestic residues can be recycled for added value, enhancing pollution control and environmental improvement
Hydric resilience planning	Programs and planning for hydric resilience plants, processes and treatments as options for better water resources utilisation
Processes and equipment for rainwater recollection	Design of intallations for uses of alternative water sources

General mobility and transportation problems, designing solutions and alternatives	Solutions offered for major mobility problems, considering random factors such as high vehicles concentration affecting schedules and performance
Geothermic Energy	Patented systems for geothermic energy use and applications
Development of permeable pavements for rainwater collection	Chemical and engineering design for pavements oriented to rainwater collection, with improved structural capabilities

Monotonic characterisation and dynamic essays in porous materials	Tests and essays for specific building materials
Design, and tests for steel, concrete and masonry structures, to fulfill international standards	Developing of test methods and processes for improving concrete, masonry and steel structures perfomance
Hydraulic properties of building materials	Checking methods to confirm fulfillment of building materials with hydraulic standards

Coastal Dynamics	Research on factors of coastal changes, both natural and anthropogenic
Superconductive technologies applied to railroad transportation	Application of artificial intelligence in several devices and processes for public transport
Sustainable water management	Systems, programs, methods and innovative technologies for water treatment plants, and for industries, aiming to improve recycling and reuse water
Photonics	Includes the synthesis of mesoporous materials, catalysts, and trimetallics for hydrotreating reactions, nanostructures for photocatalysis, and materials for controlled drug release.
Nanostructured Materials	Includes the synthesis of mesoporous materials, catalysts, and trimetallics for hydrotreating reactions, nanostructures for photocatalysis, and materials for controlled drug release.
Solid State	Crystallography, thermal and electronic properties of semiconductors; in addition to the use of characterization techniques such as electron microscopy, X-ray diffraction, and Raman and infrared spectroscopy.
Food Technology	Refers to the processes of nixtamalization, study of the physical and chemical properties of flours, production of prickly pear flour, among others.