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INTERVIEW

"THE INSTITUTE OF MATHEMATICS IS MY HOME IN BUCHAREST" INTERVIEW WITH DAN BURGHELEA[1]

Dan Burghelea is an Emeritus Professor in the Department of Mathematics at Ohio State University and an honorary member of the "Simion Stoilow" Institute of Mathematics of the Romanian Academy. He was born in Râmnicu Vâlcea, in 1943. He graduated from the Faculty of Mathematics of the University of Bucharest in 1965, when he already had seven articles published in specialized journals from Romania and abroad. In 1968, when he completed his doctorate at the Institute of Mathematics, he was already a mathematician known for his outstanding results, published in some of the most prestigious mathematical journals. In 1972 he earned the title of "Doctor Docent" from the University of Bucharest (being at that time probably the youngest scientist holding such a degree in Romania), and in 1995 he received the title of Doctor Honoris Causa from the University of Timişoara.

He worked as a researcher at the Institute of Mathematics of the Academy, after its dissolution at to the Institute of Atomic Physics, and later to INCREST. He left for the USA in 1977, and since 1979 he has become a professor at Ohio State University. Over time, he has had numerous scientific visits to many of the most famous universities and research institutes in the world, has published six books and over 100 scientific articles, and still has articles in preparation and research projects underway. This year he spent three months in Romania, on the occasion of which he held conferences at IMAR where he presented his recent results in the field of computational topology. He was very kind to grant us an interview, sharing with us some of his thoughts on mathematics and beyond. For all this, we thank him.

Q: In your childhood or adolescence, what sparked your interest in mathematics?

A: By participating in math problem-solving competitions, pre-Olympiads (in middle school), Olympiads, and the Mathematics and Physics Gazette/„Gazeta Matematică şi Fizică" (in high school), I realized that I was better than my peers and that I could convince my teachers of this.

This activity started by accident, in a way. I was good at drawing and one of the teachers asked me to draw the design of our Math Wall Gazette („Gazeta de perete") at school. Because I drew well, I was put on the editorial committee. Being on this editorial committee, I felt obliged to solve the problems proposed there. I saw that I was solving them all and I was appreciated for this.

Later I found that, by producing solutions to subtle geometry or number theory problems, I **experience a state of joy** even greater than in other activities like sports or radios fixing/building, my favorite extracurricular activities, and that I surpass myself.

[1] This interview (taken by Anca Iuliana Bonciocat) took place in the autumn of 2021 and appeared online in Romanian in the IMAR Newsletter No. 1.

In the lower grades, there were some competitions called "pre-Olympiads", with solutions sent by mail, organized on a national scale. In the pre-Olympiad I participated in in the 6th grade, I took 1st prize at the national level (I suspect there were several 1st prizes, the evaluation being determined by the correctness and elegance of the proposed solutions), while my grade in class was below what I thought I deserved, probably not the highest; I had the satisfaction that the math teacher at the time rose my grade to the maximum level, but without much joy.

In high school I participated in the Olympiads. In the final phase of the Math Olympiad, I only managed to get the 3rd prize and the 2nd prize, but at the same time I started working on problems from Mathematics and Physics Gazette, and in the annual contest I got the 1st prize, for solutions and comments. All of this brought me great satisfaction and also determined me to go to the Faculty of Mathematics.

As a child, I had a number of passions. I enjoyed assembling or repairing radios, I also had a radio station, I was probably the only one in Râmnicu Vâlcea who had something like that, although I was in the last years of high school. I also enjoyed practicing various sports, but I realized that solving problems gave me even greater satisfaction. It is true that I was greatly helped by a teacher, who had a lot of influence on me, and this was also because we shared the pleasure of going fishing.

Q: Do you remember what were the first books that took you beyond elementary mathematics, aside from the school context?

A: In high school, there were several books. Two of them, The Geometry of the Triangle, by Traian Lalescu, and The Geometry of Remarkable Elements, by C. Mihalescu, both elementary mathematics, but far above school textbooks.

In the last grades of high school I learned about, and I read part of the famous book **Algebra** by **van der Waerden** and the book **Group Theory** by **A. Kurosh**. I also purchased, I think, volume 1 of Goursat's Treatise on Analysis (in 3 or 4 volumes). As a high school student (or before entering college) I didn't read more than 30–50 pages of the first two and, I think, very little or almost nothing of the third. Also in high school, or at the latest in the first years of college, I read **Symmetry**, the book by **Hermann Weyl**. Articles from Gazeta Matematică și Fizică series A (for teachers) were often sources of additional initiation to the traditional content of the high school curriculum. I think that my high school teacher, **Pavel Guțu**, a refugee from Cernăuți, where he had been the assistant of professor Miron Nicolescu at the University, had a considerable influence in inducing in me the desire to surpass my knowledge with extracurricular mathematics. By the time I entered the Faculty of Mathematics in my first year, I had already been exposed to at least 40% of the material that was going to be taught, so I was craving courses above my level.

It's a funny story how I got Tudor Ganea, who was going to teach a fourth-year algebraic topology course, which I aspired to attend, even though I didn't have the necessary preparation, to consider me special and accept me because of

Kurosh's book. I was a first-year student, I think the end of my first year, and the course was probably going to take place the following fall. Tudor Ganea conditioned my acceptance to the course on understanding the first chapters of Kurosh's book. I didn't tell him that I had already read them. After only two weeks, I showed up for verification. I impressed him, I guess, with the speed of digesting more advanced mathematics, and he told me that I could come to that special topology course. I liked it, I think I was the most dedicated student in that class.

Q: During your student years, which professors inspired and encouraged you and in what way? What was the ambience within your generation at the Faculty of Mathematics?

A: In chronological order, the most influential professors were: Nicolae Dinculeanu, Tudor Ganea, Kostake Teleman, Theodor Hangan. I also have warm and respectful memories of Cabiria Andreian, Ionel Bucur, Gh. Galbură and Solomon Marcus.

Probably one of the most influential persons, my initiation partner in "modern mathematics", as I thought of it at the time, and my first collaborator, was my **colleague and friend Nicolae Popescu**, a student a year ahead of me. The companionship of two younger students, **Gh. Lusztig** (two years younger) and **H. Moscovici** (one year younger), both with an exceptional subsequent evolution (Gh. Lusztig, laureate of several world-famous mathematical prizes), was very stimulating, especially in the last years of college.

As a student, I learned a lot, perhaps the most, from the seminars of the Institute of Mathematics, which I attended from a very early age, and which were actually my most important learning opportunities (**Valentin Poenaru**'s Morse Theory seminar and **Martin Jurchescu**'s Function theory of several complex variables seminar). There I met and was indirectly influenced by **Cornel Constantinescu, Aristide Deleanu, Albert Felix, Ciprian Foiaş, Gh. Gussi**. In any case, the new mathematics that I learned, I learned it at the Institute of Mathematics, from the seminars, but not only. All of those names I mentioned were already accomplished mathematicians, but they were also very accessible to friendships, to hiking companionships (hiking, a common outdoor activity for mathematicians). For example, with Cornel Constantinescu, a person 12–14 years older than me, I became and remained a very good friend. It could have been more complicated if they had been professors at the faculty, and I had been a student. At the Institute we interacted differently, in the context of the seminar, we were like colleagues.

Stoilow had three or four special students, whom I knew personally, and to whom he recommended different directions of research he thought as very important. All of them made exceptional careers, especially Cornel Constantinescu, as also Cabiria Andreian-Cazacu and Martin Jurchescu. Martin Jurchescu was directed towards a new field at that time: algebra versus the theory of functions of

several complex variables versus algebraic geometry. M. Jurchescu was a more contemplative person, not predominantly creative, but with a lot of charisma as a professor. I consider all three of them my professors, although only Cabiria Andreian taught at the University and I was a student in her class.

For me and my colleagues, more precisely my friends, mathematics, an apolitical discipline, without national color, with values untouched by "what is good and what is bad" as decided by those who controlled daily life, was, together with classical music and sports, the context in which we could freely express our own personality.

Q: You published your first results in mathematics during your early undergraduate years, you obtained your doctorate at just 25, your Doctor Docent title before you were 30. It's a remarkable ascension; how exactly did things come together?

A: I began mathematical research in parallel with my initiation into mathematics.

My first paper [1], published in the **Comunicările Academiei Române** by Miron Nicolescu, had **as mentor N. Dinculeanu**, for us a very charismatic professor teaching the Mathematical Analysis course, during the first year. Miron Nicolescu was also the official supervisor of my doctoral thesis, which, however, has no connection to the topic of that first paper.

My first paper on algebraic topology [2] was in **collaboration with Nicolae Popescu** and published in the journal Studii și Cercetări Matematice. It did not have a mentor, but it was appreciated and encouraged by Kostake Teleman (part of it I believe was included as an appendix in his book on algebraic topology). These papers were written and published during the first or second year, and the second or third year of college, respectively.

My diploma thesis was an exposition with parts of "original contributions" to the theory of Serre fibrations in a semi-simplicial context and was published in Studii și Cercetări Matematice, immediately after my graduation.

Aristide Deleanu was my first important research collaborator. Our joint work [3 – 11], based on a collaboration that probably began during my student years or in the first year after our graduation, was recognized with the "Simion Stoilow Prize" awarded by the Romanian Academy for 1966.

My doctoral thesis entitled "Hilbert manifolds" is based on three original papers, two done alone [13, 14] and one in collaboration with **Nicolaas Kuiper** following a visit to Amsterdam [12]. The work with N. Kuiper contributed essentially to establishing that the differential topology of infinite-dimensional manifolds is essentially equivalent to homotopy theory, an unexpected and significant fact.

This paper with N. Kuiper is based on conjectures formulated a few years earlier at a topology congress in the USA. Participating in 1966 at the Moscow

congress, I met N. Kuiper and told him how, based on a result of his, published a few years earlier, and an infinite-dimensional analogue of Morse theory, I hoped to tackle this conjecture. It was suspected that the classifications of infinite-dimensional manifolds, which had attracted attention and were considered very interesting, should also be very complicated, given that the finite-dimensional ones were known to be complicated enough, and would require additional invariants. However, there was a result of Nicolaas Kuiper, and one of C. Bessaga, which suggested certain simplifications. I noticed them and pointed them out to him, I think he was not aware of them. As a consequence of the discussion, he invited me to Amsterdam for a 4–5 months stay and collaboration, probably in the hope of solving this conjecture. The result of my visit was a collaborative paper, which appeared in the **Annals of Mathematics,** the most important mathematical journal at the time, which answered the conjecture under a minor additional hypothesis. The hypothesis was removed by two British mathematicians a year later.

My PhD thesis contained results of this collaboration, complemented by topological applications made by myself. It was defended two years later, after the visit to Amsterdam, under the **supervision of Miron Nicolescu**.

My mathematical work had led to invitations, in various institutions and various places, and being outside Romania I could not take the exam to enter the doctorate program for two years, I believe. When I eventually enrolled as a PhD student the thesis was already finished, in the sense that the results were already published (or accepted for publication), not in preparation. Mr. Miron Nicolescu had an open position for doctorate under his (formal) supervision and things went very quickly.

The papers for which I had already won the Academy Prize and which were very dear to me, in a way, had no connection to the doctoral thesis, which had a different topic.

Q: What were the possibilities for a young mathematician to do research in Romania in the 1960s and 1970s? Did you have access to specialized literature, were you up to date with what was being done in the mathematical world, with the directions of research or with the current problems of that time? Were you able to travel abroad for scientific visits or conferences?

A: Fortunately, mathematics, being an apolitical field, made the libraries of the mathematical institutes of the Academy and of the universities in Bucharest, Iași, Cluj to have access to almost all the specialized journals. We were also favored by the translation into Russian of most of the relevant books and by the fact that Soviet mathematics was (still is) of maximum relevance, and moreover, practiced by mathematicians with remarkable teaching qualities; the materials obtained via the USSR were, without a doubt, “good and up-to-date mathematics”. My generation had essentially been forced to learn Russian in school and I had at least reached the level of following and understanding a mathematical text in Russian. **Yes, in Romania I was aware of what was of maximum interest in mathematics.**

The answer to the possibility of travel is a **YES**, but qualified.

A good part of the group of mathematicians at the Institute of Mathematics, between 1965–1975, were able to travel. But not all of them. As for me, having the chance to produce some notable mathematical results, thanks to the help of some personalities with scientific and political influence at the time, such as Gheorghe Vrânceanu, Miron Nicolescu, and I suspect also the positive recommendations of some like Ionel Bucur, Gh. Galbură and probably others, I was able to follow up on the invitations received from Amsterdam, Zurich and later Montreal, Princeton, Paris, Bonn, and other institutes or universities in Europe and the USA, where I shared with other mathematicians the results of my research and started collaborations that determined my later mathematics.

However, I never was a scholarship holder and I was unable to benefit from collaboration agreements or Romanian support, although I requested it. All my visits were based on invitations. During the research visits, my remuneration as an employee of a Romanian institution was interrupted. Leaving the country was always a problem that had to be solved from one event to another. I was somewhat lucky. The visits were carried out many times, but not always, and each time with effort.

Q: What areas of mathematics attracted you and why? I would like you to explain a little about the choices that you made, even the early ones.

A: My declared expertise, in the sense of the AMS classification, is: a) Algebraic and Differential Topology, b) Geometric Analysis, and more recently c) Computational Topology.

In my youth, I was attracted to mathematical fields that had a reputation for being in the center of attention; however, only issues that I understood why were important, had the impression or hope that I could contribute something to, and were consistent with my talents remained in my attention. However, I believe that the abundance of Fields Medals in the years 1951–1971 (J.P. Serre, R. Thom, J. Milnor, S. Smale, M. Atiyah, S.P. Novikov) for results in Topology, and perhaps my inclination for geometry, played a certain role in orienting my preferences towards topology/geometry issues.

My mathematics contains results that traditionally belong to algebra and analysis, often unrelated to the problems addressed in their initial formulation, but in my perception they are a way to approach them. To a large extent, my contribution was to realize the need for these aspects and to develop them in case they were not sufficiently developed. Most of these perceptions turned out to be correct.

I always started or have been motivated by problems considered very interesting but got fully involved only to the extent that I believed that I can make some advances. My training is that of a geometer, but with a great deal of pleasure for analysis. The problems I started with were topology problems. But what was

derived from them in order to pursue them belonged either to algebra, or analysis, or function theory... These problematics, as reflected in my research, generated by topology and geometry, have often continuations of algebraic or analytical flavor.

Over the years I became more tolerant of my possibilities, allowing myself to be drawn to issues considered important and leaving the door open to the need to learn mathematics that was still unknown to me, requiring skills I did not have, but compensated by the skills of my collaborators.

Q: How have these fields evolved in the last 30–40 years?

A: Topics that I initially dealt with alone or in collaboration with younger colleagues such as: the homotopy type of diffeomorphism groups, cyclic homology in connection with topology problems and the relationship with algebraic K-theory in the 80s–90s, determinants of elliptic operators are today in the attention of many topologists, analysts, differential geometers, algebraists. Results on the topology of infinite-dimensional manifolds have been and continue to be applied in problems of nonlinear analysis for differential equations; I could also indicate others.

The topics I deal with today are greatly aided by my expertise in Morse theory and spectral geometry, but motivated by possible applications of topology outside mathematics (data analysis, shape recognition, meteorology) and by the need to use computers and algorithm theory in the calculation of relevant topological invariants in applications outside mathematics.

I'm generally satisfied with my past choices, I would have liked a wider impact.

Since 2015, after finishing my mandatory teaching activity, my main thought was the following: I don't learn anything new in mathematics anymore, I just use the time to finalize ideas that I think were worthwhile, but that I didn't have time to develop. I didn't keep my word. I can't close my eyes to what's happening, because these are wonderful things, and I don't even find the necessary time, as I would have thought, to be able to finalize these ideas. I try... I continue to stay informed, but not with the same conscientiousness, in finding out what's happening remarkably in mathematics, at least in the areas where I feel like I understand the issues.

Q: Problem solver versus theory builder: which describes you better?

A: Probably both. Cerebrally I am a "problem solver", this was and remains my intellectual motivation. However, I consider myself a "research mathematician = producer of new mathematics" and any new mathematics also means "theory building". On the other hand, I do not have the patience to push the created methods or proposed developments to the end and I want to try them as quickly as possible to produce new results. Often new methods go unnoticed, only their applications or motivations being retained. More than once I have discovered my own results or concepts introduced by me in the past and published in high-circulation journals, rediscovered by other researchers and even presented as their own results, sometimes in different contexts.

My schematic understanding for a "problem solver mathematician" is

Problems > Theory > Problems

that is, one starts with a problem, generating and developing a theory, then, to see to what extent the theory is useful, one looks for other problems to which the theory can be applied.

And for a "theory builder mathematician" the scheme is

Theory > Problems > Theory

that is, you start with certain beautiful ideas, certain natural constructions, you develop them and you want to see what they are good for and then you look for problems to solve; then you see that you need other elements of theory or other natural developments, which you launch into.

In the essay I wrote in 1995 [16], I said that current mathematics is dominated by problems; it was a valid answer at the time. However, reflecting on the current trend, I think that mathematics is well-balanced, and in the near future it will again be dominated by conceptual theories and constructions. A few decades earlier, it had been dominated by the Bourbakist current, which was not too interested in immediate applications, but with priority for conceptual organization and rigorous foundation of mathematics.

As far as I am concerned, I repeat, my initial motivation proceeds from the problems.

Q: Please tell us a little about the interactions of mathematics with other fields. What were the more „applied" concerns that you had yourself and what generated them?

A: As a relevant observation, I mention that in the past we talked essentially about applications of mathematics in natural sciences (especially physics) and technology. Later, the number of sciences expanded and incorporates almost all natural sciences (biology, chemistry, geology, ...), as well as social sciences and humanities, but also other activities such as **computer science, statistics, data analysis**, which have become independent fields of science.

Nowadays, the reverse also occurs, meaning we also witness the applications of other sciences in mathematics; these are applications of computer science, physics and even biology in mathematics, both by inspiring solutions to conjectures that were still open, and by the creation of new subdomains of mathematics inspired by these sciences, which have led to recent solutions to **old conjectures**, or to **new solutions**, fundamentally different from the initial ones.

The recent interactions of mathematics with other fields deserve elaborate discussion. Without further preparation I allow myself to present only my own experience.

The interaction with the physicists and engineers from IFA (the Institute of Atomic Physics) played an important role in my later mathematics. I would

have very much liked to continue doing mathematics in that environment, a desire that could not be satisfied.

Despite the sad event of 1975 (the dissolution of the Institute of Mathematics), my work at IFA contributed to the initiation and my interest in: Hörmander-Maslov theory (relative to asymptotic solutions of partial differential equations), geometric optics, scattering theory, which had a great influence on my subsequent research in persistence theory, spectral geometry, L-2 invariants, regularized determinants and implicitly gave me an enormous intellectual satisfaction; indirectly it also contributed to my decision to continue my work outside Romania.

The collaboration (not finalized in publications), with a (then) young engineer (later became president of the Romanian Academy), expert in "holography", and the effort to understand and apply the mathematics dear to me in "analogue - computers" have given to me a great intellectual pleasure. Likewise the interaction with colleagues from the theoretical physics laboratory.

The collaboration with computer science experts from OSU (Ohio State University) from 2010–2014 is decisive in my current research in Computational Topology and Spectral Geometry, to which despite my age I still hope to contribute with hopefully interesting results. This began not from my curiosity to explore other fields through mathematics, but through the attendance of some computer science experts in a course of mine on Morse theory and the request for my expertise in geometry and topology by these colleagues.

Q: What do you think about machine learning?

A: I don't know much about "machine learning" beyond what you can find in the first 10–15 lines on Google. I probably should know more, because two of the computer scientists I interacted with were experts in "machine learning"; our discussions were reduced to problems related to the spectral analysis of Laplace operators (discrete vs. continuous version), which they considered very important for this field and which has also become a topic of interest for me. However, I understand that "machine learning" uses or more precisely will use a lot of mathematics, and is currently part of the field called "smart algorithms", algorithms that learn to adapt and improve as progress is made in achieving the final task. I will try to find out more.

In the essay published based on the lecture you gave in 1995 in Timișoara, Matematica văzută din interior și exterior [16], you touched some topics that a mathematician rarely spends time to write about, although they are based on fundamental questions. Among other things, you analyze what "value" means in mathematical research. Could you say whether things have changed in the meantime, given that some factors have appeared – for example, scientometrics "measures" today, even with decimals, how "good" an article or a mathematician is.

First of all, about the essay: the West University of Timișoara decided to award me the title of Doctor Honoris Causa, an occasion for giving a lecture in front of an audience with no background in mathematics. In that situation, I understood that there was no point in talking about mathematical results like theorems in infinite-dimensional topology, or other mathematical results that are dear to me. What should I talk about?! And then I thought of telling them what I think, as a mathematician, in order to connect somehow with what they might know about mathematics. That was actually the reason for this essay. Maybe I will continue these thoughts, because no more than 20 percent of those ideas have changed, but still... there is a lot to add. On the other hand, those thoughts can also be formulated better.

In the long term, the "value" is determined by the scientific value of the results produced.

In the short term, as in art, "value" is subjective. It is largely decided by the elite of the mathematical community and measurable by the number of invited talks and the reputation of the journals where the works are published. However, solutions to old conjectures, new ideas that guarantee immediate solutions to problems outside mathematics, considerably simplified proofs or verifications of old results, with the tendency to move a result from "hard mathematics" to "soft mathematics", regardless of where they are published, are guarantees for good mathematics, and not infrequently precede the admiration of the mathematical elite. This aspect makes it less subjective than art.

The role of charismatic personalities is great, and these are not always the same as those who have produced or are producing the most influential mathematics.

My essay "Mathematics seen from the inside and outside" Chapter 3, presented in 1995, shows what I thought about value in mathematics. My perception from that time remains essentially the same, and obviously could be illustrated with additional names and new domains.

Scientometrics "which measures with decimals how good an article is" has, in my opinion, a harmful effect in mathematics with a high chance of a) increasing confusion about what is valuable, b) discouraging pioneering research, c) discouraging originality and d) can be very harmful when used in decisions on funding mathematical research. Obviously a) – d) require explanations/exemplifications.

Q: What made you leave the country? Under what circumstances? I know that you left perfectly legally, you did not "flee" abroad.

A: The word "perfect" is not the most descriptive, although ultimately correct.

Under normal conditions, of free movement, and with the conviction that I wanted to study and practice mathematics, I would have completed my education and started my career in other parts of the world; under the conditions existing at

the time, for family reasons, I decided to live in Romania. In 1969, after an academic year spent at Princeton, I was offered the opportunity to continue my mathematical activity in the USA; I opted to return to Romania.

The decision to leave Romania, which happened in 1979, is explained in my interview in Observatorul Cultural [17]. In short, in 1979 my wife and I formulated a number of 10 conditions considered minimal for an acceptable scientific life in Romania. Not a single one was fulfilled.

At the beginning of a visit to the US, I formally requested, through the Romanian embassy, the status of Romanian citizen with residence abroad, a request that was practically impossible while present in Romania, but possible outside Romania, by virtue of Romania's commitment as a condition for obtaining "most-favored-nation status" from the US. After a period of almost two years and with the support of mathematicians in the US, my request was approved, so I also remained a Romanian citizen, with residence abroad. I no longer had the courage to return to Romania, even when I was already an American citizen. I feared that I might not be able to return to the US, especially since, for example, I could be brought back into the army. My status as a Romanian citizen was perfectly compatible with the status of an American citizen; however, both required loyalty. Joining the army in such a context would have created an incompatibility.

Q: Under these conditions, when did you first return to Romania, after the departure in 1979?

A: Only in 1991, I believe.

Q: Many young people are now going to study abroad, what do you think about it?

A: The education and the professional internship in another geographical location are natural and necessary, and in developed countries they are much encouraged. The accusation of lack of patriotism is primitive and inconsistent with the history of Romania and with the entirely justified admiration for scientific, cultural, and sports personalities originating from Romania.

As I understand, school and in particular university education have deteriorated considerably in Romania, much more than in other European countries. The desire of young people and of their parents to have their children exposed to a better education is natural, so the desire to study in more advanced countries, if possible, is entirely legitimate; and this regardless of the possibly higher level of expertise of that field of study in Romania. In fact, this happened frequently in the first half of the last century. I think that practically all respectable mathematicians from Miron Nicolescu's generation studied abroad. Probably, if I had had the freedom to go and study, it would have been either in France or in the so-called Soviet Union at the time – despite the fact that I did not like to live there, the attraction of mathematics was still enormous, for my generation and for my kind of mathematics.

It is worrying that, unfortunately, the confusion of values in professional (and political) activity minimizes, if not completely cancels out, the natural desire to "return to the motherland" and inhibits the consideration of even very attractive opportunities in Romania. I only hope that the current trend of permanent or long-term emigration is temporary. Can anything be done? Probably not much, as this depends on political and economic maturation, the pace of which is not encouraging and is little visible to Romanians.

In mathematics, we have a very large number of talented young people who practice mathematics abroad, but who will not return to Romania, except perhaps in old age. In my opinion, this is only a testimony to the potential of Romanian talent.

Q: Tell us a little about your collaborators and friends – there are certainly many and you couldn't name them all, but maybe you have a few steady collaborators over the years, colleagues with whom you are connected by more than just the fact that you were co-authors of the same article.

A: At my age, there are many people with whom I had or have close friendships, both abroad and in the country, friendships created from scientific, cultural motivations, from social interactions, school or college classmates. Many of these people are no longer alive. However, I imagine that the question refers exclusively to collaborators/special friends in the mathematical field.

Almost all of my collaborators were or became family friends. The same can be said of all my students in Romania, as well as those in the USA. There are far too many to be mentioned in full, and regrettable omissions are inevitable. The complete list of my collaborators and of the students in the USA can be found via Math Science Net.

However, I would certainly like to mention two mathematicians, much older than me and no longer alive, who were not only collaborators but also friends whose support was essential in my scientific and personal life: Nikolaas Kuiper and Richard Lashof.

In 1971, together with Th. Hangan, H. Moscovici and A. Verona, I organized the first summer school in Romania – in any case, the first organized by the Institute of Mathematics, and the most intense, in a certain way – whose lessons formed the content of a book "Introduction to Differential Topology" [15], a book that, I understand, has been influential over the years in the education of topologists and geometers in Romania. All these authors have remained dear friends to this day.

A special place in my affection was held by Dan Papuc and M. Craioveanu, both of whom have passed away, and currently Th. Hangan (living in France) and C. Constantinescu (living in Switzerland), whose friendship and influence I have enjoyed for more than 50 years, as well as two non-mathematician schoolmates.

Every time I return to Romania, I experience enormous joy in reuniting with former fellow members or emeritus members of the Institute of Mathematics, an institute that I consider "my home in Bucharest".

Q: Do you like teaching?

A: Yes, very much so; I am not convinced that I am a good teacher. My course-based evaluations at the university where I taught regularly were very inconclusive, I like to say with evaluations from minus infinity to plus infinity, reaching almost every possible level; so inconclusive that I was unable to retain any message and consequently possibly improve the effectiveness of my lessons with students. But, on a more optimistic note, I mention that I have found or recruited almost all my collaborators after giving talks. I really enjoy communicating the mathematics that I know or create; it is my great joy.

Q: As a professor, do you encourage your students to go to the library or do you provide them with all the necessary information? Have you ever given them more difficult assignments that force them to look for additional information on their own?

A: To this question, I prefer to share my experience with you, given the multiple situations I have found myself in as a professor/mentor.

In Romania, I did not officially have students, but I could only say "disciples". Several became mathematicians of maximum scientific visibility, well-known and respected names for significant contributions. I did not give "mass" courses, but only courses on a well-defined topic, in Bucharest and Timişoara. Moreover, these students/disciples were exceptional, and this was not due to me.

The comment I am about to make refers only to students from the US, and not to those I had while I was visiting professor at universities outside Romania (Bonn, Paris, Zurich, New Brunswick (Rutgers University)), where most of the courses were at the advanced level, with motivated students, eager to attend lectures given by a visiting professor.

In the USA, I have taught two types of courses. There are "undergraduate" or elementary courses, such as Calculus = elementary Mathematical Analysis, Linear Algebra, Differential Equations, which are based on textbooks; these are "mass courses", in which, apart from the contact in the classroom, we are mostly concerned with helping students who are overpowered by the information presented in class. The examination is always written, and the problems, required to be solved, generally need little originality – just the proof that the student has solved a similar exercise, but with different data. The examination is graded by the professor or by a teaching assistant. A tiny amount of these students are going to study mathematics, but only to use mathematics at relatively low levels of complexity.

However, I had the chance, under the cover of "initiation into research", to attract the interest among "undergraduate" students, through discussions outside the classroom, in some applied topics, such as "elementary topology for data analysis". To my regret, all of these students (in my case) later turned to business or engineering; they continued, I understand, to remain interested, possibly to use this knowledge in their further education. Most of them were interested in finding

advice and additional information, most of them (if not all) being from the Eastern world.

The second category of students is that of "graduate" students, for whom I taught more advanced mathematics courses, such as differential and partial derivative equations, elements of differential topology, basic complex analysis, again based on textbooks, but with no additional material required; possibly exercises from another textbook. The evaluation (in my case) being done on the basis of a written exam and not infrequently as a "take home exam", therefore considerably more difficult to complete. The exam was always graded by me. In such exams, plagiarism is unlikely, in fact non-existent.

Most of my graduate courses were however topic-based courses that offered the material presented from my perspective, but they always involved also references to other sources, chapters from different books or articles. The examination method in these courses is different, for example, students have to write a report on a discussed problem, and the report is evaluated by me. Those who present additional elements in this report, complementary to my given lecture, show that they have consulted other materials or thought about it on their own; I grade them with maximum grades (A or A+). In this type of advanced courses, everyone generally has good or very good grades (from B- to A+). Those who do not cope realize it themselves and drop the course before the exam. A mediocre grade (below B-) can disqualify them from financial support. Obviously, this is my evaluation policy and is not a general rule. All my PhD students in the USA have found research topics/problems via such courses. Due to their informative and quite personal nature, these courses were often attended by faculty/graduate students with other expertise, some of whom became my collaborators.

Q: What role can mathematics play in a young person's general education?

A: It is absolutely necessary in

a) Creating skills: to manipulate numbers and evaluate quantitative aspects (involving numbers), to prioritize qualitative aspects, to visualize shapes;
b) Organizing thinking;
c) Preparing the individual for the scientific components of education;
d) Training the mind for logical deductions in all kinds of situations and training the power of concentration.

All these are necessary aspects of everyday life.

It is worth noting the difference between "mathematical education in school" and its formative purpose, on the one hand, and perhaps the expected information about "modern mathematics", what it is and what it is good for. This difference between formative and informative is greater in mathematics than in any other subject taught in school.

For example, in a field like physics, you teach the basics of physics, and then you start to expand somewhat, to bring the student at least to the knowledge of the kinds of things that are being studied now and why those things are being studied. In mathematics this is not easily achievable, except perhaps for a few special problems of little justifiable importance.

Very few high school graduates can get an idea of "what" and "why" is being researched in present-day mathematics.

Q: You said that mathematics is an art as well. However, it is an "art" with a very limited audience, a fairly small group of "initiates", which is quite natural in the end. But could it convey something more to the uninitiated (and possibly even scared by their experiences in school)?

A: I begin with two observations pertinent to the mathematics-art-science rapport.

1. We often instinctively put math on the same level as art. Math, like art, is based on abilities/talents that are apparently detectable even before we know what it is. I have heard many parents of children under 10–11 say "my son/daughter is talented in math/music/drawing". I don't think I have ever heard anyone say "my son/daughter is talented in chemistry/biology/or even history" (at that age).

2. The essential difference between mathematical research and research in other sciences is that research in mathematics involves the creation of something new that previously did not exist, an aspect common to art, while research in other sciences involves the discovery of something that already exists.

This explains skills and good performance at an early age, both in art and mathematics.

I continue with a few observations regarding: a) the "fear" of mathematics b) mathematics and the "beauty", and c) can "fear" be alleviated by cultivating the "beauty"?

a) Mathematics is viewed either with pleasure or with fear because it is "interactive", just as videogames can be very attractive or disturbing, unpleasant when you are not fast enough or untrained; a good instructor/teacher can make mathematics exciting, even addictive (as in my case), and an uninspired one makes it scary.
b) Mathematics has a lot to do with "beauty", often called "naturalness" by mathematicians – like art; science does not necessarily.

The most familiar concept in mathematics is that of number. If it is an integer, it is generally "beautiful." If it is a real number, except when it is linked to a remarkable property and designated as a symbol, and is not even rational, it is somewhat "ugly" because it cannot even be accurately communicated in writing.

Another fundamental concept in mathematics is the "symmetry" and implicitly the "symmetry group", a concept related to "beauty". From Herman Weyl's perspective, the source of beauty is the **subtle violation of symmetry**.

c) Presenting the "symmetry" and in particular the concept of "group", as a fundamental mathematical concept capable of describing the "beauty", the intelligent use of elementary geometry, as well as certain mathematical results (for example the existence of only 5 regular polyhedra in the ambient space), with a demonstration intelligible to a high school student, I believe could sweeten the image of mathematics even for a frightened student. The pleasure produced by finding out / understanding such mathematical results is for me similar to contemplating a painting or listening to a musical piece; this is another aspect of similarity of mathematics with art.

Q: Do you have time for anything else besides math (and family, obviously)?

A: I would like to have, and I hope to do more in the future. I long for time dedicated to literature and music, as well as opportunities to revisit the Romanian landscape (mountains, sea, the delta).

For example, I am interested in being in Bucharest during the peak of the musical season, September-December. The Enescu Festival and the theater season are cultural attractions, of course. This year I went to about 4 concerts and also listened to what was broadcast online.

Q: What kind of music do you listen to? What musical period do you like or which composers?

A: At the moment, I'm a big fan of Russians: Rachmaninoff, Tchaikovsky, Prokofiev, and even the less melodic ones, so to speak; I even like Shostakovich. I listen to Sibelius, Dvorak, but also Chopin and Liszt with great pleasure. I generally listen to classical music.

But also something between opera and more accessible music, like Sarah Brightman, Andrea Boccelli. I was and remain passionate about "French Chansons", Jacques Brel, Aznavour, Becaud, etc. I keep up to date with classical music recordings and especially great instrumentalists (piano, violin, cello), already famous or not yet famous.

Q: How often do you come to Romania? What other bonds do you still have with this country?

A: Since 1989 I have been coming to Romania almost every year or every two years, but usually I stay for a short time (up to 10 days). I have been here three or four times, I think, for a longer period, 2–3 months. Since I am retired (emeritus professor) I hope to come to Romania regularly, for 2–3 months, between September and December. I intend to collaborate with the Romanian mathematical community via IMAR, with the desire to influence Romanian research to the extent

that at my age I still can, both through information, and especially with the hope of inducing interest and perhaps activity in projects that I consider important.

Also, during this time I hope consume Romanian cultural, theater, music, literature, which I have lacked in the last forty years of competitive mathematics. The short visits could not satisfy this need. I also hope that, to the extent that age and time would allow, I will enjoy the Romanian landscape, which I have also missed.

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