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IMPA'S COMING OF AGE IN A CONTEXT OF INTERNATIONAL RECONFIGURATION OF MATHEMATICS

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Abstract

In the middle of the 20^{th} century, the intimate link between science, industry and the state was stimulated, in its technical-scientific dimension, by the Cold War. Questions of a similar strategic nature were involved in the Brazilian political scene, when the CNPq was created. This presentation investigates the nature of the connection between this scientific policy and the presumed need for an advanced research institute in mathematics, that gave birth to IMPA. By retracing the scientific choices of the few mathematicians working at the institute in its first twenty years, we demonstrate how they paralleled the ongoing reconfiguration of scientific research. The development of dynamical systems theory provides a telling example of internationalization strategies which situated IMPA within a research network full of resources, that furnished, moreover, a modernizing drive adapted to the air of that time.

On October 19, 1952, *O Jornal do Comércio*, a newspaper published in Brazil's then capital city of Rio de Janeiro, reported that the National Research Council (CNP, Conselho Nacional de Pesquisas) had created an associated research arm called the Institute for Pure and Applied Mathematics (IMPA, Instituto de Matemática Pura e Aplicada). The National Research Council, later known as CNPq, had been created just a year beforehand and was directly connected to the country's government. On the same day, the first pages of the newspaper reported:

- The Soviet delegate presented a proposal for peace at the General Assembly of the United Nations. Stalin's Foreign Minister, Andrei Vyshinsky called for a reduction of one-third of the armaments of the great powers and an unconditional ban on atomic weapons. The "peace pact" would be a condition to stop the then ongoing Korean War;

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- As the *de facto* leader of the Republican Party, Eisenhower's campaign to become US president had become fierce. His disagreements with Truman included an alleged covert plan by the General to end the Korean War. Foreign policy was presented as a weakness of the Democrats. Eisenhower's focus was to defeat the Communists, maintain pressure on the USSR and expand the American atomic arsenal.

The reaction of the Soviet envoy had been motivated by the signing of the North Atlantic Treaty in Washington in April 1949, designed to contain an armed attack by the Soviet Union against Western Europe. The key section of the treaty was Article V, which commits each member state to consider an attack against another member state as an attack against all members. In 1951, the treaty gave rise to NATO, with General Eisenhower at the head.

In the same year of 1951, the coordination to establish the CNPq was finalized, in large part due to the stubborn efforts of Admiral Álvaro Alberto da Motta e Silva, who acted as spokesman for the interests of a small but significant group of scientists. They wanted to overcome the country's chronic backwardness and boost economic development, and attributed a strategic role to nuclear power for both industry and national security. In the early years, the National Research Council's investments concentrated on infrastructure for the nuclear sector, which was closely connected with the field of atomic physics. The Brazilian Center for Research in Physics (CBPF, Centro Brasileiro de Pesquisas Físicas) had been created in 1949, contributing significantly to the foundation of CNPq and IMPA. Due to their international recognition, particle physicists such as César Lattes and José Leite Lopes played a central role in the public discussion on science policies Vieira and Videira [2014].

This was the time when Big Science began reshaping the very meaning of science and came to symbolize modernity, occupying the center of a new social contract between scientists and the state. As Pestre and Krige propose, after the Second World War, the intimate link between science, industry and the state was stimulated, in its technical-scientific dimension, by the Cold War Krige and Pestre (eds.) [1997]. Even if "the desire to produce knowledge, to know more about 'nature' still remained the main motive of the practitioners", scientists pragmatically exploited the possibilities that only the state had to provide material resources – producing a "new identification between science and technology and state power and prestige" Krige and Pestre (eds.) [ibid., p.xxxiii].

Negotiations of a similar strategic nature were involved in the Brazilian political scene. The CNPq was meant to lay the groundwork for the purchase of reactors, assessing international scientific cooperation agreements, as well as helping to fight against monazite and thorium oxide exports, which could be useful to Brazil in the development of its own nuclear program. The goals of Álvaro Alberto were clearly to construct a sovereign position to the country in a Cold War background de Andrade [1999].

The question arises, however, as to the nature of the connection between this scientific policy and the presumed need for an advanced research institute in mathematics. What was the relationship between the mathematics stimulated by IMPA and nuclear physics that was at the center of the political power of CNPq? The institute could have been expected to focus on the mathematical foundations of atomic physics, yet this was not the case. The relationship between the political atmosphere and the core subject matter of mathematical research in the first years of IMPA is a complex question that so far has not been explored.

In fact, this weakness fits into a broader historiographical problem. Valuing the social and political context is now common practice in the history of science. What is less common, however, is to convincingly show how this context of knowledge production really matters to the knowledge being produced. This is one of the questions raised in the book *Science and Technology in the Global Cold War* Oreskes and Krige (eds.) [2014]. The authors ask how Cold War patronage specifically affected the patterns and priorities of scientific research, and seek to determine what role national ambitions played in fostering, enabling, or disabling certain lines of investigation. These questions are even more difficult to answer in the case of mathematics (not covered in the mentioned book).

There was a change in the direction of research at the end of the 1960s at IMPA, with greater focus being put on dynamical systems theory. We will show, in the final sections, how this reorientation occurred and explore the possible relationship with the development of applied mathematics in the US, which was itself related to priorities adopted due to the Cold War. This study can thus be considered as a step towards understanding the roles that patronage and Cold War geopolitics played in shaping mathematicians choices, defining spheres of possibility for concrete research (related to a question raised in Oreskes and Krige (eds.) [ibid., p.7]). This means understanding why some lines of research in mathematics were pursued while others were left out, and to what extent these choices were driven by the possibilities of patronage and international connections. In order to emphasize the changing priorities that would take place in the end of the 1960s, the first two sections describe the beginnings of IMPA, the political forces leading the project and its main directions of research before this turning point. By retracing the scientific choices of the few mathematicians working at the institute in its first twenty years, we will demonstrate how they paralleled the ongoing reconfiguration of scientific research. The development of dynamical systems theory provides a telling example of internationalization strategies which situated IMPA within a research network full of resources, that furnished, moreover, a modernizing drive adapted to the air of that time.

1 Periodization and institutional dimensions

The period of interest for this study begins in 1949, when the CBPF was founded, and ends in 1971, when IMPA began having a formally established post-graduate program and a stable research team[1]. In this same year, one of its founders, Leopoldo Nachbin, left IMPA. Nachbin's departure has not been sufficiently explored from a historiographical point of view. Testimonies evoke personal reasons and disagreements with colleagues[2]. These explanations are not good enough for a historian. The controversy surrounding Nachbin's departure is of particular interest because it opens the possibility of mapping the distinct mathematical influences that contributed to the consolidation of specific fields of research at IMPA in the 1960s.

Around 1970, the mathematical community became more numerous and institutionalized in IMPA. From then on, the organization of research changed. IMPA started its activities in a room of the CBPF. There was a director, Lélio Gama, and researchers who gave courses more or less regularly: Mauricio Peixoto, Leopoldo Nachbin and Paulo Ribenboim. Even after moving to a new building in 1957, the institute consisted of a small number of professors and students. Elon Lages Lima joined as a researcher in 1956 and helps to give an idea of the dimensions IMPA had at this time:

> At the end of every month, Mr. Antonio came, he was the one who looked after the building at the corner of Sorocaba with São Clemente. Mr. Antonio was the guardian of the building, he lived there with his wife, Dona Maria. At the end of the month, Mr. Antonio came with a paper bag containing several parcels of money, which were our salaries, and he said: sign here, professor! This money came from the CNPq. He received the money and gave it to us, that's all Lima [11 May 2016].

Since 1939, there was a department of mathematics in the Philosophy Faculty of the University of Brazil (now, Universidade Federal do Rio de Janeiro)[3]. But, in the minds of IMPA's early supporters, advanced research was associated with the possibility of creating spaces outside the university. When the CBPF was founded, Leite Lopes was convinced that Brazil had to become something other than a "science-starving country", by strongly associating this possibility with the creation of research centers outside the university: "Our hopes turned to the university where unfortunately, by virtue of the lack of

[1] Before this, the degrees depended on an agreement with the University of Brazil.

[2] Nachbin himself says: "I was one of the founders of IMPA, and I left IMPA for personal reasons, these fights can occur everywhere". In: Interview with Leopoldo Nachbin by Roberto Martins and Hiro Kumasaka. CLE/Unicamp Historical Archives.

[3] In 1964, this department has been merged with the mathematics department of the Faculty of Engineering and others in the same university, giving birth to the Institute of Mathematics of the UFRJ.

understanding and intolerance of our statesmen, science advances slowly and painfully" Videira [2004]. IMPA was the result of the efforts of a small group of very well organized and politically articulated scientists who convinced the government that a key factor in economic development is the encouragement of autonomous research institutions.

While debating the creation of IMPA as an entity directly linked to the National Research Council, Baptista Pereira, a member of the Council, asked whether it was better to create, instead of a new institute, a new course at the university. But another member, Cândido Dias, responded by stressing that independence was justified by the fact that universities could only have a very small number of professors, which made it difficult to hire all the mathematicians then dedicated to research. Dias specifically invoked the situation in Rio de Janeiro, where some prominent researchers (as Leopoldo Nachbin and Mauricio Peixoto) were not full professors at the university. The creation of an independent institute, he added, would give them a stable form of support. This also followed the understanding that high-level research needed "protected spaces", detached from the constraints imposed by universities:

> When there was a competition for a full position in mathematical analysis at the National Faculty of Philosophy, in 1950, José Abdelhay and Leopoldo Nachbin were candidates. The difference in titles between Abdelhay (baccalaureate in mathematics) and Nachbin (engineer) served as the basis for challenging Nachbin's registration, who filed an appeal and thus the competition was suspended pending the court's decision. This has become one of the longest known academic disputes at any Brazilian university. On the initiative of physicist José Leite Lopes, who would become one of the most distinguished Brazilian scientists, Monteiro[4] had been hired at the Centro Brasileiro de Pesquisas Físicas (CBPF), which was founded in Rio de Janeiro. Leopoldo Nachbin was also hired at this center. Thus, the CBPF set up the first "protected space" for mathematical research supported by the federal government [5].

The same argument applied to the need to create IMPA as an independent institute. As Nachbin says, the CBPF was established because at the University of Brazil "there were no conditions to create a post-graduate program in physics". He and Cândido Dias talked often about the necessity to have also an independent institute of mathematics. In fact, Joaquim Costa Ribeiro, the scientific director at the time, preferred to create a program

[4] Antonio Aniceto Monteiro was a Portuguese mathematician that stayed in Brazil from 1945 to 1949.

[5] Proceeding 112: meeting held at 17/10/1952; Proceeding 117: meeting held at 15/10/1952. Rio de Janeiro. MAST. Archives CNPq.

inside the university, but was convinced by Dias (with the support of the president of the Academy of Science, Artur Moses)[6].

Nachbin and Peixoto were very influential in the decision processes of the National Research Council. During the 1950s, the CNPq complemented the salaries of researchers from different universities (where there were very few stable positions), gave scholarships for students and promoted travels of Brazilian researchers inside the country or abroad, besides inviting foreign mathematicians. The decisions were centralized in the hands of the Orientation Committee (that linked IMPA to the CNPq, being above the Scientific Local Committee). A rejected proposal from the University of Brazil shows that it was probably not accommodating the role community of mathematicians.

In 1959, Carlos Alberto Aragão de Carvalho, a professor from the University of Brazil, presented to the CNPq a project to create a National Commission of Mathematics. It was conceived as a means to unify different programs of research in mathematics and to have an impact on the training of future engineers. The commission would establish an Inter-American Instituto de Matemática Pura e Aplicada, integrating other Latin American countries, giving grants and stimulating visits from foreign researchers[7]. Charged with making a report on the project for the president of CNPq, Lélio Gama saw no interest in the proposal. It would be too complex and its goals "constitute regional problems, with singular characteristics in each country, and so demanding national solutions"[8]. One significant point of Aragão's project was the assimilation of all mathematical institutes into the university, a problem that, Gama said, "in our view must be examined in light of particular circumstances in each case presented, in the sense to verify if this assimilation would imply, really, greater facilities for mathematical research in the region considered". In Brazil, the only mathematical institute was IMPA. And it is clear that the project aimed to incorporate it into the university, an idea promptly rejected by the CNPq.

The development of advanced institutions outside the university was not a Brazilian exception. The evolution of the research systems in India has been described in terms of a *dualism*, as suggested by Raina and Jain [1997]. This notion characterizes the institutions of science and technology as structured by the requirements of a rapidly evolving knowledge standards as much as by the imperatives of modernization. The role of science in constructing a sovereign and modern state had similar flavors in Brazil and India during the 1950s[9], and scientific institutions played a central role in reconfiguring the nation-state. In both countries, forming a scientific elite was seen as a key strategy to

[6]As Nachbin tells himself in an interview given to Elisabete Burigo in June 1988, available at http://www2.unifesp.br/centros/ghemat/paginas/teses.htm

[7]In 1958, a mathematical center had been created in Buenos Aires, with the support of UNESCO, that Nachbin visited in 1959.

[8]Processo 3595/59 CNPq. Arquivos Lélio Gama, MAST (LG-T-05-065).

[9]Even if the two countries have different histories with regard to colonization.

the mission of building a new nation. As Raina and Jain affirm, "the emergence of Big Science required the emergence of new institutions and the concomitant supersession of the university considered as 'the age-old site for the production of knowledge'." Raina and Jain [ibid., p.859]. The tasks of national development, linked to research in atomic energy, implied the creation of a solid infrastructure of research, conceived as elite institutions where: "young men of the highest intellectual calibre in a society" could be trained Raina and Jain [ibid., p.866].

Travels were a decisive mean to train researchers. Foundations like Guggenheim and Rockefeller, as well as the Department of State, played an important role in promoting scientific exchanges in the period. Between the two wars, a Europe weakened by reconstruction efforts and the rise of Nazism helped to explain the importance gained by American philanthropic foundations, as Reinhard Siegmund-Schultze shows, with special attention to the case of mathematics Siegmund-Schultze [2001], and John Krige develops for the period after the Second War Krige [2006]. A considerable number of Brazilian mathematics-related researchers traveled to US with a Rockefeller fellowship grant – their travels have already been elucidated in Trivizoli [2011] and Barany [2016]. Leopoldo Nachbin and Mauricio Peixoto both received grants from US foundations.

In the beginning, the University of Chicago was a preferred destination of Brazilian mathematicians. This is also due to the presence of André Weil and his close relationship with Nachbin, since the years Weil stayed at São Paulo. Marshall Stone had become chair of the Department of Mathematics at Chicago in 1946, spearheading its renewal. Policies during Stone's tenure were aligned with post-war American politics, which included training a cadre of high-level students from different countries Parshall [2009]. Nachbin has stayed in Chicago for a first time from 1948 to 1950 and Peixoto also was there from 1949 to 1951. After going to Chicago for a second time in 1957, Nachbin went to Princeton, as well as Peixoto.

During the second half of the 1960s, other Brazilian mathematicians went on to study in the United States. From 1968 onward, some of them returned and settled at IMPA, like Jacob Palis, in 1968[10], and Manfredo Perdigão do Carmo, in 1969[11]. Jacob Palis underlines the changes going on, in the late 1960s, in the conduction of mathematical research: "In fact, in 1969, a group of researchers arrived from abroad with the intention of shaking up IMPA" Palis, Camacho, and Lima (eds.) [2003, p.125].

In a move potentially related to the transformation of mathematics research at IMPA, Nachbin left the institute soon afterwards. This question requires further historical analysis.

[10]Palis was hired as assistant researcher and promoted immediately to associate researcher and then tenured professor in 1970.

[11]Carmo was officially a researcher at IMPA since 1966, but he started effectively in 1969, after a stay in the US and at the University of Brasilia.

2 Leopoldo Nachbin and the Bourbakist approach

Leopoldo Nachbin received an engineering degree from the University of Brazil in 1943, the same year as Mauricio Peixoto. He started working with Antonio Monteiro. Although more intensely devoted to logic, Monteiro also had a strong working knowledge of order structures. Connecting it to topology would be fundamental to Nachbin, who defended his *livre-docência* thesis on metrizable and pseudo-metrizable topologies in 1948. Just before, a version of this work had been sent by Dieudonné to the *Comptes Rendus de l'Académie des Sciences de Paris* L. Nachbin [1946].

In 1945, André Weil came to the University of São Paulo (where he stayed until 1947) and, after him, several mathematicians from the Bourbaki group had residences at Brazilian universities: Jean Dieudonné, Charles Ehresman, Alexander Grothendieck and Lawrence Schwartz Pires [2006]. Nachbin was 26 years old in 1948, when he published a monograph on topological vector spaces, which became very useful for training researchers L. Nachbin [1948]. Mário Carvalho de Matos credits Nachbin with having promoted the "Bourbaki spirit" in Brazil, specifically mentioning the theory of topological vector spaces, a characteristic of Nachbin's "mathematical style" Barroso and A. Nachbin [1997].

Cândido Dias' 1951 professorial thesis provides an example of how topological vector spaces were having influence in the practice of mathematics Dias [1951]. Before 1945, the mathematics department at the University of São Paulo had been frequented by Italian mathematicians, the most famous being Luigi Fantappié. However, according to Cândido Dias, the topological base of Fantappiè's theory of linear functionals was "precarious". It lacked an element that later proved to be indispensable: the generalization of normed spaces. Topological vector spaces were thus of special interest in the study of analytic functionals. The vector space that would serve as a basis and the class of functionals were perfectly clear elements, but it was still necessary to combine the two. That is to say, it was necessary to "put a topology in the vector space whose continuous functionals were the class of Fantappié's analytics". This demonstrates how the theory of analytic functionals *gets along* with modern functional analysis.

"Writing in Bourbaki language", as Cândido Dias puts it, was a trend within the small mathematical research community of the early 1950s. The question of adapting notations, definitions and demonstrations to such a language was a key one. Nachbin went frequently to São Paulo and was the main researcher at Rio de Janeiro working on related topics. In the early 1950s, a problem posed by Dieudonné (and signed by Bourbaki) drew Nachbin's attention, it was the question of knowing if any bornological space is barreled Bourbaki [1950]. A negative answer was published by the Brazilian in 1954 L. Nachbin [1954][12]. During the years 1953 and 1954, Grothendieck gave a course on topological vector spaces

[12]Cited in Bourbaki's book on topological vector spaces, edition of 1955, v.2, p.13.

at IMPA and published a book on the subject Grothendieck [1954]. In the introduction, he announced a forthcoming work that would bring together his reflections and those of Nachbin – this never materialized, perhaps because the research interests of Grothendieck changed.

In parallel, Nachbin was doing research on a generalization of Hahn-Banach's theorem, about which he had published one of his most important articles in 1950 L. Nachbin [1950]. Nachbin was also working on the theory of approximation and extended the Stone-Weierstrass theorem to differentiable functions, a result published in the *Annals of Mathematics* L. Nachbin [1959]. This research, which developed from interactions with Marshal Stone, continued throughout the 1960s and involved some doctoral students[13]. However, most of Nachbin's PhD students at IMPA worked on a subject he inaugurated around 1963 and would engage him until the end of this life: the topology of spaces of holomorphic mappings.

After his second stay in Chicago, in 1957, Nachbin wanted to go to Paris to follow Schwartz's seminar on partial differential equations. Schwartz supported the idea[14]. Nachbin did not end up going to Paris, however, perhaps because he discovered, some months afterwards, that the plans for the seminar had changed, since Schwartz wanted to study the applications of his theory of distributions to theoretical physics.

After Schwartz visited Brazil, in 1961, Nachbin finally went to Paris. In the same letter in which he had confirmed the invitation and stipulated Nachbin's salary as associate professor, Schwartz presented the subject of the conferences he was planning to make in Brazil. Schwartz seems more interested in talking about the irreducible representation of Lorenz groups in spaces of distributions with vector values than about topics related to topological vector spaces or partial differential equations (as we see in Figure 1).

In the 1960s, the point of view of topological vector spaces was not unanimously recognized as being so interesting as it was before. In 1957, Schwartz proposed extending to distributions with vector values the main properties of ordinary distributions (scalar distributions) Schwartz [1957]. In particular, he showed that the topological properties of spaces of distributions could be studied using similar tools to those already employed in the ordinary case. Other properties, however, were more difficult to extend. Nonetheless, it was important to study distributions with vector values, as Schwartz supports, because theoretical physics uses distributions with values in operator spaces. Schwartz's articles were deeply influenced by Grothendieck's works on kernel theorems and topological tensor products. However, as Anne Sandrine Paumier shows, the reception of this approach was controversial, since some mathematicians saw the introduction of topological vector

[13] As Silvio Machado, João Bosco Prolla and Guido Zapata.

[14] He says in a letter to Harry M. Miller of the 5th May 1956. I thank Lucieli Trivizoli for showing me some letters, found in the Rockfeller Foundation, suggesting the following version.

Les conférences de Berkeley contiennent notablement plus de matériel que celles de Buénos-Aires, et j'ai encore quelques autres choses à y ajouter. Je crois que la partie purement mathématique du problème, cést-à-dire la recherche des représentations irréductibles du groupe de Lorentz dans des espaces de distributions à valeurs vectorielles, serait très adaptée pour le Brésil, puisqu'il s'agit d'espaces vectoriels topologiques, des produits tensoriels, des distri-butions, convolutions , intégrales de Fourier et équations aux dérivées partielles, tous sujets qui ont été bien travaillés par les mathématiciens de Rio. Naturellement cela aura l'inconvénient de répéter un peu des choses déjà faites ailleurs, mais je crois que cela n'est pas grave.

Je crois que pour le moment, je n'ai rien à dire de nouveau sur les espaces vectoriels topologiques et équations aux dérivées partielles, qui d'ailleurs ont fait l'objet d'assez nombreuses publications pour être à la disposition de tout le monde.

Figure 1: Extracts from a letter Schwartz sent to Nachbin in November 23 1960

spaces in the theory of distributions as unnecessarily complicated. Paumier observes that: "the transformation of the kernel theorem into a nuclear property of certain topological vector spaces leads to a much more important imbrication of distributions with topological vector spaces; and this even ensues a transformation of the theory of distributions itself, as well as the creation of the theory of distributions with vector values (...) The objects considered are no more distributions that are represented by kernels but spaces of distributions to which we give a structural property of nuclearity. Developing the theory of distributions with vector values, Schwartz incorporates, in some way, the writing practices around topological vector spaces" Paumier [2014, p.170].

This point of view, namely the writing practices around topological vector spaces, may have influenced Nachbin. Beyond his usual domains of research, around 1963, he was investing on the study of topologies of spaces of holomorphic mappings. In this year, Nachbin gave a course on the theory of distributions at the University of Rochester (published in 1964 by the University of Recife as L. Nachbin [1964]). There, he treated distributions in a new way:

"In planning my course, I had to face the following dilemma. Should I teach distributions on R^n (by using the coordinatewise approach), or should I do it on a finite dimensional real vector space (by preferring the intrinsic viewpoint)? Many, many years ago, algebraists used to find it more pedagogical to talk first of permutation groups, and next of the then called 'abstract' groups (...). This is no longer the usual attitude in Algebra courses; groups are introduced from the very start, and permutation groups are mentioned as a fundamental example (...). Surprisingly enough, analysts still find it more pedagogical to present firstly analysis in R^n, and next maybe talk about analysis on a finite dimensional real vector space (...). By following a recent trend, we believe that analysis on a finite dimensional vector space should get an increasing emphasis from the very beginning of graduate courses, and should prevail over analysis on R^n" [p.3-4].

Besides this "pedagogical" reason, the adoption of an intrinsic approach in the case of finite dimensional vector spaces stems from the need for such an approach in dealing with infinite dimensional vector spaces. Nachbin wanted in fact to extend Schwartz's results to infinite-dimensional spaces. He started to work hard and to direct theses mainly on this subject[15]. John Horváth says that, in 1965, Nachbin started to build a "very important theory, totally original, the Theory of Holomorphic Functions in Banach Spaces, with applications to convolution equations and to partial differential equations in these spaces". He adds this new theory attracted some of his own students[16]. As we learn from Nachbin's writings and from interviews with some of his colleagues and former students, Nachbin believed he was founding a new field of research. Foreign students, some of whom met Nachbin in Rochester, came to IMPA attracted by this domain. This was the case of Sean Dineen, Richard Aron, and Philip Bolan. The working conditions for the subject at IMPA were favorable. As Dineen attests: "they were interested in making IMPA a world class institute, so they paid quite good salaries to all staff, including the PhD students" McGuire [2009]. In Brazil, they met other Nachbin students, such as Jorge Alberto Barroso, Mário Carvalho Matos, Soo Bong Chae and Jorge Mujica. Besides the three theses directed by Peixoto, there were six theses at IMPA in the period, that were all directed by Nachbin[17]. These theses were either about the theory of approximation or about the topology on spaces of holomorphic mappings. And there were also the thesis on this last subject that Nachbin directed in Rochester. These researches gave rise to a book published by Springer L. Nachbin [1969][18].

The number of people who continued working in this field after the end of the 1970s diminished markedly. A plausible hypothesis is that the study of topologies of spaces of holomorphic mappings, with a possible extension to infinite dimension, did not have the

[15]During his years in Paris, besides Schwartz's seminar, Nachbin frequented Pierre Lelong's seminar. He knew the works of Andre Martineau and attracted students to this field, as Philippe Noverraz, Gérard Coeuré, André Hirschcowitz and Jean-Pierre Ramis. Nachbin's contacts in Paris must have motivated him to move to this new area

[16]Testimony for the title of *honoris causa* to Nachbin given by UFPE.

[17]Just the one of Luiz Adauto Medeiros was signed by Nachbin but effectively directed by Felix Browder.

[18]Already presented in the *Sexto Colóquio Brasileiro de Matemática*, in 1967.

success and posterity expected by Nachbin. In 1972, questions were more numerous than answers and some actors admitted "'the poverty of the theory in regard of the hopes we can put in it" Hirschowitz [1972, p.256]. Dinamérico Pombo, one of Nachbin's last students, chose another domain when he started, motivated by the recognition that holomorphy theory was not a very stimulating subject (a perception shared by Luiz Adauto Medeiros)[19]. When asked if he continued working on infinite-dimensional complex analysis, Sean Dineen answered:

> In the 1970s it was very topological, locally convex spaces, pseudo- convexity, holomorphic convexity, analytic continuation and things like that. At the end of the 1970s Phil Boland moved into statistics, Richard Aron went permanently to Kent State, so that stream had sort of finished. But if you want to stay active as a research mathematician, you have to reinvent yourself regularly.

The progressive decline of what Paumier calls "writing practices of topological vector spaces" during the 1960s may have been one of the reasons for the departure of Nachbin and his group from IMPA in 1971[20]. In fact, the point of view proposed by Schwartz in 1957 had already met some resistances during the 1960s. This explains the success of the works of Lars Hörmander, since this author preferred considering the theory of distributions without any practices linked to topological vector spaces. Paumier observes that "the objects 'distributions' are very important, but the structure, mainly topological, of spaces under consideration are not essential in his work" Paumier [2014, p.170].

It is often said, mainly rooted in declarations of Elon Lima, that one reason for Nachbin's depart was his attempt to hire one of his students at IMPA Palis, Camacho, and Lima (eds.) [2003]. This explanation is not convincing *per se*. Nachbin sent a letter to Lima, in 18 September 1969, supporting the proposal to hire Jorge Alberto Barroso after the end of his thesis[21]. He strongly emphasized the key role Barroso would play in elucidating questions related to Nachbin's own interests in that time, namely the extension to locally convex complex spaces of the theory for Banach spaces developed in L. Nachbin [1969]. Beyond personal motivations, which certainly existed and had probably influenced the outcome, there were important changes going on in the global scene of mathematical research. In particular, the US was acquiring an increasingly prominent role in mathematics and, importantly, the preferred domains began shifting away from topics related to the

[19] Interviews done at Rio de Janeiro in 2017 in the writing of this article.

[20] We asked Mário Carvalho if he agrees that the field of holomophy had a decline but he contests, naming researchers that continued working on related themes. Toledo [2012] can be consulted for a list of researches in the field afterwards.

[21] Letter found in the archives of Lélio Gama at MAST (LG-D10-138-0011).

Bourbaki lineage, which had been so influential until this time. In order to fully understand the context, it is necessary to look at the wider picture, as we do in the following sections.

3 The rise of dynamical systems theory in the United States and the role of Mauricio Peixoto

In the aftermath of the Second World War, a redistribution of scientific forces took place on a global scale with major repercussions in mathematical research. Amy Dahan-Dalmedico shows that applied mathematics gained much more importance Dahan-Dalmedico [1996] and the United States became the leading mathematical power by the sheer breadth of its scientific community, the variety of fields covered, and by the dynamism of its research systems. Solomon Lefschetz was an exemplary figure in this scenario Dahan-Dalmedico [1994], since he moved from topology to differential equations during the war. Mauricio Peixoto worked with him and played a key role in shaping dynamical systems theory to be adapted to a transition towards US dominance in mathematics.

Just after the war, Lefschetz started leading a research program on Nonlinear Differential Equations and Nonlinear Oscillations funded by the Office of Naval Research. That allowed him to translate important works of the Soviet school of research in the theory of oscillations. After his stay in Chicago, where he went to work in analysis, Peixoto went back to the US in 1957, to work with Lefschetz. Just after the launch of the Sputnik, it became clear that it was necessary to fill the "mathematical gap" between Russia and the West, as Lefschetz said, so he created a mathematical center in the Research Institute for Advanced Studies (RIAS), in Baltimore, which has gained worldwide recognition. The focus was on the theory of nonlinear oscillations.

Lefschetz's laboratory is known for having introduced in the US concepts formulated in the Soviet Union by Andronov and his group. Most notably among them was the concept of structural stability, which later became central to Peixoto and Brazilian researchers. The notion of a "systèmes grossiers" was proposed by Andronov and Pontryagin in an article published in French in 1937 Andronov and Pontryagin [1937], and developed in a book that Andronov wrote (in Russian), with other researchers, about the requirements mathematical models should fulfill to be useful to physics (translated as Andronov, Vitt, and Khaikin [1949]). The mathematical definition of this idea became what is now known as *structural stability*. Mauricio Peixoto, as well as other researchers who worked with Lefschetz in the beginning, specially De Baggis and Marilia Peixoto, played a key role in these developments, giving mathematical consistence to the initial concepts Roque [2007].

In 1959, Mauricio Peixoto led a round table on structural stability in a symposium on differential equations in Mexico. Lefschetz collaborated with a PhD Program at UNAM (Universidad Nacional Autónoma de México) and organized this International Symposium on Ordinary Differential Equations. Thanks to his meeting with Peixoto, Stephen Smale came to Brazil in 1960 and began conducting a research at Berkeley. This research was an extension of the work already done by Peixoto in two dimensions to higher dimensions, and included other mathematicians at Berkeley such as Morris Hirsch and Abraham. Abraham claimed that "the new subject was well under way in the fall of 1960, when I arrived in Berkeley, and the golden age of global analysis began" Abraham [2009]. It is interesting to note that "dynamical systems" was not the official name of the field in these times. In the proceedings of the 1962 Brazilian Colloquium of Mathematics, Mauricio Peixoto presented the question of structural stability, which he maintained was a fundamental problem in "the theory of differential equations" and he felt it necessary to add that such a theory "is also called theory of vector fields of of dynamical systems" Peixoto [1961].

The first three theses done at IMPA were supervised by Mauricio Peixoto, all finished in 1964 on subjects related to structural stability or generic vector fields (Ivan Kuptka, Jorge Sotomayor and Aristides C. Barreto). In 1964, the center Lefschetz directed at the RIAS moved to Brown University, renamed as Center for Dynamical Systems. Peixoto went to work there and the research at IMPA was most conducted by Nachbin during the 1960s. It was only around 1970 after other researchers, who had done their PhDs in the United States, returned to Brazil, as Jacob Palis, that the field of dynamical systems began to establish itself. Since then, research in dynamical systems became increasingly valued and played a key role in the institutionalization of research at IMPA. Some intrinsic characteristics of dynamical systems theory help to explain why it was a better fit for the direction that mathematics was taking at the time across the world.

4 The Americanization of mathematics

Americanization is a controversial term. It has ambiguous meanings, representing either a deliberate action of conquest or the disinterested attitude of a country which sees itself as a benefactor vis-à-vis the rest of the world. These meanings were obviously constructed over time and have a long history. Here, Americanization refers to the meaning suggested by the historian Ludovic Tournès, who has studied the actions of philanthropic foundations in French science during the interwar period Tournès [2010].

Michael Barany speaks of "mathematical colonialism" to describe the scientific actions of the United States at the time Barany [2016]:

> On a geopolitical scale, postwar mathematical colonialism was an elite driven, internationally oriented endeavor that blended the lofty discourse of technical and moral development with the tangled bureaucratic negotiations that enabled substantive coordination among a diverse mix of governments, foundations, and other organizations.

Barany observes that special attention must be paid to the personal scale. In the above quote, the qualification of "elite driven" accurately highlights the key role of certain individuals during the period treated here. But the coordination between foundations, local governments and institutions that were being created in South America also played a key role in the reorientation of mathematical research. Upon closer investigation of the mathematics that was being done – that is, moving from the scale of major science policies to that of the mathematicians at work – it seems that it would be a mistake to characterize the action of US policies on Brazilian mathematics as colonialism. The notion of Americanization as a transnational action, proposed by Tournès, would be more appropriate. Analyzing the literature about the history of science in the period, we found this notion resonates better with what was going on in Brazil.

Tournès' work discusses the biological sciences and the introduction of experimental methods in the social sciences. He shows that the actions of philanthropic foundations are not limited to a disinterested financing of research, but they do not follow acculturation strategies either. The consequences of financial priorities are to be searched on the subjects chosen and on the methodologies borrowed from interactions with foreign researchers. These foundations do not necessarily have any a priori goal aimed at acculturating other countries to an American ideology. Rather, financing constitutes a transnational action aimed at intervening in existing research environments that, based on common interests, may converge with the foundation's investment priorities. It can be described as a kind of *seduction*, that is the term Antonio Pedro Tota uses to describe Americanization strategies in Brazil Tota [2009].

Within the history of mathematics, internationalization during the period under investigation is strongly linked to the action of US institutions that turned attention to Latin America after the Second World War. One of their main programs was to offer grants for young Latin American intellectuals to do internships at universities in the United States. The goal was to constitute an "invisible college", with George D. Birkhoff as a prominent proponent for the development of mathematics in Latin America. In addition to increasing interactions among mathematicians, the program also invested in libraries and opened American newspapers to mathematicians from South American countries Ortiz [2003].

Other cultural arenas in Brazil experienced a similar process. Controversy over American influence on Bossa Nova was intense in the same period. The musical style that became a symbol of Brazil abroad emerged in 1958, after a period of complaints regarding the golden age of the good neighbor policy implemented by the United States to influence Brazilian culture. Brazilian films and songs, symbolized by Carmen Miranda, had great impact in the US. But, since nationalism was a strong current in Brazilian thinking, Miranda was criticized for being "Americanized", leading her even to write a song to contest such criticism. Unlike movies and songs from this first period, marked by a more offensive action, Bossa Nova could not be said to be a product of American acculturation. It was a new kind of synthesis, that intrinsically mixed elements of Brazilian music with characteristics of American jazz, associated with a modernization trend. This merging of different cultural influences, with jazz as one important component, could have contributed to the broad and increasing international recognition of Bossa Nova during the 1960s Medaglia [2013].

The relationship of Brazilian scientific research to economic and Cold War histories has been studied by few historians of science, and mainly in health sciences Cueto (ed.) [1994]. Freire and Silva seek to remedy this situation by focusing on the role played by physicists in connecting their disciplinary communities and international scientific networks Freire and Silva [forthcoming].

In mathematics we can observe, at the same time, a decline of the highly abstract approach associated with Bourbakist (so, French) mathematics. This came along with an increasing vaporization of a more geometric point of view, symbolized by the works of René Thom and others [22]. There was a subtle malaise with the excess of formalism that the Bourbakist's orientation reinforced. Diminishing the importance of Nachbin's works as compared to Peixoto's, Elon Lima associates Nachbin to an excessively formal "French style":

> At IMPA, researchers have always had a vision that it was not necessary to learn a ton of mathematics to do high-level research, meaningful research. Many of the formalisms, general, abstract and complex theories can be ignored, and one can focus on important, basic problems, and be successful in the same way – the greatest example of this is Professor Mauricio Peixoto. Professor Nachbin had a slightly different vision, because he had a more French-style training, that is to say, he had to learn a ton of things, but he still managed to do some good quality research. He had a vision of mathematics as a formal system, while Mauricio had a vision closer to that of an engineer Palis, Camacho, and Lima (eds.) [2003, p.119].

Taking into account the place Lima occupied at IMPA in subsequent years, we can infer that this opinion influenced the choices that the Institute would later take. Lima had gone

[22] See for instance the discourse of Hassler Whitney about one of the Fields Medalist, John Milnor, in the ICM of 1962 (the other Fields Medalist was Hörmander).

to the University of Chicago in 1954, under Nachbin's advice[23]. While talking to us about the years spent there, he remembered a little song: Analysts, topologists, geometers agree / if you go for generality / there's no one but Bourbaki / one theorem by them / is almost ten by you and me / Bourbaki goes marching on Lima [11 May 2016].

Lima quoted Morris Hirsch as one author of the song, which describes a somewhat ironic atmosphere involving what was perceived as an excess of generality of Bourbakist's concerns. Hirsch himself, to whom I wrote to ask about the song (that he remembers but says not to be of his own), describes the feelings related to Bourbaki in Chicago:

> I didn't feel any unease about the Bourbaki approach, but as the song suggests, we thought it extremely, and perhaps unnecessarily, abstract. But we appreciated its logical and systematic treatment. I remember having difficulty finding standard results in Bourbaki – maybe in real analysis, or group theory – because their expositions started with the most general case, in which I had no interest or understanding, and only after many pages getting down to what I considered to be the real subject.

Bourbaki's mathematics was associated with being "too general", and therefore too restrictive for "finding standard results". At the same time, applied mathematics was acquiring greater importance. Peixoto, with his approach to dynamical systems, synthesized two strands, the declining and the ascending one, as will be explained below.

When discussing his motivation for proposing structural stability and genericity as key notions for the development of a theory of dynamical systems, Peixoto says that he was convinced that the main goal of the mathematics of his time was to classify mathematical objects, by means of equivalence relations between them, putting emphasis in their structures Peixoto [2000]. He thought that it would be fruitful to express the theory of differential equations in a set-theoretic language. The suggestion already given by Poincaré (to classify the functions defined by differential equations) had to be fulfilled with notions from set theory. In order to do that, Peixoto sought to introduce two new elements Peixoto [1987]:

1. A space of differential equations, or dynamical systems, possessing a topological structure;

2. A notion of qualitative equivalence between two differential equations.

Both requirements were fulfilled in Peixoto [1959] and Peixoto [1962]. Peixoto defined the space of dynamical systems by considering a dynamical system as a point of a Banach space, and proposed that an equivalence relation between two systems in this space should

[23] Lima was supervised by Nachbin at the beginning of his research in analysis, but ended up getting his doctorate in topology, in 1958, with a thesis directed by Edwin Spanier in Chicago.

be a homeomorphism transforming trajectories of one system into trajectories of the other. This last definition was inspired by the work of Andronov and Pontryagin. This confirms that Americanization cannot be defined as the action of a nation towards another. Indeed, one of Peixoto's major innovations was the adaptation of a proposal first introduced by – great irony – soviet mathematicians.

After Peixoto's results, an analogous program seeking to generally describe dynamical systems, in higher dimensions, was proposed, with a special role played by Smale in the beginning of the 1960s. During this decade, some counterexamples, came directly from the modeling of physical phenomena (like the works of Lorentz on meteorology), challenged the theory and made it advance in forging new definitions Aubin and Dahan-Dalmedico [2002]. The tension between physical examples and mathematical categories that could or could not express some kind of generality has been a driving force in the development of dynamical systems theory (as I show in Roque [2016]). A research program was then conceived that synthesized, on the one hand, a less formal, more applied, and more "oriented to specific problems" mathematics and, on the other, abstract and general concerns.

This program facilitated the relations with institutions in the United States and also served the project of Brazilian mathematicians to develop an autonomous and internationalized research center. The geopolitical situation restructured the relationship between governments, patronage agencies and scientists, the whole process being governed by informal evaluations and political compromises with the aim of building a new world-class institution. The focus on dynamical systems took on a strategic role, as it enabled a combination of various elements:

- Connection with research centers in the United States, guaranteeing the means for Brazilian mathematicians to access and take part in ongoing changes at the core of mathematics;

- Flexibility of an autonomous institution to build a modern image, particularly associated, at this time, with the research done in the US;

- Construction of a new field of research that did not require prior knowledge of a great number of mathematical results and that, being less formal, was adapted to the profiles of researchers;

- Association with the applied trend that was becoming dominant in the US. The field was seen as being useful to applied domains, even if it did not always focus on effective applications.

Americanization was a strategy of transnational appropriation of both the research questions and the means of making their development possible. It was a trend observed in the core of mathematics, as well as in more subtle extra-mathematical motivations (associated with scientific policies and patronage), stimulating mathematicians to follow certain directions of research instead of others.

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