RIDC NeuroMat

Ninth Report of Activities

Aug 31, 2021 - Jul 30, 2022

Contents

1 Highlights of the period

- **Estimating the interaction graph of stochastic neuronal dynamics by observing only pairs of neurons**, by E De Santis, A Galves, G Nappo, M Piccioni, which appeared in *Stochastic Processes and their Applications* **vol. 149**, pp. 224-247 (2022), is a real step forward in the direction of making statistical model selection for systems of interacting point processes with memory of variable length used to model systems of spiking neurons. This paper is a major improvement of a previous article produced by the NeuroMat team (Duarte et al. 2019).

- The Neuroscience Experiments System (NES)–A Software Tool to Manage Experimental Data and Its Provenance, by M. Ruiz-Olazar, E. S. Rocha, C. D. Vargas and K. R. Braghetto, which appeared in *Frontiers in Neuroinformatics*, **15**, pp. 1-18 (2021), presented the open-source software NES that was developed by the NeuroMat team. The software enables researchers to efficiently perform the management of their experimental data in a secure and user-friendly environment, providing a unified repository for the experimental data of an entire research group and allowing for efficient data sharing.

- **Pathways to the 2023 IHP thematic program Random Processes in the Brain** is a preparatory process for the conference "Random Processes in the Brain: From Experimental Data to Math and Back", to be held at the Institut Henri Poincaré, Paris, from February 27 to April 7, 2023. The goal of the preparatory process is to frame and pave research practices among the participants of the IHP thematic program that will eventually emerge during the actual conference in Paris. Four webinars have been organized in the context of the Pathways series, with Christophe Pouzat (Université de Strasbourg), Massimiliano Tamborrino (Department of Statistics at University of Warwick), Peter F Liddle (Institute of Mental Health, University of Nottingham), and Markus Diesmann (Jülich Research Centre). The series has also sparked research discussion groups, most notably around "Structural Learning by the Brain" and "Simulation-based Inference for Neuronal Networks", and led to the production of multimedia content, including the web portal aforementioned.

- **Technology transfer and dissemination related to the NeuroMat Parkinson Network (AMPARO)**. There have been around 80 publications on the AMPARO Facebook page, normally in video format. The initiative has also launched a podcast providing life histories and specialized information on the Parkinson's Disease and wellbeing.

- **Six PhD students under the supervision of NeuroMat PIs** obtained their doctoral degree during the period assessed in this report. Details are provided in Annex 10.

- **NeuroMat former PhD student, Victor Hugo de Oliveira e Souza, received the Award Jose**

Leite Lopes from the Brazilian Physical Society as the best PhD thesis of 2020. His thesis was called: "Development of instrumentation for neuronavigation and stimulation transcranial magnetic field". This PhD thesis was directed by NeuroMat PI Oswaldo Baffa Filho.

2 RIDC NeuroMat Identification

RIDC: Research, Innovation and Dissemination Center for Neuromathematics (NeuroMat)

Grant number: 2013/07699-0

Host institution: Instituto de Matemática e Estatística da Universidade de São Paulo

Associated institutions: Aalto University; Centre National de la Recherche Scientifique - CNRS (Strasbourg); Forschungszentrum Jülich; Gran Sasso Science Institute (GSSI); IBM Thomas J. Watson Research Center; Instituto de Matemática Pura e Aplicada (IMPA); National Institute of Neurological Disorders and Stroke (NIH); New York University Shanghai; Universidad de Buenos Aires; Universidad de la Republica; Universidad de San Andrés; Universidade Estadual de Campinas (UNICAMP); Universidade Federal do ABC (UFABC); Universidade Federal do Pará (UFPA); Universidade Federal de Pernambuco (UFPE); Universidade Federal do Rio de Janeiro (UFRJ); Universidade Federal do Rio Grande do Norte (UFRN); Universidade Federal do Rio Grande do Sul (UFRGS); Universidade Federal de São Carlos (UFSCar); Università di Roma "La Sapienza"; Université Côte d'Azur; Université Paris 1 (Pantheon-Sorbonne); University of California, Berkeley; Faculdade Cásper Líbero.

Webpage: http://neuromat.numec.prp.usp.br

Principal Investigator/Center Director: Jefferson Antonio Galves

Vice Director: Pablo Augusto Ferrari

Co-Principal Investigators: Antônio Carlos Roque da Silva Filho; Claudia D. Vargas; Ernst Hamburger (*in memoriam*); Fernando da Paixão; Jorge Stolfi; Oswaldo Baffa Filho; Pablo Augusto Ferrari

Education and Knowledge Dissemination Coordinator: Fernando Jorge da Paixão Filho

Technology Transfer Coordinator: Antônio Carlos Roque da Silva Filho

RIDC Executive Manager:

System analyst:

Administrative assistant: Lourdes Vaz da Silva Netto - IME/USP; Vera Lúcia Ribeiro - IME/USP

Manager of Education and Dissemination of Knowledge:

Manager of Technology Transfer:

The Research, Innovation and Dissemination Center for Neuromathematics (RIDC NeuroMat) is a center of mathematics which has as mission to develop the new mathematics needed to construct a Theory of the Brain accounting for the experimental data gathered by neuroscience research. Mathematician Antonio Galves coordinates this center. Hosted by the University of São Paulo, the RIDC NeuroMat was

established in 2013, with support from the São Paulo Research Foundation (FAPESP), grant 2013/07699-0, which will last until July 2024.

The RIDC NeuroMat has an interdisciplinary team, bringing together researchers in mathematics, computer science, statistics, neuroscience, biology, physiotherapy, medicine, physics and communication, among other disciplines. RIDC NeuroMat leads a worldwide university network, with ramifications that sprawl to several high-level research institutions in Brazil, Latin America, the United States, Europe and China (Annex 1). Most research output has had co-authors from more than one country, thus contributing to put NeuroMat at the center of a blossoming international scientific cooperation around Neuromathematics.

Alongside a research team that focuses on the scientific challenges pertaining to Neuromathematics, NeuroMat has active technology-transfer and dissemination teams. The technology-transfer effort is concentrated on devising tools for diagnosing and clinical guidelines for neurological conditions, and on developing free, open-source computational tools to manage and compile experimental and clinical data. This development team is part of a joint effort to create an international open database for neuroscientific data. The dissemination-team effort includes a nonstatic web portal (Creative Commons license), open multimedia productions and training projects with public-school teachers. A distinctive feature of this effort is that it relies on web-2.0 media tools as a means of communicating on-the-go scientific endeavors as well as involving a scientific and broad community around bridging the high-level science that this RIDC develops and general audiences.

Pablo Augusto Ferrari (UBA and USP), Antonio Carlos Roque da Silva Filho (USP), Fernando Jorge da Paixão Filho (UNICAMP), Ernst Wolfgang Hamburger (USP, *in memoriam*), Jorge Stolfi (UNICAMP), Claudia Domingues Vargas (UFRJ), and Oswaldo Baffa Filho (USP) remain co-principal investigators, along with PI Antonio Galves (USP). David Brillinger (UCBerkeley), Francesco Guerra (Universita di Roma "La Sapienza"), Leonard Cohen (National Institute of Neurological Disorders and Stroke), Markus Diesmann (Jülich Institute of Neuroscience and Medicine), and Wojciech Szpankowski (Purdue and NSF Center for Science of Information) take part in NeuroMat's International Advisory Board. NeuroMat's main laboratory and offices are located on a three-story building, with approximately 1,000 square meters, at 1171 Prof. Luciano Gualberto Avenue, at USP's central campus, in São Paulo. NeuroMat's main building has recently gone through an extension (+175 square meters) and renovation to support new laboratory facilities; the construction cost was BRL R$ 1,603,339 and was fully covered by USP, MaCLinC grant (recipient: Antonio Galves). NeuroMat has set up a Simulation Laboratory (SimLab) at the USP's Ribeirão Preto campus. NeuroMat's administrative staff team is composed of two administrative assistants and an IT professional. These positions are supported by USP.

3 Scientific report

3.1 Mission

The mission of NeuroMat is to develop the new mathematics which is deemed necessary to account for a Theory of the Brain, accounting for the full experimental data gathered by neuroscience research. The long-term objective is to understand and explain complex neuroscientific phenomena, with focus on plasticity mechanisms underlying learning and memory neurorehabilitation and rewiring. This Neuromathematics is envisioned, at this time, as conjoining probability theory, combinatorics, statistics, and neuroscience. This requires the definition of a full new class of mathematical models to describe and explain in a parsimonious way the different scales of neural activity and the relationship between them. The construction of these models should occur together with the development of suitable statistical and computational methods, including model selection principles and results.

3.2 Executive summary

The main goal of NeuroMat is to build the new mathematical, statistical and computational framework which is necessary to address the challenges of neurobiology. Activities presented in this report strictly relate to the goals announced in the document submitted to FAPESP in November 2012, in the third and final step of the selection process. The general goals of this research project are the following:

- Development of new classes of stochastic processes which are necessary to model brain functioning;
- Development of the statistical tools required by this new class of stochastic processes.

Detailed progresses on these two goals were exhaustively reported in the documents "First Report of Activities 2013-2014", "Second Report of Activities 2014-2015", "Complementary Form 2013-2015", the Evaluation by FAPESP International Committee in November 2015, "Third Report of Activities 2015-2016," the "Complementary Form 2015-2017," "Fourth Report of Activities 2016-2017," the presentation "NeuroMat: first 5 next 6" to FAPESP's International Assessment Committee, the 2018 Statement of Impact (SoI), "Fifth Report of Activities 2017-2018," "Sixth Report of Activities January 2019-July 2019," "Seventh Report of Activities August 2019-October 2020," and "Eighth Report of Activities November 2020-August 2021." These documents were carefully reviewed by FAPESP. The SoI is a summary of main activities and highlights our main achievements. This statement is still up-to-date and informs substantially this report, along with relevant parts of the document for the renewal of the RIDC NeuroMat by FAPESP, the "Project for the period 2018-2024."

The progresses achieved in the first term of the RIDC have opened up the path for a new stage of development. In spite of all the challenges posed by the COVID-19 pandemics, NeuroMat continued with

the construction of innovative applications of the new stochastic models and statistical tools developed in the previous years, aiming at concrete questions of Neuromathematics and computational modeling in neurobiology, electroencephalographic recordings analysis, and neurorehabilitative therapy. Research highlights and corresponding published works are listed below, in the appropriate section. Since the "Eighth Report of Activities", the NeuroMat research team has:

- published 68 papers;
- submitted 15 online pre-prints;
- published 1 book;
- had 6 PhD dissertations concluded and 9 in progress;
- had 2 MA thesis concluded and 1 in progress.

NeuroMat scientific publications in the period being assessed in this report are listed on Annex 2. A full list of publications since the inception of NeuroMat can be viewed at NeuroMat's Google Scholar (https://goo.gl/LvZV4f). Citations to these publications across the years are available on Annex 3.

In parallel to the mathematical and theoretical biological developments which are necessary to foster the scientific project of NeuroMat, the RIDC has also sustained two laboratories. In April 2016, NeuroMat launched a new research facility: the NeuroMat Simulation Laboratory (SimLab). The simulation of large-scale network models remains a key activity to test analytical results, and the NeuroMat SimLab allows for such tests, providing the NeuroMat team with a new experimental tool to test and construct large-scale computational implementations of NeuroMat's newly developed models. The SimLab is installed at the Laboratory of Neural Systems (SisNe) of the Department of Physics of USP Ribeirão Preto, under the direction of NeuroMat PI and Technology transfer coordinator A.C. R. da Silva Filho (USP-Ribeirão Preto). In July 2017, NeuroMat launched an Electroencephalography Laboratory, with an EEG DC actiCHamp 128CH System. The creation of NeuroMat's EEG lab was made possible by the expansion of the building, through a grant from the University of São Paulo (value of support: BRL R$ 1,603,339).

3.3 Research results highlights

There are two main axes in the NeuroMat research agenda, which follow:

- the development of a new class of stochastic processes aimed at a realistic description of nets of spiking neurons;
- the introduction of a new mathematical approach to address the classical conjecture that the brain retrieves statistical regularities from sequences of stimuli.

The first axis appears to be by now a well-established area of research in Probability Theory. For instance, according to Google Scholar, there have been around 120 papers with direct references to the paper (Galves and Löcherbach, 2013). Since 2021, there have been 39 publications with direct references to this paper.

The second research axis has evolved in 2022 into a new research program to look at the brain activity before and following the responses in the Goalkeeper's game. In this program, a comparison is made between the law of the EEG segments between successful predictions and prediction failures (Hernández et al. 2021). In this program, the correlation between the Beta band coefficients and successful predictions and failures of the goalkeeper are checked. The team conjectures that the Beta band coefficients will give us a good indication whenever a given segment of EEG is discrepant with respect to the law characteristic of that context and prediction.

In the same line of research, the dissertations by Paulo Roberto Cabral Passos and Fernando Araujo Najman have contributed new dimensions to the framework proposed by Duarte et al (2019). Passos' PhD dissertation has relied on the Goalkeeper Game. Experimental results and a new statistical analysis have shown evidences that besides the succession of contexts embedded in the sequence of stimuli the successive predictions made by the volunteers have an influence on the law of their reaction times. Najman's PhD dissertation has revisited data previously studied in Hernández et al (2021). Using a new cluster analysis statistical approach, it has found out that the brain encodes the sequence of stimuli through the regular, periodic structure embedded in the random sequence of stimuli generated by the ternary and quaternary context tree models.

A complete list of papers is available as Annex 2.

3.4 Scientific meetings organized by NeuroMat in the period

An important aspect of the work NeuroMat produces depends on fostering a tight relationship among members of the NeuroMat worldwide. As emphasized in our interaction with FAPESP International Committee, we are especially aware of this challenge, and we have sustained partnerships among scientists from different parts of the world —of which the high rate of papers with co-authors from different countries is an evidence. The fostering of a tight community around Neuromathematics strongly meets the expectations of FAPESP's Committee.

A key part of the community-building entrepreneurship NeuroMat has sustained relates to organizing frequent conferences and meetings on topics pertaining to Neuromathematics. In the period covered by this report, we continued with this endeavor and were not stopped by the COVID-19 Pandemics. The meetings organized in the period are listed below.

During the period of activities being reported in this document, the NeuroMat team has organized the "Pathways to the 2023 IHP thematic program Random Processes in the Brain" series, in which four

seminars were organized. More details on these events are available as Annex 8.

4 Technology transfer report

The main focuses of this area have been the development of supporting tools for the diagnosis and neuro-rehabilitation researches being conducted by the AMPARO and ABRAÇO initiatives on Parkinson's Disease and Brachial Plexus Injury, respectively. These tools are the Goalkeeper Game, a robot arm for accurate real-time positioning of a transcranial magnetic stimulator on the head, and the Neuroscience Experiments System (NES).

An important milestone has been the publication of Ruiz-Olazar et al (2022). This article has rigorously presented the software tool to manage experimental data and its provenance developed by NeuroMat, the Neuroscience Experiments System (NES). NES enables researchers to efficiently perform the management of their experimental data in a secure and user-friendly environment, providing a unified repository for the experimental data of an entire research group. Furthermore, its modular software architecture is aligned with several initiatives of the neuroscience community and promotes standardized data formats for experiments and analysis reporting.

The highlight of the period was related to the robot arm development. The communication and closed-loop control systems were constructed, and now the robot can be instructed to move to a desired place on the scalp and apply the stimulation while keeping the coil on the same position even if the head moves.

4.1 Neuro-rehabilitation and diagnosis

4.1.1 ABRAÇO Initiative

NeuroMat's Brachial Plexus Injuries focus area is called ABRAÇO Initiative, or Ação NeuroMat para a Lesão do Plexo Braquial. The website of ABRAÇO is abraco.numec.prp.usp.br. This website is the first worldwide platform devoted to this health condition and is aimed at being both a source of help and support for patients, caregivers, students and professionals, and a powerful scientific knowledge sharing platform.

4.1.1.1 Assessing plasticity associated to Brachial Plexus Injuries The team led by NeuroMat CO-PI Claudia Domingues Vargas (INDC/UFRJ) is using the Goalkeeper Game (Section 4.2.1) to study mechanisms of plasticity in the brain after a brachial plexus injury aiming at developing new tools to assess plastic changes in the brain induced by this traumatic injury. In the motor context, prediction can be seen as an automatic process of choosing and implementing a next step in a sequence of events. Tests are being conducted with healthy human subjects playing the Goalkeeper Game to determine which parameters of the context tree generating stochastic sequences of events in the Goalkeeper Game are best associated with the optimal processing of sequences of motor events. Furthermore, data collection from the brachial plexus injury patients has already started in order to investigate how this injury interferes in

the ability of these individuals to predict events compared with the healthy subjects. This important step to better understanding the prediction process after a brachial plexus injury could help in the development of new treatments for this injury, more specifically, Tthe objective is to check the possibility of using the Goalkeeper Game as a tool for rehabilitation of brachial plexus injury patients.

4.1.1.2 New transcranial magnetic stimulation protocol This endeavor involves a collaboration between Neuromat CO-PI Oswaldo Baffa Filho (FFCLRP/USP), Neuromat CO-PI Claudia Domingues Vargas (INDC/UFRJ) and R. Ilnomiemi (Aalto) for the development of a closed-loop robotic system for the positioning of a transcranial magnetic stimulation (TMS) coil on a subject's scalp (see Section 4.3.1). Besides the technological aspects of this initiative, a team of researchers led by NeuroMat CO-PI Claudia Domingues Vargas (INDC/UFRJ) is developing a new protocol to test whether the primary motor cortex (M1) holds the memory of a sequence of TMS pulses driven by a stochastic chain. If so, it should be possible to recover in the motor evoked response (MEP) a signature of a sequence of TMS pulses applied in M1. In other words, can a sequence of TMS pulses generated by a stochastic chain be recovered on the MEP response? Having this answer, then it would be interesting to test if this recovered signature is affected by a brachial plexus lesion.

4.1.2 AMPARO Initiative

The NeuroMat focus area towards Parkinson's Disease is called AMPARO Initiative, or Rede de Apoio NeuroMat a Amigos e Pessoas com Doença de Parkinson. The link to the website of AMPARO is amparo.numec.prp.usp.br.

4.1.2.1 A tool for early Parkinson's Disease diagnosis The team led by NeuroMat researcher Maria Elisa Pimentel Piemonte (FM-USP) is using the Goalkeeper Game (see Section 4.2.1) to study putative novel relationships between the main cardinal Parkinson's Disease symptom, bradykinesia, and implicit probabilistic learning and lack of ability in automatic motor control. The study aims at developing a new measure and typology to establish the limits between normal decline associated to aging process and abnormal alterations associated to the onset of the pathological process of Parkinson's disease. The clinical implication of this work is to offer a free and friendly test to early diagnosis of Parkinson's disease by e.g. cell phones using the Goalkeeper Game.

4.1.2.2 Collaborative network for Parkinson's disease clinical guideline AMPARO Initiative organizes monthly meetings with NeuroMat members, professionals, patients and caregivers. The goal is to share knowledge towards the collaborative building of guidelines for Parkinson's disease in Brazil, especially for the public health system. An important achievement in the period was the publication of the first multicenter trial assessing the impact of the COVID-19 pandemics on people living with Parkinson's

disease in Brazil. This pioneering study involved 14 centers distributed over all regions of the country under the coordination of AMPARO.

4.2 Computational tools

4.2.1 Goalkeeper Game

NeuroMat researchers devised experimental protocols to test the performance of human subjects in identifying sequences of stimuli represented by context trees. An innovation spin-off from NeuroMat's research project is the "Goalkeeper Game". It is an online game with desktop and mobile device versions in which the player, taking the role of a goalkeeper in a penalty shootout, guesses the position in the goal where the ball will hit (left side, right side or center) after being kicked by the opponent. The game consists in a sequence of penalty kicks in which the ball positions are generated by a context tree model. As the player (the goalkeeper) succeeds in guessing the right sequence, the complexity of context tree model increases and the game becomes more difficult. The goalkeeper game has potential to be used as diagnosis and rehabilitation tool in neurology, and the NeuroMat technology transfer team is currently testing its applicability in its two main clinical development fronts: Parkinson's Disease and Brachial Plexus Injuries (see Sections 4.1.2.1 and 4.1.1.1). The game is openly, freely available at: game.numec.prp.usp.br and also at Apple Store and Google Play.

4.2.2 Neuroscience Experiments System

The Neuroscience Experiments System (NES) is a free software to manage data and metadata from neuroscience experiments. It integrates data records from different types such as clinical, electrophysiological, and behavioral. NES is currently being used by the teams involved in both ABRAÇO (Section 4.1.1) and AMPARO (Section 4.1.2) initiatives. NES is integrated to the Goalkeeper Game (Section 4.2.1) and to the NeuroMat Open Database (Section 4.2.3). The main functionalities, which include Electrophysiology and Export modules, were improved in the period, and modules that deal with the data using machine learning are being developed. The development team of the Neuroscience Experiments System is led by the Associate Investigator K. R. Braghetto (IME/USP).

4.2.3 NeuroMat open database

The NeuroMat open database provides an open-access platform for sharing and searching data and metadata from neuroscience experiments. The platform is constituted by a web portal and a REST (Representational State Transfer) API (Application Programming Interface). The web portal was designed to have a user-friendly interface. The REST API is used to feed the open database with experimental data generated by NeuroMat's researchers. Currently, the API intermediates the receiving and retrieving of data from research laboratories which use NES (Section 4.2.2). It can be can easily adapted to receive (or transfer) data from (for) other client systems. The development team of the NeuroMat open database

is led by K. R. Braghetto. The platform is hosted at https://neuromatdb.numec.prp.usp.br/ and its source code is available at https://github.com/neuromat/portal.

4.3 Hardware tools

4.3.1 Closed-loop system of robotic stimulator positioning in the brain

The effect of transcranial magnetic stimulation (TMS) on the brain is highly specific; variations of the order of 1 mm in the positioning and a few degrees in tree angles of the coil can evoke substantially different responses. In addition, the patient or volunteer being awake throughout the procedure performs small involuntary movements, even with the head secured on a head strain. If the subject moves during stimulation, the stimulator must be repositioned. As a solution to this problem, robotic arms have been proposed to help position the TMS coil. Robotic positioning also enables the development of new methods for automated motor mapping. However, the combination of TMS and robotic arms is not yet commonly used by the clinical and scientific communities due to three main factors. The first is low portability, that is, the systems are fixed and cannot be transported between rooms and clinics. The second is the high cost of commercial equipment. And the third is that commercial navigation programs are closed systems, making it impossible for new tools to be developed to test different research protocols. A closed-loop system is a set of mechanical or electronic devices that automatically regulates a variable to the desired state, without human interaction. Closed-loop systems are designed to automatically achieve and maintain the desired condition (exit condition), comparing it to its condition at the given moment (real condition).

Since the last report, the team led by NeuroMat PI O. Baffa Filho and R. Ilmoniemi finished the assembling of two robot arms (Elfin 5) in their stands. The first set-up was a table-like stand and the second used a wheeled stand with a wider free area. The main achievements were intensive tests of the communication protocols within the InVesalius software to operate the robot arms using different positioning devices (Polhemus, Claron Camera and NDI Camera). It is now possible to instruct the robot to move to a certain position on the scalp and to stimulate a specific area of the brain in an open loop configuration. The first version of the closed-loop control was also tested, and it is possible to keep the coil in the same position even if the head moves. During this step, it was clear that the best positioning device is the NDI Camera e new cameras were bought and will be tested in the next period. To ensure the safety of the TMS robotic control, we developed four software security layers: 1) securing the visibility of the patient's head markers; 2) filtering sudden fluctuations of the tracking-determined device coordinates, 3) pre-defining the volume where the coil is allowed to move; 4) restricting the coil trajectory. Another issue is the force applied by the coil on the patient's scalp. To ensure the reproducibility of the TMS brain response, the applied force needs to be constant and under a safety threshold, requiring a force and torque (FT) sensor combined with the robot arm. Several solutions were tested and the best is to acquire

a commercial FT sensor compatible with the robotic arms. The development of the multilocus TMS stimulator continues at Aalto University and the PhD Student Renan Matsuda is in Helsinki now working in this area also to assure a smooth transfer of skills and technology from this group to Neuromat´s group. The electrical field induced by the multilocus transducer, coupled to the robot arm, was measured and no significant difference has been found compared without the robot arm. Confirming that the robot causes no electromagnetic interference on the multilocus. For the next step, the electronic changes of the multilocus TMS will be integrated with the robotic closed-loop control. Then, small head displacements (a few centimeters) will be corrected by electronically compensation of the magnetic field, and the robot will deal with bigger displacements.

The paper TMS with fast and accurate electronic control: Measuring the orientation sensitivity of corticomotor pathways, published by VH Souza, JO Nieminen, S Tugin, LM Koponen, O Baffa, RJ Ilmoniemi, in Brain Stimulation 15 (2), 306-315 shows the importance to produce high-quality data of a fast and accurate positioning of the magnetic stimuli using the multilocus TMS device. Another paper was published (Tardelli, G.P., Souza, V.H., Matsuda, R.H. et al. Forearm and Hand Muscles Exhibit High Coactivation and Overlapping of Cortical Motor Representations. Brain Topogr 35, 322–336 (2022)). This study contributes to a more detailed cortical motor representation towards a synergistic, functional arrangement of M1. Understanding the muscle group coactivation may provide more accurate motor maps when delineating the eloquent brain tissue during pre-surgical planning.

The works developed by the group are drawing attention during conferences, symposia and invitations for seminars and collaborations. Another relevant fact is that our former student, Victor Hugo de Oliveira e Souza with the thesis: "Development of instrumentation for neuronavigation and stimulation transcranial magnetic field" received the Award Jose Leite Lopes from the Brazilian Physical Society as the best PhD thesis of 2020 for all the areas of physics in Brazil. As far as we know, this is the first time that this prestigious award was given to a thesis in the area of physics applied to medicine (Medical Physics). The thesis has three highlights:

- Development of the neuronavigation system (new technology): A published article and a patent application. InVesalius Navigator is the first free and open source neuronavigation software to guide brain stimulation and is already used in research laboratories in several countries and renowned institutions, such as Stanford University (USA), Aalto University (Finland), Federal Universities of Rio de Janeiro and Juiz de Fora. This software is the basis of our best poster award-winning work at the 4th International Brain Stimulation Conference, held in December 2021 in Charleston, USA.

- Creation of multichannel transducers for automation of non-invasive brain stimulation procedures (new technology and basic science): Two published articles, one accepted for publication and one

in the submission process. One of the transducers is the first to allow fast (sub-milliseconds) and accurate (1°) electronic control of stimulus orientation in the brain. Thus, we studied for the first time some anatomical and functional properties of neuronal populations related to motor control. This technology has been used for the development of algorithms for the automation of brain stimulation procedures.

- Method for phantom creation for training in neurosurgery (education). This method has been applied in clinical practice and was crucial for the success of a conjoined twin separation surgery that took place in Ribeirão Preto, throughout 2018.

5 Dissemination report

NeuroMat's dissemination activities have as a compass point working as a collaborative hub, developing web-2.0 media tools as a means of communicating on-the-go scientific endeavors as well as involving a scientific and broad community around the high-level science that this RIDC develops. Activities are envisioned to use innovative means to transform scientific culture, overcoming artificial field boundaries and contributing to foment an integrated and genuinely multidisciplinary approach to the study of the brain. These activities have seen a significant increase in production and viewers in the context of the pandemic.

NeuroMat's milestone dissemination activities include in the period of interest:

- the Pathways to the 2023 IHP thematic program Random Processes in the Brain series
- the *A Matemática do Cérebro* podcast
- the Wikipedia Initiative
- the Wikimedia Commons Initiative
- Media Exposure and Newsletter
- Web resources: portal, Facebook page, dissemination blog
- NeuroCineMat
- the Introduction to Science Journalism course

5.1 The Pathways to the 2023 IHP thematic program Random Processes in the Brain series

Pathways to the 2023 IHP thematic program Random Processes in the Brain is a preparatory process for the conference "Random Processes in the Brain: From Experimental Data to Math and Back", to be held at the Institut Henri Poincaré, Paris, from February 27 to April 7, 2023. The goal of the preparatory process is to frame and pave research practices among the participants of the IHP thematic program that will eventually emerge during the actual conference in Paris.

5.2 The *A Matemática do Cérebro* podcast

The RIDC NeuroMat launched in August 2019 the podcast "A Matemática do Cérebro" – in Portuguese, Mathematics of the Brain. This resource is available on the most important podcast technologies and also hosted on its own website. The production of the podcast is led by NeuroMat director Antonio Galves and NeuroMat associate investigator Eduardo Vicente.

NeuroMat's podcast is aimed at covering three main topics: the model for systems of spiking neurons that the research team developed; the Statistician Brain conjecture; and pertaining institutional aspects of doing research in Brazil. The overall goal is to bring public awareness on work that is being done within the NeuroMat community.

5.3 The Wikipedia Initiative

NeuroMat's Wikipedia Initiative has become a strategic activity at the interface of communication and education. It has been recognized in Brazilian and foreign outlets as a "success case" of the use of Wikipedia and other collaborative projects as a means of scientific dissemination.

In the period covered by this report, an on-wiki portal for the Wikipedia Initiative has been launched at: https://pt.wikipedia.org/wiki/Wikipédia:GLAM/CEPID_NeuroMat

Main achievements are:

- 174 million content viewers in Wikimedia;
- 193 million words added to Portuguese Wikipedia and related projects;
- 103 thousand entries created on Wikimedia projects; and
- 202 thousand entries improved on Wikimedia projects.

The control panel of the NeuroMat Wikipedia Initiative is available at: https://outreachdashboard.wmflabs.org/campaigns/neuromat/programs.

5.4 The Wikimedia Commons Initiative

NeuroMat has been engaged in uploading media files to the open repository Wikimedia Commons. In the period assessed by this report, 63.1 thousand files had been uploaded by the NeuroMat team in this repository.

Files NeuroMat added to Wikimedia Commons were viewed 13,208,441 times in June 2022.

This figure is obtained from the web visualization control tool of the Dashboard (aforelinked).

5.5 Media Exposure

Activities from FAPESP'S RIDC NeuroMat were featured in around a hundred external media outlets since its inception in 2013. NeuroMat's media clipping for this year is attached to this report as Annex 4.

NeuroMat's newsletter has had 71 issues since it was first released in February 2014. Due to the pandemic, there has been a temporary interruption of the newsletter.

5.6 Web resources: portal, Facebook page, dissemination blog

NeuroMat's web portal was launched in early February 2014, and is thought of as the main official reference of the RIDC. It provides robust updates on research, technology transfer and dissemination activities. Publications are in English and Portuguese. There have been 14 thousand pageviews in the period of interest of this report different users — around 65% of which did not come from Brazil.

NeuroMat's Facebook page was launched in September 2014 to serve as a reference space for the diverse community that is involved with and interested in Neuromathematics. Since its creation (9/20/2014), the page has reached 1,730 followers, as of July, 2022, with steady progress. The community growth has been organic.

Since April 2016, the NeuroMat dissemination team has maintained a blog on scientific challenges and activities pertaining to science communication, especially relying on web-2.0 platforms. The blog is called "Traço de Ciência".

Posts on this resource have been published continuously; a detailed report is provided on Annex 6.

References are:

- web portal: https://neuromat.numec.prp.usp.br
- Facebook page: https://www.facebook.com/neuromathematics
- ABRAÇO Facebook page: https://www.facebook.com/iniciativaabraco/
- blog: https://difusaoneuromat.wordpress.com

5.7 NeuroCineMat

The NeuroMat dissemination team has fully produced 345 movies. A full list is available on the NeuroMat Youtube channel. There has also been continuous streaming of activities on YouTube. A full list is available on:

https://www.youtube.com/user/neuromathematics

5.8 The Introduction to Science Journalism course

The NeuroMat dissemination team launched in 2021 an Introduction to Science Journalism course to contribute to capacity building of communications professionals who are interested in specializing in science coverage. The course strictly abides to curriculum expectations of the Mídia & Ciência call.

The course has been developed under the supervision of NeuroMat PI Fernando J. Paixão, supported by NeuroMat team members and FAPESP science-journalism fellows.

The course is available freely on Wikiversity:

https://pt.wikiversity.org/wiki/Introdução_ao_Jornalismo_Científico.

6 Annexes

Annex 1 - NeuroMat global network of scientific, institutional affiliations

Annex 2 - NeuroMat scientific publications

Annex 3 - NeuroMat Scientific Publications: Citations

Annex 4 - NeuroMat's media clipping

Annex 5 - Website's analytics

- Annex 5a - NeuroMat's web portal
- Annex 5b - NeuroMat's podcast web portal
- Annex 5c - Abraço's web portal
- Annex 5d - Rede AMPARO's web portal

Annex 6 - NeuroMat dissemination blog "Traço de Ciência"

Annex 7 - Scientific Missions

Annex 8 - Seminars

Annex 9 - Post-doctoral fellows

Annex 10 - PhD dissertations

Annex 11 - MSc dissertations

Annex 12 - Scientific Initiation

Annex 13 - Scientific Journalism

Annex 14 - Technical Training

Annex 15 - Reports from FAPESP scholarships

- Annex 15a – Camilla Tsuji Oviedo – BJC2
- Annex 15b – Eduardo Werley Silva dos Ângelos -TT5
- Annex 15c – Nilton Liuji Kamiji – TT5
- Annex 15d1 – Carolina Salles Carvalho – BJC2
- Annex 15d2 – Carolina Salles Carvalho – BJC2
- Annex 15d3 – Carolina Salles Carvalho – BJC2
- Annex 15e1 – Arthur Lopes da Silva Valencio – Pdoc
- Annex 15e2 – Arthur Lopes da Silva Valencio - PDoc
- Annex 15f1 – Monique Ribeiro Polera Sampaio – BJC2
- Annex 15f2 – Monique Ribeiro Polera Sampaio – BJC2
- Annex 15g – Karine Damásio Guimarães - PDoc
- Annex 15h – Flávio Roberto Rusch – PDoc
- Annex 15i – Morgan Florian Thibault André – Pdoc
- Annex 15j – Eliezer Francisco de Santana Júnior – BCJ3
- Annex 15k1 – Erika Guetti Suca – TT4
- Annex 15k2 – Erika Guetti Suca – TT4
- Annex 15l1– Noslen Hernandez Gonzalez-TT5
- Annex 15l2– Noslen Hernandez Gonzalez-TT5