RIDC NeuroMat

Seventh Report of Activities

Aug 1, 2019 - Oct 31, 2020

Contents

1 RIDC NeuroMat Identification **3**

2 Scientific report **4**

2.1 Mission 4

2.2 Executive summary 5

2.3 Research results highlights 6

2.4 Scientific meetings organized by NeuroMat in the period 9

2.4.1 Research events & seminars 10

3 Technology transfer report **11**

3.1 Neuro-rehabilitation and diagnosis 11

3.1.1 AMPARO Initiative 11

3.1.2 ABRAÇO Initiative 12

3.2 Computational tools 13

3.2.1 Goalkeeper Game 13

3.2.2 SeqROCTM - Matlab toolbox for the analysis of Sequence of Random Objects driven by Context Tree Models 13

3.2.3 Neuroscience Experiments System 14

3.2.4 NeuroMat open database 14

3.3 Hardware tools 14

3.3.1 Closed-loop system of robotic stimulator positioning in the brain 14

4 Dissemination report **16**

4.1 Faísca NeuroMat 16

4.2 A Matemática do Cérebro podcast 17

4.3 Wikipedia Initiative 17

4.4 Wikimedia Commons Initiative 17
4.5 Training Courses 18
4.6 Media Exposure and Newsletter 18
4.7 Web resources: portal, Facebook page, dissemination blog 18
4.8 NeuroCineMat 19
4.9 Research on Communication Science 19

5 Annexes **20**

1 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 de Ouro Preto (UFOP); 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: Antonio 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: Antonio Carlos Roque da Silva Filho

RIDC Executive Manager: Carlos Eduardo Ribas - IME/USP (until September 2, 2019)

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.

2 Scientific report

2.1 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.

2.2 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," and "Sixth Report of Activities January 2019-July 2019." 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 the last year, the object of this report, NeuroMat started 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 "Sixth Report of Activities January 2019-July 2019", the NeuroMat research team has:

- published 55 papers;
- pre-prints 21;
- had 2 communications in meetings with referee

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).

2.3 Research results highlights

The most general challenge the NeuroMat team faces is the development of new classes of probabilistic models to study different aspects of brain functioning. As presented on the 2018 Statement of Impact:

"A main scientific achievement was the introduction by the NeuroMat team of a new class of stochastic processes aimed at a realistic description of nets of spiking neurons. These processes are systems with infinitely many interacting chains with memory of variable length. Since their introduction, these stochastic processes have become part of the research agenda of several centers in the world.

Our contributions to the investigation of this new class of stochastic processes include:

- the identification of mathematical conditions assuring the existence of the processes together with the design of a perfect simulation algorithm for their numerical implementation;
- results on the hydrodynamical limit of processes belonging to the class. This is an important step to relate different scales of description of the system, from the microscopic level, modelling systems of spiking neurons, to the mesoscopic and macroscopic levels, describing EEG and fMRI data;

- existence of phase transition for a specific instantiation of these models with leakage, setting a new framework for the rigorous investigation of spontaneous transitions of brain activity states, e.g. healthy to seizure-like activity. This is the first phase transition result rigorously proved for a mathematical model describing a system of interacting spiking neurons;

- introduction of a novel estimator of the interaction graph for models in this class and the proof of its strong consistency, not requiring the usual assumptions of stationarity and uniqueness of the invariant measure. This contribution addresses an important issue in contemporary neurobiology, namely the question of how to infer neural interactions from the activity of an ensemble of neurons.

- introduction of a simple microscopic stochastic model that describes short term plasticity in a large homogeneous network of interacting neurons. In this framework it is possible to describe short time memory of the system in a precise mathematical way. Namely, short time memory can be seen as the tendency of the system to keep track of an initial stimulus by staying within a certain region of the space of configurations during a short but macroscopic amount of time before finally being kicked out of this region and relaxing to equilibrium.

A second major achievement is the introduction of a new mathematical approach to address the classical conjecture that the brain retrieves statistical regularities from sequences of stimuli. This approach is based on a new class of stochastic processes, namely sequences of random objects driven by chains with memory of variable length. These processes appear as good candidates to model the relationship between sequences of stimuli and sequences of suitably parsed brain signals and behavioral states registered while exposed to stimuli.

This framework offers a new way to model structural learning and memory in the brain, including the following promising directions of research:

- It provides an effective way to identify brain sensitivity and reaction to sequences of stimuli which goes much beyond the possibilities offered by current averaging-based methods;

- As a consequence, it allows the introduction of a entire new class of experimental protocols in which physiological or behavioral data are recorded while a volunteer is exposed to sequences of stimuli generated by a stochastic chain with memory of variable length;

- This approach offers promising perspectives in clinical neuroscience by identifying different signatures in response to structured sequences of stimuli in neurological disorders;

From a purely statistical point of view, sequences of random objects driven by chains with memory of variable length constitute an innovative tool in functional data analysis and high dimension statistics."

An ongoing list of projects along the lines presented above include:

- Hebbian time evolution for the interaction graph of a network of spiking neurons
- Statistical analysis of stochastic processes
- Simulation of large-scale cortical network models
- Phase transitions, criticality and oscillations in stochastic neuronal networks
- Structural learning and decision making
- Modeling the plasticity in the brain after a traumatic brachial plexus injury in adults
- Instrumentation issues to address brain plasticity: the state of the art
- Stochastic modeling of spatio-temporal patterns of epileptic seizures
- Random networks for the brain
- Random graphs and computational psychiatry

A third major achievement, with possible clinical implications (see Section 3.1.1.1) was the application of the Goalkeeper Game to identify gait impairments in people with Parkinson's disease. As described in an article published in Frontiers in Aging Neuroscience by NeuroMat researchers M. E. Pimentel Piemonte, A. F. Helene, A. C. Roque da Silva Filho, M. D. Gubitoso, Y. L. Uscapi, M. S. d'Alencar and R. B. Stern, the Goalkeeper Game showed better predictive capacity than the traditional Montreal Cognitive Assessment (MoCA) test in assessing gait performance under complex conditions in people with Parkinson's disease as measured with the Dynamic Gait Index (DGI). This suggests a possible use of the Goalkeeper game as a screening instrument to identify gait impairments in people with Parkinson's disease.

These research directions are elements within the general challenge the NeuroMat team faces: the development of new classes of probabilistic models to study different aspects of brain functioning. This general challenge has been associated to: developing a new class of stochastic processes describing nets of spiking; making steps towards a mathematical and statistical framework to formulate the phenomenon of brain plasticity; and developing stochastic models, statistical procedures and neurobiological experimental protocols to address the classical conjecture of the Statistician Brain. Specific summaries of the research directions within the NeuroMat agenda may be found at the NeuroMat website.

Finally, it is worth mentioning that the Center Director, A. Galves, and the Associate Investigator F. Leonardi, together with the colleagues from UNICAMP, C. Galves, J. E. Garcia and N. L. Garcia, were the winners of the first edition of the Johannes Kepler award from *Sociedade Brasileira de Matemática Aplicada e Computacional* (SBMAC) for the publication of the article "Context tree selection and linguistic rhythm retrieval for written texts", in the journal Annals of Applied Statistics (Volume 6, Number

1 (2012), 186-209). This SBMAC award was named Johannes Kepler because the Society considered Kepler to be the first data scientist in history and this article was considered meritorious from the perspective of Data Science. For more details, see: "Artigo Científico é Premiado na Primeira Edição do Prêmio Johannes Kepler".

2.4 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.

- NeuroMat/NeuroMod Webinars 2020. The webinars were part of a partnership with the Institute for Modeling in Neuroscience and Cognition of Université Côte d'Azur (NeuroMod), France. The virtual meetings occurred fortnightly between April 16 and May 28, 2020, and the program can be seen at "NeuroMat/NeuroMod Webinars 2020".

- NeuroMat Online Seminars 2020. This was a series of online seminars given by team and guest members of NeuroMat. The virtual meetings occurred fortnightly between April 23 and June 4, 2020, and the program can be seen at "NeuroMat Online Seminars 2020".

- Second NeuroMat Young Researchers Workshop. The objective of the meeting was to give opportunity to NeuroMat's graduate students and postdocs to present their current work to all members of the Center. The workshop was held on November 27, 2019 at the Multipurpose Auditorium at NeuroMat. Further information can be seen at "Second NeuroMat Young Researchers Workshop".

- LASCON 2020 - VIII Latin American School on Computational Neuroscience. This was the eighth edition of this traditional worldwide school on computational neuroscience, which since 2016 has been a NeuroMat activity. The school was held entirely at the NeuroMat building in the main campus of USP in São Paulo between January 6 and 31, 2020. More information on the school, including its program, can be seen at "LASCON 2020".

A. Galves together with NeuroMat's PI C. Vargas and Associate Investigators E. Löcherbach, C. Pouzat and R. Fernandez, have articulated a proposal of a Thematic Program to the Institute Henri Poincaré (IHP). The proposal, titled "Random Processes in the Brain", was for a long program to be held in 2023 (see more details at IHP's website "Propose a Thematic Program". If accepted, this will be an excellent opportunity to disseminate the research developed at the Center as well as strengthen the ties among our internation team of members and collaborators.

2.4.1 Research events & seminars

During the period of activities being reported in this document, the NeuroMat team has also taken part in smaller-scale research events and seminars. NeuroMat's seminars compilation is attached to this report as Annex 9.

3 Technology transfer report

The development of two neuro-rehabilitation and diagnosis initiatives, directed to Parkinson's Disease (AMPARO) and Brachial Plexus Injuries (ABRAÇO), has been a main focus area of activity. Both initiatives took advantage of a computational tool NeuroMat had previously developed, namely the Neuroscience Experiments System (NES). Recent developments of NES and the NeuroMat Open Database have been oriented towards the needs of AMPARO and ABRAÇO.

During the period assessed in this report, NeuroMat has continued the development of a new tool for neuro-rehabilitation and diagnosis, the Goalkeeper Game. This tool is a direct result of the theoretical and experimental research developed by NeuroMat around brain functioning. By doing this NeuroMat reaches one of its main goals, which is to produce new technology based on new scientific results.

In particular, in a a study conducted by members of the AMPARO initiative it was shown that the Goalkeeper Game can be used as a tool for noninvasive screening in people with Parkinson's disease. The result of the study, which was published in the journal Frontiers in Aging Neuroscience (Volume 12, Article 50, 2020), showed that the Goalkeeper Game has a superior predictive power in assessing gait performance under complex condition in people with Parkinson's disease than the well-established Montreal Cognitive Assessment (MoCA) test.

In the period, members of the ABRAÇO initiative have started a collaboration with Prof. R. Imoniemi from Aalto University in Finland. The goal is to develop a new protocol to investigate the mechanism of memory formation in the human primary motor cortex employing sequences of transcranial magnetic stimulation (TMS) pulses driven by stochastic chains of variable length. To perform the experimental protocol with increased accuracy they will employ techniques recently developed within this partnership, in particular involving the participation of NeuroMat's PI O. Baffa Filho. This will allow precise neuronavigation as well as the development of a robot (cobot) arm. ABRAÇO researchers expect to test a new multilocus TMS stimulator in the next period, allowing to stimulate different areas of the brain within a millisecond time interval.

3.1 Neuro-rehabilitation and diagnosis

3.1.1 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.

3.1.1.1 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 3.2.1) 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.

3.1.1.2 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. Comments are also gathered through online interactions and web surveys, as meetings are video streamed. Relevant early findings suggest the need to build instructions for clinical professionals, such as easing diagnosis and collaborating with an interprofessional team, and caregivers, especially around motricity, sleep and emotional support. Summaries of meetings are being produced as educational resources.

3.1.2 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.

3.1.2.1 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 3.2.1) 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 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. The objective is to check the possibility of using the Goalkeeper Game as a tool for rehabilitation of brachial plexus injury patients. Data of these patients have fed NeuroMat's database.

3.1.2.2 New transcranial magnetic stimulation protocol Within the newly established collaboration with R. Ilnomiemi and O. Baffa Filho for the development of a closed-loop robotic system for the positioning of a transcranial magnetic stimulation (TMS) coil on the subject's scalp (see Section 3.3.1),

NeuroMat's AMPARO researchers now implementing a new protocol to test whether the primary motor cortex (M1) holds the memory of a sequence of transcranial magnetic stimulation (TMS) pulses driven by a stochastic chain. If so, it should be possible to recover in the motor evoked response (MEP) response 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? If so, then it would be interesting to test if this recovered signature is affected by a brachial plexus lesion.

3.2 Computational tools

3.2.1 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 3.1.1.1 and 3.1.2.1). The game is openly, freely available at: game.numec.prp.usp.br and also at Apple Store and Google Play. The development team of the Goalkeeper Game is led by the Associate Investigator M. D. Gubitoso (IME/USP).

3.2.2 SeqROCTM - Matlab toolbox for the analysis of Sequence of Random Objects driven by Context Tree Models

NeuroMat researchers are actively engaged in the study of problems that involve probabilistic sequences of inputs (e.g., sequence of stimuli) to which an agent generates corresponding sequences of responses. The challenge is to find and model some kind of relation between the input and response sequences. To model such relation in the context of statistical learning in neuroscience, a new class of stochastic process has been introduced (see the 2018 Statement of Impact (SoI)), namely sequences of random objects driven by context tree models. To give support to researchers worldwide who work on these stochastic processes, the Associate Investigator A. Duarte de Oliveira together with the postdoctoral fellow N. Hernández González have developed in the period a freely available Matlab toolbox called "Sequences of Random Objects Driven by Context Tree Models" (SeqROCTM). The toolbox implements three model selection methods to make inference about the parameters of this kind of stochastic process.

3.2.3 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 3.1.2) and AMPARO (Section 3.1.1) initiatives. NES is integrated to the Goalkeeper Game (Section 3.2.1) and to the NeuroMat Open Database (Section 3.2.4). 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).

3.2.4 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 3.2.3). 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.

3.3 Hardware tools

3.3.1 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 of the coil evoke substantially different responses. Currently, the coil is positioned manually through neuronavigation, which causes variations in the observations according to the experimenter. In addition, the patient being awake throughout the procedure performs small involuntary movements, even with the head secured on a support. If the patient moves during stimulation, the stimulator must be repositioned. As a solution to this problem, robotic arms have been used 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 the 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, making it impossible for new tools to be developed. A closed-loop system is a set of mechanical or electronic devices that automatically regulates a variable to a desired state, without human interaction. Closed-loop systems are designed to automatically achieve and maintain a desired condition (exit condition), comparing it to

its condition at the given moment (real condition). The comparison is made using an error signal, which is the difference between the output and the reference input.

In the period, NeuroMat's PI O. Baffa Filho started a new collaboration with Prof. R. Ilmoniemi from Aalto University with the goal of developing a closed-loop system to control the position of the TMS coil in relation to the patient's head with a robot arm. The first step of this development was focused to establish the connection between the neuronavigation system ("InVesalius Navigator") and the robot. Therefore, a Python library of TCP/IP communication was developed. Functions to control the robot were implemented, for example, electrify the robot, turn the robot off, and set the movement speed. And also functions to read the actual position of the robot end-effector. Lastly, functions to request different types of movements, as linear, circular, and elliptic trajectories. The library is available in the following repository: https://github.com/rmatsuda/Elfin-python. And it was included in the InVesalius Navigator.

4 Dissemination report

The NeuroMat dissemination team has built 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 using 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.

The dissemination team is committed to the development of a new language for NeuroMat's communication and education efforts, so as to bring the scientific frontier to general audiences. As part of this effort, the dissemination team creates its own media, like the Web Portal and the newsletter, promotes educational activities in schools and invests in the use of collaborative electronic platforms, like Wikipedia, to improve science contents available to the public. NeuroMat's dissemination activities are:

- the Faísca NeuroMat YouTube show
- the A Matemática do Cérebro podcast
- the Wikipedia Initiative
- the Wikimedia Commons Initiative
- Training courses
- Media Exposure and Newsletter
- Web resources: portal, Facebook page, dissemination blog
- NeuroCineMat

4.1 Faísca NeuroMat

The RIDC NeuroMat launched in May the YouTube show "Faísca NeuroMat" –in Portuguese, NeuroMat Spark. The show is coordinated by the NeuroMat science dissemination coordinator Fernando da Paixão, who every other week hosts a guest to discuss scientific novelties associated with news stories. Technical support is provided by the NeuroMat dissemination team and content is licensed under a free license for wide sharing.

Faísca NeuroMat was envisioned to provide high-quality information in the context of the COVID-19 pandemic. Topics that were covered are often directly related to the pandemic. Content on YouTube may be found at: https://www.youtube.com/playlist?list=PLXUXkbNfNLDYLr6R480lafiKTqJDqds0C. Twelve videos were released in 2020.

4.2 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 the newest member of the RIDC NeuroMat, Eduardo Vicente, from the University of São Paulo School of Communications and Arts.

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.

Six episodes of the podcast were produced and may be found at: https://podcast.numec.prp.usp.br/. A second season is in the making for 2020-2021.

4.3 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.

Main achievements are:

- 29.7 million content viewers in Portuguese Wikipedia;
- 98.4 million words added to Portuguese Wikipedia and related projects;
- 59.7 thousand entries created on Wikimedia projects; and
- 97.4 thousand entries improved on Wikimedia projects.

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

4.4 Wikimedia Commons Initiative

NeuroMat has been engaged in uploading media files to the open repository Wikimedia Commons. At the end of October, 22,861 files had been uploaded by the NeuroMat team in this repository.

Files NeuroMat added to Wikimedia Commons were viewed 12,179,693 times in August 2020. This figure is obtained from the web visualization control tool GLAMorgan (https://shorturl.at/kAZ45).

4.5 Training Courses

NeuroMat has hosted the eighth edition of the Latin American School on Computational Neuroscience (LASCON 2020) in the NeuroMat main building at the University of Sao Paulo from January 6th to 31st of 2020. The school director, NeuroMat PI A. C. Roque da Silva Filho, was awarded a FAPESP grant (project no. 2019/10696-9) to fund the participation of the international team of lecturers who will teach at LASCON. More details on LASCON 2020 can be seen at its webpage: https://www.sisne.org/lascon.

4.6 Media Exposure and Newsletter

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. It runs monthly, generally being sent to subscribers at the end of each month. It is distributed to around 672 people, always in English. NeuroMat's newsletter compilation is attached to this report as Annex 5.

4.7 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. 27,945 different users —around 51

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 1,564 followers, as of October, 2020, with steady progress. The community growth has been organic.

The NeuroMat dissemination team has also sustained since 2018 a Facebook page in Portuguese for patients with brachial plexus injury. In October 2020, there were 338 subscribers to this page, with weekly updates associated to the ongoing initiative ABRAÇO. This project is supported by a BJC/FAPESP fellowship.

Since April 2016, the NeuroMat dissemination team has sustained 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." The blog has been viewed 41,202, since its inception as of September, 2016. Posts on this resource have been published continuously; a detailed is provided on Annex 7.

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

4.8 NeuroCineMat

The NeuroMat dissemination team has fully produced seventeen movies. A full list is available on the NeuroMat Youtube channel. There has also been continuous streaming of activities on Youtube, which have attracted over 2,000 subscribers and 50,000 views since 2017. A full list is available on:

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

4.9 Research on Communication Science

The NeuroMat dissemination team has presented twelve conference papers, included in the annals of the Congresso Brasileiro de Ciências da Comunicação, COMPÓS and ABCiber. Research output is presented on the general documentation on publications.

5 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 - NeuroMat's newsletter

Annex 6 - NeuroMat's web portal

Annex 7 - NeuroMat dissemination blog "Traço de Ciência"

Annex 8 - Scientific Missions

Annex 9 - Seminars and Training Program

Annex 10 - Post-doctoral fellows

Annex 11 - PhD dissertations

Annex 12 - MSc dissertations

Annex 13 - Scientific Initiation

Annex 14 - Scientific Journalism

Annex 15 - Technical Training

Annex 16 - Reports from FAPESP scholarships

- Annex 16a - Raymundo Machado de Azevedo Neto

- Annex 16b - Ioannis Papageorgiou
- Annex 16c - Mauricio Girardi Schappo
- Annex 16d - Nilton Liuji Kamiji
- Annex 16e - Noslen Hernández González
- Annex 16f - Karine Damásio Guimarães
- Annex 16g - Arthur Lopes da Silva Valencio
  - Annex 16g.1 - Appendix A-B
  - Annex 16g.2 - Appendix C-D-E-F-G
  - Annex 16g.3 - Appendix H-1
  - Annex 16g.4 - Appendix H-2
  - Annex 16g.5 - Appendix I-J-K-L
  - Annex 16g.6 - Appendix M
- Annex 16h - Morgan Florian Thibault André
- Annex 16i - Sofia Franco Guilherme
  - Annex 16i.1 - Certificado WFSJ Sofia Guilherme
- Annex 16j - Matheus Cornely Sayão
- Annex 16k - Thais May Carvalho
- Annex 16l - Fernanda Volchan Cruz
  - Annex 16l.1 - Annex 1 - Video O cerebro estatistico.pdf
  - Annex 16l.2 - Annex 2 - Postagens no Blog Traço de Ciencia.pdf
  - Annex 16l.3 - Annex 3 - Documento submissao.pdf
  - Annex 16l.4 - Annex 4 - certificado do curso de Jornalismo Cientifico.pdf
  - Annex 16l.5 - Annex 5 - Certificado curso Youtube e suas potencialidades.pdf
  - Annex 16l.6 - Annex 6 - Aula de Estatistica de Redes Sociais.pdf
- Annex 16m - Miréia Arruda Figueiredo
  - Annex 16m.1 - Annex 1 - Tópicos produzidos e editados na Wikiversidade

  - Annex 16m.2 - Annex 2 - Postagens no Blog Traço de Ciência
  - Annex 16m.3 - Annex 3 - Submissão Intercom
  - Annex 16m.4 - Annex 4 - Carta de Aceite coautoria de artigo
  - Annex 16m.5 - Annex 5 - Certificado Curso de Jornalismo Cientifico
  - Annex 16m.6 - Annex 6 - Lições Curso de Jornalismo Científico
  - Annex 16m.7 - Annex 7 - Certificado Cientista de Dados
  - Annex 16m.8 - Annex 8 - Informações Curso Cientista de Dados
- Annex 16n - Lucas Cardoso Santos
- Annex 16o - Celso Oviedo da Silva Lopes
- Annex 16p - Cassiano Reinert Novais dos Santos