DAAD Deutscher Akademischer Austauschdienst
German Academic Exchange Service

Project description

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Funding programme:	**Programmes for Project-Related Personal Exchange (PPP) from 2022 with** Brazil
Programme objective/s (outcomes of the funding programme)[1]:	
Objective 1	**Junior scientists have gained international research experience and undergone further training at an international level**
Objective 2	**Binational research cooperation has been promoted and can be used as a starting point for future cooperations**
Results of the measures/activities of the programme (outputs of the funding programme)[2]:	
Result 1	**There are joint research results**
Result 2	**International joint publications have been created**

General information			
Project name	Efficient statistical tools for networks and their applications		
Applicant institution	Universität Leipzig		
Those responsible for the project	Peter F. Stadler		
Those responsible for the project (outside Germany)	André Fujita		
Partner country/countries	Brazil		
Partners (within and outside Germany)	University of São Paulo and Universität Konstanz		
Are there parallel funding streams and/or applications under other DAAD programmes in the context of this project application?		Yes ☐	No ☒
If yes, under which?	Please specify		
Are there any parallel funding streams and/or applications under any other funding programme provided by another funding organisation in the context of this project application?		Yes ☐	No ☒

For follow-up applications: Previous project progress
Please describe the previous project progress (implementation of measures/activities and achievement of objectives).

[1] The project does not necessarily need to aim at achieving all programme objectives (outcomes of the funding programme). 'Funding programme' and 'programme' are used synonymously.
[2] Only the results of the measures/activities (outputs of the funding programme) which are relevant for the selected programme objectives (outcomes of the funding programme) must be taken into account.

Project objectives, detailed project description and reference to results logic

1 State your project objectives (outcomes), which must be consistent with the programme objectives (outcomes) mentioned above, and describe the specialised content of the project. Explain with reference to the results logic which specific project results (outputs or results of the measures/activities) are used to achieve these project objectives (outcomes)[3].

2 Touch upon the relevance of your project and ensure that you address all selection criteria in the programme description, which are listed again here:

- Relationship of the project to the programme objectives (as per the impact analysis structure) and results-oriented planning using indicators that meet the SMART criteria[4].
- The quality of the project (clarity of project objectives and methods) and scientific relevance of the project (topical nature of the subject matter and the project's degree of innovativeness).
- Appropriate involvement of junior scientists
- Transfer of knowledge between the groups of researchers,
  Value (subject-specific, institutional, interdisciplinary) created through the cooperation for both groups of researchers,
  Scientific and, if applicable, industrial usability of the project results
- Feasibility of the research project (in particular: financial backing, preliminary work and further plans, adequate planning for trips abroad),
  Project-related competence of both groups of researchers,
  Complementarity of the groups of researchers in relation to the joint project (methodically, content-related, instrumentally, etc.)

3 Describe any potential risks in relation to the success of the overall project and how you will handle them.

Note:
The project objectives (outcomes) and intended results of the project's measures/activities (outputs) must be entered in the project planning overview table in the form of results-oriented project planning.

Outcomes
This proposal aims to consolidate the relationship between all partner groups. New collaboration opportunities will be identified, especially in regard to junior scientists research network expansion. We will specifically initiate the development of computationally efficient statistical tools to analyze extensive empirical networks from a spectral distribution as well as a cycle-base angle.

Outputs
1. In person meetings in Brazil and Germany will enable all involved scientists to engage in topic specific discussions as well as get first hand impressions of the work and living environments for future collaborations and research stays. We plan to organize talks every year and two short courses/workshops to also allow other students and researchers to participate.
2. The methods developed here will impact several fields of science. As aforementioned, random networks are ubiquitous. Thus, they will be helpful to analyze chemical compounds, social interactions, metabolic pathways, neural networks, and the internet. We expect that the works generated in this proposal will have a high impact, given the widespread interest in random networks. Thus we expect that joint publications will strengthen the scientific footprint for all participating researches, especially young scientists, which will be advantageous for funding applications of their own.
3. All developed algorithms will be implemented as reference software packages e.g. in R or Python libraries. Collaboration in that regard will help junior scientists to develop a set of skills, from collaborative software development via open source platforms like GitHub to planning skills for software and project development as well as distribution and maintenance of open source software.
4. As the funding periods of DAAD ends after 2 years, while the PROBAL funding ends after 4, we will apply for a second round of funding towards the end of the German project time. Junior scientists will be tightly integrated in both, report composition as well as reapplication for DAAD funding,

[3] For the definitions of 'Outcomes' and 'Outputs', please refer to the 'Guide to Results-oriented Monitoring'.

[4] See 'Guide to Results-oriented Project Planning and Monitoring', Chapter 2.

thus providing them with hands-on experience in funding acquisition and project execution.

Project description

Unlike deterministic graphs, empirical networks are stochastic, either by the underlying processes that generate them or the measurement procedures. For example, brain networks are different even among healthy individuals. Thus, many typical properties used to characterize graphs do not apply to large empirical networks. The reason is that they are not robust against the insertion or deletion of a small number of vertices or edges. Therefore, we need measures that quantify how close a graph is to exhibit a specific property, rather than the strict notion of isomorphism, which we rarely, if ever, attain.

Furthermore, empirical networks are usually massive. For example, it is estimated that the brain is composed of approximately 100 billion neurons. Thus, we cannot use current statistical approaches to analyze big data. The main reason is that we need to calculate the graph's spectrum, which is computationally expensive. Suppose a network is composed of n nodes. Then, the computational cost of naïve approaches, such as the diagonalization method, is O(n^3). Recently, Cantwell and Newman (2019) introduced a message-passing approach for the normalized Laplacian spectral density. Still, it requires computing matrix inversions and matrix-vector multiplications, which are computationally expensive.

We know that the spectrum has codified structural characteristics of the network. For example, by analyzing the Laplacian spectrum, we can obtain its diameter (Chung et al., 1989), the number of spanning trees (Bollobás, 1998), vertex covers (Chen and Jost, 2012), Kemeny's constant (Pan et al., 2018), and chromatic number (Sun and Das, 2020). However, we do not know the contribution of a node to a network's spectral distribution. In other words, although we identify differences in the networks' spectra, we cannot associate these differences with the networks' structures. Therefore, we cannot interpret them.

Initial effort will be focused on the curation of datasets. The latter build the basis for collaborative investigation of properties which can be used to characterize large empirical networks. The partners will then work in parallel on complementary measures to quantify how close a graph is to exhibit a specific property.

A common approach is determining graph invariants such as centrality measures (van den Heuvel and Sporns, 2013). However, graphs generated by different models may present similar centralities. Conversely, graphs generated by the same set of parameters may present a vastly different centrality measure. Thus, the analyses of empirical networks using methods grounded on deterministic graph theory seem to be inappropriate.

One potential solution is to assume that graphs are generated by probabilistic processes and then develop statistical methods, which will be the focus of the Brazilian partners. Statistical approaches for random graphs are new, with few reports in the literature (Asta and Shalizi, 2015; Ginestet et al., 2017; Tang et al., 2017; Cerqueira et al., 2017; Ghoshdastidar et al., 2017; Schieber et al., 2017, Kolaczyk et al., 2019). One of the reasons that graphs are challenging to study from a statistical viewpoint is that graphs are objects composed of vertices and edges, i.e., they are not numbers.

The group of Fujita has therefore experimented on the analysis of the graph spectrum, which “codifies” information about the graph structure(Takahashi et al., 2012, Fujita et al., 2017a, 2019), and developed a concept of correlation between vectors of graphs (Fujita et al., 2017b) which showed to be helpful to better understand new biological mechanisms, identify biomarkers, and find differences between controls and patients. The German side under Prof. Stadler has ample experience with the analysis of graph theoretical problems (BrianDavies et al., 2001; Gu et al., 2016; Hellmuth et al., 2009; Fritz et al., 2020) and will meanwhile focus on cycles. Cycles encapsulate semi-local information in a graph. Cycle bases provide well-defined, manageable cycle sets that can be computed efficiently. The length distribution of cycle sets such as the relevant cycles, i.e., those that are contained in at least one minimum cycle basis can be computed efficiently even without enumerating the sometimes exponentially large cycle sets. We therefore plan to use cycle distributions as complementary source of information. In particular we will investigate the relationships between Laplacian eigenvalues and cycle distribution and explore to what extent and which graph classes they can be used for alternative classification tasks. Properties of cycle bases also characterize planarity

and potentially other embedding properties. The latter is likely of particular relevance to application in brain-neworks and other networks that are embedded into low-dimensional (Euklidean) spaces. As the german funding period ends after 2 years, we will apply for a second round of funding, in which we will systematically investigate the contraints of embeddings on the cycle distributions.

Studying the dynamic brain interaction network is vital to understand the brain's role in behavior. In the last decade, we witnessed the introduction of many methods to measure the presence or absence of dynamic interaction between brain parts. Nevertheless, little progress has been made on developing strategies to interpret and rigorously test the characteristics of the entire inferred brain interaction networks. We will develop rigorous statistical methods to compare ultra-high-dimensional networks and expect that these methods will allow us to correctly interpret the results of massive brain interaction networks obtained with state-of-art methods.

Our algorithms will allow us to identify genes or brain regions associated with diseases, abnormal connectivity structures, and changes over time, space, and subjects which will potentially lead to the development of drugs for treatment, biomarkers for diagnosis and prognosis, and a better understanding of the biological mechanisms.

Furthermore our algorithms will be helpful in computer science, engineering, physics, and chemistry. E.g., for network feature extraction (Newman, 2018), low-rank approximation (Le et al., 2016; Luo et al., 2018), spectral clustering, and community detection (Newman, 2006). It also has applications in the dynamical systems theory (Porter and Gleeson, 2014), including structural phase transitions, such as percolation (Bollobás et al., 2010), localization (Martin et al., 2014), and detectability (Nadakuditi and Newman, 2012).

For all goals proposed in this project, we already supervise Ph.D. students and post-docs /post-doc candidates for the internships in Brazil/Germany which will be tightly integrated in the development and application process.

We plan to send Ph.D. students and post-docs in all four years of the project to maintain constant communication. PIs will interact mostly via videoconference over the year and visit once a year. PIs will discuss manuscript and other proposals design during the scientific missions every year. We also plan talks in every Ph.D., post-doc, PIs visit. We will organize short courses/workshops and invite students/researchers of other universities to participate remotely (via videoconference) in the second and fourth years. We plan to submit a proposal to the Research Group Linkage Programme (https://bit.ly/3f1zS4k) of the Alexander von Humboldt Foundation for further interaction between Brazilian and German groups. Dr. Fujita is an Alexander von Humboldt Fellow as such he satisfies the minimum requirement to submit a proposal to this call.

Available infrastructure

Prof. Fujita is the Brazilian coordinator. He has a fully equipped IT laboratory composed of dozens of high-performance workstations and computer servers. Together with the Interdisciplinary Center for Bioinformatics, the Stadler group at Leipzig University has sufficient computing power for all high performance-computing tasks associated with the proposed research. In addition, the group has access to the High-Performance Computer Center in Dresden and the de.NBI cloud, maintained by the German Network for Bioinformatics Infrastructure

Takahashi's lab is in the Brain Institute. The institute has a state-of-art primate facility, a primate surgery room, level 2 bio-security rooms, two-photon microscopy, molecular biology, and viral core facilities. The Brain Institute also has access to a supercomputer. Takahashi's lab has access to a fully trained veterinarian, animal welfare specialist, and husbandry team.

Dr. El Hady is affiliated with Universität Konstanz and the Max Planck Institute (MPI) of Animal Behavior. The MPI has one of the most advanced facilities to study animal behavior in the world. It is equipped with virtual reality arenas where researchers can change the environment in real-time. We can record animal behavior using multiple sensors (high time-of-flight cameras, ultrasound microphones) simultaneously.

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Measures/activities planning

Description of the measures/activities

Describe the planned measures/activities (also see the category 'Measures/activities eligible for funding' in the programme call for applications). Explain the extent to which the measures/activities and expenditure are necessary and appropriate to achieving the objectives. *(Keep the description of the measures as brief as necessary).*

Insert new rows in the table for further planned measures/activities.

Note: The measures/activities must also be entered in the project planning overview table in the sense of results-oriented project planning, and must be assigned to the project objectives (outcomes). When describing the measures, you should also indicate, which work step will be performed by which groups of researchers, using which method and **where**.

Title of measure/activity 1:	Kickoff meeting
Description:	In a first meeting of all involved research group we will give all junior scientist the opportunity to present their current work and plans for the project at hand to their peers. PostDocs and PIs will discuss the presented workplans and give valuable feedback. In this meeting we will also start curation of data which will be used as basis for the development and testing of algorithms developen in the course of this project.
Place/time frame	Germany: 01/2022
Title of measure/activity 2:	First travel of the German group to Brazil
Description:	During our first meeting in Brazil all junior scientist will present their results and the state of their progress to a broader audience. We will consolidate results, discuss future directions and start work on first manuscripts.
Place/time frame	Brazil: 11/2022
Title of measure/activity 3:	Second visit in Germany
Description:	Shortly after our visit in Brazil we will again meet in Germany to finalize work on Manuscripts and begin work on the application for a second round of funding from the DAAD. Again, junior scientist will get the opportunity to present their results and discuss future approaches, this time to an audience from the German science network. Furthermore we will work on the first project report.
Place/time frame	Germany: 01/2023
Title of measure/activity 4:	Second visit in Brazil
Description:	During the second and last visit of the German side to Brazil in the first funding period, we will focus on the finalization of manuscripts and discuss potential follow up projects as well as funding possibilities. Junior Scientist will present their (final) results in an international setting.

Place/time frame	Brazil: 11/2023

Planned international mobility of the groups of researchers
Please enter the planned stays at the respective partner institute abroad of both groups of researchers during the funding period in the tables in chronological order.

German project participant performing the stay	Academic status/ position	Research task to be performed	Duration in days	Date of the stay (MMYYYY)
Peter F. Stadler	Professor	Review of progress; Discussion of further directions	8	11/2022
Peter F. Stadler	Professor	Review of progress; Manuscript writing	8	11/2023
Jörg Fallmann	PostDoc	Discussion of results; Adaptation of workflows	10	11/2022
Jörg Fallmann	PostDoc	Manuscript and follow-up grant proposal finalization	10	11/2023
NN (Thomas Gatter)	PostDoc	Discussion of results; Adaptation of workflows	10	11/2022
NN (Thomas Gatter)	PostDoc	Manuscript and follow-up grant proposal finalization	10	11/2023
Thomas Gatter (NN)	Doktorand	Presentation of results; work on manuscripts; exchange with students from Brazil	21	11/2022
Thomas Gatter (NN)	Doktorand	Presentation of results; work on manuscripts; exchange with students from Brazil	21	11/2023
David Schaller	Doktorand	Presentation of results; work on manuscripts; exchange with students from Brazil	21	11/2022
David Schaller	Doktorand	Presentation of results; work on manuscripts; exchange with students from Brazil	21	11/2023
Non-German project participant performing the stay	**Academic status/ position**	**Research task to be performed**	**Duration in days**	**Date of the stay (MMYYYY)**
André Fujita	Associate Professor	Workshop and proposal writing to be submitted to AvH	10	01/2022
André Fujita	Associate Professor	Manuscript writing	10	01/2023
Daniel Y. Takahashi	Assistant Professor	Dr. El Hady's data analysis and discussions	10	01/2023
Eduardo Lira	Graduate student	Develop algorithm described in goal 1	180	04/2022
Vinicius Jardim Carvalho	Graduate student	Analyze Dr. El Hady's data	180	04/2022
Heitor Baldo	Graduate student	Develop algorithm described in goal 2	180	04/2023
Victor Chavauty Villela	Graduate student	Analyze Dr. El Hady's data	180	04/2023

Grover E.C. Guzman	Postdoc	Develop algorithm described in goal 1	270	04/2022
Diogo Costa	Postdoc	Develop algorithm described in goal 2	270	04/2023

Further programme-specific information

Roles in the project
List the project participants in Germany and outside Germany and state the tasks for which they are responsible in the project.

Peter F. Stadler (German coordinator) and André Fujita (Brazilian coordinator) will supervise the development of methods/algorithms and analysis of empirical data.

Daniel Y. Takahashi (Brazilian collaborator) and Ahmed El Hady (German collaborator) will provide the biological data to be analyzed and help with the interpretation of results.

Structure of the group of researchers and role of project participants

Explain the structure of the group of researchers and the criteria based on which you selected the project participants.

Dr. Fujita coordinates a FAPESP thematic project in network statistics, including dozens of graduate students and postdocs to whom we will provide training and internship. Thus, this proposal complements the FAPESP thematic project. The Stadler Lab in Leipzig has worked on several aspects of graph theory. While Fujita's team is specialized in statistics and will focus on spectral analysis, the Stadler group will tackle the problem from a cycle-base angle, thus both teams are complementing each others work. Furthermore, two neuroscience teams, one in each country will be involved in the project, providing the groups with datasets for development and testing of developed algorithms.

Our proposal ranges from theoretical/methodology development to application in neuroscience. Thus, this proposal comprises two groups of researchers, one of mathematics/computer science and one of neuroscience. Each group is composed of two labs. Mathematics/computer science: Dr. Stadler's and Dr. Fujita's labs. Neuroscience: Dr. El Hady's and Dr. Takahashi's labs. We based the participants selection criteria on the fitness for our problems treated in this proposal. Thus, participants should have background in at least one of the following areas: mathematics, theoretical computer science, statistics, neuroscience.

Will third-party funds be introduced?	Yes	☐	No	☒
Has the third-party funder provided a legally binding declaration / commitment?	Yes	☐	No	☒
Reason:	Please specify			

Commitment to comply with the recommendations for good scientific practice

Project coordinator:	Peter F. Stadler

☒	If my research project is accepted for the DAAD Programme for Project-Related Personal Exchange, I undertake to comply with the rules of good scientific practice.[5] Scientific misconduct is given if false statements are made in a context of scientific importance either intentionally or by gross negligence, if intellectual property rights of others are violated, or if the research activities of others are otherwise affected. The circumstances of the individual case are decisive.

Application checklist

	Application documents relevant to selection	✓
1	Project application (in the DAAD portal)	☐
2	Financing plan (in the DAAD portal)	☐
3	Project description	☐
4	Project planning overview	☐
5	Research profile/CVs of the German project coordinator(s)	☐
6	List of the German project coordinators' publications in the past 5 years that are relevant to the project	☐
7	Research profile/CVs of the project coordinator(s) abroad	☐
8	List of the non-German project coordinators' publications in the past 5 years that are relevant to the project	☐
9	Brief CVs of any other project participants that have already been selected at the time of application	☐
10	For applications for PPP Canada and PPP USA: a confirmation letter by the cooperation partner in addition to attachments 1-8	☐

[5] The rules of good scientific practice are detailed in the memorandum 'Safeguarding Good Scientific Practice' (WILEY-VCH Verlag) and in the Guidelines for the Use of Funds – DFG templates 2.01 and 2.02 – (available on the DFG website: http://www.dfg.de – 'Proposals' section). This version is based on the suggestions of the international commission for self-regulation in science and it corresponds to a resolution passed by the General Assembly of the DFG on 17 June 1998 in coordination with the HRK.