DAAD Deutscher Akademischer Austauschdienst German Academic Exchange Service

Project description

(Arial, font size 10)

Funding programme:	**Programme for Project-Related Personal Exchange (PPP) from 2024 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 programme 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 organization 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.

During the first funding phase we were able to complete reseach on tree-like networks, resulting in a an efficient algorithm for estimating eigenvalue counts for this type of networks. This resulted in joint publication in J. Complex Networks. In addition to the DAAD-funded short travel, two PhD students from the Fujita lab in Sao Paulo are currently spending extentended reseach stays in the Stadler lab in Leipzig. Bruno Ilha is working on metabolic networks, and Grover Guzman just arrived in Leipzig. He will continue the joint work on eigenvalues in simple network classes. The DAAD exchange has been very helpful in securing external funding. As planned, a network meeting in Sao Paulo has taken place in 2002 with participation of 4 researchers from Leipzig including the PI, and Andre Fujita and collaborators have visited Leipzig in 2022 and in spring 2023. The second scheduled visit of the Leipzig group to Sao Paulo in the current funding period is scheduled for Nov/Dec. Software development is ongoing. Current focus of the work is on improvements of the theoretical results. Early stage researches, notably Nora Beier, have been closely involved in preparing the annual report for 2022 and this renewal application.

Workshop on Network Statistics
The workshop occurred between September 15th and 16th at Prof. Imre Simon Auditorium at the Institute of Mathematics and Statistics of the University of São Paulo. Approximately 30 people attended this workshop, including (under) graduate students and faculty members from the University of São Paulo, Federal University of ABC, Federal University of Technology - Paraná, Sírio Libanês Hospital, Leipzig University, and the Hamburg University of Technology. We had two main talks - one by Prof. Peter Stadler (German coordinator) and one by Prof. André Fujita (Brazilian coordinator), seven oral presentations, and two group meetings (one each day) to allow all participants to build new and extend existing collaborations.

A short summary of visits and publications follows:

Personnel exchange
1. Prof. Stadler, Dr. Stephan Bernhart, and Ms. Nora Beier visited Prof. Fujita's lab from September 12th to 19th, 2022.
2. Prof. André Fujita, the Brazilian PI, visited Prof. Stadler's lab from December 11th to 19th, 2022.
3. Prof. André Fujita, the Brazilian PI, visited Prof. Stadler's lab from May 17th to 22nd, 2023.
4. The Bioinformatics graduate program student Bruno Iha (University of São Paulo) is visiting Prof. Stadler at Leipzig University. Bruno will work at Prof. Stadler's lab from April to October 2023 (six months) to do his sandwich Ph.D.
5. The postdoc, Grover Enrique Castro Guzman, will visit Prof. Stadler's lab from July 2022 to February 2023.

Publications:
1. Guzman, G.E.C., Stadler, P.F., and Fujita, A. (2022). Efficient eigenvalue counts for tree-like networks. Journal of Complex Networks 10, cnac040. 10.1093/comnet/cnac040.
2. Guzman, G.E.C., Stadler, P.F., and Fujita, A. (2021). Efficient Laplacian spectral density computations for networks with arbitrary degree distributions. Network Science 9, 312–327. 10.1017/nws.2021.10.

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 specialized 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 me 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

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

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 scientist's 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 firsthand 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. The PROBAL funding for the partner group has been granted for the current funding period, It is imperative therefore that to extend the DAAD funding to enable the continuation of the success cooperation.
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 in the first funding period junior scientists will be closely involved with the composition of the reports and the organization of the joint meetings. The project has already lead to additional longer-term scientific visits by members of the Fujita lab in Germany. This will form the basis for initiatives for further funding.

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

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

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). The message passing approach of Cantwell and Newman (2019) for the normalized Laplacian constituted a major advance. 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. In the first funding phase we in particular obtained results for tree-like networks.

The partners will continue to work in parallel on complementary measures to quantify how close a graph is to exhibit a specific property. In the second project phase the project will in particular benefit from synergies with the MATOMICs project with produces detailed metabolic networks that can be reused in the context of the project, The added focus on metabolic networks also matches Bruno Ilha's interests, a member of Fujita's lab who spends most of 2023 in the Stadler lab in Leipzig. 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 (Euclidean) 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 constraints 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. Having been able to secure external funding sources, this exchange also includes extended research stays for Bruno Iha and Grover Guzman in Leipzig in 2023/24.

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 further 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:	First visit in Germany
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 development in the course of this project.
Place/time frame	Germany: 01/2024
Title of measure/activity 2:	Travel of the German group to Brazil
Description:	During our meeting in Brazil all junior scientists 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: 11/2024
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: 01/2025
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: 11/2025

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	Academic status/	Research task to be performed	Duration in days	Date of the stay

stay	position			(MMYYYY)
Peter F. Stadler	Professor	Review of progress; Discussion of further directions	8	11/2024
Peter F. Stadler	Professor	Review of progress; Manuscript writing	8	11/2025
Jörg Fallmann	PostDoc	Discussion of results; Adaptation of workflows	10	11/2024
Jörg Fallmann	PostDoc	Manuscript and follow-up grant proposal finalization	10	11/2025
Thomas Gatter	PostDoc	Discussion of results; Adaptation of workflows	10	11/2024
Thomas Gatter	PostDoc	Manuscript and follow-up grant proposal finalization	10	11/2025
Bruno Schmidt	Doktorand	Presentation of results; work on manuscripts; exchange with students from Brazil	21	11/2024
Bruno Schmidt	Doktorand	Presentation of results; work on manuscripts; exchange with students from Brazil	21	11/2025
Nora Beier	Doktorand	Presentation of results; work on manuscripts; exchange with students from Brazil	21	11/2024
Nora Beier	Doktorand	Presentation of results; work on manuscripts; exchange with students from Brazil	21	11/2025
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	04/2024
André Fujita	Associate Professor	Manuscript writing	10	04/2025
Daniel Y. Takahashi	Assistant Professor	Dr. El Hady’s data analysis and discussions	10	04/2024
Daniela Bizinelli	Graduate student	Develop algorithm described in goal 1	180	04/2024
Jaqueline Yu Ting Wang	Graduate student	Develop algorithm described in goal 2	180	06/2024
Leonardo Sanches	Graduate student	Analyze Dr. El Hady'sHady's data	180	04/2024
Caio Matheus Prates Batalha Faria	Postdoc	Develop algorithm described in goal 1	270	04/2024
Diego Trindade de Souza	Postdoc	Develop algorithm described in goal 2	270	04/2024

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 other's 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

[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.

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	☐