Mitacs Globalink

Globalink Research Award
Research Proposal

- Complete this proposal using the same language used in your application form. For further information, please visit the Globalink Research Award website.

1. Student statement of interest *(approximately 0.5 pages)*

This is a unique opportunity for me to get exposed to state-of the-art research at the intersection of clinical research and artificial intelligence applied in real-world scenarios. More specifically, the proposed project is centered around clinical electroencephalographic (EEE) scans recorded at public hospitals and evaluated by practising neurologists. The collaborative team is highly interdisciplinary, including neurologists (local health authority), neuroscientists and data scientists with expertise in studying clinical and typically developing populations with a variety of neuroimaging and neurophysiological methods. I will be exposed to collaborations with a diverse extended team centered around the Behavioral and Cognitive Neuroscience Institute at Simon Fraser University (SFU). BCNI Institute is a multidisciplinary environment, with multiple collaborations across the province, and is supported by leading neuroscientists, psychologists, physicists, and engineers.

The proposed project will offer an exceptional opportunity for training in the emerging intersection of digital signal processing and machine learning, including applications of deep neural networks. Deep learning penetrates all domains rich in data, such as language processing, computer vision, speech, and audio processing. Signal processing and time series analysis were somewhat forgotten in terms of machine learning but are quickly catching up. Time series data and their analysis are increasingly important due to the massive production of such data through finances, digitalization of healthcare, or the internet of things. Humans themselves are a great source of time-series signals like brain activity (EEG), heart activity (ECG), muscle tension (EMG), or data from wearables. Apart from that, in the UCU Data Science Master program we have specific course related to time series analysis. Being able to work with real clinical records will provide me practical experience which is vital for growing as a specialist in the Data Science field. As far as I am aware, data collection stored in Behavioral and Cognitive Neuroscience Institute at Simon Fraser University consists of plenty of important observations and insights which can be extracted and used for boosting decision making quality of clinicians. Estimating the “brain age” of the patients based on electroencephalographic scans can provide additional information during diagnostics as it reduces the risk of missing abnormal cases.

As continuous monitoring becomes more common, the need for competent time series analysis with both statistical and machine learning techniques will increase. In the current proposal, we focus on neurophysiological recordings, such as EEGs, with their complex multivariate dynamics, but the acquired skills can be easily extrapolated to other types of time series.

2. Research proposal *(1.5 to 2.5 pages single spaced excluding timeline and cited literature)*

2.1 Background

The proposed project is part of a large-scale collaboration between SFU's Behavioral and Cognitive Neuroscience Institute (BCNI) and Fraser Health Authority(FHA) in the domain of AI applied to clinical electroencephalographic (EEG) scans recorded and evaluated in the process of diagnostic workup in FHA's public hospitals (n>40'000). The key goal of the SFU/FHA collaboration is to automate the process of EEG reporting by building a decision support system. EEGs are widely and routinely used for the evaluation of neurological patients. Conventional review of EEG relies on neurologists to visually inspect complex, noisy, high-dimensional digital data. Such an approach is slow, not fully reliable, and suboptimal. There is considerable variability in EEG interpretation, and this variability is affected by specific reader characteristics. Given these challenges, clinical reporting of EEG is highly suitable for machine-driven automation.

2.2 Objectives for the Mitacs Globalink research project

The project is based on virtually all EEGs recorded at FHA. Information on diagnoses and neurological reports were also extracted from electronic health records. Applications include the development of AI tools for predicting the neurological pathology from routine clinical EEG scans. Natural language processing tools can be implemented to make sense of medical texts such as semi-structured neurological reports. The BCNI team has already obtained ethics committee approval. The initial stage of the collaboration between FHA and SFU was supported by SFU's KEY Big Data program. Two grant applications are now under review at NSERC and CIHR. Also, The BCNI team is proceeding further with establishing a collaboration with the National Research Council (NRC) of Canada, under the umbrella of a new SFU-NRC Collaboration Center in AI and NRC's Innovation Supercluster Initiatives in digital health. Within the framework of the MITACS/SFU program, two small sub-projects are proposed in AI and clinical EEG to support the initiatives in AI and health care by bringing international expertise in deep learning, a state-of-art form of AI, to SFU.

The aim of one proposed project is to develop and validate deep learning models for predicting "brain age" from routine clinical EEG. Focusing on brain age allows us to immediately start testing and validating prediction models, taking into account the heterogeneity of routine clinical EEG from all kinds of neurological patients. Such data are generated in public hospitals to the best clinical standards and are already used for clinical decision-making and reflect a full spectrum of real-world scenarios. Importantly, these typical data are necessary to avoid algorithmic bias for the development of socially responsible AI tools for more effective health care.

The traditional approaches, as applied in cognitive and clinical neuroscience, are based on extracting features from EEG signals and applying classical machine learning like random forest or support vector machine. In deep learning, we are aiming to partly address the following questions:

- Can a deep learning approach, applied to EEGs, support a more accurate prediction of age, and, most importantly, what new information can be extracted through learned EEG features, in comparison to the conventionally engineered ones?
- What current deep learning approaches can be used to reach state-of-the-art performance for EEG classification, and what type of deep learning architectures works best for such a task?
- What type of features are learned, and how are they related to conventional, human-engineered features?

2.3 **Significance** of the project

The collaboration between SFU's BCNI Institute and FHA at larger scales seeks to address the primary question: can a novel state-of-the-art machine learning approach, applied to routine clinical EEGs recorded in hospital, support a more accurate diagnosis with higher efficiency? A key set of beneficiaries will be clinical professionals (especially neurologists and clinical neurophysiologists) who review and report EEGs. We expect to produce a prototype decision support system, which will benefit clinicians by providing extremely rapid access to AI-driven analysis of new EEG cases. Such a classification will enable workflow prioritization (concentrate on cases classified as abnormal), which saves time and reduces the risk of missing abnormal cases. Finer levels of classification (e.g. diagnostic category) will provide additional decision support, enhancing and bringing value to healthcare.

EEG, due to its attractive properties, such as relatively low costs, non-invasiveness, and direct measurement of neural activity, promises to revolutionize brain-computer interface (BCI) applications, such as emotion recognition, mental workload, and motor imagery, detection of epilepsy, and classification of sleep stages. Deep learning has the potential to relax the requirements for feature extraction, performing EEG classification on raw or minimally-processed data.

The transparency of AI models is becoming one of the key problems in machine learning. For example, federal law in the USA already requires explanations for certain consumer finance decisions. Probably the Canadian healthcare system is still far from that. Anyway, clinicians have had a hard time adopting AI tools to their practice to help them make diagnoses without understanding how the AI algorithms arrive at their decisions. Many deep learning models have shown competitive performance under the end-to-end framework (from raw data to prediction or classification). However, the black-box nature of deep learning applied to raw or minimally preprocessed signals makes it challenging to understand what kind of information is learned by the deep networks. Machine learning studies are often dichotomized in their ultimate goal: to explain or to predict? At the conceptual level, a combination of expertise at SFU and UCU represents an attempt to mitigate this dichotomy and to elaborate on the interpretability of EEG features learned through deep learning.

2.4 **Timeline** showing which task will be done when to achieve each objective planned during the internship

The expected duration of the project is 4 months.

Months 1-3: In contrast to feature engineering, end-to-end deep learning (from raw signals to labels) aims to incorporate the feature learning process into fine-tuning the regression model. Convolutional Neural Networks (CNN) will be our first choice. For feature learning, we will feed raw or minimally preprocessed EEG data. EEG time-series will be normalized separately for each channel. The network parameters (convolution filters) will be optimized via mini-batch stochastic gradient descent using analytical gradients computed via back propagation. The performance will be estimated from the validation set in terms of mean absolute error (MAE), mean squared error (MSE), or root mean squared error (RMSE).

Months 3-4: For explainability, we will analyze the sensitivity of the CNN models by identifying EEG sub-segments that are most relevant for making age prediction, using the CNN models in the prediction mode. This will be done based on occlusion. To find the most sensitive EEG sub-segments, we compute occlusion sensitivities by destroying parts of the original input EEG signals and observing the changes (a sharp drop) in prediction accuracies. We will also interpret the features (convolution filters) learned by deep networks at different layers and explore their properties. The feature maps of CNN models capture the result of applying the filters to an input signal, i.e., at each CNN channel (filter or layer), and the feature map is the output of that CNN channel. We will explore the filters (convolution channels) in CNN by looking for EEG signals that maximize the mean activation of a given convolution filter.

2.5 Cited literature

- Acharya, U. Rajendra; Vinitha Sree, S.; Swapna, G.; Martis, Roshan Joy; Suri, Jasjit S. (June 2013). "Automated EEG analysis of epilepsy: A review". Knowledge-Based Systems. 45: 147–165. doi:10.1016/j.knosys.2013.02.014. ISSN 0950-7051
- Schirrmeister, R.; Gemein, L.; Eggensperger, K.; Hutter, F.; Ball, T. (December 2017). Deep learning with convolutional neural networks for decoding and visualization of EEG

pathology. 2017 IEEE Signal Processing in Medicine and Biology Symposium (SPMB). IEEE. arXiv:1708.08012. doi:10.1109/spmb.2017.8257015. ISBN 9781538648735

- Subasi, Abdulhamit; Erçelebi, Ergun (May 2005). "Classification of EEG signals using neural network and logistic regression". Computer Methods and Programs in Biomedicine. 78 (2): 87–99. doi:10.1016/j.cmpb.2004.10.009. ISSN 0169-2607. PMID 15848265

3. Benefits to Canada

3.1 Strengthening Canada's innovation capacity

A partnership between SFU's BCNI Institute and Graduate Program in Data Science/Machine Learning Lab at UCU (Academic Program Director – Dr. Oleksii Molchanovskyi) will expand local expertise in deep learning, in addition to classical methods of machine learning based on traditional approaches based on extracting specific features from EEG signals. Deep learning can be highly competitive. Learned features may provide extra information complementary to the traditional features. However, the black-box nature of deep learning makes it challenging to understand what kind of information is learned and how it relates to traditionally engineered features. The proposed Mitacs projects at smaller scales seek to address the primary question: What deep learning approaches, applied to EEGs, support a more accurate prediction of age and diagnoses, and, most importantly, what new information could be extracted through learned EEG features, in comparison to the engineered ones? The proposed framework could be naturally adapted to a vast array of applications based on other types of neurophysiological signals.

3.2 Collaborations between participating researchers

3.2.1 Does this project build on an existing international collaboration?

Yes _____ No __X__

3.2.2 Does this project create potential for future collaborations?

Yes __X__ No _____

3.2.3 Please describe briefly the existing, planned or future collaboration.

A partnership between SFU's BCNI Institute and Graduate Program in Data Science/Machine Learning Lab at UCU (Academic Program Director – Dr. Oleksii Molchanovskyi) allows to expand SFU expertise in deep learning, in addition to classical methods of machine learning based on traditional approaches based on extracting specific features from EEG signals. Deep learning can be highly competitive. Learned features may provide extra information complementary to the traditional features. However, the blackbox nature of deep learning makes it challenging to understand what kind of information is learned and how it relates to traditionally engineered features. The proposed two Mitacs projects at smaller scales seek to address the primary question: What deep learning approaches, applied to EEGs, support a more accurate prediction of age and diagnoses, and, most importantly, what new information could be extracted through learned EEG features, in comparison to the engineered ones? The proposed framework could be naturally adapted to a vast array of applications based on other types of neurophysiological signals.

4. Interaction

The training environment centers around SFU's Behavioral and Cognitive Neuroscience Institute (BCNI), a collaborative and multidisciplinary strategy/platform across disciplines and institutions to facilitate and expand brain imaging infrastructure, technology development, research, neuroinformatics, and intervention. Through collaborative research in this environment, trainees gain in-depth expertise in neurophysiology and data science and receive training on technical aspects of data acquisition, analysis, and interpretation, which is vital for applying artificial intelligence (AI) tools to non-invasive brain imaging. Additionally, trainees learn how to interpret clinical and psychometric data correctly and integrate this with imaging data.

Computational and storage facilities for the project are available through: (i) SFU's BCNI; (ii) ImageTech Lab, SFU's core imaging facilities; and (iii) Compute Canada cluster, with privileged access to Compute Canada resources through the Resource Allocation Competition (RAC) program.

The students are expected to work in collaboration with scientists at the BCNI Institute, attend regular lab meetings, analyze and interpret clinical EEG data, develop deep learning models used for research, perform a literature search, assist in reporting of findings (presentation and manuscript writing), and assist in defining methodological priorities of research. During the project, the interns will spend 85% of time at the host university (SFU).