Compressive sensing pipeline to improve efficiency of the reverse correlation method

Project Summary

Overview

Each proposal must contain a summary of the proposed project not more than **one page in length**. The Project Summary consists of an overview, a statement on the intellectual merit of the proposed activity, and a statement on the broader impacts of the proposed activity. The overview includes a description of the activity that would result if the proposal were funded and a statement of objectives and methods to be employed.

The Project Summary should be written in the third person, informative to other persons working in the same or related fields, and, insofar as possible, understandable to a scientifically or technically literate lay reader. It should not be an abstract of the proposal.

If the Project Summary contains special characters it may be uploaded as a Supplementary Document. **Project Summaries submitted as a PDF must be formatted with separate headings for the overview, statement on the intellectual merit of the proposed activity, and statement on the broader impacts of the proposed activity**. Failure to include these headings may result in the proposal being returned without review. Additional instructions for preparation of the Project Summary are available in FastLane.

Intellectual Merit

The statement on intellectual merit should describe the potential of the proposed activity to advance knowledge.

Broader Impacts Of The Proposed Work

The statement on broader impacts should describe the potential of the proposed activity to benefit society and contribute to the achievement of specific, desired societal outcomes.

Project Description

Introduction

Current attempts to characterize perceptual mechanism are limited in scope due to inefficiencies of a primary method used to characterize neural tuning, *reverse correlation*. Reverse correlation allows for unconstrained and unbiased estimation of latent neural representations using fairly simple stimulus-response data representations, including psychophysical kernels that drive the top-down processes of perception (*e.g.*, face or phoneme recognition) and even abstract psychological categories (*e.g.*, "male" vs "female" faces). The method has broad applicability for characterizing any aspect of neurological, cognitive, or psychological function that can be modeled as a transductive process.

In reverse correlation, stimulus-response data are elicited via the presentation of richly-varying stimuli (*e.g.*, white noise). Latent representations inherent in the system of interest can be estimated by regressing observed responses against the stimuli over many trials. However, the number of stimulus-response samples required for accurate estimation is typically very large. This inefficiency limits the feasibility of applying reverse correlation to only those experimental protocols that are very stable, such as *in-vivo* preparations or where subject participation can be maintains over long timelines (*i.e.*, two weeks). To circumvent this limitation, studies often (a) limit the richness of the stimuli, or (b) impose some constraints on the inferred representations, for instance, by smoothing the raw estimates. The constraints imposed by these approaches ultimately inhibit the full expressiveness of reverse correlation, leading to estiamtes that are biased.

We propose to develop an advanced signal processing pipeline based on *compressive sensing* that will enable the research community to overcome the inefficiencies of existing reverse correlation methods. Compressive sensing is a signal processing technique that can dramatically improve the efficiency of traditional sampling and signal estimation methods. The technique has recently gained wide recognition in domains such as medical imaging, where considerations of efficiency and bias reduction are critical. Compressive sensing holds promise to similarly improve the efficiency of reverse correlation, without the drawbacks of biasing estimates. This will extend the range of experimental protocols that are feasible as well as the range of perceptual mechanisms that can be estimated in correspondence with this technical improvements. Moreover, compressive sensing can be directly substituted for conventional, regression-based estimation with no other required changes to existing experimental protocols.

Latent representations, like many signals of interest, are compressible, meaning that they can be represented as a linear combination of a small number of functions from an appropriately-selected basis set (*i.e.*, $s = \Psi^T x$, for weights s, basis Ψ, and signal x). A key insight of compressive sensing is that, if one assumes that the responses stem from a process of comparing stimuli to the latent representation (*i.e.*, $y = \Phi x$, for responses y and measurement operation Φ), then it becomes possible to estimate the latent representation using only a small number of measurements by acquiring the basis function representation directly (*i.e.*, $y = \Phi\Psi s$) via sparse optimization approaches (to find s). The responses can be continuous (*e.g.*, neural firing rates), ordinal similarity scores, or binary (*i.e.*, yes/no).

Proposed Study

The objective of this work is to develop and validate a compressive sensing data processing pipeline, culminating in an open-source software tool, that will allow for efficient and accurate reconstructions of latent representations using data obtained via the reverse correlation method.

Specific Aim #1 We will validate the proposed use of compressive sensing for relevant types of neural, cognitive, and behavioral data. Validation will be accomplised through simulation studies, analysis of existing databases (*e.g.*, those available in *Dryad*), and through the collection of novel psychophysical data. Outcomes will be assessed by examining estimation performance as a function of sample size, including (a) reconstruction accuracy with few samples, (b) gains in high-sample reconstruction accuracy, and (c) minimal sample size to achieve high-end convergent accuracy. We will determine the optimal parameters for compressive sensing, which we expect to depend on the latent representation of interest, stimulus type, and response noise. Considered parameters will include appropriate input/output representations, reconstruction algorithm, and basis type/sparsity.

Specific Aim #2 We will develop and distribute an open-source software implementation of the compressive sensing framework, informed by the findings above, for use by the research community. In order to make the platform maximally accessible, interfaces will be developed for widely-used, high-level programming languages (including MATLAB, Python, R, and Julia) in addition to command-line executables. Making the platform open-source provides opportunities for the community to better understand, customize, and improve the software for their own specific needs.

In sum, reverse correlation has the potential to uncover latent representations underlying perception, and transform our understanding perceptual mechanisms at various levels of investigation: neural, cognitive and psychological. However, in order for this potential to be fully realized, the fundamental inefficiency of reverse correlation paradigms must be overcome. Compressive sensing holds promise to overcome this limitation by dramatically improving the efficiency of reverse correlation, enabling its extension to perceptual mechanisms that are out of reach using current methods. The work proposed here will enable researchers to access the promise of compressive sensing for broadening the impact of reverse correlation.

Broader Impacts Of The Proposed Work

The Project Description must contain, as a separate section within the narrative, a section labeled "Broader Impacts of the Proposed Work". This section should provide a discussion of the broader impacts of the proposed activities. Broader impacts may be accomplished through the research itself, through the activities that are directly related to specific research projects, or through activities that are supported by, but are complementary to the project. NSF values the advancement of scientific knowledge and activities that contribute to the achievement of societally relevant outcomes. Such outcomes include, but are not limited to: full participation of women, persons with disabilities, and underrepresented minorities in science, technology, engineering, and mathematics (STEM); improved STEM education and educator development at any level; increased public scientific literacy and public engagement with science and technology; improved well-being of individuals in society; development of a diverse,globally competitive STEM workforce; increased partnerships between academia, industry, and others; improved national security; increased economic competitiveness of the United States; and enhanced infrastructure for research and education.

Results From Prior NSF Support

If any PI or co-PI identified on the project has received NSF funding (including any current funding) in the past five years, in formation on the award(s) is required, irrespective of whether the support was directly related to the proposal or not. In cases where the PI or co-PI has received more than one award (excluding amendments), they need only report on the one award most closely related to the proposal. Funding includes not just salary support, but any funding awarded by NSF. The following information must be provided:

Name of PI: NSF-Program (Award Number) "Title of the Project" ($AMOUNT, PERIOD OF SUPPORT). **Publications:** List of publications resulting from the NSF award. A complete bibliographic citation for each publication must be provided either in this section or in the References Cited section of the proposal); if none, state: "No publications were produced under this award." **Research Products:** evidence of research products and their availability, including, but not limited to: data, publications, samples, physical collections, software, and models, as described in any Data Management Plan.

References Cited

Budget Justification

A. Senior Personnel

A1. Includes PI at 10% CY.

B. Other Personnel

B3. Includes stipend for one graduate student for each calendar year of the project.

C. Fringe Benefits

Fringe benefits are calculated at a rate of X% for faculty, Y% for graduate students.

E. Travel

1) all travel (both domestic and foreign) must now be justified. 2) temporary dependent care costs above and beyond regular dependent care that directly result from travel to conferences are allowable costs provided that the conditions established in 2 CFR § 200.474 are met.

G. Other Direct Costs

1) Includes coverage on costs of computing devices 2) The charging of computing devices as a direct cost is allowable for devices that are essential and allocable, but not solely dedicated, to the performance of the NSF award **G5.** Includes tuition for graduate students participating in the program.

H. Indirect Costs

Overhead at a rate of X% is charged on all direct salaries and wages, applicable fringe benefits, materials and supplies, services, travel and subawards up to the first $X of each subaward. Excluded are equipment and the portion of each subaward in excess of $X.

Current & Pending Support

Investigator:	
Project Title:	Put your Proposal title here
Project Location:	
Source of Support:	NSF
Total Award Amount:	
Total Award Period:	
Status:	Pending (this project)

Facilities, Equipments, & Other Resources

This section of the proposal is used to assess the adequacy of the resources available to perform the effort proposed to satisfy both the Intellectual Merit and Broader Impacts review criteria. Proposers should describe only those resources that are directly applicable. Proposers should include an aggregated description of the internal and external resources (both physical and personnel) that the organization and its collaborators will provide to the project, should it be funded. Such information must be provided in this section, in lieu of other parts of the proposal (e.g., budget justification, project description). The description should be narrative in nature and must not include any quantifiable financial information. Reviewers will evaluate the information during the merit review process and the cognizant NSF Program Officer will review it for programmatic and technical sufficiency.

Data Management Plan

Proposals must include a supplementary document of no more than two pages labeled "Data Management Plan". This supplementary document should describe how the proposal will conform to NSF policy on the dissemination and sharing of research results (see AAG Chapter VI.D.4)