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What Do You See? Perception, Algorithms, and Statistical Graphics

Statistical graphics are powerful and efficient tools to convey data to support human decision making; however, studies of graphical perception are a patchwork of different methods and conflicting results. Recommendations are often based on opinion, not empirical study, rendering many scientific communications sub-optimal or ineffective. This is alarming: effective science communication is critical for cultivating public trust in the scientific process and ensuring that decision makers accurately interpret information when making choices with real impact. Addressing these challenges, the PI's long-term career goal is to examine statistical graphics with the goal of *helping humans and algorithms work together more effectively*, and to apply this research to educate a new generation of scientists and the broader public.

Toward this vision, the overall **research goal** of this CAREER program is to advance understanding of the use, design, and perception of data displays. Three research objectives (ROs) support this goal. RO1: Create a framework for comprehensive graphical testing by developing and comparing methods that examine multiple levels of engagement. RO2: Empirically validate chart design guidelines, measuring the impact of design on task performance. RO3: Re-imagine explainable machine learning by designing inputs that mimic human perception and are explainable by design.

Integrated with these research efforts, the overall **education goal** is to cultivate statistical learning and scientific decision making in society. Three education objectives (EOs) address this goal: EO1: Develop and implement experiential learning activities for undergraduate introductory statistics courses. EO2: Create and implement open educational resources (OER) to promote reproducible science, responsible machine learning, and open-source software development in statistical programming courses. EO3: Educate and engage with members of the legal system (lawyers and law students, judges, and forensic scientists) and the general public to promote the importance of statistics, scientific validity, and open, reproducible scientific methods.

Intellectual Merit This work will expand our understanding of scientific communication with graphics by examining conflicting research and opinions using comprehensive empirical testing, producing nuanced guidelines for chart design based on intended use. New methods of empirical graphical testing will be developed to cover a wider range of engagement with charts; examination of experimental design choices will provide additional guidance to researchers in this space. This work approaches explainable machine learning by designing explainable features that mimic human perception of data features and using these features to build statistical models. This combined process of exploratory data analysis, perception, introspection, and machine learning leverages techniques for graphical testing to create reproducible quantitative models that can be explained conceptually, building trust with outside experts and the public. Incorporating experiential learning, graphics research, and forensics into statistics courses will advance knowledge of pedagogy and reduce barriers to interest and engagement in STEM. Finally, assessing the OER curricula developed for reproducibility and open-source science will allow us to measure and explore the development of students' attitudes toward ethical science and responsible conduct of research.

Broader Impacts This research will produce nuanced, empirically driven guidelines to support better science communication, enhancing scientists' ability to disseminate their research to the general public through data visualization. In addition, this project reimagines explainable machine learning (EML), reducing the cognitive demands of decision-making with complex models by building these models with explainable inputs that mimic human perception. EML is applicable across many fields, but one immediate application area is forensic pattern evidence: the validity of subjective methods for evaluating this evidence has recently resulted in limitations on the admissibility of such evidence in court. Introducing objective algorithms to supplement subjective visual comparisons promises to provide large benefits to society and improve the fairness of the legal system. This application area will also provide opportunities for graduate students to converse with lawyers, judges, and forensic scientists about statistics, machine learning, error rate estimation, and open science. Experiential learning and research engagement will produce students who are more engaged in STEM coursework and less averse to STEM careers (while accelerating research productivity). Incorporating reproducibility and open-source software development into statistical coursework will foster a well-trained future generation of scientists who will contribute to the open-science community, emphasize the importance of reproducible and open science, and build new infrastructure to support future research.