AI-Empowered Optical Coherence Tomography

Overview/Abstract:

Optical Coherence Tomography (**OCT**) is a pivotal technology with extensive applications across various preclinical/clinical diagnoses. Although recent advancements have been propelled by the integration of contemporary machine learning techniques, existing OCT systems continue to seek improvements in data sensing, anatomical structure analysis, and robust analytical methods. The integration of machine learning in OCT faces three significant challenges: (1) most methods are limited to analyzing reconstructed data, overlooking the nuanced yet informative raw signals; (2) the absence of accurate ground truth data hampers the efficacy of current methodologies; (3) there is a notable deficiency in studies on generalization across different data collection protocols and imaging devices, exacerbating the data scarcity issue.

The primary goal of this project is to transform OCT research and development by creating a series of innovative and transformative AI-empowered OCT technologies. This initiative will tackle the aforementioned challenges in a systematic and scalable manner. The project will unfold across three interconnected objectives:

- **AI-Driven OCT Reconstruction (Aim 1)**: We will overhaul the OCT reconstruction process within a modern machine learning framework to substantially enhance sensing quality and efficiency. Our initial focus will be on developing a Generative Pre-trained Representation (GPR) for the raw 1D OCT signal trace, named GPR-A. This model will capture complex information typically discarded in existing spectral-domain OCT processes. GPR-A will form the foundation for various reconstruction tasks, including OCT Angiography (OCA) and Doppler OCT (ODT). These processes will be optimized through end-to-end learnable algorithms that integrate traditional imaging principles to guide network design and regularization.

- **AI-Enhanced Vasculature Analysis in OCT (Aim 2)**: Our approach will refine the detection and interpretation of vascular morphologies, particularly in awake animals—a notably challenging context. By developing GPRs for 2D and 3D OCT data, we aim to harness extensive pre-existing knowledge through mask prediction pretext tasks. A novel attribute graph representation, paired with a graph transformer network, will be utilized in conjunction with GPRs for targeted vasculature analysis tasks, including vessel segmentation and completion.

- **Domain Adaptation Across OCT Applications (Aim 3)**: We aim to generalize the models and techniques achieved in Aims 1 and 2 across a broad spectrum of OCT applications. This includes devising domain adaptation (DA) strategies to transfer insights gained from one specific OCT task to others, thereby minimizing the need for extensive data annotation and reducing computational demands. Our efforts will focus on both the sensing/reconstruction and vascular structure analysis aspects, leveraging our deep expertise in domain adaptation and transfer learning especially in unsupervised DA and knowledge-guided DA.

This project represents a profound shift in OCT research by embedding advanced AI methodologies at the foundational stages of data handling and analysis. It promises not only to enhance the capabilities of OCT but also to catalyze further interdisciplinary collaborations at Stony Brook University, particularly between the Computer Science and Bioengineering departments. This venture is expected to lead to groundbreaking shifts in biophotonic research, with wide-reaching implications for medical and healthcare applications.

Our interdisciplinary team, comprising experts in computer science, artificial intelligence, bioengineering and biophotonics, has a proven track record of collaboration, evidenced by joint NIH awards and numerous publications. Committed to securing further support, we plan to pursue extramural funding from sources such as the NSF and NIH.