A major obstacle in the study of human brain function is that we have limited understanding of how the measurements made by different instruments, such as fMRI and EEG, relate to one another and to the underlying neuronal circuitry. Significant efforts have led to development of models within several specialist fields, but fragmentation has limited our capacity to accurately interpret the spatiotemporal characteristics of non-invasive imaging signals. In this project, we will develop a set of connecting, empirically driven models to predict how sensory stimuli are encoded in neuronal population activity underlying electrophysiological measures (AIM 1) and hemodynamic measures (AIM 2). These specific models will allow us to formulate a comprehensive integrative model (AIM 3). The integrative model will improve our understanding of the information we can obtain from fMRI, the modality with the highest potential for mapping detailed functions non-invasively in humans. To achieve this, we will combine electrophysiological and hemodynamic measurements at multiple spatial scales in humans. This will include non-invasive (fMRI at 3T and 7T, MEG and EEG) and invasive (optical imaging, ECoG) modalities. Models across spatial scales will be constructed and validated with data from the multiple modalities and three brain systems (visual, somatosensory, and motor). We will link measurements and models to the detailed micro-scale models available from invasive animal research, by comparing the same somatosensory paradigms in humans and in rodents, using high resolution rodent measurements (9.4T fMRI, optical imaging, and intra-cranial electrophysiology). By obtaining multiple modality recordings from the same individuals, using the same stimuli and tasks, we will unequivocally link precisely defined electrophysiological information to widely used fMRI technology, while significantly improving our understanding of the electrical and hemodynamic phenomena underlying human brain activity.