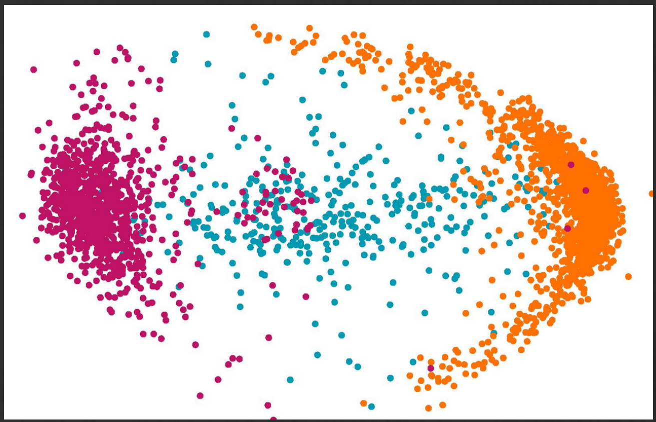
Biomedical time series such as the electrocardiogram (ECG) are non-invasive windows through which we may observe human systems. Although a vast amount of information is hidden in the medical field's growing collection of long-term, high-resolution, and multi-modal biomedical time series, effective algorithms for extracting that information have not yet been developed. We are particularly interested in the physiological dynamics of a human system, namely the changes in state that the system experiences over time. We introduce a mathematical model for a particular class of biomedical time series, called the wave-shape oscillatory model, which quantifies the sense in which dynamics are hidden in those time series, and we propose an algorithm to extract those dynamics. We provide several applications of the wave-shape oscillatory model and the associated algorithm for dynamics recovery, including unsupervised and supervised heartbeat classification, derived respiratory monitoring, intra-operative cardiovascular monitoring, supervised and unsupervised sleep stage classification, and f-wave extraction (a single-channel blind source separation problem).

John Malik

PhD Thesis

A Geometric Approach to Biomedical Time Series Analysis



There are two key ideas behind the wave-shape oscillatory model for biomedical time series. First, instead of viewing a biomedical time series as a sequence of measurements made at the sampling rate of the signal, we can often view it as a sequence of cycles (heartbeats) occurring at irregularly-sampled time points. Second, the "shape" of an individual cycle is assumed to have a one-to-one correspondence with the state of the system being monitored; as such, changes in system state (dynamics) can be inferred by tracking changes in cycle shape. Since physiological dynamics are not random but are well-regulated (except in the most pathological of cases), we can assume that all of the system's states lie on a low-dimensional, abstract Riemannian manifold called the phase manifold. When we model the correspondence between the hidden system states and the observed cycle shapes using a diffeomorphism, we allow the topology of the phase manifold to be recovered by methods belonging to the field of unsupervised manifold learning. In particular, we prove that the physiological dynamics hidden in a time series adhering to the wave-shape oscillatory model can be well-recovered by applying the diffusion maps algorithm to the time series' set of oscillatory cycles.

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