Constructing Ventricular Digital Twins From Multi-Modal Clinical Data at Large Scale

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In contemporary cardiac research, the development of digital twins represents a critical innovation, providing personalized virtual models that mirror individual cardiac anatomy and function. This paper introduces CARDIA, a novel framework developed to construct these digital twins by overcoming significant data integration challenges associated with multi-modal datasets. These datasets, comprising various data formats and scale discrepancies—from time series to high-resolution images—pose substantial barriers to accurately representing cardiac functions.

One of the foremost challenges in developing cardiac digital twins through CARDIA is the harmonization of diverse data types, which often vary in dimension and scale, complicating their aggregation and analysis. This issue is critical when studying complex cardiac dynamics, including the heart's structural features, functional mechanisms, and myocardial excitation and repolarization patterns. The variation in data types necessitates sophisticated strategies for data integration to ensure that the digital twins accurately reflect the intricate nature of heart mechanics.

CARDIA incorporates advanced methodologies for creating precise, patient-specific cardiac models to address these challenges. This includes detailed mapping of functional regions, orientation of myocytes, and indicators of structural remodeling. These features are crucial for producing simulations that reliably replicate individual cardiac behavior under various scenarios, enhancing understanding of heart diseases and potential treatments.

By resolving the complexities of multi-modal data integration, CARDIA facilitates the large-scale development of accurate and actionable cardiac digital twins. The framework's capability to incorporate comprehensive cardiac data and generate detailed simulations offers profound implications for personalized medicine. It allows for better predictions of disease progression, tailored therapeutic interventions, and improved patient outcomes. This paper describes CARDIA's functionality, highlights practical use cases, and discusses its potential to revolutionize the creation of digital twins at a large scale.