Exploring Latent Representations of RR-Interval Dynamics Beyond Poincaré Maps

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Introduction. Poincaré-plot Heart Rate Variability analysis is widely used for noninvasive characterization of cardiac rhythm dynamics, but limited by its static 2D geometry and handcrafted features, which miss nonlinear arrhythmia dynamics. Representation-learning approaches enable feature-free, temporally aware embeddings. We investigate contrastive latent-space representations of tachograms to discriminate sinus rhythm (SR), atrial fibrillation (AF), and paced rhythms using an end-to-end LSTM autoencoder with contrastive projection.

Materials and Methods. The dataset comprised nine 24-hour Holter recordings, with three subjects for each of the three target rhythms. RR-interval series were manually cleaned, resampled to 1 Hz, z-score normalized, and segmented into 5-minute windows. The model consists of an LSTM encoder mapping each window into a three-dimensional latent manifold, an LSTM decoder for reconstruction, and a self-attention contrastive module. Training optimized a joint objective combining the MSE reconstruction loss with an InfoNCE contrastive loss to enforce invariance across original–augmented pairs.

Experiments and Results. The resulting 3-D embeddings were compared against classical Poincaré plots and UMAP using spatial dispersion and structural organization metrics, including the Besag L-function and its area under the curve (AUC-L), where higher values indicate more organized spatial patterns. The AUC-L scores for SR, AF, and paced rhythms were: *Contrastive*-101.818, 72.528, 165.928; *UMAP*-60.056, 38.250, 41.031; *Poincaré*-55.320, 115.691, 239.514.

Conclusions. Contrastive latent-space embeddings capture tachogram structure more distinctly than geometric baselines, providing a compact and well-organized representation suited for robust automated rhythm characterization.

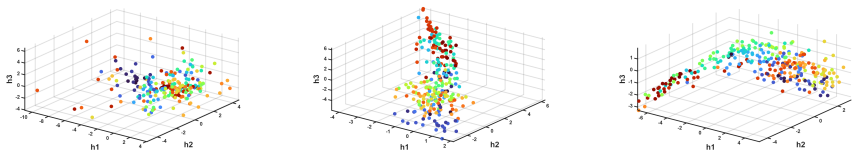

Figure 1: Contrastive-encoder latent space for paced, SR, and AF rhythms. Color represents time: cool tones correspond to the beginning of the recording, while warm tones indicate the end.