How Effective Is Your Encoding? Task-Aware Mutual Information for Evaluating Event-Based Representations

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Event-based encoding is a cornerstone of neuromorphic computing, yet principled methods to evaluate the quality of event representations remain limited. In practice, encoding schemes are often assessed indirectly through downstream classifiers, entangling encoding quality with model-specific effects and obscuring what makes an event informative for a given task.

In this work, we introduce Task Mutual Information (Task-MI), a task-driven, information-theoretic metric to quantify how much task-relevant information (with respect to target labels in supervised settings) is preserved in event-based representations, independently of the decoding architecture applied after the analog-to-spike conversion (see Fig. 1). This enables a decoder-agnostic and featureless evaluation of encoding schemes and their operating regimes, effectively decoupling representation quality from downstream model design, thus facilitating front-end optimization.

We validate the proposed framework across noisy biosignal modalities (ECG, EMG, EEG), distinct binary classification tasks (atrial fibrillation vs normal, gesture vs rest, seizure vs non-seizure state detection, respectively), encoding strategies (delta-modulation, level-crossing with hysterisis, integrate-and-fire), and classification models/decoders (Logistic Regression, XGBoost, TinySNN). By analyzing the relationship between Task MI and classification performance, measured by the area under the receiver operating characteristic curve (AUC), we show that Task MI consistently tracks downstream performance trends across conditions, irrespective of the classifier used, with strong monotonic associations. Furthermore, by controlling for potential confounds such as event rate and class imbalance under a leave-one-subject-out (LOSO) evaluation, we demonstrate that normalized Task MI provides a robust proxy for event-based encoding quality.

These results establish Task MI as a principled, featureless, and decoder-agnostic metric for evaluating neuromorphic analog-to-spike encoders, providing a foundation for designing efficient and task-relevant event-driven sensing systems.

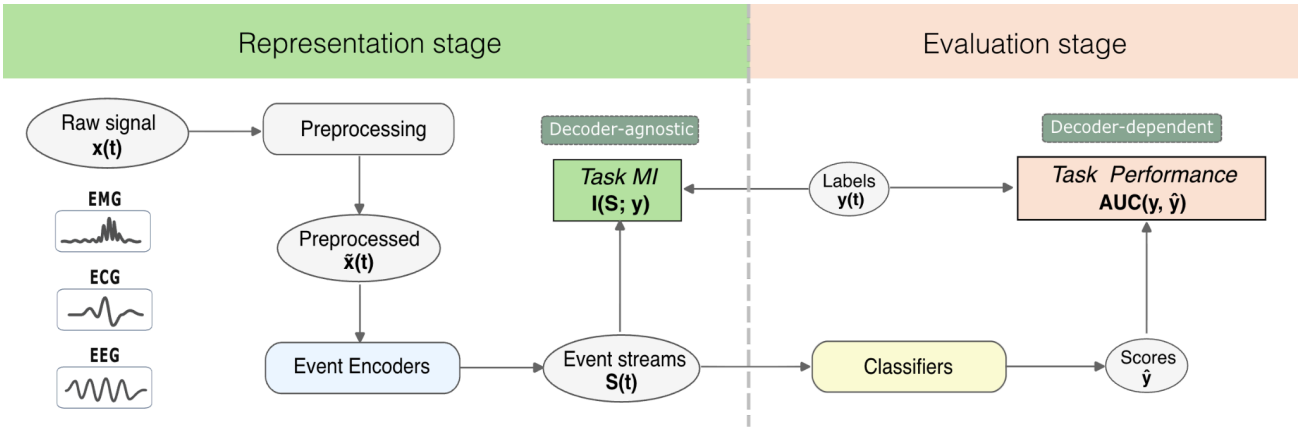

Figure 1: Overview of the proposed framework, decoupling event-based representations from decoding (downstream performance) and enabling classifier-agnostic evaluation via Task-aware Mutual Information (Task-MI).