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A Monte Carlo Fuzzy Logistic Regression Framework against Imbalance and Separation

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Abstract : Two of the most impactful issues in classical logistic regression are class imbalance and complete separation. These can result in model predictions heavily leaning towards the imbalanced class on the binary response variable or over-fitting issues. Fuzzy methodology offers key solutions for handling these problems. However, most studies propose the transformation of the binary responses into a continuous format limited within [0,1]. This is called the possibilistic approach within fuzzy logistic regression. Following this approach is more aligned with straightforward regression since a logit-link function is not utilized, and fuzzy probabilities are not generated. In contrast, we propose a method of fuzzifying binary response variables that allows for the use of the logit-link function; hence, a probabilistic fuzzy logistic regression model with the Monte Carlo method. The fuzzy probabilities are then classified by selecting a fuzzy threshold. Different combinations of fuzzy and crisp input, output, and coefficients are explored, aiming to understand which of these perform better under different conditions of imbalance and separation. We conduct numerical experiments using both synthetic and real datasets to demonstrate the performance of the fuzzy logistic regression framework against seven crisp machine learning methods. The proposed framework shows better performance irrespective of the degree of imbalance and presence of separation in the data, while the considered machine learning methods are significantly impacted.

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