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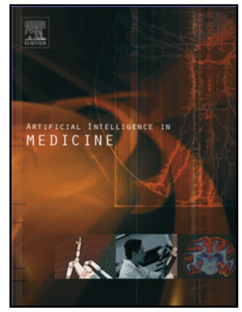

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Dynamically weighted evolutionary ordinal neural network for solving an imbalanced liver transplantation problem

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Abstract

Objective: Create an efficient decision-support model to assist medical experts in the process of organ allocation in liver transplantation. The mathematical model proposed here uses different sources of information to predict the probability of organ survival at different thresholds for each donor-recipient pair considered. Currently, this decision is mainly based on the Model for End-stage Liver Disease, which depends only on the severity of the recipient and obviates donor-recipient compatibility. We therefore propose to use information concerning the donor, the recipient and the surgery, with the objective of allocating the organ correctly.
Methods and materials: The database consists of information concerning transplants conducted in 7 different Spanish hospitals and the King's College hospital (United Kingdom). The state of the patients is followed up for 12 months. We propose to treat the problem as an ordinal classification one, where we predict the organ survival at different thresholds: less than 15 days, between 15 and 90 days, between 90 and 365 days and more than 365 days. This discretization is intended to produce finer-grain survival information (compared with the common binary approach). However, it results in a highly imbalanced dataset in which more than 85% of cases belong to the last class. To solve this, we combine two approaches, a cost-sensitive evolutionary ordinal artificial neural network (ANN) (in which we propose to incorporate dynamic weights to make more emphasis on the worst classified classes) and an ordinal over-sampling technique (which adds virtual patterns to the minority classes and thus alleviates the imbalanced nature of the dataset).
Results: The results obtained by our proposal are promising and satisfactory, considering the overall accuracy, the ordering of the classes and the sensitivity of minority classes. In this sense, both the dynamic costs and the over-sampling technique improve the base results of the considered ANN-based method. Comparing our model with other state-of-the-art techniques in ordinal classification, competitive results can also be appreciated. The results achieved with this proposal improve the ones obtained by other state-of-the-art models: we were able to correctly predict more than 73% of the transplantation results, with a geometric mean of the sensitivities of 31.46%, which is much higher than the one obtained by other models.
Conclusions: The combination of the proposed cost-sensitive evolutionary algorithm together with the application of an over-sampling technique improves the predictive capability of our model in a significant way (especially for minority classes), which can help the surgeons make more informed decisions about the most appropriate recipient for an specific donor organ, in order to maximize the probability of survival after the transplantation and therefore the fairness principle.

Keywords: Artificial neural networks, Ordinal classification, Imbalanced classification, Survival analysis, Liver transplantation

1. Introduction

Liver transplantation is an accepted treatment for patients who present end-stage liver disease. However, transplantation is restricted by the lack of suitable donors, where this imbalance between supply and demand results in significant waiting list deaths. With the objective of approaching this problem, several techniques have been proposed to find a better system to prioritize recipients on the waiting list. The first attempt at developing a system is the Donor Risk Index [1], which establishes the quantitative risk associated to the surgery considering only donor information. The opposite methodology, and the pillar of the current allocation policy, is the Model for End-stage Liver Disease (MELD) [2], which only considers the severity of the recipient.

Nonetheless, the above-mentioned methods can not be considered good predictors of graft failure after transplantation, because they only take into account either characteristics of donors or recipients (but not both). Rana *et al.* [3] created a scoring system to predict recipient survival three months after liver transplantation using information of both donor and recipient. P. Dutkowski *et al.* recently proposed a balance of risk score [4] also based on donor and recipient characteristics. A rule-based system is used to determine graft survival one year after transplantation in [5, 6] using donor, recipient and transplanted organ characteristics. These studies show that artificial neural networks (ANN) perform better at this task than the rest