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aorsf: An R package for supervised learning using the oblique random survival forest

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Summary

The random survival forest (RSF) is a supervised learning method for right-censored time-to-event data that combines predictions from a large set of survival decision trees (Ishwaran, Kogalur, Blackstone, & Lauer, 2008). Similar to random forests for classification and regression (Breiman, 2001), trees in the RSF are de-correlated by using random subsets of training data to grow each tree and considering a random subset of predictor variables at each non-terminal node. Decision trees in the RSF may be axis based or oblique. Axis-based trees split non-terminal nodes using individual predictor variables, whereas oblique trees use a linear combination of variables. Although using oblique instead of axis based decision trees to grow the RSF improves its Brier score and concordance index in prediction tasks, the computational overhead of fitting an oblique RSF may be substantially higher than an axis based RSF (Jaeger et al., 2019), making it difficult to use the oblique RSF in applied settings.

`aorsf` is an R package designed to develop and compute predictions with oblique RSFs efficiently. Extensions of `aorsf`'s core features are supported by allowing users to supply their own function to identify a linear combination of inputs when growing oblique survival trees. The target audience includes both **analysts** aiming to develop an accurate risk prediction model (e.g., see Segar et al. (2021)) and **researchers** who want to conduct experiments comparing different techniques for identifying linear combinations of predictor variables (e.g., see Katuwal, Suganthan, & Zhang (2020)). Key features of `aorsf` include computational efficiency compared to existing software, extensive unit and integration testing that ensure cross-platform consistency and reproducibility, and user-friendly documentation paired with an application programming interface that facilitates proper usage of the core algorithms.

Existing software

The `obliqueRF` and `RLT` R packages support oblique classification and regression random forests but not oblique RSFs. The `ranger` and `randomForestSRC` packages support axis based RSFs but not oblique RSFs. The `obliqueRSF` R package fits oblique RSFs, but its computational inefficiency is a barrier in applied settings. `aorsf` is designed for computational efficiency and flexibility, allowing users to grow oblique RSFs using Newton Raphson scoring (the default), penalized Cox regression (the method used by `obliqueRSF`), or a user-defined function to identify linear combinations of variables.

Newton Raphson scoring

The default routine for creating linear combinations of predictor variables in `aorsf` applies Newton Raphson scoring to the partial likelihood function of the Cox regression model.

`aorsf` uses the same approach as the `survival` package to complete this estimation procedure efficiently. Full details on the steps involved have been made available by Therneau (2022). Briefly, a vector of estimated regression coefficients, $\hat{\beta}$, is updated in each step of the procedure based on its first derivative, $U(\hat{\beta})$, and second derivative, $H(\hat{\beta})$:

$$\hat{\beta}^{k+1} = \hat{\beta}^{k} + U(\hat{\beta} = \hat{\beta}^{k})\, H^{-1}(\hat{\beta} = \hat{\beta}^{k})$$

While it is standard practice in statistical modeling to iteratively update $\hat{\beta}$ until a convergence threshold is met, the default approach in `aorsf` only completes one iteration (see `?orsf_control_cph`). The rationale for this approach is based on three points. First, while completing more iterations reduces bias in the regression coefficients, general benchmarking experiments have found it does not improve the discrimination or Brier score of the oblique RSF (Jaeger et al., 2022). Second, computing U and H requires computation and exponentiation of the vector $X\hat{\beta}$, where X is the matrix of predictor values, but these steps can be skipped on the first iteration if an initial value of $\hat{\beta} = 0$ is chosen, allowing for a reduction in required computation. Third, using only one iteration with all initial values of $\hat{\beta}$ set to 0 allows the user to bypass the scaling of predictors prior to running Newton Raphson scoring, as this step is usually done to improve numeric stability in later iterations.

Benchmarking

The increased efficiency of `aorsf` versus `obliqueRSF` results from improved memory management and Newton Raphson scoring. In general benchmarks of prediction accuracy and computational efficiency, `aorsf` has matched or exceeded the prediction accuracy of `obliqueRSF` while running two orders of magnitude faster (Jaeger et al., 2022).

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