

# A Large-Scale Neutral Comparison Study of Survival Models

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# Introduction

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$\Rightarrow$  Needs **comprehensive comparison!**

## Quick Summary

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- 18 learners
- 2 tuning measures
- 9 evaluation measures

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$\Rightarrow$  The **largest survival benchmark** to date as far as we know

The “Standard Setting”:

- Single-event outcome:  $\delta_i \in \{0, 1\}$
- Low-dimensional:  $2 \leq p < n$
- No time-varying covariates
- Right-censoring only
- At least 100 observed events

# Tasks

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32 tasks collected from R packages on CRAN

	Minimum	q25%	Median	q75%	Maximum
N	137	446	820	2378	52410
p	2	4	5	7	25
Observed Events	101	194	323	699	5616
Cens. %	6	32	48	74	95

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18 learners implemented in R and available via the `mlr3`<sup>1</sup> framework

- **Baseline:** Kaplan-Meier & Nelson-Aalen

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- **Classical:** Cox, penalized, parametric
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- **Boosting:** Gradient- and likelihood-based
- **Other:** Akritas, SVM

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## List of Learners (Baseline, Classical)



6

Name	Abbreviation	Package
Kaplan-Meier	KM	survival
Nelson-Aalen	NA	survival
Cox Regression	CPH	survival
Penalized Cox Regression (L1, L2)	GLM	glmnet
Penalized Cox Regression (L1, L2)	Pen	penalized
Parametric (AFT)	Par	survival
Flexible Parametric Splines	Flex	flexsurv
Akritis	AK	survivalmodels
Survival SVM	SSVM	survivalsvm

# List of Learners (Trees, Boosting)



7

Name	Abbreviation	Package
Decison Tree	RRT	rpart
Random Survival Forest	RFSRC	randomForestSRC
Random Survival Forest	RAN	ranger
Conditional Inference Forest	CIF	partykit
Oblique RSF	ORSF	aorsf
Model-Based Boosting	MBO	mboost
Likelihood-Based Boosting	CoxB	CoxBoost
Gradient Boosting (Cox objective)	XGB Cox	xgboost
Gradient Boosting (AFT objective)	XGB AFT	xgboost

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- **Budget:** Tuning stopped if **either** is reached
  1. Number of evaluations:  $n_{\text{evals}} = n_{\text{parameters}} \times 50$
  2. Tuning time of 150 hours ( $6\frac{1}{4}$  days)

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- Main Results:

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- Tuned on 2 different measures

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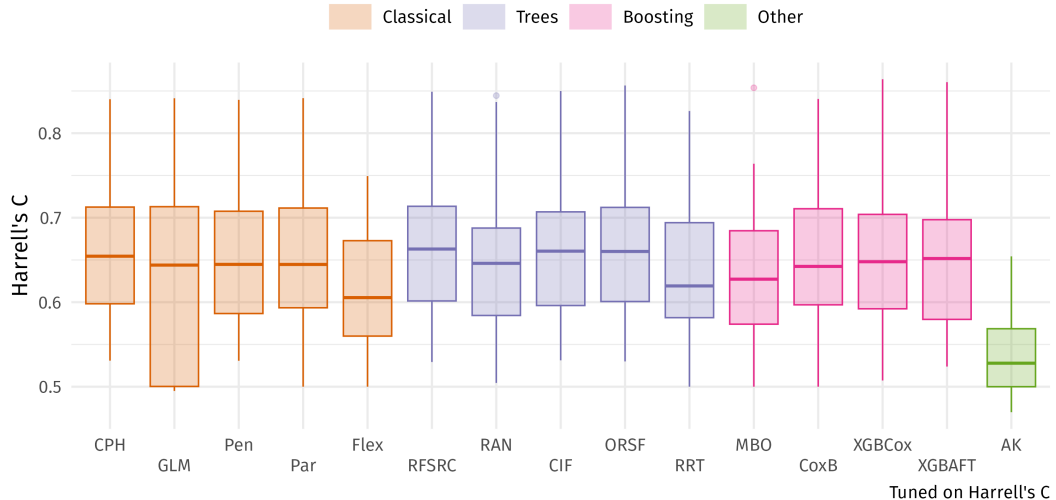
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- 3 types of metrics: Discrimination, Calibration, [Scoring Rules](#)
- Tuned on 2 different measures
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- Evaluation spans all 3 types

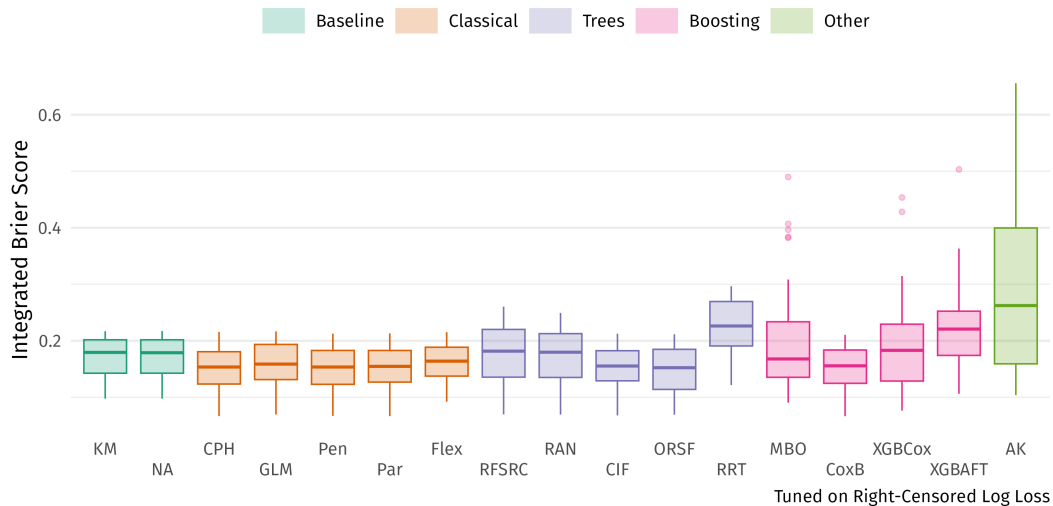
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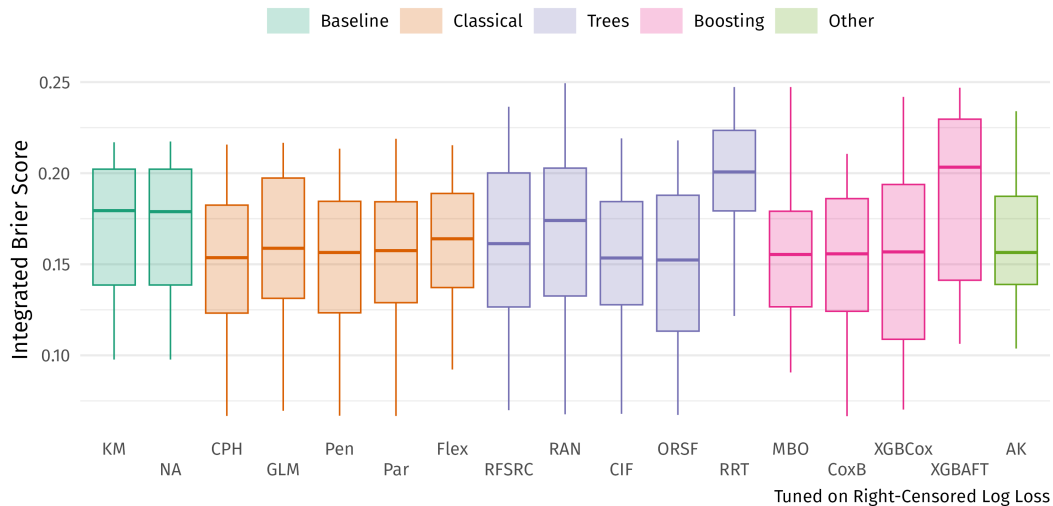
# Boxplot (Harrel's C, higher is better)



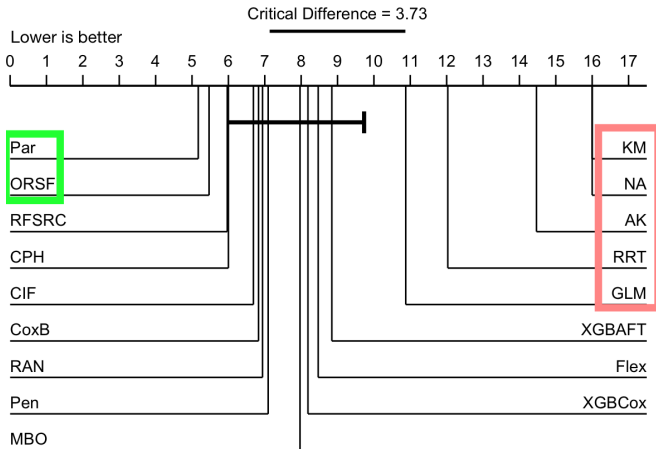
## Boxplot (IBS, lower is better)



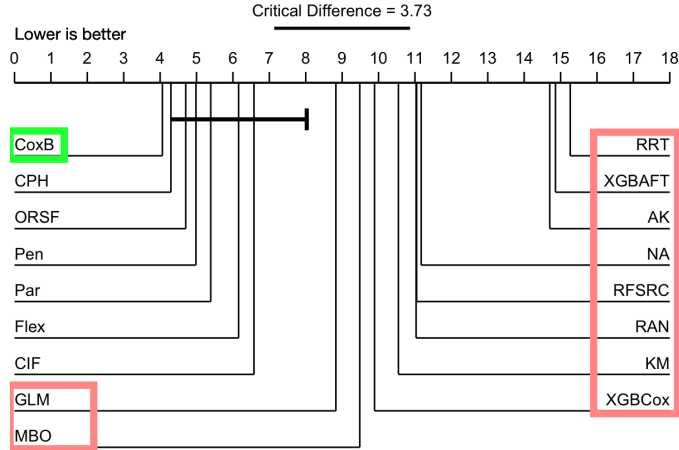
# Boxplot (IBS, truncated)



# Critical Difference: Bonferroni-Dunn (Harrell's C)



# Critical Difference: Bonferroni-Dunn (IBS/RCLL)





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- Only computationally feasible due to resources of ARCC<sup>3</sup>

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  - Sequential runtime:  $\approx 18$  years

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- The “standard setting”  $\approx$  the “do you need ML?”-setting

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Thank you for your attention!

[www.leibniz-bips.de/en](http://www.leibniz-bips.de/en)

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## References I

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-  Demšar, Janez (2006). “Statistical comparisons of classifiers over multiple data sets”. In: [Journal of Machine learning research 7.1](#), pp. 1–30.
-  Lang, Michel et al. (2019). “mlr3: A modern object-oriented machine learning framework in R”. In: [Journal of Open Source Software 4.44](#), p. 1903. DOI: [10.21105/joss.01903](#).