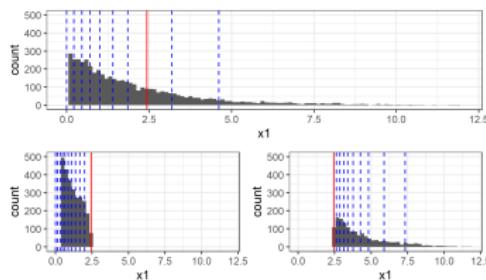


Introduction to Machine Learning

Boosting

Gradient Boosting: XGBoost



Learning goals

- Overview over XGB
- Regularization in XGB
- Approximate split finding

XBG - EXTREME GRADIENT BOOSTING

- Open-source and scalable tree boosting system
- Efficient implementation in *C++* with interfaces to many other programming languages
- Parallel approximate split finding
- Additional regularization techniques
- Feature and data subsampling
- Cluster and GPU support
- Highly optimized and often achieves top performance in benchmarks – if properly tuned



3 EXTRA REGULARIZATION TERMS

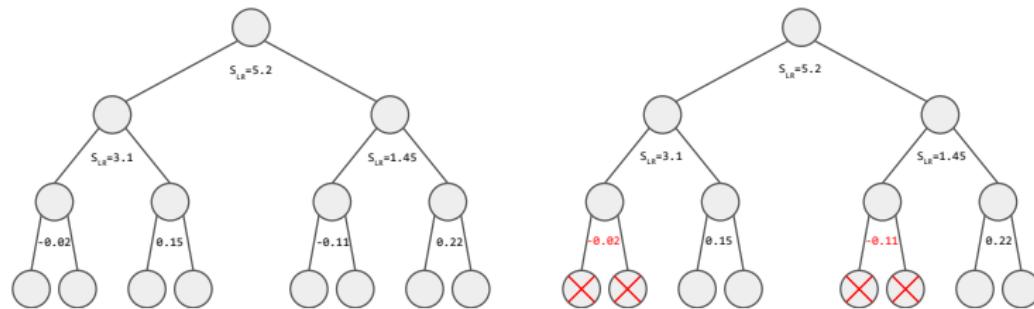
$$\begin{aligned}\mathcal{R}_{\text{reg}}^{[m]} = & \sum_{i=1}^n L \left(y^{(i)}, f^{[m-1]}(\mathbf{x}^{(i)}) + b^{[m]}(\mathbf{x}^{(i)}) \right) \\ & + \lambda_1 J_1(b^{[m]}) + \lambda_2 J_2(b^{[m]}) + \lambda_3 J_3(b^{[m]}),\end{aligned}$$



- $J_1(b^{[m]}) = T^{[m]}$: Nr of leaves to penalize tree depth
- $J_2(b^{[m]}) = \|\mathbf{c}^{[m]}\|_2^2$: L2 penalty over leaf values
- $J_3(b^{[m]}) = \|\mathbf{c}^{[m]}\|_1$: L1 penalty over leaf values

TREE GROWING

- Grown to max depth
- Fully expanded and leaves split even if no improvement
- At the end, each split that did not improve risk is pruned



SUBSAMPLING

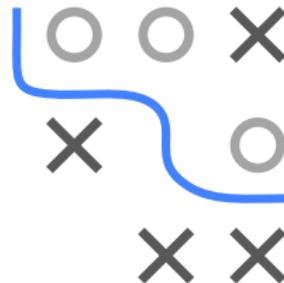
Data Subsampling: XGB uses stochastic GB.

Feature Subsampling: Similar to `mtry` in a random forest only a random subset of features is used for split finding.

The fraction of features for a split can be randomly sampled for each

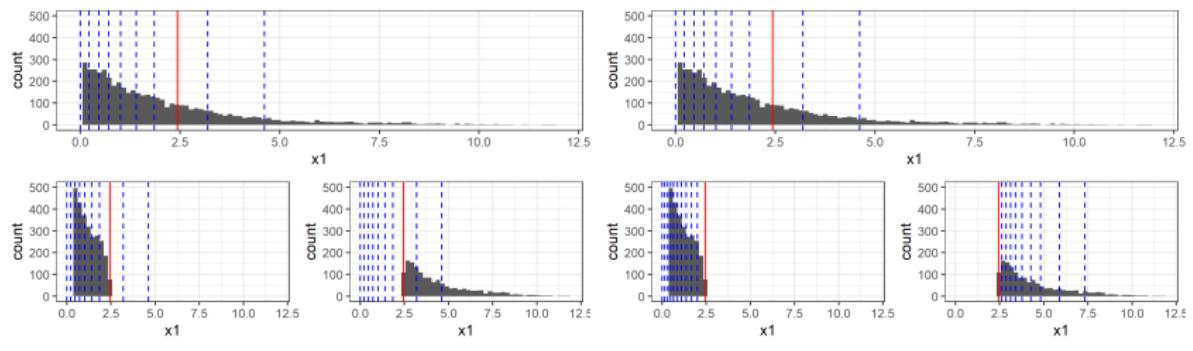
- ① tree
- ② level of a tree
- ③ split

Feature subsampling speeds up training even further and can create a more diverse ensemble that often performs better.

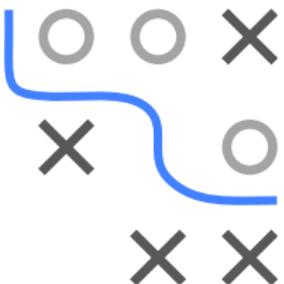


APPROXIMATE SPLIT-FINDING ALGORITHMS

- Speeds up tree building for large data
- Considers not all, but only ℓ splits per feature
- Usually percentiles of the empirical distribution of each feature
- Computed once (global) or recomputed after each split (local)
- Called **Histogram-based Gradient Boosting**



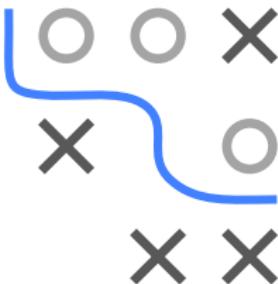
Blue lines are percentiles and red = selected split



DROPOUT ADDITIVE-REGRESSION TREES

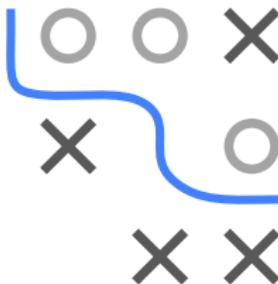
DART introduces idea of *dropout* regularization used in DL to boosting

- In iteration m we construct $\hat{b}^{[m]}$
 - To compute PRs we need $\hat{f}^{[m-1]}$
 - We compute this differently, by using random subset $D \subset \hat{b}^{[1]}, \dots, \hat{b}^{[m-1]}$ of size $(m-1) \cdot p_{\text{drop}}$ is ignored
 - To avoid *overshot predictions* in ensemble, we scale the BLs at the end of the iteration, by $\frac{1}{|D|+1} \hat{b}^{[m]}$ and $\frac{|D|}{|D|+1} \hat{b} \quad \forall \hat{b} \in D$.
-
- $p_{\text{drop}} = 0$: Ordinary GB
 - $p_{\text{drop}} = 1$: All BLs are trained independently, and equally weighted.
Model is very similar to random forest.
- ⇒ p_{drop} is smooth transition from GB to RF



PARALLELISM AND GPU COMPUTATION

- GB is inherently sequential, not easy to parallelize
- **But:** Building of BLs can be parallelized
- Data sort and split eval in different branches of tree BLs can be computed in parallel by using efficient block data structures
- Can also gain huge speed-up by moving from CPU to GPU



OVERVIEW OF IMPORTANT HYPERPARAMETERS

| HP (as named in software) | Type | Typical Range | Trafo | Default | Description |
|---------------------------|------|----------------------|--------|---------|--|
| eta | R | $[-4, 0]$ | 10^x | 0.3 | learning rate (also called ν) shrinks contribution of each boosting update |
| nrounds | I | $\{1, \dots, 5000\}$ | - | - | number of boosting iterations. Can also be optimized with early stopping. |
| gamma | R | $[-7, 6]$ | 2^x | 0 | minimum loss reduction required to make a further partition on a leaf node of the tree |
| max_depth | I | $\{1, \dots, 20\}$ | - | 6 | maximum depth of a tree |
| colsample_bytree | R | $[0.1, 1]$ | - | 1 | subsample ratio of columns for each tree |
| colsample_bylevel | R | $[0.1, 1]$ | - | 1 | subsample ratio of columns for each depth level |
| lambda | R | $[-10, 10]$ | 2^x | 1 | L_2 regularization term on weights |
| alpha | R | $[-10, 10]$ | 2^x | 0 | L_1 regularization term on weights |
| subsample | R | $[0.1, 1]$ | - | 1 | subsample ratio of the training instances |

