

LightGBM cheat sheet

GBT is a popular machine learning algorithm and has quite a few effective implementations such as XGBoost. Although many engineering optimizations have been adopted in these implementations, the efficiency is still unsatisfactory when the feature dimension is high and the data size is large. A major reason is that for each feature they need to scan all the data instances to estimate the information gain of all possible split points (or build the histogram for histogram-based algorithm). To tackle this problem, LightGBM propose two novel techniques : Gradient-based One-Side Sampling (GOSS) and Exclusive Feature Bundling (EFB). All this work is based on author's paper : <http://www.audentia-gestion.fr/MICROSOFT/lightgbm.pdf>

Prerequisites : GBT, XGBoost

1) Histogram-based model

First, as XGBoost, LightGBM support histogram-based algorithm (also called approximate algorithm in opposite of greedy exact algorithm where all the instances are scanned for split finding) for trees construction :

Algorithm 1: Histogram-based Algorithm

Input: I : training data, d : max depth
Input: m : feature dimension
 $nodeSet \leftarrow \{0\}$ ▷ tree nodes in current level
 $rowSet \leftarrow \{\{0, 1, 2, \dots\}\}$ ▷ data indices in tree nodes

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for  $i = 1$  to  $d$  do
  for  $node$  in  $nodeSet$  do
     $usedRows \leftarrow rowSet[node]$ 
    for  $k = 1$  to  $m$  do
       $H \leftarrow new\ Histogram()$ 
      ▷ Build histogram
      for  $j$  in  $usedRows$  do
         $bin \leftarrow I[k][j].bin$ 
         $H[bin].y \leftarrow H[bin].y + I.y[j]$ 
         $H[bin].n \leftarrow H[bin].n + 1$ 
      Find the best split on histogram  $H$ .
    ...
  Update  $rowSet$  and  $nodeSet$  according to the best split points.
  ...
```

2) Gradient-based One-Side Sampling (GOSS)

GOSS is a new sampling method that can achieve a good balance between reducing the number of data instances and keeping a good accuracy.

It's based on the fact that the larger the gradient of an instance is, the more it contributes to the information gain computation in the split finding. (recall: GBT is an iterative addition of a regression tree model that fits the negative gradients).

Indeed, as we have the information gain for a split equals to :

$$gain_{split} = V(I) - [(\#I_L / \#I) * V(I_L) + (\#I_R / \#I) * V(I_R)] \quad (1)$$

with $V(I)$ the variance in the node I , and $I = I_R \cup I_L$ the right and left children nodes. As :

$$V(I) = \frac{1}{n} \sum_{x_i \in I} (g_i - \bar{g}_I)^2$$

by developing (1) we find :

$$V(I) = \frac{1}{\#I} \left[\frac{1}{\#I_R} \left(\sum_{x_i \in I_R} g_i \right)^2 + \frac{1}{\#I_L} \left(\sum_{x_i \in I_L} g_i \right)^2 \right] - cste$$

which shows that larger the gradient is the more it contributes to information gain computation.

GOSS is set up with two parameters : it select the top $\alpha * 100\%$ percent of the top gradient absolute value instances, and randomly sample $\beta * 100\%$ from the rest. After that, it amplifies the "small gradient" sampled data by a constant $\frac{1-\alpha}{\beta}$ to balance the two data sets and not overfit the model on the top gradient data by giving them too much weight.

Author's shows that this strategy outperform in many case a random sampling, and that with n high the accuracy is close to a model with all the instances.

Algorithm 2: Gradient-based One-Side Sampling

Input: I : training data, d : iterations
Input: a : sampling ratio of large gradient data
Input: b : sampling ratio of small gradient data
Input: $loss$: loss function, L : weak learner
 $models \leftarrow \{\}$, $fact \leftarrow \frac{1-a}{b}$
 $topN \leftarrow a \times \text{len}(I)$, $randN \leftarrow b \times \text{len}(I)$
for $i = 1$ **to** d **do**
 $preds \leftarrow models.predict(I)$
 $g \leftarrow loss(I, preds)$, $w \leftarrow \{1, 1, \dots\}$
 $sorted \leftarrow \text{GetSortedIndices}(abs(g))$
 $topSet \leftarrow sorted[1:topN]$
 $randSet \leftarrow \text{RandomPick}(sorted[topN:\text{len}(I)], randN)$
 $usedSet \leftarrow topSet + randSet$
 $w[randSet] \times = fact$ \triangleright Assign weight $fact$ to the small gradient data.
 $newModel \leftarrow L(I[usedSet], -g[usedSet], w[usedSet])$
 $models.append(newModel)$

3) Exclusive Feature Bundling (EFB)

In a sparse feature space, many features are mutually exclusive, i.e., they never take nonzero values simultaneously. We can safely bundle exclusive features into a single feature (which we call an exclusive feature bundle).

By a carefully designed feature scanning algorithm, we can build the same feature histograms from the feature bundles as those from individual features. In this way, the complexity of histogram building changes from $O(\#data \times \#feature)$ to $O(\#data \times \#bundle)$, while $\#bundle \ll \#feature$. Then we can significantly speed up the training of GBDT without hurting the accuracy.

→ Bundling can be set up with a small recovery rate γ .

Algorithm 3: Greedy Bundling

Input: F : features, K : max conflict count

Construct graph G

$\text{searchOrder} \leftarrow G.\text{sortByDegree}()$

$\text{bundles} \leftarrow \{\}$, $\text{bundlesConflict} \leftarrow \{\}$

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for  $i$  in  $\text{searchOrder}$  do
  needNew  $\leftarrow$  True
  for  $j = 1$  to  $\text{len}(\text{bundles})$  do
    cnt  $\leftarrow$  ConflictCnt( $\text{bundles}[j]$ ,  $F[i]$ )
    if  $\text{cnt} + \text{bundlesConflict}[i] \leq K$  then
      bundles[j].add( $F[i]$ ), needNew  $\leftarrow$  False
      break
  if needNew then
    Add  $F[i]$  as a new bundle to  $\text{bundles}$ 
```

Output: bundles

Algorithm 4: Merge Exclusive Features

Input: numData : number of data

Input: F : One bundle of exclusive features

$\text{binRanges} \leftarrow \{0\}$, $\text{totalBin} \leftarrow 0$

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for  $f$  in  $F$  do
  totalBin +=  $f.\text{numBin}$ 
  binRanges.append(totalBin)
newBin  $\leftarrow$  new Bin( $\text{numData}$ )
for  $i = 1$  to  $\text{numData}$  do
  newBin[i]  $\leftarrow$  0
  for  $j = 1$  to  $\text{len}(F)$  do
    if  $F[j].\text{bin}[i] \neq 0$  then
      newBin[i]  $\leftarrow$   $F[j].\text{bin}[i] + \text{binRanges}[j]$ 
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Output: newBin , binRanges
