Optimizing Ensemble Performance with Condorcet Voting: A Study on Weak Learners for Image Classification

Pedro Cesar Camargo, Leopoldo Lusquino Filho

ICTS - Instituto de Ciência e Tecnologia de Sorocaba

Introduction

This study presents an innovative approach to improve ensemble learning, introducing a modification to the voting rule for aggregating individual classifier results.

While simple majority and weighted majority rules are common, recent research suggests that alternatives, such as the Condorcet voting rule, may offer greater efficiency in complex multi-class image classification tasks

Objectives

To demonstrate the robustness of the Condorcet voting rule in multi-classification tasks and its superior energy efficiency compared to traditional methods.

Methodology

We addressed the Condorcet rule to improve accuracy in multi-classification tasks, surpassing the limitations of traditional rules, especially with weak learners (accuracy < 30%).

We tested with classical neural networks (VGG, ResNet, EfficientNet) and evaluated with models limited to 35 layers and less than 4 million parameters.

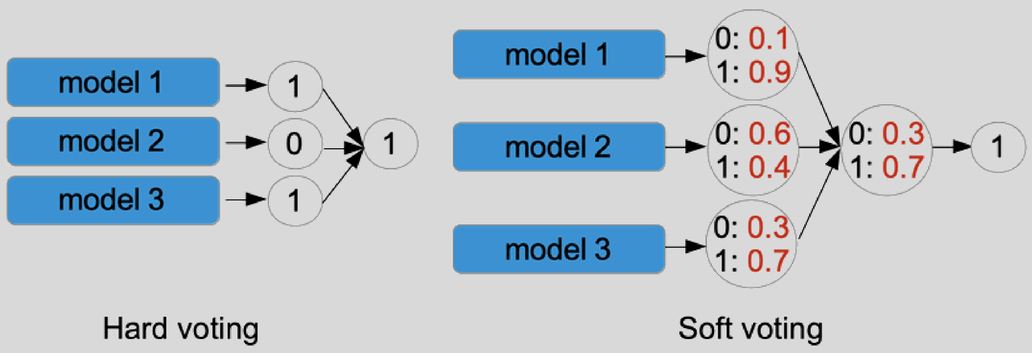

Figure 1: Flowchart indicating how the result of 3 voters is aggregated with the voting rules standard

- a vs b: $n_{ab} = 11, n_{ba} = 10 \Rightarrow a > b$
- a vs c: $n_{ac} = 19, n_{ca} = 2 \Rightarrow a > c$
- b vs c: $n_{bc} = 19, n_{cb} = 2 \Rightarrow b > c$

- $a > b > c$ - 11 voters
- $b > a > c$ - 8 voters
- $c > b > a$ - 2 voters

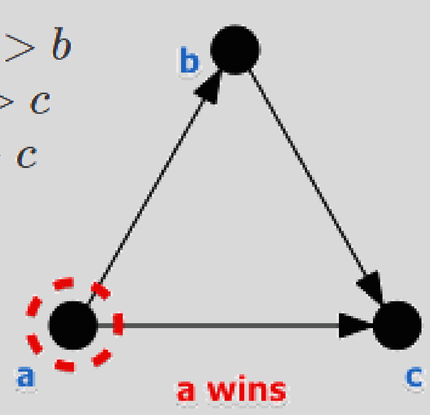

Figure 2: Preference graph that indicates the situation of voters described in the text on the left, showing how a winner is selected by the Condorcet method

Results

Metric	Hard-V	Soft-V	Condorcet-V	Model Average
Accuracy	0.4015	0.4055	**0.4310**	0.2752
Precision	0.4241	**0.4750**	0.4481	0.3049
Recall	0.4015	0.4055	**0.4481**	0.2756
F1-Score	0.3898	0.4133	**0.4394**	0.2846
AUC	0.956	0.956	**0.966**	0.852

Table 1: Comparison of Voting Methods and Model Averages

Result Analysis

The Condorcet rule increased accuracy by up to 14% compared to individual models and outperformed simple and weighted majority rules by 3%. In addition to improving accuracy, it provides greater stability and consistency in scenarios with high variability among classifiers, evaluated on the CIFAR-100 dataset.

The AUC of 0.966 highlights the Condorcet rule's capability to discriminate between classes, offering an optimal balance between sensitivity and specificity in complex multi-classification environments involving 100 classes.

Conclusion

The Condorcet rule improves ensemble accuracy and stability in complex multi-classification environments. It represents a viable alternative for enhancing efficiency in both accuracy and energy consumption, with potential applications in low-resource settings.

References

[1] U, C.; SONG, F.; WANG, Y.; et al. Breast cancer histopathology image classification through assembling multiple compact CNNs. *BMC Medical Informatics and Decision Making* , v. 19, p. 198, 2019. DOI: [10.1186/s12911-019-0913- x] (https://doi.org/10.1186/s12911-019-0913-x).

[2] A Soft-Voting Ensemble Classifier for Detecting Patients Affected by COVID-19 - Scientific Figure on ResearchGate. Available: https://www.researchgate.net/figure/The-figure-shows-with-an-example-how-both-hard-and-softvoting-work-The-ensemble_fig3_362311832. Acessed at: 4 set. 20

[3] WERBIN-OFIR, Havi; DERY, Lihi; SHMUELI, Erez. Beyond majority: Label ranking ensembles based on voting rules. Expert Systems with Applications, v. 136, p. 50-61, 2019. DOI: https://doi.org/10.1016/j.eswa.2019.06.022

[4] ML WIKI. Condorcet's Rule. Available at: http://mlwiki.org/index.php/Condorcet's_Rule. Acessed at: 2 dez. 2024.

[5] Krizhevsky, A. (2009). Learning Multiple Layers of Features from Tiny Images (CIFAR-100 dataset). Retrieved from https://www.cs.toronto.edu/~kriz/cifar.html