The Shapley Value in Machine Learning

Sophie Greenwood · March 7, 2023 · CPSC 532L Presentation

Learning Goals

- Become **familiar with popular ML applications** of the Shapley value
- **Interpret** the Shapley value and its properties in ML contexts
- Recognize the **need for efficient computation** of the Shapley value
- Understand key **properties** of common **estimators / approximations**

Outline

- **Applications** of the Shapley value in machine learning
  - Data Valuation
  - Feature Attribution
  - Additional applications
- Efficient **computation**
- Limitations

Applications of the Shapley value in ML

(Supervised) Machine Learning

Features

Label

Observations

i	Name	Degree	Position	Has dog named Peach?	Cooperate in PD?
1	Ruiyu	MSc	Student	N	N
2	Lironne	MSc	Student	Y	Y
3	Sophie	BSc	Student	N	N
4	Narun	MSc	TA	N	Y
5	Prayus	BSc	Student	N	Y
	Shruthi	MSc	Student	N	?

Data Attribution

Data Attribution

- Identify the **contribution of a data point** to performance
- Applications:
  - Data valuation/pricing
  - Assessing data quality
  - Identifying poisoned or mislabeled data
  - Explaining the model
- Several existing approaches: leave-one-out, influence functions
- Most recently: **data Shapley**

Data Attribution – a coalitional game!

- Players (N): training set
- Characteristic function (v):

$$v(S) = \text{performance of the model trained on } S \subseteq N$$

- Performance
  - measured by log-likelihood, accuracy, …
  - on a test *dataset* or an individual test *data point*

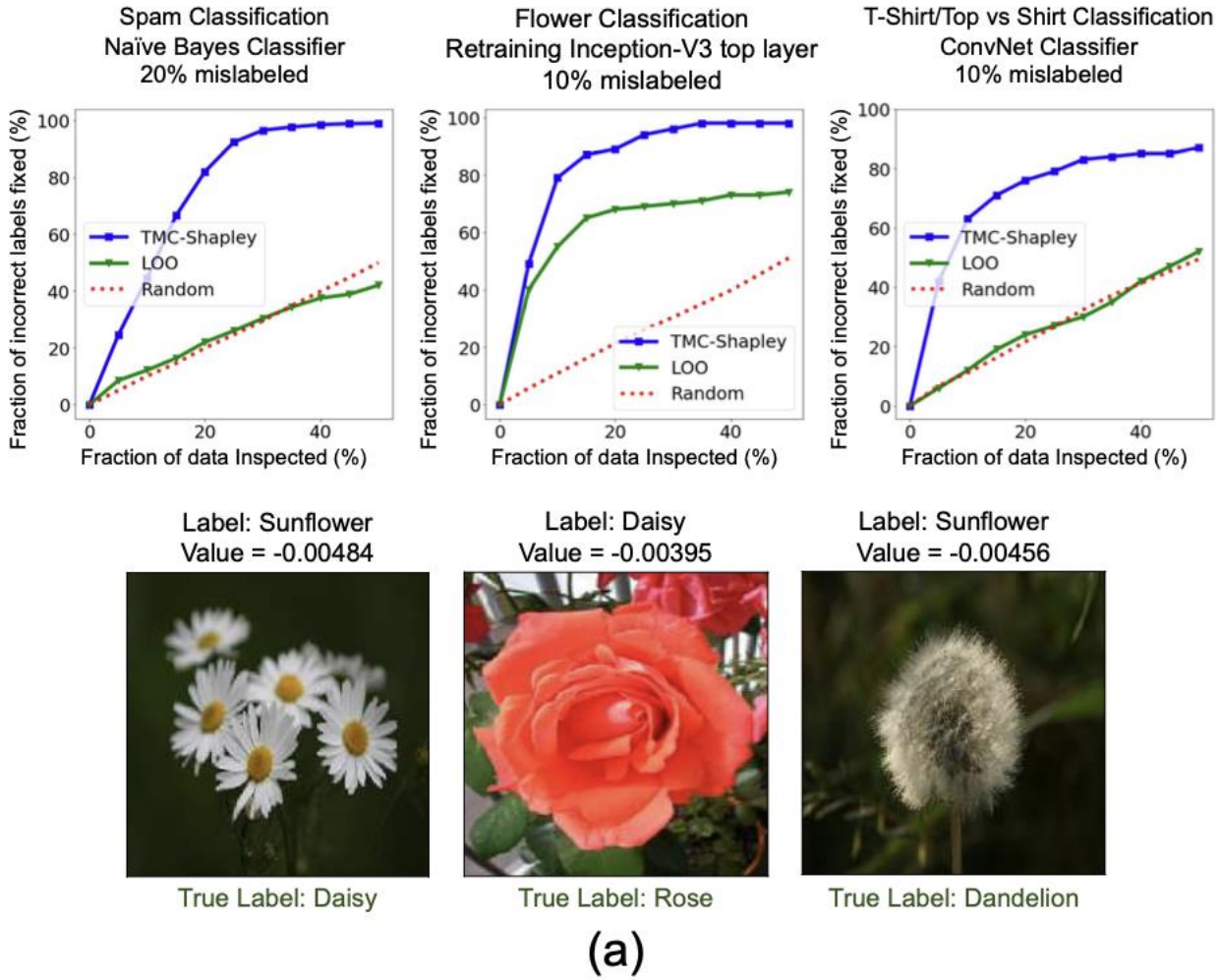
Data Shapley

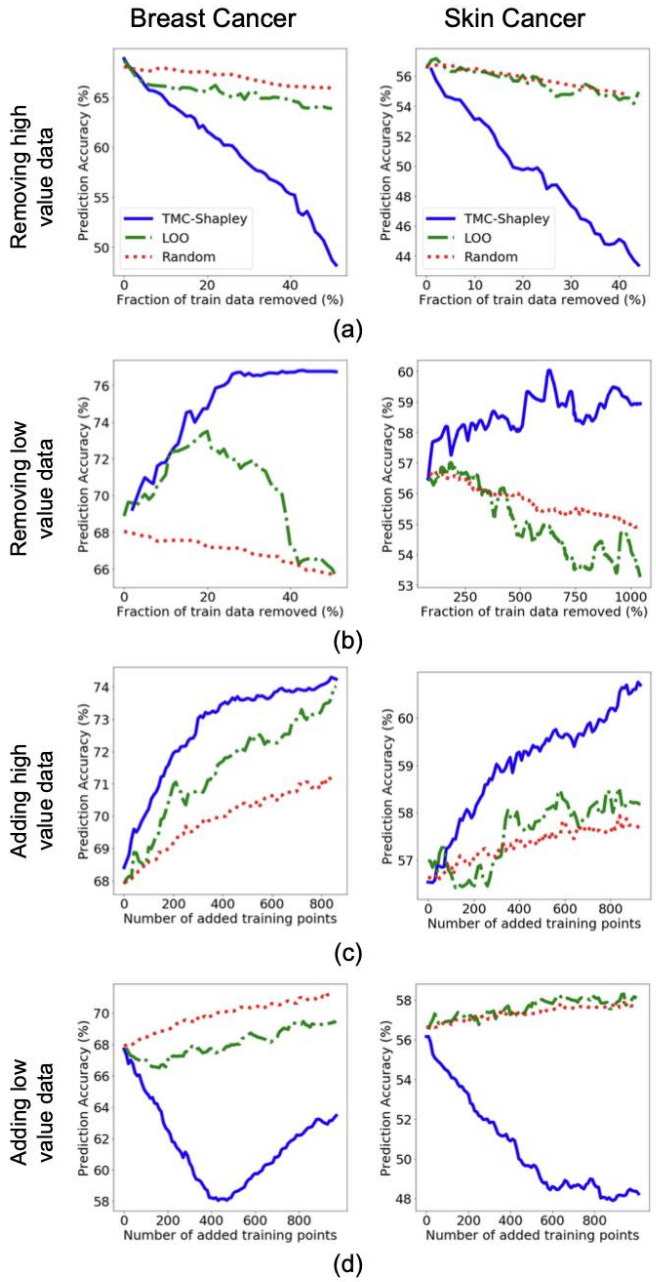
- Desirable **fairness properties**: analogues of Shapley axioms!

- Ex: Points i, j with identical contributions have attributions $\phi_i = \phi_j$

Use the Shapley value to quantify a point's contribution

Data Shapley: Results





Figures from "Data Shapley: Equitable Valuation of Data for Machine Learning" (Ghorbani and Zou 2019)

Other Solution Concepts – Beta Shapley

- Shapley values can be seen as computing

$$\phi_i = \sum_{k=1}^{n} \frac{1}{n} \Delta_i(k)$$

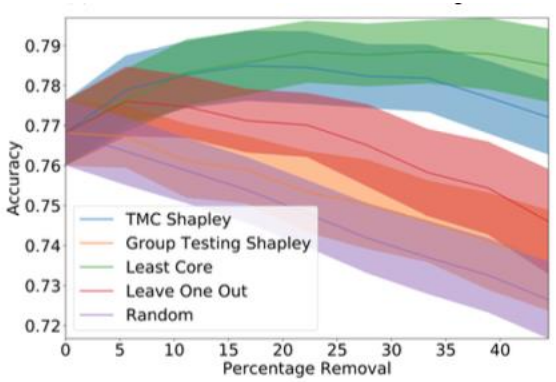
Average marginal contribution among subsets of size k

- **Semi-values:** compute

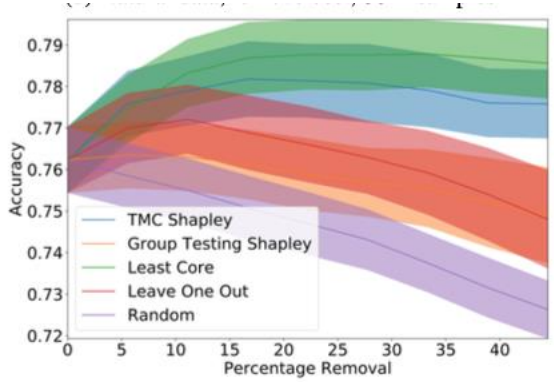
$$\phi_i = \sum_{k=1}^{n} w_k \Delta_i(k)$$

- Satisfy symmetry, dummy player, and additivity!?

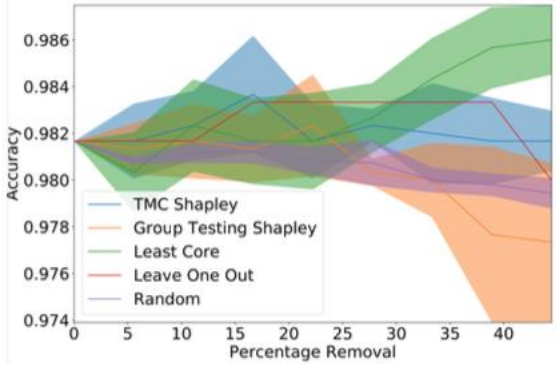
Other Solution Concepts – The Core



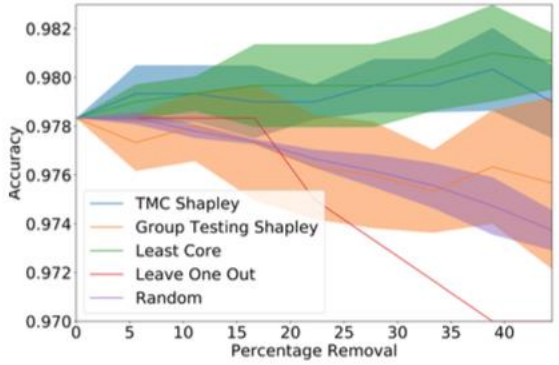
(e) Synthetic data, remove worst, $10K$ samples



(f) Synthetic data, remove worst, $50K$ samples



(g) Natural data, remove worst, $10K$ samples



(h) Natural data, remove worst, $50K$ samples

Figures from "If You Like Shapley Then You'll Love the Core" (Yan and Procaccia 2021)

Feature Attribution

Feature Attribution

- Players: **features** of the data
- Characteristic function:

$$v(S) = \text{performance of the model trained with features } S \subseteq N$$

- Similar axiomatic motivation

- Original application: Feature selection (Cohen 2007)
- Popular application: Interpretable ML (Lundberg and Lee 2017)
  - SHAP: **11,563 citations**

SHAP Applications

Interpretable and accurate fine-grained recognition via region grouping
Z Huang, Y Li - Proceedings of the IEEE/CVF Conference …, 2020 - openaccess.thecvf.com
We present an interpretable deep model for fine-grained visual recognition. At the core of our method lies the integration of region-based part discovery and attribution within a deep …

Interpretable XGBoost-SHAP machine-learning model for shear strength prediction of squat RC walls
DC Feng, WJ Wang, S Mangalathu… - Journal of Structural …, 2021 - ascelibrary.org
RC shear walls are commonly used as lateral load-resisting elements in seismic regions, and the estimation of their shear strengths can become simultaneously design-critical and …

[HTML] Initial whole-genome sequencing and analysis of the host genetic contribution to COVID-19 severity and susceptibility
F Wang, S Huang, R Gao, Y Zhou, C Lai, Z Li, W Xian… - Cell discovery, 2020 - nature.com
The COVID-19 pandemic has accounted for millions of infections and hundreds of thousand deaths worldwide in a short-time period. The patients demonstrate a great diversity in …

Additional Applications

Other applications

- Multi-agent RL
- Ensemble pruning
- Federated learning
- Other topics in explainable AI

Efficient Computation

Food for thought

- Data valuation:
  - Dataset size: 10 points
  - How many **models** do we need to **train**?

Food for thought

- Data valuation:
  - Dataset size: 10 points
  - How many **models** do we need to **train**?

- Need to estimate **efficiently** and **accurately**

Monte Carlo Sampling

- Sample permutation, update the Shapley values, repeat
- Many variations on this (restricted, stratified sampling, etc.)
- For fixed number of iterations, $O(|N|)$

Linear Regression

- **Trick:** SV is the solution to a weighted linear regression problem
- Find an approximate (biased) estimator in $O(|N|)$
- Unbiased estimator exists, but has **high variance**

Other

- Multilinear Extension
- Structure-specific (e.g. Voting game approximation)
- ML-specific (e.g., Gradient Shapley)
- …

Discussion & Conclusion

Limitations

- Shapley value axioms don’t necessarily hold when approximated
- Sometimes produce **incorrect results**
- More **ordinal** than **cardinal**

Conclusion

- The Shapley value is a **powerful tool** in a variety of ML problems
  - Guarantees fair solutions
  - Excellent performance in practice

- Other solution concepts are less widespread but promising

- Wide array of algorithms exist for efficient computation

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