Duke UNIVERSITY

Yale SCHOOL OF MANAGEMENT

NEURAL INFORMATION PROCESSING SYSTEMS

Improving Decision Sparsity

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Sparsity is important for interpretability

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The Magical Number Seven, Plus or Minus Two

18 languages

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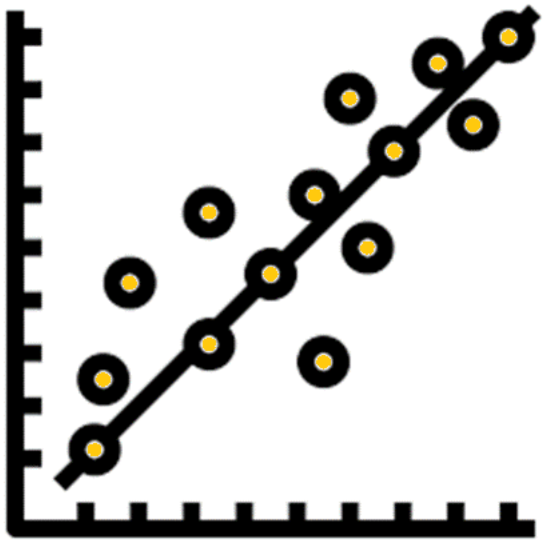
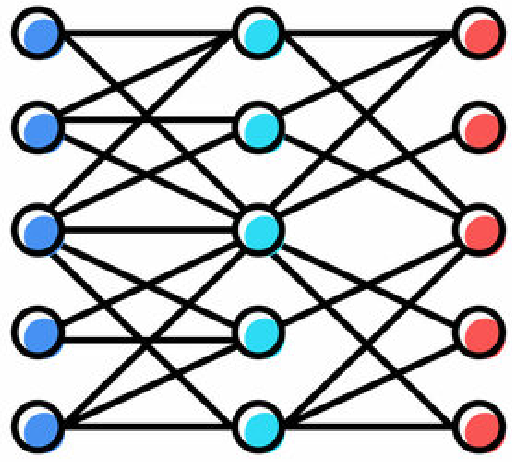
"**The Magical Number Seven, Plus or Minus Two: Some Limits on Our Capacity for Processing Information**"[1] is one of the most highly cited papers in psychology.[2][3][4] It was written by the cognitive psychologist George A. Miller of Harvard University's Department of Psychology and published in 1956 in *Psychological Review*. It is often interpreted to argue that the number of objects an average human can hold in short-term memory is 7 ± 2. This has occasionally been referred to as *Miller's law*.[5][6][7]

Common metrics for evaluating sparsity of the model



# of terms
in linear regressions

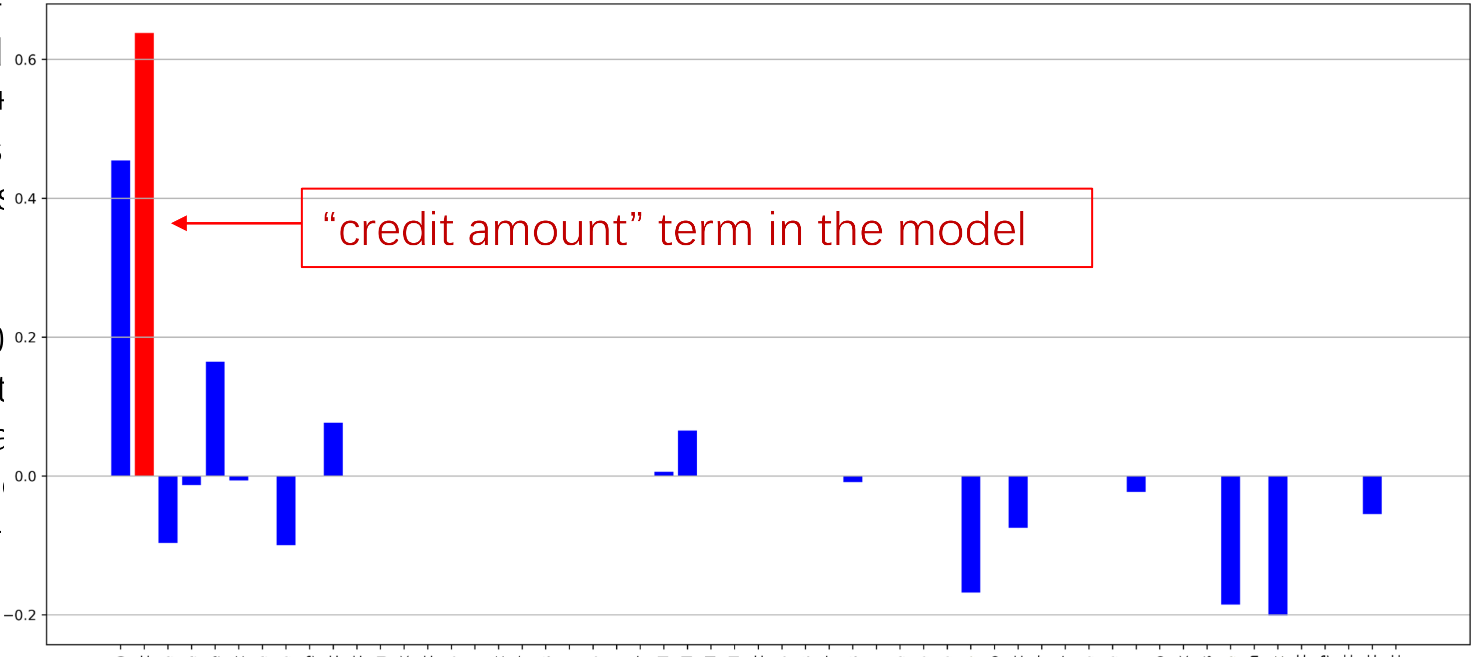
# of leaf nodes
in decision trees



# of parameters
in neural networks

This is not a sparse model.

(duration(month))*0.21+(credit_amount)*0.33+(installment_rate)*0.13+(present_residence_since)*-0.01+(age)*-0.11 +(number_of_credit)*0.03 +(number_of_people_being_liable)*-0.01 +(provide_maintenance)*-0.09+(telephone)*-0.07 +(check_acocunt_existence=0-200DM)*0.06 +(checking account = none)*0.35 +(credit_history=all_credit)*0.08 +(credit_history=critical_account)*-0.19
+(credit_history=delay_in_paying)*0.01 +
+(purpose=business)*0.02+(purpose=ed ... ɔose=others)*-
0.01 +(purpose=radio/television)*-0.12 +
+(saving_account=100-500DM)*0.02 +(s
+(saving_account=>=1000DM)*-0.04 +(s
+(present_employment=4-7years)*-0.11
+(present_employment=unemployed)*0. ... ed_male)*0.03
+(personal_status_sex=married_male)*-0 ... ɔtors=co-
applicant)*0.02 +(other_debtors=guarant ... te)*-0.13
+(property=unknown)*0.04 +(other_insta ... stores)*0.03
+(housing=free)*0.0 +(housing=doesn't ...).06
+(job=unemployed_non-resident)*-0.0+



Why was Arun's loan application denied?

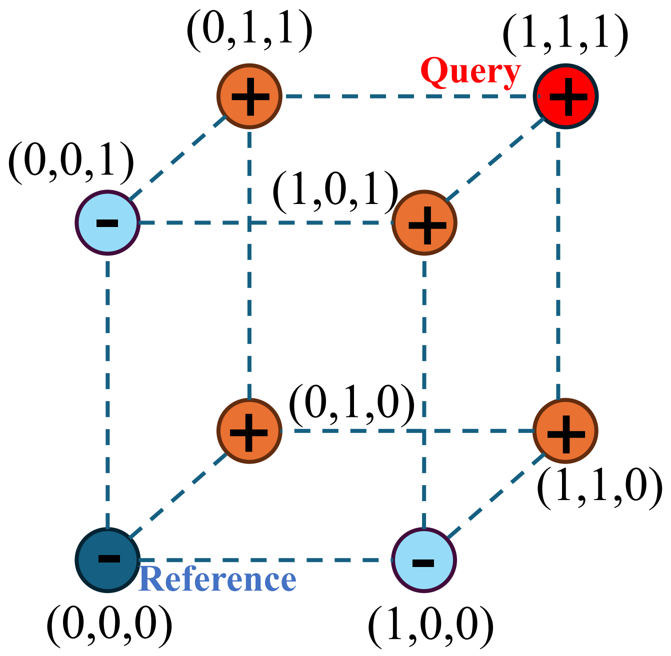
The prediction is determined by *one feature*!

He asked for over $10K!

Recap of Decision Sparsity: SEV$^-$

- Step 1: Define reference (usually either **0** or average of negative class)

- Step 2: Define Boolean hypercube for query ***x***:
  - coordinate$_j$ is 1 if feature j is x_j
  - coordinate$_j$ is 0 if feature j is at reference value r_j

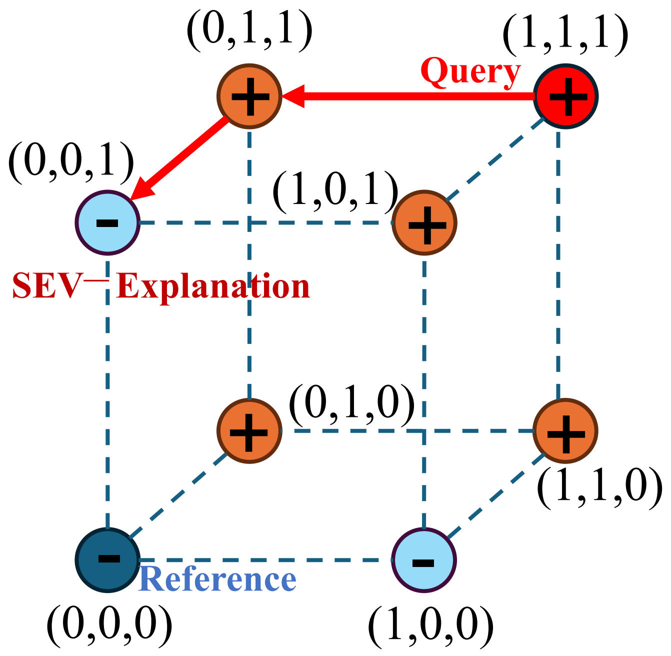


Recap of Explanation Sparsity: SEV^{-}

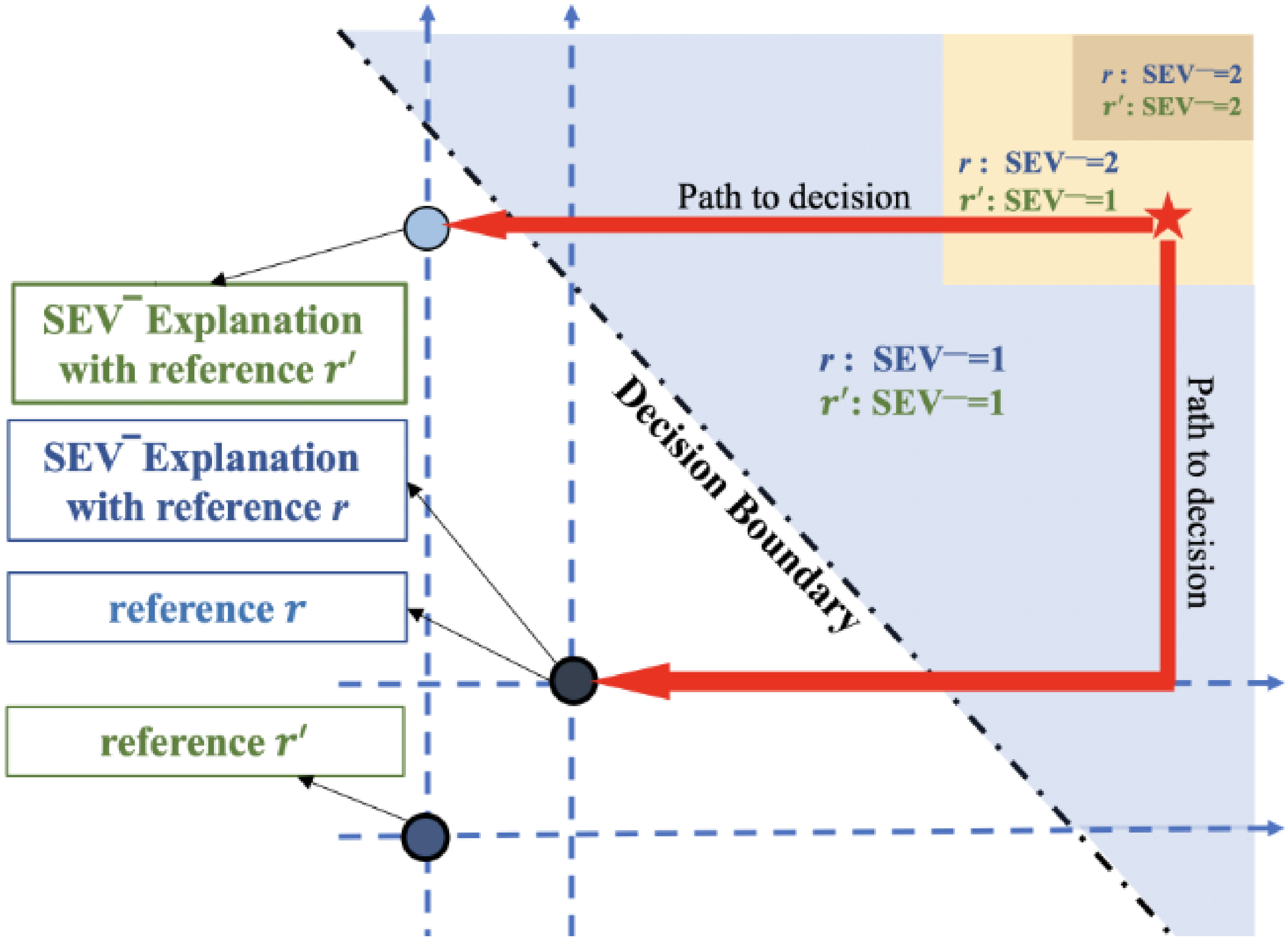
- Step 1: Define reference (usually either **0** or average of negative class)

- Step 2: Define Boolean hypercube for query $\boldsymbol{x}$:
  - coordinate$_j$ is 1 if feature j is x_j
  - coordinate$_j$ is 0 if feature j is at reference value r_j

- Step 3: Define SEV^{-} for $\boldsymbol{x}$. Moving from $\boldsymbol{x}$ towards reference, SEV^{-} is the minimum l_0 distance to a negative label.



SEV⁻ is sensitive to the reference selection



Selection criteria for references

Reference and Query are under the same subpopulations

Minimum number of features used for explaining decisions

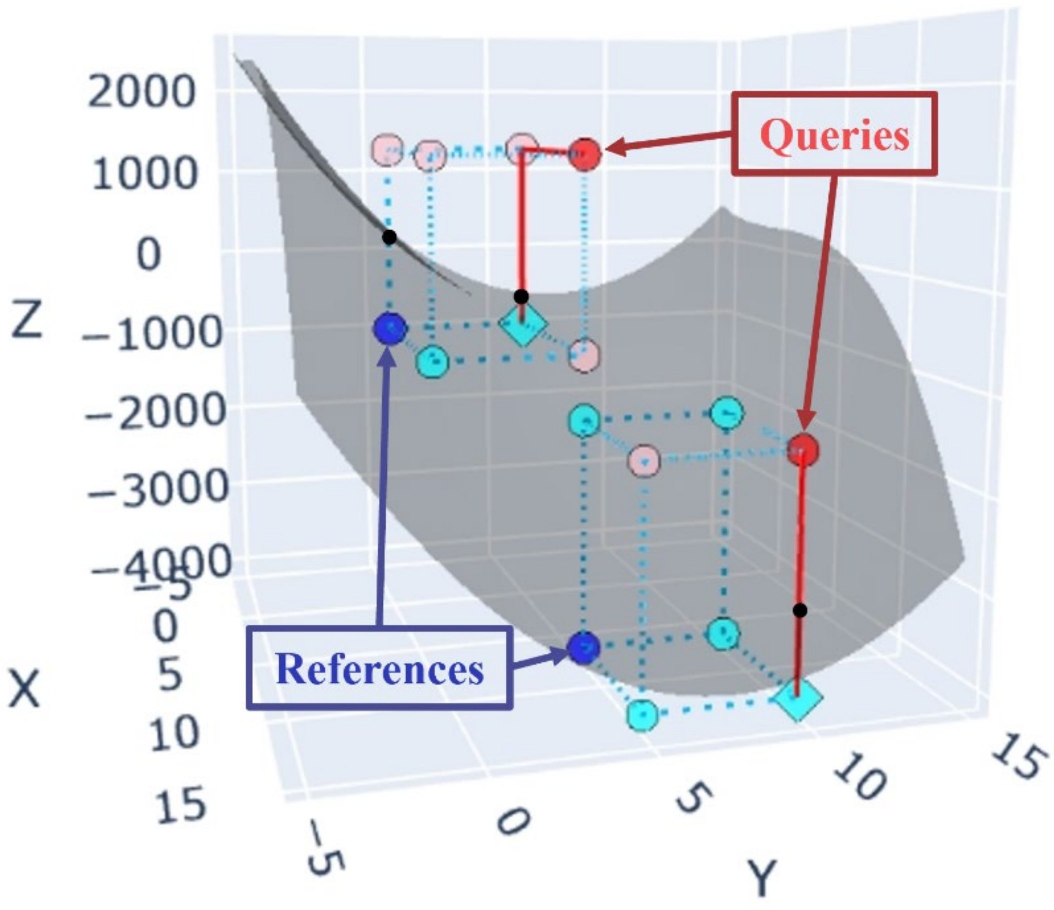
$$\|\boldsymbol{x}_i - \boldsymbol{r}_i\|, \boldsymbol{r}_i \in \mathcal{R} \quad \text{(Closeness)}$$

$$\text{SEV}^-(f, \boldsymbol{x}_i, \boldsymbol{r}_i), \boldsymbol{r}_i \in \mathcal{R} \quad \text{(Sparsity)}$$

$$-P(\boldsymbol{x}_i^{\text{expl},\boldsymbol{r}_i} | X^-) \quad \text{(Negated Credibility)}$$

Sparse explanations are under the original data distribution

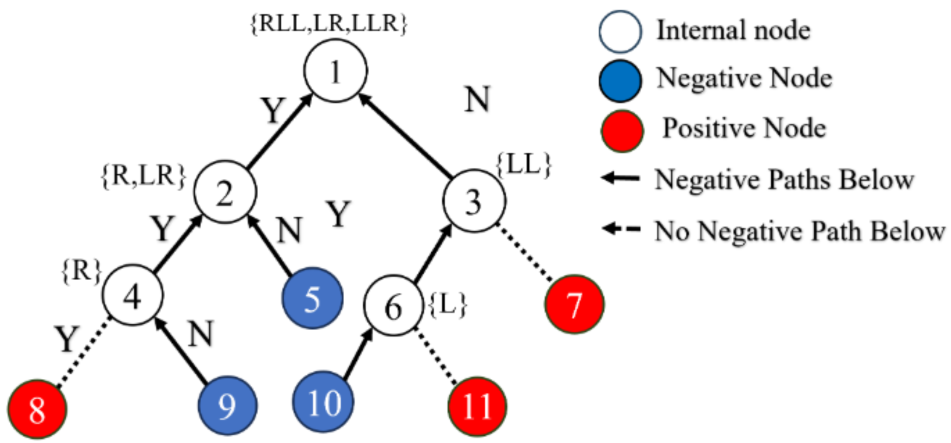
Improving Closeness: Cluster-based SEV (SEV-C)



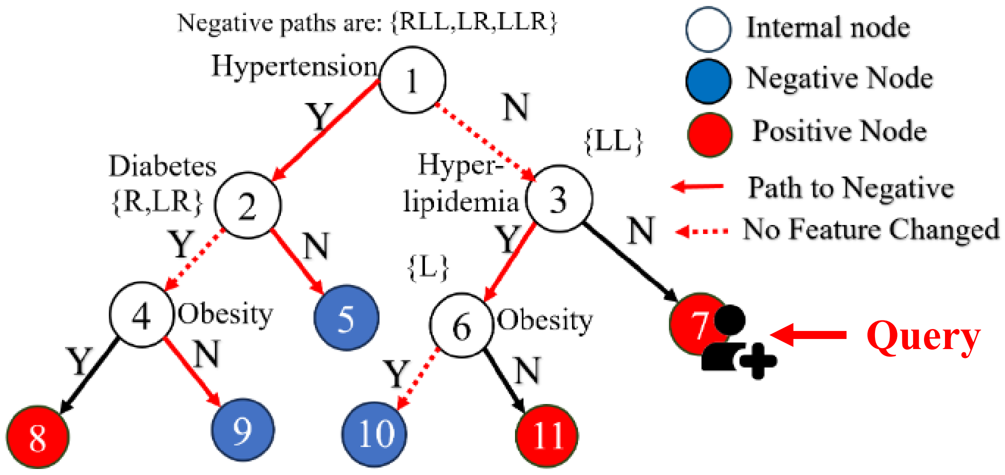
The process for calculating the SEV-C:

- **Step 1:** Selects the references by clustering the negative populations, and regarding the cluster centroid points as the references.
- **Step 2:** Assign each query their closest cluster centroid as their reference points.
- **Step 3:** Go over the original SEV Calculation

Special case for SEV-C: Tree-based SEV



Step 1: SEV-T Preprocessing: Collect negative leaf node information for each internal nodes



Step 2: Efficient SEV-T Calculation: Go over internal node of decision path, and check all negative paths

It have many useful properties and computational benefits!

Optimizing SEV Variants for Models

Gradient-based Optimization (AllOpt)

- Maximize the fraction of points with $SEV^{-}=1$

Search-based Optimization (TOpt)

- Find a model with the lowest SEV with in a set of classification models with the best performance

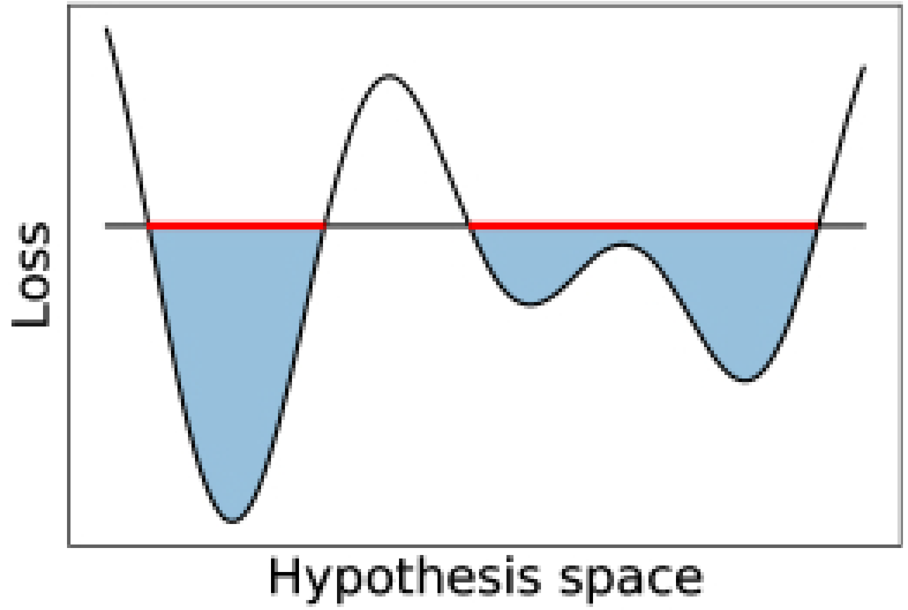
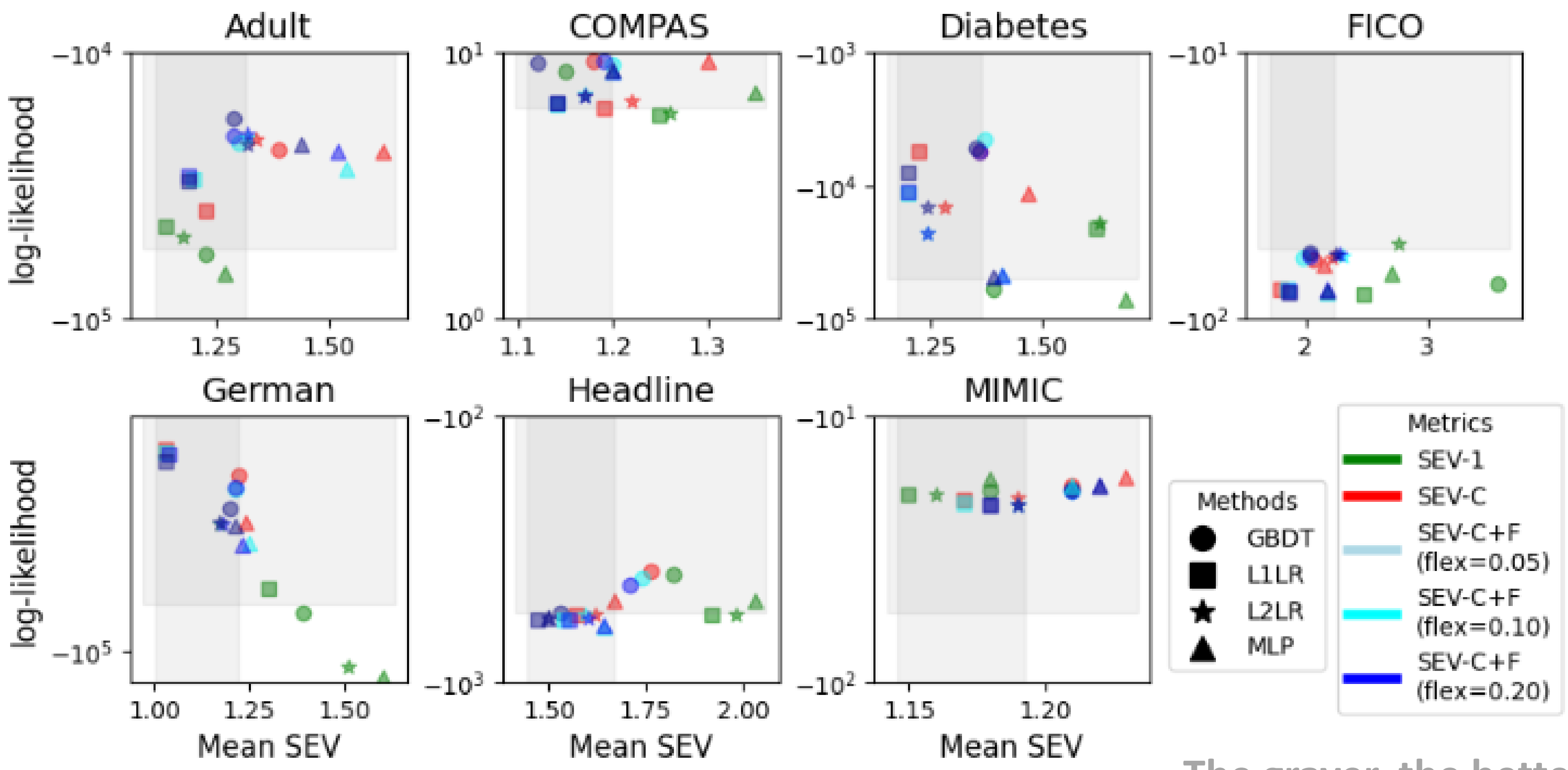


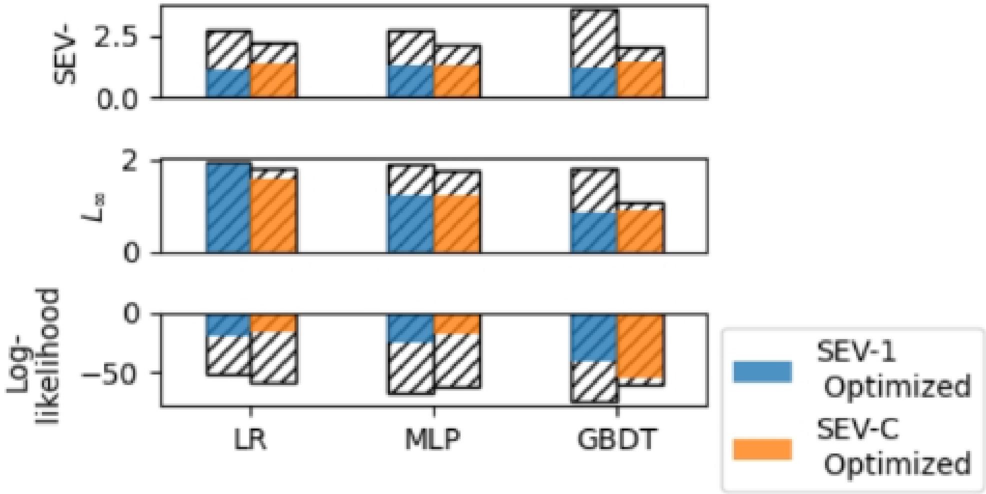
Figure 1: Rashomon Sets

SEV-C improves in credibility and closeness



The grayer, the better.

Optimization improves explanations while preserving model performance



(a) All-Opt^{-} Performance

	Train Acc	Test Acc	Mean SEV^{T}
CART	0.71 ± 0.01	0.71 ± 0.01	1.10 ± 0.03
C4.5	0.71 ± 0.01	0.71 ± 0.01	1.13 ± 0.05
GOSDT	0.70 ± 0.01	0.70 ± 0.01	1.08 ± 0.02
TOpt	0.70 ± 0.01	0.70 ± 0.01	$\boxed{1.00 \pm 0.00}$

(b) SEV^{T} performance on different tree-based models

The model performance are not changed before and after optimization

More in the paper

- SEV Variants for further improving the sparsity and credibility of the explanations.
- Sparsity and Credibility comparison with counterfactual explanation methods.
- Score-based soft K-Means for avoiding positive predicted references
- Detailed Algorithms for tree-based SEV
- Timing experiments
- …

SEV Paper NeurIPS Paper