Interpretable Rules in Relaxed Logical Form

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ML algorithms continue to permeate critical application domains

- medicine
- legal
- transportation
- ...

It becomes increasingly important to

- understand ML decisions
- interact with ML solutions

Interpretability has become a central thread in ML research

ML predictions in the form of **rules** are arguably more interpretable.

- Decision lists
- Decision trees
- Decision rules (CNF/DNF)

CNF/DNF Formula

- A CNF (Conjunctive Normal Form) formula is a conjunction of clauses where each clause is a disjunction of literals
- A DNF (Disjunctive Normal Form) formula is a disjunction of clauses where each clause is a conjunction of literals
- Example
  - CNF: $(a \vee b \vee c) \wedge (d \vee e)$
  - DNF: $(a \wedge b \wedge c) \vee (d \wedge e)$

Example of CNF classification rules

A sample is Iris Versicolor if
(sepal length > 6.3 **OR** sepal width > 3 **OR** petal width ≤ 1.5)
AND
(sepal width ≤ 2.7 **OR** petal length > 4 **OR** petal width > 1.2)
AND
(petal length ≤ 5)

Key Contribution

- generalize the widely popular CNF rules
- introduce relaxed-CNF rules

Definition of Relaxed-CNF formula

- Relaxed-CNF formula has two extra parameters η_l and η_c
- A clause is satisfied if at least η_l literals are satisfied
- A formula is satisfied if at least η_c clauses are satisfied

more restriction on literals, less restriction on clauses

Relaxed-CNF rule for Breast Cancer Prediction

Tumor is diagnosed as malignant if,

$[($ smoothness $\geq 0.089 +$ standard error of area ≥ 53.78

$+$ largest radius $\geq 18.225) \geq \mathbf{2}]$

$+$

$[(98.76 \leq$ perimeter $< 114.8 +$ largest smoothness $\geq$

$0.136 + 105.95 \leq$ largest perimeter $< 117.45) \geq \mathbf{2}] \geq \mathbf{1}$

Benefit of Relaxed-CNF

- Relaxed-CNF is more succinct than CNF
- Relaxed-CNF has similar interpretability/expressiveness as CNF
- Smaller relaxed-CNF rules reach the same level of accuracy compared to plain CNF/DNF rules and decision lists

IRR: **I**nterpretable **R**ules in **R**elaxed Form

- We formulate an Integer Linear Program (ILP) for learning relaxed rules
- We incorporate incremental learning in ILP formulation to achieve scalability

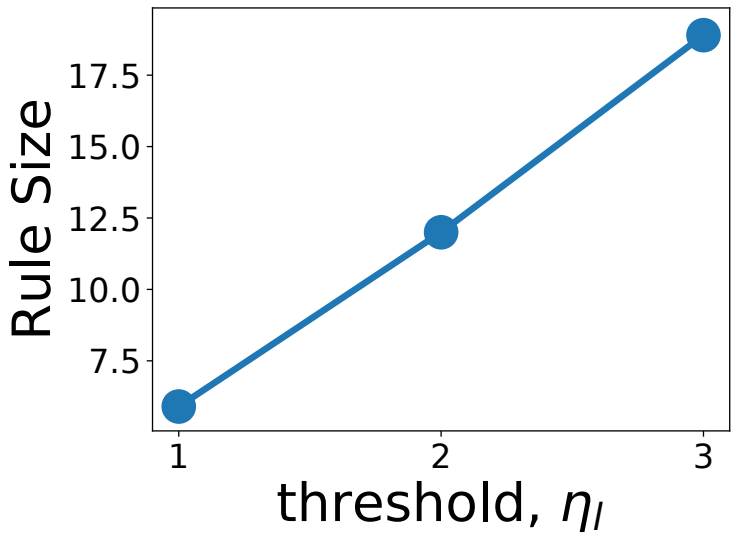
Accuracy of relaxed-CNF rules and other classifiers

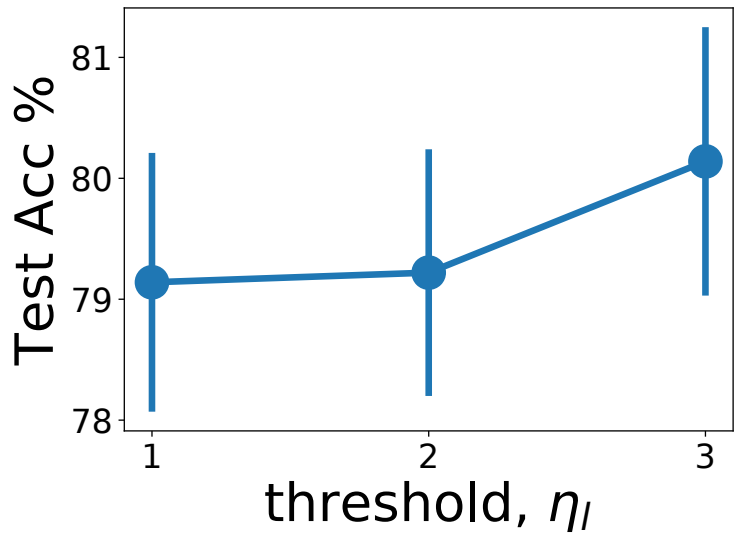
Dataset	Size	Features	NN	SVC	RF	RIPPER	BRS	IMLI	**IRR**	**inc-IRR**
Heart	303	31	83.6	85.48	83.87	81.59	80.65	80.65	**86.65**	86.44
WDBC	569	88	96.49	98.23	96.49	96.49	**97.35**	96.46	97.34	96.49
ILPD	583	14	71.56	71.19	71.19	72.41	66.67	71.31	69.57	**74.14**
Pima	768	30	79.22	77.13	78.57	77.27	77.92	74.51	**78.57**	77.27
Tic Tac Toe	958	27	87.5	98.44	99.47	98.44	**100**	82.72	84.37	84.46
Titanic	1309	26	77.1	78.54	79.01	78.63	77.78	79.01	**81.22**	78.63
Tom's HW	28179	910	—	97.6	97.46	**97.6**	—	96.01	97.34	96.52
Credit	30000	110	80.69	82.17	82.12	82.13	—	81.75	**82.15**	81.94
Adult	32561	144	84.72	87.19	86.98	84.89	—	83.63	**85.23**	83.14
Twitter	49999	1511	—	—	96.48	**96.14**	—	94.57	95.44	93.22

Rule-size of different interpretable models

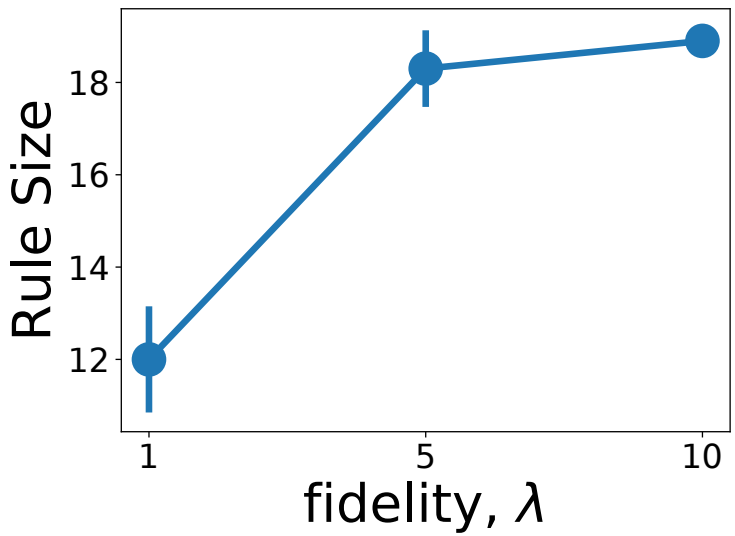
Dataset	RIPPER	BRS	IMLI	inc-IRR
Heart	**7**	35.5	14	19.5
WDBC	**7**	18	11	10
ILPD	5	3	5	**2**
Pima	**8**	**8**	15	21.5
Tic Tac Toe	25	24	**11.5**	12
Titanic	5	**2**	7	12.5
Tom's HW	16.5	—	32	**5.5**
Credit	33	—	9	**3**
Adult	106	—	35.5	**13**
Twitter	56	—	67.5	**7**

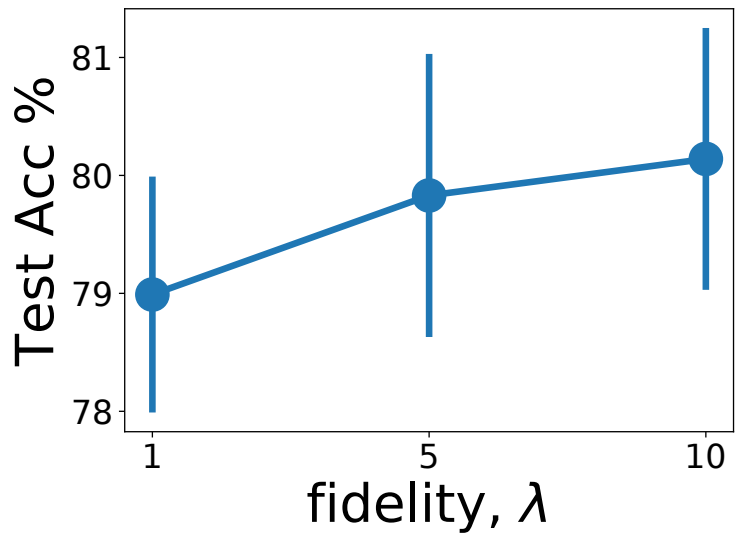
Effect of threshold parameter



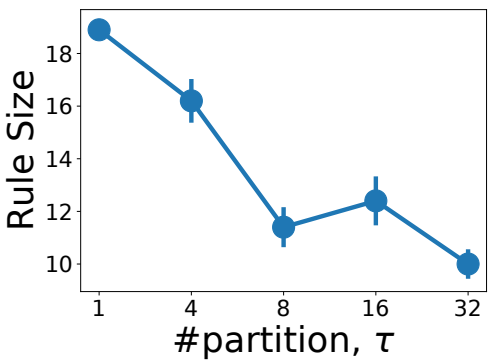


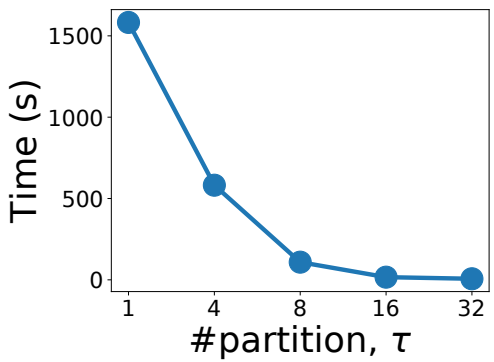
Effect of data-fidelity parameter

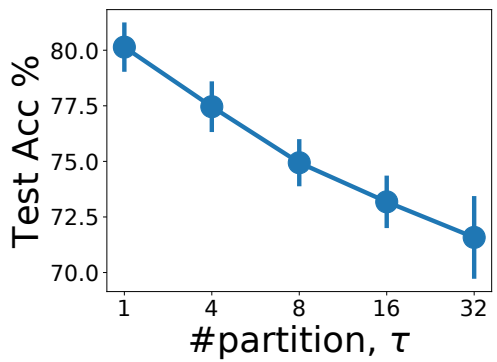




Effect of partitioning







Conclusion

- Relaxed-CNF rules allow increased flexibility to fit data
- The size of relaxed-CNF rule is less for larger datasets, indicating higher interpretability
- Relaxed-CNF rule can be applied to various applications, for example checklists