



# Splitting Stump Forests: Tree Ensemble Compression for Edge Devices

Fouad Alkhoury and Pascal Welke

Discovery Science 2024 – October 15<sup>th</sup>

Partner institutions:



Institutionally funded by:



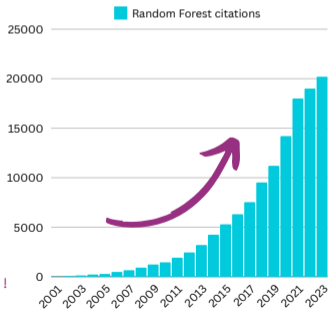
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138,466  
citations

4th  
most cited machine  
learning paper ever!!



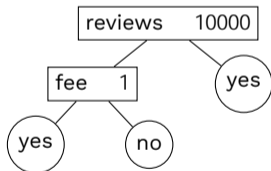
## Decision Trees

place	distance	fee	reviews	rating	visit
Pisa Tower	1.3	20	160800	4.7	yes
Cattedrale di Pisa	1.3	8	10923	4.8	yes
Palazzo blu	1.2	5	5205	4.6	no
Tuttomondo	1.8	0	2422	4.6	yes
Botanical Garden	1.0	4	3752	4.4	no
Piazza dei Cavalieri	0.8	0	10534	4.5	yes



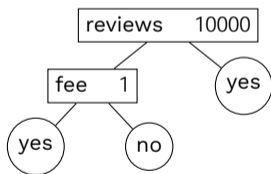
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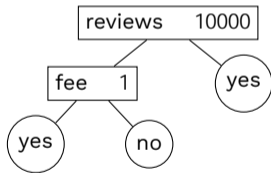
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✓ Interpretable and fast

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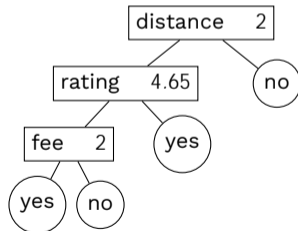
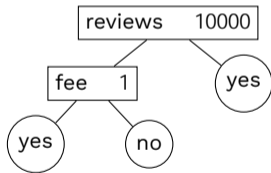
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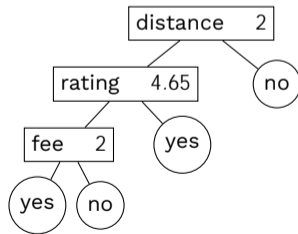
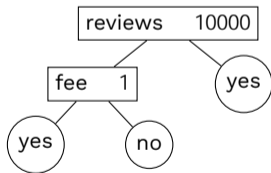
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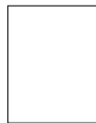
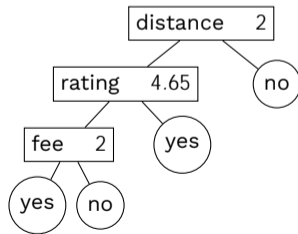
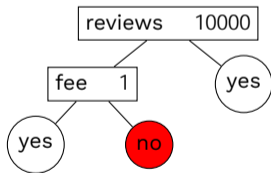
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Battistero	1.4	8	3047	4.7	?



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## Decision Trees

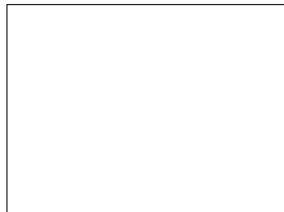
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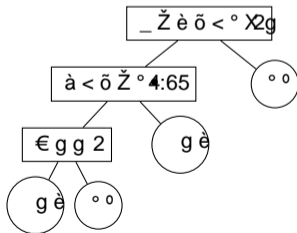
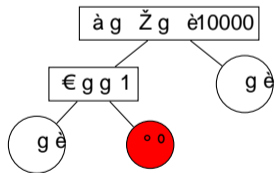
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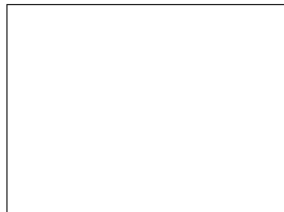


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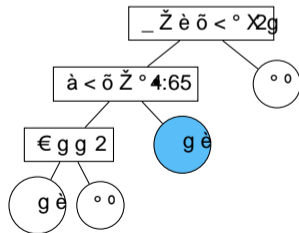
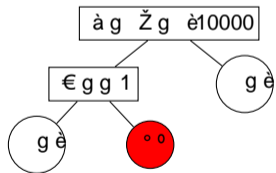


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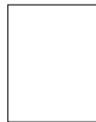
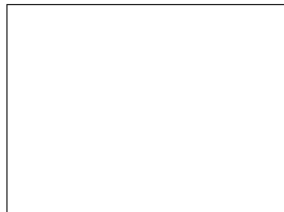


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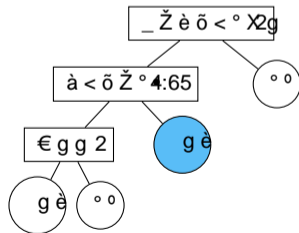
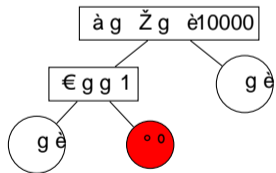


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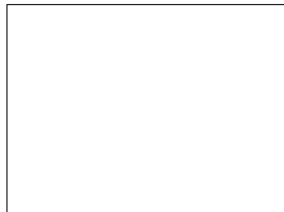


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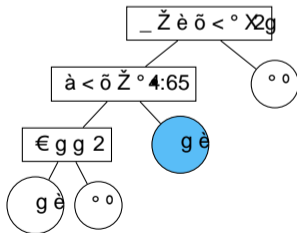
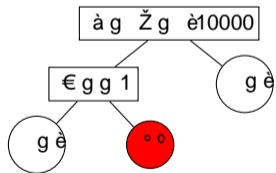
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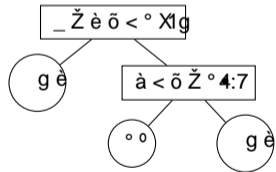
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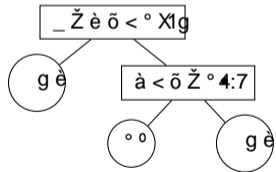
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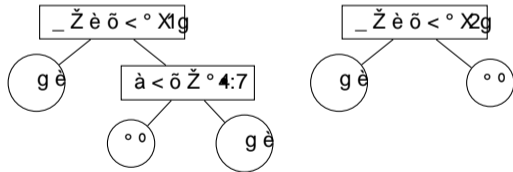
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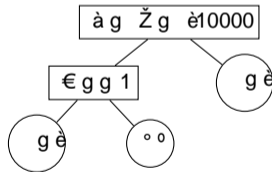
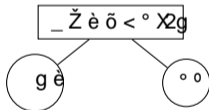
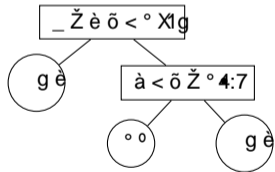
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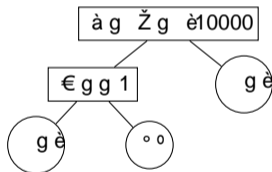
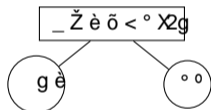
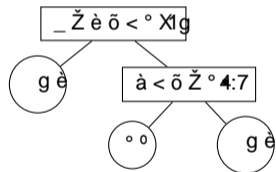
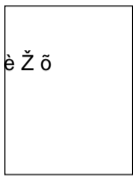


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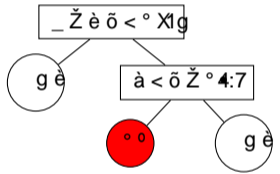
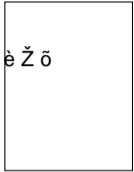


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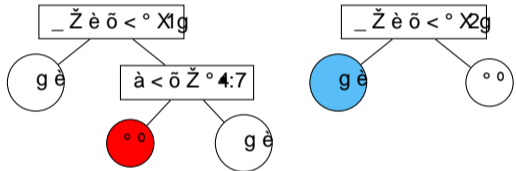
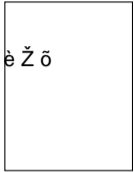


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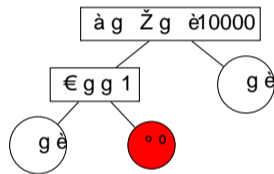
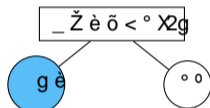
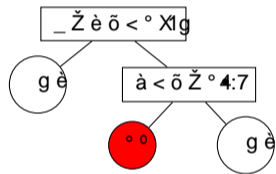
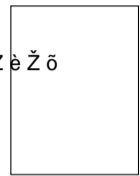
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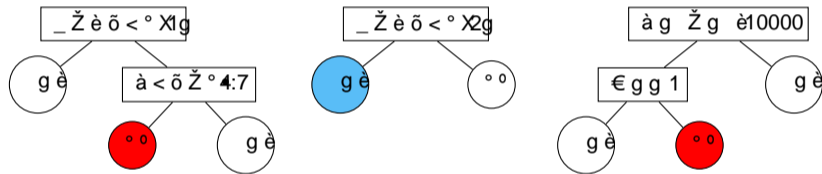
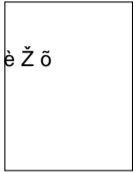
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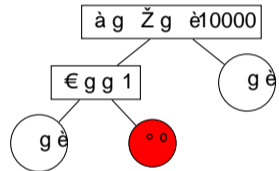
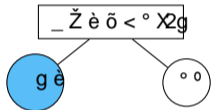
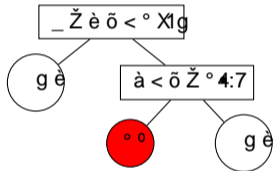
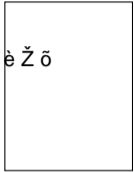


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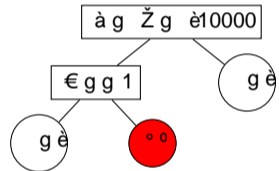
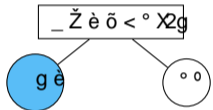
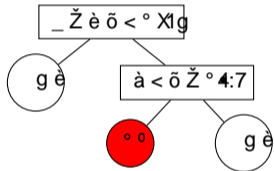
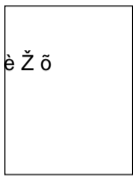
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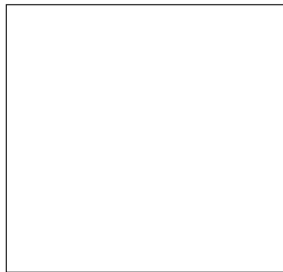
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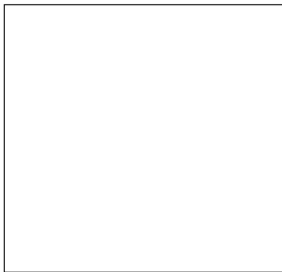
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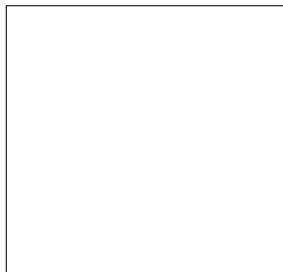
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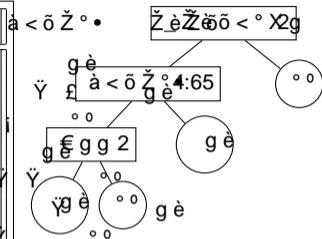
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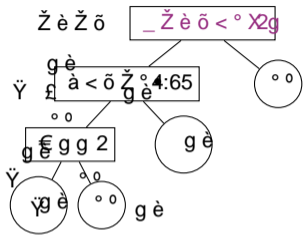
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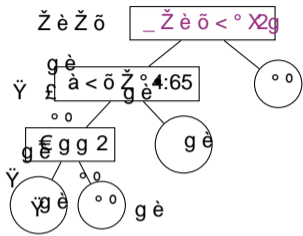
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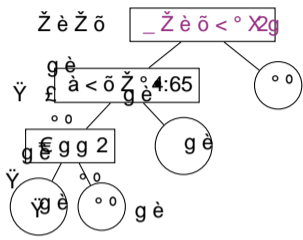


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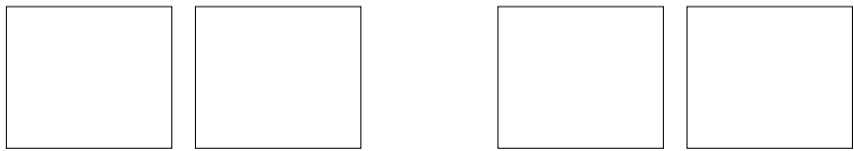
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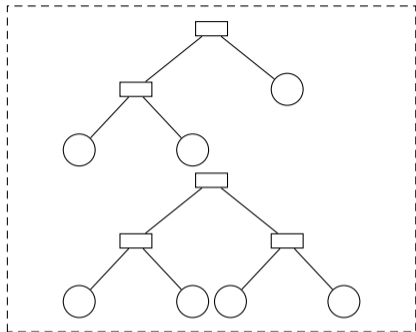
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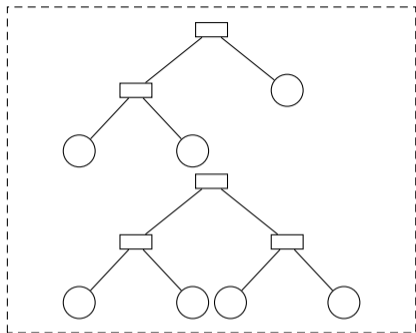
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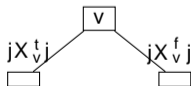
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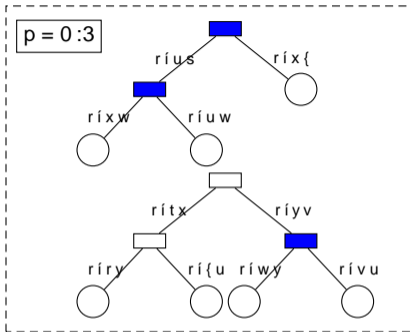
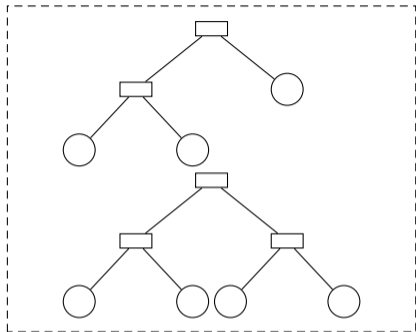
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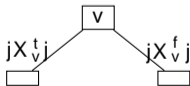
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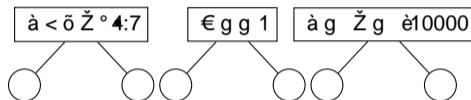
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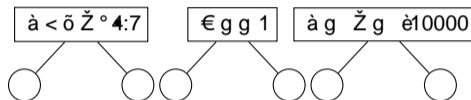
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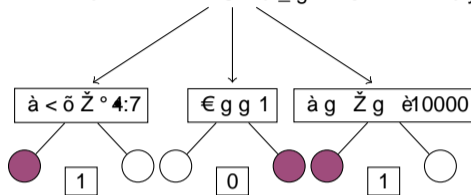
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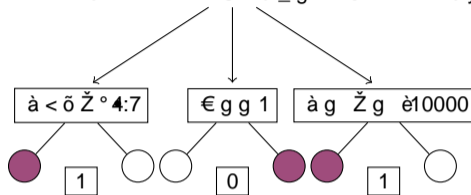


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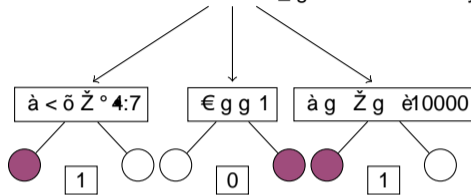
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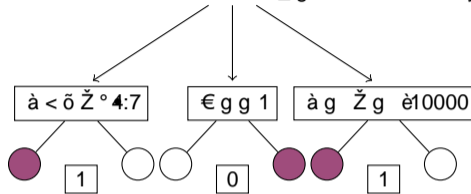
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$$(f_{F \circ}(x); y) = (f 1; 0; 1g; 0)$$



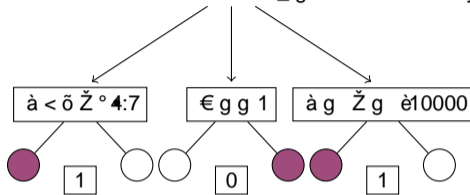
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÷\$gm°g <®<ÝÝŽ°• €f\_F°X®Ž!P 0;1g<sup>k</sup>

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$$(f_F \circ(x); y) = (f 1; 0; 1g; 0)$$

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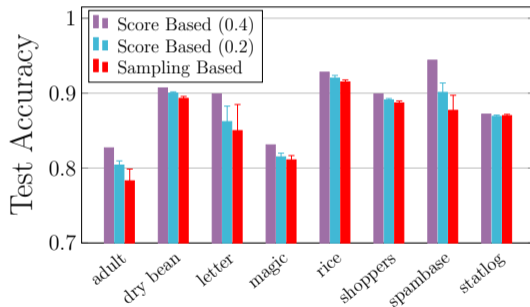
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# Experiments

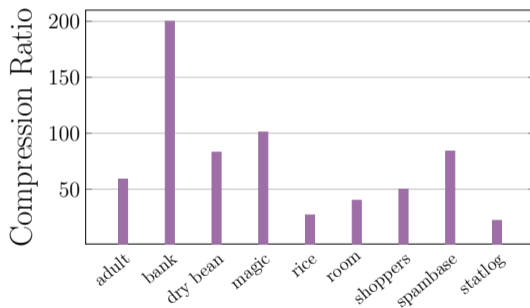
- The selected splitting nodes are informative and not accidental.



# Experiments



- The compression rate achieved while permitting a 2% accuracy drop.



# Experiments



- Splitting Stump Forests outperform competitive methods.

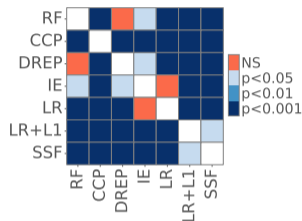
Method		$d = 5$	$d = 10$	$d = 15$	Global
RF (Random Forest)	Acc.	5	4.69	3.23	4.31
	Size	7	7	7	7
	Inf.	6.08	5.46	5.46	5.67
CCP (Cost Complexity Pruning)	Acc.	6.46	6.62	6.85	6.64
	Size	4	2.38	1.85	2.74
	Inf.	4.69	3.54	3.46	3.90
DREP (Diversity Regularized Ensemble Pruning, 2012)	Acc.	4.23	3.62	3.69	3.85
	Size	3.62	4.69	5	4.44
	Inf.	3.07	3.08	2.85	3
IE (Individual Error, 2017)	Acc.	4	3.23	3.38	3.54
	Size	3.69	4.54	5.08	4.43
	Inf.	2.92	3.23	2.92	3.03
LR (Leaf Refinement, 2015)	Acc.	2.69	3.15	4.38	3.41
	Size	5.23	4.77	4.85	4.95
	Inf.	4.92	6.77	6.69	6.13
LR+L1 (Joint Leaf Refinement, 2023)	Acc.	2.23	2.77	2.69	2.56
	Size	3.38	3.46	3	3.28
	Inf.	6	4.85	5.15	5.33
<b>SSF</b>	Acc.	<b>2</b>	<b>2.38</b>	<b>2.39</b>	<b>2.26</b>
	Size	<b>1.23</b>	<b>1.15</b>	<b>1.30</b>	<b>1.23</b>
	Inf.	<b>1.69</b>	<b>1.69</b>	<b>1.92</b>	<b>1.77</b>

# Experiments

- Splitting Stump Forests outperform competitive methods.



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# Conclusion



# Conclusion



- Splitting Stump Forests extract balanced splitting nodes.

# Conclusion



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- Large Random Forest is compressed into a compact model without sacrificing accuracy.

# Conclusion



- Splitting Stump Forests extract balanced splitting nodes.
- Large Random Forest is compressed into a compact model without sacrificing accuracy.
- The compressed models are suited for resource-constrained edge devices.



LAMARR

INSTITUTE FOR  
MACHINE LEARNING  
AND ARTIFICIAL  
INTELLIGENCE

”Like the leaning Tower of Pisa, the Splitting Stump Forests find strength in balance”

Contact: [alkhoury@iai.uni-bonn.de](mailto:alkhoury@iai.uni-bonn.de)

Partner institutions:



Institutionally funded by:



Ministerium für  
Kultur und Wissenschaft  
des Landes Nordrhein-Westfalen





Dataset	16 KB							32 KB						
	RF	CCP	DREP	IE	LR	LRL1	SSF	RF	CCP	DREP	IE	LR	LRL1	SSF
adult	82	81.9	80.5	82.9	84.4	85.7	<b>86.1</b>	85.1	82.3	83.4	84.3	85.9	<b>86.2</b>	86.1
	$\pm 0.4$	$\pm 0.3$	$\pm 0.2$	$\pm 0.6$	$\pm 0.4$	$\pm 0.3$	$\pm 0.3$	$\pm 0.3$	$\pm 0.4$	$\pm 0.4$	$\pm 0.5$	$\pm 0.3$	$\pm 0.3$	$\pm 0.3$
aloi	96.7	96.2	96.9	96.9	96.1	97.0	<b>97.1</b>	96.8	96.2	96.9	97	96.1	<b>97.1</b>	<b>97.1</b>
	$\pm 0.4$	$\pm 0.1$	$\pm 0.1$	$\pm 0.1$	$\pm 0.1$	$\pm 0.1$	$\pm 0.1$	$\pm 0.1$	$\pm 0.1$	$\pm 0.1$	$\pm 0.1$	$\pm 0.1$	$\pm 0.1$	$\pm 0.1$
bank	89.9	88.9	89.8	89.7	90.0	<b>90.2</b>	90.1	90	88.9	89.8	89.7	90.1	<b>90.4</b>	90.1
	$\pm 0.1$	$\pm 0.5$	$\pm 0.1$	$\pm 0.1$	$\pm 0.3$	$\pm 0.3$	$\pm 0.2$	$\pm 0.1$	$\pm 0.3$	$\pm 0.1$	$\pm 0.1$	$\pm 0.2$	$\pm 0.2$	$\pm 0.1$
credit	81	80.7	80.8	81.1	<b>81.4</b>	81.1	81.1	80.9	80.7	81	81.3	<b>81.4</b>	80.9	81.2
	$\pm 0.2$	$\pm 0.3$	$\pm 0.1$	$\pm 0.2$	$\pm 0.3$	$\pm 0.1$	$\pm 0.2$	$\pm 0.1$	$\pm 0.2$	$\pm 0.1$	$\pm 0.1$	$\pm 0.2$	$\pm 0.1$	$\pm 0.1$
dry bean	88.1	85.4	89.1	88.7	89.2	<b>91.8</b>	91.4	87.9	87.4	89.3	89.9	89.4	<b>91.8</b>	91.4
	$\pm 0.7$	$\pm 0.3$	$\pm 0.1$	$\pm 0.3$	$\pm 0.3$	$\pm 0.1$	$\pm 0.4$	$\pm 1.0$	$\pm 0.4$	$\pm 0.5$	$\pm 0.6$	$\pm 0.5$	$\pm 0.3$	$\pm 0.4$
letter	62.5	64.3	62.6	62.1	62.9	76.3	<b>93.0</b>	63.3	61.2	65.9	65.8	78.2	71.4	<b>93.0</b>
	$\pm 2.2$	$\pm 1.1$	$\pm 0.9$	$\pm 1.2$	$\pm 0.9$	$\pm 0.9$	$\pm 1.7$	$\pm 3.6$	$\pm 1.4$	$\pm 1.0$	$\pm 1.7$	$\pm 1.5$	$\pm 1.4$	$\pm 1.9$
magic	84.9	83.2	83.7	84.2	84.9	85.8	<b>86.3</b>	86	83.5	83.8	83.9	86.1	<b>86.5</b>	86.3
	$\pm 0.5$	$\pm 0.9$	$\pm 0.5$	$\pm 0.5$	$\pm 0.01$	$\pm 0.2$	$\pm 0.7$	$\pm 0.7$	$\pm 0.7$	$\pm 0.3$	$\pm 0.5$	$\pm 0.6$	$\pm 0.2$	$\pm 0.4$
rice	92.5	93.7	93.1	0.93	93.2	93.5	<b>93.8</b>	93.4	93.7	93.6	93.5	93.2	93.5	<b>93.8</b>
	$\pm 0.6$	$\pm 0.7$	$\pm 0.3$	$\pm 0.4$	$\pm 0.7$	$\pm 0.1$	$\pm 0.1$	$\pm 0.7$	$\pm 0.5$	$\pm 0.2$	$\pm 0.3$	$\pm 0.6$	$\pm 0.1$	$\pm 0.1$
room	99.2	97.0	99.5	99.6	99.2	99.8	<b>99.9</b>	99.5	99.3	99.7	<b>99.9</b>	99.2	99.8	<b>99.9</b>
	$\pm 0.3$	$\pm 0.4$	$\pm 0.1$	$\pm 0.2$	$\pm 0.6$	$\pm 0.2$	$\pm 0.2$	$\pm 0.1$	$\pm 0.2$	$\pm 0.1$	$\pm 0.2$	$\pm 0.3$	$\pm 0.1$	$\pm 0.1$
shoppers	87.2	86.9	90.1	91.0	<b>91.6</b>	91.3	90.7	90.2	86.9	90.3	91.2	91.6	<b>91.3</b>	90.7
	$\pm 1.5$	$\pm 0.6$	$\pm 0.3$	$\pm 0.2$	$\pm 0.4$	$\pm 0.3$	$\pm 0.4$	$\pm 1.2$	$\pm 0.2$	$\pm 0.4$	$\pm 0.1$	$\pm 0.4$	$\pm 0.2$	$\pm 0.2$
spambase	90.8	91.3	90.9	92.4	91.6	92.7	<b>95.3</b>	91.1	91.7	92.9	92.4	94.3	93.2	<b>95.3</b>
	$\pm 0.6$	$\pm 0.4$	$\pm 0.2$	$\pm 1.0$	$\pm 0.5$	$\pm 0.2$	$\pm 0.4$	$\pm 0.6$	$\pm 0.6$	$\pm 0.6$	$\pm 1.2$	$\pm 0.4$	$\pm 0.2$	$\pm 0.2$
statlog	85.2	84.1	84.7	84.8	84.9	86.5	<b>87.4</b>	85.1	84.9	84.8	84.7	87.1	<b>87.9</b>	87.4
	$\pm 1.6$	$\pm 1.0$	$\pm 0.4$	$\pm 0.4$	$\pm 0.8$	$\pm 0.2$	$\pm 0.3$	$\pm 0.8$	$\pm 0.6$	$\pm 0.7$	$\pm 0.6$	$\pm 0.5$	$\pm 0.2$	$\pm 0.1$
waveform	96.9	95.1	96.9	96.9	96.9	97.0	<b>97.1</b>	96.6	95.1	97	97	96.9	<b>97.2</b>	97.1
	$\pm 0.2$	$\pm 0.2$	$\pm 0.1$	$\pm 0.1$	$\pm 0.3$	$\pm 0.1$	$\pm 0.1$	$\pm 0.2$	$\pm 0.1$	$\pm 0.1$	$\pm 0.1$	$\pm 0.2$	$\pm 0.1$	$\pm 0.1$
avg rank	4.79	5.86	4.79	4.17	3.94	2.09	<b>1.54</b>	4.72	6.32	4.45	4.28	3.51	2.1	<b>1.88</b>