Generalized additive models via direct optimization of regularized decision stump forests

Table 1. Train and test RMSE, model size (number of parameters) and training time (average ± standard deviation over 5 runs) for different GAMs. N refers to the dataset size, D is the feature dimension. Green color is the best test error, and blue is the second best.

Dataset		ORSF	GB	EBM	Splines	NAM	FLAM	FastSparse
Cpuact	train	2.12±0.01	2.20±0.04	2.19±0.02	2.53±0.02	3.38±0.26	2.88±0.01	2.76±0.03
N=8.2k	test	2.37±0.03	2.43±0.06	2.50±0.05	2.69±0.06	3.41±0.28	2.99±0.05	2.91±0.17
D=21	size	642±0	3.4k±133	16.6k±36	271±3	134k±0	77.9k±123	119±4
	time (s)	~~184±25~~ 9.4±0.3	46±17	39±2	37±0.03	99±1	85±2	3.8±0.5
Wine	train $\times 10^{-2}$	65.70±0.15	68.13±0.27	66.73±0.27	67.99±0.29	74.40±0.16	67.39±0.21	68.01±0.25
N=6.5k	test $\times 10^{-2}$	70.02±0.66	70.92±0.51	70.12±0.39	71.79±1.40	76.07±2.11	70.19±0.84	71.77±0.63
D=11	size	724±12	770±32	3.9k±11	197±7	70.1k±0	5041±11	182±4
	time (s)	~~64±3~~ 6.0±0.3	2.87±0.58	4.44±1.33	56±16	64±0	53±3	0.57±0.07
Housing	train $\times 10^{-2}$	51.84±0.16	54.24±0.27	52.70±0.04	53.37±0.21	71.56±0.30	55.08±0.20	54.62±0.20
N=21k	test $\times 10^{-2}$	54.80±0.65	56.15±0.58	55.23±0.68	55.49±0.61	72.23±0.88	56.24±0.74	56.29±0.65
D=8	size	1.4k±20	2.4k±31	7.2k±8	528±2	51.0k±0	118k±101	579±9
	time (s)	~~600±140~~ 13.6±0.4	42±8	36±2	37±2	175±2	73±2	3.94±0.73
Diamond	train $\times 10^{2}$	9.95±0.02	10.07±0.05	10.11±0.03	10.02±0.02	13.53±0.22	11.75±0.03	10.01±0.02
N=54k	test $\times 10^{2}$	10.15±0.08	10.19±0.08	10.23±0.06	10.96±1.45	13.59±0.25	11.70±0.12	10.17±0.09
D=26	size	934±16	1182±81	3.4k±7	273±24	86k±0	4139±12	516±11
	time (s)	~~648±20~~ 25.1±0.9	140±58	20±2	42±0.4	708±2	805±11	45±10
Year	train	9.12±0.03	9.30±0.03	7.53±0.02	9.14±0.03	10.22±0.05		9.14±0.03
N=423k	test	9.30±0.01	9.35±0.00	9.82±0.02	9.38±0.03	10.22±0.08	out of time	9.29±0.01
D=90	size	1379±0.8	1490±25	368k±0	2158±55	573k±0	> 2 days	2601±63
	time (s)	~~9681±205~~ 1402±43	4368±256	4262±437	3618±45	8858±88		973±65
FPS	train	55.40±0.09	55.48±0.09	55.42±0.09	55.41±0.09	56.23±0.10		55.41±0.09
N=401k	test	55.41±0.34	55.45±0.34	55.42±0.34	55.42±0.34	55.62±0.24	out of time	55.42±0.34
D=100	size	983±37	824±57	2372±12	411±1	288k±0	> 2 days	1250±17
	time (s)	~~6010±314~~ 798±21	1803±466	655±84	2043±2	4397±10		625±10

Dataset	λ	Train Error	Test Error	Leaves	Depth	Time
diamond	0.001	out-of-time				
diamond	0.005	out-of-time				
diamond	0.01	2615.15	2741.46	5	5	273.13
diamond	0.05	2806.17	2857.79	2	2	0.70
housing	0.001	0.83	0.96	42	9	0.62
housing	0.005	0.91	0.93	8	5	0.28
housing	0.01	0.90	0.95	5	4	0.20
housing	0.05	0.96	0.99	2	2	0.12
wine	0.001	0.60	0.89	120	11	29.20
wine	0.005	0.72	0.83	26	10	7.87
wine	0.01	0.80	0.80	5	4	2.68
wine	0.05	0.79	0.82	2	2	0.17
cpuact	0.001	out-of-time				
cpuact	0.005	out-of-time				
cpuact	0.01	8.58	19.50	24	11	1658.88
cpuact	0.05	12.39	16.19	8	7	11.03

Dataset	Alpha	Train Error	Test Error	Leaves	Depth	Time
bank	0.001		out-of-time			
bank	0.005		out-of-time			
bank	0.01		out-of-time			
bank	0.05	12.50	11.16	1	1	0.07
fico	0.001		out-of-time			
fico	0.005		out-of-time			
fico	0.01	30.40	30.35	2	2	363.54
fico	0.05	30.40	30.74	2	2	0.65
ijcnn	0.001	6.70	10.27	27	9	18.01
ijcnn	0.005	10.90	9.84	1	1	1.61
ijcnn	0.01	9.40	9.84	1	1	0.12
ijcnn	0.05	9.10	9.84	1	1	0.05
letter	0.001	10.30	23.72	88	12	1272.58
letter	0.005	22.40	25.85	10	6	166.80
letter	0.01	29.70	33.85	4	4	41.59
letter	0.05	33.20	34.08	2	2	0.19
telco	0.001		out-of-time			
telco	0.005		out-of-time			
telco	0.01		out-of-time			
telco	0.05	29.40	26.23	1	1	0.53

Table 2. As in Table 1 but for classification datasets. The error is a 0/1 misclassification (%).

Dataset		ORSF	GB	EBM	Splines	NAM	FLAM	FastSparse
Letter	train	15.94±0.14	16.38±0.17	16.12±0.20	15.87±0.14	21.54±1.1	17.94±0.18	15.88±0.14
N=20k	test	16.40±0.52	16.88±0.41	16.63±0.42	16.55±0.70	22.53±1.88	17.95±0.51	16.57±0.67
D=16	size	403±13	420±15	502±2	224±1	68k±0	510±2	399±5
	time (s)	~~150±9~~ 14.9±0.2	32±3	31±1	58±2	153±0	71±1	18±2
Churn	train	18.88±0.19	19.00±0.23	18.84±0.08	18.78±0.15	22.59±2.13	19.85±0.18	18.88±0.11
N=7.0k	test	19.28±0.29	19.32±0.37	19.47±0.51	19.32±0.48	21.69±2.02	20.30±0.88	19.87±0.36
D=45	size	129±5	644±48	7292±11	40±0.04	120k±0	13.7k±15	105±8
	time (s)	~~36±8~~ 6.8±0.4	3±1	15±1	0.5±0.03	120±2	113±2	0.59±0.07
FICO	train	24.86±0.13	26.54±0.15	26.37±0.10	26.79±0.15	28.23±0.41	27.15±0.21	25.87±0.16
N=10k	test	27.33±0.04	27.62±0.30	27.43±0.31	27.35±0.17	28.08±0.61	27.64±0.52	27.80±0.33
D=23	size	550±28	1002±66	3680±9	83±1	130k±0	3791±11	196±10
	time (s)	~~231±18~~ 7.8±0.1	1.6±0.6	7±0.2	1.96±0.10	180±1	61±1	1.74±0.12
IJCNN	train	4.42±0.05	4.56±0.07	4.51±0.03	4.44±0.04	7.51±0.44	6.86±0.08	4.84±0.16
N=50k	test	4.95±0.14	5.10±0.15	5.00±0.14	4.92±0.20	7.48±0.55	7.14±0.15	5.52±0.21
D=22	size	414±23	918±21	12.3k±0	266±0.5	101k±0	828k±242	883±18
	time (s)	~~1090±200~~ 46±1	148±24	19±0	153±40	501±1	249±6	47±1
Covtype	train	22.50±0.03	22.56±0.02	22.46±0.02	22.48±0.02	26.16±0.50		22.49±0.02
N=581k	test	22.71±0.11	22.77±0.10	22.68±0.12	22.72±0.10	26.08±0.54	out of time	22.68±0.10
D=54	size	504±4	1090±32	6402±4	403±1	170k±0	> 2 days	841±15
	time (s)	~~4354±32~~ 1091±16	1202±49	325±5	15624±84	5373±16		2763±177
Bank	train	9.81±0.04	10.00±0.03	9.75±0.05	9.79±0.04	10.09±0.08	11.27±0.04	9.79±0.04
N=41k	test	9.83±0.17	9.99±0.13	9.91±0.17	9.88±0.12	9.87±0.26	11.23±0.15	9.86±0.14
D=62	size	231±4	530±15	1103±7	95±2	174k±0	1182±1	64±4
	time (s)	~~153±11~~ 47±2	34±7	40±3	22±2	662±10	916±3	19.6±3.3

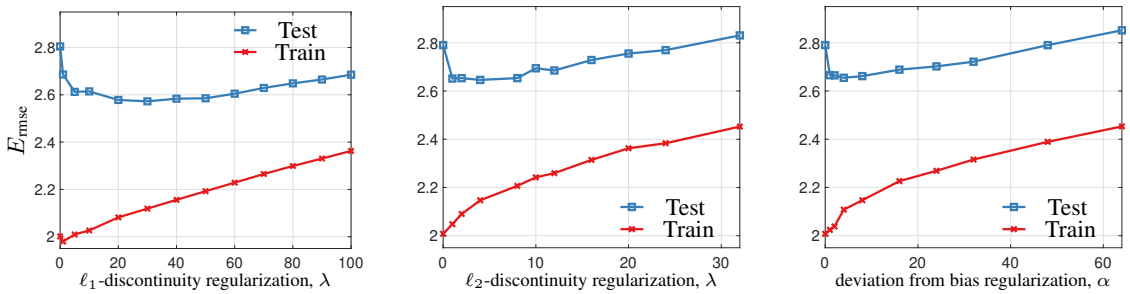

Figure 1. The effect of different regularization types in stump forests for the cpuact dataset. The number of stumps $T = 200$. For our final method we use the combination of ℓ_1-discontinuity and the deviation from the bias regularizations.

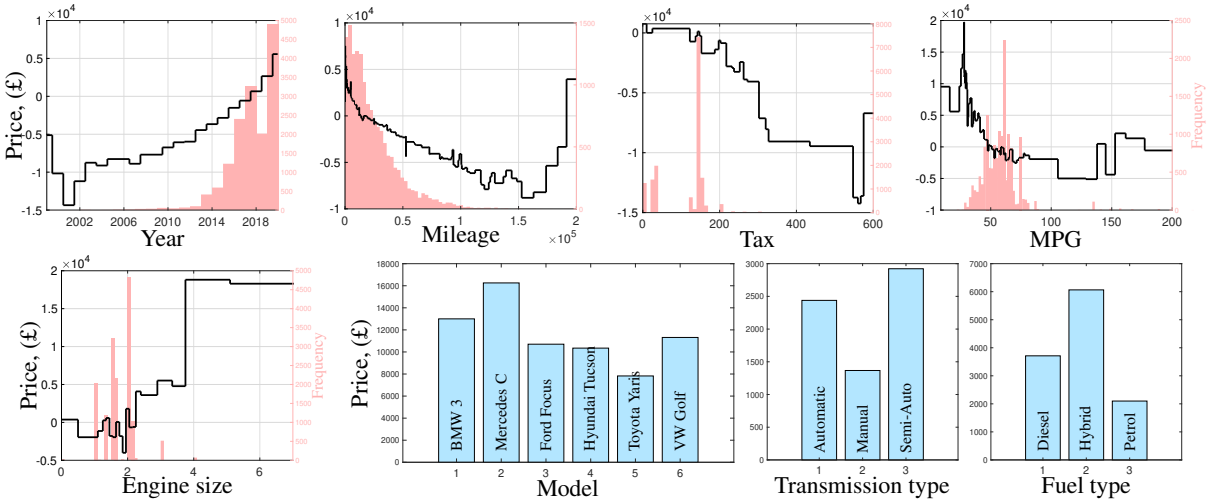

Figure 2. Visualization of the resulting additive model shape functions from our optimized stump forests for the UK used car dataset. For the numerical features, the light red bars show the histogram of the training points with the frequency values given on the right y-axis.

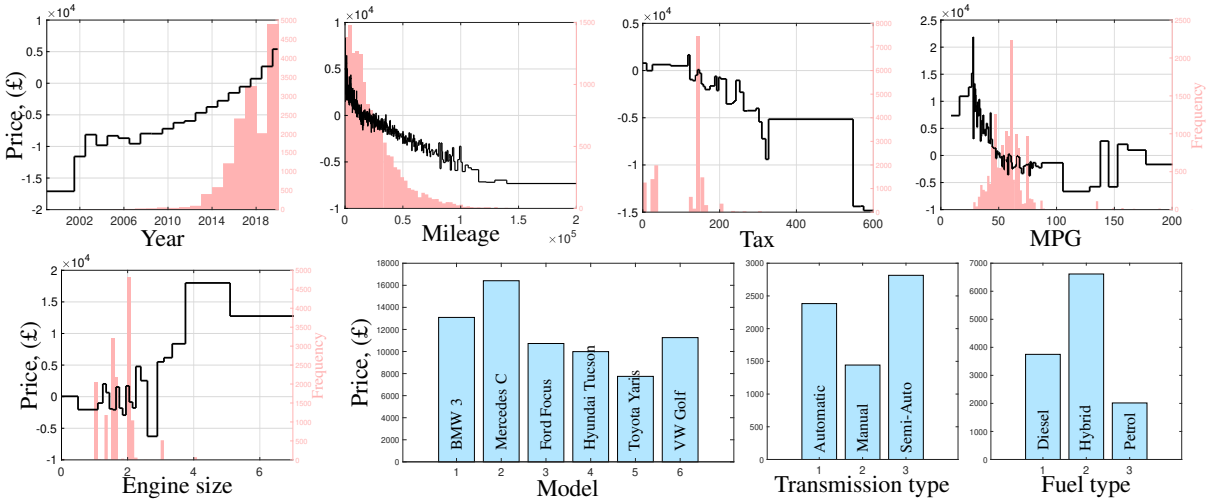

Figure 3. EBM shape functions.

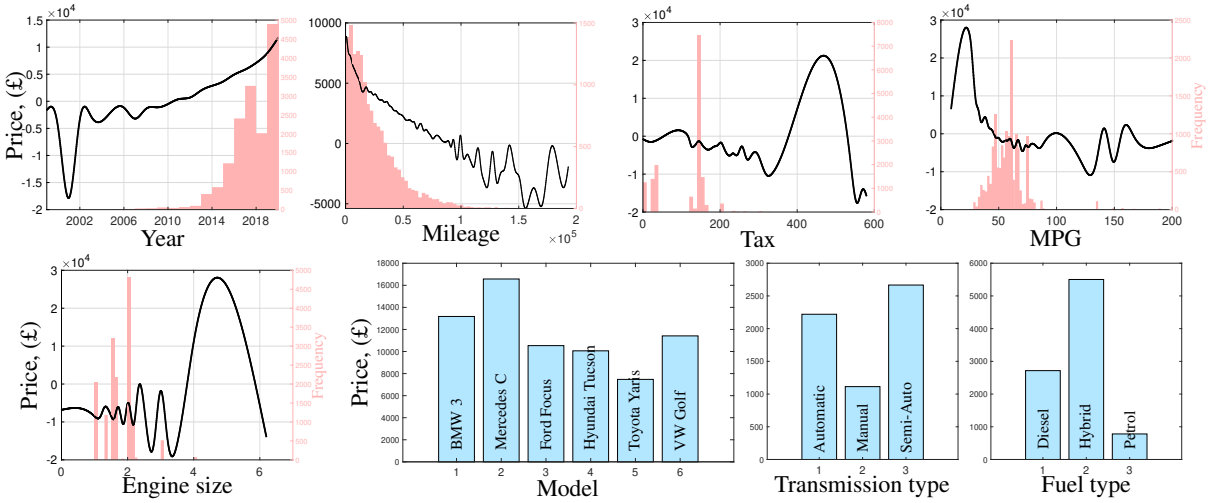

Figure 4. PyGAM shape functions.