



Trees, trees, trees

An introduction to classification tree,
random forest, bagging, and boosting models

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Dataset and problem

Why does someone decide to buy hearing aids?

	Age	Sex	Hearing test	Reported handicap	Stigma	$x = 28$	Purchased aids $\frac{1}{5}$
Case 1	76	M	65	32	3	...	1
Case 2	61	M	45	26	4	...	0
Case 3	68	F	50	24	4	...	0
n = 753

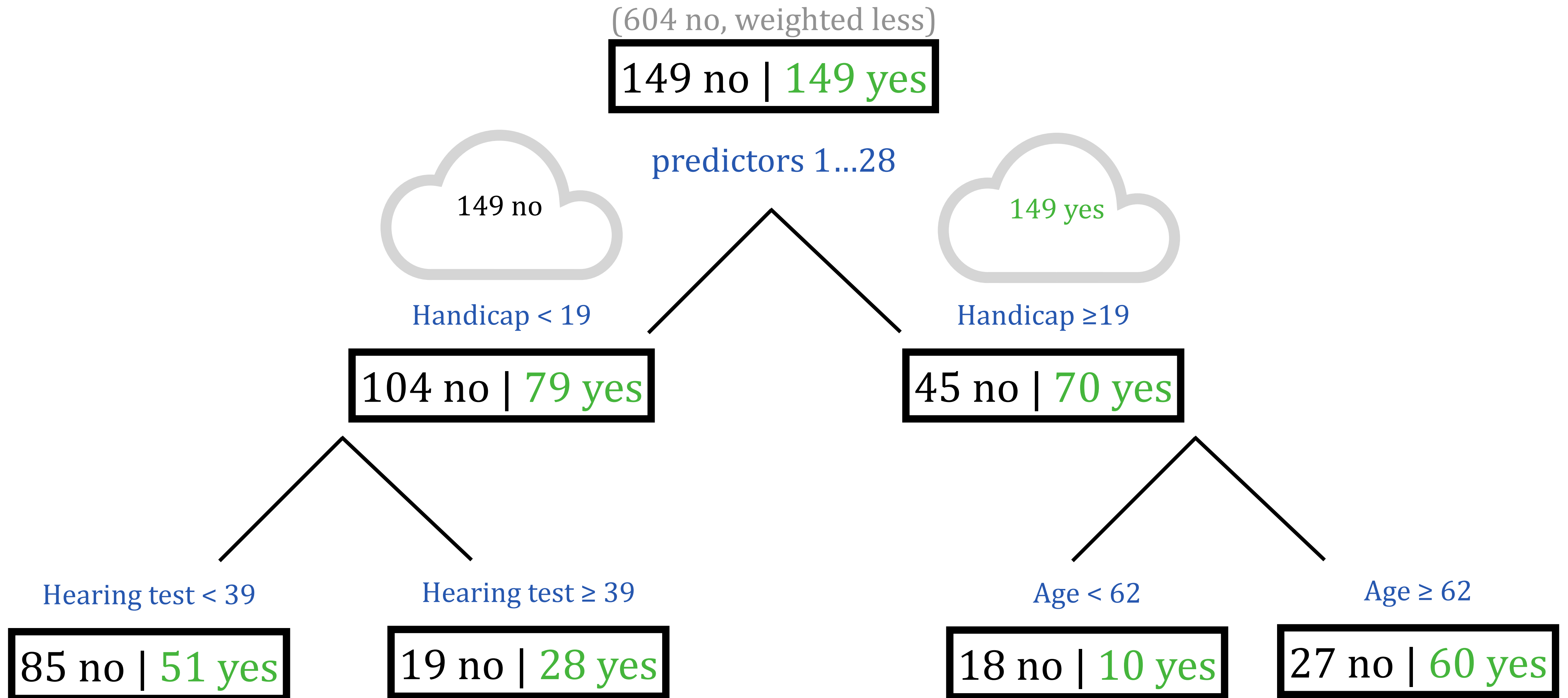
Initial analysis: Logistic regression

> glmnet (Purchased ~ Age + Sex + Hearing + Handicap... , data = df, family = “binomial”)

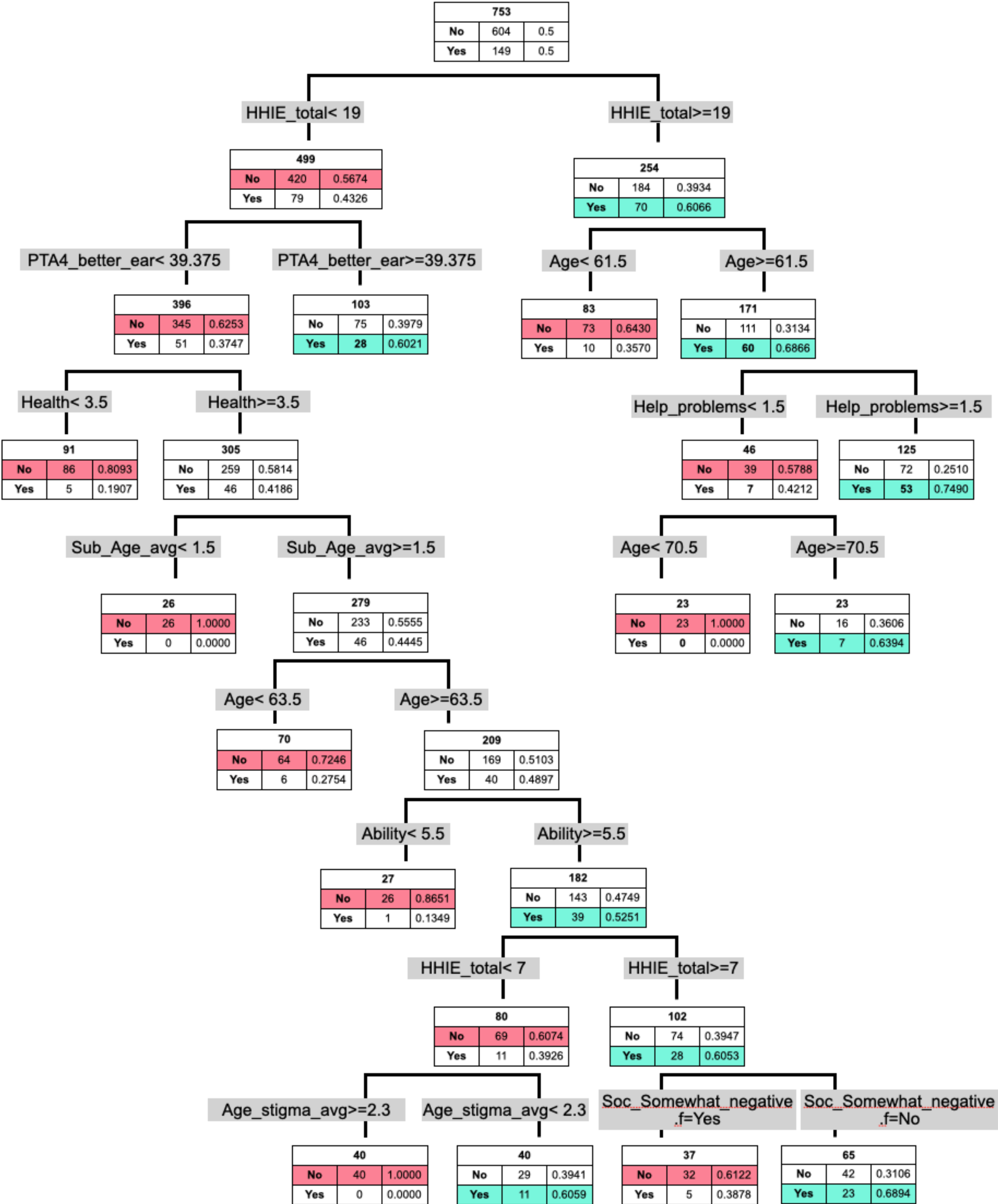
	Odds ratio	CI lower	CI upper	p-value
Age	1.046	1.024	1.069	<0.0001
Handicap	1.047	1.027	1.068	<0.0001
Stigma	0.85	0.71	1.01	0.065
Know someone	2.10	1.12	4.30	0.029

	LR
Accuracy	63.5
Sensitivity	59.7
Specificity	64.4

Classification tree (CART)



Complexity Parameter	Number of splits in tree	Overall accuracy	Sensitivity	Specificity	Area Under Curve
0.2	0	0.50	0.000	1.000	0.5000
0.1	1	0.6507	0.46980	0.69536	0.5826
0.05	3	0.672	0.5906	0.6921	0.6413
0.03	3	0.672	0.5906	0.6921	0.6413
0.025	3	0.672	0.5906	0.6921	0.6413
0.02	3	0.672	0.5906	0.6921	0.6413
0.015	5	0.7025	0.5906	0.7301	0.6604
0.013	12	0.6534	0.8188	0.6126	0.7157
0.012	12	0.6534	0.8188	0.6126	0.7157
0.011	15	0.6454	0.8792	0.5877	0.7335
0.01	22	0.7211	0.8725	0.6838	0.7781
0.005	31	0.745	0.9262	0.7003	0.8133
0	41	0.7822	0.9195	0.7483	0.8339



	LR	Tree
Accuracy	63.5	67.5
Sensitivity	59.7	78.5
Specificity	64.4	64.7



Model stability

Changes in model metrics (%) across data subsets, CP = 0.013

metric	subset_1	subset_2	subset_3	subset_4	subset_5
Accuracy	69.32	70.27	73.3	69.60	75.08
Sensitivity	73.95	63.03	72.5	67.23	82.35
Specificity	68.18	72.05	73.5	70.19	73.29
AUC	71.07	67.54	73.0	68.71	77.82

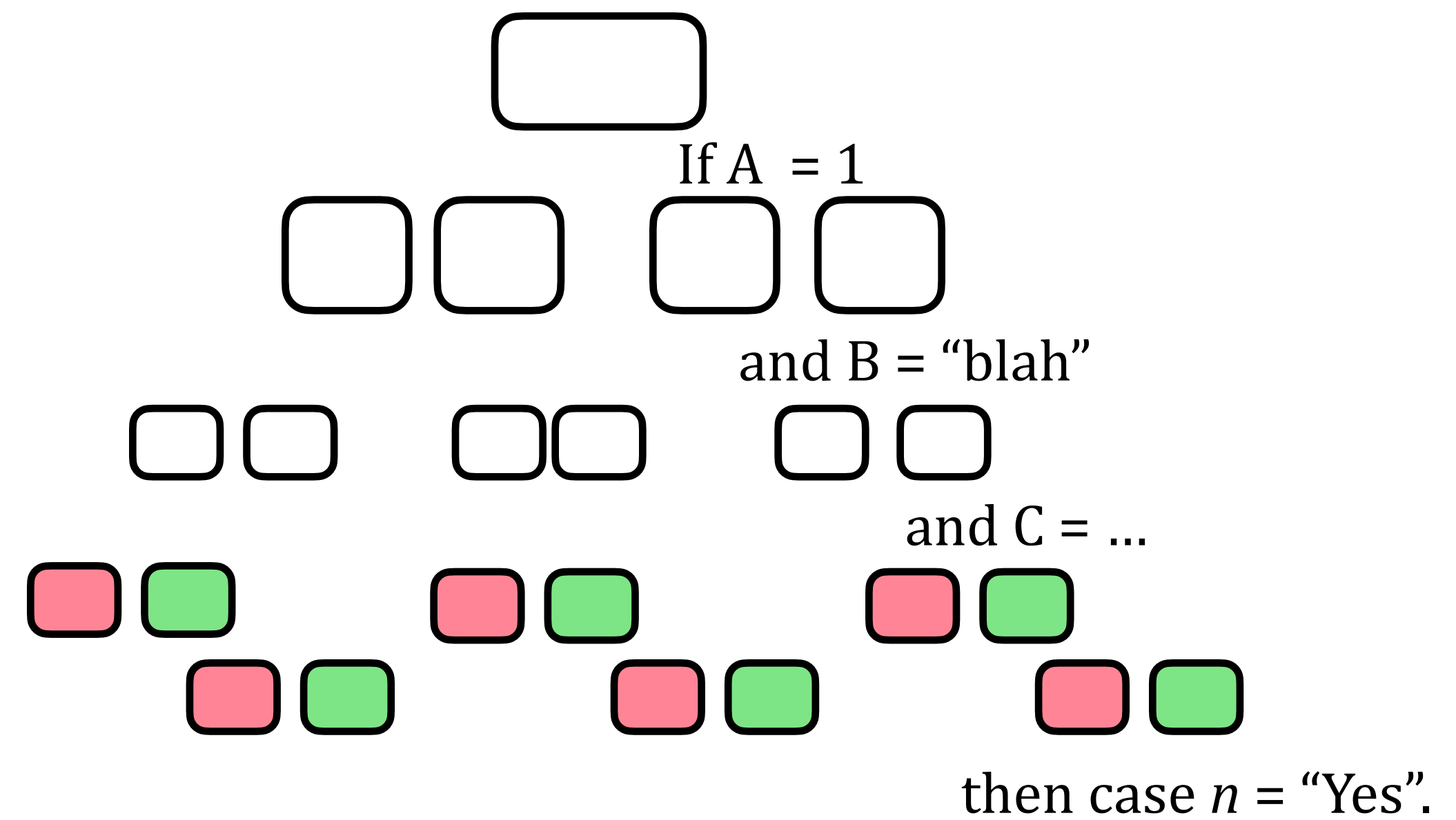
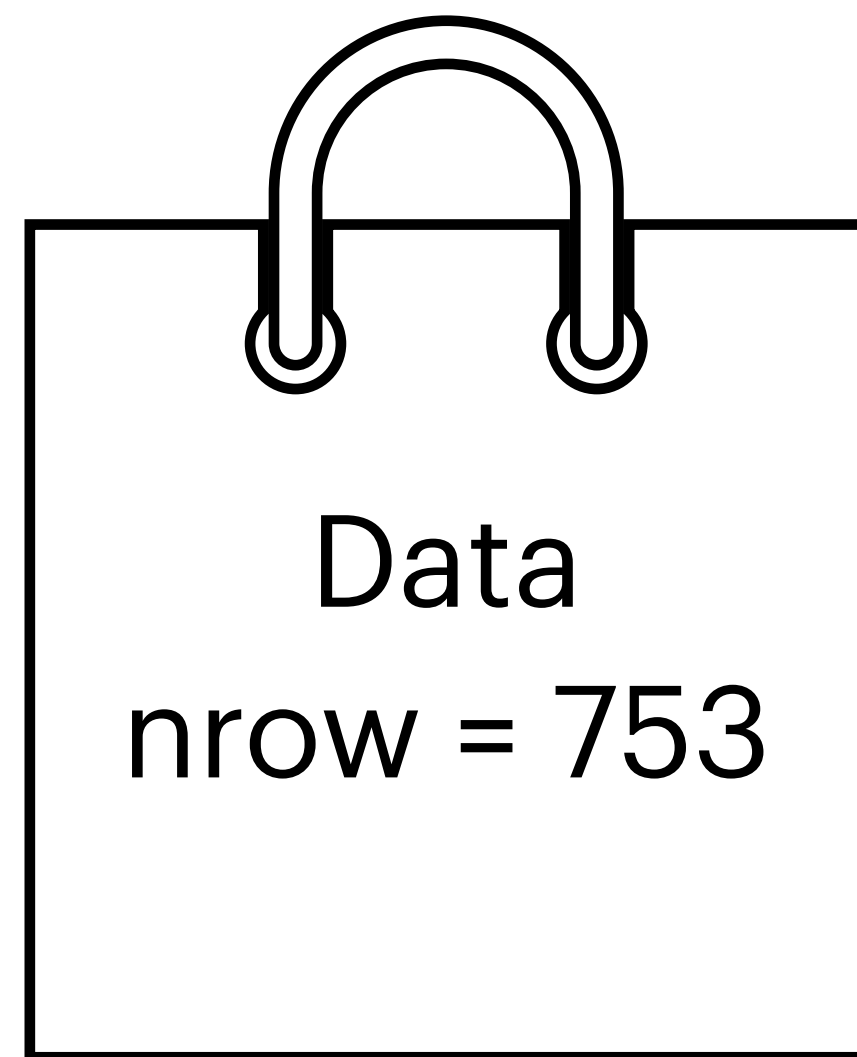
Changes in variable importance (%) across data subsets, CP = 0.013

variable	subset_1	subset_2	subset_3	subset_4	subset_5
Ability	*	*	9.15	*	*
Accomp.f	*	*	*	*	*
Age	25.18	40.85	21.86	29.31	13.59
Age_stigma_avg	20.41	*	*	12.02	6.59
Concern	*	*	4.48	*	*
Edu	*	*	*	*	4.15
HA_stigma_avg	*	*	*	*	8.22
Health	*	*	*	*	4.61
Help_neighbours	*	*	*	*	*
Help_problems	11.92	11.64	*	9.96	*
HHIE_total	21.5	26.56	13.63	22.81	9.63
Lonely	*	*	*	*	5.19
Married.f	*	*	*	*	8.42
PTA4_better_ear	3.48	20.96	22.59	25.91	12.87
QoL	7.94	*	*	*	3.73

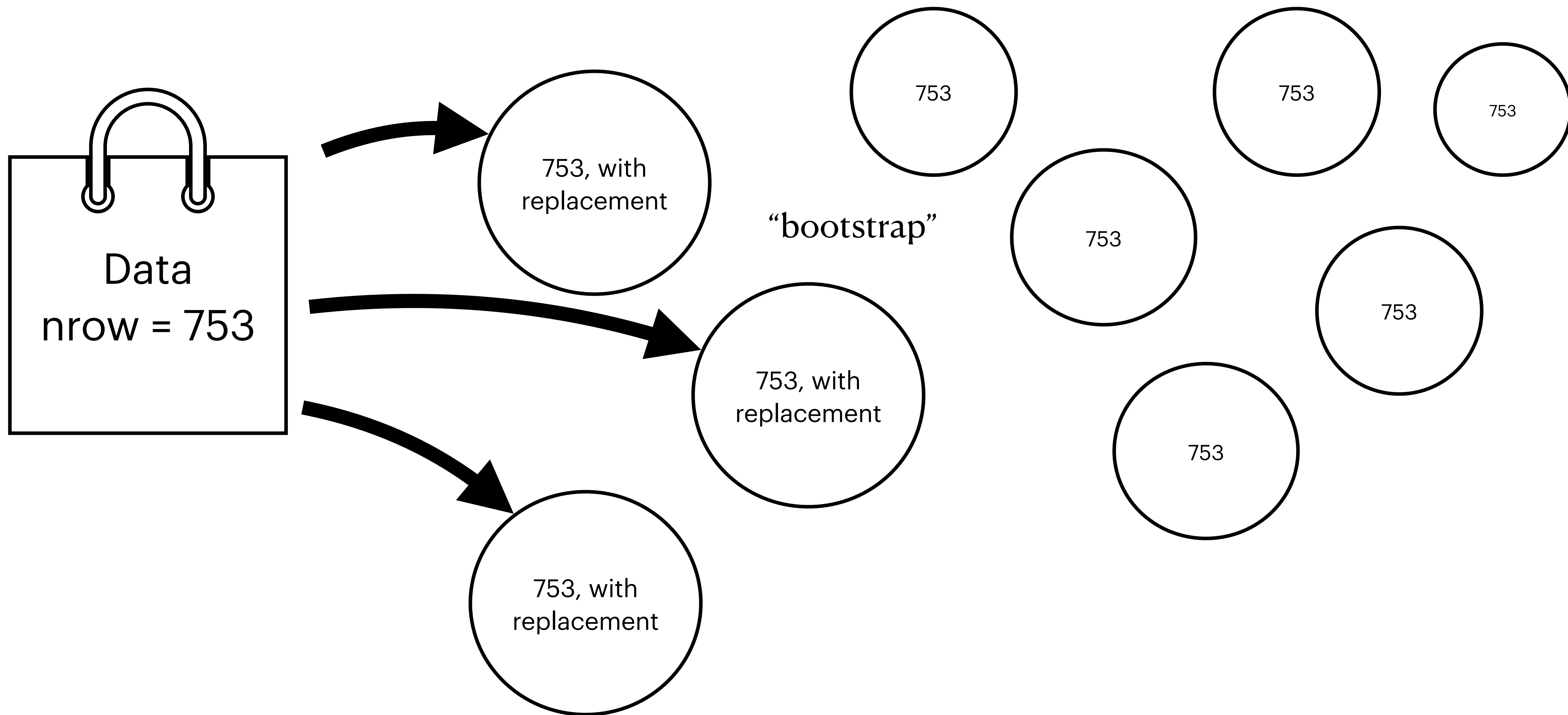
Pros & cons

LR	Single tree				
Interpretation?	Easy to interpret High variance				

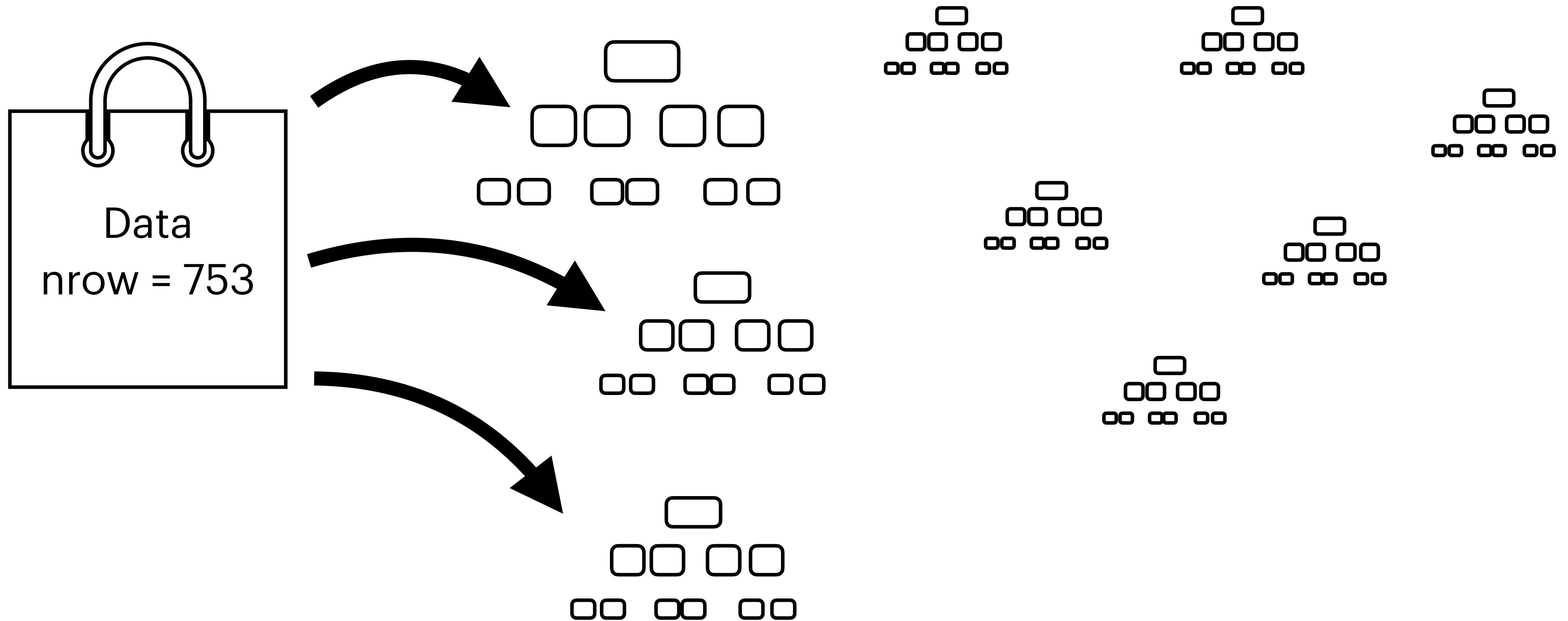
Classification tree



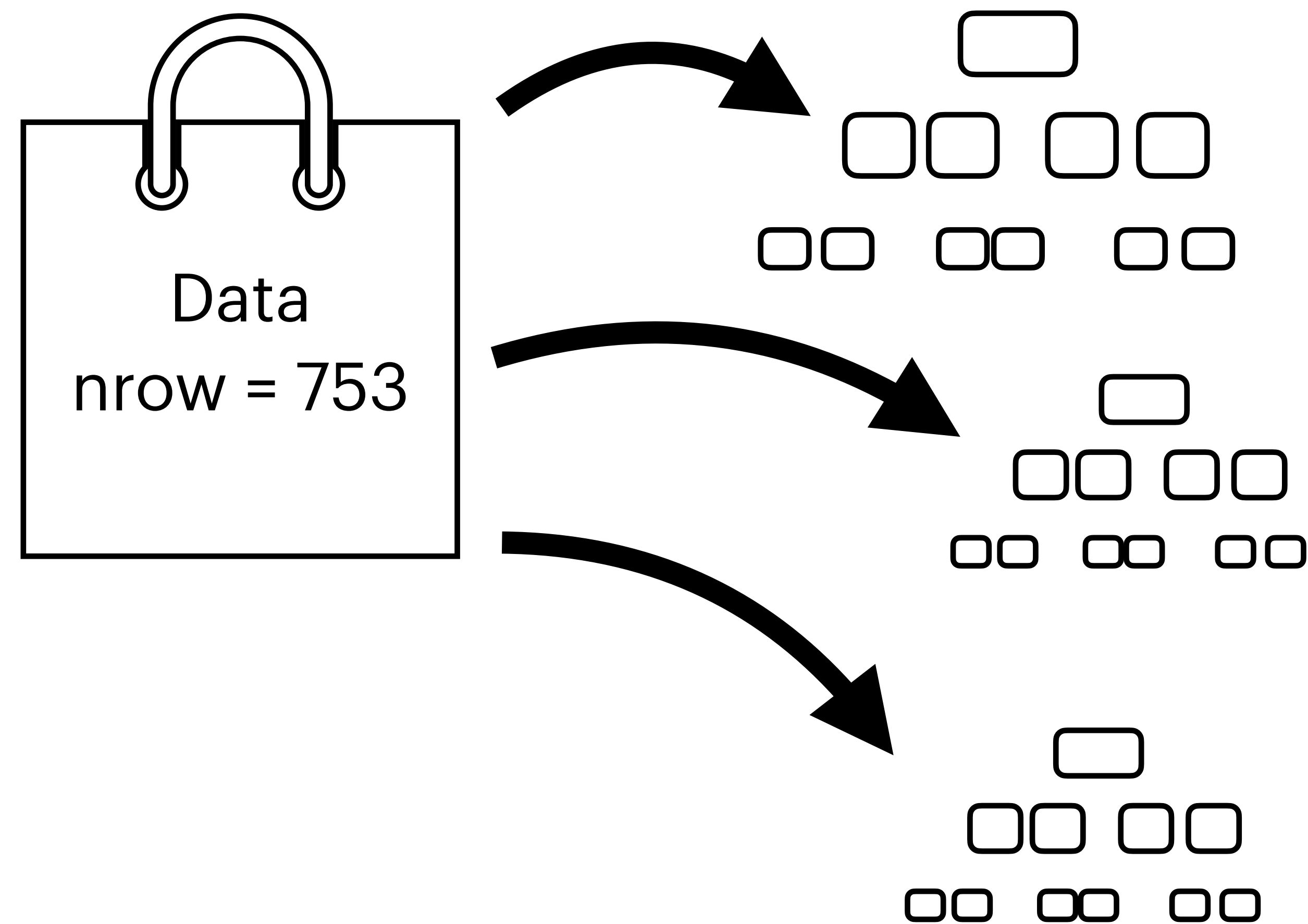
Bagging: Bootstrap aggregating



Bagging: Bootstrap aggregating



Bagging: Bootstrap aggregating



“aggregating”

	Tree 1	Tree 2	Tree ...	Majority vote
Case 1	Yes	No	No	No
Case 2	No	No	Yes	No
Case 3	Yes	No	Yes	Yes
...	No	Yes	No	No
Case 753	No	No	No	No

Bagging: Bootstrap aggregating

ntrees = 250

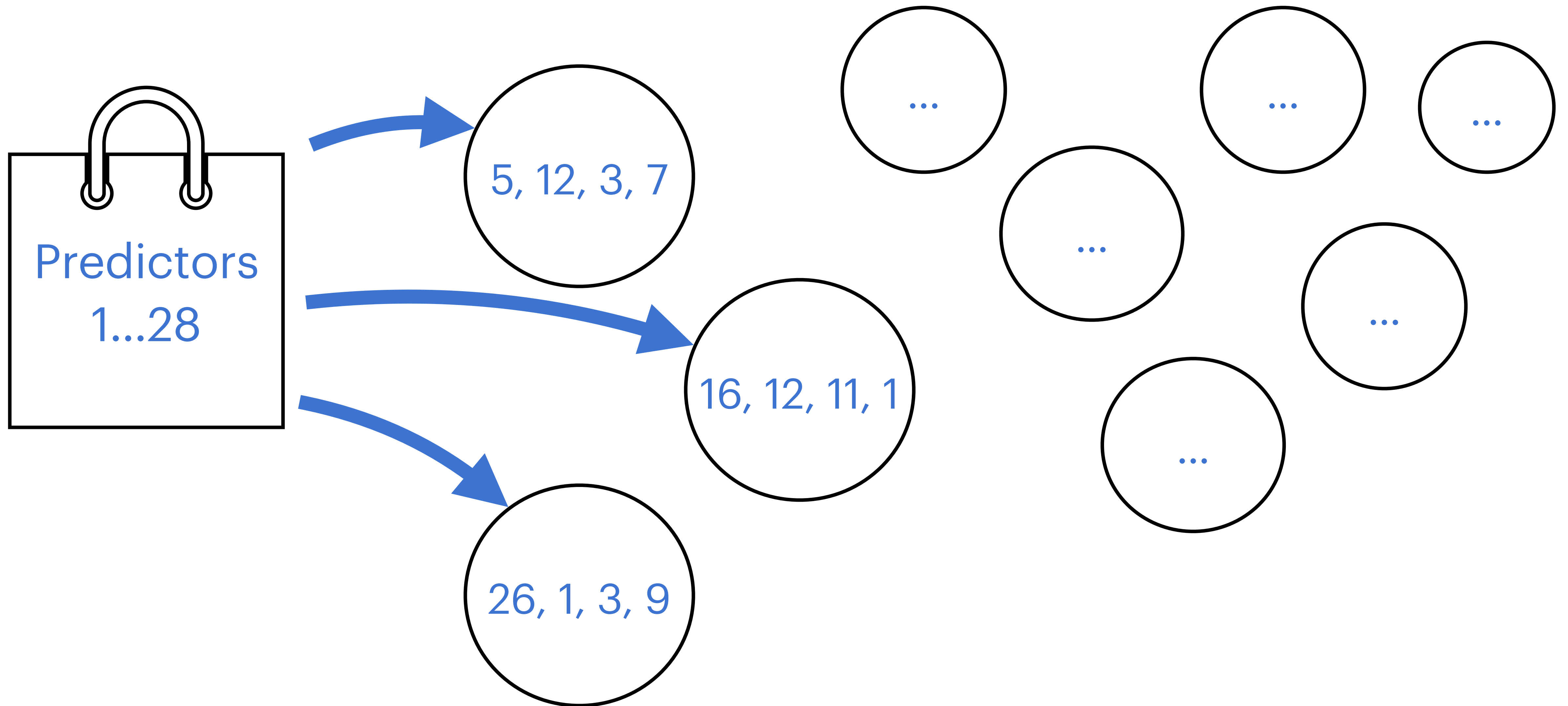
	LR	Tree	Bag*
Accuracy	64	65	77
Sensitivity	59	81	32
Specificity	64	61	89

*Downsampled majority class

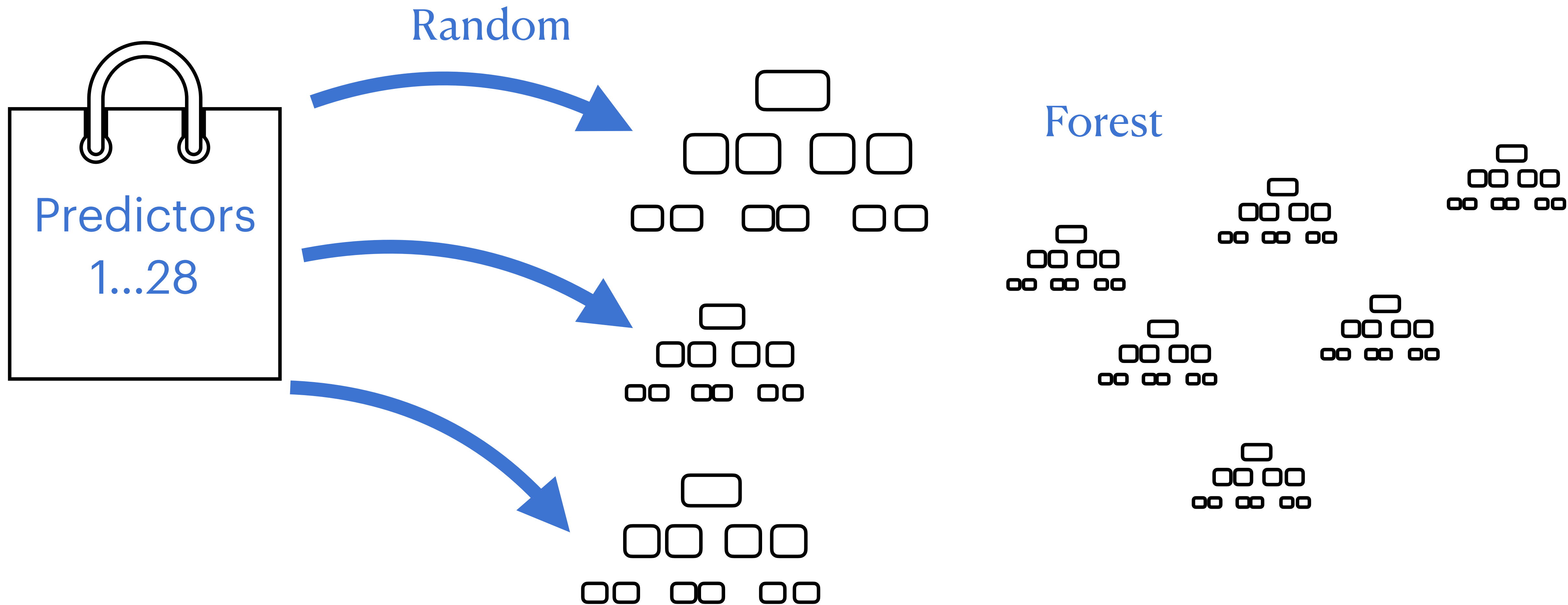
Pros & cons

LR	Single tree	Bagging		
Interpretation?	Easy to interpret	Less easy to interpret		
	High variance	Less variance		
		All trees look alike... less accurate		

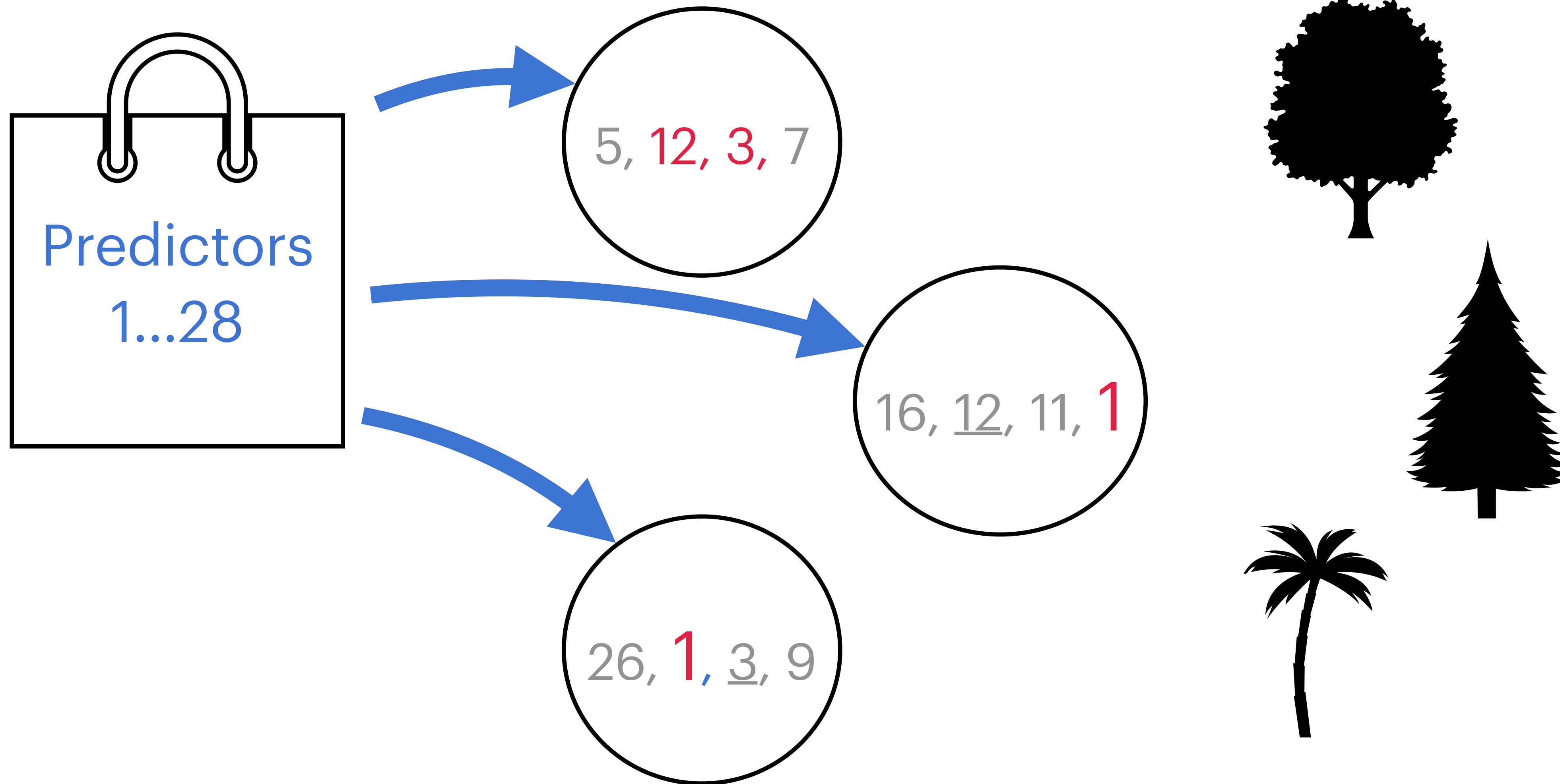
Random forest



Random forest



Random forest



Random forest

ntrees = 200
m = 4

	LR	Tree	Bag	RF*
Accuracy	64	65	77	98
Sensitivity	60	81	32	100
Specificity	64	61	89	98

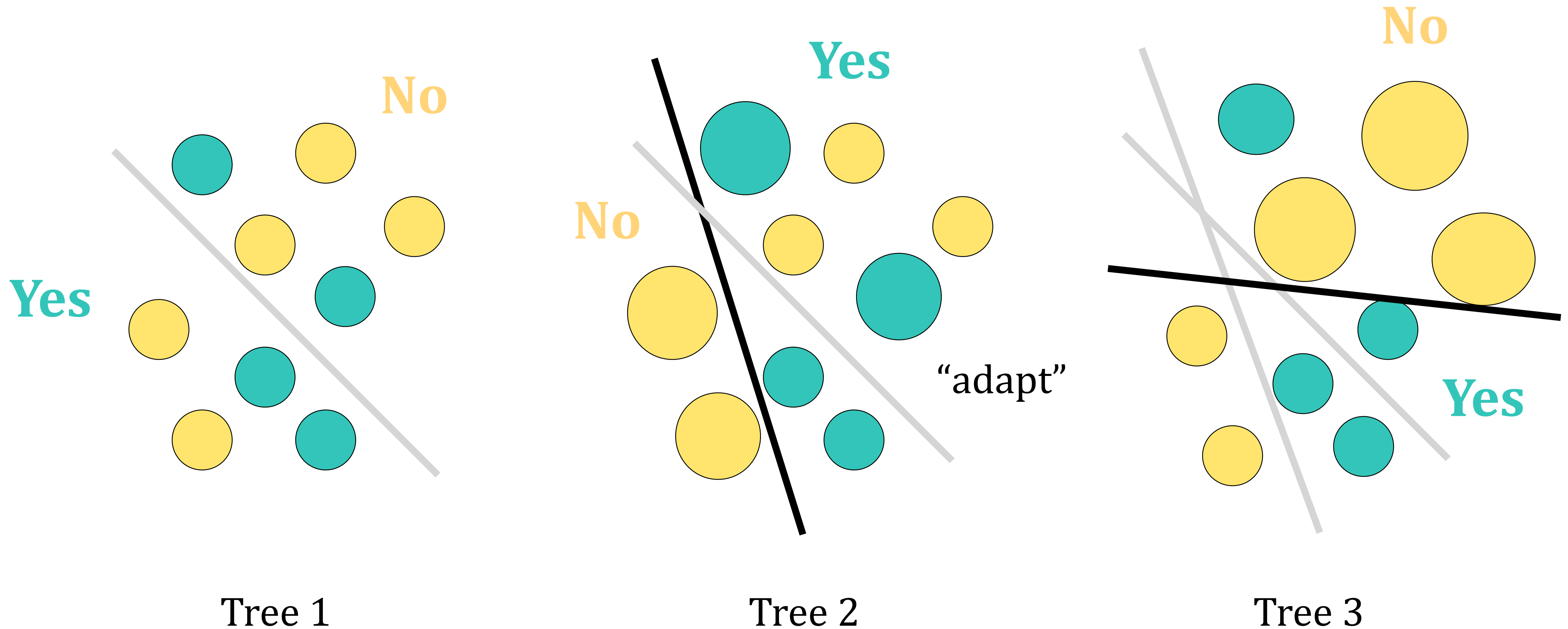
*Oversampling of minority class

*Beware inflation; OOB accuracy = 77

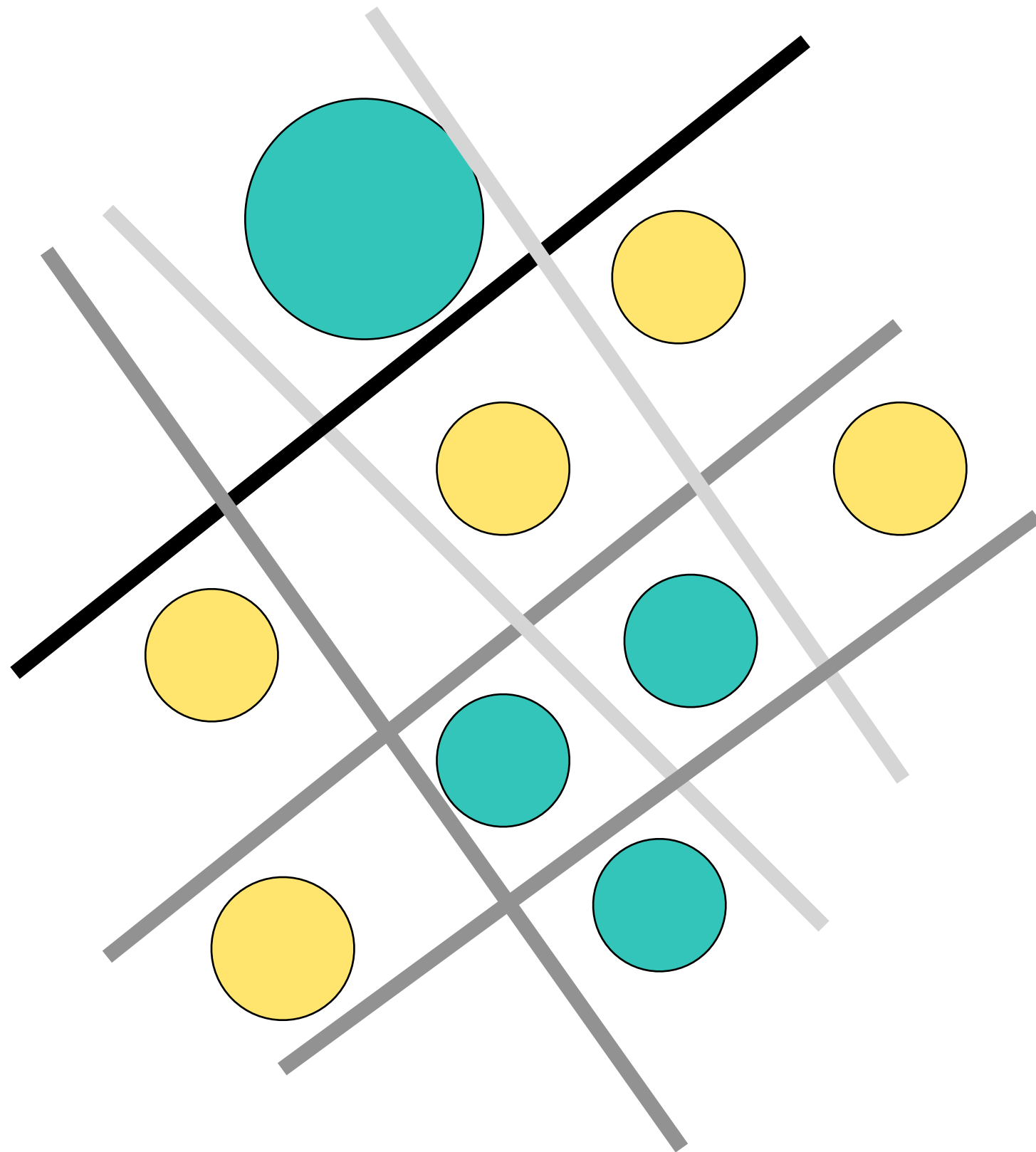
Pros & cons

LR	Single tree	Bagging	Random forest	
Interpretation?	Easy to interpret	Less easy to interpret	Less easy to interpret	
	High variance	Less variance	Less variance	
		All trees look alike... less accurate	De-correlated trees; more accurate	

AdaBoost: Adaptive boosting



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$$\text{Final model} = (W1)\text{Tree 1} + (W2)\text{Tree 2} + (W3)\text{Tree 3}$$

Tree *Gazillion!*



Over-fitting

AdaBoost: Adaptive boosting

ntrees = 5
maxdepth = 1
 $\nu = 0.25$

	LR	Tree	Bag	RF	Ada*	
Accuracy	64	65	77	98	80	
Sensitivity	60	81	32	100	0	
Specificity	64	61	89	98	1	

*No case weights!

Gradient boosting

	Age	Sex	Hearing test	...	Predict	Actual	Tree1 diff
Case 1	76	M	65	...	-0.482	1	1.482
Case 2	61	M	45	...	-0.482	0	0.482
Case 3	68	F	50	...	-0.482	0	0.482
...

Gradient boosting

	Tree1 diff	Tree2 predict	T2-T1 diff	Tree3 predict	T3-T2 diff	...	Ty-Tx diff
Case 1	1.482		1.263		0.994		-0.05
Case 2	0.482		0.388		0.268		0.03
Case 3	0.482		0.425		0.379		0.01
...	...						

Gradient boosting

Final model = Tree 1 + W * Tree 2 + W * Tree 3 + ...

(Individual cases are not weighted, like in AdaBoost)

(Weight for all trees is the same, the “learning rate”)

Gradient boosting

ntrees = 10
maxdepth = 3
 $\nu = 0.1$

	LR	Tree	Bag	RF	Ada	Gra*
Accuracy	64	65	77	98	80	68
Sensitivity	60	81	32	100	0	50
Specificity	64	61	89	98	1	72

*Case weights, but conditional inference trees

Pros & cons

LR	Single tree	Bagging	Random forest	Boosting
Interpretation?	Easy to interpret	Less easy to interpret	Less easy to interpret	Less easy to interpret
	High variance	Less variance	Less variance	Less variance
		All trees look alike... less accurate	De-correlated trees; more accurate	Build on previous trees; accurate??
			Can't overfit	Possible to overfit

Trees, trees, trees

- Ensembles are usually better than a single tree; “wisdom of the crowd”
- Consider the quirks of the dataset
- How useful are the results from that method?
- How open is the field to that method?
- Each method has parameters to tune; see [GitHub](#)