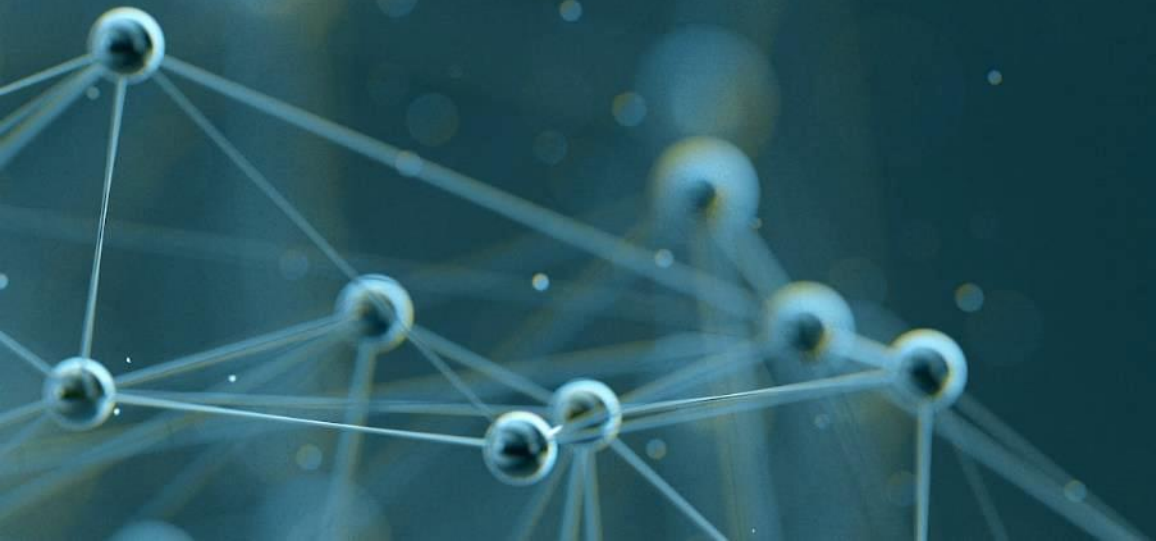
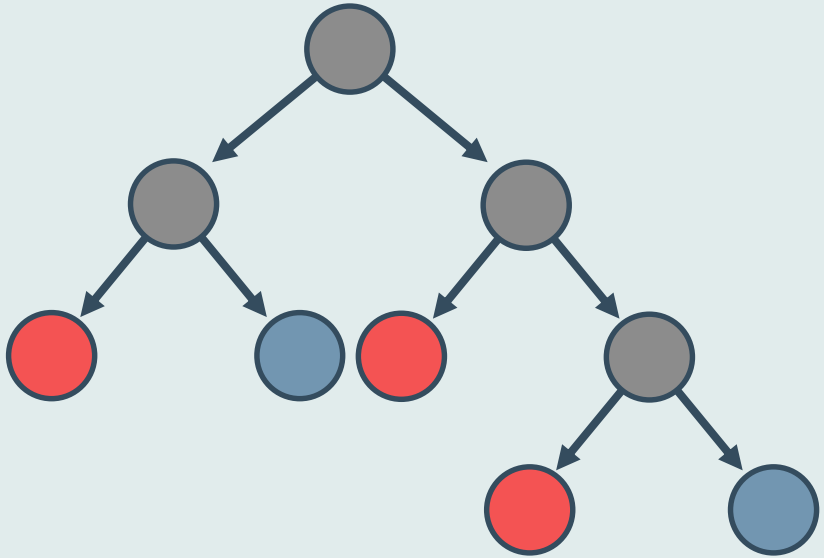
BAGGING

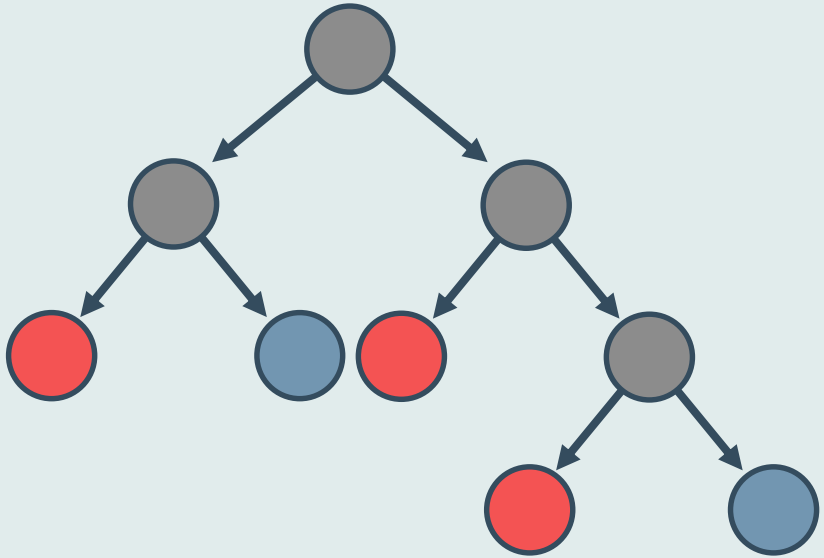


DECISION TREES ARE HIGH VARIANCE



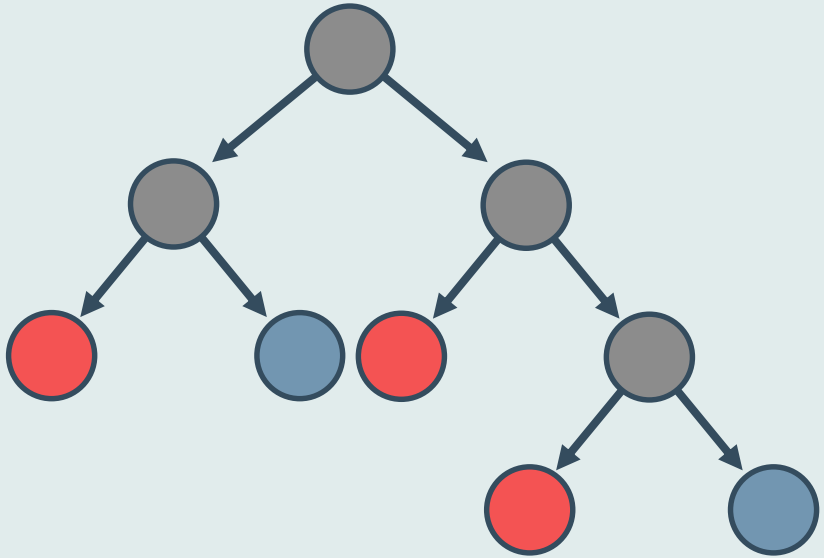
- Problem: decision trees tend to overfit

DECISION TREES ARE HIGH VARIANCE



- Problem: decision trees tend to overfit
- Pruning helps reduce variance to a point

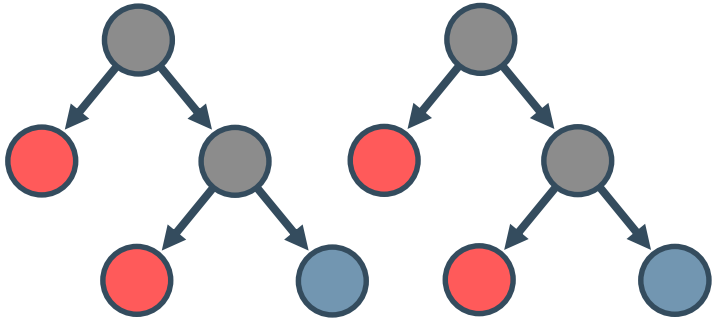
DECISION TREES ARE HIGH VARIANCE



- Problem: decision trees tend to overfit
- Pruning helps reduce variance to a point
- Often not significant for model to generalize well

IMPROVEMENT: USE MANY TREES

Create many different trees.



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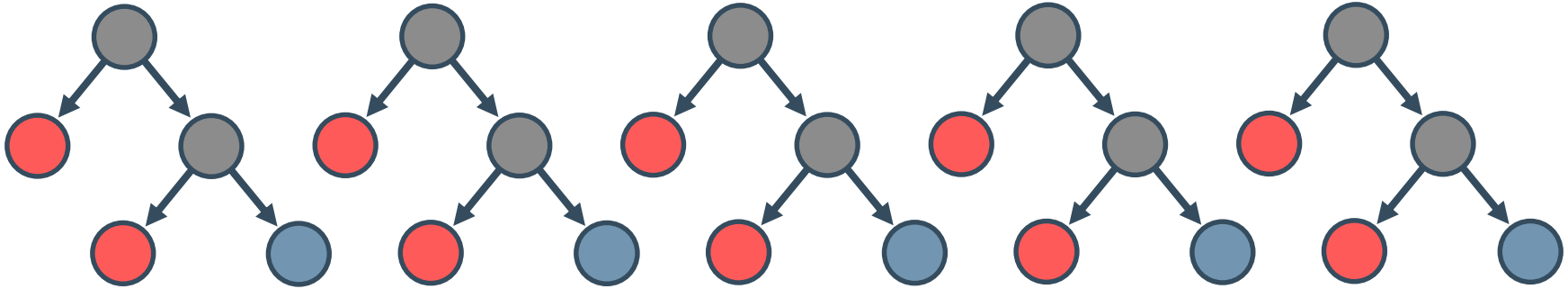

IMPROVEMENT: USE MANY TREES

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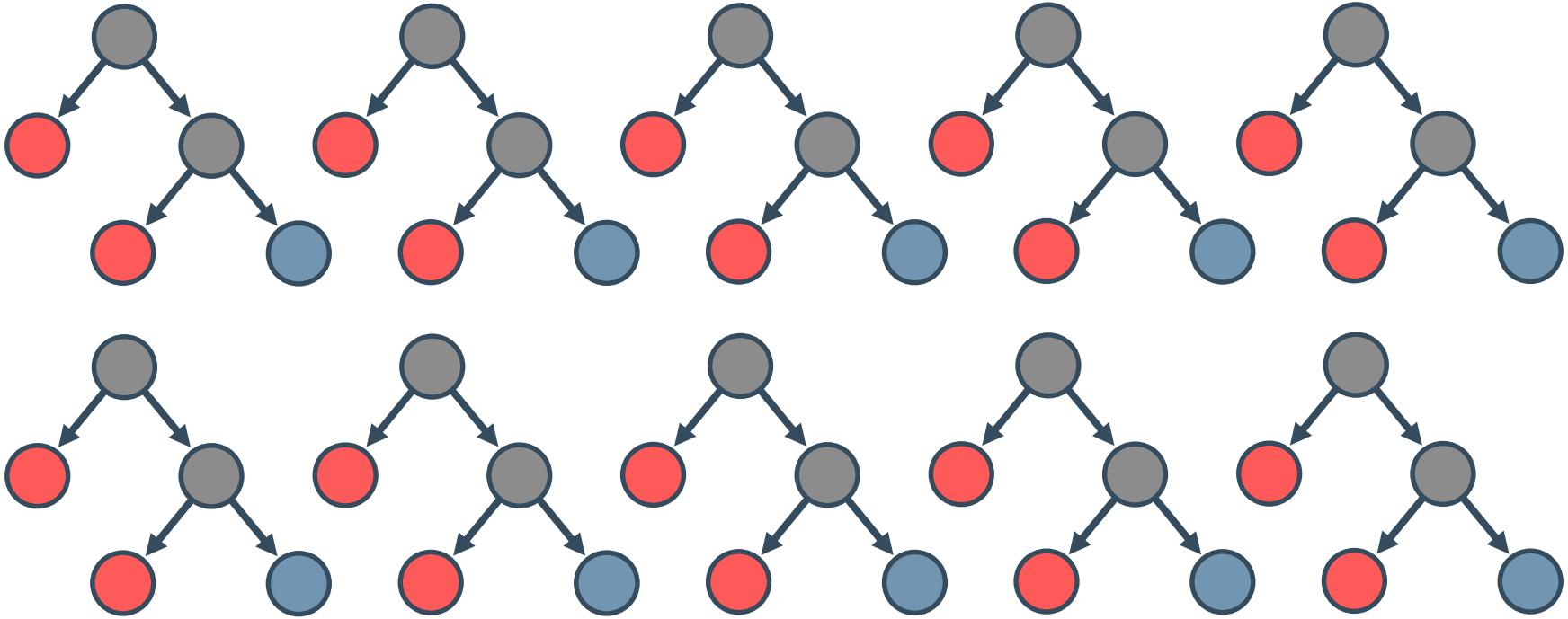
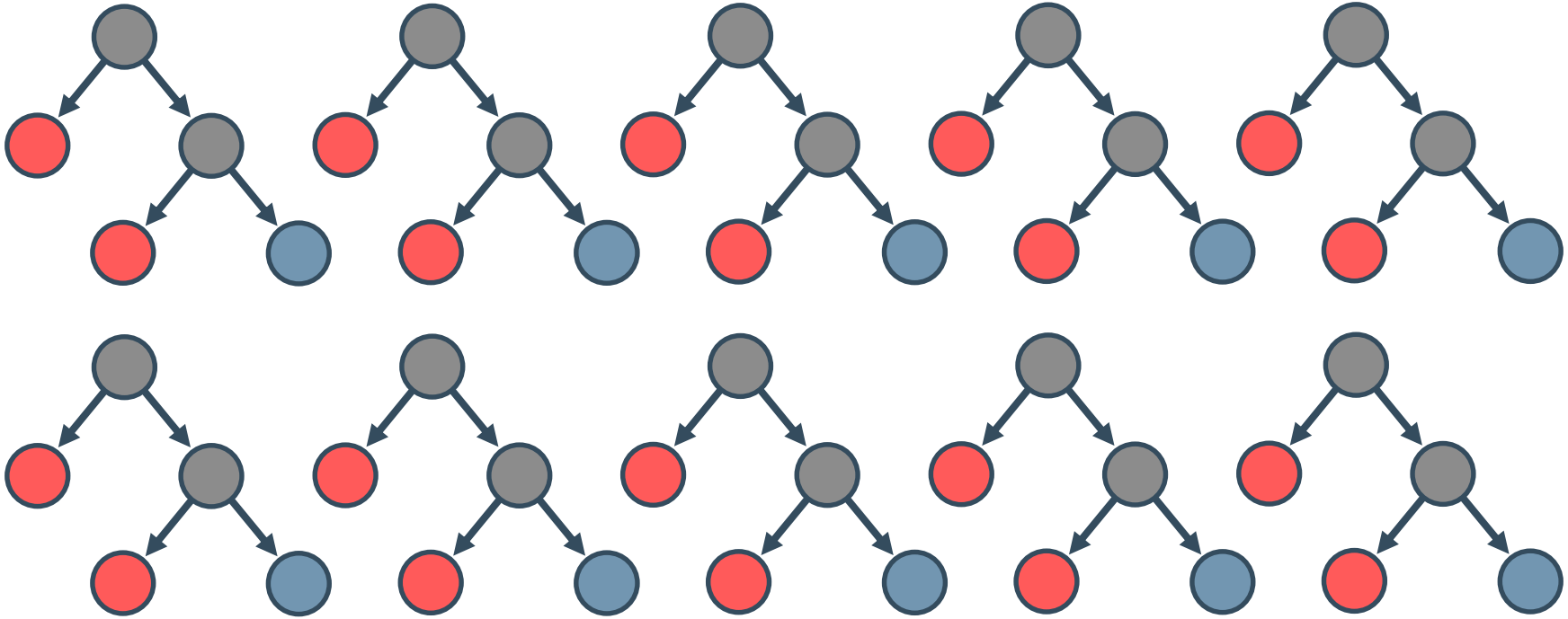


IMPROVEMENT: USE MANY TREES

Combine predictions to reduce variance.



HOW TO CREATE MULTIPLE TREES?

Use bootstrapping: sample data with replacement.

	Date	Title	Budget	DomesticTotalGross	Director	Rating	Runtime
0	2013-11-22	The Hunger Games: Catching Fire	130000000	424668047	Francis Lawrence	PG-13	146
1	2013-05-03	Iron Man 3	200000000	409013994	Shane Black	PG-13	129
2	2013-11-22	Frozen	150000000	400738009	Chris BuckJennifer Lee	PG	108
3	2013-07-03	Despicable Me 2	76000000	368061265	Pierre CoffinChris Renaud	PG	98
4	2013-06-14	Man of Steel	225000000	291045518	Zack Snyder	PG-13	143
5	2013-10-04	Gravity	100000000	274092705	Alfonso Cuaron	PG-13	91
6	2013-06-21	Monsters University	NaN	268492764	Dan Scanlon	G	107
7	2013-12-13	The Hobbit: The Desolation of Smaug	NaN	258366855	Peter Jackson	PG-13	161
8	2013-05-24	Fast & Furious 6	160000000	238679850	Justin Lin	PG-13	130
9	2013-03-08	Oz The Great and Powerful	215000000	234911825	Sam Raimi	PG	127
10	2013-05-16	Star Trek Into Darkness	190000000	228778661	J.J. Abrams	PG-13	123
11	2013-11-08	Thor: The Dark World	170000000	206362140	Alan Taylor	PG-13	120
12	2013-06-21	World War Z	190000000	202359711	Marc Forster	PG-13	116
13	2013-03-22	The Croods	135000000	187168425	Kirk De MiccoChris Sanders	PG	98
14	2013-06-28	The Heat	43000000	159582188	Paul Feig	R	117
15	2013-08-07	We're the Millers	37000000	150394119	Rawson Marshall Thurber	R	110
16	2013-12-13	American Hustle	40000000	150117807	David O. Russell	R	138
17	2013-05-10	The Great Gatsby	105000000	144840419	Baz Luhrmann	PG-13	143

HOW TO CREATE MULTIPLE TREES?

Create multiple bootstrapped samples.

	Date	Title	Budget	DomesticTotalGross	Director	Rating	Runtime
0	2013-11-22	The Hunger Games: Catching Fire	130000000	424668047	Francis Lawrence	PG-13	146
1	2013-05-03	Iron Man 3	200000000	409013994	Shane Black	PG-13	129
2	2013-11-22	Frozen	150000000	400738009	Chris BuckJennifer Lee	PG	108
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12	2013-06-21	World War Z	190000000	202359711	Marc Forster	PG-13	116
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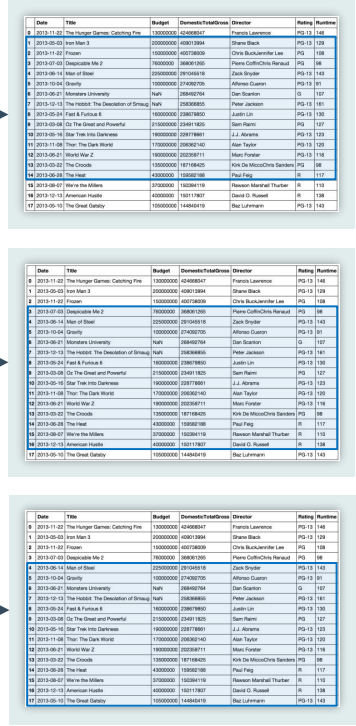

HOW TO CREATE MULTIPLE TREES?

Grow decision tree from each bootstrapped sample.

	Date	Title	Budget	DomesticTotalGross	Director	Rating	Runtime
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1	2013-05-03	Iron Man 3	200000000	409013994	Shane Black	PG-13	129
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5	2013-10-04	Gravity	100000000	274092705	Alfonso Cuaron	PG-13	91
6	2013-06-21	Monsters University	NaN	268492764	Dan Scanlon	G	107
7	2013-12-13	The Hobbit: The Desolation of Smaug	NaN	258368855	Peter Jackson	PG-13	161
8	2013-05-24	Fast & Furious 6	160000000	238679850	Justin Lin	PG-13	130
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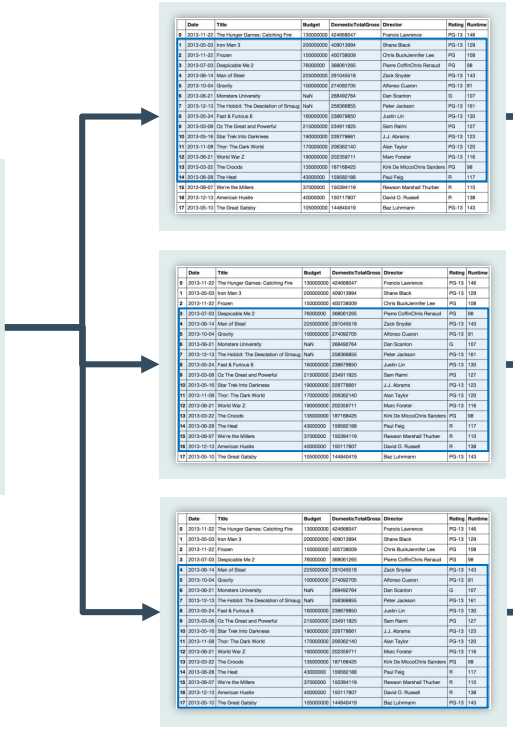
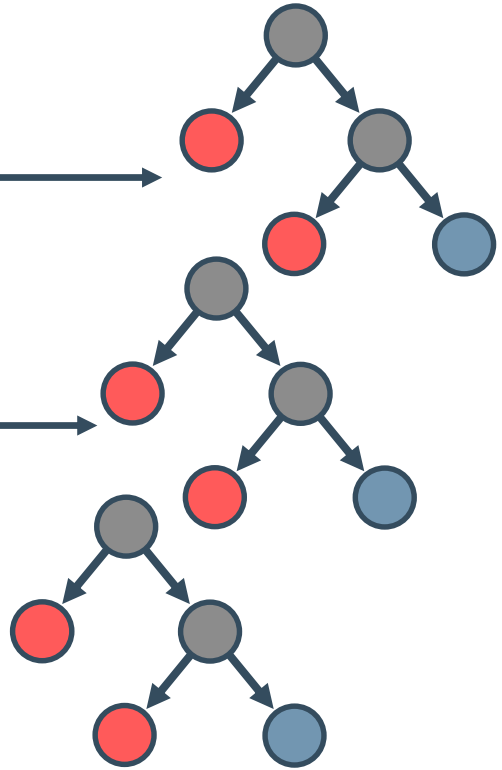
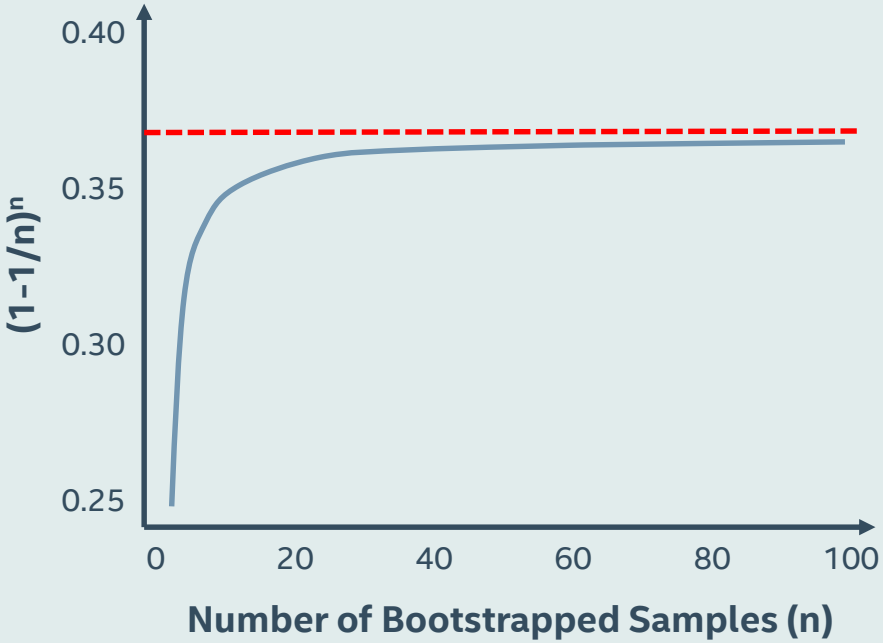


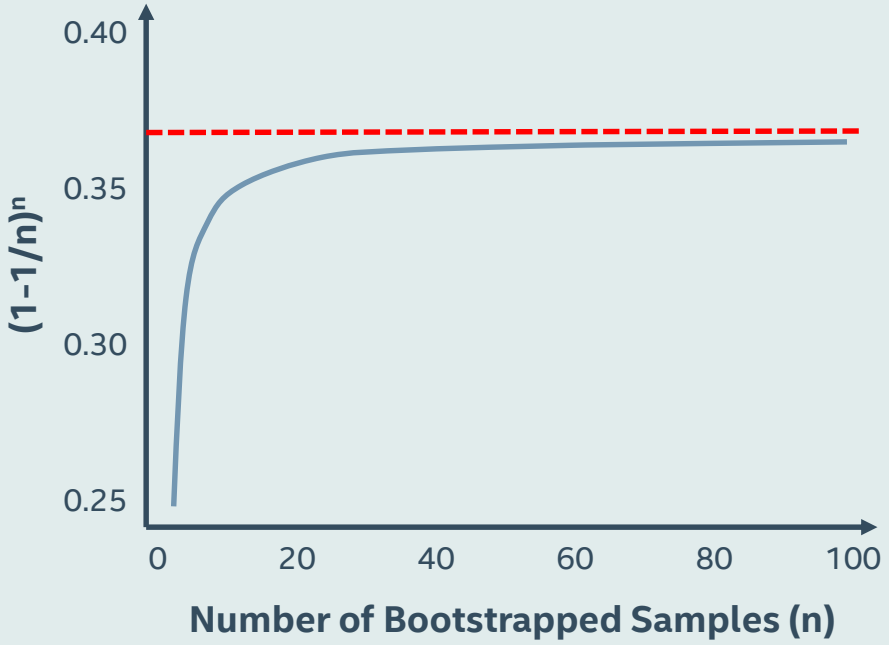


DISTRIBUTION OF DATA IN BOOTSTRAPPED SAMPLES



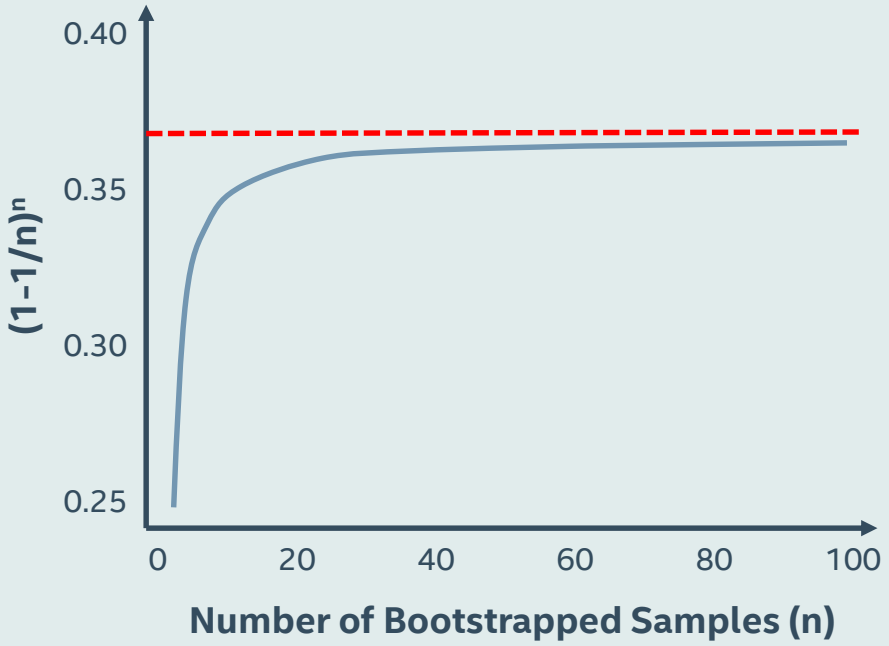
- Given a dataset, create n bootstrapped samples

DISTRIBUTION OF DATA IN BOOTSTRAPPED SAMPLES



- Given a dataset, create n bootstrapped samples
- For a given record x,
  $P(rec\ x\ not\ selected) = (1 - {}^{1}/_{n})^{n}$

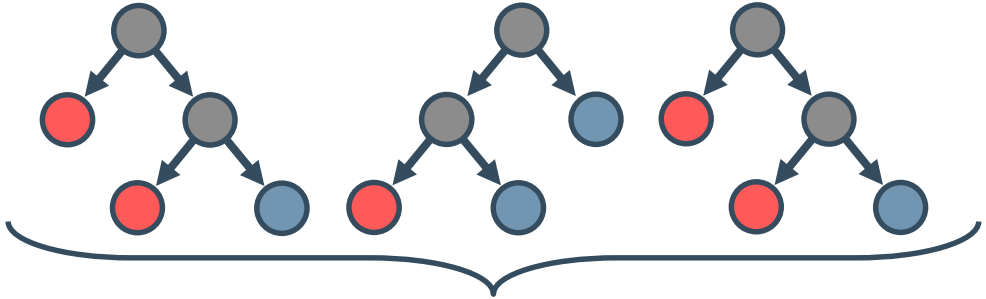
DISTRIBUTION OF DATA IN BOOTSTRAPPED SAMPLES



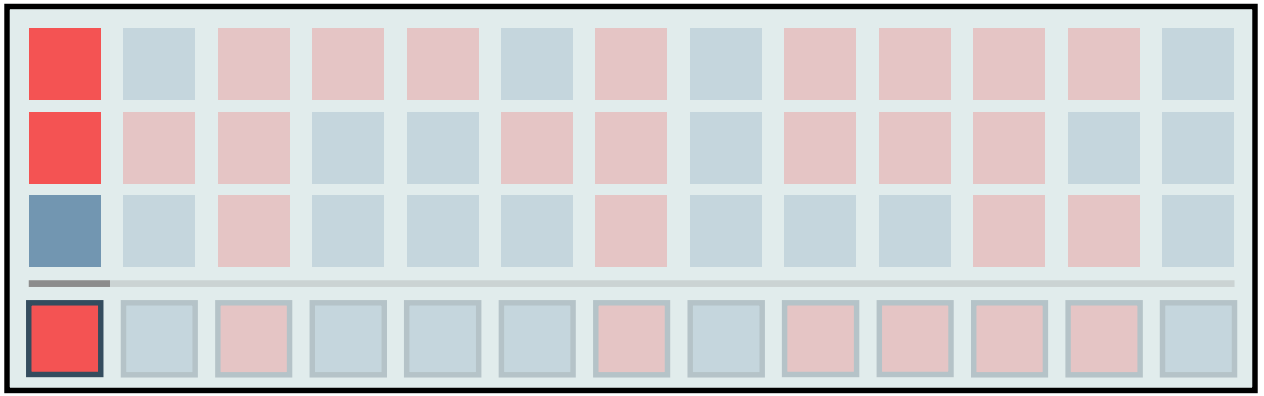
- Given a dataset, create n bootstrapped samples
- For a given record x, $P(rec\ x\ not\ selected) = (1 - {}^{1}/_{n})^{n}$
- Each bootstrap sample contains approximately ${}^{2}/_{3}$ of the records

AGGREGATE RESULTS

Trees vote on or average result for each data point.



Vote to Form a Single Classifier



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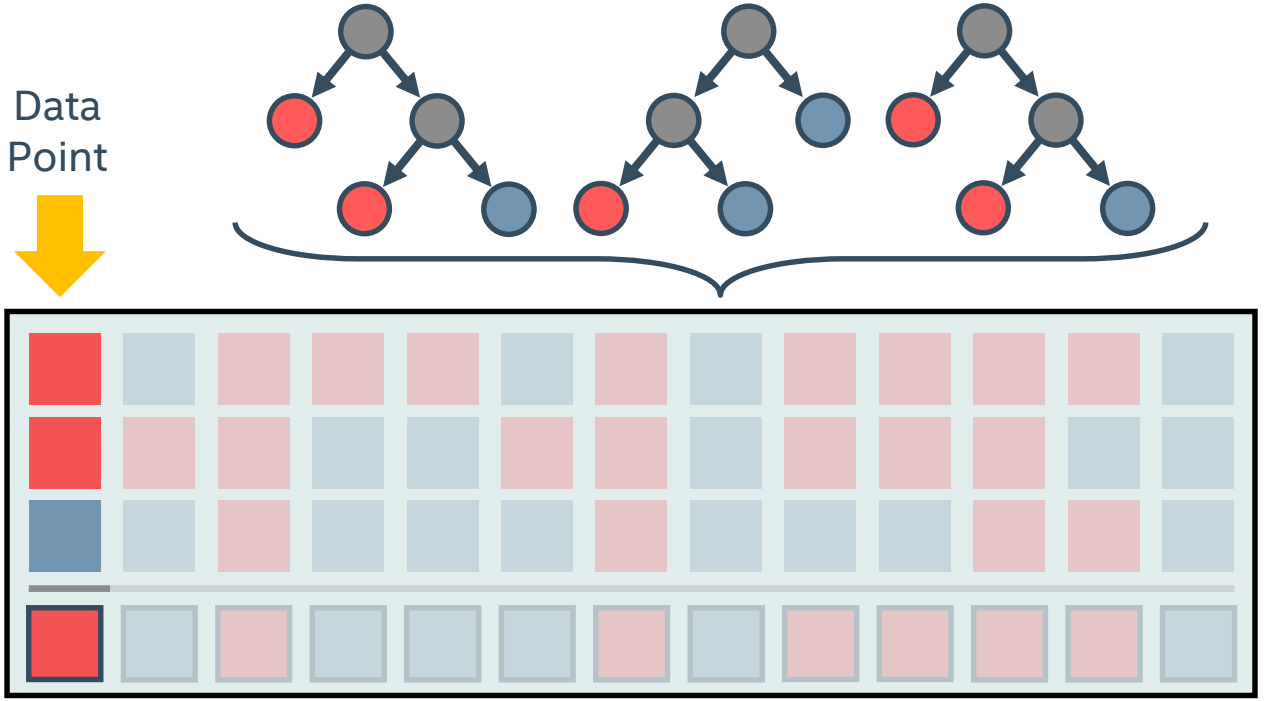

AGGREGATE RESULTS

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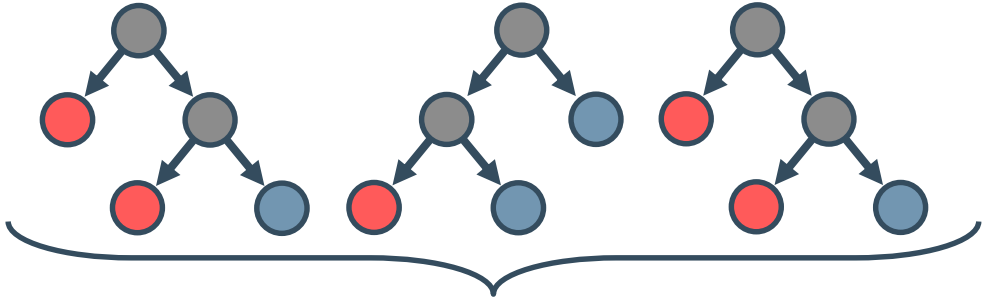
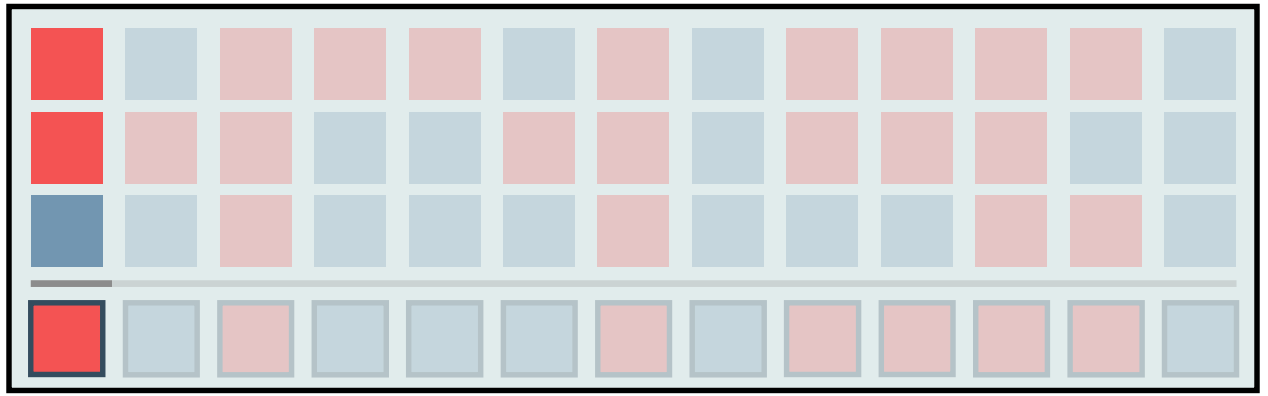


Vote to Form a Single Classifier

Results



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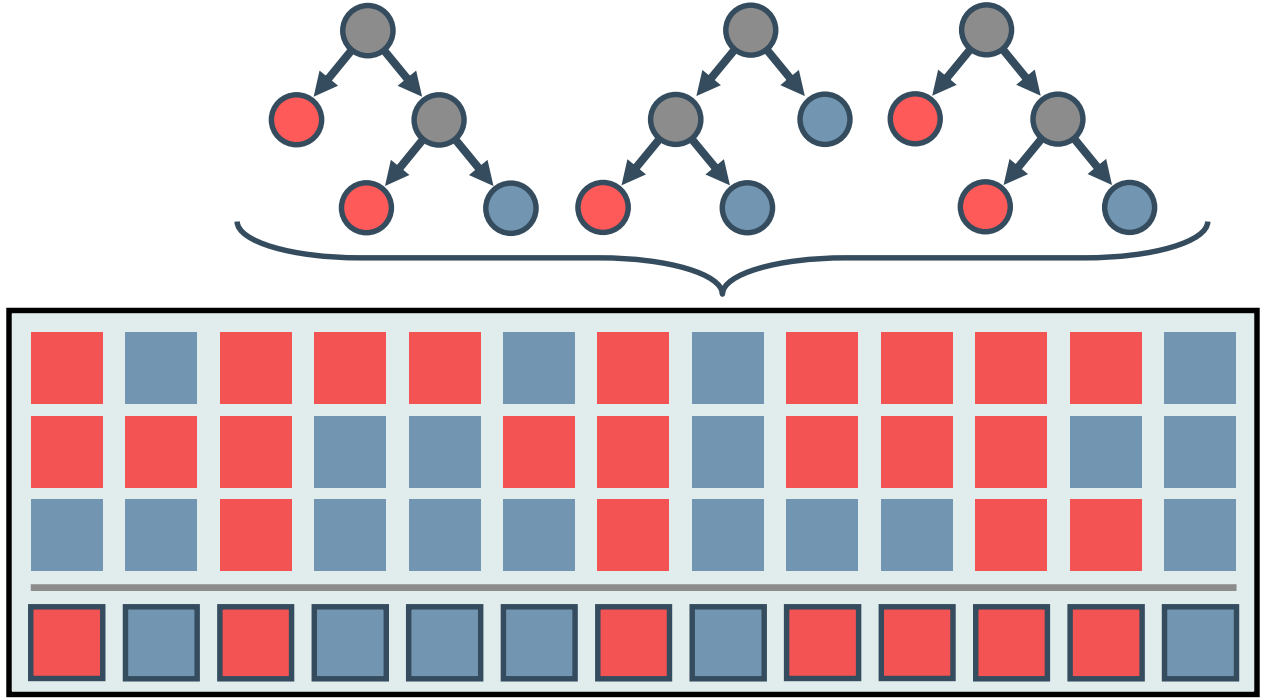

Vote to Form a Single Classifier

AGGREGATE RESULTS

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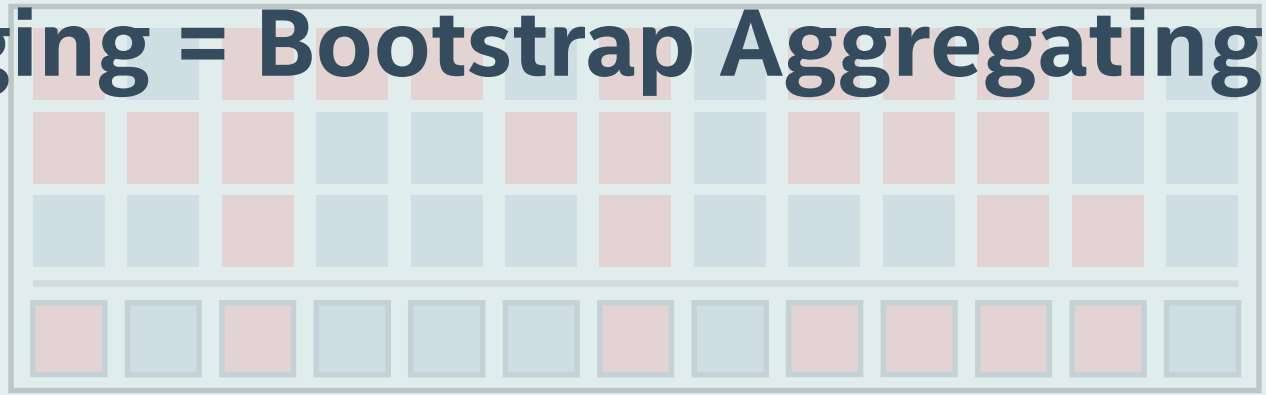
Bagging = Bootstrap Aggregating

Vote to Form a Single Classifier



BAGGING ERROR CALCULATIONS

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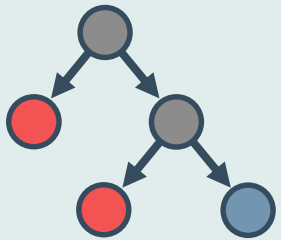

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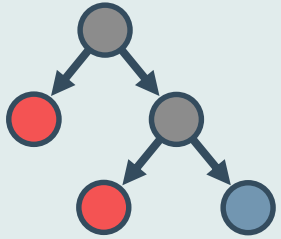

- Bootstrapped samples provide built-in error estimate for each tree

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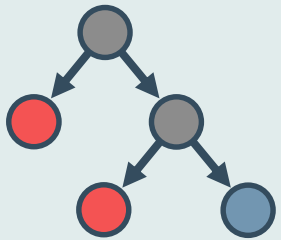

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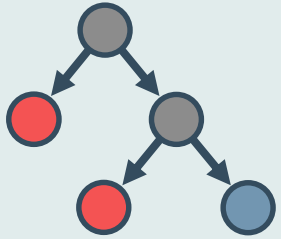
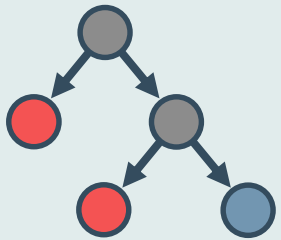


- Bootstrapped samples provide built-in error estimate for each tree
- Create tree based on subset of data

BAGGING ERROR CALCULATIONS

	Date	Title	Budget	DomesticTotalGross	Director	Rating	Runtime
0	2013-11-22	The Hunger Games: Catching Fire	130000000	424668047	Francis Lawrence	PG-13	146
1	2013-05-03	Iron Man 3	200000000	409013994	Shane Black	PG-13	129
2	2013-11-22	Frozen	150000000	400738009	Chris BuckJennifer Lee	PG	108
3	2013-07-03	Despicable Me 2	76000000	368061265	Pierre CoffinChris Renaud	PG	98
4	2013-06-14	Man of Steel	225000000	291045518	Zack Snyder	PG-13	143
5	2013-10-04	Gravity	100000000	274092705	Alfonso Cuaron	PG-13	91
6	2013-06-21	Monsters University	NaN	268492764	Dan Scanlon	G	107
7	2013-12-13	The Hobbit: The Desolation of Smaug	NaN	258366855	Peter Jackson	PG-13	161
8	2013-05-24	Fast & Furious 6	160000000	238679850	Justin Lin	PG-13	130
9	2013-03-08	Oz The Great and Powerful	215000000	234911825	Sam Raimi	PG	127
10	2013-05-16	Star Trek Into Darkness	190000000	228778661	J.J. Abrams	PG-13	123
11	2013-11-08	Thor: The Dark World	170000000	206362140	Alan Taylor	PG-13	120
12	2013-06-21	World War Z	190000000	202359711	Marc Forster	PG-13	116
13	2013-03-22	The Croods	135000000	187168425	Kirk De MiccoChris Sanders	PG	98
14	2013-06-28	The Heat	43000000	159582188	Paul Feig	R	117
15	2013-08-07	We're the Millers	37000000	150394119	Rawson Marshall Thurber	R	110
16	2013-12-13	American Hustle	40000000	150117807	David O. Russell	R	138
17	2013-05-10	The Great Gatsby	105000000	144840419	Baz Luhrmann	PG-13	143



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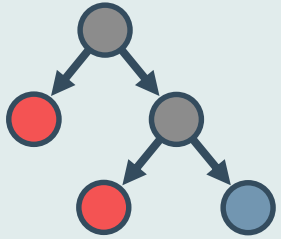

- Bootstrapped samples provide built-in error estimate for each tree
- Create tree based on subset of data
- Measure error for that tree on unused samples

BAGGING ERROR CALCULATIONS

	Date	Title	Budget	DomesticTotalGross	Director	Rating	Runtime
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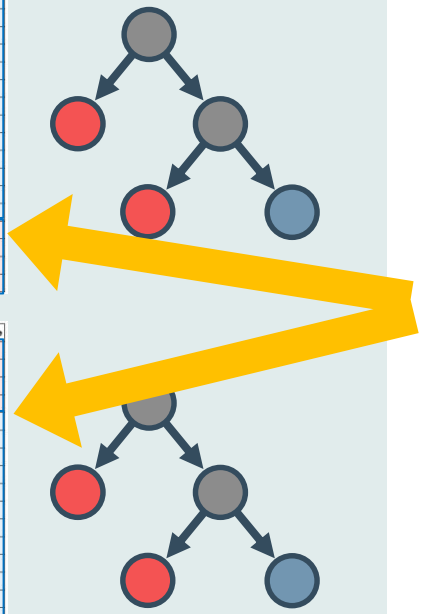

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- Bootstrapped samples provide built-in error estimate for each tree
- Create tree based on subset of data
- Measure error for that tree on unused samples

BAGGING ERROR CALCULATIONS

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0	2013-11-22	The Hunger Games: Catching Fire	130000000	424668047	Francis Lawrence	PG-13	146
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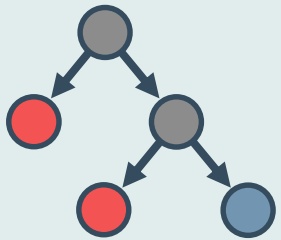

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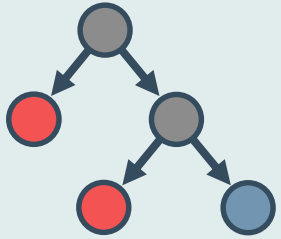

- Bootstrapped samples provide built-in error estimate for each tree
- Create tree based on subset of data
- Measure error for that tree on unused samples
- Called “Out-of-Bag” error

CALCULATION OF FEATURE IMPORTANCE

	Date	Title	Budget	DomesticTotalGross	Director	Rating	Runtime
0	2013-11-22	The Hunger Games: Catching Fire	130000000	424668047	Francis Lawrence	PG-13	146
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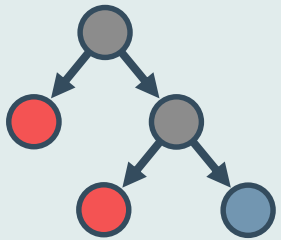

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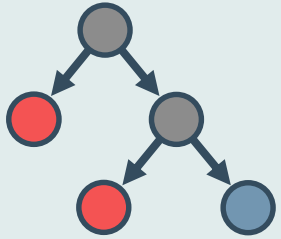

- Fitting a bagged model doesn't produce coefficients like logistic regression

CALCULATION OF FEATURE IMPORTANCE

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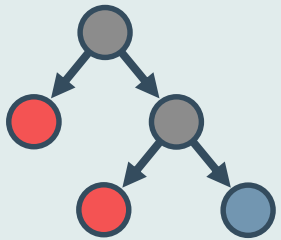

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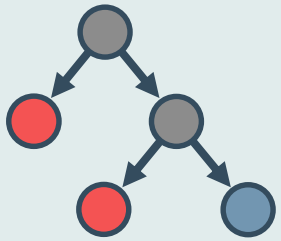

- Fitting a bagged model doesn't produce coefficients like logistic regression
- Instead, feature importances are estimated using oob error

CALCULATION OF FEATURE IMPORTANCE

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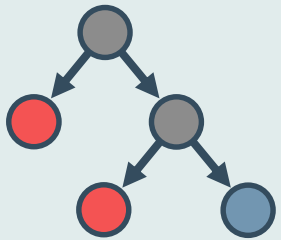

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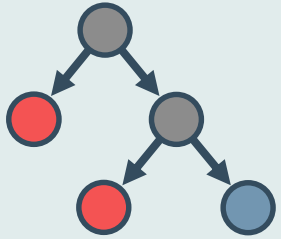
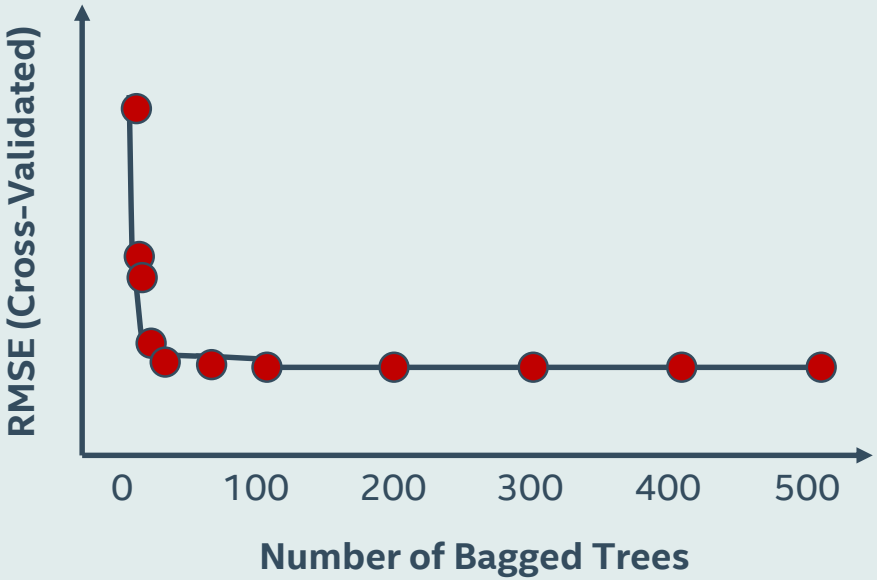


- Fitting a bagged model doesn't produce coefficients like logistic regression
- Instead, feature importances are estimated using oob error
- Randomly permute data for particular feature and measure change in accuracy

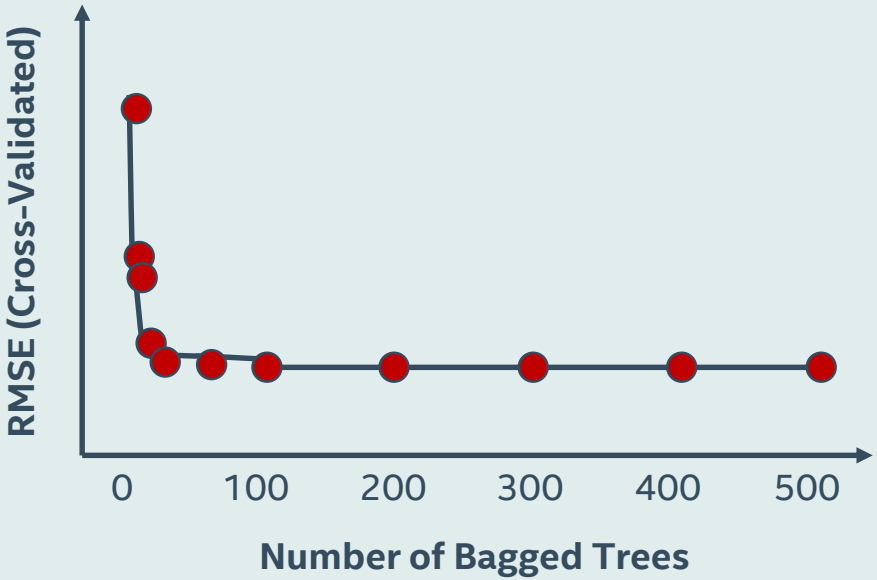
HOW MANY TREES TO FIT?

- Bagging performance improvements increase with more trees



HOW MANY TREES TO FIT?

- Bagging performance improvements increase with more trees
- Maximum improvement generally reached ~50 trees



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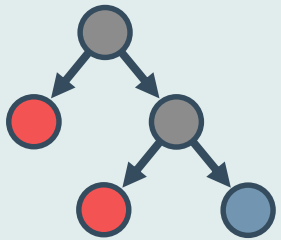

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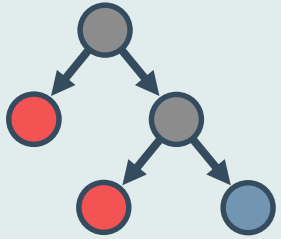

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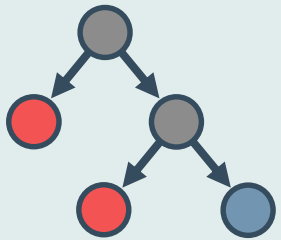

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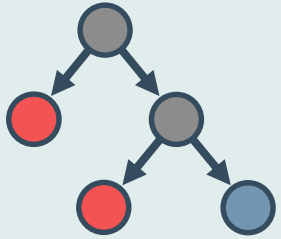

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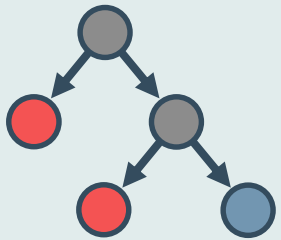

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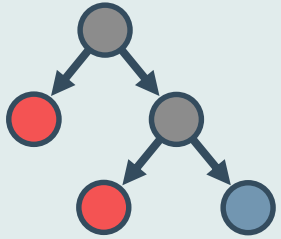

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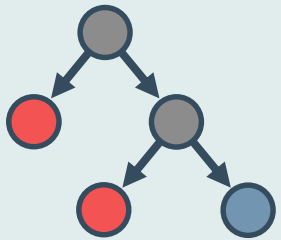

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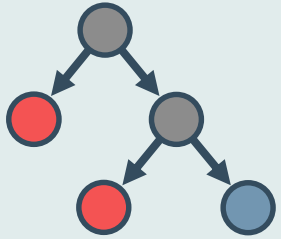

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BAGGINGCLASSIFIER: THE SYNTAX

Import the class containing the classification method.

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Fit the instance on the data and then predict the expected value.

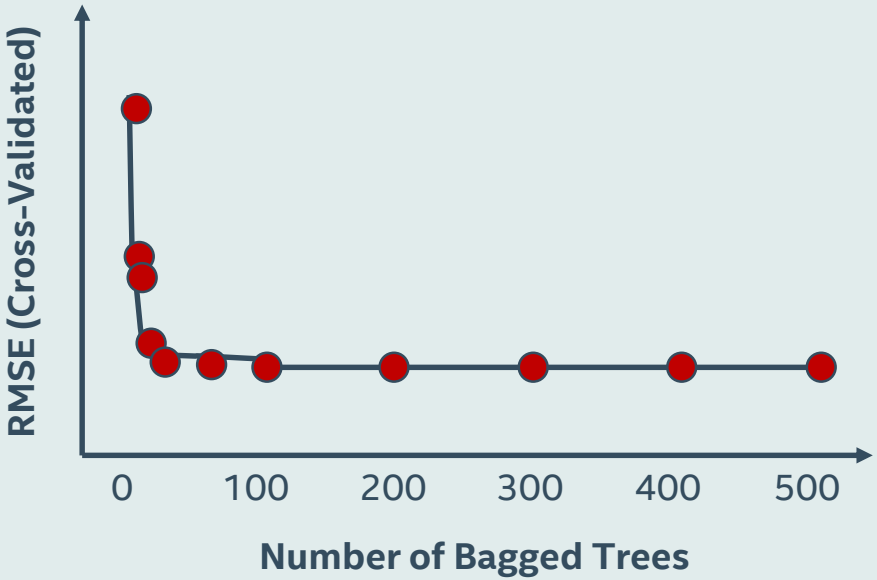
```
BC = BC.fit(X_train, y_train)
y_predict = BC.predict(X_test)
```

Tune parameters with cross-validation. Use **BaggingRegressor** for regression.

REDUCTION IN VARIANCE DUE TO BAGGING

- For n independent trees, each with variance σ^2, the bagged variance is:

$$\frac{\sigma^2}{n}$$



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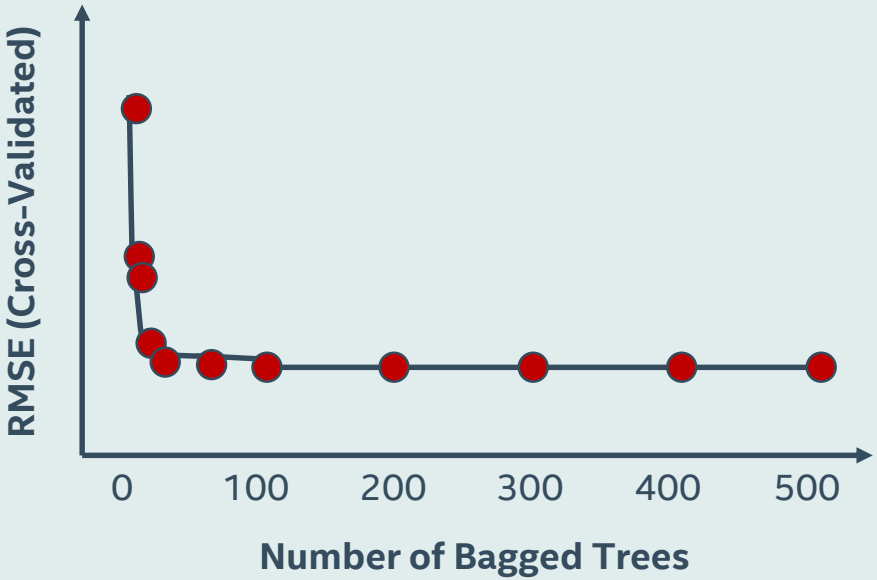
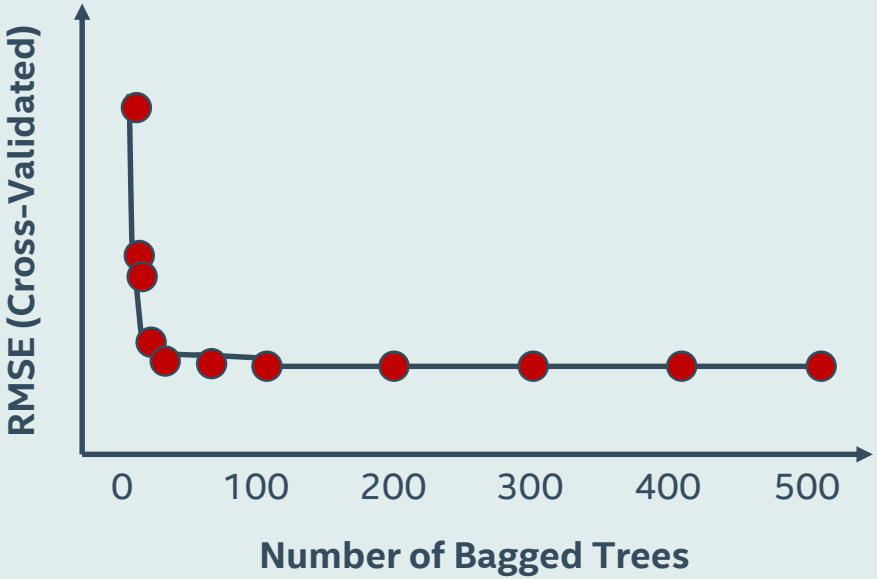
- However, bootstrap samples are correlated (ρ):

$$\rho\sigma^2 + \frac{1-\rho}{n}\sigma^2$$



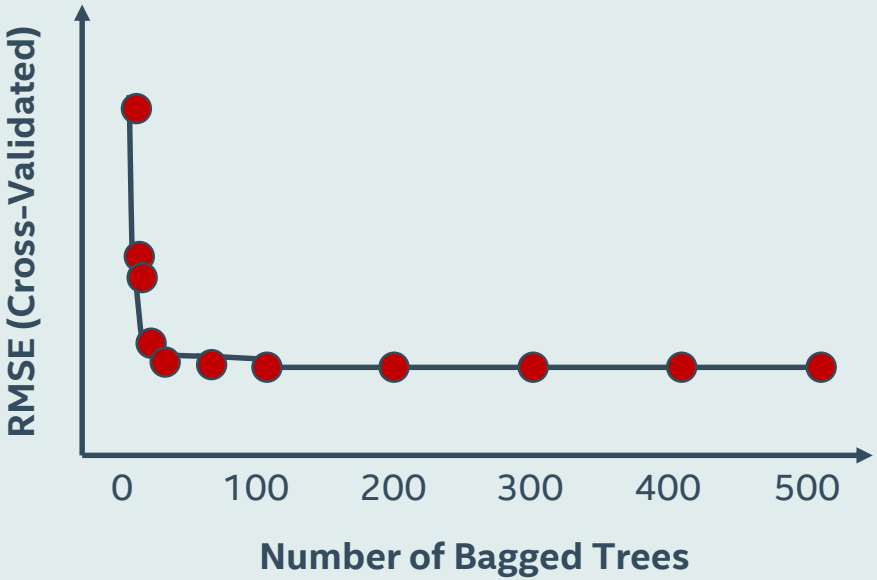
INTRODUCING MORE RANDOMNESS

- Solution: further de-correlate trees



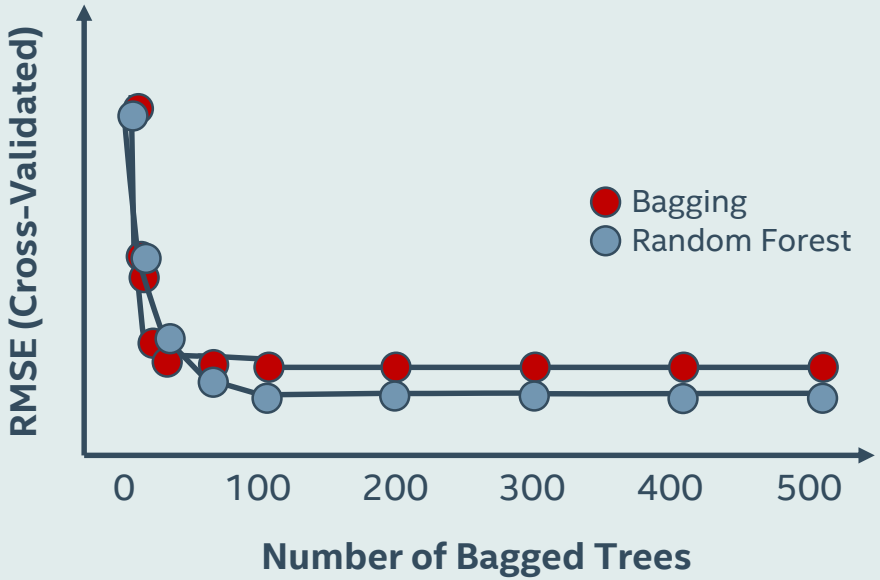
INTRODUCING MORE RANDOMNESS

- **Solution: further de-correlate trees**
- **Use random subset of features for each tree**
  - Classification: $\sqrt{m}$
  - Regression: $m/3$



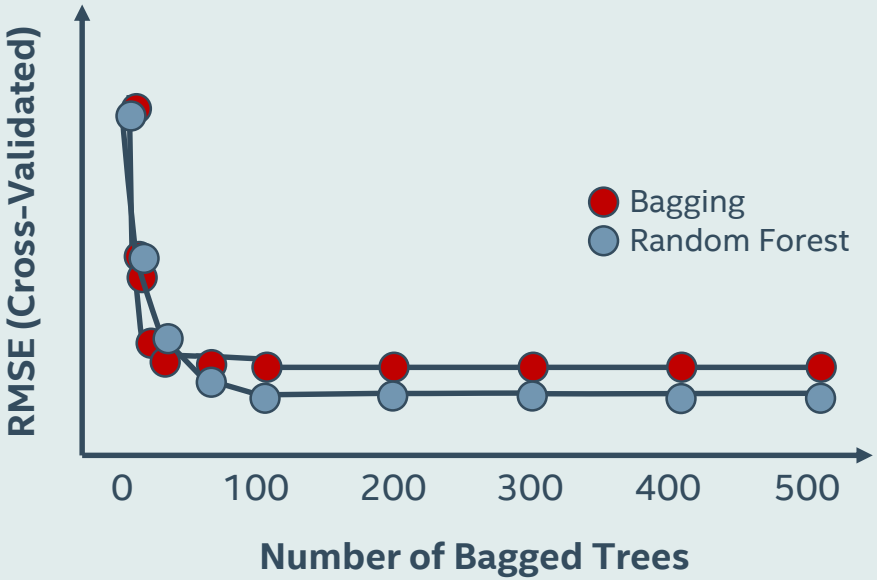
INTRODUCING MORE RANDOMNESS

- **Solution:**
  further de-correlate trees
- **Use random subset of features for each tree**
  - Classification: $\sqrt{m}$
  - Regression: $m/3$
- **Called "Random Forest"**



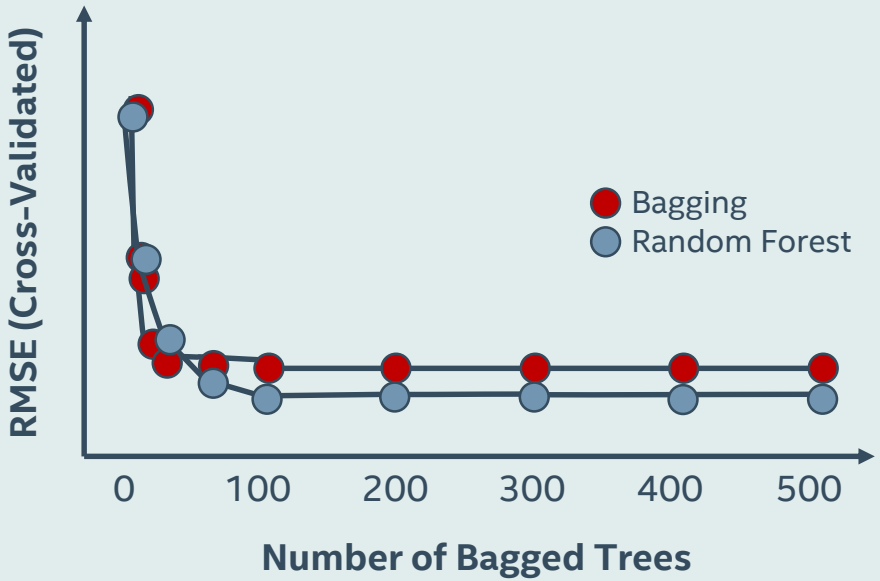
HOW MANY RANDOM FOREST TREES?

- Errors are further reduced for Random Forest relative to Bagging



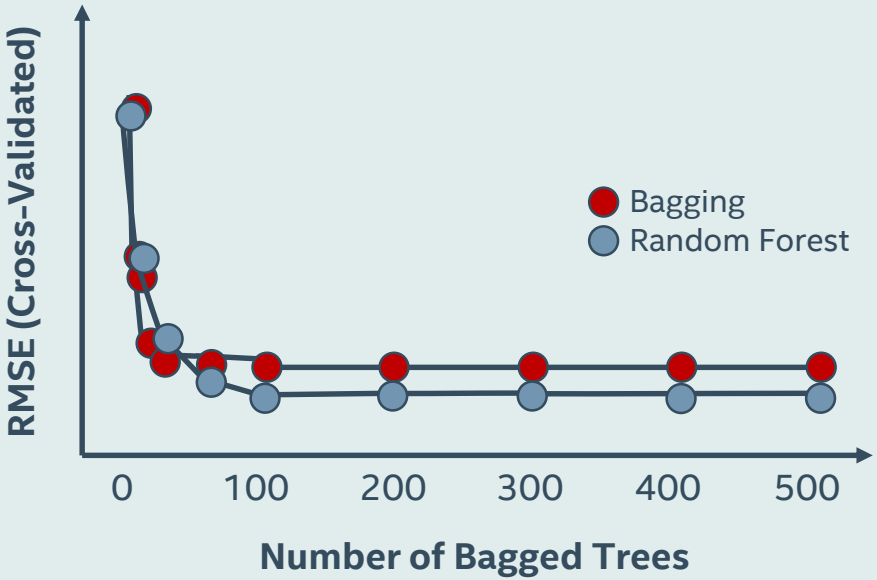
HOW MANY RANDOM FOREST TREES?

- Errors are further reduced for Random Forest relative to Bagging
- Grow enough trees until error settles down



HOW MANY RANDOM FOREST TREES?

- Errors are further reduced for Random Forest relative to Bagging
- Grow enough trees until error settles down
- Additional trees won't improve results



RANDOMFOREST: THE SYNTAX

Import the class containing the classification method.

```
from sklearn.ensemble import RandomForestClassifier
```

Create an instance of the class.

```
RC = RandomForestClassifier(n_estimators=100, max_features=10)
```

Fit the instance on the data and then predict the expected value.

```
RC = RC.fit(X_train, y_train)
y_predict = RC.predict(X_test)
```

Tune parameters with cross-validation. Use **RandomForestRegressor** for regression.

INTRODUCING EVEN MORE RANDOMNESS

- Sometimes additional randomness is desired beyond Random Forest

INTRODUCING EVEN MORE RANDOMNESS

- Sometimes additional randomness is desired beyond Random Forest
- Solution: select features randomly and create splits randomly—don't choose greedily

INTRODUCING EVEN MORE RANDOMNESS

- Sometimes additional randomness is desired beyond Random Forest
- Solution: select features randomly and create splits randomly—don't choose greedily
- Called “Extra Random Trees”

EXTRATREESCLASSIFIER: THE SYNTAX

Import the class containing the classification method.

```
from sklearn.ensemble import ExtraTreesClassifier
```

Create an instance of the class.

```
EC = ExtraTreesClassifier(n_estimators=100, max_features=10)
```

Fit the instance on the data and then predict the expected value.

```
EC = EC.fit(X_train, y_train)
y_predict = EC.predict(X_test)
```

Tune parameters with cross-validation. Use **ExtraTreesRegressor** for regression.

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