Bagging

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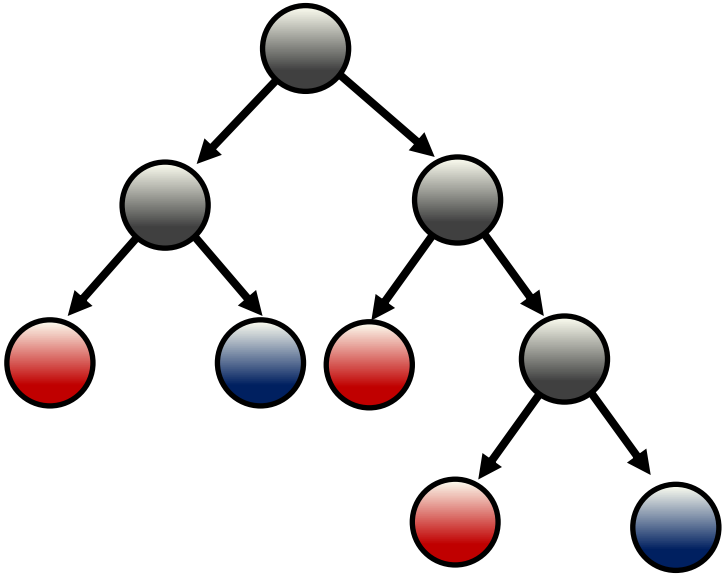
Learning Objectives

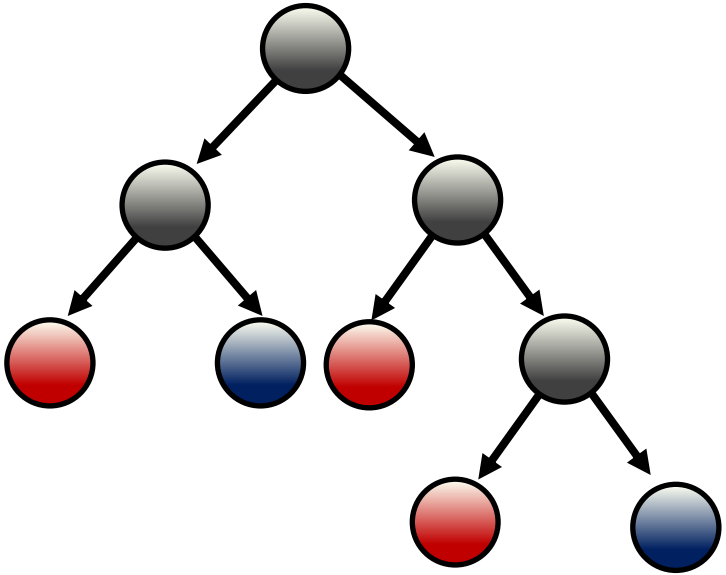
- Associate concepts of bootstrapping and aggregating (commonly known as “bagging”) to reduce variance
- Apply Random Forest algorithm that further reduces the correlation seen in bagging models
- Apply Intel® Extension for Scikit-learn* to leverage underlying compute capabilities of hardware

Decision Trees are High Variance



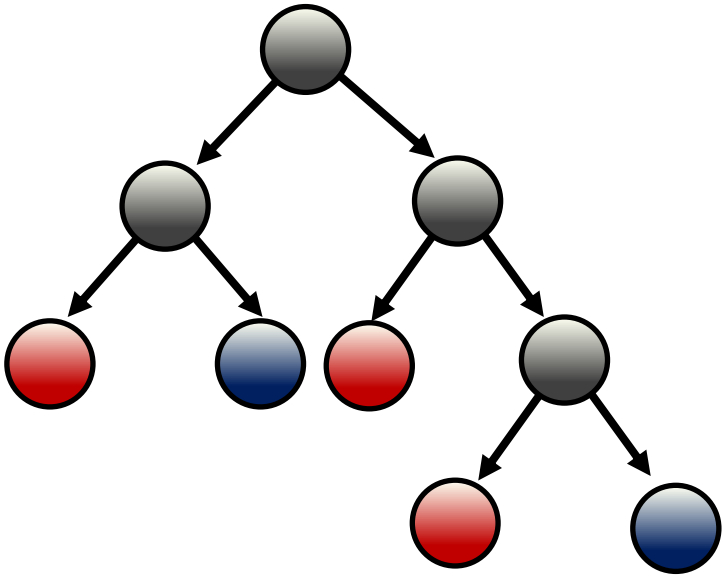
- Problem: decision trees tend to overfit

Decision Trees are High Variance



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

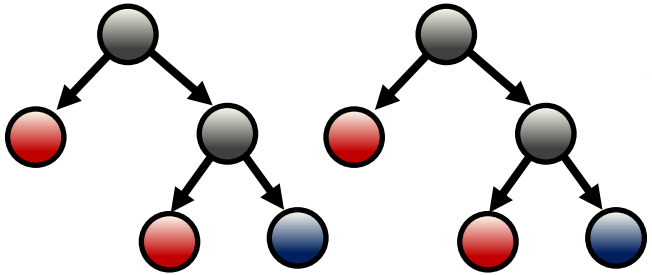
Decision Trees are High Variance



- 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



Improvement: Use Many Trees

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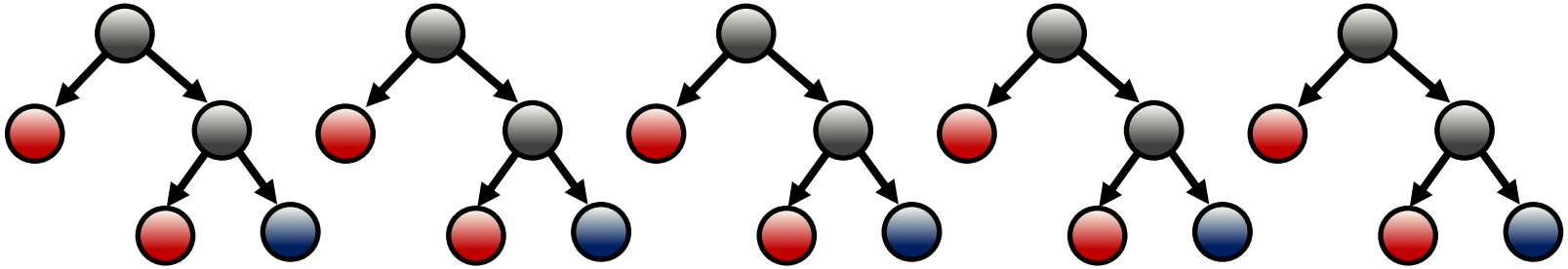

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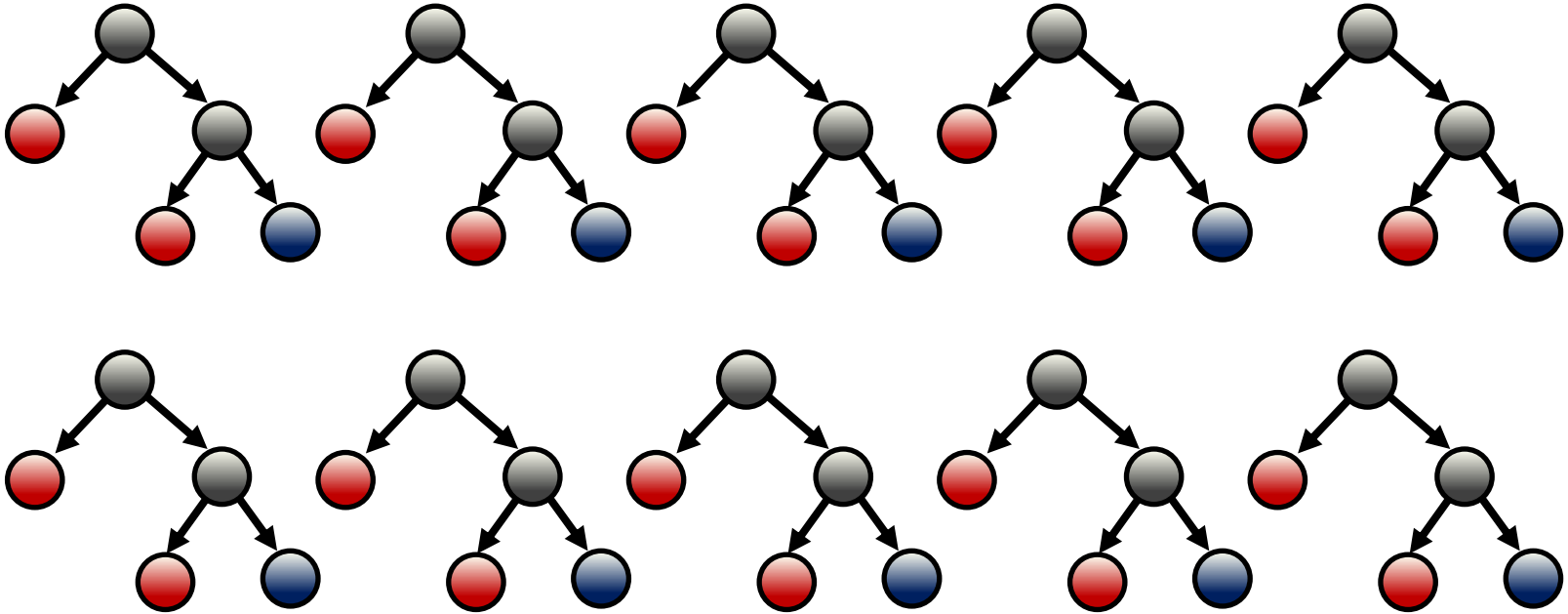
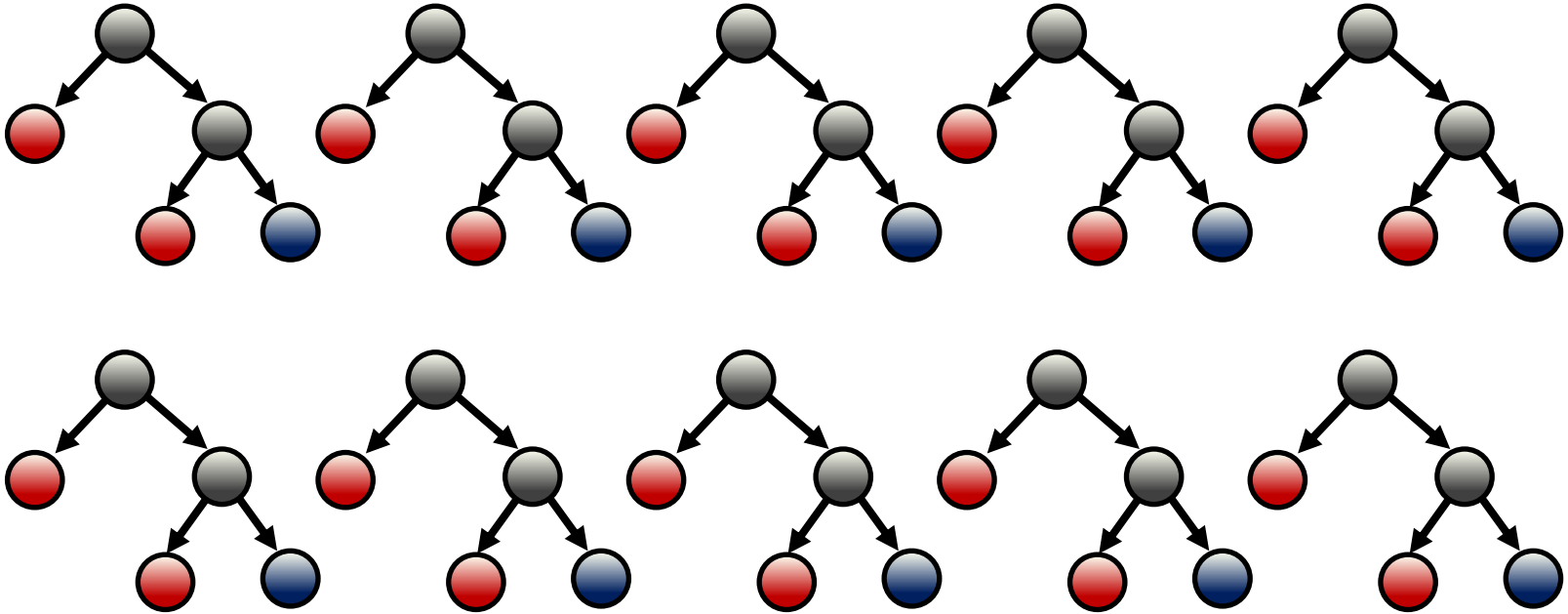


Improvement: Use Many Trees

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
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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	258366855	Peter Jackson	PG-13	161
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How to Create Multiple Trees?

Create multiple bootstrapped samples

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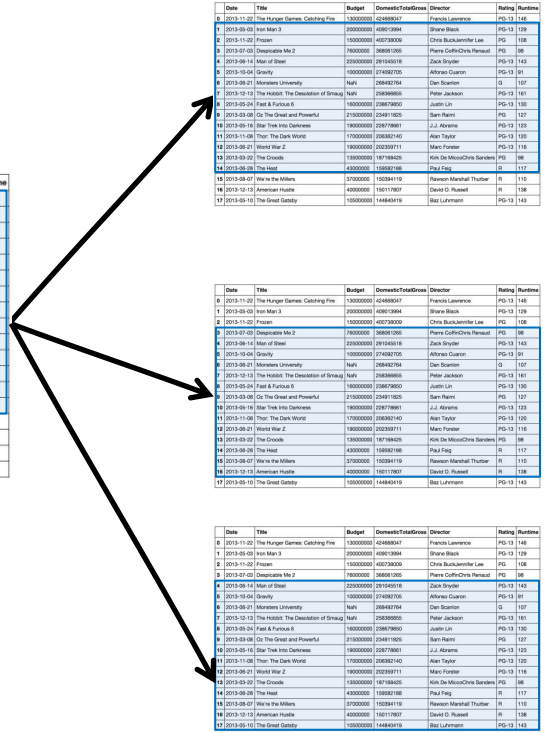

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How to Create Multiple Trees?

Grow decision tree from each bootstrapped sample

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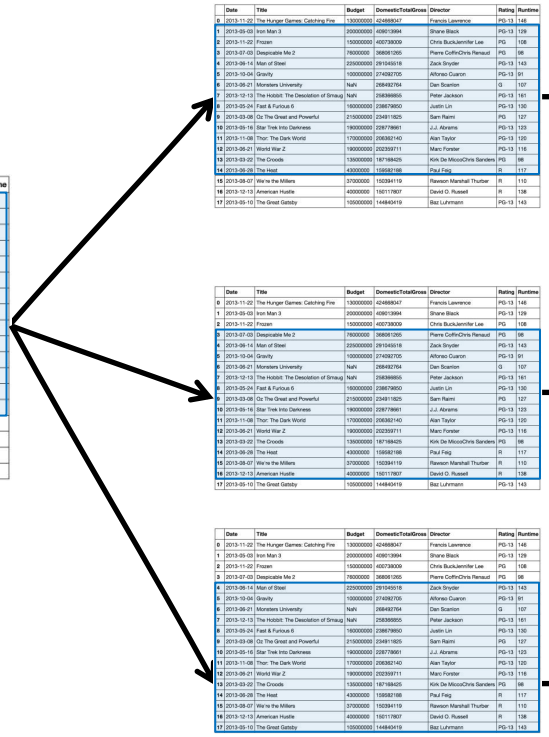

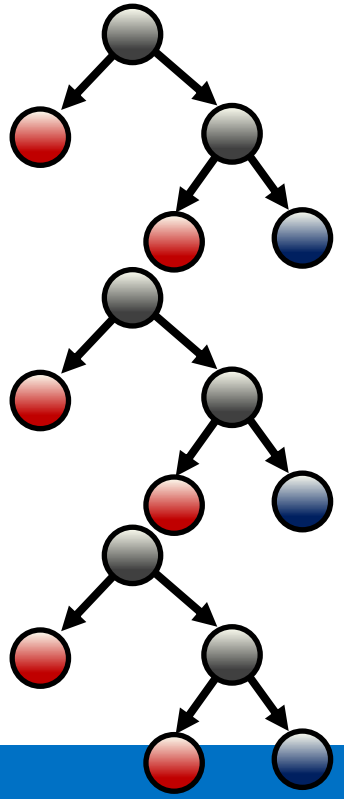

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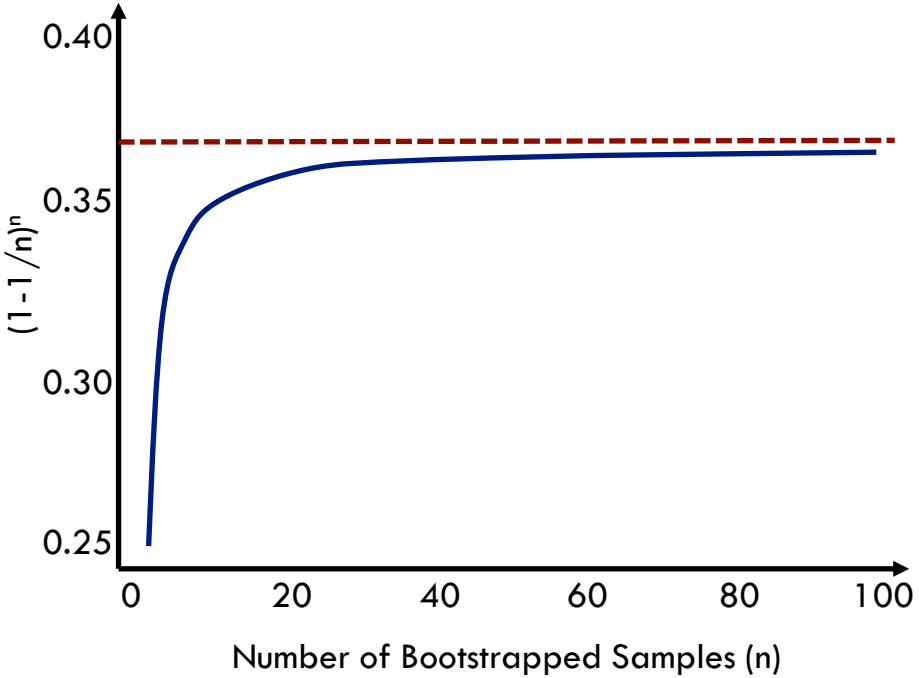
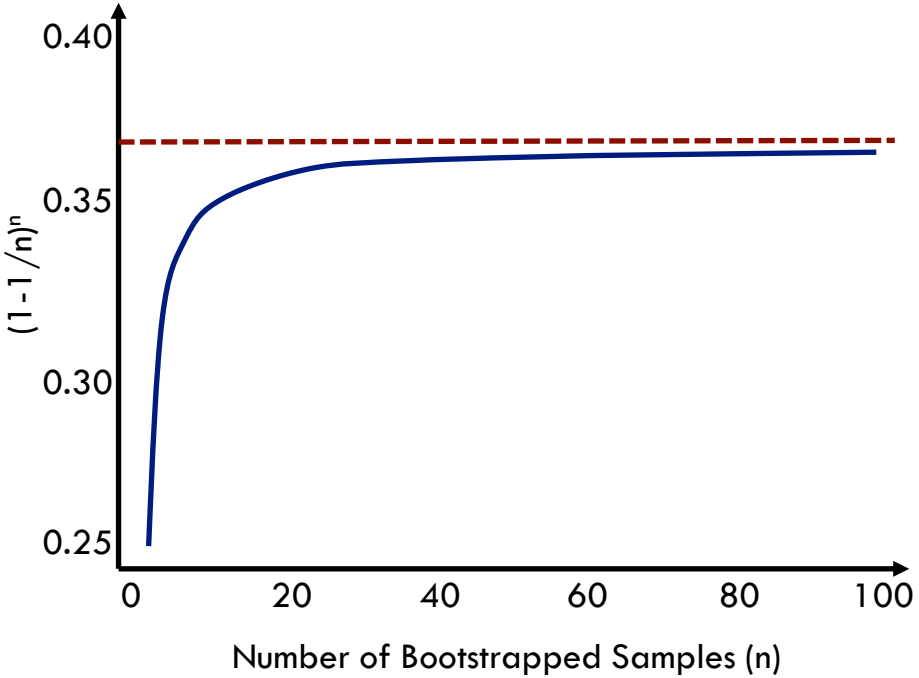
Distribution of Data in Bootstrapped Samples



- Given a dataset, create n bootstrapped samples

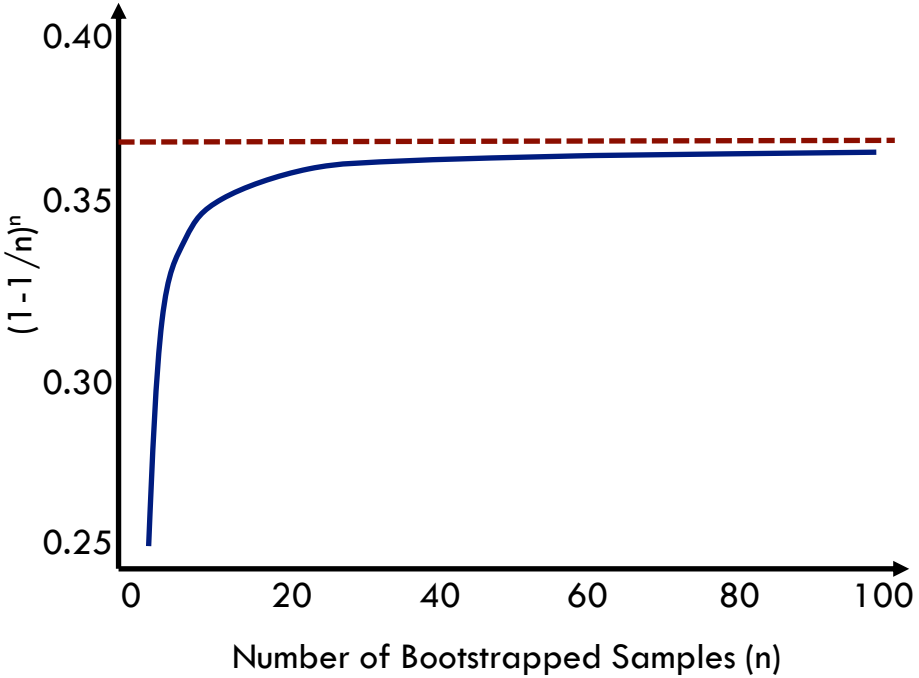
Distribution of Data in Bootstrapped Samples



- 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

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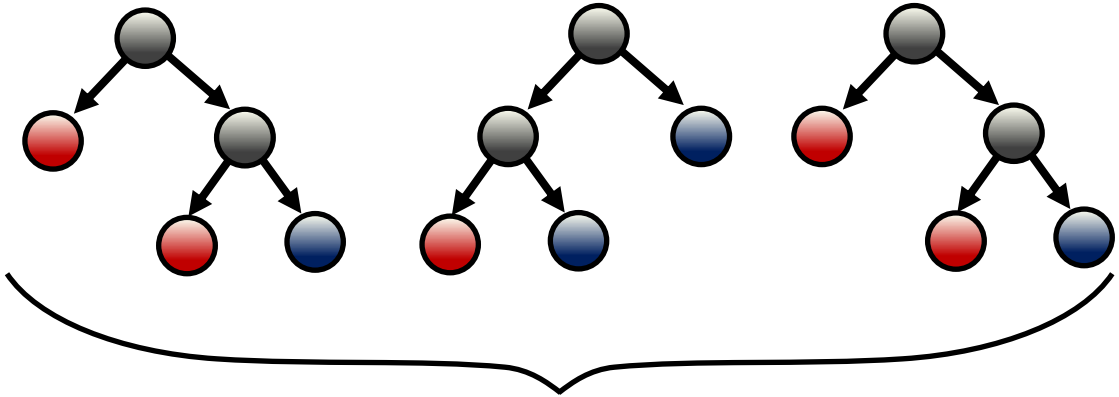
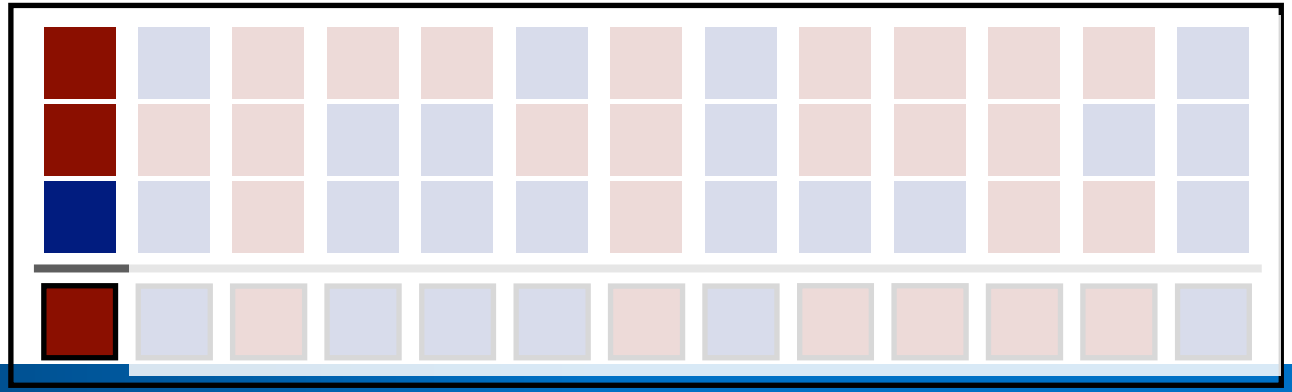
Aggregate Results

Trees vote on or average result for each data point



Vote to Form a Single Classifier



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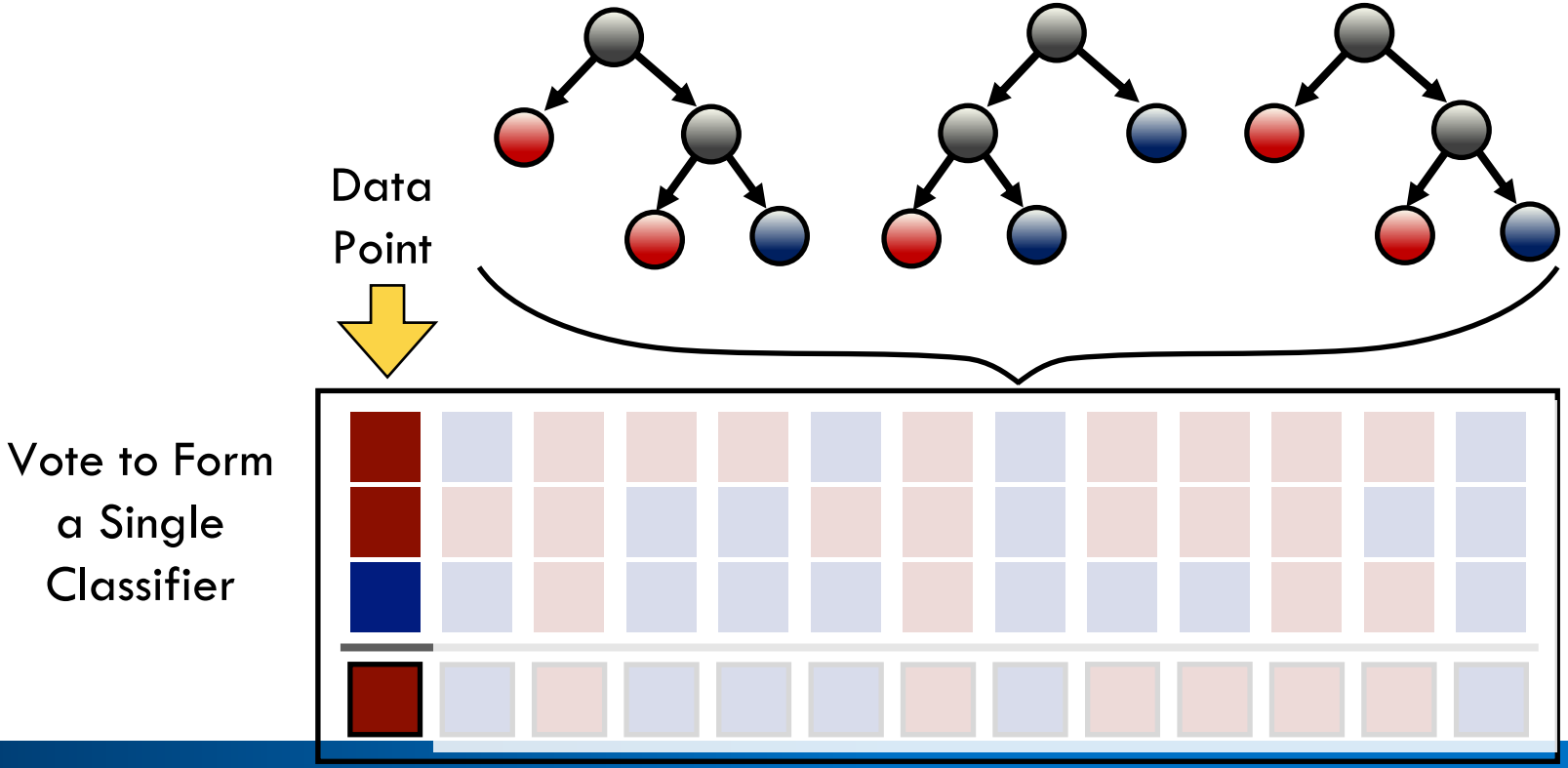

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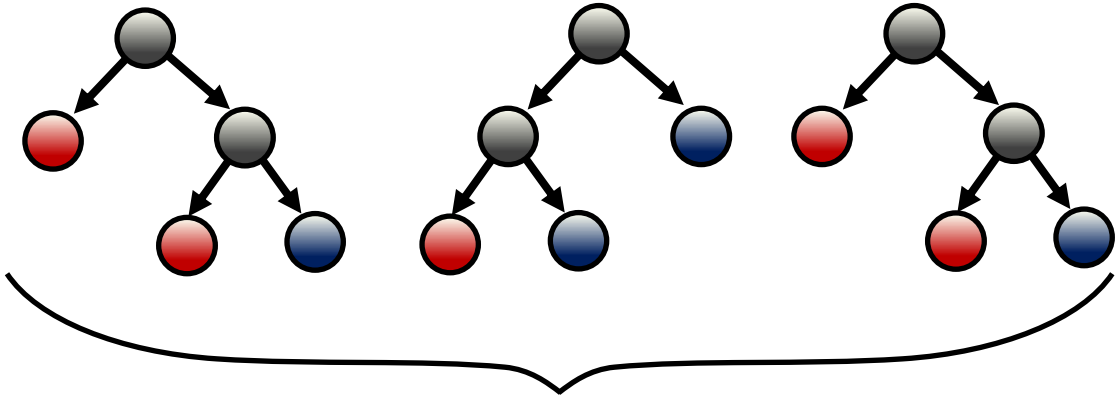

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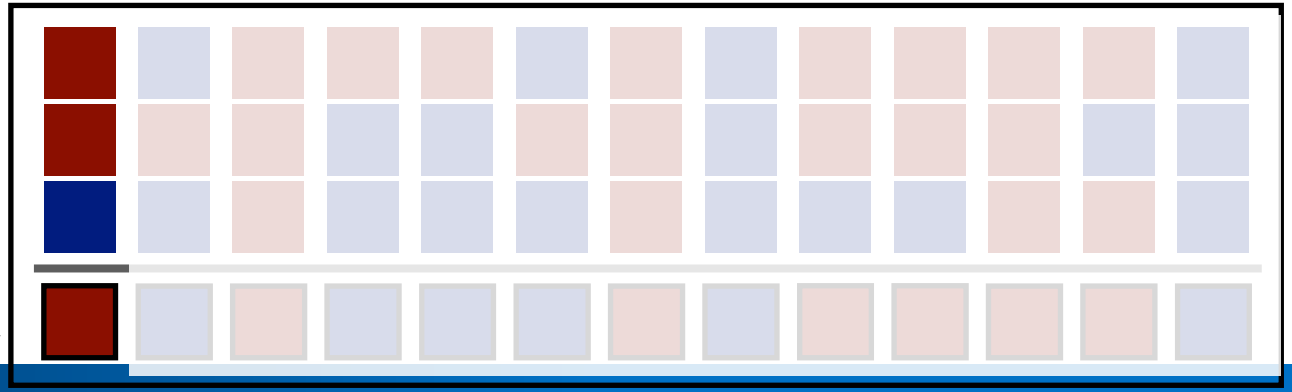

Results

Aggregate Results

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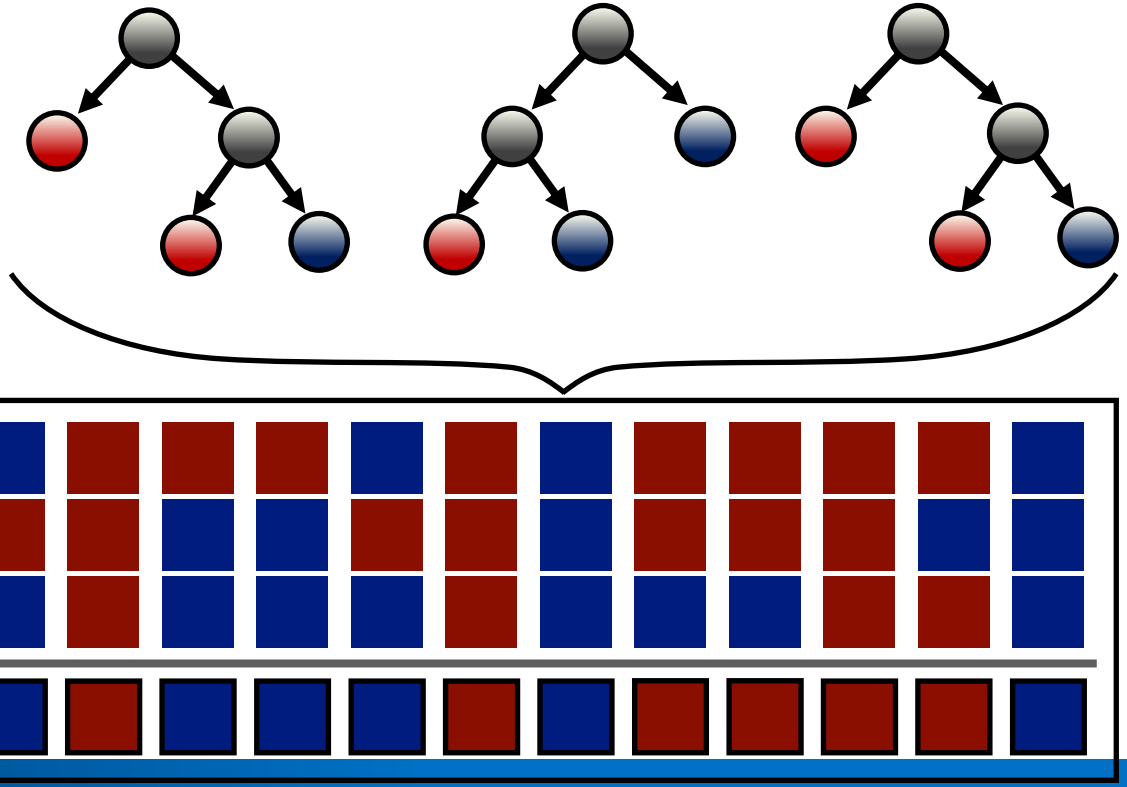

Vote to Form a Single Classifier

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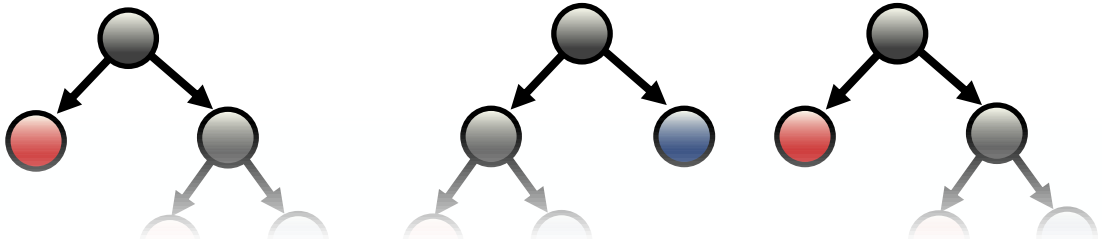

Bagging = Bootstrap Aggregating

a Single
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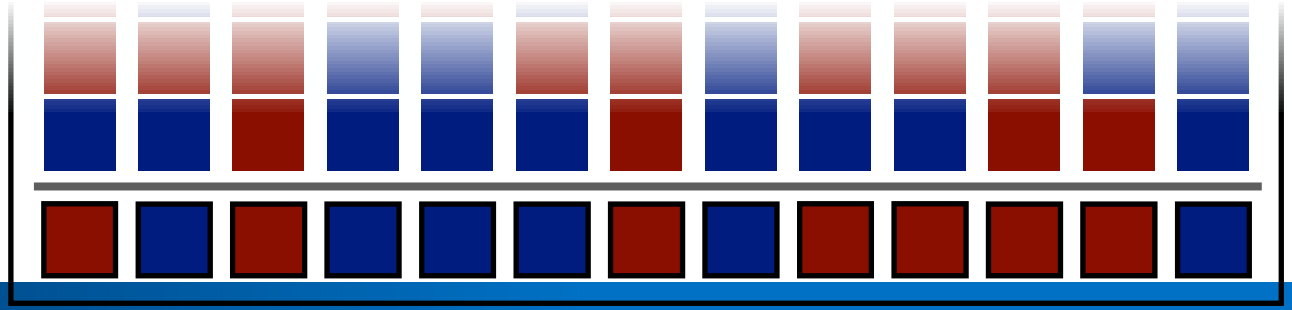

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Bagging error calculations

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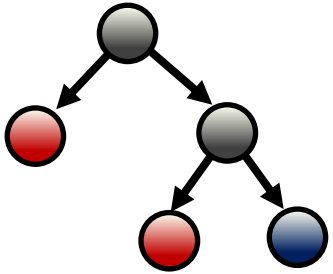

- Bootstrapped samples provide built-in error estimate for each tree
- Create tree based on subset of

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2	2013-11-22	Frozen	150000000	400738009	Chris BuckJennifer Lee	PG	108
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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
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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
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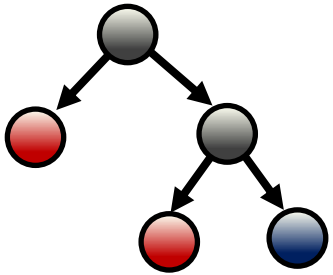

Bagging error calculations

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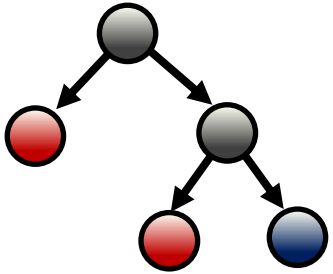

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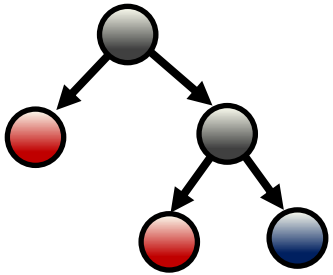

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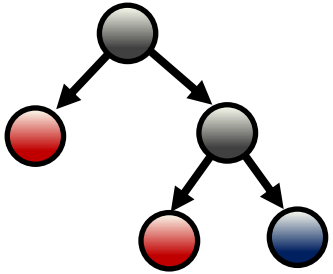

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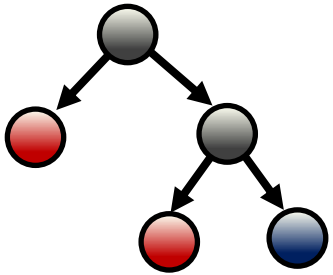

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Bagging error calculations

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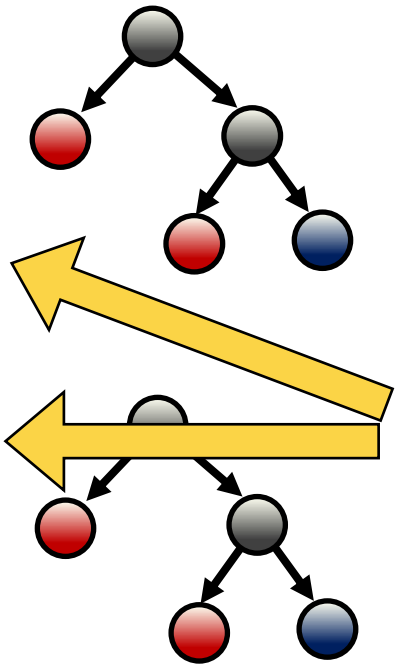

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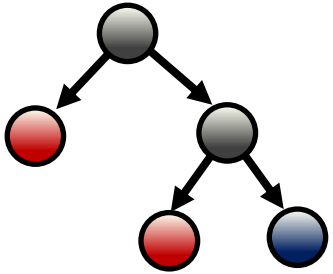

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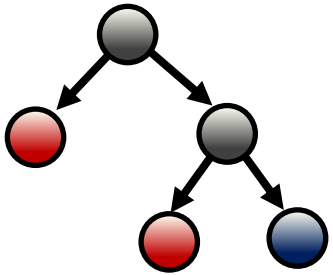

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Calculation of Feature Importance

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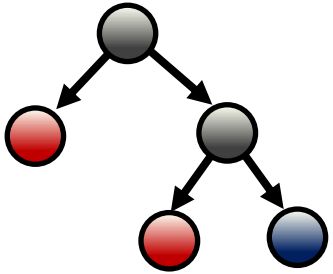

- Fitting a bagged model doesn't produce coefficients like logistic regression

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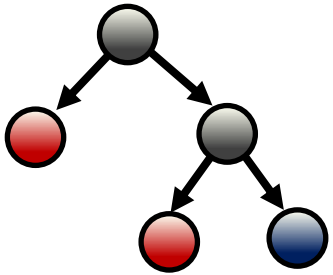

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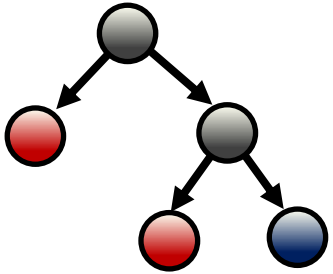

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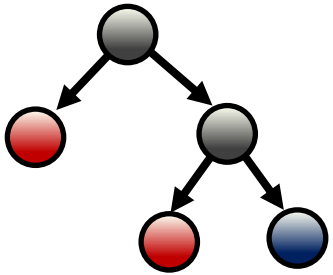

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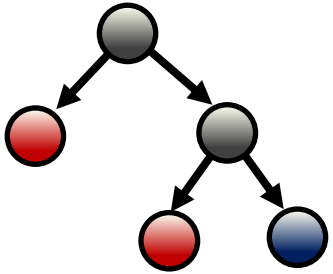

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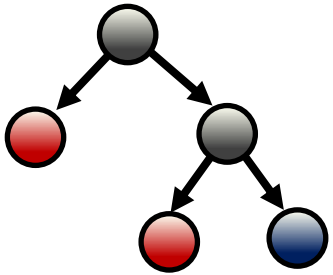
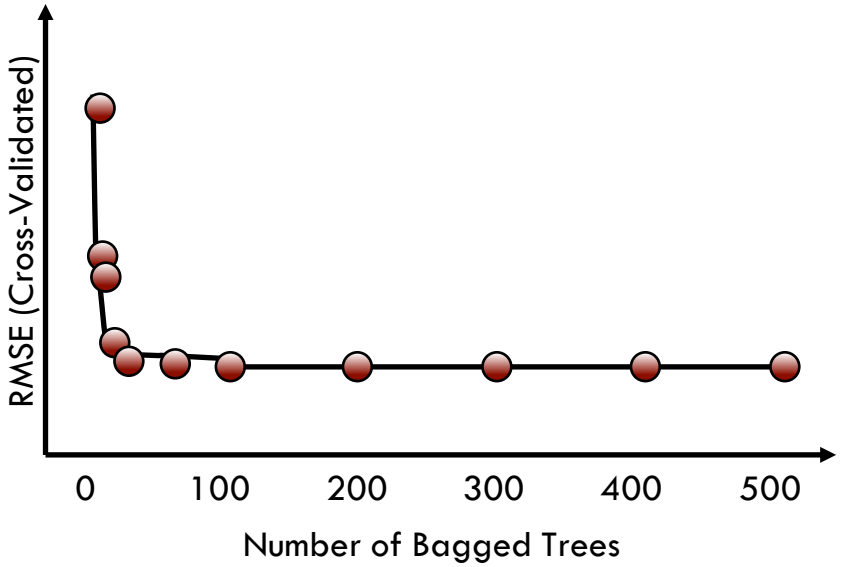


- Randomly permute data for particular feature and measure change in accuracy

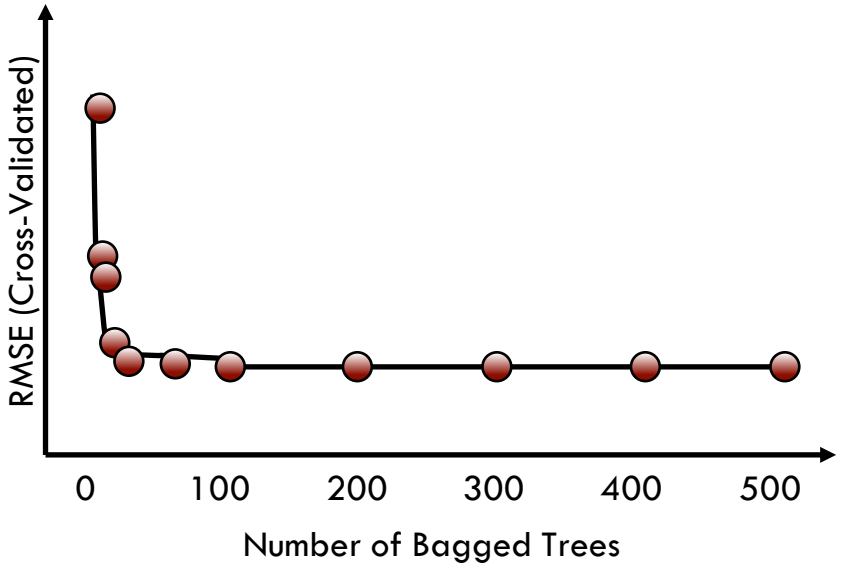
How Many Trees to Fit?

- 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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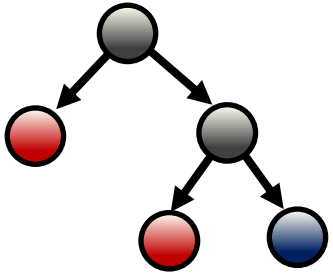

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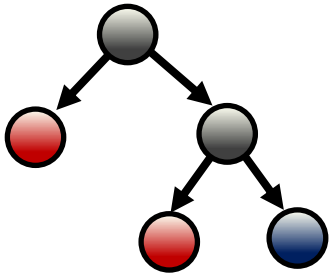

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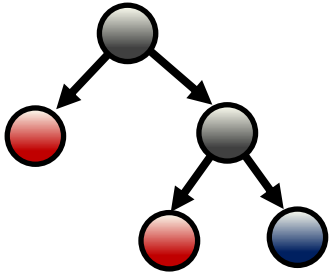

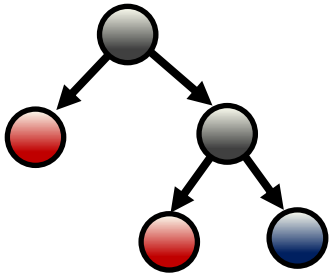

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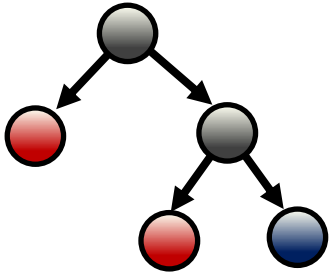

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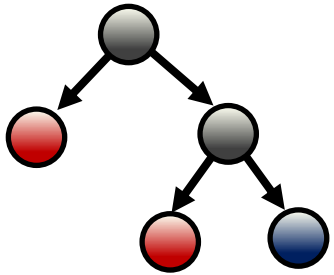

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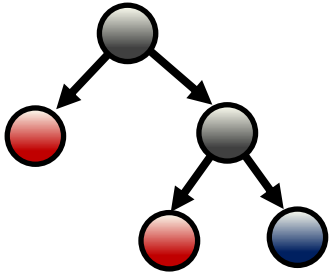
Specific to bagging:

- Less variability than decision trees

Strengths of Bagging

	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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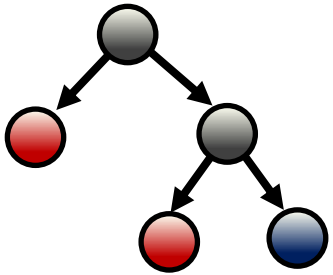

Same as decision trees:

- Easy to interpret and implement
- Heterogeneous input data allowed, no preprocessing required

Specific to bagging:

- Less variability than decision trees
- Can grow trees in parallel

BaggingClassifier: The Syntax

Import the class containing the classification method

```
from sklearn.ensemble import BaggingClassifier
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Create an instance of the class

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BC = BaggingClassifier(n_estimators=50)
```

BaggingClassifier: The Syntax

Import the class containing the classification method

```
from sklearn.ensemble import BaggingClassifier
```

Create an instance of the class

```
BC = BaggingClassifier(n_estimators=50)
```

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

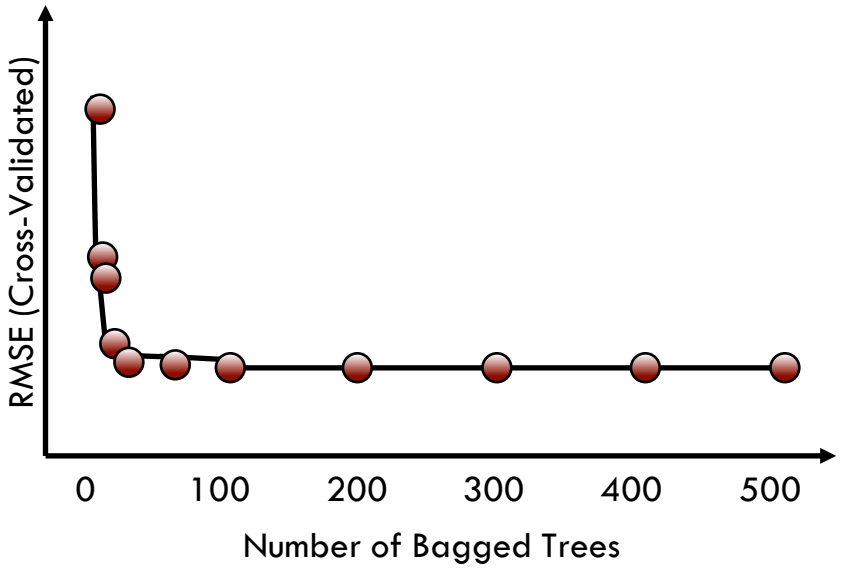
```
BC = BC.fit(X_train, y_train)
y_predict = BC.predict(X_test)
```

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:

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



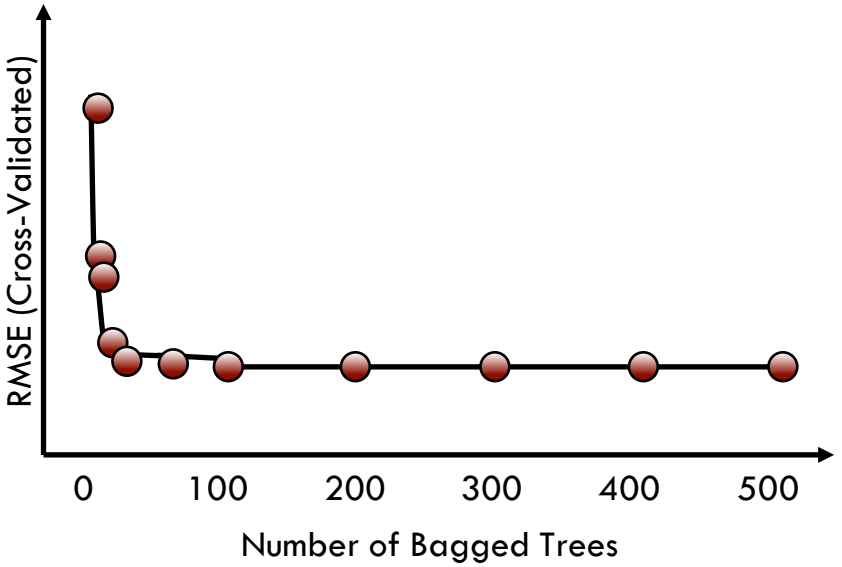
Reduction in Variance Due to Bagging

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

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

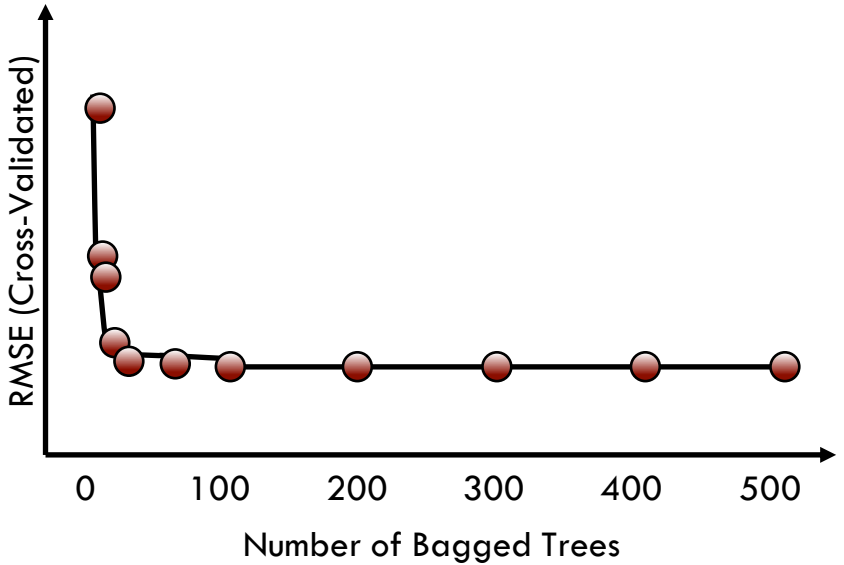
- However, bootstrap samples are correlated (ρ):

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



Introducing More Randomness

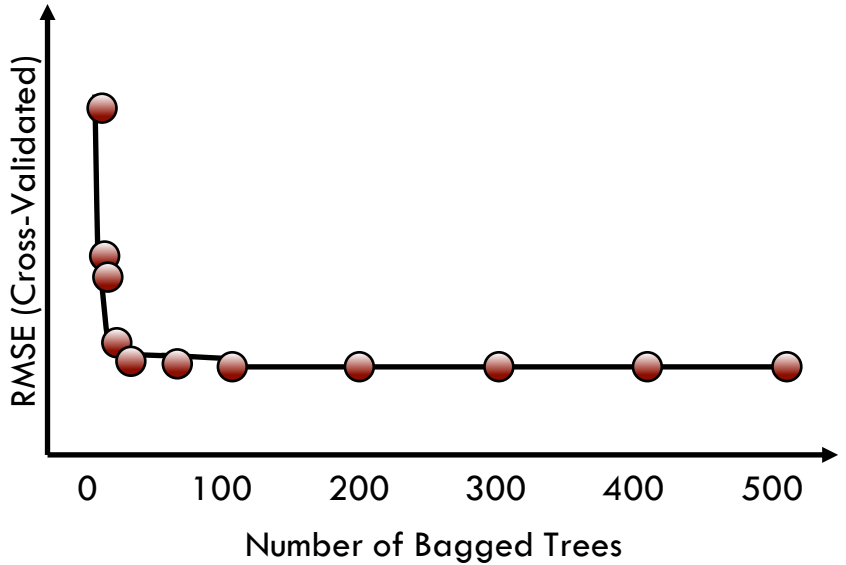
- Solution: further de-correlate trees



Introducing More Randomness

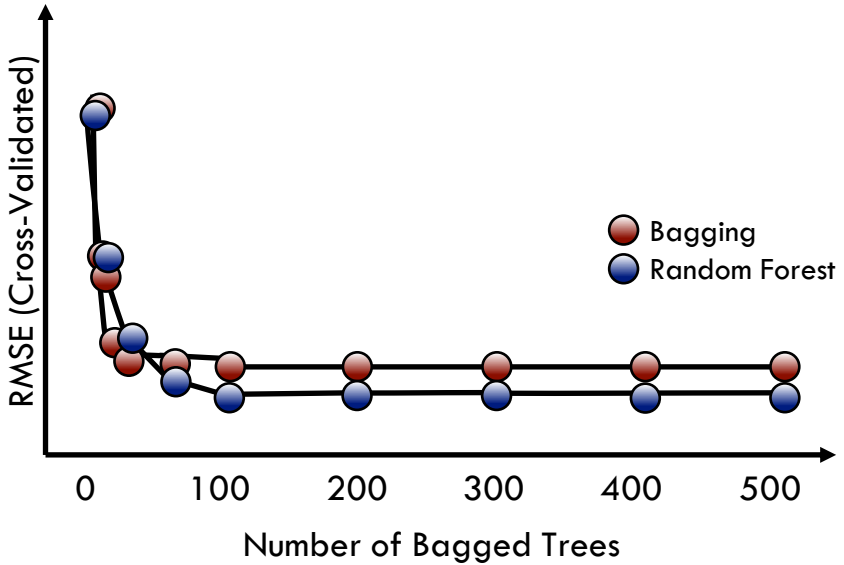
- Solution: further de-correlate trees

- Use random subset of features for each tree
  - Classification: $\sqrt{m}$
  - Regression: $m/3$



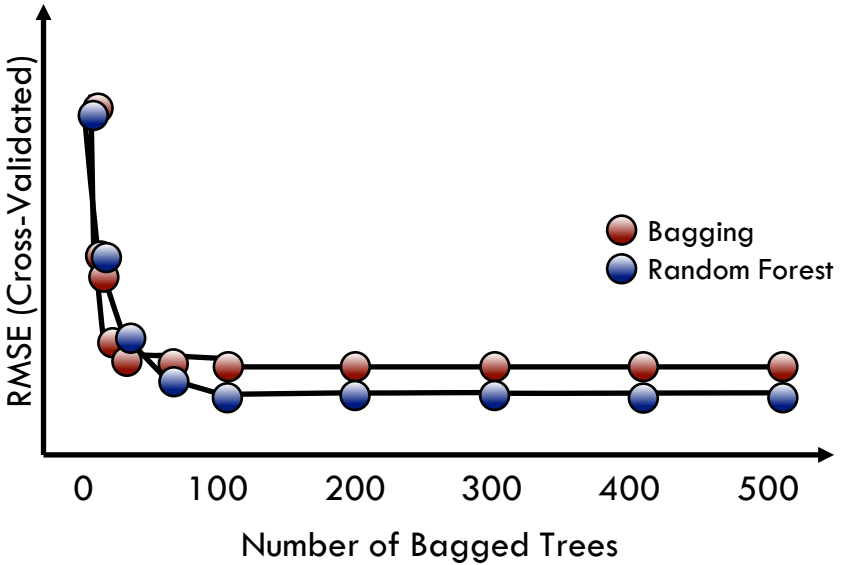
Introducing More Randomness

- 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?

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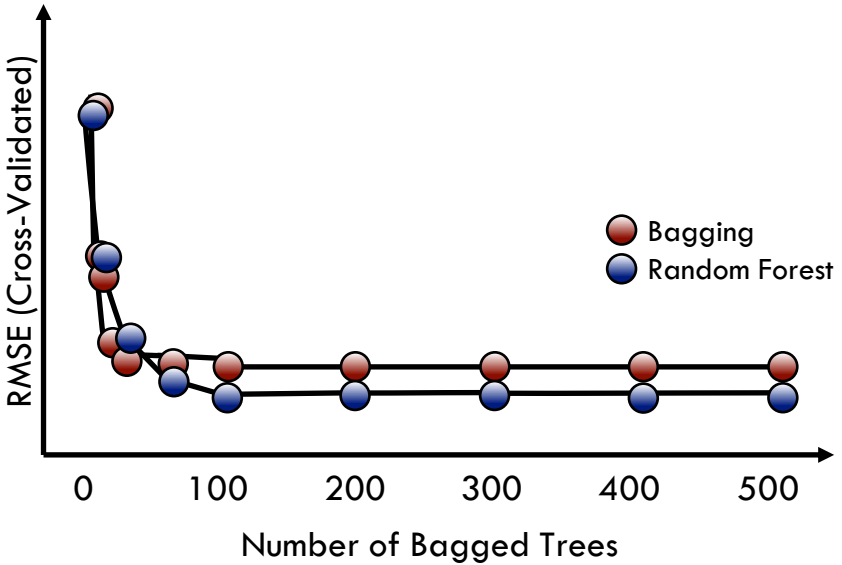
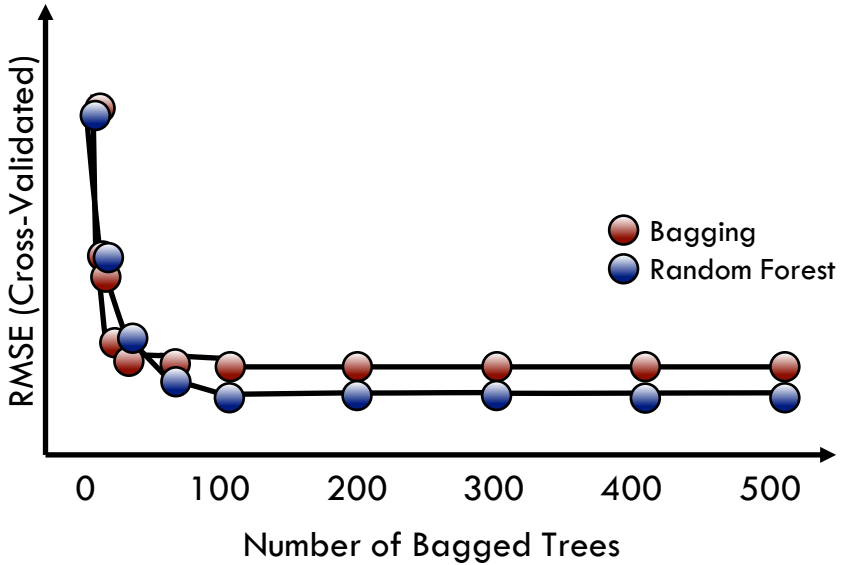
- Grow enough trees until error settles down

e



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
```

To use the Intel® Extension for Scikit-learn* variant of this algorithm:

- **Install Intel® oneAPI AI Analytics Toolkit (AI Kit)**
- **Add the following two lines of code after the above code:**

```
import patch_sklearn
patch_sklearn()
```

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
- Solution: select features randomly and create splits randomly—

Introducing Even More Randomness

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- Solution: select features randomly and create splits randomly—don't choose greedily
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ExtraTreesClassifier: The Syntax

Import the class containing the classification method

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

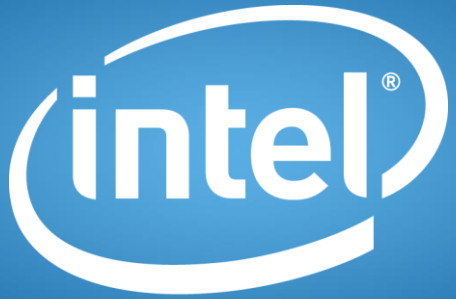
Create an instance of the class

```
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.



Software