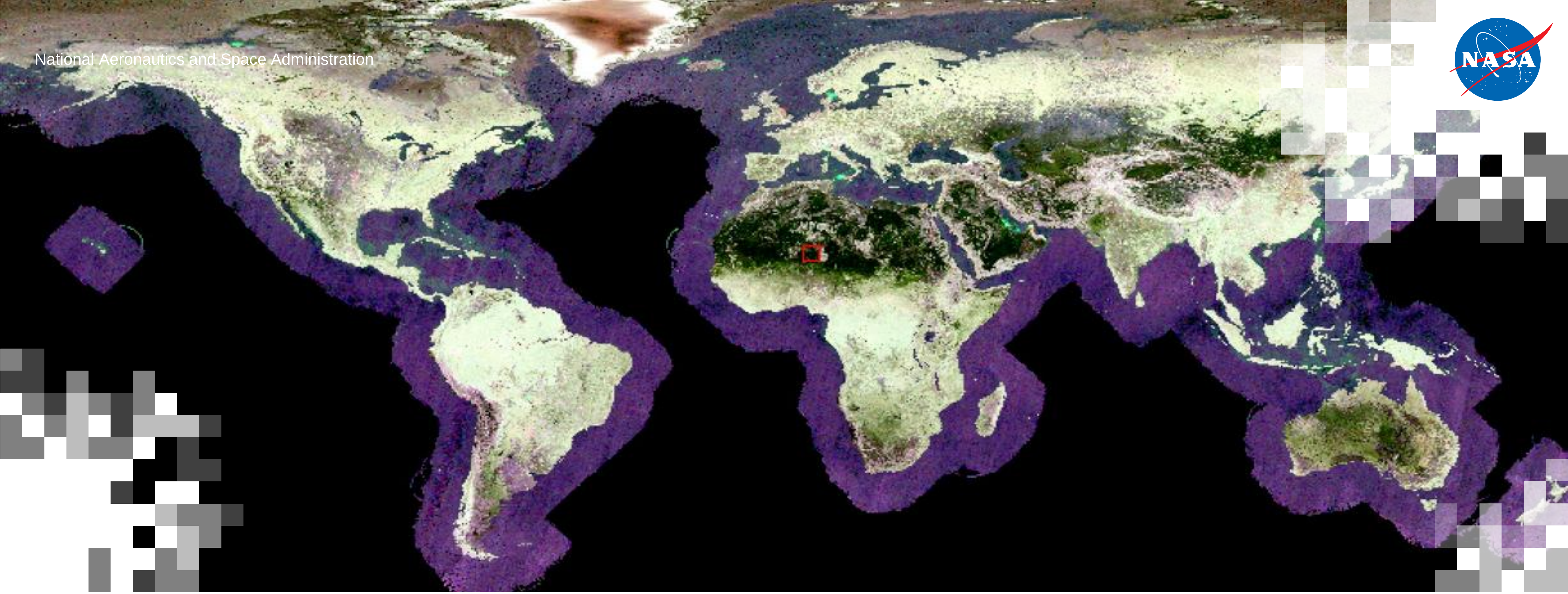
National Aeronautics and Space Administration



Exploiting SAR to Monitor Agriculture

Heather McNairn, Xianfeng Jiao, Sarah Banks and Amir Behnamian

4 September 2019

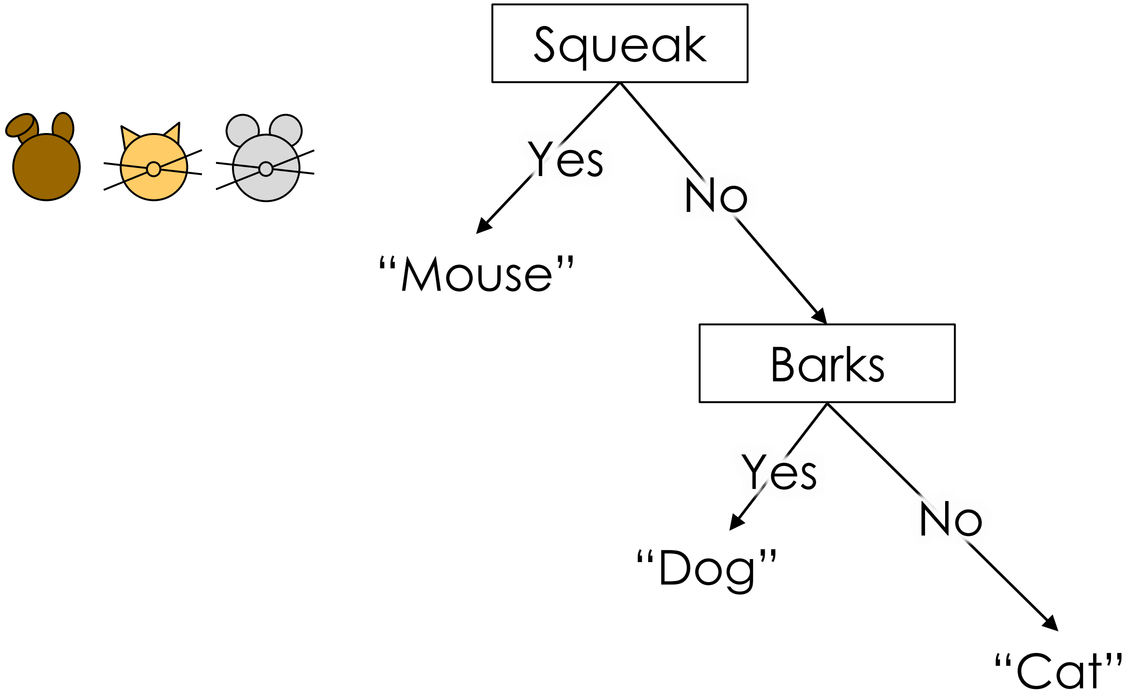
Learning Objectives

By the end of this presentation, you will be able to understand:

- Classification and Regression Trees (CART)
- Random Forests Advantages
- Random Forests:
  - Basics
  - Inputs and parameters
- How to implement Random Forests in R

Classification and Regression Trees (CART): Basics

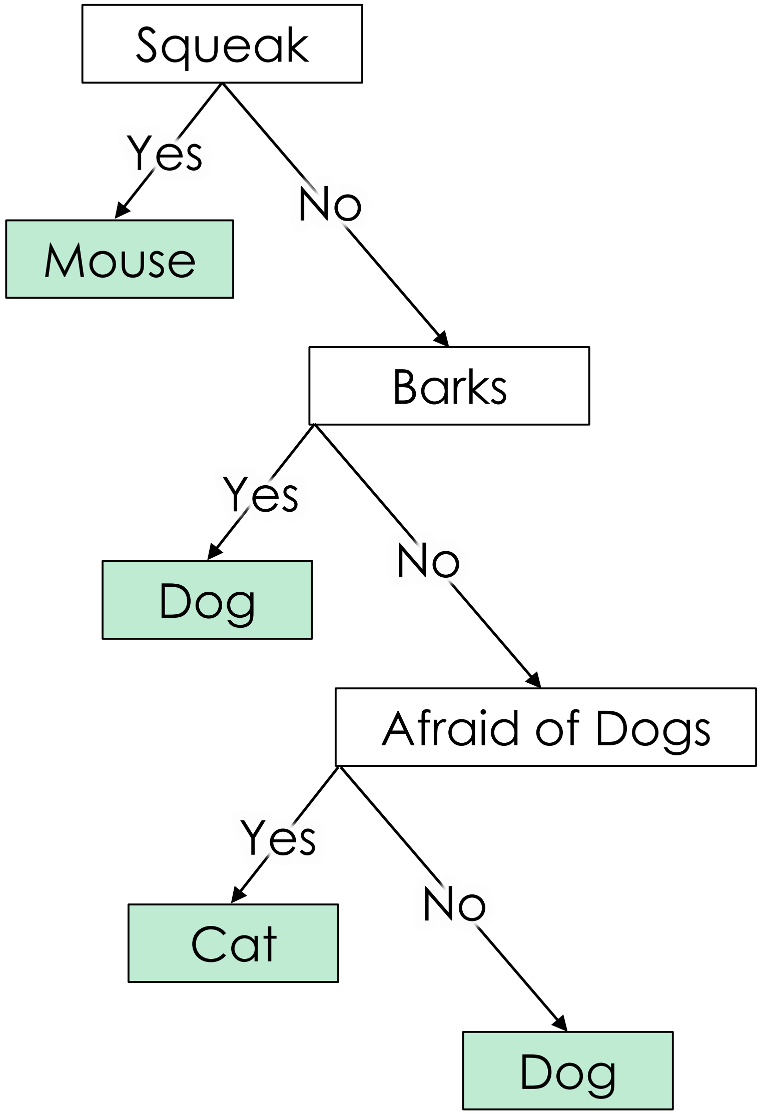
- Partitions or "splits" the data based on a set of binary tests
- Produces an easily-interpretable "tree" of tests and outcomes
- Tries to make groups that are as homogeneous as possible



Classification and Regression Trees (CART): Basics

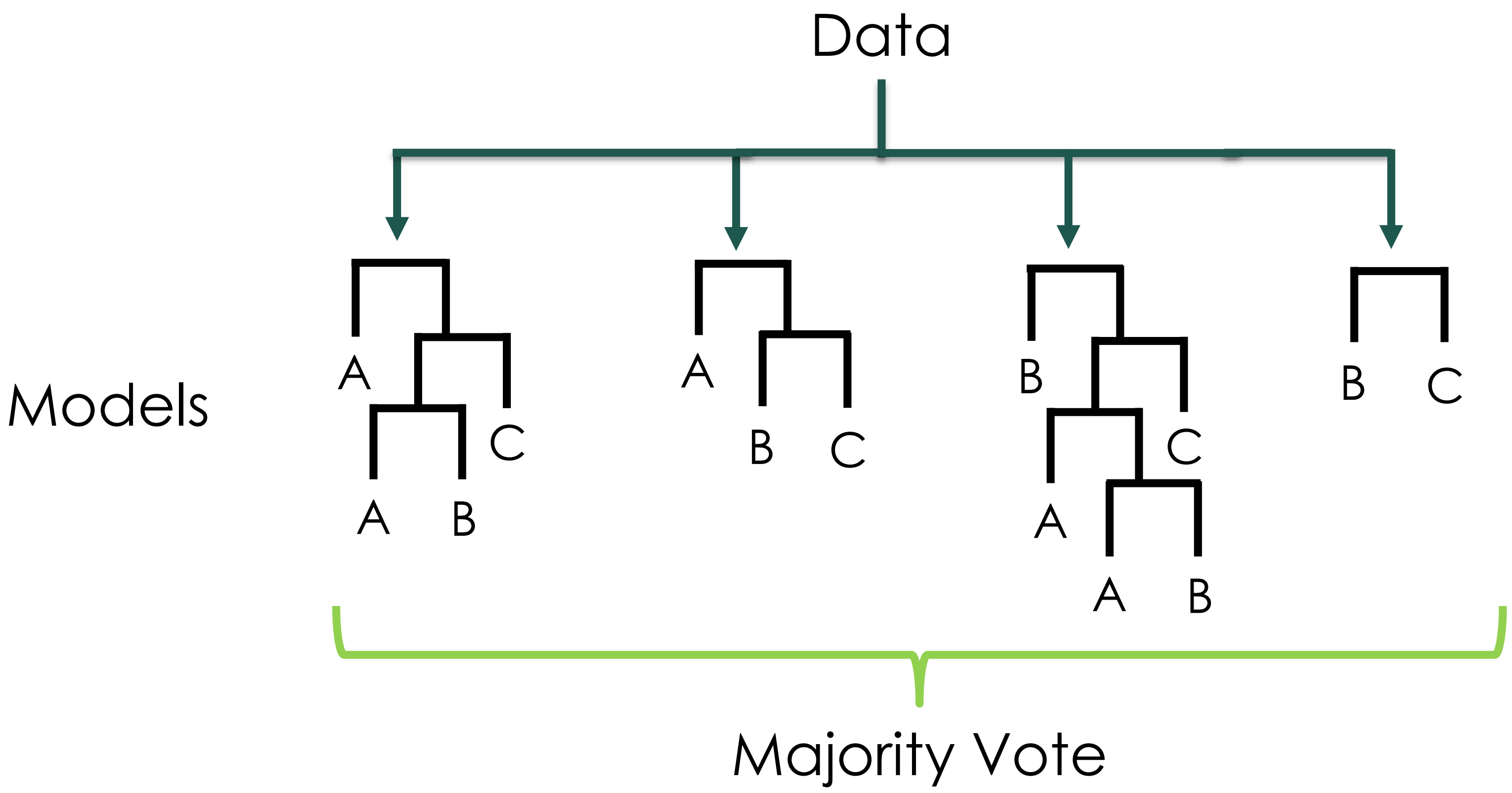
- Important Terms:

	Species	Barks	Pet	Squeeks	Meows	Collar	Afraid of Dogs	Length	Height	Likes Cheese
1	Mouse	No	Yes	Yes	No	No	Yes	0.14	0.07	Yes
2	Mouse	No	No	Yes	No	No	Yes	0.18	0.09	Yes
4	Mouse	No	Yes	Yes	No	No	Yes	0.13	0.06	Yes
4	Mouse	No	Yes	Yes	No	No	Yes	0.13	0.06	Yes
5	Mouse	No	No	Yes	No	No	Yes	0.13	0.07	Yes
6	Mouse	No	No	Yes	No	No	Yes	0.11	0.05	Yes
9	Mouse	No	No	Yes	No	No	Yes	0.15	0.08	Yes
9	Mouse	No	No	Yes	No	No	Yes	0.15	0.08	Yes
12	Cat	No	Yes	No	No	Yes	Yes	0.40	0.15	No
13	Cat	No	Yes	No	Yes	Yes	Yes	0.37	0.09	Yes
14	Cat	No	Yes	No	Yes	Yes	Yes	0.36	0.17	Yes
15	Cat	No	Yes	No	Yes	Yes	No	0.30	0.16	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.30	0.16	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.30	0.16	Yes
18	Cat	No	Yes	No	Yes	Yes	Yes	0.33	0.22	Yes
18	Cat	No	Yes	No	Yes	Yes	Yes	0.33	0.22	Yes
20	Dog	Yes	Yes	No	No	Yes	No	0.53	0.35	Yes
20	Dog	Yes	Yes	No	No	Yes	No	0.53	0.35	Yes
21	Dog	Yes	Yes	No	No	Yes	No	0.51	0.33	Yes
21	Dog	Yes	Yes	No	No	Yes	No	0.51	0.33	Yes
22	Dog	Yes	Yes	No	No	Yes	No	0.16	0.32	Yes
22	Dog	Yes	Yes	No	No	Yes	No	0.16	0.32	Yes
23	Dog	No	No	No	No	No	No	0.52	0.26	Yes
24	Dog	Yes	Yes	No	No	Yes	No	0.53	0.27	Yes
24	Dog	Yes	Yes	No	No	Yes	No	0.53	0.27	Yes
27	Dog	No	Yes	No	No	Yes	No	0.58	0.29	Yes
27	Dog	No	Yes	No	No	Yes	No	0.58	0.29	Yes



Random Forests: Basics

- A "forest" of binary decision trees (Breiman, 2001)
- Works well with high-dimensional datasets (continuous or categorical)
- Ensemble learning technique



Random Forests: Basics

- Random Forests vs. CART

	CART	Random Forests
Number of Trees	1	n>>1
Pruning	Applied	All fully grown
Variables tested for splitting	All	m<<M (all variables)
Training Set	All	≈ 2/3
Accuracy	Independent required	Internally estimated (OOBE)

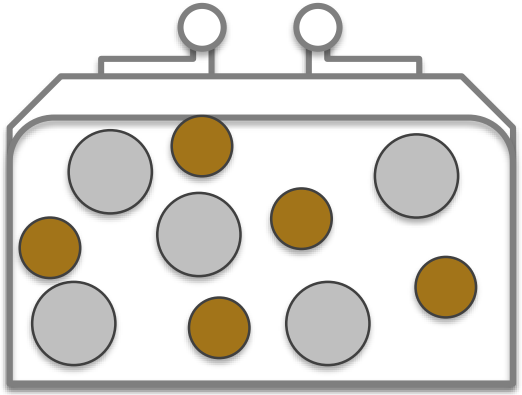
Random Forests: Parameters and Important Terms

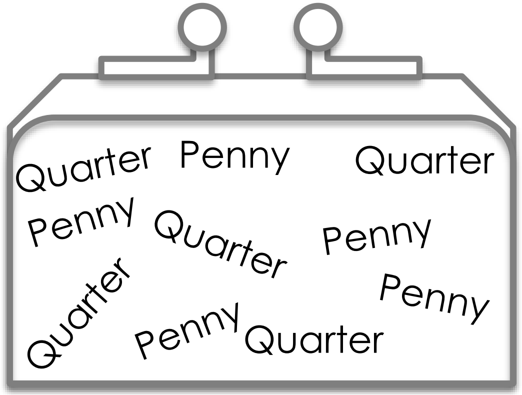
- ntree – number of trees per forest.
- Probability – number of trees that voted with the majority divided by the total number of trees.
- mtry – number of variables tested to determine optimal split at each node.
- Out of Bag Accuracy – internal validation; based on ≈ 1/3 of the dataset not used during the construction of a given tree.
- Mean Decrease in Accuracy (MDA) – quantifies variable “importance” by measuring the change in accuracy after the values of the variable are randomly permuted.

Random Forests: Basics

- Gini Impurity: probability of classifying a data point incorrectly
- Randomly pick data point & randomly classify it according to class distribution
- 25% + 25% = 50%; Gini Impurity = 0.5

Event	Probability
Choose quarter (50%), classify penny (50%)	50% x 50% = 25%
Choose penny (50%), classify quarter (50%)	50% x 50% = 25%

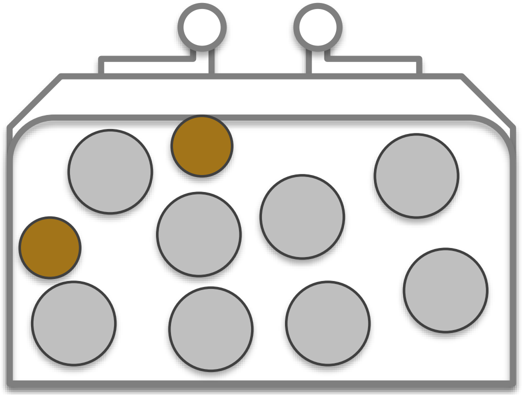


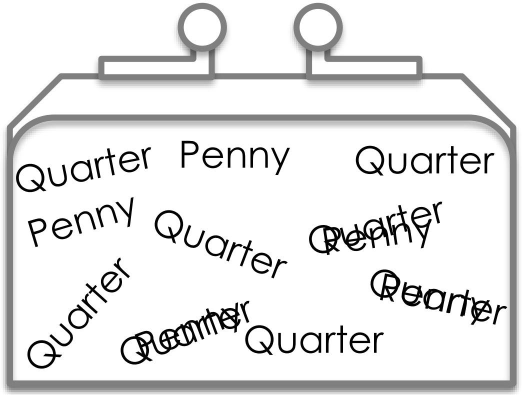


Random Forests: Basics

- Gini Impurity: probability of classifying a data point incorrectly
- Randomly pick data point & randomly classify it according to class distribution
- 16% + 16% = 32%; Gini Impurity = 0.32

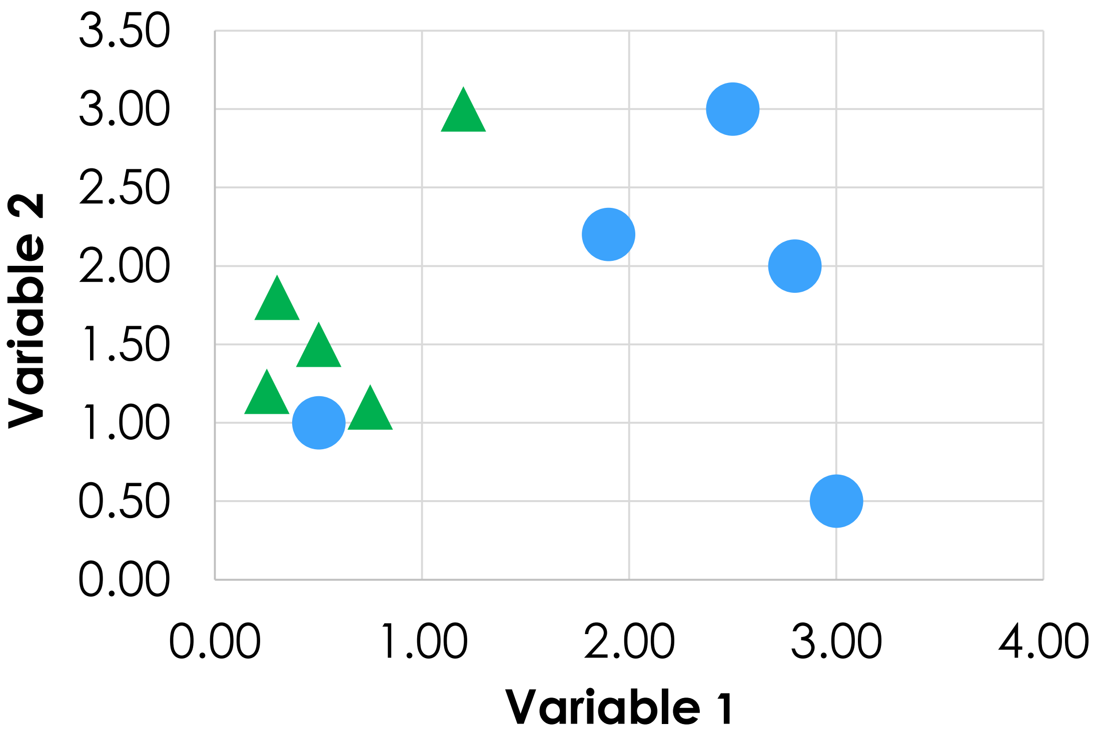
Event	Probability
Choose quarter (80%), classify penny (20%)	80% x 20% = 16%
Choose penny (20%), classify quarter (80%)	20% x 80% = 16%





Random Forests: Basics

- How Gini Impurity is used for splitting:
  - Don't know where the perfect split is, but can test all possible splits
  - Determine split quality by weighting impurity of subsequent nodes by number of data points it has



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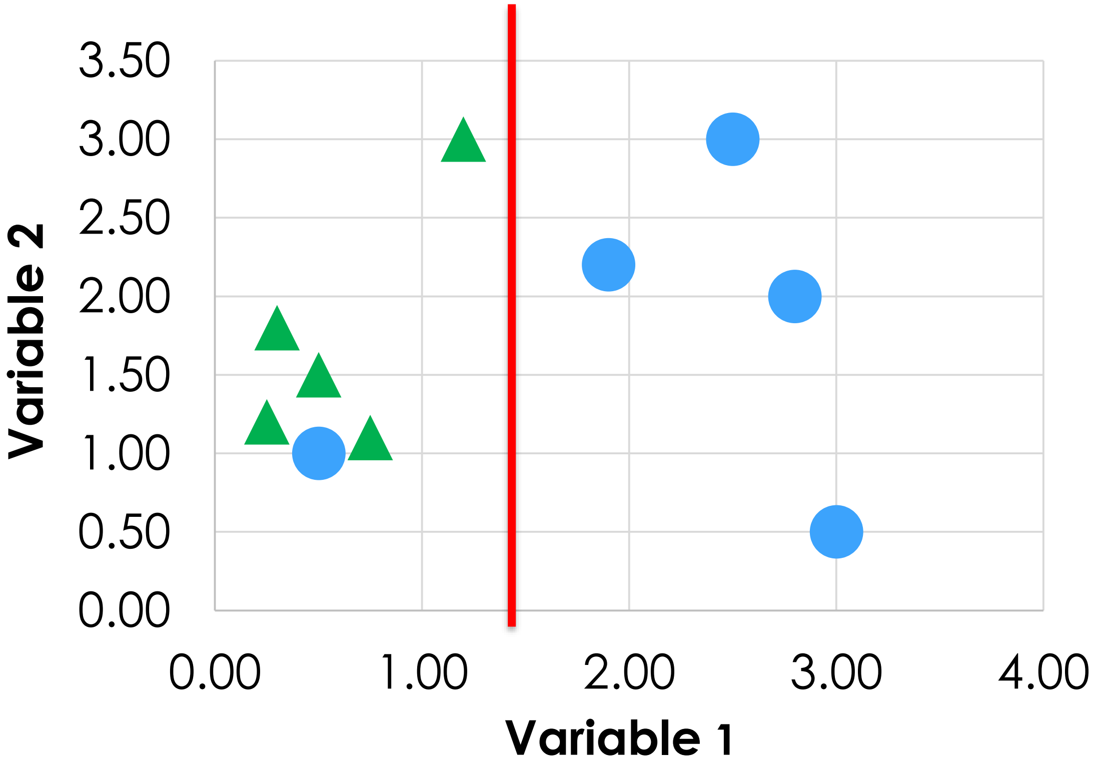
Gini Impurities

Before the Split= 0.50

Right Note = 0.00

Left Node = 0.28



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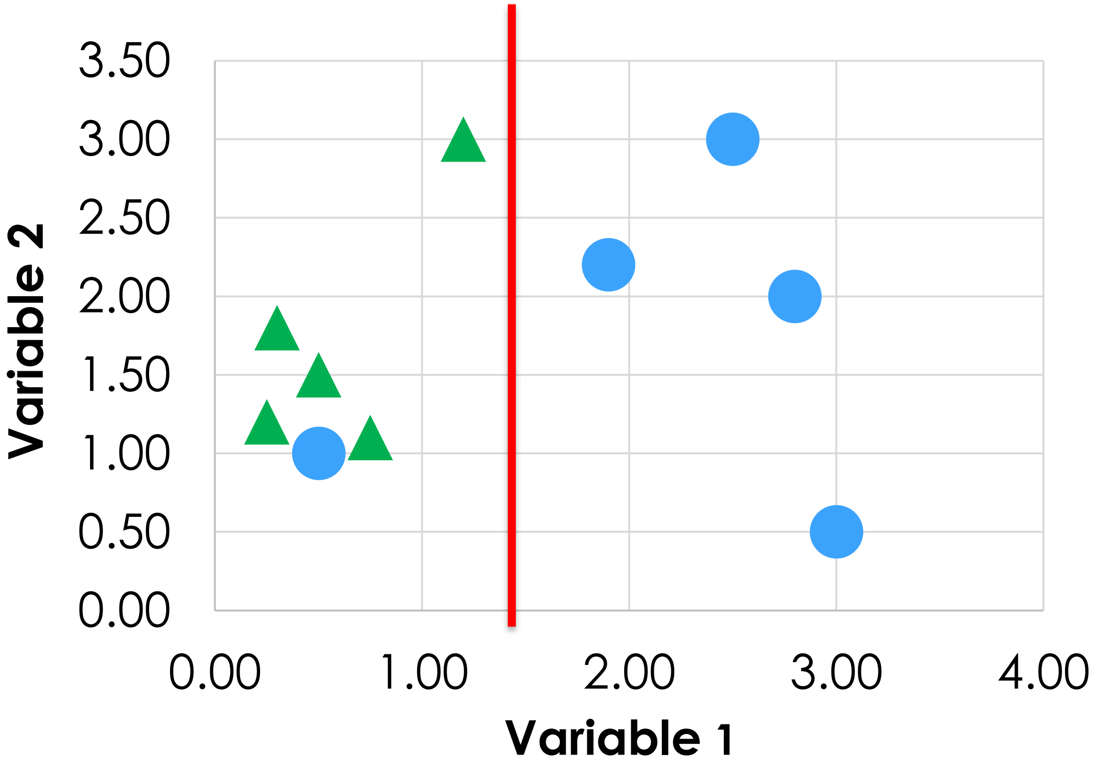

Right node has 40% data points, left node has 60%

(0.40*0.00) + (0.60*0.28) = 0.17

With this split, the amount of impurity removed is:

0.5 – 0.17 = 0.33

Random Forests: Basics

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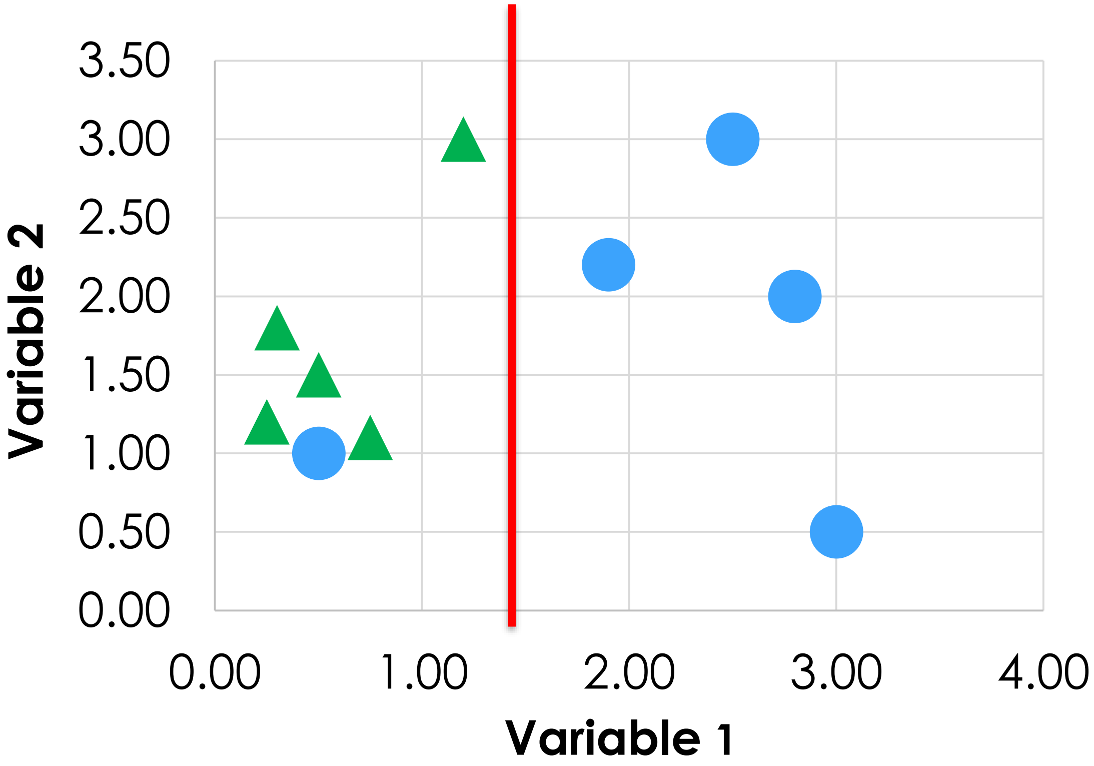

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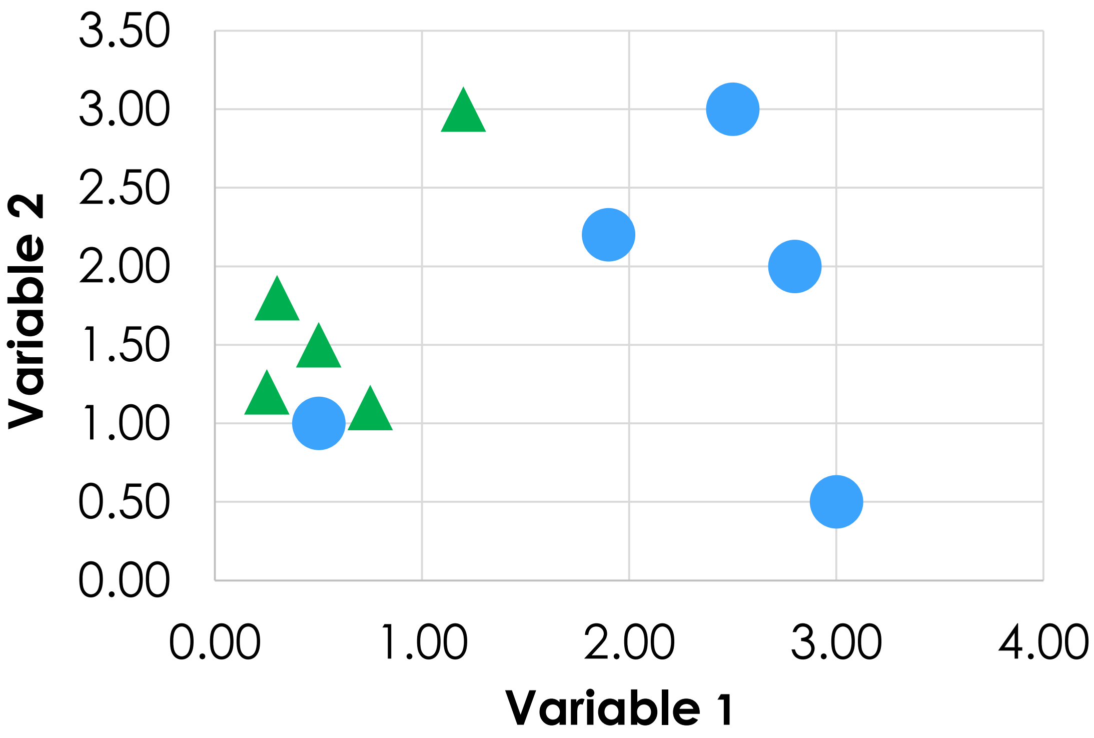

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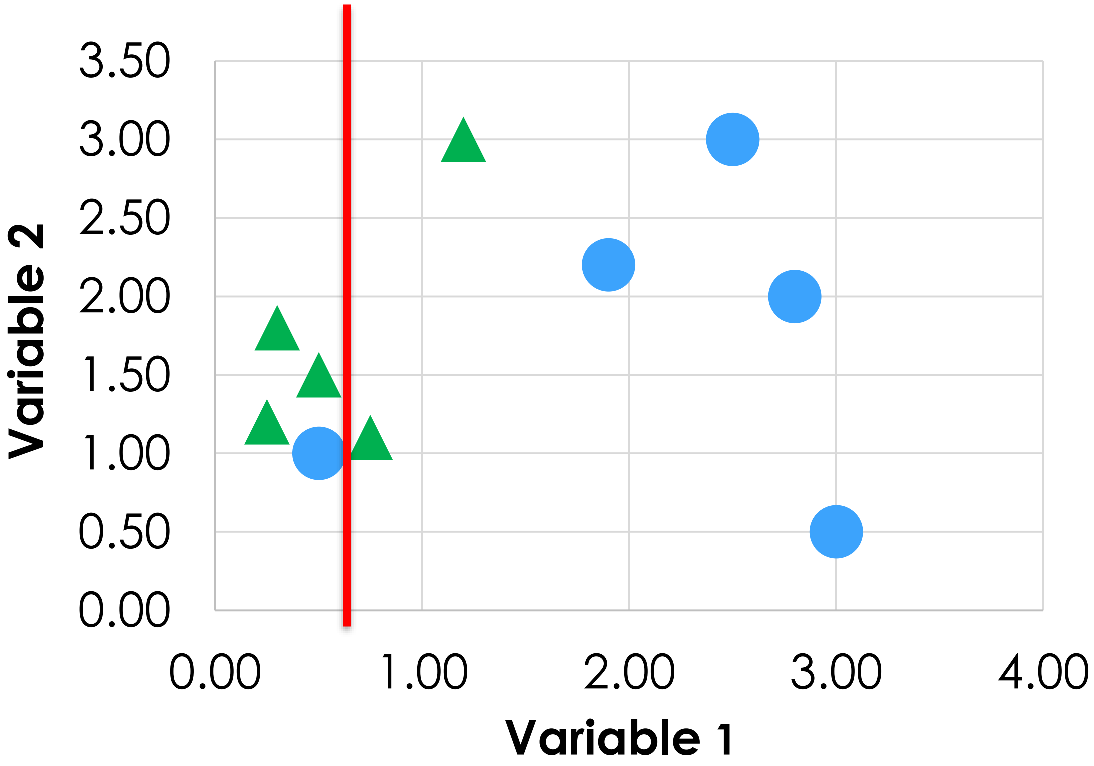
  - Determine split quality by weighting impurity of subsequent nodes by number of data points it has

Gini Impurities

Before the Split= 0.50

Right Note = 0.44

Left Node = 0.38



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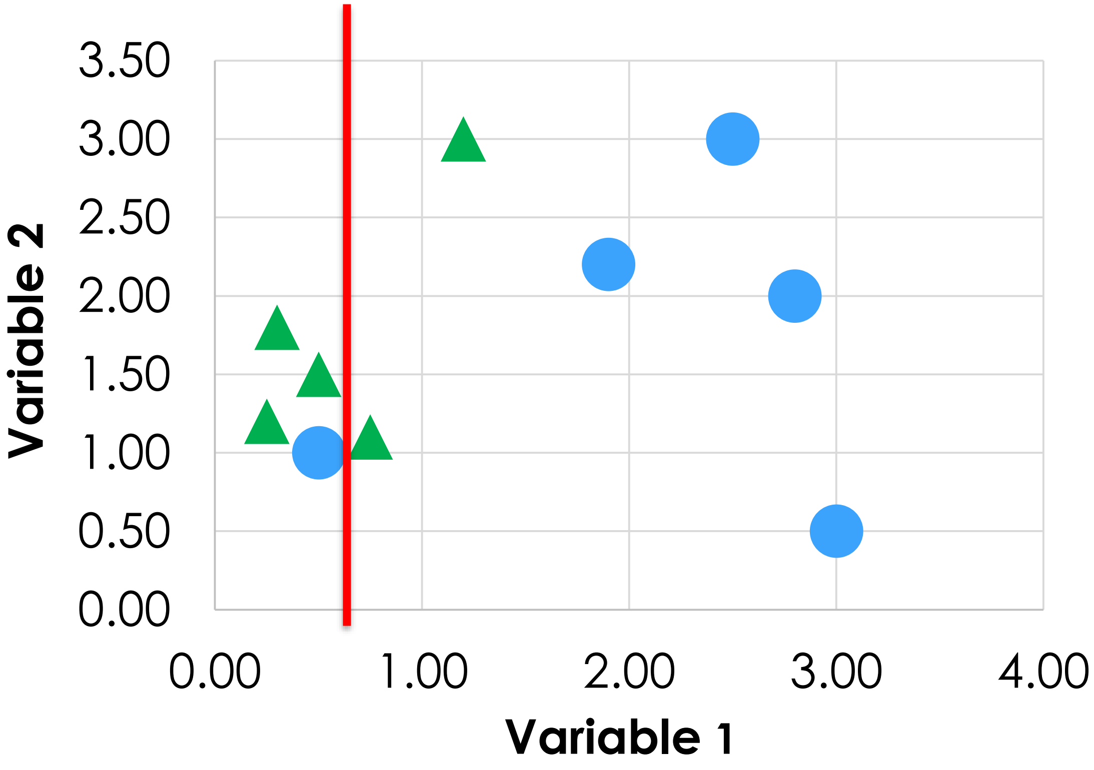

Right node has 60% data points, left node has 40%

(0.60*0.38) + (0.40*0.44)=0.42

With this split the amount of impurity removed is:

0.5 – 0.42 = 0.08

Random Forests: Basics

- How Gini Impurity is used for splitting:
  - Don't know where the perfect split is, but can test all possible splits
  - Determine split quality by weighting impurity of subsequent nodes by number of data points it has

Gini Impurities

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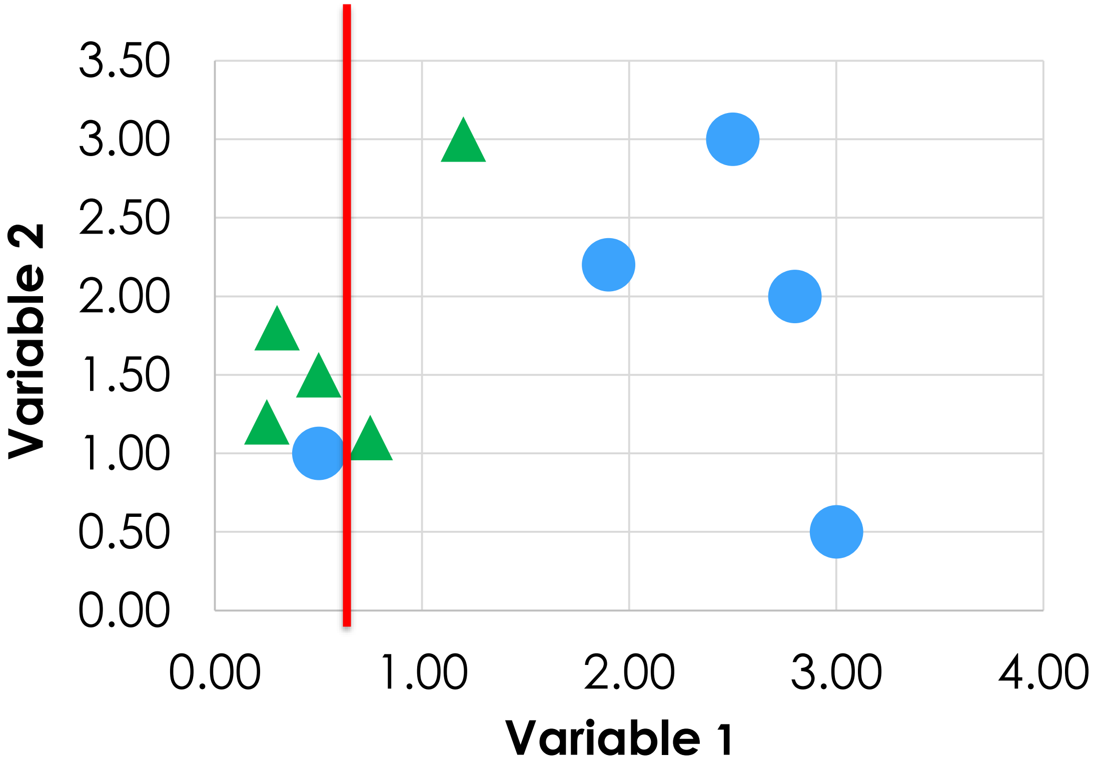

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(0.60*0.38) + (0.40*0.44)=0.42

With this split the amount of impurity removed is:

0.5 – 0.42 = 0.08

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Random Forests: Basics

- Random Forests Inputs:
- Labelled classes with associated predictor variables
  - Categorical or continuous

	Species	Barks	Pet	Squeaks	Meows	Collar	Afraid of Dogs	Length	Height	Likes Cheese
1	Mouse	No	Yes	Yes	No	No	Yes	0.14	0.07	Yes
2	Mouse	No	No	Yes	No	No	Yes	0.18	0.09	Yes
3	Mouse	No	No	Yes	No	No	Yes	0.13	0.06	Yes
4	Mouse	No	Yes	Yes	No	No	Yes	0.13	0.06	Yes
5	Mouse	No	No	Yes	No	No	Yes	0.13	0.07	Yes
6	Mouse	No	No	Yes	No	No	Yes	0.11	0.05	Yes
7	Mouse	No	No	Yes	No	No	Yes	0.13	0.06	Yes
8	Mouse	No	No	Yes	No	No	Yes	0.16	0.08	Yes
9	Mouse	No	No	Yes	No	No	Yes	0.15	0.08	Yes
10	Cat	No	Yes	No	Yes	Yes	Yes	0.31	0.19	Yes
11	Cat	No	Yes	No	Yes	No	Yes	0.38	0.20	Yes
12	Cat	No	Yes	No	Yes	Yes	Yes	0.40	0.15	No
13	Cat	No	Yes	No	Yes	Yes	Yes	0.37	0.09	Yes
14	Cat	No	Yes	No	Yes	Yes	Yes	0.36	0.17	Yes
15	Cat	No	No	No	Yes	No	No	0.32	0.22	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.30	0.16	Yes
17	Cat	No	Yes	No	Yes	Yes	Yes	0.35	0.24	Yes
18	Cat	No	Yes	No	Yes	Yes	Yes	0.33	0.22	Yes
19	Dog	Yes	No	No	No	No	No	0.58	0.33	Yes
20	Dog	Yes	Yes	No	No	Yes	No	0.53	0.35	Yes
21	Dog	Yes	Yes	No	No	Yes	No	0.51	0.33	Yes
22	Dog	Yes	Yes	No	No	Yes	No	0.16	0.32	Yes
23	Dog	No	No	No	No	No	No	0.52	0.26	Yes
24	Dog	Yes	Yes	No	No	Yes	No	0.53	0.27	Yes
25	Dog	Yes	Yes	No	No	Yes	No	0.37	0.16	Yes
26	Dog	Yes	Yes	No	No	Yes	No	0.53	0.29	Yes
27	Dog	Yes	Yes	No	No	Yes	No	0.58	0.29	Yes

Random Forests: Example

1. Create the training data to grow the tree
   – For N number of data points, randomly sample N cases (with replacement)

Random Forests: Example

Original

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1	Mouse	No	Yes	Yes	No	No	Yes	0.14	0.07	Yes
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26	Dog	Yes	Yes	No	No	Yes	No	0.53	0.29	Yes
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Training Set

Species	Barks	Pet	Squeaks	Meows	Collar	Afraid of Dogs	Length	Height	Likes Cheese

Random Forests: Example

Original

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27	Dog	Yes	Yes	No	No	Yes	No	0.58	0.29	Yes

Training Set

	Species	Barks	Pet	Squeaks	Meows	Collar	Afraid of Dogs	Length	Height	Likes Cheese
16	Cat	No	Yes	No	Yes	Yes	Yes	0.30	0.16	Yes
18	Cat	No	Yes	No	Yes	Yes	Yes	0.33	0.22	Yes
27	Dog	Yes	Yes	No	No	Yes	No	0.58	0.29	Yes
20	Dog	Yes	Yes	No	No	Yes	No	0.53	0.35	Yes
24	Dog	Yes	Yes	No	No	Yes	No	0.53	0.27	Yes
21	Dog	Yes	Yes	No	No	Yes	No	0.51	0.33	Yes
23	Dog	Yes	No	No	No	No	No	0.52	0.26	Yes
4	Mouse	No	Yes	Yes	No	No	Yes	0.13	0.06	Yes
9	Mouse	No	No	Yes	No	No	Yes	0.15	0.08	Yes
2	Mouse	No	No	Yes	No	No	Yes	0.18	0.09	Yes
18	Cat	No	Yes	No	Yes	Yes	Yes	0.33	0.22	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.30	0.16	Yes
22	Dog	Yes	Yes	No	No	Yes	No	0.16	0.32	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.30	0.16	Yes
13	Cat	No	Yes	No	Yes	Yes	Yes	0.37	0.21	Yes
12	Cat	No	Yes	No	Yes	Yes	Yes	0.40	0.15	No
21	Dog	Yes	Yes	No	No	Yes	No	0.51	0.33	Yes
9	Mouse	No	No	Yes	No	No	Yes	0.15	0.08	Yes
5	Mouse	No	No	Yes	No	No	Yes	0.13	0.07	Yes
4	Mouse	No	Yes	Yes	No	No	Yes	0.13	0.06	Yes
27	Dog	Yes	Yes	No	No	Yes	No	0.58	0.29	Yes
20	Dog	Yes	Yes	No	No	Yes	No	0.53	0.35	Yes
1	Mouse	No	Yes	Yes	No	No	Yes	0.14	0.07	Yes
22	Dog	Yes	Yes	No	No	Yes	No	0.16	0.32	Yes
6	Mouse	No	No	Yes	No	No	Yes	0.11	0.05	Yes
24	Dog	Yes	Yes	No	No	Yes	No	0.53	0.27	Yes
14	Cat	No	Yes	No	Yes	Yes	Yes	0.36	0.17	Yes

Random Forests: Example

Original

	Species	Barks	Pet	Squeaks	Meows	Collar	Afraid of Dogs	Length	Height	Likes Cheese
1	Mouse	No	Yes	Yes	No	No	Yes	0.14	0.07	Yes
2	Mouse	No	No	Yes	No	No	Yes	0.18	0.09	Yes
3	Mouse	No	No	Yes	No	No	Yes	0.13	0.06	Yes
4	Mouse	No	Yes	Yes	No	No	Yes	0.13	0.06	Yes
5	Mouse	No	No	Yes	No	No	Yes	0.13	0.07	Yes
6	Mouse	No	No	Yes	No	No	Yes	0.11	0.05	Yes
7	Mouse	No	No	Yes	No	No	Yes	0.13	0.06	Yes
8	Mouse	No	No	Yes	No	No	Yes	0.16	0.08	Yes
9	Mouse	No	No	Yes	No	No	Yes	0.15	0.08	Yes
10	Cat	No	Yes	No	Yes	Yes	Yes	0.31	0.19	Yes
11	Cat	No	Yes	No	Yes	No	Yes	0.38	0.20	Yes
12	Cat	No	Yes	No	Yes	Yes	Yes	0.40	0.15	No
13	Cat	No	Yes	No	Yes	Yes	Yes	0.37	0.09	Yes
14	Cat	No	Yes	No	Yes	Yes	Yes	0.36	0.17	Yes
15	Cat	No	No	No	Yes	No	No	0.32	0.22	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.30	0.16	Yes
17	Cat	No	Yes	No	Yes	Yes	Yes	0.35	0.24	Yes
18	Cat	No	Yes	No	Yes	Yes	Yes	0.33	0.22	Yes
19	Dog	Yes	No	No	No	No	No	0.58	0.33	Yes
20	Dog	Yes	Yes	No	No	Yes	No	0.53	0.35	Yes
21	Dog	Yes	Yes	No	No	Yes	No	0.51	0.33	Yes
22	Dog	Yes	Yes	No	No	Yes	No	0.16	0.32	Yes
23	Dog	No	No	No	No	No	No	0.52	0.26	Yes
24	Dog	Yes	Yes	No	No	Yes	No	0.53	0.27	Yes
25	Dog	Yes	Yes	No	No	Yes	No	0.37	0.16	Yes
26	Dog	Yes	Yes	No	No	Yes	No	0.53	0.29	Yes
27	Dog	Yes	Yes	No	No	Yes	No	0.58	0.29	Yes

Training Set

	Species	Barks	Pet	Squeaks	Meows	Collar	Afraid of Dogs	Length	Height	Likes Cheese
1	Mouse	No	Yes	Yes	No	No	Yes	0.14	0.07	Yes
2	Mouse	No	No	Yes	No	No	Yes	0.18	0.09	Yes
4	Mouse	No	Yes	Yes	No	No	Yes	0.13	0.06	Yes
4	Mouse	No	Yes	Yes	No	No	Yes	0.13	0.06	Yes
5	Mouse	No	No	Yes	No	No	Yes	0.13	0.07	Yes
6	Mouse	No	No	Yes	No	No	Yes	0.11	0.05	Yes
9	Mouse	No	No	Yes	No	No	Yes	0.15	0.08	Yes
9	Mouse	No	No	Yes	No	No	Yes	0.15	0.08	Yes
12	Cat	No	Yes	No	Yes	Yes	Yes	0.4	0.15	No
13	Cat	No	Yes	No	Yes	Yes	Yes	0.37	0.21	Yes
14						Yes	Yes	0.36	0.17	Yes
16						Yes	Yes	0.3	0.16	Yes
16						Yes	Yes	0.3	0.16	Yes
16						Yes	Yes	0.3	0.16	Yes
18						Yes	Yes	0.33	0.22	Yes
18						Yes	Yes	0.33	0.22	Yes
20	Dog	Yes	Yes	No	No	Yes	No	0.53	0.35	Yes
20	Dog	Yes	Yes	No	No	Yes	No	0.53	0.35	Yes
21	Dog	Yes	Yes	No	No	Yes	No	0.51	0.33	Yes
21	Dog	Yes	Yes	No	No	Yes	No	0.51	0.33	Yes
22	Dog	Yes	Yes	No	No	Yes	No	0.16	0.32	Yes
22	Dog	Yes	Yes	No	No	Yes	No	0.16	0.32	Yes
23	Dog	Yes	No	No	No	No	No	0.52	0.26	Yes
24	Dog	Yes	Yes	No	No	Yes	No	0.53	0.27	Yes
24	Dog	Yes	Yes	No	No	Yes	No	0.53	0.27	Yes
27	Dog	Yes	Yes	No	No	Yes	No	0.58	0.29	Yes
27	Dog	Yes	Yes	No	No	Yes	No	0.58	0.29	Yes

Remaining for internal accuracy assessment ≈ 1/3

Random Forests: Example

2. For M number of variables, randomly select a subset (m<<M) to determine how each node is split (**mtry**)

	Species	Barks	Pet	Squeaks	Meows	Collar	Afraid of Dogs	Length	Height	Likes Cheese
1	Mouse	No	Yes	Yes	No	No	Yes	0.14	0.07	Yes
2	Mouse	No	No	Yes	No	No	Yes	0.18	0.09	Yes
4	Mouse	No	Yes	Yes	No	No	Yes	0.13	0.06	Yes
4	Mouse	No	Yes	Yes	No	No	Yes	0.13	0.06	Yes
5	Mouse	No	No	Yes	No	No	Yes	0.13	0.07	Yes
6	Mouse	No	No	Yes	No	No	Yes	0.11	0.05	Yes
9	Mouse	No	No	Yes	No	No	Yes	0.15	0.08	Yes
9	Mouse	No	No	Yes	No	No	Yes	0.15	0.08	Yes
12	Cat	No	Yes	No	No	Yes	Yes	0.4	0.15	No
13	Cat	No	Yes	No	Yes	Yes	Yes	0.37	0.09	Yes
14	Cat	No	Yes	No	Yes	Yes	Yes	0.36	0.17	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.3	0.16	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.3	0.16	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.30	0.16	Yes
18	Cat	No	Yes	No	Yes	Yes	Yes	0.33	0.22	Yes
18	Cat	No	Yes	No	Yes	Yes	Yes	0.33	0.22	Yes
20	Dog	Yes	Yes	No	No	Yes	No	0.53	0.35	Yes
20	Dog	Yes	Yes	No	No	Yes	No	0.53	0.35	Yes
21	Dog	Yes	Yes	No	No	Yes	No	0.51	0.33	Yes
21	Dog	Yes	Yes	No	No	Yes	No	0.51	0.33	Yes
22	Dog	Yes	Yes	No	No	Yes	No	0.16	0.32	Yes
22	Dog	Yes	Yes	No	No	Yes	No	0.16	0.32	Yes
23	Dog	No	No	No	No	No	No	0.52	0.26	Yes
24	Dog	Yes	Yes	No	No	Yes	No	0.53	0.27	Yes
24	Dog	Yes	Yes	No	No	Yes	No	0.53	0.27	Yes
27	Dog	No	Yes	No	No	Yes	No	0.58	0.29	Yes
27	Dog	No	Yes	No	No	Yes	No	0.58	0.29	Yes

Random Forests: Example

Training Set

	Species	Barks	Pet	Squeaks	Meows	Collar	Afraid of Dogs	Length	Height	Likes Cheese
1	Mouse	No	Yes	Yes	No	No	Yes	0.14	0.07	Yes
2	Mouse	No	No	Yes	No	No	Yes	0.18	0.09	Yes
4	Mouse	No	Yes	Yes	No	No	Yes	0.13	0.06	Yes
4	Mouse	No	Yes	Yes	No	No	Yes	0.13	0.06	Yes
5	Mouse	No	No	Yes	No	No	Yes	0.13	0.07	Yes
6	Mouse	No	No	Yes	No	No	Yes	0.11	0.05	Yes
9	Mouse	No	No	Yes	No	No	Yes	0.15	0.08	Yes
9	Mouse	No	No	Yes	No	No	Yes	0.15	0.08	Yes
12	Cat	No	Yes	No	No	Yes	Yes	0.4	0.15	No
13	Cat	No	Yes	No	Yes	Yes	Yes	0.37	0.09	Yes
14	Cat	No	Yes	No	Yes	Yes	Yes	0.36	0.17	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.3	0.16	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.3	0.16	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.30	0.16	Yes
18	Cat	No	Yes	No	Yes	Yes	Yes	0.33	0.22	Yes
18	Cat	No	Yes	No	Yes	Yes	Yes	0.33	0.22	Yes
20	Dog	Yes	Yes	No	No	Yes	No	0.53	0.35	Yes
20	Dog	Yes	Yes	No	No	Yes	No	0.53	0.35	Yes
21	Dog	Yes	Yes	No	No	Yes	No	0.51	0.33	Yes
21	Dog	Yes	Yes	No	No	Yes	No	0.51	0.33	Yes
22	Dog	Yes	Yes	No	No	Yes	No	0.16	0.32	Yes
22	Dog	Yes	Yes	No	No	Yes	No	0.16	0.32	Yes
23	Dog	No	No	No	No	No	No	0.52	0.26	Yes
24	Dog	Yes	Yes	No	No	Yes	No	0.53	0.27	Yes
24	Dog	Yes	Yes	No	No	Yes	No	0.53	0.27	Yes
27	Dog	No	Yes	No	No	Yes	No	0.58	0.29	Yes
27	Dog	No	Yes	No	No	Yes	No	0.58	0.29	Yes

Classification Results Based on Split Points

	Mouse	Cat	Dog
Yes	8	0	0
No	0	8	11

Gini Gain to Identify Optimal Split

Variable	Evaluated Split Points	Gini
Squeaks	Yes or No	0.32

Random Forests: Example

Training Set

	Species	Barks	Pet	Squeaks	Meows	Collar	Afraid of Dogs	Length	Height	Likes Cheese
1	Mouse	No	Yes	Yes	No	No	Yes	0.14	0.07	Yes
2	Mouse	No	No	Yes	No	No	Yes	0.18	0.09	Yes
4	Mouse	No	Yes	Yes	No	No	Yes	0.13	0.06	Yes
4	Mouse	No	Yes	Yes	No	No	Yes	0.13	0.06	Yes
5	Mouse	No	No	Yes	No	No	Yes	0.13	0.07	Yes
6	Mouse	No	No	Yes	No	No	Yes	0.11	0.05	Yes
9	Mouse	No	No	Yes	No	No	Yes	0.15	0.08	Yes
9	Mouse	No	No	Yes	No	No	Yes	0.15	0.08	Yes
12	Cat	No	Yes	No	No	Yes	Yes	0.4	0.15	No
13	Cat	No	Yes	No	Yes	Yes	Yes	0.37	0.09	Yes
14	Cat	No	Yes	No	Yes	Yes	Yes	0.36	0.17	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.3	0.16	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.3	0.16	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.30	0.16	Yes
18	Cat	No	Yes	No	Yes	Yes	Yes	0.33	0.22	Yes
18	Cat	No	Yes	No	Yes	Yes	Yes	0.33	0.22	Yes
20	Dog	Yes	Yes	No	No	Yes	No	0.53	0.35	Yes
20	Dog	Yes	Yes	No	No	Yes	No	0.53	0.35	Yes
21	Dog	Yes	Yes	No	No	Yes	No	0.51	0.33	Yes
21	Dog	Yes	Yes	No	No	Yes	No	0.51	0.33	Yes
22	Dog	Yes	Yes	No	No	Yes	No	0.16	0.32	Yes
22	Dog	Yes	Yes	No	No	Yes	No	0.16	0.32	Yes
23	Dog	No	No	No	No	No	No	0.52	0.26	Yes
24	Dog	Yes	Yes	No	No	Yes	No	0.53	0.27	Yes
24	Dog	Yes	Yes	No	No	Yes	No	0.53	0.27	Yes
27	Dog	No	Yes	No	No	Yes	No	0.58	0.29	Yes
27	Dog	No	Yes	No	No	Yes	No	0.58	0.29	Yes

Classification Results Based on Split Points

	Mouse	Cat	Dog
Yes	0	7	0
No	8	1	11

Gini Gain to Identify Optimal Split

Variable	Evaluated Split Points	Gini
Squeaks	Yes or No	0.32
Meows	Yes or No	0.28

Random Forests: Example

Training Set

	Species	Barks	Pet	Squeaks	Meows	Collar	Afraid of Dogs	Length	Height	Likes Cheese
1	Mouse	No	Yes	Yes	No	No	Yes	0.14	0.07	Yes
2	Mouse	No	No	Yes	No	No	Yes	0.18	0.09	Yes
4	Mouse	No	Yes	Yes	No	No	Yes	0.13	0.06	Yes
4	Mouse	No	Yes	Yes	No	No	Yes	0.13	0.06	Yes
5	Mouse	No	No	Yes	No	No	Yes	0.13	0.07	Yes
6	Mouse	No	No	Yes	No	No	Yes	0.11	0.05	Yes
9	Mouse	No	No	Yes	No	No	Yes	0.15	0.08	Yes
9	Mouse	No	No	Yes	No	No	Yes	0.15	0.08	Yes
12	Cat	No	Yes	No	No	Yes	Yes	0.4	0.15	No
13	Cat	No	Yes	No	Yes	Yes	Yes	0.37	0.09	Yes
14	Cat	No	Yes	No	Yes	Yes	Yes	0.36	0.17	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.3	0.16	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.3	0.16	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.30	0.16	Yes
18	Cat	No	Yes	No	Yes	Yes	Yes	0.33	0.22	Yes
18	Cat	No	Yes	No	Yes	Yes	Yes	0.33	0.22	Yes
20	Dog	Yes	Yes	No	No	Yes	No	0.53	0.35	Yes
20	Dog	Yes	Yes	No	No	Yes	No	0.53	0.35	Yes
21	Dog	Yes	Yes	No	No	Yes	No	0.51	0.33	Yes
21	Dog	Yes	Yes	No	No	Yes	No	0.51	0.33	Yes
22	Dog	Yes	Yes	No	No	Yes	No	0.16	0.32	Yes
22	Dog	Yes	Yes	No	No	Yes	No	0.16	0.32	Yes
23	Dog	No	No	No	No	No	No	0.52	0.26	Yes
24	Dog	Yes	Yes	No	No	Yes	No	0.53	0.27	Yes
24	Dog	Yes	Yes	No	No	Yes	No	0.53	0.27	Yes
27	Dog	No	Yes	No	No	Yes	No	0.58	0.29	Yes
27	Dog	No	Yes	No	No	Yes	No	0.58	0.29	Yes

Classification Results Based on Split Points

	Mouse	Cat	Dog
<=0.05	1	0	0
>0.05	7	8	11

Gini Gain to Identify Optimal Split

Variable	Evaluated Split Points	Gini
Squeaks	Yes or No	0.32
Meows	Yes or No	0.28
Height	<=0.05	0.03

Random Forests: Example

Training Set

	Species	Barks	Pet	Squeaks	Meows	Collar	Afraid of Dogs	Length	Height	Likes Cheese
1	Mouse	No	Yes	Yes	No	No	Yes	0.14	0.07	Yes
2	Mouse	No	No	Yes	No	No	Yes	0.18	0.09	Yes
4	Mouse	No	Yes	Yes	No	No	Yes	0.13	0.06	Yes
4	Mouse	No	Yes	Yes	No	No	Yes	0.13	0.06	Yes
5	Mouse	No	No	Yes	No	No	Yes	0.13	0.07	Yes
6	Mouse	No	No	Yes	No	No	Yes	0.11	0.05	Yes
9	Mouse	No	No	Yes	No	No	Yes	0.15	0.08	Yes
9	Mouse	No	No	Yes	No	No	Yes	0.15	0.08	Yes
12	Cat	No	Yes	No	No	Yes	Yes	0.4	0.15	No
13	Cat	No	Yes	No	Yes	Yes	Yes	0.37	0.09	Yes
14	Cat	No	Yes	No	Yes	Yes	Yes	0.36	0.17	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.3	0.16	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.3	0.16	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.30	0.16	Yes
18	Cat	No	Yes	No	Yes	Yes	Yes	0.33	0.22	Yes
18	Cat	No	Yes	No	Yes	Yes	Yes	0.33	0.22	Yes
20	Dog	Yes	Yes	No	No	Yes	No	0.53	0.35	Yes
20	Dog	Yes	Yes	No	No	Yes	No	0.53	0.35	Yes
21	Dog	Yes	Yes	No	No	Yes	No	0.51	0.33	Yes
21	Dog	Yes	Yes	No	No	Yes	No	0.51	0.33	Yes
22	Dog	Yes	Yes	No	No	Yes	No	0.16	0.32	Yes
22	Dog	Yes	Yes	No	No	Yes	No	0.16	0.32	Yes
23	Dog	No	No	No	No	No	No	0.52	0.26	Yes
24	Dog	Yes	Yes	No	No	Yes	No	0.53	0.27	Yes
24	Dog	Yes	Yes	No	No	Yes	No	0.53	0.27	Yes
27	Dog	No	Yes	No	No	Yes	No	0.58	0.29	Yes
27	Dog	No	Yes	No	No	Yes	No	0.58	0.29	Yes

Classification Results Based on Split Points

	Mouse	Cat	Dog
<=0.06	3	0	0
>0.06	5	8	11

Gini Gain to Identify Optimal Split

Variable	Evaluated Split Points	Gini
Squeaks	Yes or No	0.32
Meows	Yes or No	0.28
Height	<=0.05	0.03
Height	<=0.06	0.09

Random Forests: Example

Training Set

	Species	Barks	Pet	Squeaks	Meows	Collar	Afraid of Dogs	Length	Height	Likes Cheese
1	Mouse	No	Yes	Yes	No	No	Yes	0.14	0.07	Yes
2	Mouse	No	No	Yes	No	No	Yes	0.18	0.09	Yes
4	Mouse	No	Yes	Yes	No	No	Yes	0.13	0.06	Yes
4	Mouse	No	Yes	Yes	No	No	Yes	0.13	0.06	Yes
5	Mouse	No	No	Yes	No	No	Yes	0.13	0.07	Yes
6	Mouse	No	No	Yes	No	No	Yes	0.11	0.05	Yes
9	Mouse	No	No	Yes	No	No	Yes	0.15	0.08	Yes
9	Mouse	No	No	Yes	No	No	Yes	0.15	0.08	Yes
12	Cat	No	Yes	No	No	Yes	Yes	0.4	0.15	No
13	Cat	No	Yes	No	Yes	Yes	Yes	0.37	0.09	Yes
14	Cat	No	Yes	No	Yes	Yes	Yes	0.36	0.17	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.3	0.16	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.3	0.16	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.30	0.16	Yes
18	Cat	No	Yes	No	Yes	Yes	Yes	0.33	0.22	Yes
18	Cat	No	Yes	No	Yes	Yes	Yes	0.33	0.22	Yes
20	Dog	Yes	Yes	No	No	Yes	No	0.53	0.35	Yes
20	Dog	Yes	Yes	No	No	Yes	No	0.53	0.35	Yes
21	Dog	Yes	Yes	No	No	Yes	No	0.51	0.33	Yes
21	Dog	Yes	Yes	No	No	Yes	No	0.51	0.33	Yes
22	Dog	Yes	Yes	No	No	Yes	No	0.16	0.32	Yes
22	Dog	Yes	Yes	No	No	Yes	No	0.16	0.32	Yes
23	Dog	No	No	No	No	No	No	0.52	0.26	Yes
24	Dog	Yes	Yes	No	No	Yes	No	0.53	0.27	Yes
24	Dog	Yes	Yes	No	No	Yes	No	0.53	0.27	Yes
27	Dog	No	Yes	No	No	Yes	No	0.58	0.29	Yes
27	Dog	No	Yes	No	No	Yes	No	0.58	0.29	Yes

Classification Results Based on Split Points

	Mouse	Cat	Dog
<=0.07	5	0	0
>0.07	3	8	11

Gini Gain to Identify Optimal Split

Variable	Evaluated Split Points	Gini
Squeaks	Yes or No	0.32
Meows	Yes or No	0.28
Height	<=0.05	0.03
Height	<=0.06	0.09
Height	<=0.07	0.17

...

Random Forests: Example

Training Set

	Species	Barks	Pet	Squeaks	Meows	Collar	Afraid of Dogs	Length	Height	Likes Cheese
1	Mouse	No	Yes	Yes	No	No	Yes	0.14	0.07	Yes
2	Mouse	No	No	Yes	No	No	Yes	0.18	0.09	Yes
4	Mouse	No	Yes	Yes	No	No	Yes	0.13	0.06	Yes
4	Mouse	No	Yes	Yes	No	No	Yes	0.13	0.06	Yes
5	Mouse	No	No	Yes	No	No	Yes	0.13	0.07	Yes
6	Mouse	No	No	Yes	No	No	Yes	0.11	0.05	Yes
9	Mouse	No	No	Yes	No	No	Yes	0.15	0.08	Yes
9	Mouse	No	No	Yes	No	No	Yes	0.15	0.08	Yes
12	Cat	No	Yes	No	No	Yes	Yes	0.4	0.15	No
13	Cat	No	Yes	No	Yes	Yes	Yes	0.37	0.09	Yes
14	Cat	No	Yes	No	Yes	Yes	Yes	0.36	0.17	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.3	0.16	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.3	0.16	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.30	0.16	Yes
18	Cat	No	Yes	No	Yes	Yes	Yes	0.33	0.22	Yes
18	Cat	No	Yes	No	Yes	Yes	Yes	0.33	0.22	Yes
20	Dog	Yes	Yes	No	No	Yes	No	0.53	0.35	Yes
20	Dog	Yes	Yes	No	No	Yes	No	0.53	0.35	Yes
21	Dog	Yes	Yes	No	No	Yes	No	0.51	0.33	Yes
21	Dog	Yes	Yes	No	No	Yes	No	0.51	0.33	Yes
22	Dog	Yes	Yes	No	No	Yes	No	0.16	0.32	Yes
22	Dog	Yes	Yes	No	No	Yes	No	0.16	0.32	Yes
23	Dog	No	No	No	No	No	No	0.52	0.26	Yes
24	Dog	Yes	Yes	No	No	Yes	No	0.53	0.27	Yes
24	Dog	Yes	Yes	No	No	Yes	No	0.53	0.27	Yes
27	Dog	No	Yes	No	No	Yes	No	0.58	0.29	Yes
27	Dog	No	Yes	No	No	Yes	No	0.58	0.29	Yes

Gini Gain to Identify Optimal Split

Variable	Evaluated Split Points	Gini
Squeaks	Yes or No	0.32
Meows	Yes or No	0.28
Height	<=0.05	0.03
Height	<=0.06	0.09
Height	<=0.07	0.17
Height	<=0.08	0.26
Height	<=0.09	0.28
Height	<=0.15	0.25
Height	<=0.16	0.26
Height	<=0.17	0.28
Height	<=0.22	0.27
Height	<=0.26	0.31
Height	<=0.27	0.22
Height	<=0.29	0.18
Height	<=0.32	0.09
Height	<=0.33	0.04
Height	<=0.35	0.00

Random Forests: Example

Training Set

	Species	Barks	Pet	Squeaks	Meows	Collar	Afraid of Dogs	Length	Height	Likes Cheese
1	Mouse	No	Yes	Yes	No	No	Yes	0.14	0.07	Yes
2	Mouse	No	No	Yes	No	No	Yes	0.18	0.09	Yes
4	Mouse	No	Yes	Yes	No	No	Yes	0.13	0.06	Yes
4	Mouse	No	Yes	Yes	No	No	Yes	0.13	0.06	Yes
5	Mouse	No	No	Yes	No	No	Yes	0.13	0.07	Yes
6	Mouse	No	No	Yes	No	No	Yes	0.11	0.05	Yes
9	Mouse	No	No	Yes	No	No	Yes	0.15	0.08	Yes
9	Mouse	No	No	Yes	No	No	Yes	0.15	0.08	Yes
12	Cat	No	Yes	No	No	Yes	Yes	0.4	0.15	No
13	Cat	No	Yes	No	Yes	Yes	Yes	0.37	0.09	Yes
14	Cat	No	Yes	No	Yes	Yes	Yes	0.36	0.17	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.3	0.16	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.3	0.16	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.30	0.16	Yes
18	Cat	No	Yes	No	Yes	Yes	Yes	0.33	0.22	Yes
18	Cat	No	Yes	No	Yes	Yes	Yes	0.33	0.22	Yes
20	Dog	Yes	Yes	No	No	Yes	No	0.53	0.35	Yes
20	Dog	Yes	Yes	No	No	Yes	No	0.53	0.35	Yes
21	Dog	Yes	Yes	No	No	Yes	No	0.51	0.33	Yes
21	Dog	Yes	Yes	No	No	Yes	No	0.51	0.33	Yes
22	Dog	Yes	Yes	No	No	Yes	No	0.16	0.32	Yes
22	Dog	Yes	Yes	No	No	Yes	No	0.16	0.32	Yes
23	Dog	No	No	No	No	No	No	0.52	0.26	Yes
24	Dog	Yes	Yes	No	No	Yes	No	0.53	0.27	Yes
24	Dog	Yes	Yes	No	No	Yes	No	0.53	0.27	Yes
27	Dog	No	Yes	No	No	Yes	No	0.58	0.29	Yes
27	Dog	No	Yes	No	No	Yes	No	0.58	0.29	Yes

Gini Gain to Identify Optimal Split

Variable	Evaluated Split Points	Gini
Squeaks	Yes or No	0.32
Meows	Yes or No	0.28
Height	<=0.05	0.03
Height	<=0.06	0.09
Height	<=0.07	0.17
Height	<=0.08	0.26
Height	<=0.09	0.28
Height	<=0.15	0.25
Height	<=0.16	0.26
Height	<=0.17	0.28
Height	<=0.22	0.27
Height	<=0.26	0.31
Height	<=0.27	0.22
Height	<=0.29	0.18
Height	<=0.32	0.09
Height	<=0.33	0.04
Height	<=0.35	0.00

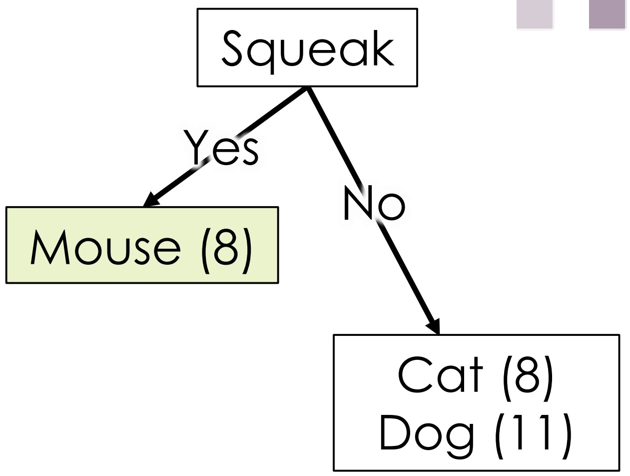
Random Forests: Example

Training Set

	Species	Barks	Pet	Squeaks	Meows	Collar	Afraid of Dogs	Length	Height	Likes Cheese
1	Mouse	No	Yes	Yes	No	No	Yes	0.14	0.07	Yes
2	Mouse	No	No	Yes	No	No	Yes	0.18	0.09	Yes
4	Mouse	No	Yes	Yes	No	No	Yes	0.13	0.06	Yes
4	Mouse	No	Yes	Yes	No	No	Yes	0.13	0.06	Yes
5	Mouse	No	No	Yes	No	No	Yes	0.13	0.07	Yes
6	Mouse	No	No	Yes	No	No	Yes	0.11	0.05	Yes
9	Mouse	No	No	Yes	No	No	Yes	0.15	0.08	Yes
9	Mouse	No	No	Yes	No	No	Yes	0.15	0.08	Yes
12	Cat	No	Yes	No	No	Yes	Yes	0.4	0.15	No
13	Cat	No	Yes	No	Yes	Yes	Yes	0.37	0.09	Yes
14	Cat	No	Yes	No	Yes	Yes	Yes	0.36	0.17	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.3	0.16	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.3	0.16	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.30	0.16	Yes
18	Cat	No	Yes	No	Yes	Yes	Yes	0.33	0.22	Yes
18	Cat	No	Yes	No	Yes	Yes	Yes	0.33	0.22	Yes
20	Dog	Yes	Yes	No	No	Yes	No	0.53	0.35	Yes
20	Dog	Yes	Yes	No	No	Yes	No	0.53	0.35	Yes
21	Dog	Yes	Yes	No	No	Yes	No	0.51	0.33	Yes
21	Dog	Yes	Yes	No	No	Yes	No	0.51	0.33	Yes
22	Dog	Yes	Yes	No	No	Yes	No	0.16	0.32	Yes
22	Dog	Yes	Yes	No	No	Yes	No	0.16	0.32	Yes
23	Dog	No	No	No	No	No	No	0.52	0.26	Yes
24	Dog	Yes	Yes	No	No	Yes	No	0.53	0.27	Yes
24	Dog	Yes	Yes	No	No	Yes	No	0.53	0.27	Yes
27	Dog	No	Yes	No	No	Yes	No	0.58	0.29	Yes
27	Dog	No	Yes	No	No	Yes	No	0.58	0.29	Yes

Gini Gain to Identify Optimal Split

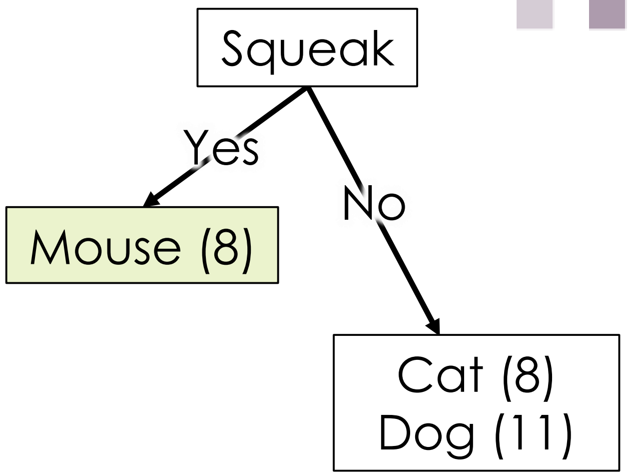
Variable	Evaluated Split Points	Gini
Squeaks	Yes or No	0.32
Meows	Yes or No	0.28
Height	<=0.05	0.03
Height	<=0.06	0.09
Height	<=0.07	0.17
Height	<=0.08	0.26
Height	<=0.09	0.28
Height	<=0.15	0.25
Height	<=0.16	0.26
Height	<=0.17	0.28
Height	<=0.22	0.27
Height	<=0.26	0.31
Height	<=0.27	0.22
Height	<=0.29	0.18
Height	<=0.32	0.09
Height	<=0.33	0.04
Height	<=0.35	0.00



Random Forests: Example

Training Set

	Species	Barks	Pet	Squeaks	Meows	Collar	Afraid of Dogs	Length	Height	Likes Cheese
12	Cat	No	Yes	No	No	Yes	Yes	0.4	0.15	No
13	Cat	No	Yes	No	Yes	Yes	Yes	0.37	0.09	Yes
14	Cat	No	Yes	No	Yes	Yes	Yes	0.36	0.17	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.3	0.16	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.3	0.16	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.30	0.16	Yes
18	Cat	No	Yes	No	Yes	Yes	Yes	0.33	0.22	Yes
18	Cat	No	Yes	No	Yes	Yes	Yes	0.33	0.22	Yes
20	Dog	Yes	Yes	No	No	Yes	No	0.53	0.35	Yes
20	Dog	Yes	Yes	No	No	Yes	No	0.53	0.35	Yes
21	Dog	Yes	Yes	No	No	Yes	No	0.51	0.33	Yes
21	Dog	Yes	Yes	No	No	Yes	No	0.51	0.33	Yes
22	Dog	Yes	Yes	No	No	Yes	No	0.16	0.32	Yes
22	Dog	Yes	Yes	No	No	Yes	No	0.16	0.32	Yes
23	Dog	No	No	No	No	No	No	0.52	0.26	Yes
24	Dog	Yes	Yes	No	No	Yes	No	0.53	0.27	Yes
24	Dog	Yes	Yes	No	No	Yes	No	0.53	0.27	Yes
27	Dog	No	Yes	No	No	Yes	No	0.58	0.29	Yes
27	Dog	No	Yes	No	No	Yes	No	0.58	0.29	Yes



Random Forests: Example

Training Set

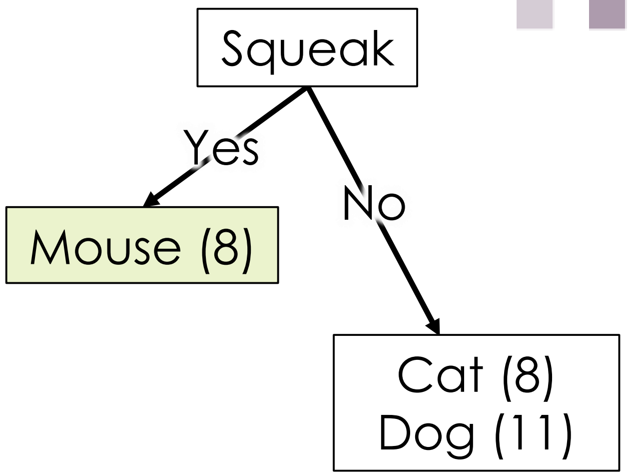
	Species	Barks	Pet	Squeaks	Meows	Collar	Afraid of Dogs	Length	Height	Likes Cheese
12	Cat	No	Yes	No	No	Yes	Yes	0.4	0.15	No
13	Cat	No	Yes	No	Yes	Yes	Yes	0.37	0.09	Yes
14	Cat	No	Yes	No	Yes	Yes	Yes	0.36	0.17	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.3	0.16	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.3	0.16	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.30	0.16	Yes
18	Cat	No	Yes	No	Yes	Yes	Yes	0.33	0.22	Yes
18	Cat	No	Yes	No	Yes	Yes	Yes	0.33	0.22	Yes
20	Dog	Yes	Yes	No	No	Yes	No	0.53	0.35	Yes
20	Dog	Yes	Yes	No	No	Yes	No	0.53	0.35	Yes
21	Dog	Yes	Yes	No	No	Yes	No	0.51	0.33	Yes
21	Dog	Yes	Yes	No	No	Yes	No	0.51	0.33	Yes
22	Dog	Yes	Yes	No	No	Yes	No	0.16	0.32	Yes
22	Dog	Yes	Yes	No	No	Yes	No	0.16	0.32	Yes
23	Dog	No	No	No	No	No	No	0.52	0.26	Yes
24	Dog	Yes	Yes	No	No	Yes	No	0.53	0.27	Yes
24	Dog	Yes	Yes	No	No	Yes	No	0.53	0.27	Yes
27	Dog	No	Yes	No	No	Yes	No	0.58	0.29	Yes
27	Dog	No	Yes	No	No	Yes	No	0.58	0.29	Yes

Classification Results Based on Split Points

	Cat	Dog
Yes	1	0
No	7	11

Gini Gain to Identify Optimal Split

Variable	Evaluated Split Points	Gini
Cheese	Yes or No	0.04



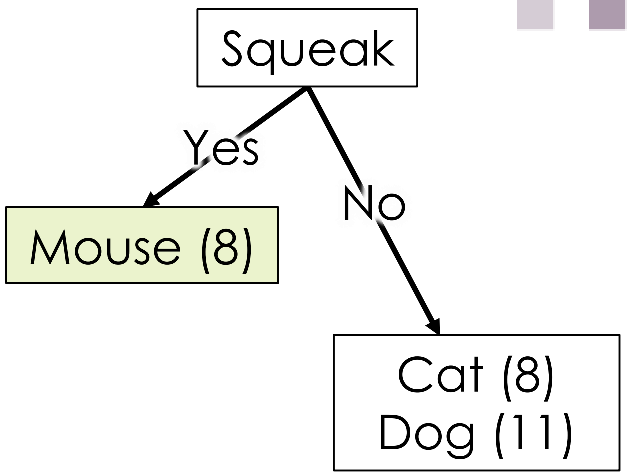
Random Forests: Example

Training Set

	Species	Barks	Pet	Squeaks	Meows	Collar	Afraid of Dogs	Length	Height	Likes Cheese
12	Cat	No	Yes	No	No	Yes	Yes	0.4	0.15	No
13	Cat	No	Yes	No	Yes	Yes	Yes	0.37	0.09	Yes
14	Cat	No	Yes	No	Yes	Yes	Yes	0.36	0.17	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.3	0.16	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.3	0.16	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.30	0.16	Yes
18	Cat	No	Yes	No	Yes	Yes	Yes	0.33	0.22	Yes
18	Cat	No	Yes	No	Yes	Yes	Yes	0.33	0.22	Yes
20	Dog	Yes	Yes	No	No	Yes	No	0.53	0.35	Yes
20	Dog	Yes	Yes	No	No	Yes	No	0.53	0.35	Yes
21	Dog	Yes	Yes	No	No	Yes	No	0.51	0.33	Yes
21	Dog	Yes	Yes	No	No	Yes	No	0.51	0.33	Yes
22	Dog	Yes	Yes	No	No	Yes	No	0.16	0.32	Yes
22	Dog	Yes	Yes	No	No	Yes	No	0.16	0.32	Yes
23	Dog	No	No	No	No	No	No	0.52	0.26	Yes
24	Dog	Yes	Yes	No	No	Yes	No	0.53	0.27	Yes
24	Dog	Yes	Yes	No	No	Yes	No	0.53	0.27	Yes
27	Dog	No	Yes	No	No	Yes	No	0.58	0.29	Yes
27	Dog	No	Yes	No	No	Yes	No	0.58	0.29	Yes

Classification Results Based on Split Points

	Cat	Dog
Yes	0	8
No	8	3



Gini Gain to Identify Optimal Split

Variable	Evaluated Split Points	Gini
Cheese	Yes or No	0.04
Barks	Yes or No	0.26

Random Forests: Example

Training Set

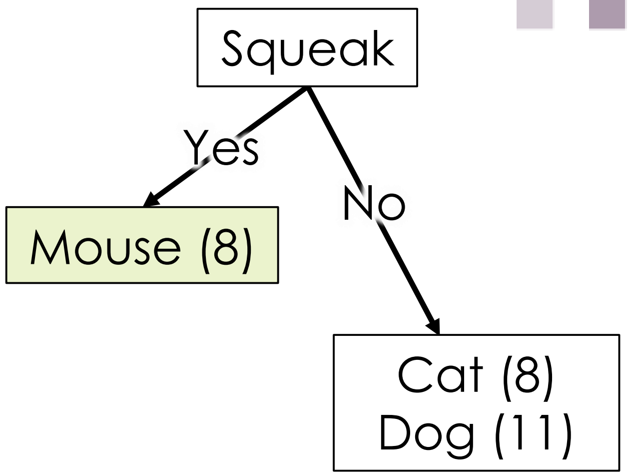
	Species	Barks	Pet	Squeaks	Meows	Collar	Afraid of Dogs	Length	Height	Likes Cheese
12	Cat	No	Yes	No	No	Yes	Yes	0.4	0.15	No
13	Cat	No	Yes	No	Yes	Yes	Yes	0.37	0.09	Yes
14	Cat	No	Yes	No	Yes	Yes	Yes	0.36	0.17	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.3	0.16	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.3	0.16	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.30	0.16	Yes
18	Cat	No	Yes	No	Yes	Yes	Yes	0.33	0.22	Yes
18	Cat	No	Yes	No	Yes	Yes	Yes	0.33	0.22	Yes
20	Dog	Yes	Yes	No	No	Yes	No	0.53	0.35	Yes
20	Dog	Yes	Yes	No	No	Yes	No	0.53	0.35	Yes
21	Dog	Yes	Yes	No	No	Yes	No	0.51	0.33	Yes
21	Dog	Yes	Yes	No	No	Yes	No	0.51	0.33	Yes
22	Dog	Yes	Yes	No	No	Yes	No	0.16	0.32	Yes
22	Dog	Yes	Yes	No	No	Yes	No	0.16	0.32	Yes
23	Dog	No	No	No	No	No	No	0.52	0.26	Yes
24	Dog	Yes	Yes	No	No	Yes	No	0.53	0.27	Yes
24	Dog	Yes	Yes	No	No	Yes	No	0.53	0.27	Yes
27	Dog	No	Yes	No	No	Yes	No	0.58	0.29	Yes
27	Dog	No	Yes	No	No	Yes	No	0.58	0.29	Yes

Classification Results Based on Split Points

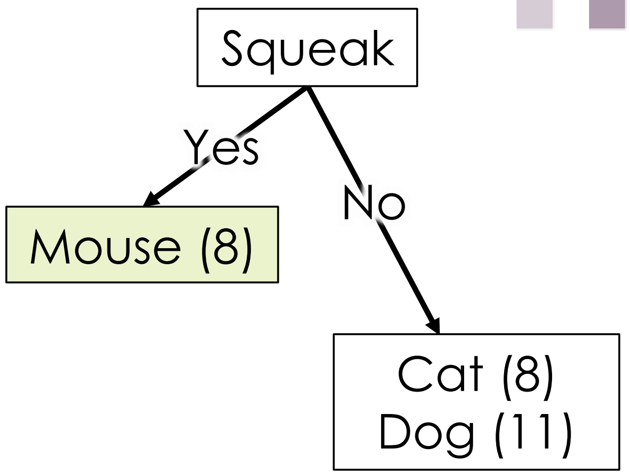
	Cat	Dog
Yes	8	10
No	0	1

Gini Gain to Identify Optimal Split

Variable	Evaluated Split Points	Gini
Cheese	Yes or No	0.04
Barks	Yes or No	0.26
Collar	Yes or No	0.02



Random Forests: Example



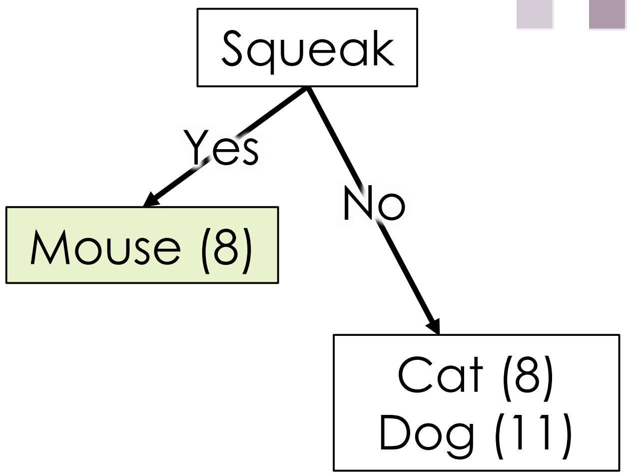
Training Set

	Species	Barks	Pet	Squeaks	Meows	Collar	Afraid of Dogs	Length	Height	Likes Cheese
12	Cat	No	Yes	No	No	Yes	Yes	0.4	0.15	No
13	Cat	No	Yes	No	Yes	Yes	Yes	0.37	0.09	Yes
14	Cat	No	Yes	No	Yes	Yes	Yes	0.36	0.17	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.3	0.16	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.3	0.16	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.30	0.16	Yes
18	Cat	No	Yes	No	Yes	Yes	Yes	0.33	0.22	Yes
18	Cat	No	Yes	No	Yes	Yes	Yes	0.33	0.22	Yes
20	Dog	Yes	Yes	No	No	Yes	No	0.53	0.35	Yes
20	Dog	Yes	Yes	No	No	Yes	No	0.53	0.35	Yes
21	Dog	Yes	Yes	No	No	Yes	No	0.51	0.33	Yes
21	Dog	Yes	Yes	No	No	Yes	No	0.51	0.33	Yes
22	Dog	Yes	Yes	No	No	Yes	No	0.16	0.32	Yes
22	Dog	Yes	Yes	No	No	Yes	No	0.16	0.32	Yes
23	Dog	No	No	No	No	No	No	0.52	0.26	Yes
24	Dog	Yes	Yes	No	No	Yes	No	0.53	0.27	Yes
24	Dog	Yes	Yes	No	No	Yes	No	0.53	0.27	Yes
27	Dog	No	Yes	No	No	Yes	No	0.58	0.29	Yes
27	Dog	No	Yes	No	No	Yes	No	0.58	0.29	Yes

Gini Gain to Identify Optimal Split

Variable	Evaluated Split Points	Gini
Cheese	Yes or No	0.04
Barks	Yes or No	0.26
Collar	Yes or No	0.02

Random Forests: Example



Training Set

	Species	Barks	Pet	Squeaks	Meows	Collar	Afraid of Dogs	Length	Height	Likes Cheese
12	Cat	No	Yes	No	No	Yes	Yes	0.4	0.15	No
13	Cat	No	Yes	No	Yes	Yes	Yes	0.37	0.09	Yes
14	Cat	No	Yes	No	Yes	Yes	Yes	0.36	0.17	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.3	0.16	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.3	0.16	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.30	0.16	Yes
18	Cat	No	Yes	No	Yes	Yes	Yes	0.33	0.22	Yes
18	Cat	No	Yes	No	Yes	Yes	Yes	0.33	0.22	Yes
20	Dog	Yes	Yes	No	No	Yes	No	0.53	0.35	Yes
20	Dog	Yes	Yes	No	No	Yes	No	0.53	0.35	Yes
21	Dog	Yes	Yes	No	No	Yes	No	0.51	0.33	Yes
21	Dog	Yes	Yes	No	No	Yes	No	0.51	0.33	Yes
22	Dog	Yes	Yes	No	No	Yes	No	0.16	0.32	Yes
22	Dog	Yes	Yes	No	No	Yes	No	0.16	0.32	Yes
23	Dog	No	No	No	No	No	No	0.52	0.26	Yes
24	Dog	Yes	Yes	No	No	Yes	No	0.53	0.27	Yes
24	Dog	Yes	Yes	No	No	Yes	No	0.53	0.27	Yes
27	Dog	No	Yes	No	No	Yes	No	0.58	0.29	Yes
27	Dog	No	Yes	No	No	Yes	No	0.58	0.29	Yes

Gini Gain to Identify Optimal Split

Variable	Evaluated Split Points	Gini
Cheese	Yes or No	0.04
Barks	Yes or No	0.26
Collar	Yes or No	0.02

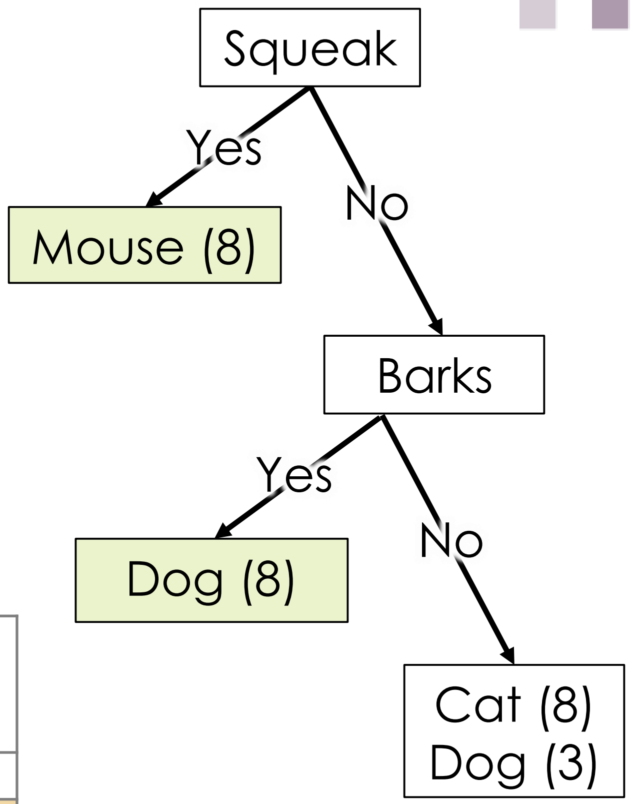
Random Forests: Example

Training Set

	Species	Barks	Pet	Squeaks	Meows	Collar	Afraid of Dogs	Length	Height	Likes Cheese
12	Cat	No	Yes	No	No	Yes	Yes	0.4	0.15	No
13	Cat	No	Yes	No	Yes	Yes	Yes	0.37	0.09	Yes
14	Cat	No	Yes	No	Yes	Yes	Yes	0.36	0.17	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.3	0.16	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.3	0.16	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.30	0.16	Yes
18	Cat	No	Yes	No	Yes	Yes	Yes	0.33	0.22	Yes
18	Cat	No	Yes	No	Yes	Yes	Yes	0.33	0.22	Yes
20	Dog	Yes	Yes	No	No	Yes	No	0.53	0.35	Yes
20	Dog	Yes	Yes	No	No	Yes	No	0.53	0.35	Yes
21	Dog	Yes	Yes	No	No	Yes	No	0.51	0.33	Yes
21	Dog	Yes	Yes	No	No	Yes	No	0.51	0.33	Yes
22	Dog	Yes	Yes	No	No	Yes	No	0.16	0.32	Yes
22	Dog	Yes	Yes	No	No	Yes	No	0.16	0.32	Yes
23	Dog	No	No	No	No	No	No	0.52	0.26	Yes
24	Dog	Yes	Yes	No	No	Yes	No	0.53	0.27	Yes
24	Dog	Yes	Yes	No	No	Yes	No	0.53	0.27	Yes
27	Dog	No	Yes	No	No	Yes	No	0.58	0.29	Yes
27	Dog	No	Yes	No	No	Yes	No	0.58	0.29	Yes

Gini Gain to Identify Optimal Split

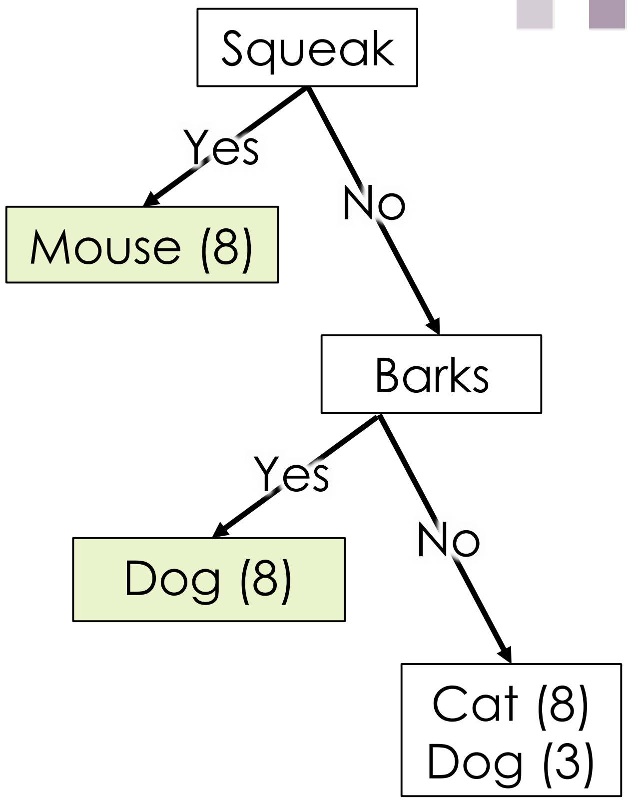
Variable	Evaluated Split Points	Gini
Cheese	Yes or No	0.04
Barks	Yes or No	0.26
Collar	Yes or No	0.02



Random Forests: Example

Training Set

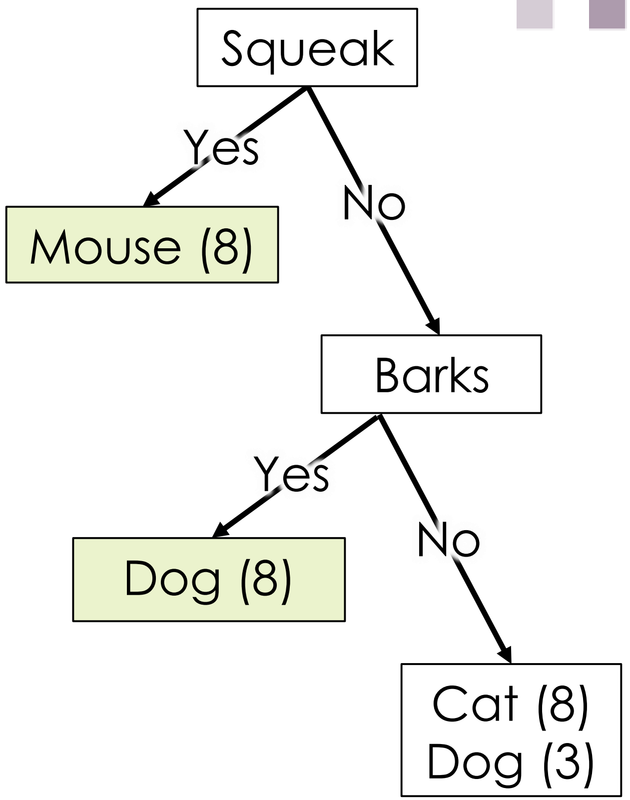
	Species	Barks	Pet	Squeaks	Meows	Collar	Afraid of Dogs	Length	Height	Likes Cheese
12	Cat	No	Yes	No	No	Yes	Yes	0.4	0.15	No
13	Cat	No	Yes	No	Yes	Yes	Yes	0.37	0.09	Yes
14	Cat	No	Yes	No	Yes	Yes	Yes	0.36	0.17	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.3	0.16	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.3	0.16	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.30	0.16	Yes
18	Cat	No	Yes	No	Yes	Yes	Yes	0.33	0.22	Yes
18	Cat	No	Yes	No	Yes	Yes	Yes	0.33	0.22	Yes
23	Dog	No	No	No	No	No	No	0.52	0.26	Yes
27	Dog	No	Yes	No	No	Yes	No	0.58	0.29	Yes
27	Dog	No	Yes	No	No	Yes	No	0.58	0.29	Yes



Random Forests: Example

Training Set

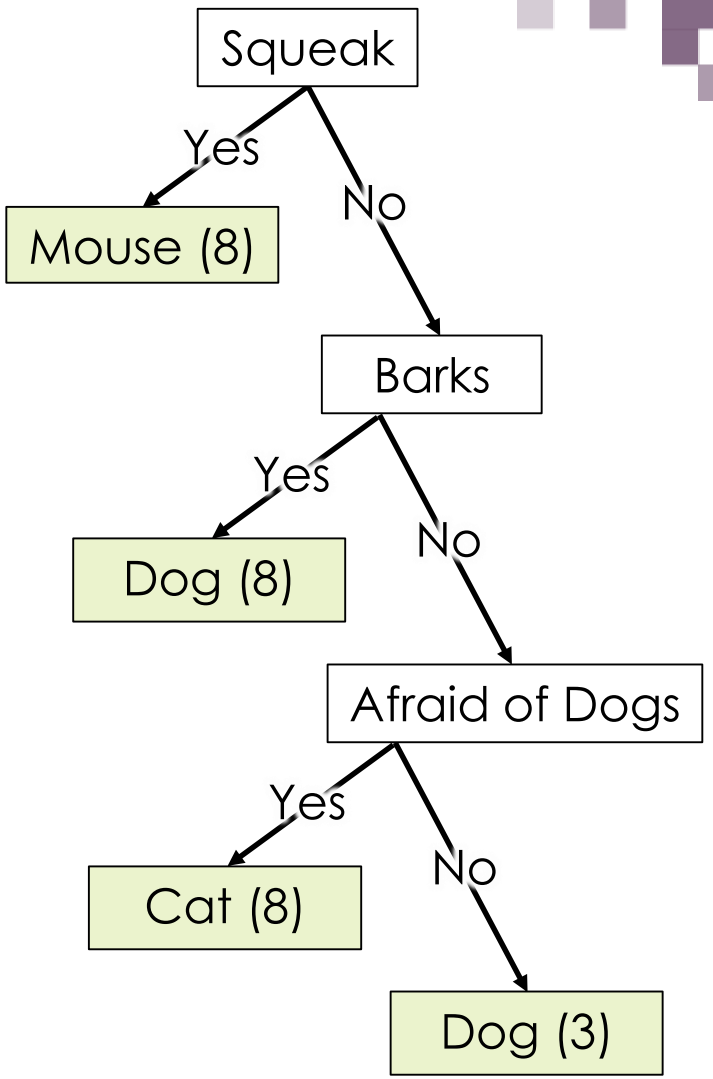
	Species	Barks	Pet	Squeaks	Meows	Collar	Afraid of Dogs	Length	Height	Likes Cheese
12	Cat	No	Yes	No	No	Yes	Yes	0.4	0.15	No
13	Cat	No	Yes	No	Yes	Yes	Yes	0.37	0.09	Yes
14	Cat	No	Yes	No	Yes	Yes	Yes	0.36	0.17	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.3	0.16	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.3	0.16	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.30	0.16	Yes
18	Cat	No	Yes	No	Yes	Yes	Yes	0.33	0.22	Yes
18	Cat	No	Yes	No	Yes	Yes	Yes	0.33	0.22	Yes
23	Dog	No	No	No	No	No	No	0.52	0.26	Yes
27	Dog	No	Yes	No	No	Yes	No	0.58	0.29	Yes
27	Dog	No	Yes	No	No	Yes	No	0.58	0.29	Yes



Random Forests: Example

Training Set

	Species	Barks	Pet	Squeaks	Meows	Collar	Afraid of Dogs	Length	Height	Likes Cheese
12	Cat	No	Yes	No	No	Yes	Yes	0.4	0.15	No
13	Cat	No	Yes	No	Yes	Yes	Yes	0.37	0.09	Yes
14	Cat	No	Yes	No	Yes	Yes	Yes	0.36	0.17	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.3	0.16	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.3	0.16	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.30	0.16	Yes
18	Cat	No	Yes	No	Yes	Yes	Yes	0.33	0.22	Yes
18	Cat	No	Yes	No	Yes	Yes	Yes	0.33	0.22	Yes
23	Dog	No	No	No	No	No	No	0.52	0.26	Yes
27	Dog	No	Yes	No	No	Yes	No	0.58	0.29	Yes
27	Dog	No	Yes	No	No	Yes	No	0.58	0.29	Yes



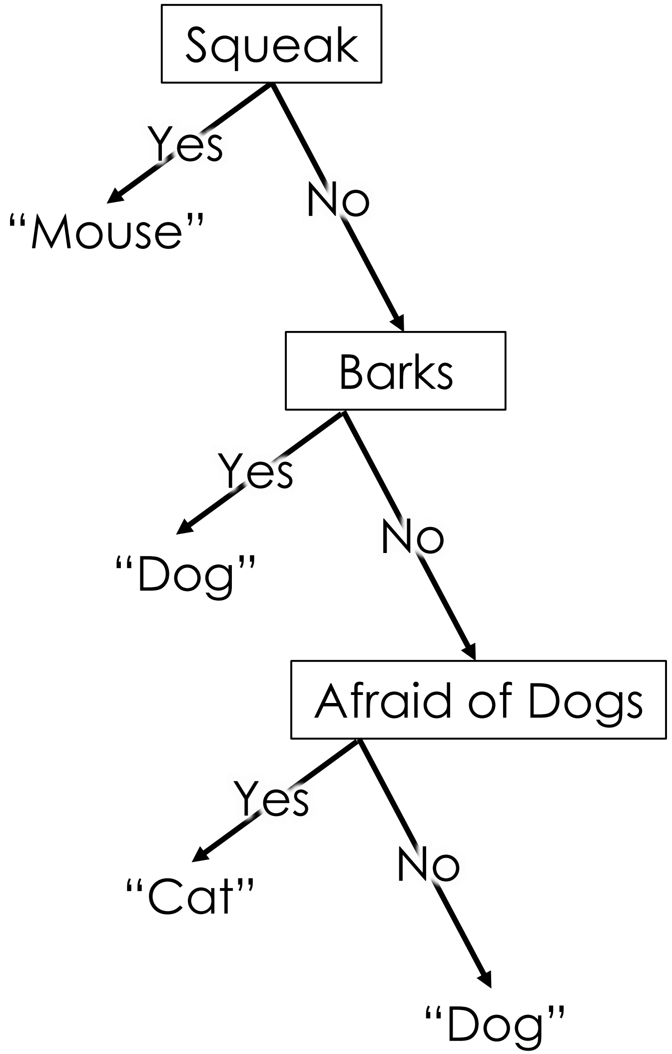
Random Forests: Example

3. Take the mode prediction of all trees (**ntree**) to determine the final classification

Random Forests: Example

Original

Species	Barks	Pet	Squeaks	Meows	Collar	Afraid of Dogs	Length	Height	Likes Cheese
Cat	No	Yes	No	Yes	Yes	No	0.35	0.24	Yes

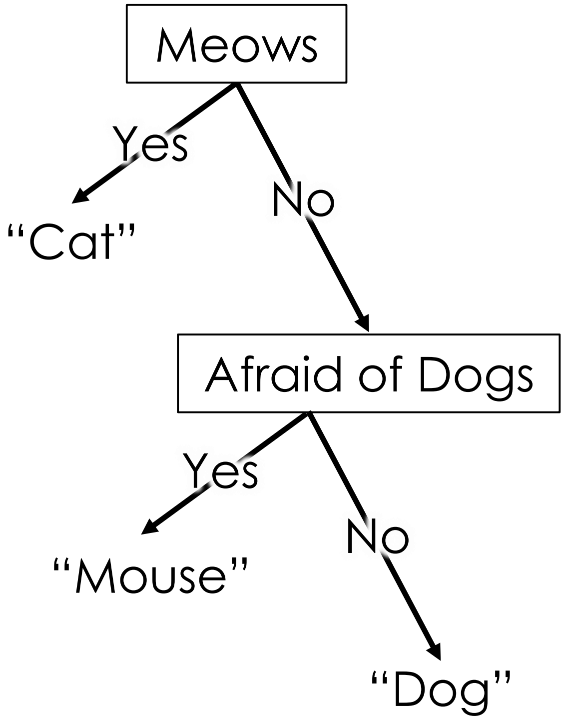


Tree	Vote
1	Dog

Random Forests: Example

Original

Species	Barks	Pet	Squeaks	Meows	Collar	Afraid of Dogs	Length	Height	Likes Cheese
Cat	No	Yes	No	Yes	Yes	No	0.35	0.24	Yes

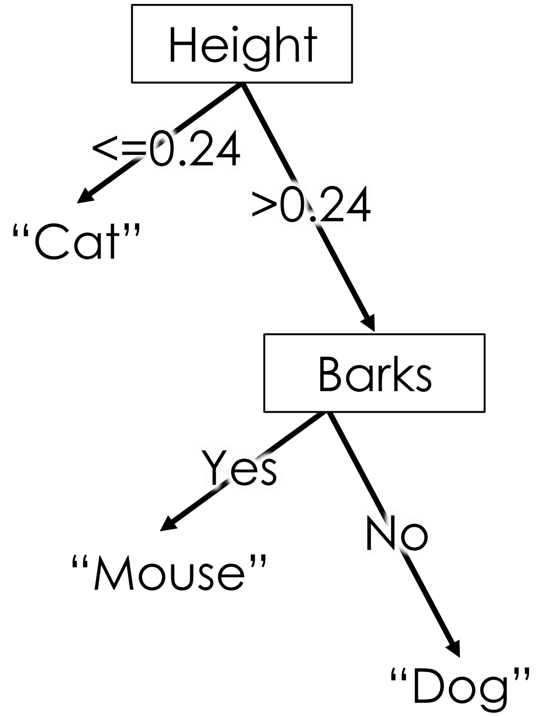


Tree	Vote
1	Dog
2	Cat

Random Forests: Example

Original

Species	Barks	Pet	Squeaks	Meows	Collar	Afraid of Dogs	Length	Height	Likes Cheese
Cat	No	Yes	No	Yes	Yes	No	0.35	0.24	Yes



Tree	Vote
1	Dog
2	Cat
3	Cat

Random Forests: Example

Original

	Species	Barks	Pet	Squeaks	Meows	Collar	Afraid of Dogs	Length	Height	Likes Cheese
17	Cat	No	Yes	No	Yes	Yes	No	0.35	0.24	Yes

Tree	Vote
1	Dog
2	Cat
3	Cat
4	Mouse
5	Cat
6	Cat
7	Cat
8	Cat
9	Dog

Majority = Cat

Final Classification= Cat

Random Forests: Example

Original

	Species	Barks	Pet	Squeaks	Meows	Collar	Afraid of Dogs	Length	Height	Likes Cheese
17	Cat	No	Yes	No	Yes	Yes	No	0.35	0.24	Yes

Tree	Vote
1	Dog
2	Cat
3	Cat
4	Mouse
5	Cat
6	Cat
7	Cat
8	Cat
9	Cat

Probability:
=2/3
=67%

Random Forests: Example

Original

	Species	Barks	Pet	Squeaks	Meows	Collar	Afraid of Dogs	Length	Height	Likes Cheese
17	Cat	No	Yes	No	Yes	Yes	No	0.35	0.24	Yes

ntree = 9

Tree	Vote
1	Dog
2	Cat
3	Cat
4	Mouse
5	Cat
6	Cat
7	Cat
8	Cat
9	Cat

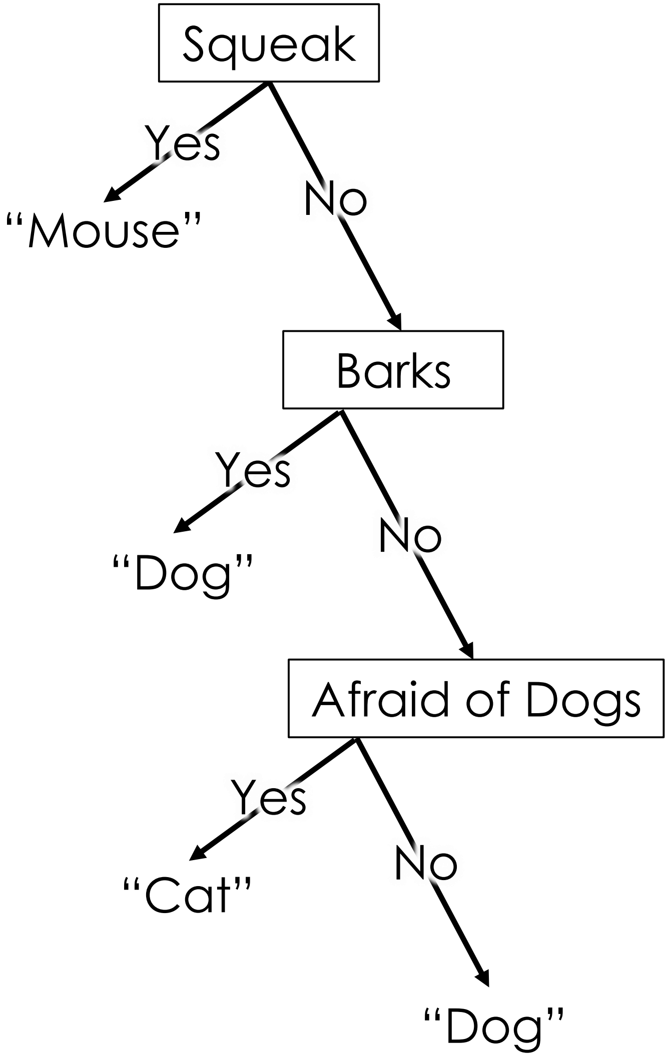
Random Forests: Example

- Run the Out of Bag Samples down the tree and calculate the Out of Bag Error (for a given tree)

Random Forests: Example

	Species	Barks	Pet	Squeaks	Meows	Collar	Afraid of Dogs	Length	Height	Likes Cheese
1	Mouse	No	Yes	Yes	No	No	Yes	0.14	0.07	Yes
2	Mouse	No	No	Yes	No	No	Yes	0.18	0.09	Yes
	Mouse	No	No	Yes	No	No	Yes	0.13	0.06	Yes
4	Mouse	No	Yes	Yes	No	No	Yes	0.13	0.06	Yes
5	Mouse	No	No	Yes	No	No	Yes	0.13	0.07	Yes
6	Mouse	No	No	Yes	No	No	Yes	0.11	0.05	Yes
	Mouse	No	No	Yes	No	No	Yes	0.13	0.06	Yes
	Mouse	No	No	Yes	No	No	Yes	0.16	0.08	Yes
	Mouse	No	No	Yes	No	No	Yes	0.15	0.08	Yes
10	Cat	No	Yes	No	Yes	Yes	Yes	0.31	0.19	Yes
11	Cat	No	Yes	No	Yes	No	Yes	0.38	0.20	Yes
12	Cat	No	Yes	No	Yes	Yes	Yes	0.40	0.15	No
13	Cat	No	Yes	No	Yes	Yes	Yes	0.37	0.09	Yes
14	Cat	No	Yes	No	Yes	Yes	Yes	0.36	0.17	Yes
15	Cat	No	No	No	Yes	No	No	0.32	0.22	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.30	0.16	Yes
17	Cat	No	Yes	No	Yes	Yes	Yes	0.35	0.24	Yes
18	Cat	No	Yes	No	Yes	Yes	Yes	0.33	0.22	Yes
19	Dog	Yes	No	No	No	No	No	0.58	0.33	Yes
20	Dog	Yes	Yes	No	No	Yes	No	0.53	0.35	Yes
21	Dog	Yes	Yes	No	No	Yes	No	0.51	0.33	Yes
22	Dog	Yes	Yes	No	No	Yes	No	0.16	0.32	Yes
23	Dog	No	No	No	No	No	No	0.52	0.26	Yes
24	Dog	Yes	Yes	No	No	Yes	No	0.53	0.27	Yes
25	Dog	Yes	Yes	No	No	Yes	No	0.37	0.16	Yes
26	Dog	Yes	Yes	No	No	Yes	No	0.53	0.29	Yes
27	Dog	Yes	Yes	No	No	Yes	No	0.58	0.29	Yes

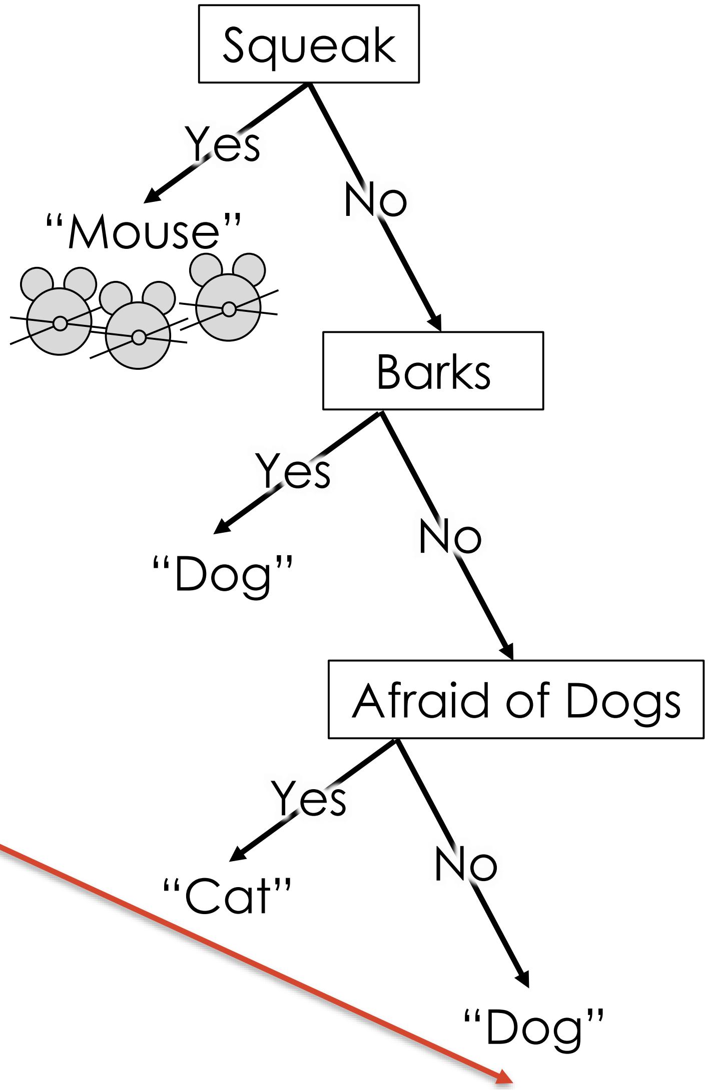
Remaining for internal accuracy assessment ≈ 1/3



Random Forests: Example

	Species	Barks	Pet	Squeaks	Meows	Collar	Afraid of Dogs	Length	Height	Likes Cheese
1	Mouse	No	Yes	Yes	No	No	Yes	0.14	0.07	Yes
2	Mouse	No	No	Yes	No	No	Yes	0.18	0.09	Yes
3	Mouse	No	No	Yes	No	No	Yes	0.13	0.06	Yes
4	Mouse	No	Yes	Yes	No	No	Yes	0.13	0.06	Yes
5	Mouse	No	No	Yes	No	No	Yes	0.13	0.07	Yes
6	Mouse	No	No	Yes	No	No	Yes	0.11	0.05	Yes
7	Mouse	No	No	Yes	No	No	Yes	0.13	0.06	Yes
8	Mouse	No	No	Yes	No	No	Yes	0.16	0.08	Yes
9	Mouse	No	No	Yes	No	No	Yes	0.15	0.08	Yes
[illegible]	Cat	No	Yes	No	Yes	Yes	Yes	0.31	0.19	Yes
[illegible]	Cat	No	Yes	No	Yes	No	Yes	0.38	0.20	Yes
[illegible]	Cat	No	Yes	No	Yes	Yes	Yes	0.40	0.15	No
13	Cat	No	Yes	No	Yes	Yes	Yes	0.37	0.09	Yes
14	Cat	No	Yes	No	Yes	Yes	Yes	0.36	0.17	Yes
[illegible]	Cat	No	No	No	Yes	No	No	0.32	0.22	Yes
[illegible]	Cat	No	Yes	No	Yes	Yes	Yes	0.30	0.16	Yes
[illegible]	Cat	No	Yes	No	Yes	Yes	Yes	0.35	0.24	Yes
[illegible]	Cat	No	Yes	No	Yes	Yes	Yes	0.33	0.22	Yes
19	Dog	Yes	No	No	No	No	No	0.58	0.33	Yes
20	Dog	Yes	Yes	No	No	Yes	No	0.53	0.35	Yes
21	Dog	Yes	Yes	No	No	Yes	No	0.51	0.33	Yes
22	Dog	Yes	Yes	No	No	Yes	No	0.16	0.32	Yes
23	Dog	No	No	No	No	No	No	0.52	0.26	Yes
24	Dog	Yes	Yes	No	No	Yes	No	0.53	0.27	Yes
25	Dog	Yes	Yes	No	No	Yes	No	0.37	0.16	Yes
26	Dog	Yes	Yes	No	No	Yes	No	0.53	0.29	Yes
27	Dog	Yes	Yes	No	No	Yes	No	0.58	0.29	Yes

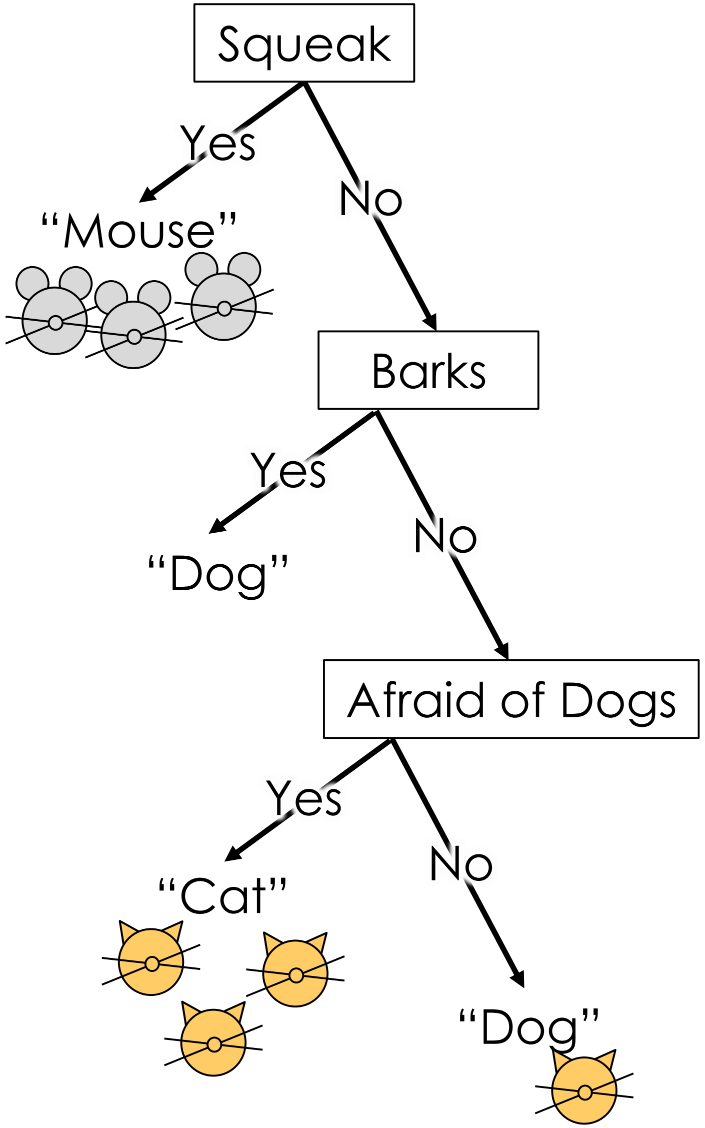
Remaining for internal accuracy assessment ≈ 1/3



Random Forests: Example

Remaining for internal accuracy assessment ≈ 1/3

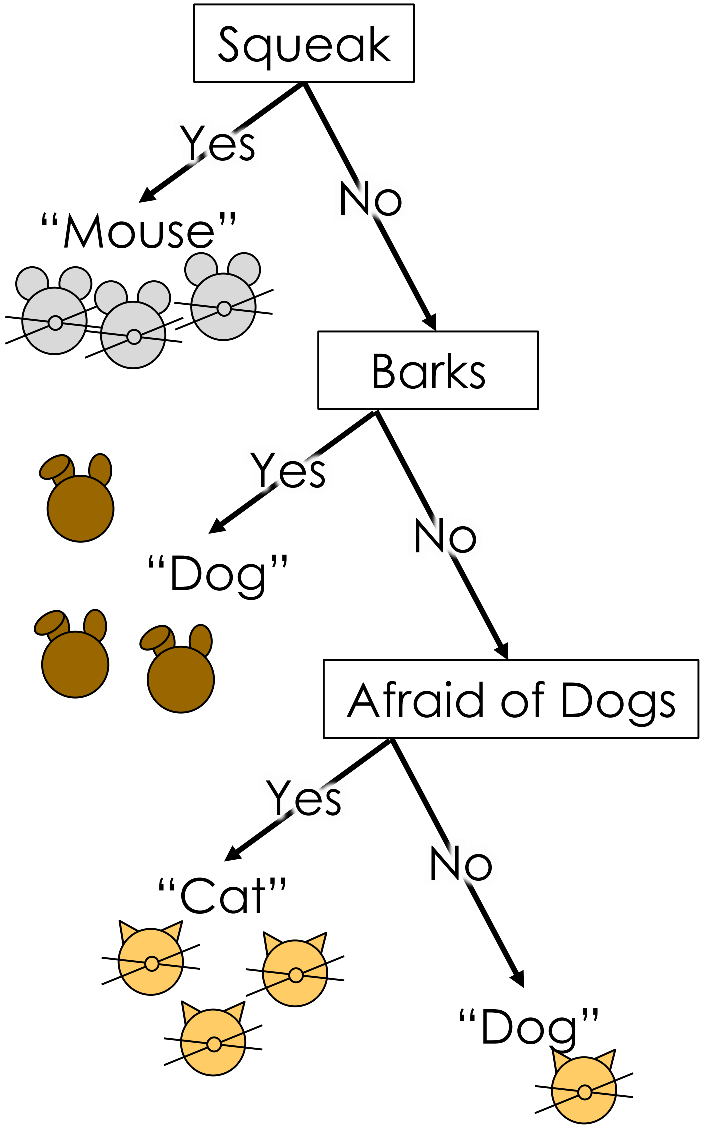
	Species	Barks	Pet	Squeaks	Meows	Collar	Afraid of Dogs	Length	Height	Likes Cheese
1	Mouse	No	Yes	Yes	No	No	Yes	0.14	0.07	Yes
2	Mouse	No	No	Yes	No	No	Yes	0.18	0.09	Yes
3	Mouse	No	No	Yes	No	No	Yes	0.13	0.06	Yes
4	Mouse	No	Yes	Yes	No	No	Yes	0.13	0.06	Yes
5	Mouse	No	No	Yes	No	No	Yes	0.13	0.07	Yes
6	Mouse	No	No	Yes	No	No	Yes	0.11	0.05	Yes
7	Mouse	No	No	Yes	No	No	Yes	0.13	0.06	Yes
8	Mouse	No	No	Yes	No	No	Yes	0.16	0.08	Yes
9	Mouse	No	No	Yes	No	No	Yes	0.15	0.08	Yes
10	Cat	No	Yes	No	Yes	Yes	Yes	0.31	0.19	Yes
11	Cat	No	Yes	No	Yes	No	Yes	0.38	0.20	Yes
12	Cat	No	Yes	No	Yes	Yes	Yes	0.40	0.15	No
13	Cat	No	Yes	No	Yes	Yes	Yes	0.37	0.09	Yes
14	Cat	No	Yes	No	Yes	Yes	Yes	0.36	0.17	Yes
15	Cat	No	No	No	Yes	No	No	0.32	0.22	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.30	0.16	Yes
17	Cat	No	Yes	No	Yes	Yes	Yes	0.35	0.24	Yes
18	Cat	No	Yes	No	Yes	Yes	Yes	0.33	0.22	Yes
[illegible]	Dog	Yes	No	No	No	No	No	0.58	0.33	Yes
20	Dog	Yes	Yes	No	No	Yes	No	0.53	0.35	Yes
21	Dog	Yes	Yes	No	No	Yes	No	0.51	0.33	Yes
22	Dog	Yes	Yes	No	No	Yes	No	0.16	0.32	Yes
23	Dog	No	No	No	No	No	No	0.52	0.26	Yes
[illegible]	Dog	Yes	Yes	No	No	Yes	No	0.53	0.27	Yes
[illegible]	Dog	Yes	Yes	No	No	Yes	No	0.37	0.16	Yes
[illegible]	Dog	Yes	Yes	No	No	Yes	No	0.53	0.29	Yes
27	Dog	Yes	Yes	No	No	Yes	No	0.58	0.29	Yes



Random Forests: Example

	Species	Barks	Pet	Squeaks	Meows	Collar	Afraid of Dogs	Length	Height	Likes Cheese
1	Mouse	No	Yes	Yes	No	No	Yes	0.14	0.07	Yes
2	Mouse	No	No	Yes	No	No	Yes	0.18	0.09	Yes
3	Mouse	No	No	Yes	No	No	Yes	0.13	0.06	Yes
4	Mouse	No	Yes	Yes	No	No	Yes	0.13	0.06	Yes
5	Mouse	No	No	Yes	No	No	Yes	0.13	0.07	Yes
6	Mouse	No	No	Yes	No	No	Yes	0.11	0.05	Yes
7	Mouse	No	No	Yes	No	No	Yes	0.13	0.06	Yes
8	Mouse	No	No	Yes	No	No	Yes	0.16	0.08	Yes
9	Mouse	No	No	Yes	No	No	Yes	0.15	0.08	Yes
10	Cat	No	Yes	No	Yes	Yes	Yes	0.31	0.19	Yes
11	Cat	No	Yes	No	Yes	No	Yes	0.38	0.20	Yes
12	Cat	No	Yes	No	Yes	Yes	Yes	0.40	0.15	No
13	Cat	No	Yes	No	Yes	Yes	Yes	0.37	0.09	Yes
14	Cat	No	Yes	No	Yes	Yes	Yes	0.36	0.17	Yes
15	Cat	No	No	No	Yes	No	No	0.32	0.22	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.30	0.16	Yes
17	Cat	No	Yes	No	Yes	Yes	Yes	0.35	0.24	Yes
18	Cat	No	Yes	No	Yes	Yes	Yes	0.33	0.22	Yes
19	Dog	Yes	No	No	No	No	No	0.58	0.33	Yes
20	Dog	Yes	Yes	No	No	Yes	No	0.53	0.35	Yes
21	Dog	Yes	Yes	No	No	Yes	No	0.51	0.33	Yes
22	Dog	Yes	Yes	No	No	Yes	No	0.16	0.32	Yes
23	Dog	No	No	No	No	No	No	0.52	0.26	Yes
24	Dog	Yes	Yes	No	No	Yes	No	0.53	0.27	Yes
25	Dog	Yes	Yes	No	No	Yes	No	0.37	0.16	Yes
26	Dog	Yes	Yes	No	No	Yes	No	0.53	0.29	Yes
27	Dog	Yes	Yes	No	No	Yes	No	0.58	0.29	Yes

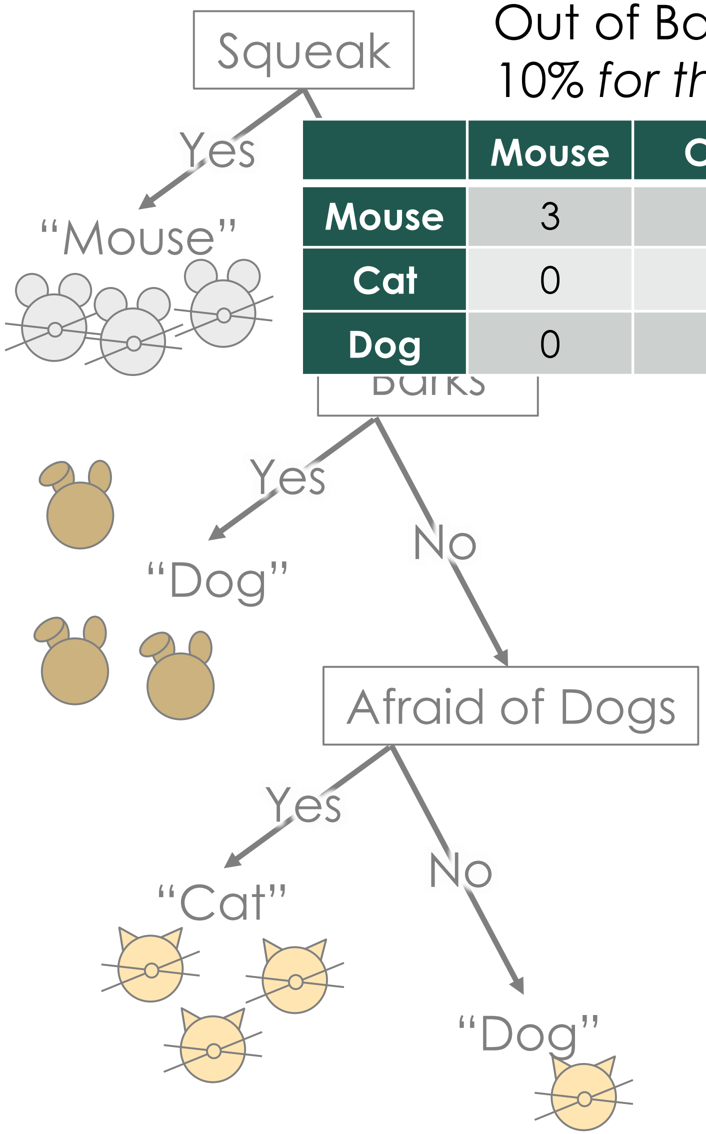
Remaining for internal accuracy assessment ≈ 1/3



Random Forests: Example

	Species	Barks	Pet	Squeaks	Meows	Collar	Afraid of Dogs	Length	Height	Likes Cheese
1	Mouse	No	Yes	Yes	No	No	Yes	0.14	0.07	Yes
2	Mouse	No	No	Yes	No	No	Yes	0.18	0.09	Yes
3	Mouse	No	No	Yes	No	No	Yes	0.13	0.06	Yes
4	Mouse	No	Yes	Yes	No	No	Yes	0.13	0.06	Yes
5	Mouse	No	No	Yes	No	No	Yes	0.13	0.07	Yes
6	Mouse	No	No	Yes	No	No	Yes	0.11	0.05	Yes
7	Mouse	No	No	Yes	No	No	Yes	0.13	0.06	Yes
8	Mouse	No	No	Yes	No	No	Yes	0.16	0.08	Yes
9	Mouse	No	No	Yes	No	No	Yes	0.15	0.08	Yes
10	Cat	No	Yes	No	Yes	Yes	Yes	0.31	0.19	Yes
11	Cat	No	Yes	No	Yes	No	Yes	0.38	0.20	Yes
12	Cat	No	Yes	No	Yes	Yes	Yes	0.40	0.15	No
13	Cat	No	Yes	No	Yes	Yes	Yes	0.37	0.09	Yes
14	Cat	No	Yes	No	Yes	Yes	Yes	0.36	0.17	Yes
15	Cat	No	No	No	Yes	No	No	0.32	0.22	Yes
16	Cat	No	Yes	No	Yes	Yes	Yes	0.30	0.16	Yes
17	Cat	No	Yes	No	Yes	Yes	Yes	0.35	0.24	Yes
18	Cat	No	Yes	No	Yes	Yes	Yes	0.33	0.22	Yes
19	Dog	Yes	No	No	No	No	No	0.58	0.33	Yes
20	Dog	Yes	Yes	No	No	Yes	No	0.53	0.35	Yes
21	Dog	Yes	Yes	No	No	Yes	No	0.51	0.33	Yes
22	Dog	Yes	Yes	No	No	Yes	No	0.16	0.32	Yes
23	Dog	No	No	No	No	No	No	0.52	0.26	Yes
24	Dog	Yes	Yes	No	No	Yes	No	0.53	0.27	Yes
25	Dog	Yes	Yes	No	No	Yes	No	0.37	0.16	Yes
26	Dog	Yes	Yes	No	No	Yes	No	0.53	0.29	Yes
27	Dog	Yes	Yes	No	No	Yes	No	0.58	0.29	Yes

Remaining for internal accuracy assessment ≈ 1/3

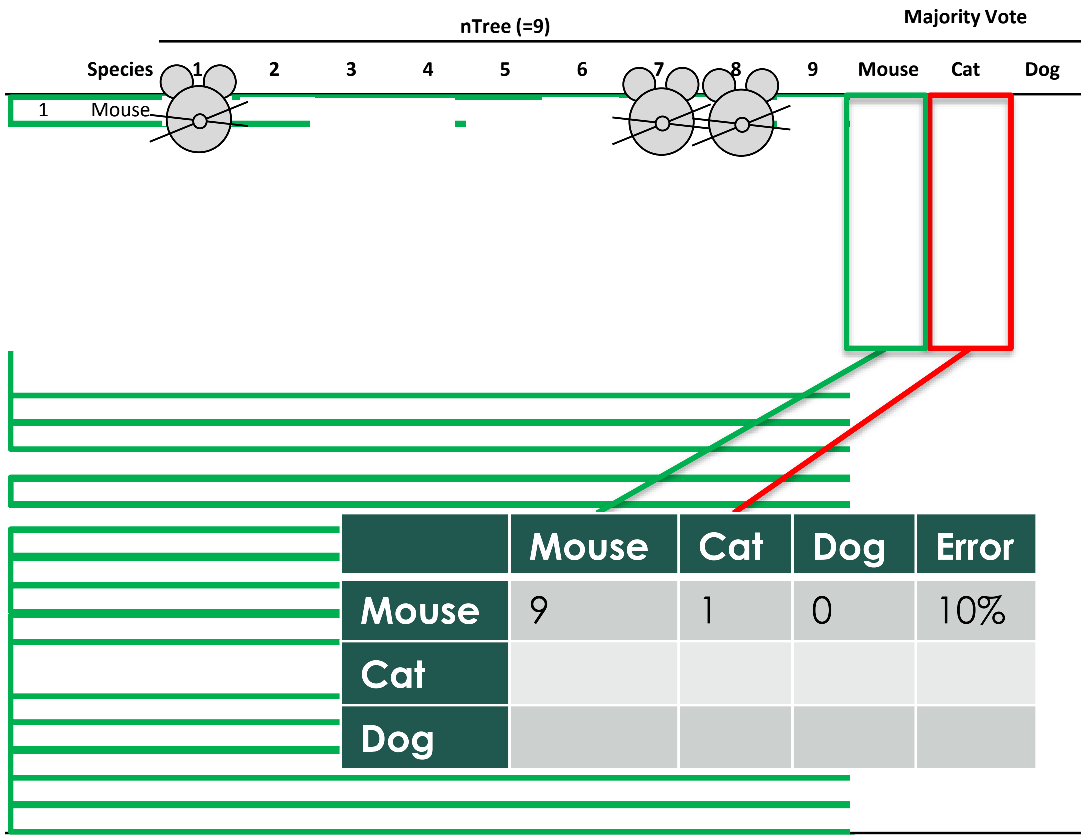


Out of Bag Error is 10% *for this tree…*

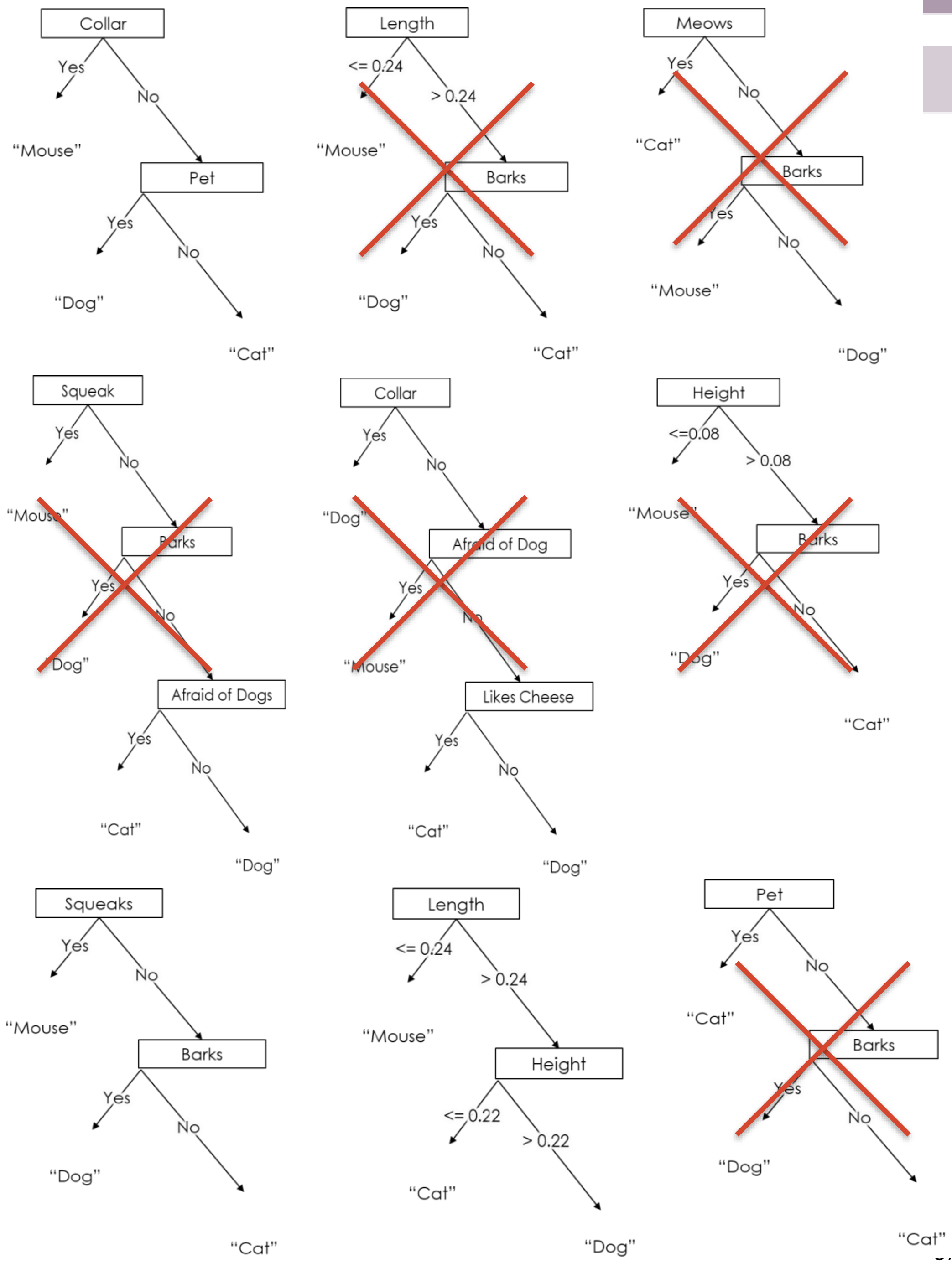
	Mouse	Cat	Dog
Mouse	3	0	0
Cat	0	3	1
Dog	0	0	3

Random Forests: Example

- Calculate the overall Out of Bag Error



	Mouse	Cat	Dog	Error
Mouse	9	1	0	10%
Cat				
Dog				



Random Forests: Example

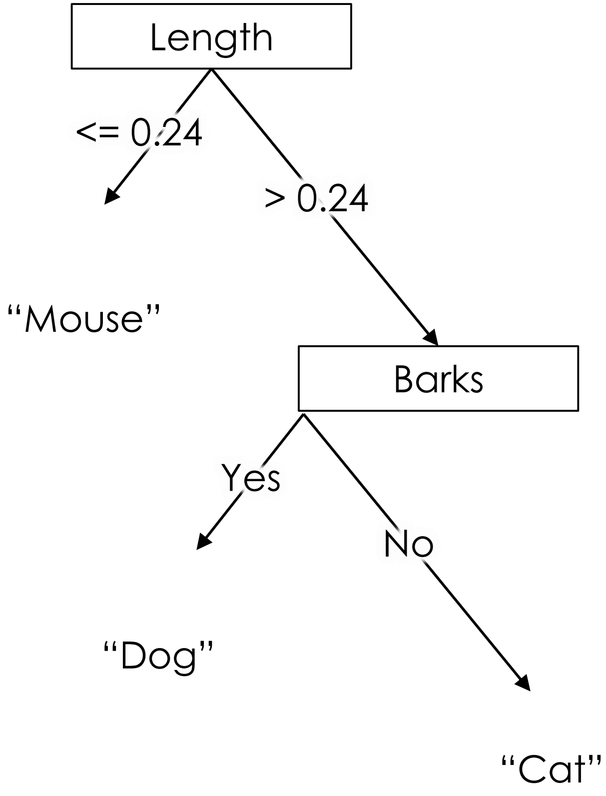
Decrease in Accuracy
= 90% – 40%
= 50%

5. Calculating the Mean Decrease in Accuracy (**MDA**)
   - Values permuted across all trees
   - Average decrease in accuracy; normalize by standard deviation

Original

	Species	Barks	Pet	Squeaks	Meows	Collar	Afraid of Dogs	Length	Height	Likes Cheese
1	Mouse	No	Yes	Yes	No	No	Yes		0.07	Yes
	Mouse	No	No	Yes	No	No	Yes		0.09	Yes
	Mouse	No	No	Yes	No	No	Yes	0.31	0.06	Yes
	Mouse	No	Yes	Yes	No	No	Yes		0.06	Yes
5	Mouse	No	No	Yes	No	No	Yes		0.07	Yes
	Mouse	No	No	Yes	No	No	Yes		0.05	Yes
	Mouse	No	No	Yes	No	No	Yes	0.32	0.06	Yes
	Mouse	No	No	Yes	No	No	Yes	0.38	0.08	Yes
	Mouse	No	No	Yes	No	No	Yes		0.08	Yes
	Cat	No	Yes	No	Yes	Yes	Yes	0.37	0.19	Yes
	Cat	No	Yes	No	Yes	No	Yes	0.53	0.20	Yes
	Cat	No	Yes	No	Yes	Yes	Yes		0.15	No
13	Cat	No	Yes	No	Yes	Yes	Yes		0.09	Yes
	Cat	No	Yes	No	Yes	Yes	Yes		0.17	Yes
	Cat	No	No	No	Yes	No	No	0.35	0.22	Yes
	Cat	No	Yes	No	Yes	Yes	Yes		0.16	Yes
	Cat	No	Yes	No	Yes	Yes	Yes	0.13	0.24	Yes
	Cat	No	Yes	No	Yes	Yes	Yes		0.22	Yes
	Dog	Yes	No	No	No	No	No	0.58	0.33	Yes
	Dog	Yes	Yes	No	No	Yes	No		0.35	Yes
21	Dog	Yes	Yes	No	No	Yes	No		0.33	Yes
22	Dog	Yes	Yes	No	No	Yes	No		0.32	Yes
23	Dog	No	No	No	No	No	No		0.26	Yes
	Dog	Yes	Yes	No	No	Yes	No		0.27	Yes
	Dog	Yes	Yes	No	No	Yes	No	0.13	0.16	Yes
	Dog	Yes	Yes	No	No	Yes	No	0.16	0.29	Yes
	Dog	Yes	Yes	No	No	Yes	No		0.29	Yes

Original Length Data
Randomly Permuted Length Data



Original Out of Bag Accuracy 90%

	Mouse	Cat	Dog
Mouse	3	0	0
Cat	0	3	1
Dog	0	0	3

Out of Bay Accuracy After Permutation 40%

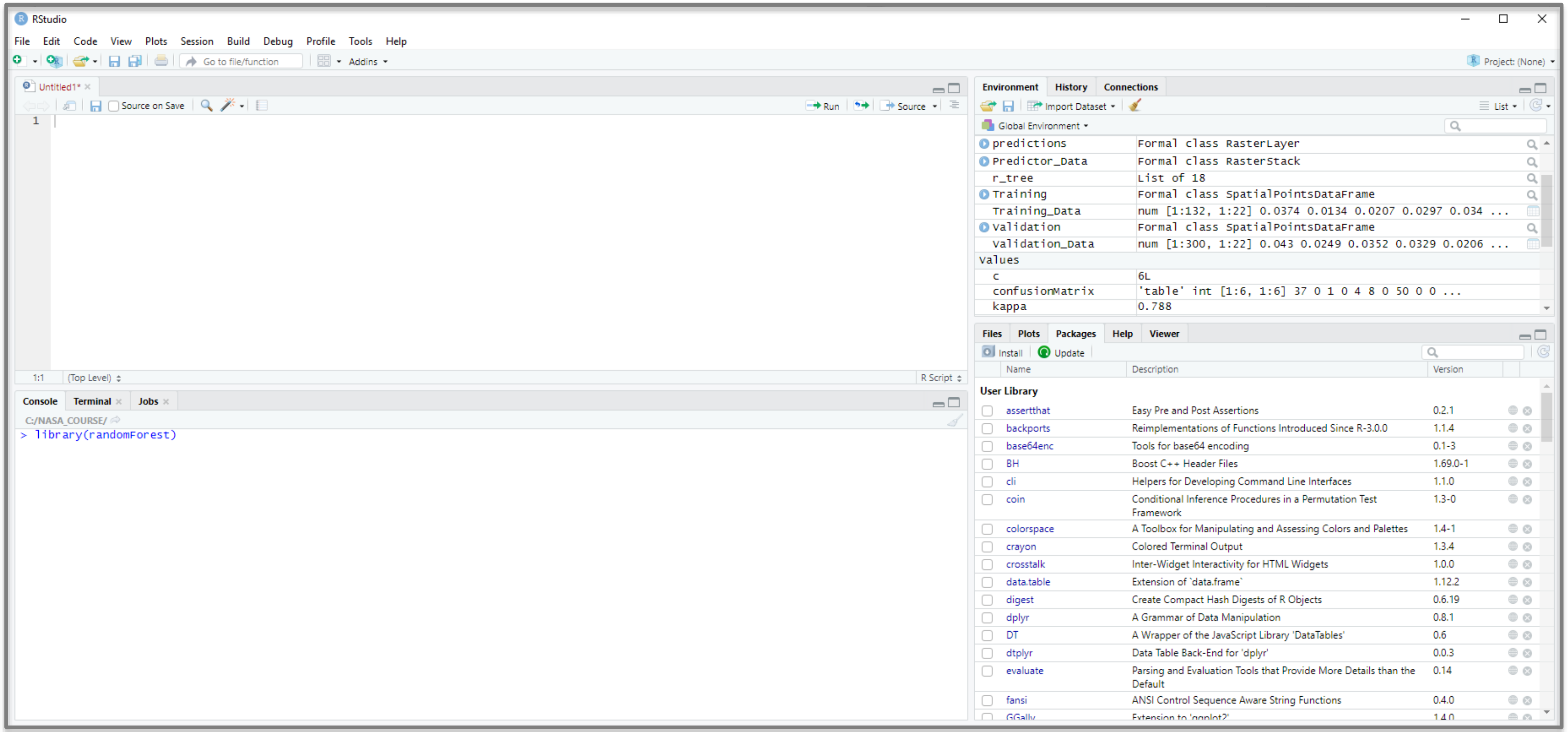
	Mouse	Cat	Dog
Mouse	0	3	0
Cat	1	3	0
Dog	2	0	1

Random Forests: Hands on Demonstration of Crop Classification

1. Install the latest version of R and RStudio
   – https://cran.r-project.org/bin/windows/base/
   – https://www.rstudio.com/products/rstudio/download/
2. Open Rstudio

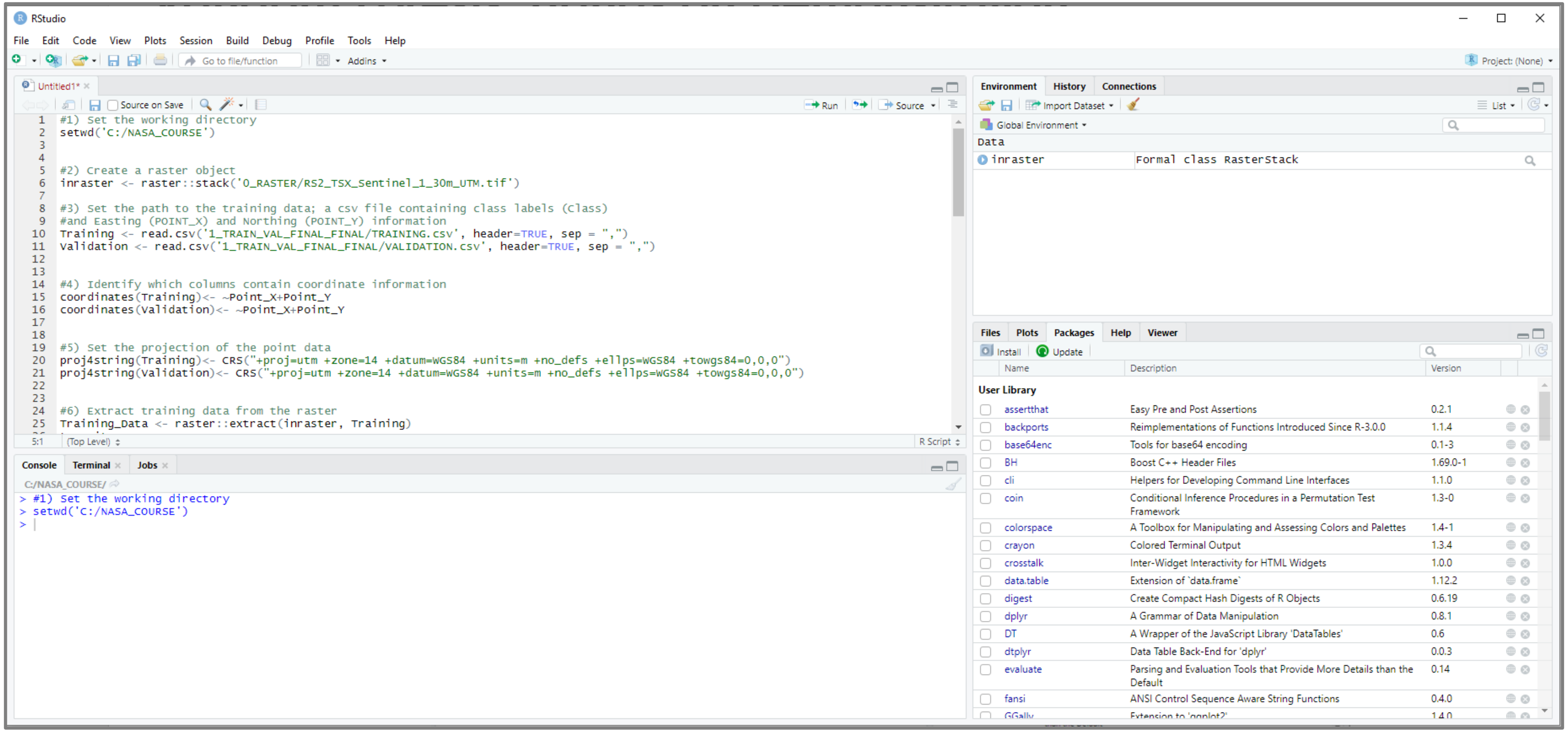
Random Forests: Hands on Demonstration

3. Install (raster, randomForest, sp, rgdal)
4. Load (raster, randomForest, sp, rgdal)



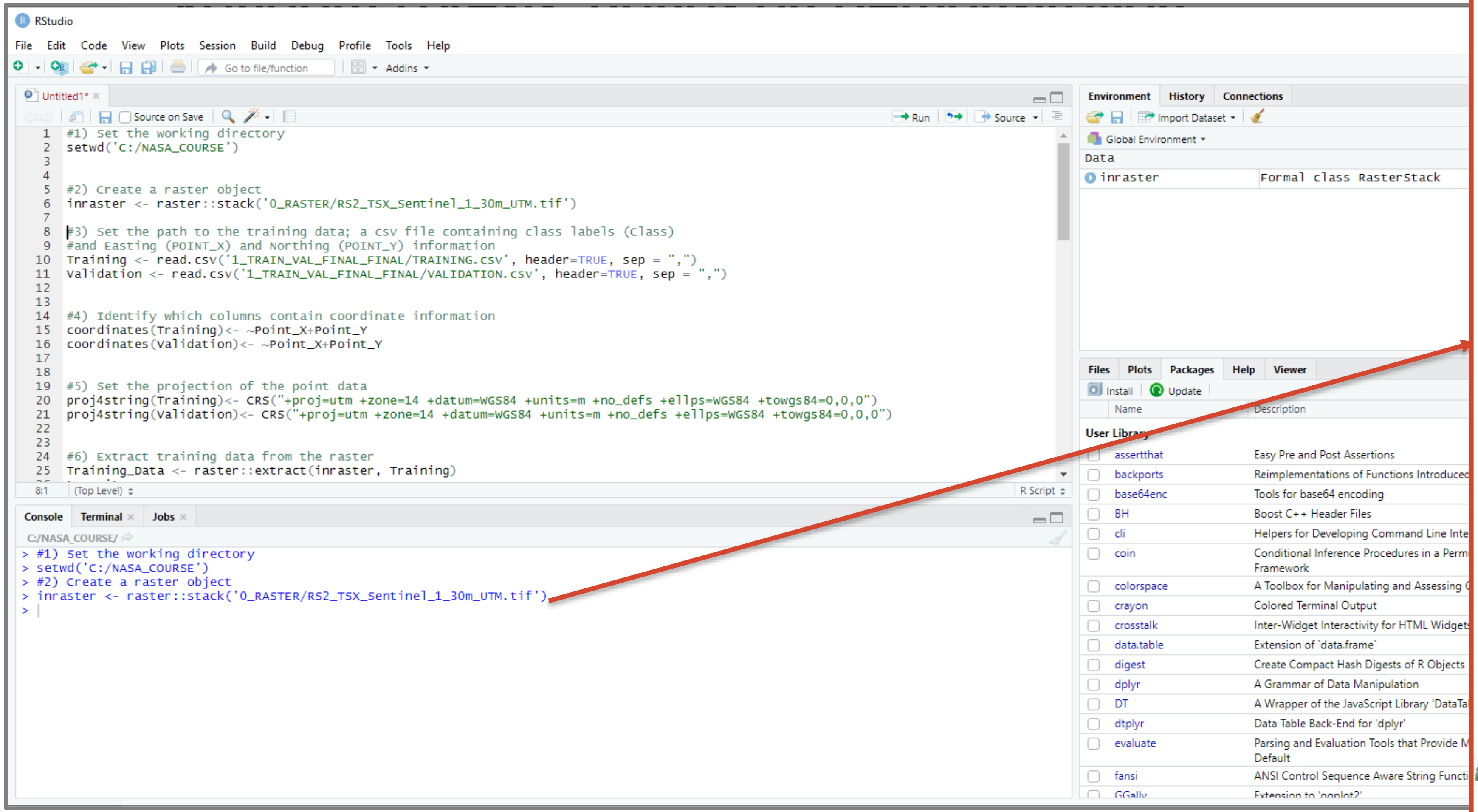
Random Forests: Hands on Demonstration

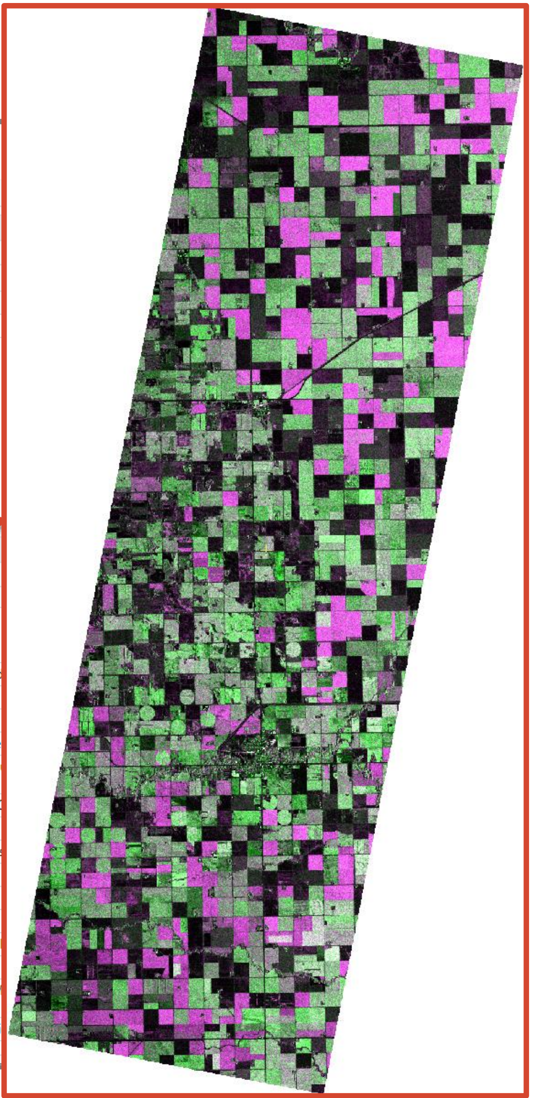
5. Set the Working Directory



Random Forests: Hands on Demonstration

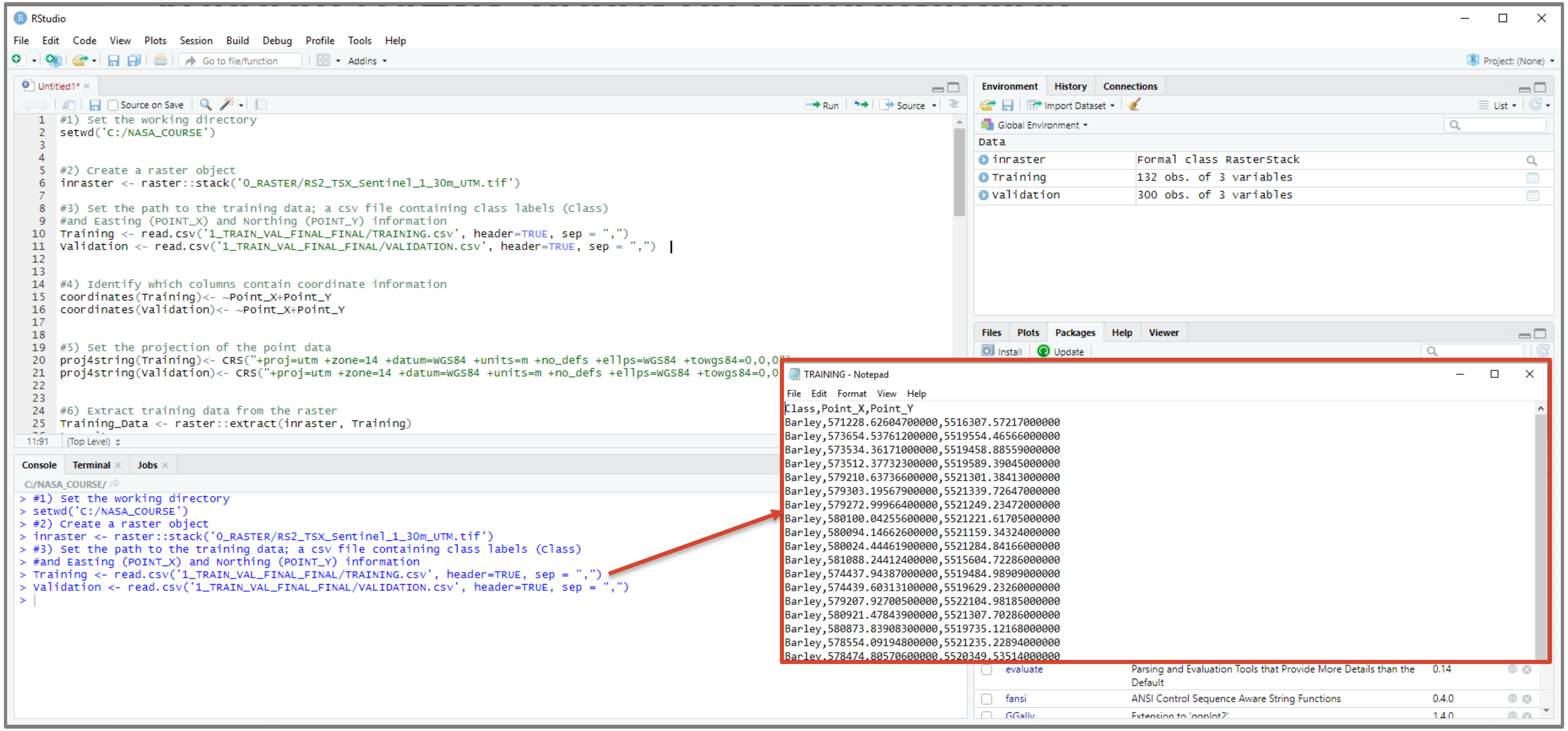
6. Create a raster object





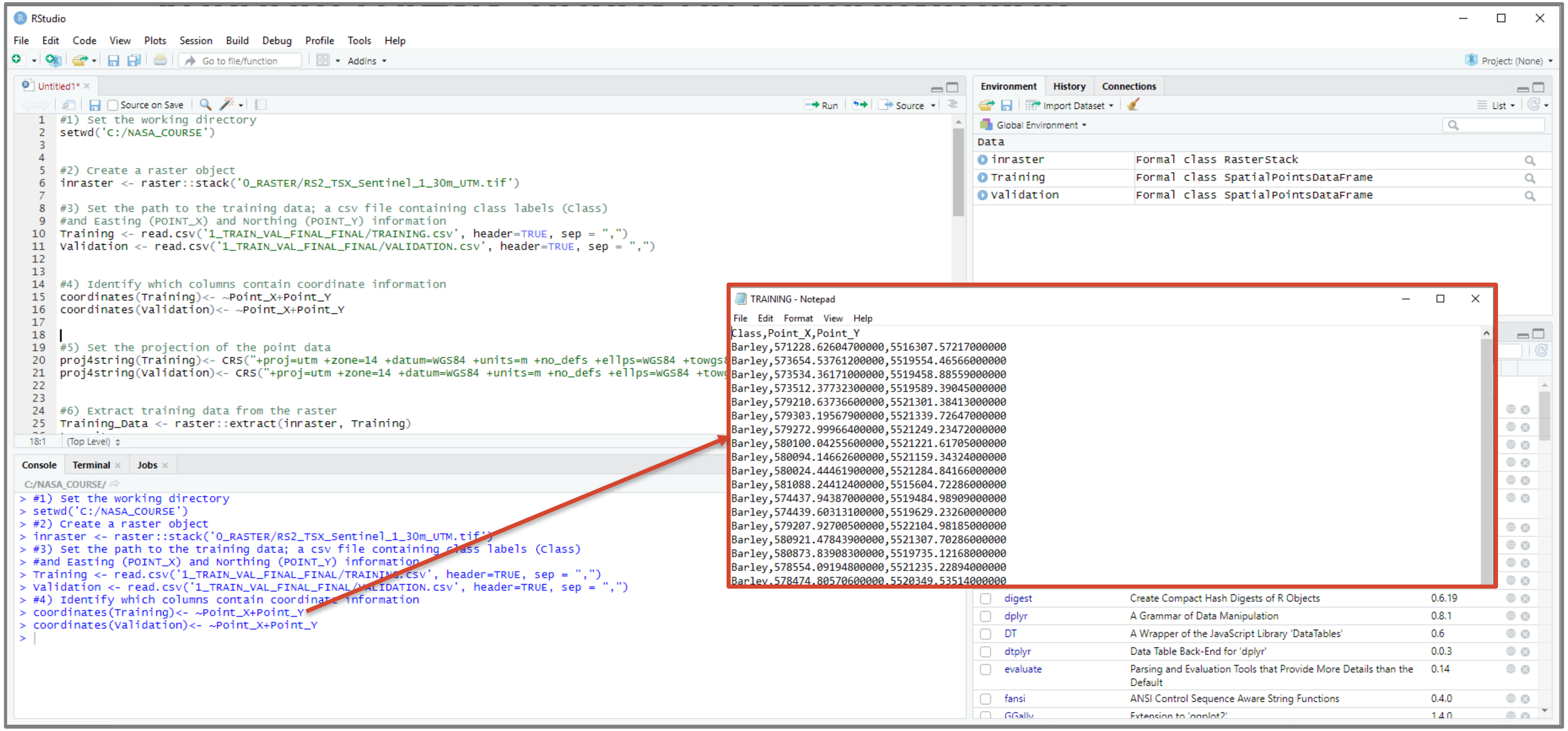
Random Forests: Hands on Demonstration

7. Read training and validation data (csv files)



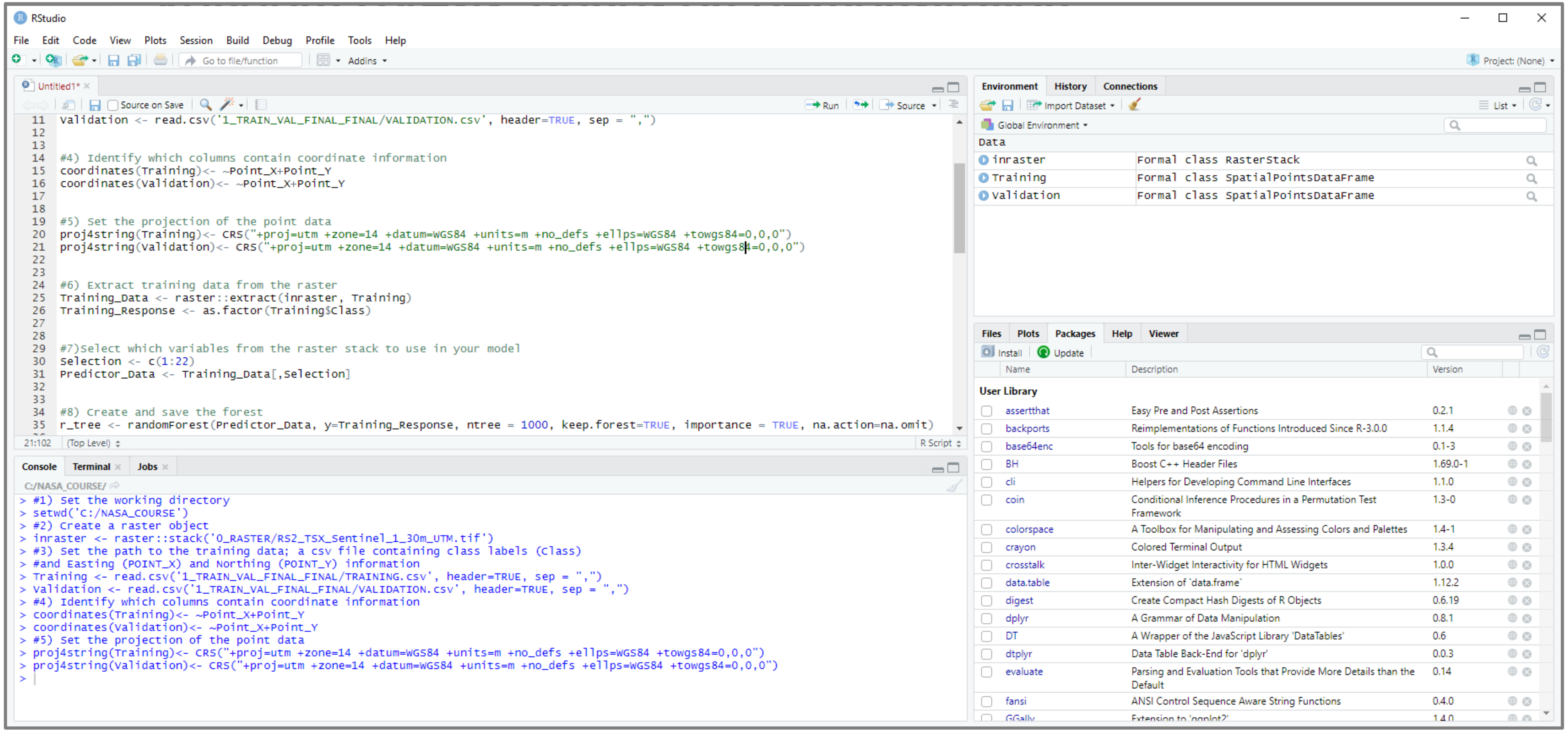
Random Forests: Hands on Demonstration

8. Identify which columns from the csv files contain coordinate information



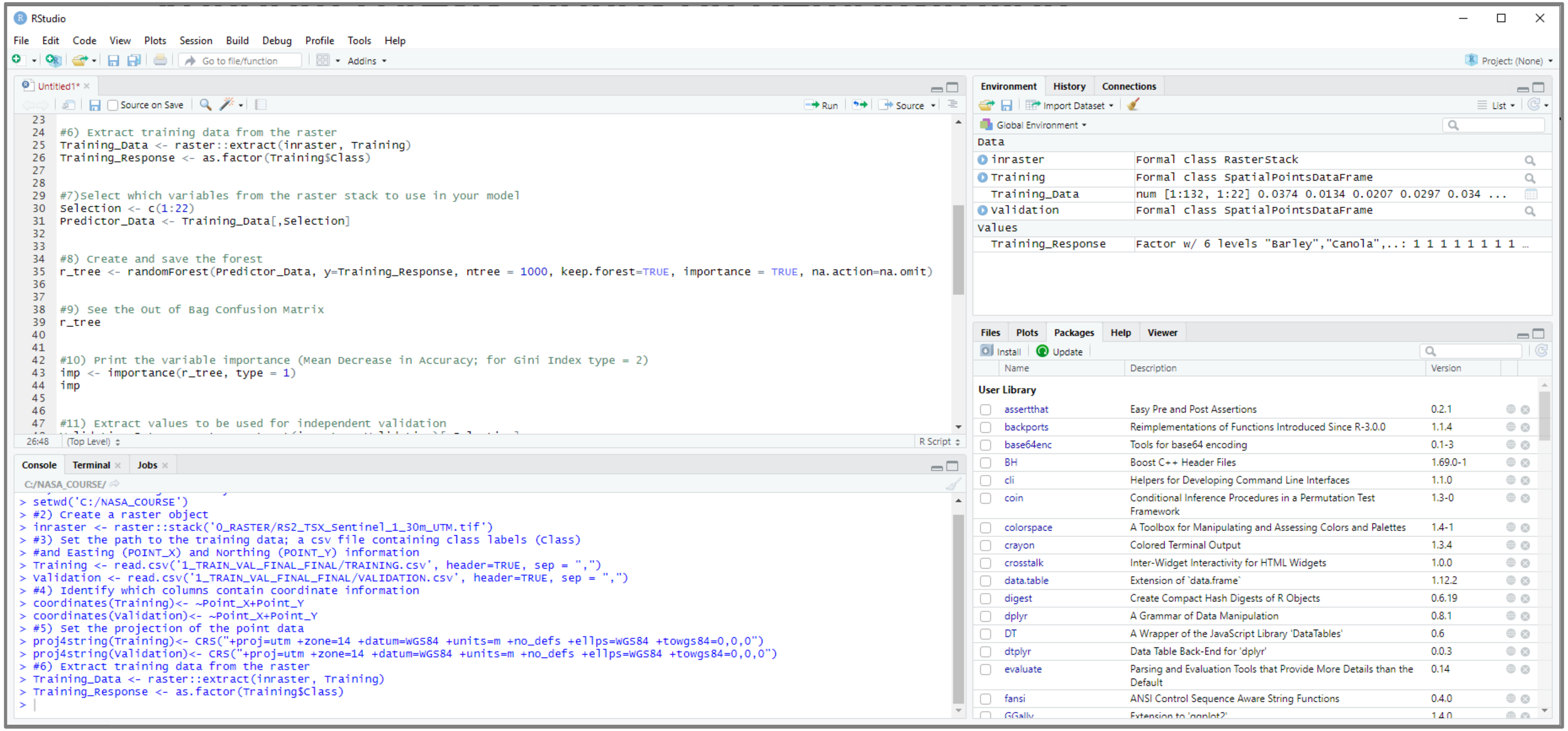
Random Forests: Hands on Demonstration

9. Define the projection of the point data in the csv files



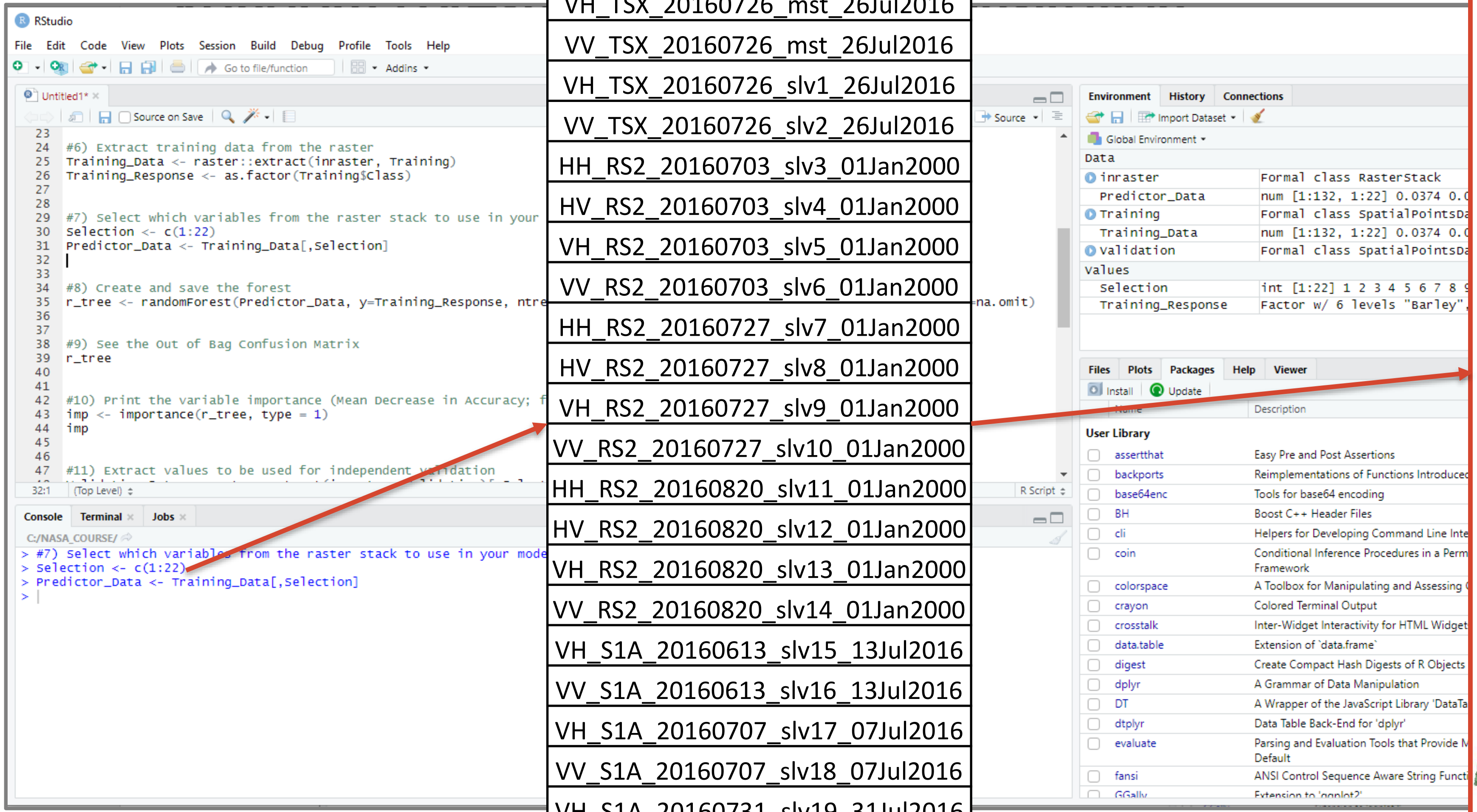
Random Forests: Hands on Demonstration

10. Extract the training data (values of each raster band coincident with point data)

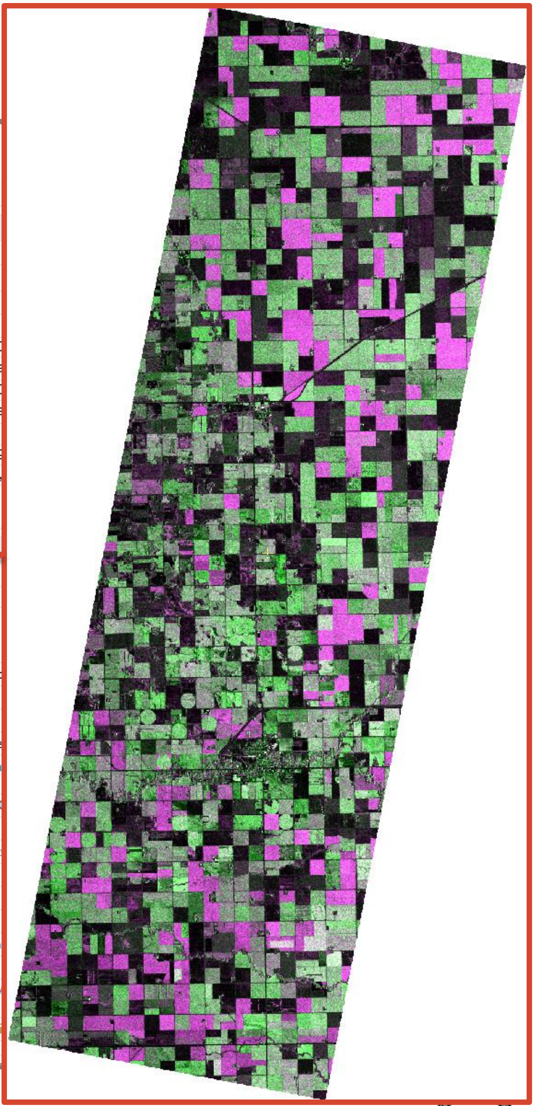


Random Forests: Hands on Demonstration

11. Select which variables to use in the model

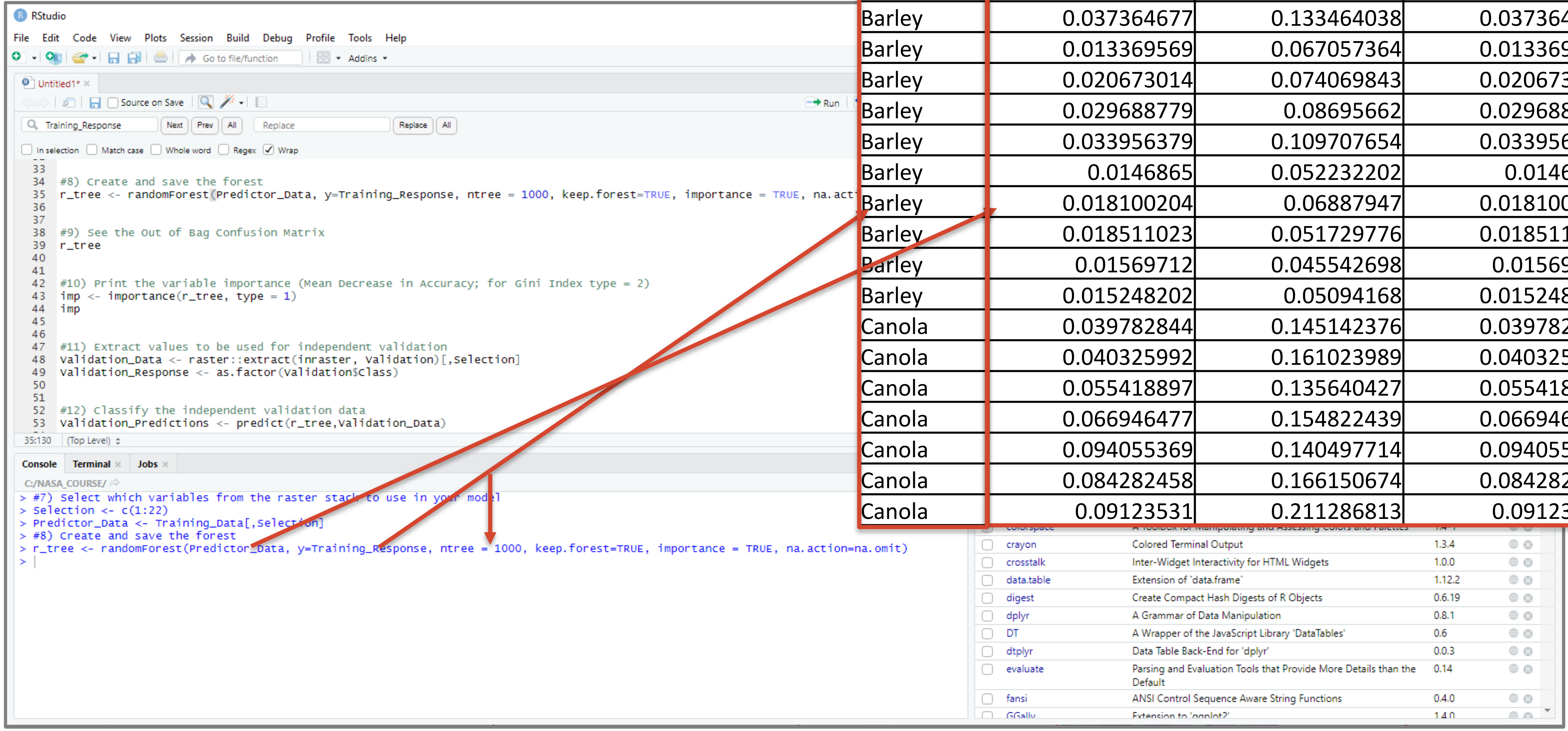


VH_TSX_20160726_mst_26Jul2016
VV_TSX_20160726_mst_26Jul2016
VH_TSX_20160726_slv1_26Jul2016
VV_TSX_20160726_slv2_26Jul2016
HH_RS2_20160703_slv3_01Jan2000
HV_RS2_20160703_slv4_01Jan2000
VH_RS2_20160703_slv5_01Jan2000
VV_RS2_20160703_slv6_01Jan2000
HH_RS2_20160727_slv7_01Jan2000
HV_RS2_20160727_slv8_01Jan2000
VH_RS2_20160727_slv9_01Jan2000
VV_RS2_20160727_slv10_01Jan2000
HH_RS2_20160820_slv11_01Jan2000
HV_RS2_20160820_slv12_01Jan2000
VH_RS2_20160820_slv13_01Jan2000
VV_RS2_20160820_slv14_01Jan2000
VH_S1A_20160613_slv15_13Jul2016
VV_S1A_20160613_slv16_13Jul2016
VH_S1A_20160707_slv17_07Jul2016
VV_S1A_20160707_slv18_07Jul2016
VH_S1A_20160731_slv19_31Jul2016
VV_S1A_20160731_slv20_31Jul2016



Random Forests: Hands on Demonstration

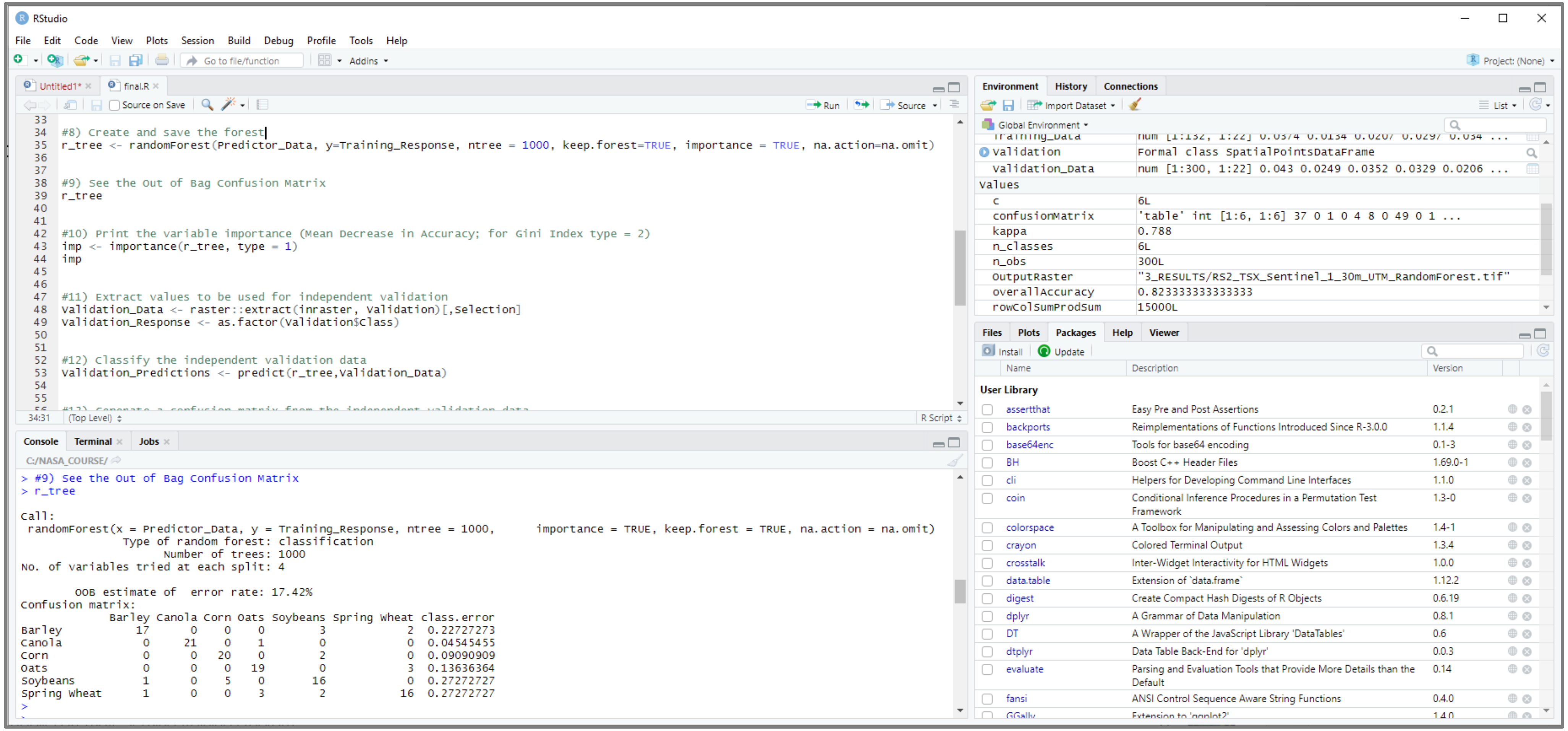
12. Create your Random Forest Model



Class	VH_TSX_20160726_ mst_26Jul2016	VV_TSX_20160726_ mst_26Jul2016	VH_TSX_20160726_ slv1_26Jul2016
Barley	0.037364677	0.133464038	0.037364677
Barley	0.013369569	0.067057364	0.013369569
Barley	0.020673014	0.074069843	0.020673014
Barley	0.029688779	0.08695662	0.029688779
Barley	0.033956379	0.109707654	0.033956379
Barley	0.0146865	0.052232202	0.0146865
Barley	0.018100204	0.06887947	0.018100204
Barley	0.018511023	0.051729776	0.018511023
Barley	0.01569712	0.045542698	0.01569712
Barley	0.015248202	0.05094168	0.015248202
Canola	0.039782844	0.145142376	0.039782844
Canola	0.040325992	0.161023989	0.040325992
Canola	0.055418897	0.135640427	0.055418897
Canola	0.066946477	0.154822439	0.066946477
Canola	0.094055369	0.140497714	0.094055369
Canola	0.084282458	0.166150674	0.084282458
Canola	0.09123531	0.211286813	0.09123531

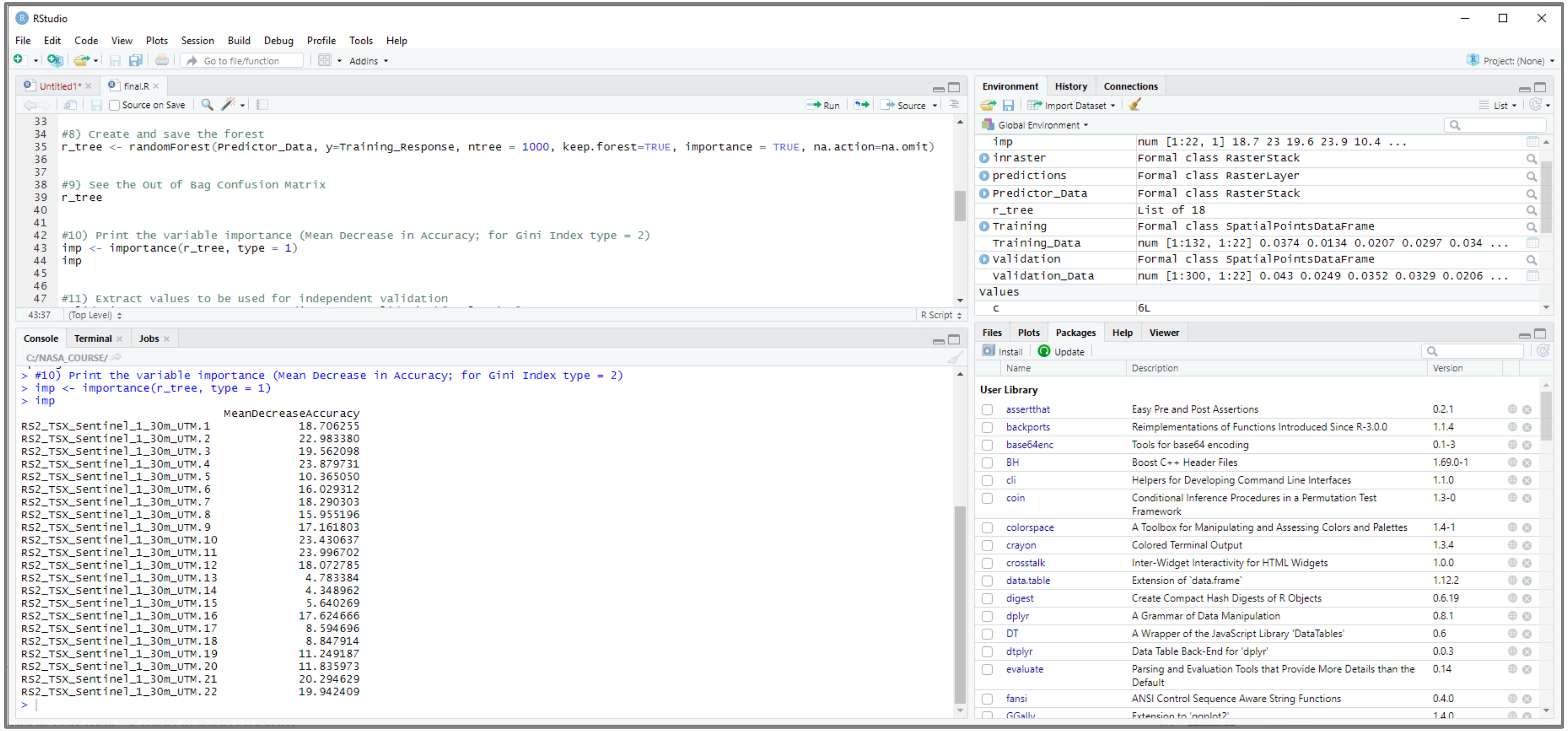
Random Forests: Hands on Demonstration

13. Print the Out of Bag confusion matrix



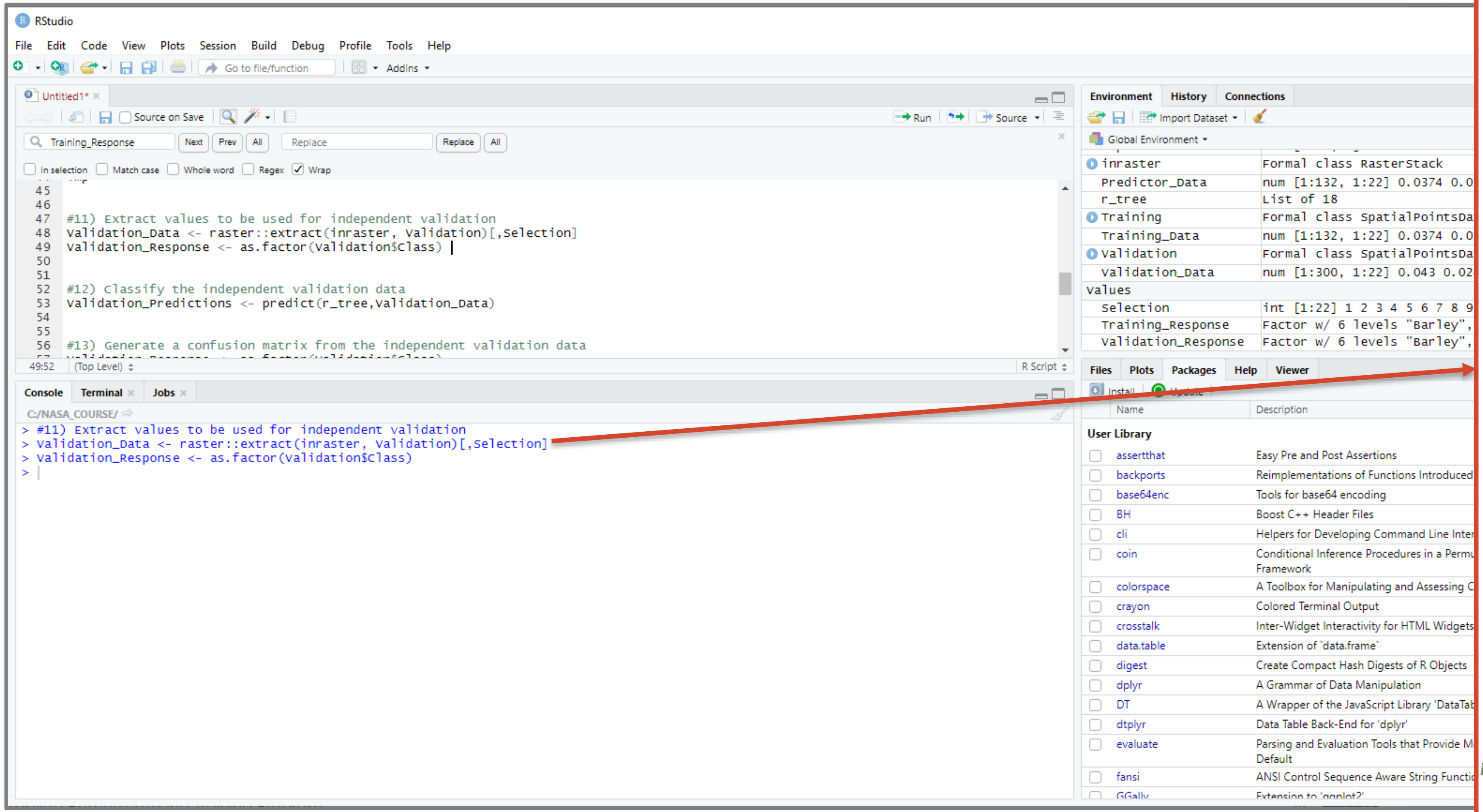
Random Forests: Hands on Demonstration

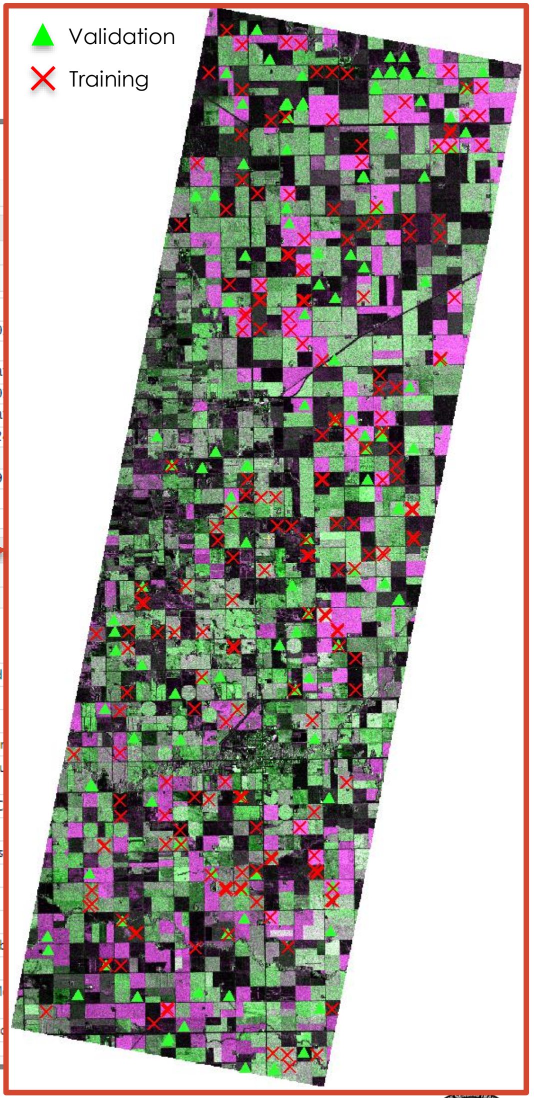
14. Print the variable importance values



Random Forests: Hands on Demonstration

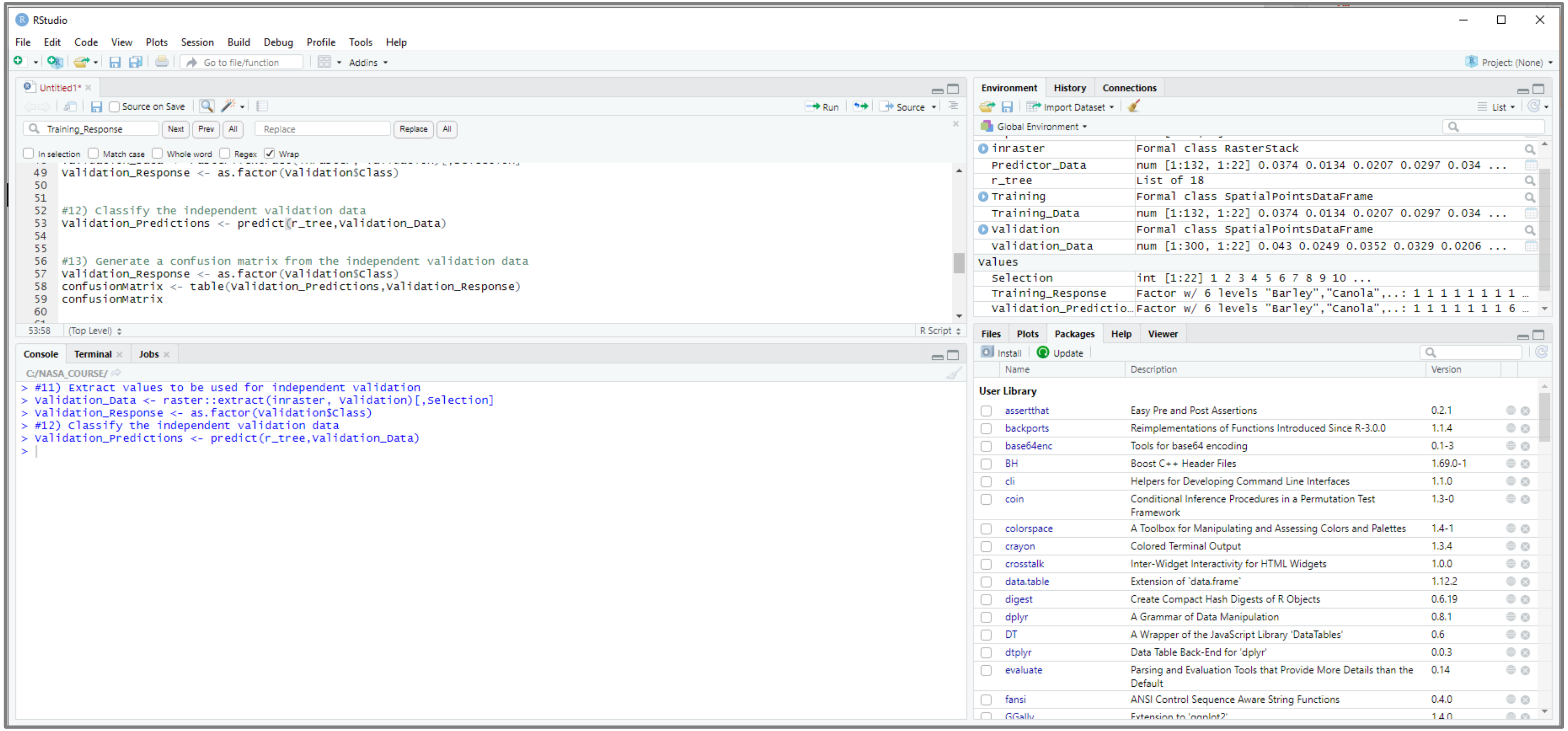
15. Extract the validation data





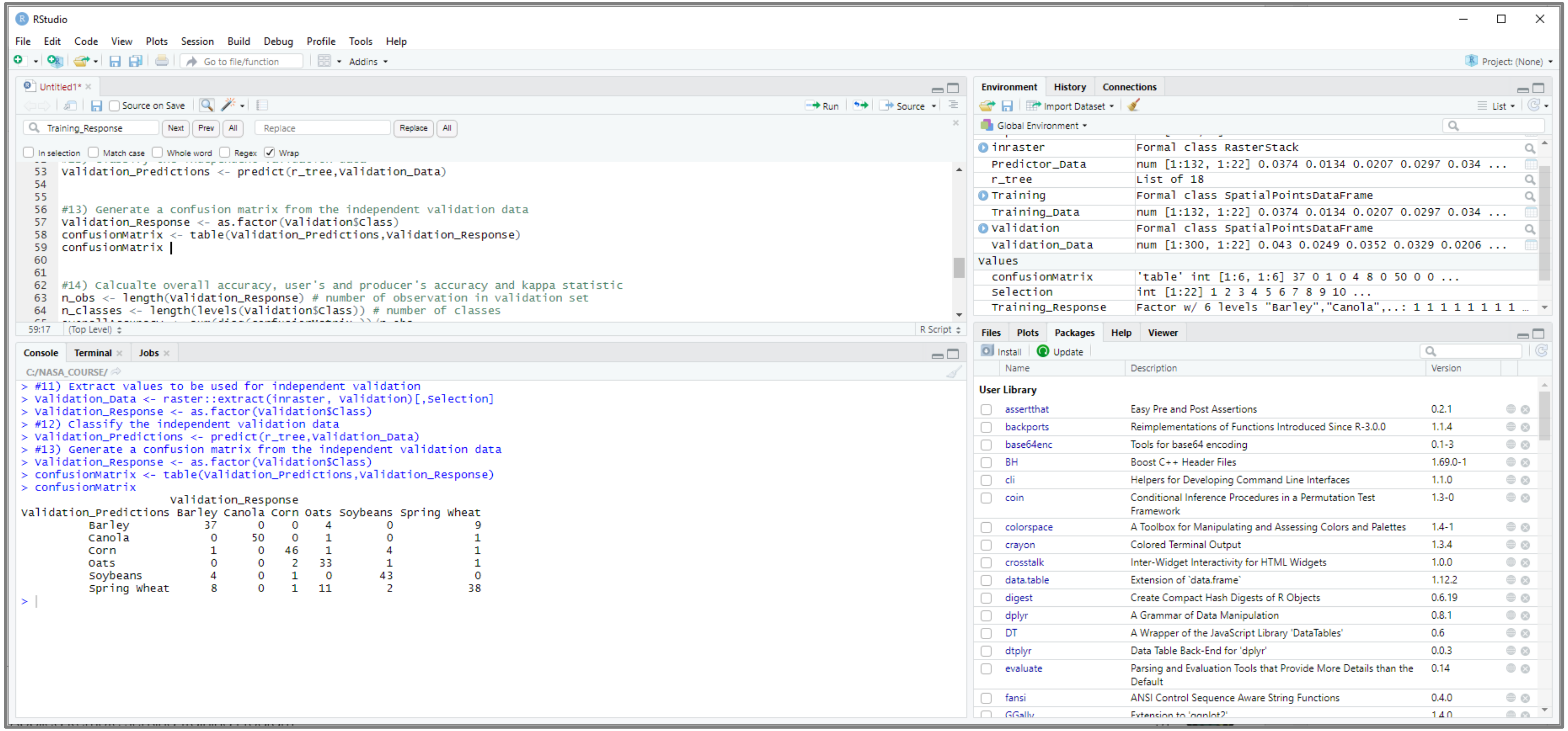
Random Forests: Hands on Demonstration

16. Classify the independent validation data



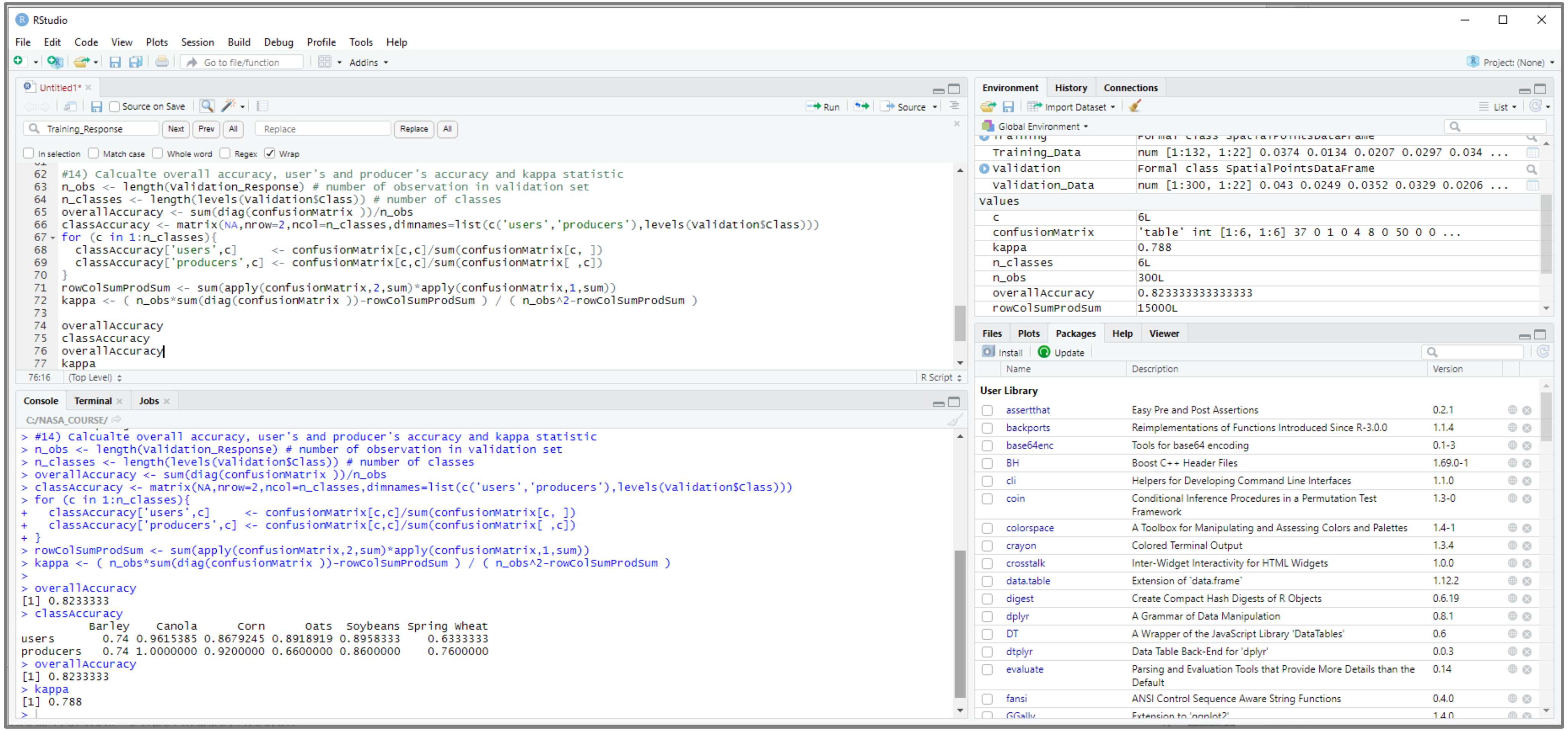
Random Forests: Hands on Demonstration

17. Generate a confusion matrix



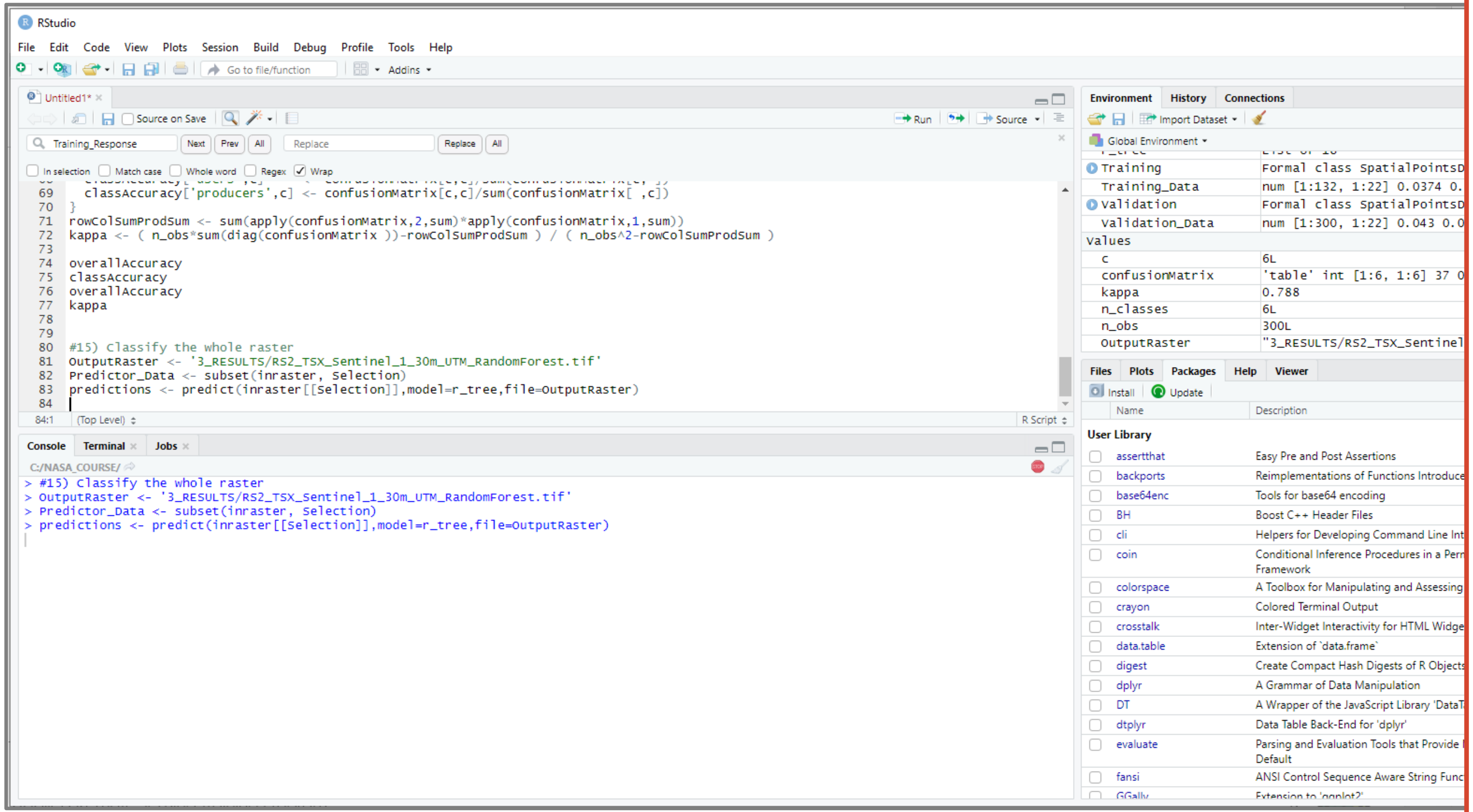
Random Forests: Hands on Demonstration

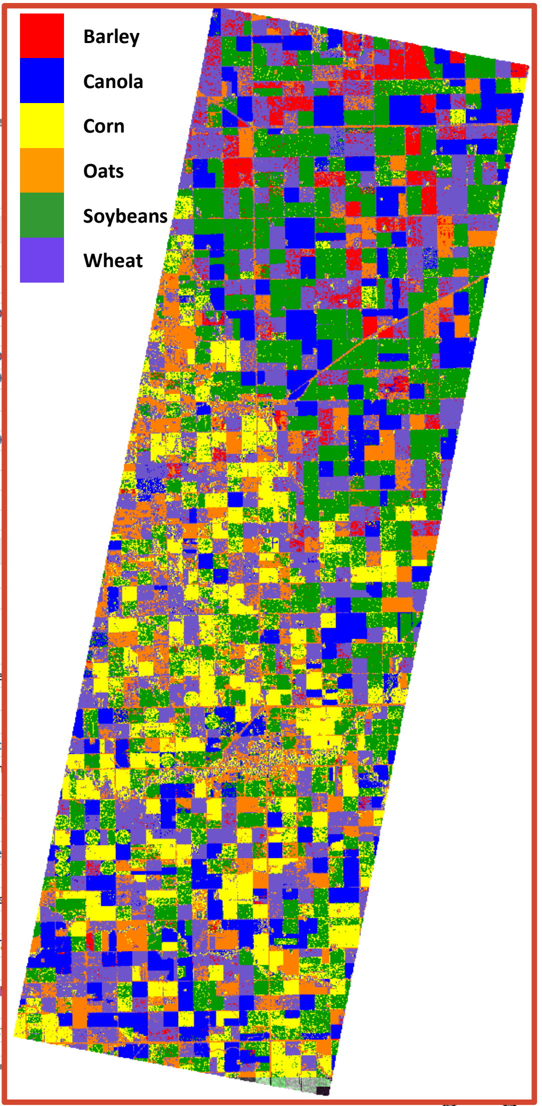
18. Calculate the independent accuracies and kappa statistic



Random Forests: Hands on Demonstration

19. Classify the whole raster





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