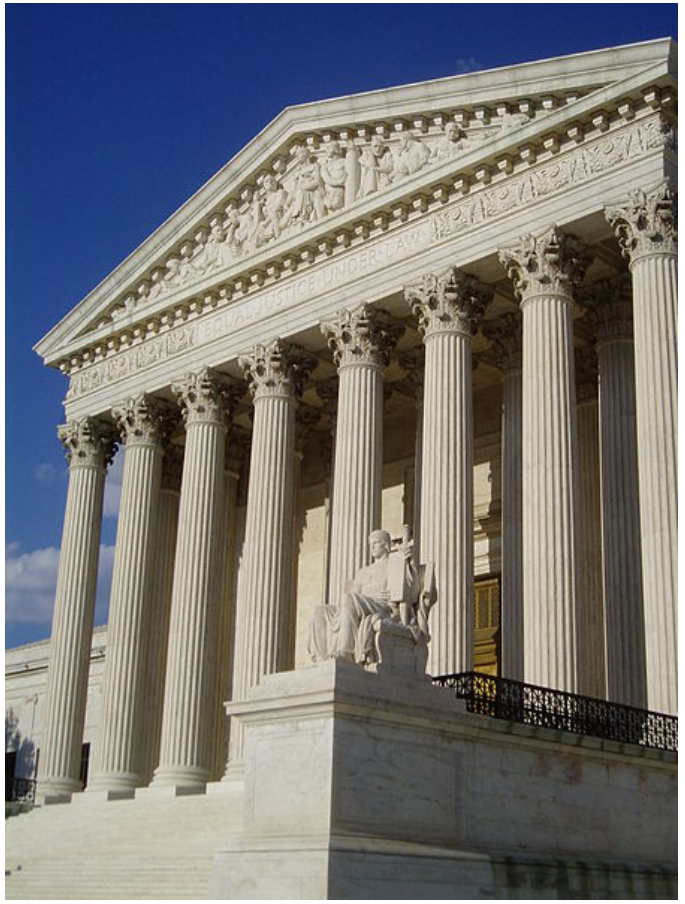
JUDGE, JURY AND CLASSIFIER

An Introduction to Trees

15.071x – The Analytics Edge

The American Legal System

- The legal system of the United States operates at the state level and at the federal level
- Federal courts hear cases beyond the scope of state law
- Federal courts are divided into:
  - **District Courts**
    - Makes initial decision
  - **Circuit Courts**
    - Hears appeals from the district courts
  - **Supreme Court**
    - Highest level – makes final decision



The Supreme Court of the United States

- Consists of nine judges ("justices"), appointed by the President
  - Justices are distinguished judges, professors of law, state and federal attorneys
- The Supreme Court of the United States (SCOTUS) decides on most difficult and controversial cases
  - Often involve interpretation of Constitution
  - Significant social, political and economic consequences

Notable SCOTUS Decisions

- Wickard v. Filburn (1942)
  - Congress allowed to intervene in industrial/economic activity
- Roe v. Wade (1973)
  - Legalized abortion
- Bush v. Gore (2000)
  - Decided outcome of presidential election!
- National Federation of Independent Business v. Sebelius (2012)
  - Patient Protection and Affordable Care Act ("ObamaCare") upheld the requirement that individuals must buy health insurance

Predicting Supreme Court Cases

- Legal academics and political scientists regularly make predictions of SCOTUS decisions from detailed studies of cases and individual justices
- In 2002, Andrew Martin, a professor of political science at Washington University in St. Louis, decided to instead predict decisions using a statistical model built from data
- Together with his colleagues, he decided to test this model against a panel of experts

Predicting Supreme Court Cases

- Martin used a method called Classification and Regression Trees (CART)
- Why not logistic regression?
  - Logistic regression models are generally not *interpretable*
  - Model coefficients indicate importance and relative effect of variables, but do not give a simple explanation of how decision is made

Data

- Cases from 1994 through 2001
- In this period, same nine justices presided SCOTUS
  - Breyer, Ginsburg, Kennedy, O'Connor, Rehnquist (Chief Justice), Scalia, Souter, Stevens, Thomas
  - Rare data set – longest period of time with the same set of justices in over 180 years
- We will focus on predicting Justice Stevens' decisions
  - Started out moderate, but became more liberal
  - Self-proclaimmed conservative

Variables

- **Dependent Variable**: Did Justice Stevens vote to reverse the lower court decision? 1 = reverse, 0 = affirm
- **Independent Variables**: Properties of the case
  - Circuit court of origin (1^{st} – 11^{th}, DC, FED)
  - Issue area of case (e.g., civil rights, federal taxation)
  - Type of petitioner, type of respondent (e.g., US, an employer)
  - Ideological direction of lower court decision (conservative or liberal)
  - Whether petitioner argued that a law/practice was unconstitutional

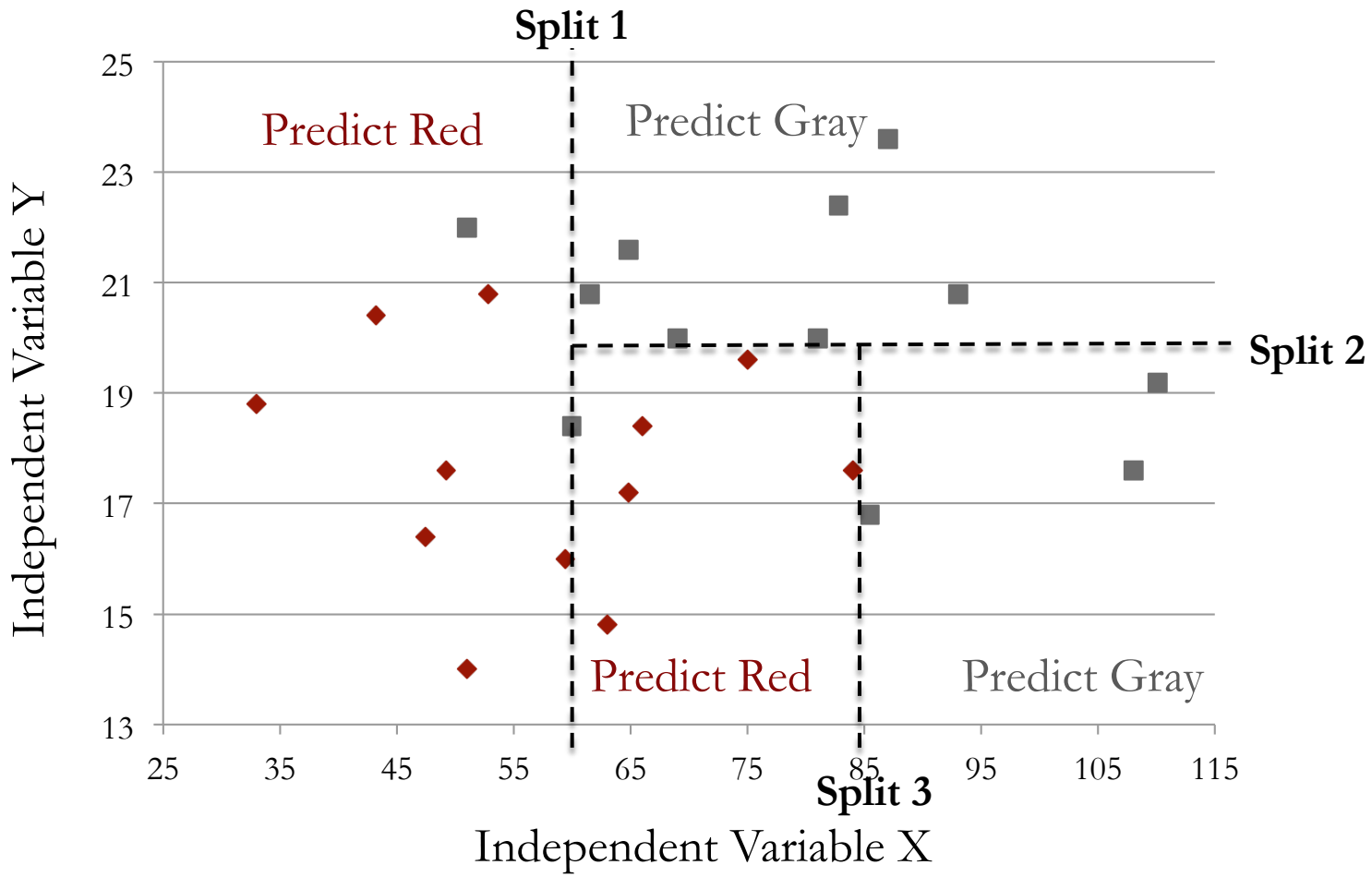
Logistic Regression for Justice Stevens

- Some significant variables and their coefficients:
  - Case is from 2nd circuit court: +1.66
  - Case is from 4th circuit court: +2.82
  - Lower court decision is liberal: -1.22
- This is complicated…
  - Difficult to understand which factors are more important
  - Difficult to quickly evaluate what prediction is for a new case

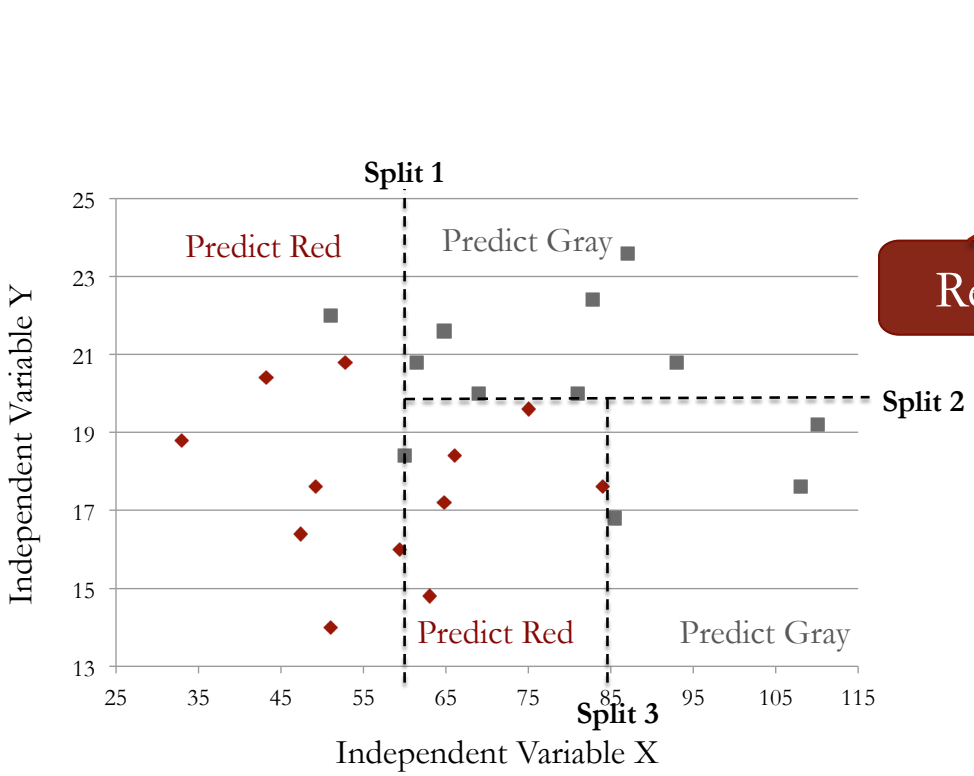
Classification and Regression Trees

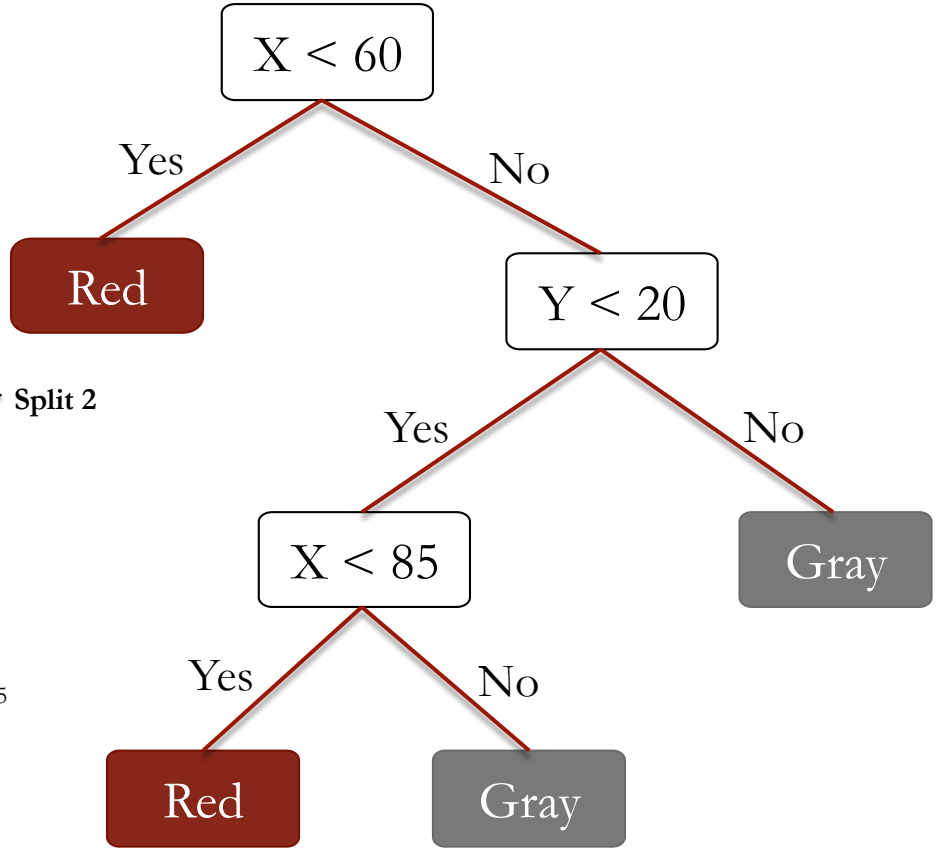
- Build a tree by splitting on variables
- To predict the outcome for an observation, follow the splits and at the end, predict the most frequent outcome
- Does not assume a linear model
- Interpretable

Splits in CART



Final Tree


Split 1
Split 2
Split 3
Predict Red
Predict Gray
Predict Red
Predict Gray
Independent Variable Y
Independent Variable X
25
23
21
19
17
15
13
25
35
45
55
65
75
85
95
105
115


X < 60
Yes
No
Red
Y < 20
Yes
No
X < 85
Gray
Yes
No
Red
Gray

When Does CART Stop Splitting?

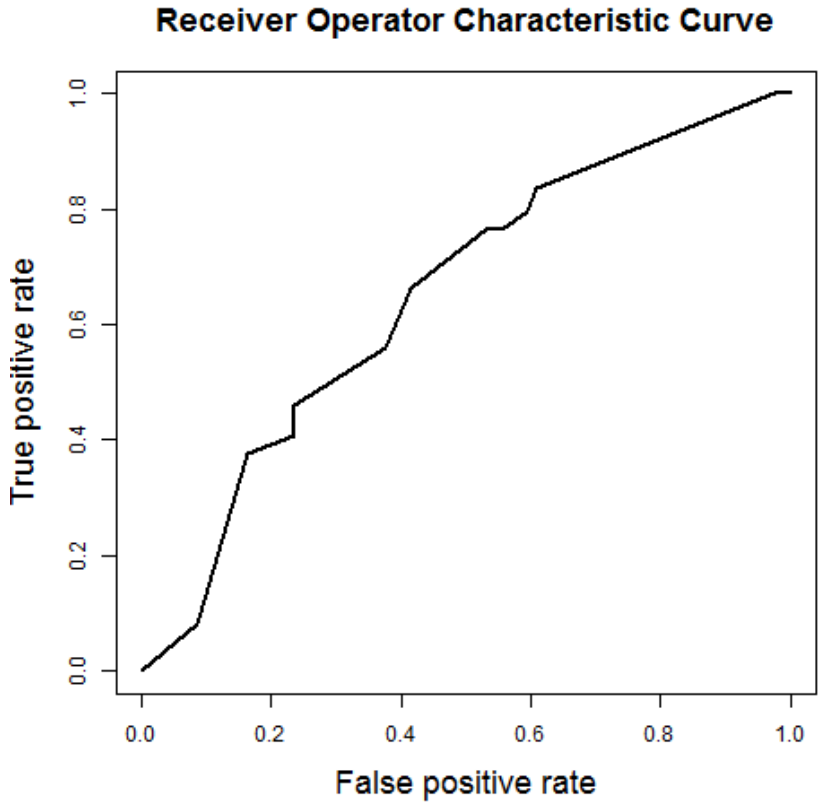
- There are different ways to control how many splits are generated
  - One way is by setting a lower bound for the number of points in each subset
- In R, a parameter that controls this is minbucket
  - The smaller it is, the more splits will be generated
  - If it is too small, overfitting will occur
  - If it is too large, model will be too simple and accuracy will be poor

Predictions from CART

- In each subset, we have a bucket of observations, which may contain both outcomes (i.e., affirm and reverse)
- Compute the percentage of data in a subset of each type
  - Example: 10 affirm, 2 reverse → 10/(10+2) = 0.83
- Just like in logistic regression, we can threshold to obtain a prediction
  - Threshold of 0.5 corresponds to picking most frequent outcome

ROC curve for CART

- Vary the threshold to obtain an ROC curve



Random Forests

- Designed to improve prediction accuracy of CART
- Works by building a large number of CART trees
  - Makes model less interpretable
- To make a prediction for a new observation, each tree "votes" on the outcome, and we pick the outcome that receives the majority of the votes

Building Many Trees

- Each tree can split on only a random subset of the variables
- Each tree is built from a "bagged"/"bootstrapped" sample of the data
  - Select observations randomly with replacement
  - Example – original data: 1 2 3 4 5
  - New "data":

    2 4 5 2 1 → 1st tree

    3 5 1 5 2 → 2nd tree

    ⋮

Random Forest Parameters

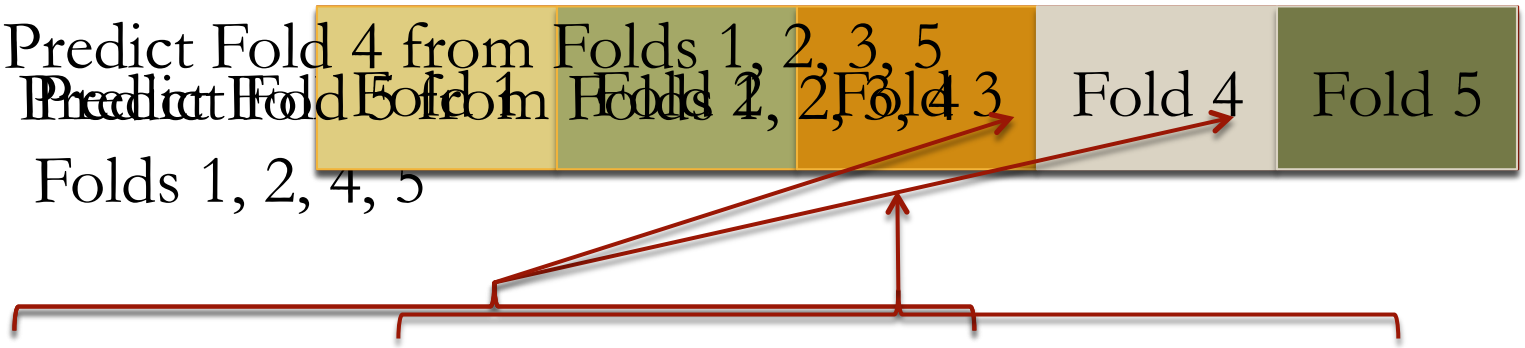
- Minimum number of observations in a subset
  - In R, this is controlled by the nodesize parameter
  - Smaller nodesize may take longer in R
- Number of trees
  - In R, this is the ntree parameter
  - Should not be too small, because bagging procedure may miss observations
  - More trees take longer to build

Parameter Selection

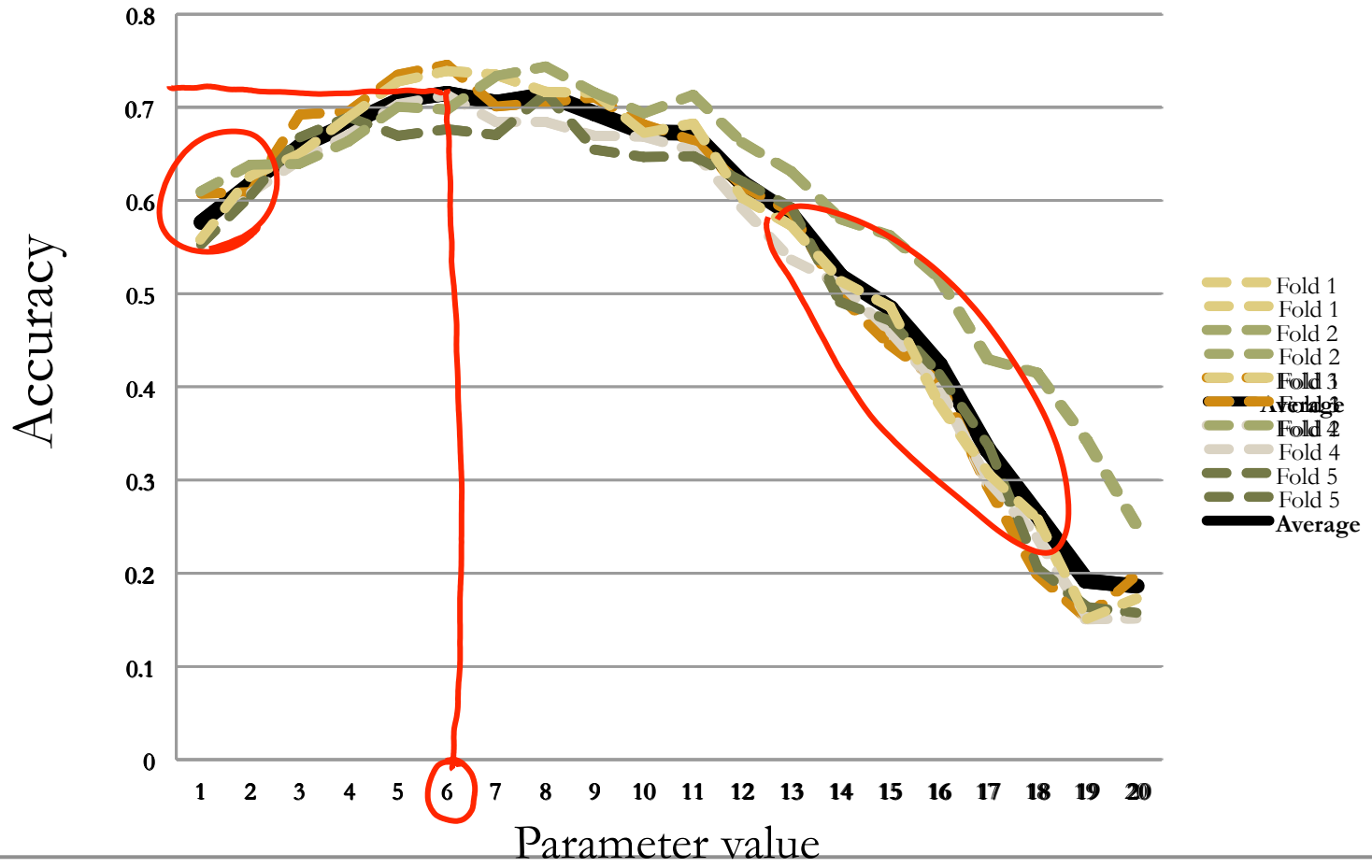
- In CART, the value of "minbucket" can affect the model's out-of-sample accuracy
- How should we set this parameter?
- We could select the value that gives the best testing set accuracy
  - This is not right!

K-fold Cross-Validation

- Given training set, split into k pieces (here k = 5)
- Use k-1 folds to estimate a model, and test model on remaining one fold ("validation set") for each candidate parameter value
- Repeat for each of the k folds



Output of k-fold Cross-Validation



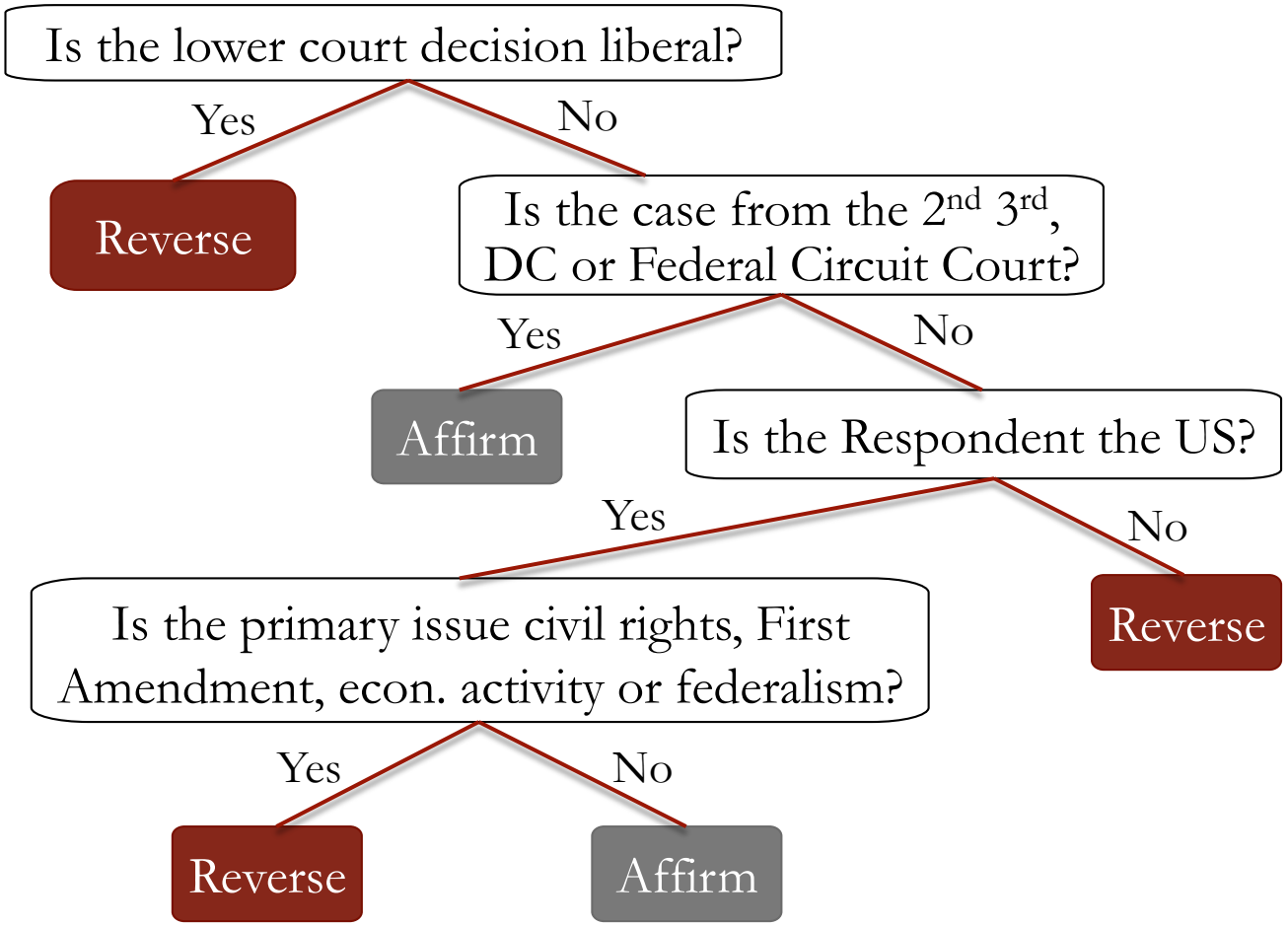
Cross-Validation in R

- Before, we limited our tree using minbucket
- When we use cross-validation in R, we'll use a parameter called cp instead
  - Complexity Parameter
- Like Adjusted R^2 and AIC
  - Measures trade-off between model complexity and accuracy on the training set
- Smaller cp leads to a bigger tree (might overfit)

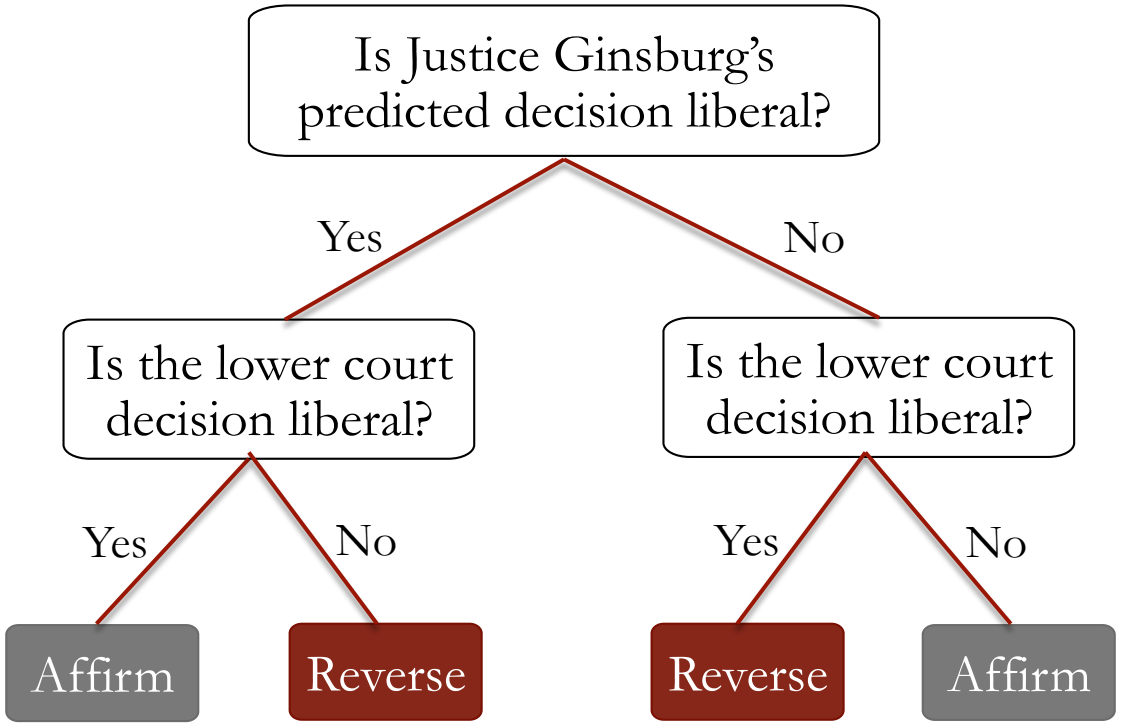
Martin's Model

- Used 628 previous SCOTUS cases between 1994 and 2001
- Made predictions for the 68 cases that would be decided in October 2002, before the term started
- Two stage approach based on CART:
  - First stage: one tree to predict a unanimous liberal decision, other tree to predict unanimous conservative decision
    - If conflicting predictions or predict no, move to next stage
  - Second stage consists of predicting decision of each individual justice, and using majority decision as prediction

Tree for Justice O'Connor



Tree for Justice Souter



"Make a liberal decision"

"Make a conservative decision"

The Experts

- Martin and his colleagues recruited 83 legal experts
  - 71 academics and 12 attorneys
  - 38 previously clerked for a Supreme Court justice, 33 were chaired professors and 5 were current or former law school deans
- Experts only asked to predict within their area of expertise; more than one expert to each case
- Allowed to consider any source of information, but not allowed to communicate with each other regarding predictions

The Results

- For the 68 cases in October 2002:
- Overall case predictions:
  - Model accuracy: 75%
  - Experts accuracy: 59%
- Individual justice predictions:
  - Model accuracy: 67%
  - Experts accuracy: 68%

The Analytics Edge

- Predicting Supreme Court decisions is very valuable to firms, politicians and non-governmental organizations
- A model that predicts these decisions is both more accurate and faster than experts
  - CART model based on very high-level details of case beats experts who can process much more detailed and complex information