COMP20008 Elements of Data Processing

Semester 2 2018

Lecture 11: Classification Methodologies: Decision Tree

Announcements

- Phase 3 Oral Presentation Schedule is on the LMS

Where have we got to? Halfway …

- **Preprocessing** (4 lectures): Weeks 1-3
  – *Data types and processing, data cleaning including outliers, missing data*
- **Visualisation** (3 lectures): Weeks 3-4
  – *Plotting and visualisation methods, clustering, dimensionality reduction*
- **Analysis** (4 lectures): Weeks 5-6
  – *Correlations*, basic prediction techniques
- **Infrastructure and Distributed** (4 lectures): Weeks 7-9
  – Data linkage and integration, blockchain
- **Social, ethical and privacy issues** (3 lectures): Weeks 10-12
  – K-anonymity, l-diversity, location privacy, ethics

Plan

- Introduction to classification (prediction)
  – Decision tree classification (start today)
  – k nearest neighbor classification (on Friday)

Classification

- We now start the topic of classification
  - Making predictions about the future, based on historical data
- Predictive modelling/classification
  - The sexy part of data science ?!
  - A foundation for machine intelligence, AI, machines replacing humans and taking our jobs ….

Classification

- Predicting disease from microarray data

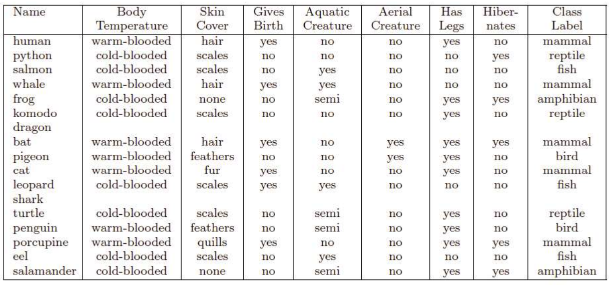
	Gene 1	Gene 2	Gene 3	…	Gene n	Cancer
Person 1	2.3	1.1	0.3	…	2.1	1
Person 2	3.2	0.2	1.2	…	1.1	1
Person 3	1.9	3.8	2.7	…	0.2	0
…	…	…	…	…	…	…
Person m	2.8	3.1	2.5	…	3.4	0

Test data

	Gene 1	Gene 2	Gene 3	…	Gene n	Cancer
Person m+1	2.1	0.9	0.6	…	1.9	?

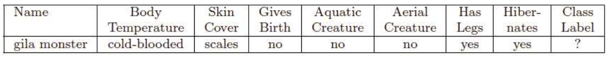
Classification example

- Animal classification



Name	Body Temperature	Skin Cover	Gives Birth	Aquatic Creature	Aerial Creature	Has Legs	Hiber-nates	Class Label
human	warm-blooded	hair	yes	no	no	yes	no	mammal
python	cold-blooded	scales	no	no	no	no	yes	reptile
salmon	cold-blooded	scales	no	yes	no	no	no	fish
whale	warm-blooded	hair	yes	yes	no	no	no	mammal
frog	cold-blooded	none	no	semi	no	yes	yes	amphibian
komodo dragon	cold-blooded	scales	no	no	no	yes	no	reptile
bat	warm-blooded	hair	yes	no	yes	yes	yes	mammal
pigeon	warm-blooded	feathers	no	no	yes	yes	no	bird
cat	warm-blooded	fur	yes	no	no	yes	no	mammal
leopard shark	cold-blooded	scales	yes	yes	no	no	no	fish
turtle	cold-blooded	scales	no	semi	no	yes	no	reptile
penguin	warm-blooded	feathers	no	semi	no	yes	no	bird
porcupine	warm-blooded	quills	yes	no	no	yes	yes	mammal
eel	cold-blooded	scales	no	yes	no	no	no	fish
salamander	cold-blooded	none	no	semi	no	yes	yes	amphibian

Test data

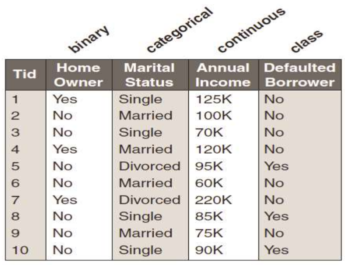


Name	Body Temperature	Skin Cover	Gives Birth	Aquatic Creature	Aerial Creature	Has Legs	Hiber-nates	Class Label
gila monster	cold-blooded	scales	no	no	no	yes	yes	?

https://www-users.cs.umn.edu/~kumar/dmbook/ch4.pdf

Classification example

- Banking: classifying borrower



binary
categorical
continuous
class

Tid	Home Owner	Marital Status	Annual Income	Defaulted Borrower
1	Yes	Single	125K	No
2	No	Married	100K	No
3	No	Single	70K	No
4	Yes	Married	120K	No
5	No	Divorced	95K	Yes
6	No	Married	60K	No
7	Yes	Divorced	220K	No
8	No	Single	85K	Yes
9	No	Married	75K	No
10	No	Single	90K	Yes

Training set for predicting borrowers who will default on loan payments.

Test data

Tid	Home Owner	Marital status	Annual Income	Defaulted Borrower
11	No	Single	55K	?

Classification example

- Detecting tax fraud/tax cheats

categorical categorical continuous class

Tid	Refund	Marital Status	Taxable Income	Cheat
1	Yes	Single	125K	No
2	No	Married	100K	No
3	No	Single	70K	No
4	Yes	Married	120K	No
5	No	Divorced	95K	Yes
6	No	Married	60K	No
7	Yes	Divorced	220K	No
8	No	Single	85K	Yes
9	No	Married	75K	No
10	No	Single	90K	Yes

Test data

Tid	Refund	Marital Status	Taxable Income	Tax Cheat
11	Yes	Married	125K	?

Classification: Definition

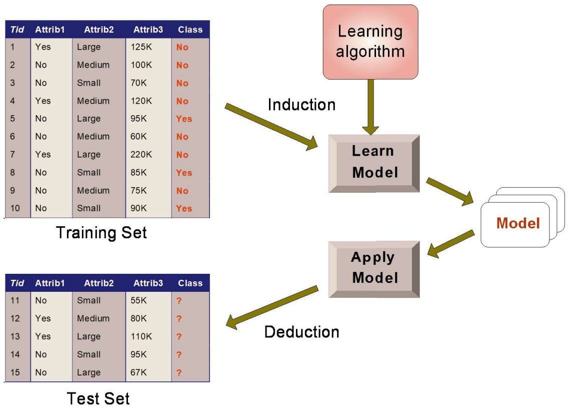
- Given a collection of records (*training set*)
  - Each record contains a set of *attributes*, one *class label*.
- Find a predictive *model* for class label as a function of the values of other attributes.

$$y = f(x_1, x_2, \ldots, x_n)$$

  - y: *discrete value*, target variable
  - $x_1, \ldots x_n$: attributes, predictors
  - f: is the predictive model (a tree, a rule, a mathematical formula, ..)

- Goal: previously unseen records should be assigned a class as accurately as possible.
  - A *test set* is used to determine the accuracy of the model. Usually, the given data set is divided into training and test sets, with training set used to build the model and test set used to validate it.

Classification framework



Tid	Attrib1	Attrib2	Attrib3	Class
1	Yes	Large	125K	No
2	No	Medium	100K	No
3	No	Small	70K	No
4	Yes	Medium	120K	No
5	No	Large	95K	Yes
6	No	Medium	60K	No
7	Yes	Large	220K	No
8	No	Small	85K	Yes
9	No	Medium	75K	No
10	No	Small	90K	Yes

Training Set

Tid	Attrib1	Attrib2	Attrib3	Class
11	No	Small	55K	?
12	Yes	Medium	80K	?
13	Yes	Large	110K	?
14	No	Small	95K	?
15	No	Large	67K	?

Test Set

Learning algorithm

Induction

Learn Model

Model

Apply Model

Deduction

Regression

- Given a collection of records (*training set*)
  - Each record contains a set of *attributes*, one of *target variable*.

- Learn predictive model from data

$$y = f(x_1, x_2, \ldots, x_n)$$

- y: continuous real value, target variable
- $x_1, \ldots x_n$: attributes, predictors

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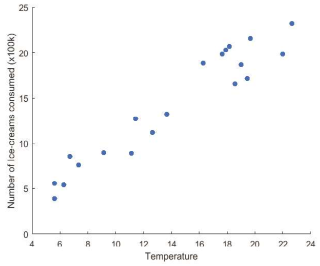
Regression

- Predicting ice-creams consumption from temperature: y = f(x)



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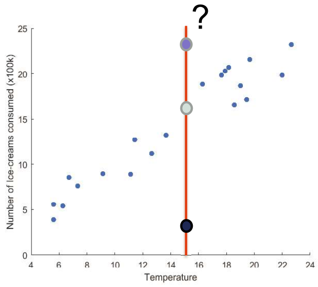
Regression

- Predicting ice-creams consumption from temperature: y = f(x)



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Regression

- Predicting activity level of a target gene

	Gene 1	Gene 2	Gene 3	…	Gene n	Gene n+1
Person 1	2.3	1.1	0.3	…	2.1	3.2
Person 2	3.2	0.2	1.2	…	1.1	1.1
Person 3	1.9	3.8	2.7	…	0.2	0.2
…	…	…	…	…	…	…
Person m	2.8	3.1	2.5	…	3.4	0.9

	Gene 1	Gene 2	Gene 3	…	Gene n	Gene n+1
Person m+1	2.1	0.9	0.6	…	1.9	?

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Machine prediction is everywhere

- Exercise
  - Write down two circumstances where your mobile phone software is making predictions. What is the historical data, what is the test data, what is being predicted?
    - Word suggestion and autocorrect
    - Facebook friend suggestions
    - Face recognition and
    - Recommendations: spotify
    - Personal assistants: voice recognition – finger print…

Classification and Regression

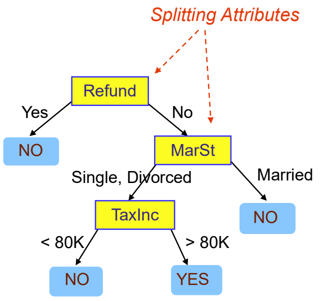
- What is Classification and Regression?
- Classification algorithms:
  - Decision tree (starting today)
  - K-Nearest Neighbor Classifier (K-NN) (Friday)

Example of a Decision Tree

categorical categorical continuous class

Tid	Refund	Marital Status	Taxable Income	Cheat
1	Yes	Single	125K	No
2	No	Married	100K	No
3	No	Single	70K	No
4	Yes	Married	120K	No
5	No	Divorced	95K	Yes
6	No	Married	60K	No
7	Yes	Divorced	220K	No
8	No	Single	85K	Yes
9	No	Married	75K	No
10	No	Single	90K	Yes

Training Data



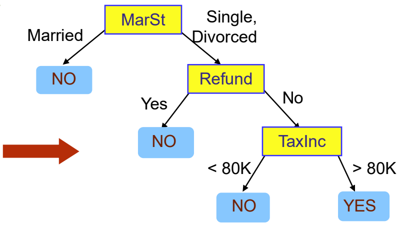
Model: Decision Tree

Another Example of Decision Tree

categorical categorical continuous class

Tid	Refund	Marital Status	Taxable Income	Cheat
1	Yes	Single	125K	No
2	No	Married	100K	No
3	No	Single	70K	No
4	Yes	Married	120K	No
5	No	Divorced	95K	Yes
6	No	Married	60K	No
7	Yes	Divorced	220K	No
8	No	Single	85K	Yes
9	No	Married	75K	No
10	No	Single	90K	Yes

Training Data



Model: Decision Tree

There could be more than one tree that fits the same data!

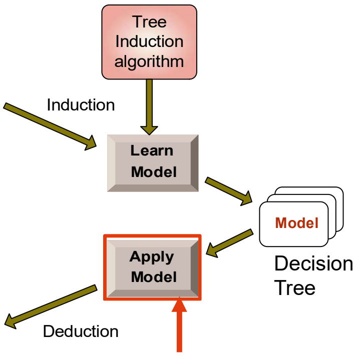
Decision Tree Classification Task

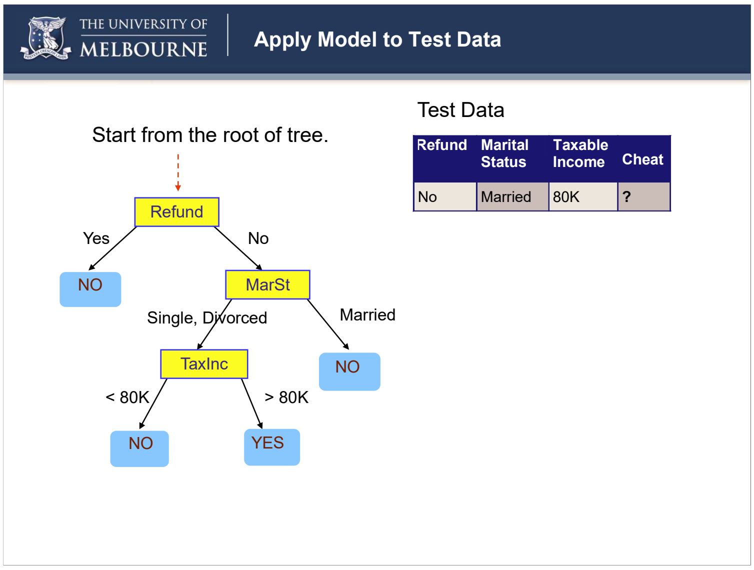
Tid	Attrib1	Attrib2	Attrib3	Class
1	Yes	Large	125K	No
2	No	Medium	100K	No
3	No	Small	70K	No
4	Yes	Medium	120K	No
5	No	Large	95K	Yes
6	No	Medium	60K	No
7	Yes	Large	220K	No
8	No	Small	85K	Yes
9	No	Medium	75K	No
10	No	Small	90K	Yes

Training Set

Tid	Attrib1	Attrib2	Attrib3	Class
11	No	Small	55K	?
12	Yes	Medium	80K	?
13	Yes	Large	110K	?
14	No	Small	95K	?
15	No	Large	67K	?

Test Set



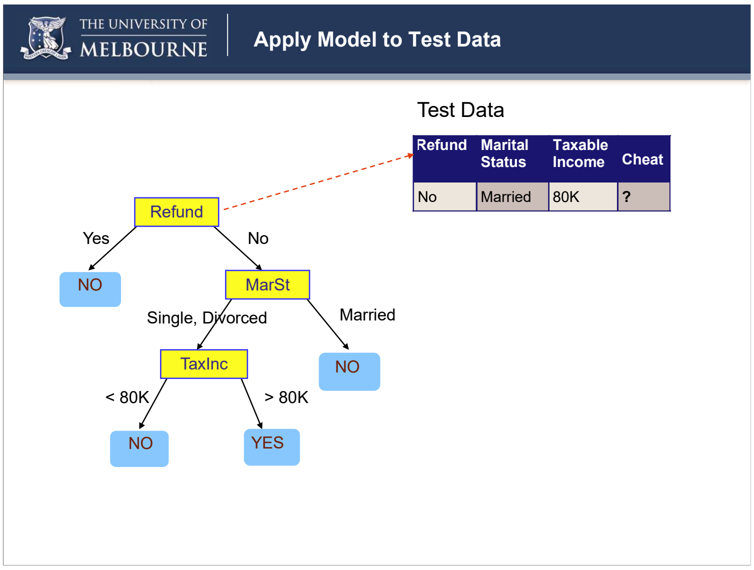


Apply Model to Test Data

Start from the root of tree.

Test Data

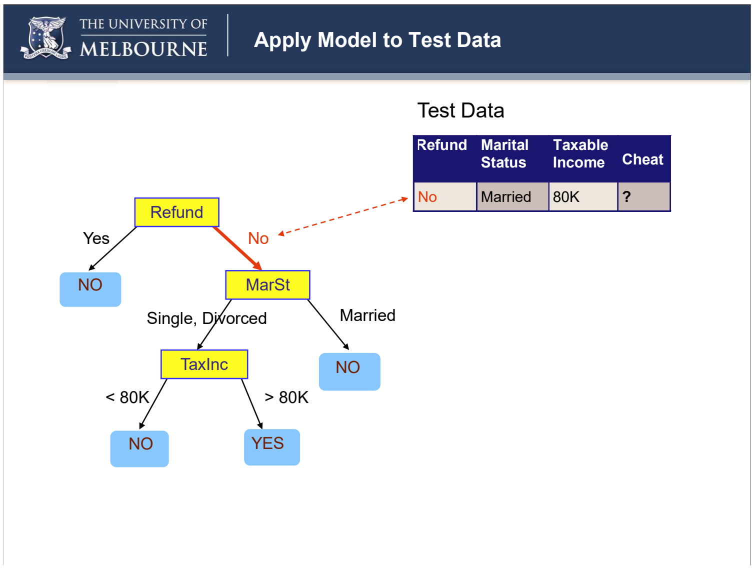
Refund	Marital Status	Taxable Income	Cheat
No	Married	80K	?



Apply Model to Test Data

Test Data

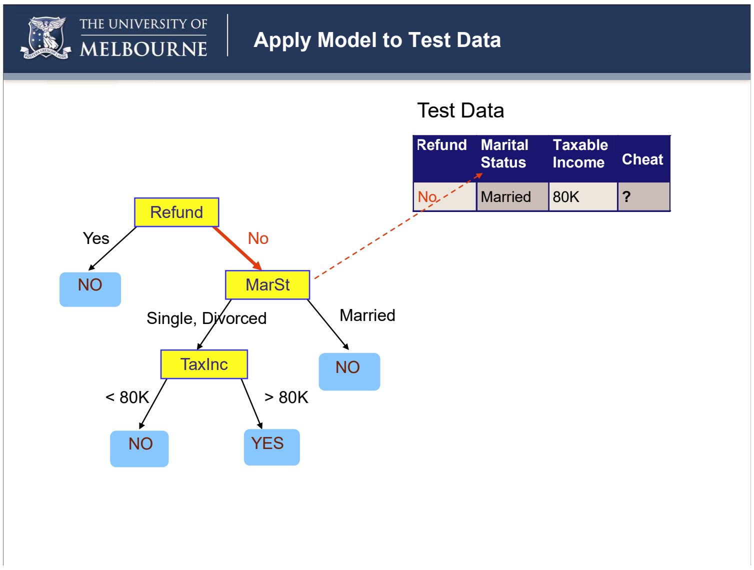
Refund	Marital Status	Taxable Income	Cheat
No	Married	80K	?



Apply Model to Test Data

Test Data

Refund	Marital Status	Taxable Income	Cheat
No	Married	80K	?



Apply Model to Test Data

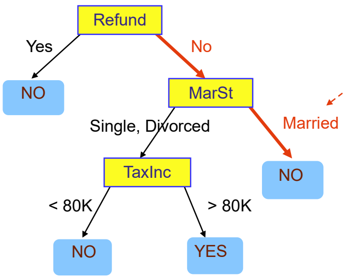
Test Data

Refund	Marital Status	Taxable Income	Cheat
No	Married	80K	?

Apply Model to Test Data

Test Data

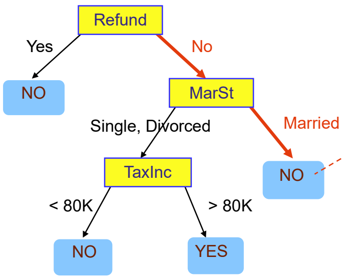
Refund	Marital Status	Taxable Income	Cheat
No	Married	80K	?



Apply Model to Test Data

Test Data

Refund	Marital Status	Taxable Income	Cheat
No	Married	80K	?



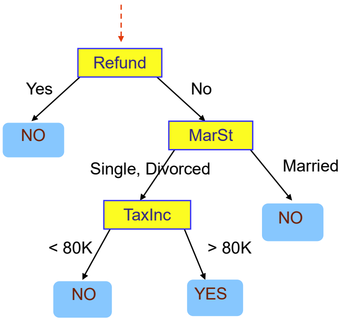
Assign Cheat to “No”

Apply Model to Test Data

Test Data

Refund	Marital Status	Taxable Income	Cheat
No	Single	100K	?

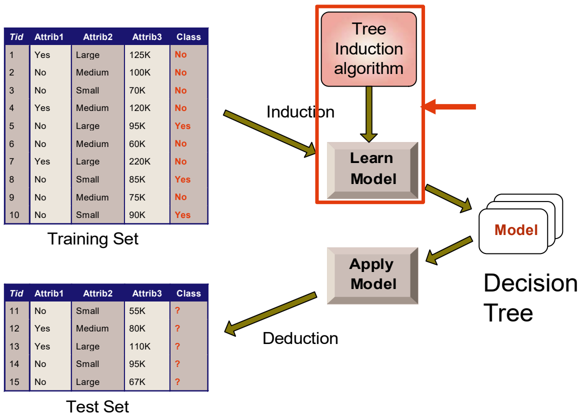
Start from the root of tree.



Decision Trees

- Decision tree
  - A flow-chart-like tree structure
  - Internal node denotes a test on an attribute
  - Branch represents an outcome of the test
  - Leaf nodes represent class labels or class distribution

Decision Tree Classification Task



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Training Set

Tid	Attrib1	Attrib2	Attrib3	Class
11	No	Small	55K	?
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Test Set

Decision Tree

Decision Tree Creation

- Many Algorithms:
  - We will look at a representative one (Hunt's algorithm)

General Structure of Hunt's Algorithm

- Let D_t be the set of training records that reach a node t
- General Procedure:
  - If D_t contains records that belong the same class y_t, then t is a leaf node labeled as y_t
  - If D_t is an empty set, then t is a leaf node labeled by the default class, y_d
  - If D_t contains records that belong to more than one class, use an attribute test to split the data into smaller subsets. Recursively apply the procedure to each subset.

Tid	Refund	Marital Status	Taxable Income	Cheat
1	Yes	Single	125K	No
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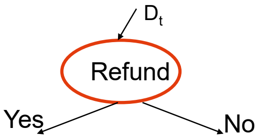
7	Yes	Divorced	220K	No
8	No	Single	85K	Yes
9	No	Married	75K	No
10	No	Single	90K	Yes



Example

If D_t contains records that belong to more than one class, use an attribute test to split the data into smaller subsets. Recursively apply the procedure to each subset.

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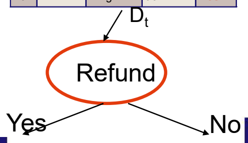
9	No	Married	75K	No
10	No	Single	90K	Yes



Tid	Refund	Marital Status	Taxable Income	Cheat
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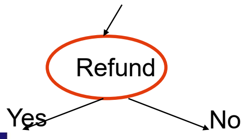
Tid	Refund	Marital Status	Taxable Income	Cheat
2	No	Married	100K	No
3	No	Single	70K	No
5	No	Divorced	95K	Yes
6	No	Married	60K	No
8	No	Single	85K	Yes
9	No	Married	75K	No
10	No	Single	90K	Yes

Stopping condition: leaf node

- If D_t contains records that belong the same class y_t, then t is a leaf node labeled as y_t
- If D_t is an empty set, then t is a leaf node labeled by the default class, y_d



Tid	Refund	Marital Status	Taxable Income	Cheat
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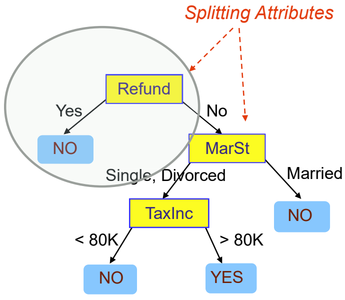


Model: Decision Tree

Tree Induction (creation)

- Issues
  - Determine how to split the records
    - How to specify the attribute test condition?
    - How to determine the best split?
  - Determine when to stop splitting
    - When node has only a single class of instances

Tree Induction

- Issues
  - Determine how to split the records
    - How to specify the attribute test condition?
    - How to determine the best split?
  - Determine when to stop splitting

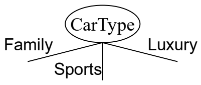
How to Specify Test Condition?

- Depends on attribute types
  - Nominal
  - Ordinal
  - Continuous

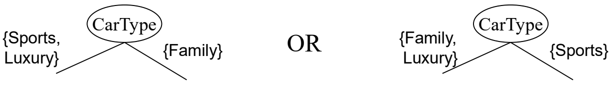
- Depends on number of ways to split
  - 2-way split
  - Multi-way split

Splitting Based on Nominal Attributes

- Multi-way split: Use as many partitions as distinct values.

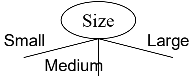


- Binary split: Divides values into two subsets.
  Need to find optimal partitioning.

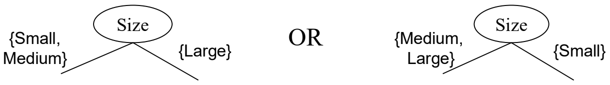


Splitting Based on Ordinal Attributes

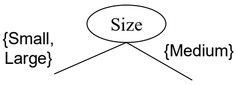
- Multi-way split: Use as many partitions as distinct values.



- Binary split: Divides values into two subsets.
  Need to find optimal partitioning.



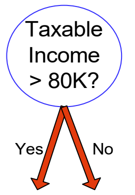
- What about this split?



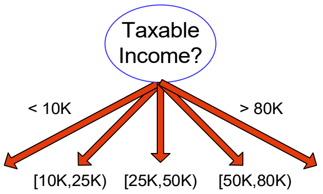
Splitting Based on Continuous Attributes

- Different ways of handling
  - Discretization to form an ordinal categorical attribute
    - Static – discretize once at the beginning
    - Dynamic – ranges can be found by equal interval bucketing, equal frequency bucketing (percentiles), or clustering.
  - Binary Decision: (A < v) or (A ≥ v)
    - consider all possible splits and finds the best cut
    - can be more compute intensive

Splitting Based on Continuous Attributes



(i) Binary split



(ii) Multi-way split

Points to remember from this lecture

- Understand what is meant by the terms classification and regression and why it is useful to build models for these tasks
- Understand how a decision tree may be used to make predictions about the class of a test instance
- Understand the key steps in building a decision tree
  - How to split the instances, how to specify the attribute test condition, how to determine the best split and how to decide when to stop splitting
- Understand the use of entropy as a node impurity measure for decision tree node splitting. Understand the benefits of entropy for this task and why it is effective for assessing the goodness of a split

References and Acknowledgement

This lecture was prepared using some material adapted from:

- https://www-users.cs.umn.edu/~kumar/dmbook/ch4.pdf
- CS059 - Data Mining -- Slides
- http://www-users.cs.umn.edu/~kumar/dmbook/dmslides/chap4_basic_classification.ppt