

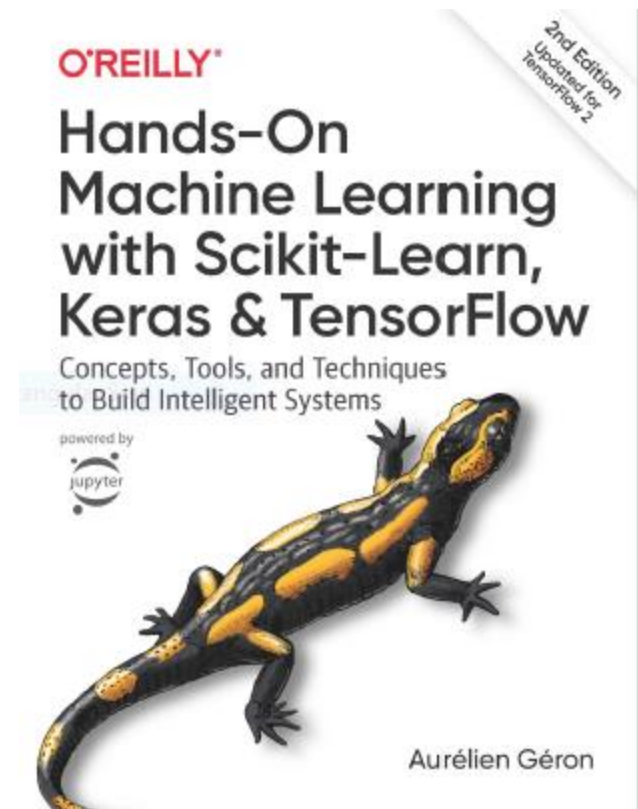
End-to-End Machine Learning Project

Prof. Gheith Abandah

Reference

- Chapter 2: **End-to-End Machine Learning Project**

- Aurélien Géron, **Hands-On Machine Learning with Scikit-Learn, Keras and TensorFlow**, O'Reilly, 2nd Edition, 2019
 - Material: <https://github.com/ageron/handson-ml2>



The 7 Steps of Machine Learning

- YouTube Video: **The 7 Steps of Machine Learning** from Google Cloud Platform

<https://youtu.be/nKW8Ndu7Mjw>

Caution: *Alcohol is forbidden in the Islamic religion and causes addiction and has negative effects on health.*

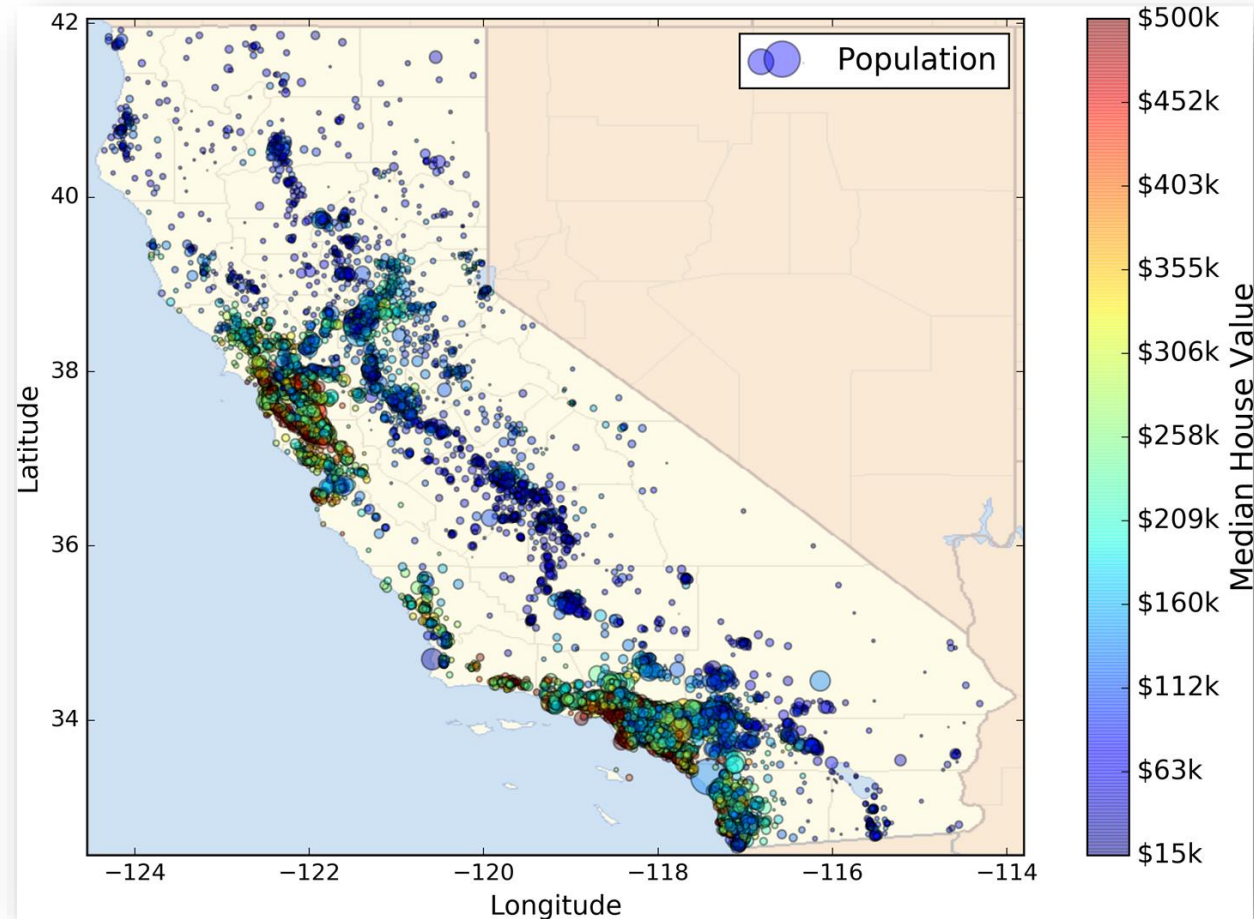
Outline

1. Look at the big picture
2. Get the data
3. Discover and visualize the data to gain insights
4. Prepare the data for Machine Learning algorithms
5. Select a model and train it
6. Fine-tune your model
7. Present your solution
8. Launch, monitor, and maintain your system
9. Exercises

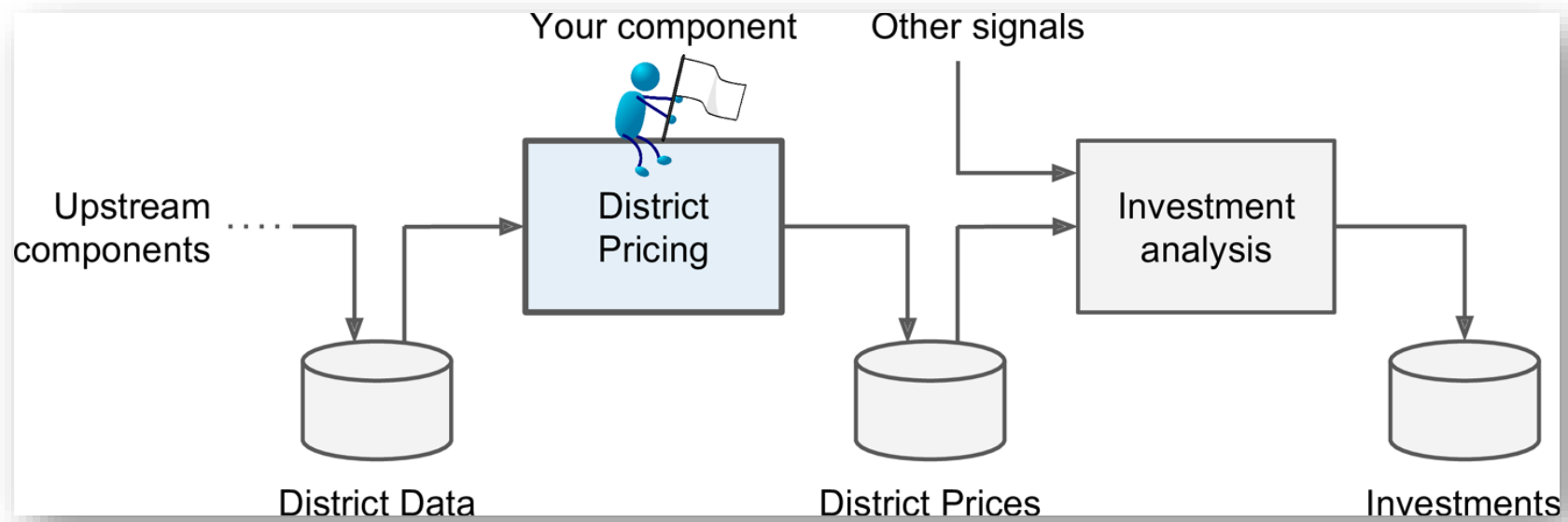
Working with Real Data

- Popular open data repositories:
 - [Tensorflow Datasets \(GitHub\)](#)
 - [UC Irvine Machine Learning Repository](#)
 - [Kaggle datasets](#)
 - [Amazon's AWS datasets](#)
 - [IEEE DataPort](#)
- Meta portals (they list open data repositories):
 - [Google Dataset Search](#)
 - <http://dataportals.org/>
 - <http://opendatamonitor.eu/>
 - <http://quandl.com/>
- Other pages listing many popular open data repositories:
 - [Wikipedia's list of Machine Learning datasets](#)
 - [Quora.com question](#)
 - [Datasets subreddit](#)

1. Look at the Big Picture: CA Housing Data



1.1. Frame the Problem

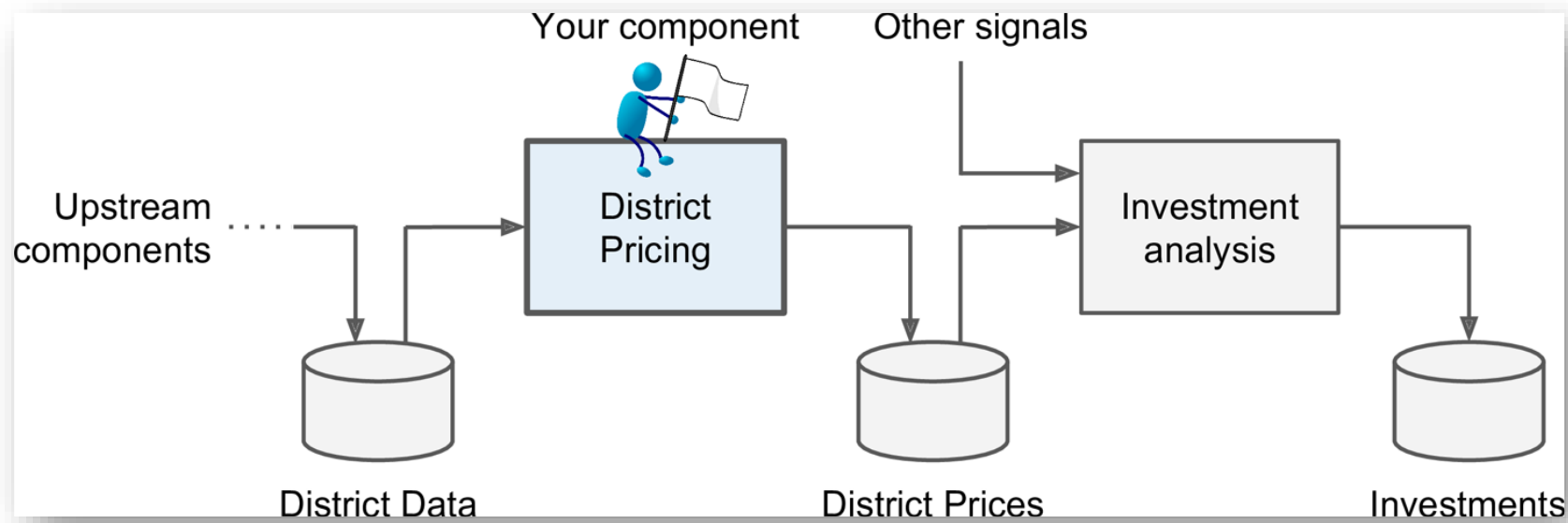


Is it supervised, unsupervised, or Reinforcement Learning?

Is it a classification task, a regression task, or something else? Should you use batch learning or online learning techniques?

Instance-based or Model-based learning?

1.1. Frame the Problem



Is it **supervised**, unsupervised, or Reinforcement Learning?

Is it a classification task, a **regression** task, or something else? Should you use **batch** learning or online learning techniques?

Instance-based or **Model-based** learning?

1.2. Select a Performance Measure

- **Root Mean Square Error (RMSE)**

$$\text{RMSE}(\mathbf{X}, h) = \sqrt{\frac{1}{m} \sum_{i=1}^m \left(h(\mathbf{x}^{(i)}) - y^{(i)} \right)^2}$$

- m is the number of samples
- $\mathbf{x}^{(i)}$ is the feature vector of Sample i
- $y^{(i)}$ is the label or desired output
- \mathbf{X} is a matrix containing all the feature values

$$\mathbf{X} = \begin{pmatrix} (\mathbf{x}^{(1)})^T \\ (\mathbf{x}^{(2)})^T \\ \vdots \\ (\mathbf{x}^{(1999)})^T \\ (\mathbf{x}^{(2000)})^T \end{pmatrix} = \begin{pmatrix} -118.29 & 33.91 & 1,416 & 38,372 \\ \vdots & \vdots & \vdots & \vdots \end{pmatrix}$$

1.2. Select a Performance Measure

- **Mean Absolute Error**

$$\text{MAE}(\mathbf{X}, h) = \frac{1}{m} \sum_{i=1}^m \left| h(\mathbf{x}^{(i)}) - y^{(i)} \right|$$

- MAE is better than RMSE when there are outlier samples.

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2. Get the Data

- If you didn't do it before, it is time now to **download** the **Jupyter notebooks** of the textbook from

<https://github.com/ageron/handson-ml2>

- Start Jupyter notebook and open [Chapter 2 notebook](#).
- Hint: If you get kernel connection problem, try
`C:\>jupyter notebook -port 8889`
- The following slides summarize the code used in this notebook.

2. Get the Data

1. Download the `housing.tgz` file from **Github** using `urllib.request.urlretrieve()` from the `urllib` package
2. Extract the data from this compressed tar file using `tarfile.open()` and `extractall()`. The data will be in the CSV file `housing.csv`
3. Read the CSV file into a Pandas DataFrame called `housing` using `pandas.read_csv()`

2.1. Take a Quick Look at the Data Structure

- Display the top five rows using the DataFrame's `head()` method
- The `info()` method is useful to get a quick description of the data
- To find categories and repetitions of some column use `housing['key'].value_counts()`
- The `describe()` method shows a summary of the numerical attributes.
- Show histogram using the `hist()` method and `matplotlib.pyplot.show()`

```
housing.info()
```

```
<class 'pandas.core.frame.DataFrame'>  
RangeIndex: 20640 entries, 0 to 20639  
Data columns (total 10 columns):  
longitude          20640 non-null float64  
latitude           20640 non-null float64  
housing_median_age 20640 non-null float64  
total_rooms        20640 non-null float64  
total_bedrooms     20433 non-null float64  
population         20640 non-null float64  
households         20640 non-null float64  
median_income      20640 non-null float64  
median_house_value 20640 non-null float64  
ocean_proximity    20640 non-null object  
dtypes: float64(9), object(1)  
memory usage: 1.6+ MB
```

207 missing
features

```
>>> housing["ocean_proximity"].value_counts()  
<1H OCEAN      9136  
INLAND         6551  
NEAR OCEAN     2658  
NEAR BAY       2290  
ISLAND          5  
Name: ocean_proximity, dtype: int64
```

2.2. Create a Test Set

- **Split** the available data randomly to:
 - Training set (80%)
 - Test set (20%)
- The example defines a function called `split_train_test()` for illustration.
- Scikit-Learn has `train_test_split()`.
- Scikit-Learn also has `StratifiedShuffleSplit()` that does stratified sampling.
- **Stratification** ensures that the test samples are representative of the target categories.

2.2.1. Create a Test Set: User-defined function

```
import numpy as np

def split_train_test(data, test_ratio):
    shuffled_indices = np.random.permutation(len(data))
    test_set_size = int(len(data) * test_ratio)
    test_indices = shuffled_indices[:test_set_size]
    train_indices = shuffled_indices[test_set_size:]
    return data.iloc[train_indices], data.iloc[test_indices]
```

You can then use this function like this:

```
>>> train_set, test_set = split_train_test(housing, 0.2)
>>> print(len(train_set), "train +", len(test_set), "test")
16512 train + 4128 test
```

2.2.2. Create a Test Set: Using Scikit-Learn functions

```
from sklearn.model_selection import train_test_split

train_set, test_set = train_test_split(housing, test_size=0.2, random_state=42)
```

Stratification is usually done on the target class.

```
from sklearn.model_selection import StratifiedShuffleSplit

split = StratifiedShuffleSplit(n_splits=1, test_size=0.2, random_state=42)
for train_index, test_index in split.split(housing, housing["income_cat"]):
    strat_train_set = housing.loc[train_index]
    strat_test_set = housing.loc[test_index]
```

Outline

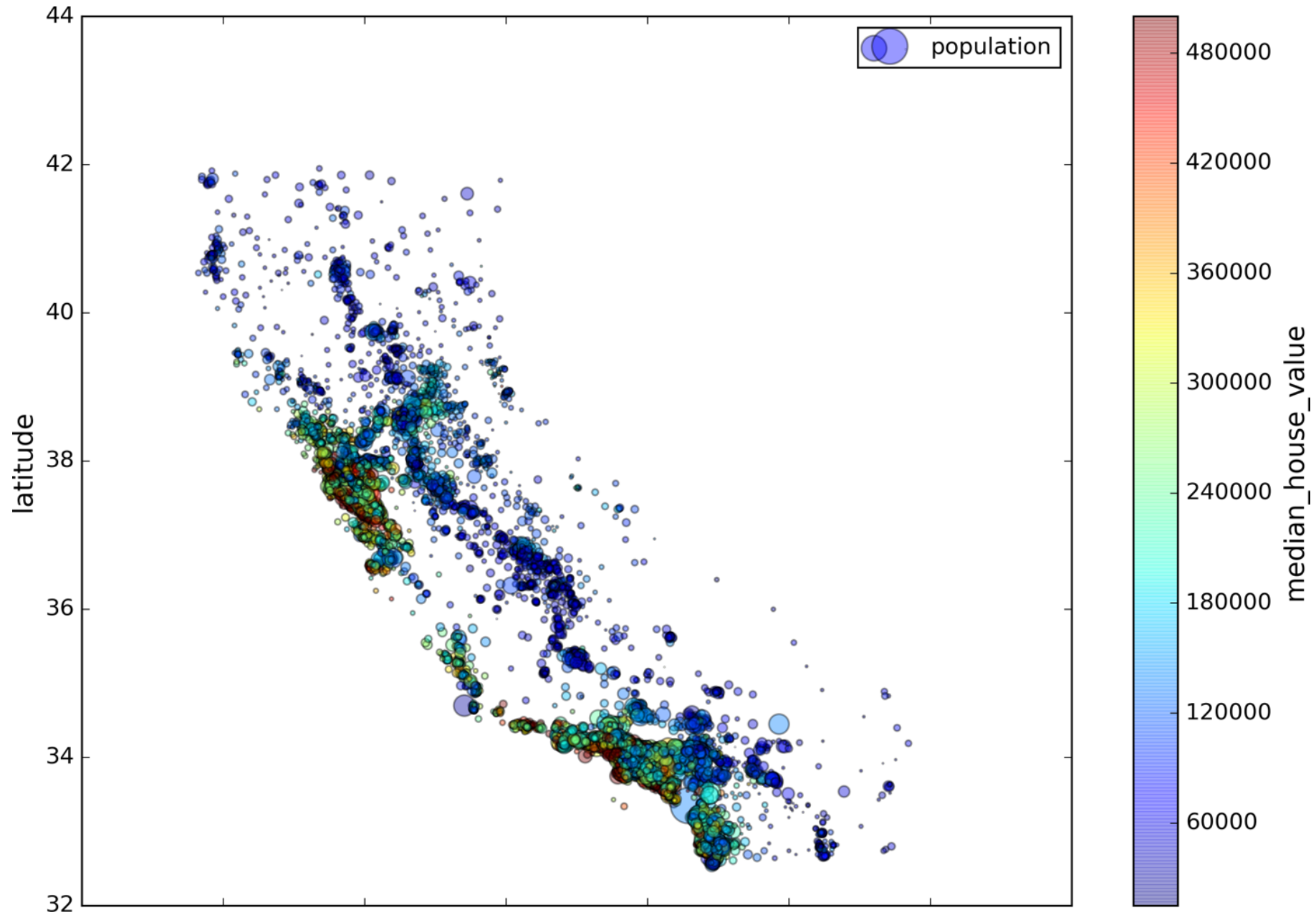
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3. Discover and Visualize the Data to Gain Insights

- **Visualize** geographical data using

```
housing.plot(kind="scatter", x="longitude", y="latitude", alpha=0.4,  
             s=housing["population"]/100, label="population",  
             c="median_house_value", cmap=plt.get_cmap("jet"), colorbar=True,  
             )  
plt.legend()
```

alpha: Transparency, **s**: size, **c**: color, **cmap**: blue to red



3.1. Looking for Correlations

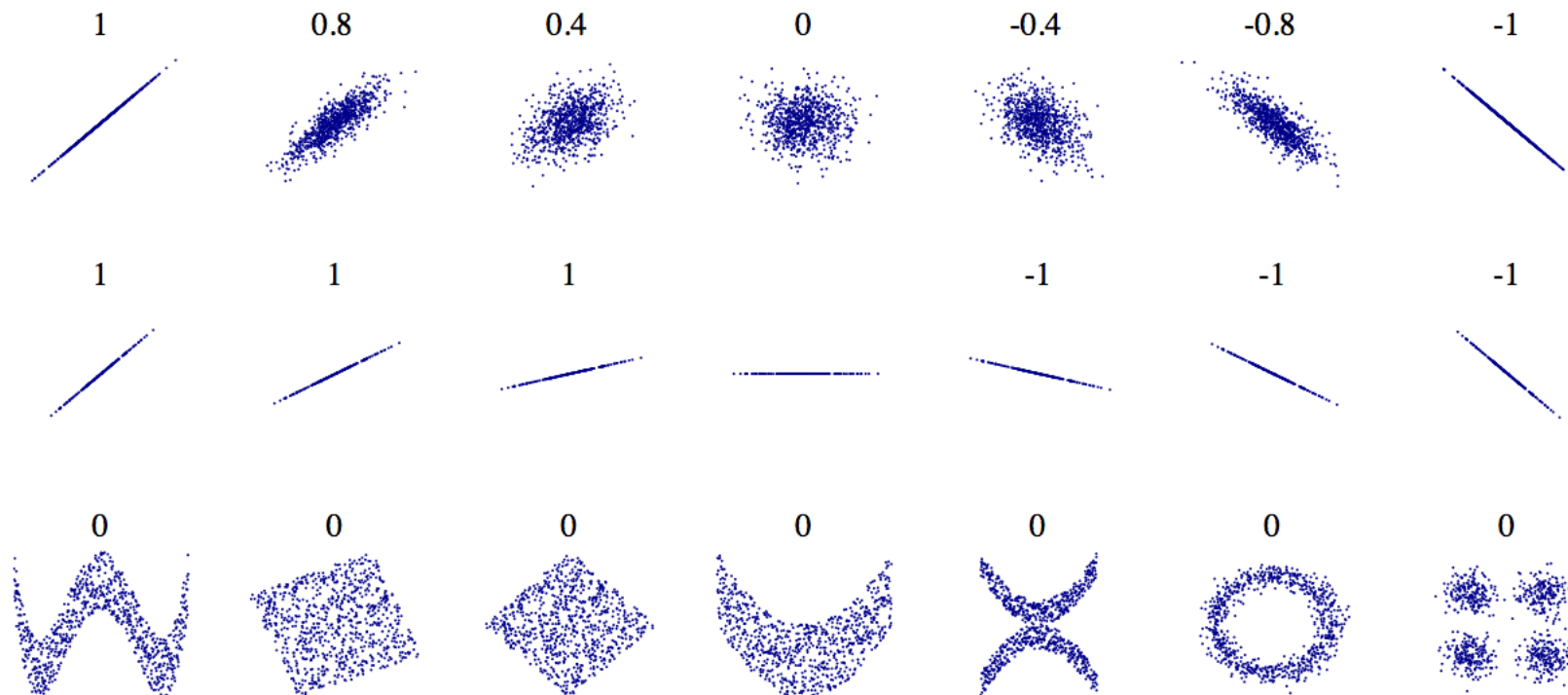
- Compute the **standard correlation coefficient** (also called **Pearson's r**) between every pair of attributes using **corr_matrix = housing.corr()**

$$r = \frac{\sum_{i=1}^n (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^n (x_i - \bar{x})^2} \sqrt{\sum_{i=1}^n (y_i - \bar{y})^2}}$$

```
>>> corr_matrix["median_house_value"].sort_values(ascending=False)
median_house_value    1.000000
median_income         0.687170
total_rooms           0.135231
housing_median_age   0.114220
households            0.064702
total_bedrooms        0.047865
population            -0.026699
longitude             -0.047279
latitude              -0.142826
```

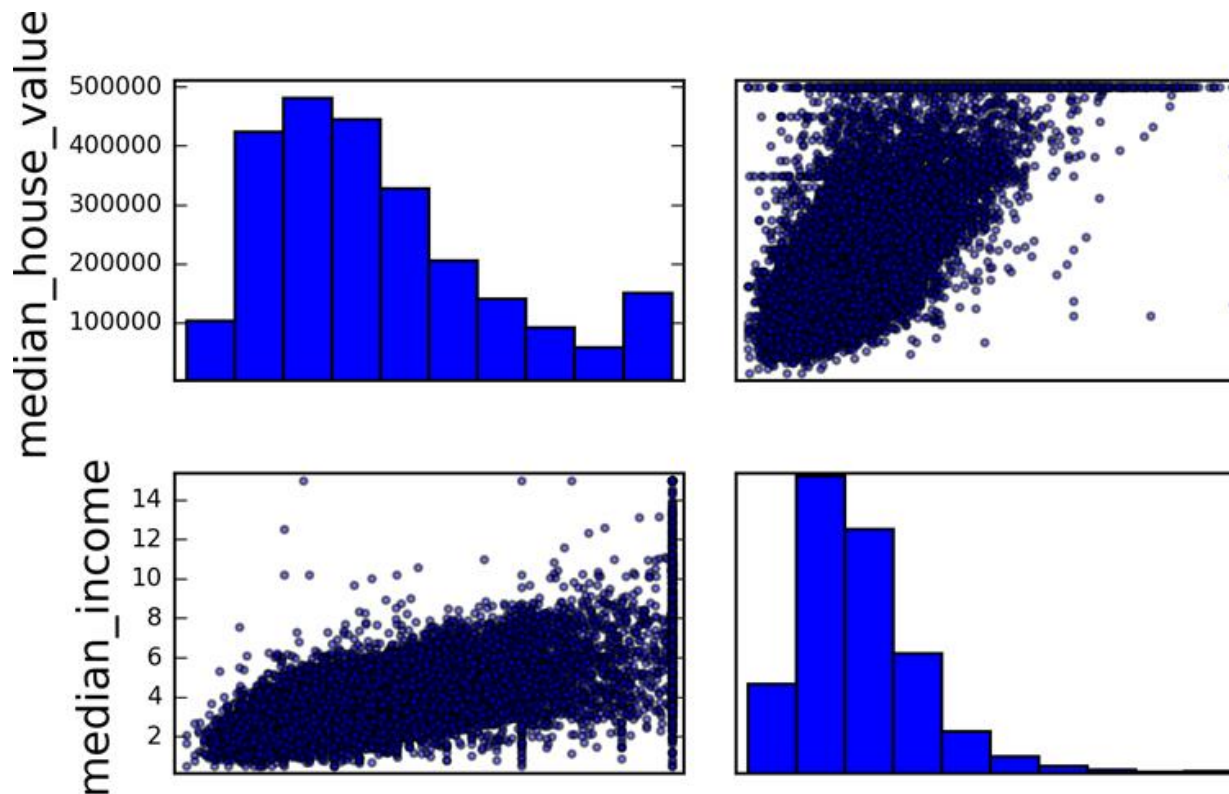
3.1. Looking for Correlations

- Zero linear correlation ($r = 0$) does not guarantee **independence**.



3.2. Pandas Scatter Matrix

```
from pandas.tools.plotting import scatter_matrix
attributes = ["median_house_value", "median_income"]
scatter_matrix(housing[attributes], figsize=(12, 8))
```



3.3. Experimenting with Attribute Combinations

- Rooms per household is better than total rooms:

```
housing["rooms_per_household"] = housing["total_rooms"]/housing["households"]
```

```
>>> corr_matrix = housing.corr()
>>> corr_matrix["median_house_value"].sort_values(ascending=False)
median_house_value      1.000000
median_income           0.687170
rooms_per_household     0.199343
total_rooms             0.135231
```

- Similarly, BMI is better than weight or height for medical purposes.

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4. Prepare the Data for Machine Learning Algorithms

- **Split** to train and test (Done)
- **Separate** features from response
- Handle **missing** data
- Handle text and **categorical** features
- **Scale** (normalize) features
- Build preparation **pipeline**

4. Prepare the Data for Machine Learning Algorithms

- **Separate** the **features** from the **response**.

```
housing = strat_train_set.drop("median_house_value", axis=1)
housing_labels = strat_train_set["median_house_value"].copy()
```

- **Options** of handling **missing features**:

1. **Get rid** of the corresponding **districts**
2. **Get rid** of the whole **attribute**
3. **Set the values** to some value (0, mean, median, etc.)

```
housing.dropna(subset=["total_bedrooms"])    # option 1
housing.drop("total_bedrooms", axis=1)      # option 2
median = housing["total_bedrooms"].median() # option 3
housing["total_bedrooms"].fillna(median, inplace=True)
```

4.1. Handling Missing Features Using Scikit-Learn

- Use **SimpleImputer** on the numerical features. Need to remove categorical variables before doing the fit. The attribute **statistics_** has the means.

```
from sklearn.preprocessing import SimpleImputer
imputer = SimpleImputer(strategy="median")
housing_num = housing.drop("ocean_proximity", axis=1)
imputer.fit(housing_num)
>>> imputer.statistics_
array([ -118.51 ,  34.26 ,  29.   , 2119.   ,  433.   , 1164.   ,  408.   ,  3.5414])
>>> housing_num.median().values
array([ -118.51 ,  34.26 ,  29.   , 2119.   ,  433.   , 1164.   ,  408.   ,  3.5414])
X = imputer.transform(housing_num)
```



NumPy array

4.2. Handling Text and Categorical Attributes

- **ocean_proximity** is categorical feature.

```
>>> housing_cat = housing[["ocean_proximity"]]
>>> housing_cat.head(10)
      ocean_proximity
17606      <1H OCEAN
18632      <1H OCEAN
14650      NEAR OCEAN
 3230           INLAND
 3555      <1H OCEAN
19480           INLAND
 8879      <1H OCEAN
13685           INLAND
 4937      <1H OCEAN
 4861      <1H OCEAN
```

4.2. Handling Text and Categorical Attributes

- Most machine learning algorithms prefer to work with numbers.

Converting to numbers:

```
>>> from sklearn.preprocessing import OrdinalEncoder
>>> ordinal_encoder = OrdinalEncoder()
>>> housing_cat_encoded = ordinal_encoder.fit_transform(housing_cat)
>>> housing_cat_encoded[:10]
```

```
array([[0.],
       [0.],
       [4.],
       [1.],
       [0.],
       [1.],
       [0.],
       [1.],
       [0.],
       [0.]])
```

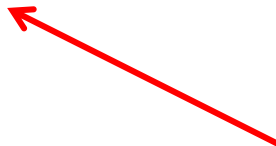
Numerical values
imply distances

```
>>> ordinal_encoder.categories_
[array(['<1H OCEAN', 'INLAND', 'ISLAND', 'NEAR BAY', 'NEAR OCEAN'],
       dtype=object)]
```

4.2. Handling Text and Categorical Attributes

- To ensure encoding neutrality, we can use the one-hot encoding.

```
>>> from sklearn.preprocessing import OneHotEncoder
>>> cat_encoder = OneHotEncoder()
>>> housing_cat_1hot = cat_encoder.fit_transform(housing_cat)
>>> housing_cat_1hot
<16512x5 sparse matrix of type '<class 'numpy.float64'>'
  with 16512 stored elements in Compressed Sparse Row format>
>>> housing_cat_1hot.toarray()
array([[1., 0., 0., 0., 0.],
       [1., 0., 0., 0., 0.],
       [0., 0., 0., 0., 1.],
       ...,
       [0., 1., 0., 0., 0.],
       [1., 0., 0., 0., 0.],
       [0., 0., 0., 1., 0.]])
```



Converts sparse matrix
to dense matrix.

4.3. Custom Transformers

- Scikit-Learn allows you to create your **own transformers**.
- You can create a transformer to create **derived features**.
- Create a class and implement three methods: **fit()** (returning self), **transform()**, and **fit_transform()**. Include base classes:
 - **TransformerMixin** to get **fit_transform()**
 - **BaseEstimator** to get **get_params()** and **set_params()**

4.3. Custom Transformers

```
from sklearn.base import BaseEstimator, TransformerMixin

rooms_ix, household_ix = 3, 6

class CombinedAttributesAdder(BaseEstimator, TransformerMixin):
    def fit(self, X, y=None):
        return self # nothing else to do
    def transform(self, X, y=None):
        rooms_per_household = X[:, rooms_ix] / X[:, household_ix]
        return np.c_[X, rooms_per_household]

attr_adder = CombinedAttributesAdder()
housing_extra_attribs = attr_adder.transform(housing.values)
```

4.4. Feature Scaling

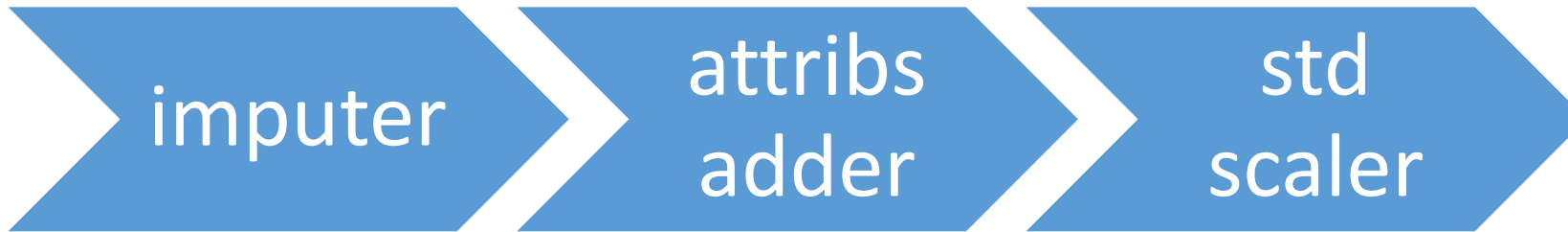
- ML algorithms generally **don't perform well** when the input numerical attributes have **very different scales**.
- Scaling techniques:
 - **Min-max scaling**

$$x' = \frac{x - \min(x)}{\max(x) - \min(x)}$$

- **Standardization**

$$x' = \frac{x - \bar{x}}{\sigma}$$

4.5. Transformation Pipelines



```
from sklearn.pipeline import Pipeline
from sklearn.preprocessing import StandardScaler

num_pipeline = Pipeline([
    ('imputer', SimpleImputer(strategy="median")),
    ('attribs_adder', CombinedAttributesAdder()),
    ('std_scaler', StandardScaler()),
])

housing_num_tr = num_pipeline.fit_transform(housing_num)
```

4.6. Full Pipeline

```
from sklearn.compose import ColumnTransformer

num_attribs = list(housing_num)
cat_attribs = ["ocean_proximity"]

full_pipeline = ColumnTransformer([
    ("num", num_pipeline, num_attribs),
    ("cat", OneHotEncoder(), cat_attribs),
])

housing_prepared = full_pipeline.fit_transform(housing)
```



Dense array

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5. Select and Train a Model

- **Linear regressor**
- Using **RMSE** for evaluation
- **Decision tree regressor**
- **k-fold** cross validation
- **Random forests regressor**

5. Select and Train a Model

- Let us start by training a simple **linear regressor**.

```
from sklearn.linear_model import LinearRegression

lin_reg = LinearRegression()
lin_reg.fit(housing_prepared, housing_labels)
```

- Try it out on five instances from the training set.

```
>>> some_data = housing.iloc[:5]
>>> some_labels = housing_labels.iloc[:5]
>>> some_data_prepared = full_pipeline.transform(some_data)
>>> print("Predictions:\t", lin_reg.predict(some_data_prepared))
Predictions:      [ 303104.   44800.  308928.  294208.  368704.]
>>> print("Labels:\t\t", list(some_labels))
Labels:           [359400.0, 69700.0, 302100.0, 301300.0, 351900.0]
```

50% off

5.1. Evaluate the Model on the Entire Training Set

- Use RMSE

```
>>> from sklearn.metrics import mean_squared_error
>>> housing_predictions = lin_reg.predict(housing_prepared)
>>> lin_mse = mean_squared_error(housing_labels, housing_predictions)
>>> lin_rmse = np.sqrt(lin_mse)
>>> lin_rmse
68628.413493824875
```

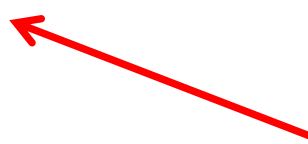
This is not a satisfactory result as the **median_housing_values** range between \$120,000 and \$265,000.

5.2. Try the Decision Tree Regressor

```
from sklearn.tree import DecisionTreeRegressor

tree_reg = DecisionTreeRegressor()
tree_reg.fit(housing_prepared, housing_labels)

>>> housing_predictions = tree_reg.predict(housing_prepared)
>>> tree_mse = mean_squared_error(housing_labels, housing_predictions)
>>> tree_rmse = np.sqrt(tree_mse)
>>> tree_rmse
0.0
```



Overfitting: It has memorized
the entire training set!

5.3. Better Evaluation Using Cross-Validation

- Segment the training data into **10 sets** and repeat training and evaluation 10 times.

```
from sklearn.model_selection import cross_val_score
scores = cross_val_score(tree_reg, housing_prepared, housing_labels,
                        scoring="neg_mean_squared_error", cv=10)
rmse_scores = np.sqrt(-scores)

>>> def display_scores(scores):
...     print("Scores:", scores)
...     print("Mean:", scores.mean())
...     print("Standard deviation:", scores.std())
...
>>> display_scores(tree_rmse_scores)
Scores: [70194.33680785 66855.16363941 ... ]
Mean: 71407.68766037929 ←
Standard deviation: 2439.4345041191004
```

Worse than Linear
Regressor

5.4. Try the Random Forests Regressor

- Repeating training and evaluation:

```
>>> from sklearn.ensemble import RandomForestRegressor
>>> forest_reg = RandomForestRegressor()
>>> forest_reg.fit(housing_prepared, housing_labels)
>>> [...]
>>> forest_rmse
18603.515021376355
>>> display_scores(forest_rmse_scores)
Scores: [49519.80364233 47461.9115823 50029.02762854 52325.28068953
 49308.39426421 53446.37892622 48634.8036574 47585.73832311
 53490.10699751 50021.5852922 ]
Mean: 50182.303100336096 ← Best Accuracy
Standard deviation: 2097.0810550985693
```

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6. Fine-Tune Your Model

- Fine-tune your system by fiddling with:
 - The hyperparameters
 - Removing and adding features
 - Changing feature preprocessing techniques
- Can experiment manually. But it is best to automate this process using Scikit-Learn:
 - **GridSearchCV**
 - or **RandomizedSearchCV**

6.1. Grid Search

- Can automate exploring a search space of $3 \times 4 + 2 \times 3 = 12 + 6 = 18$

```
from sklearn.model_selection import GridSearchCV

param_grid = [
    {'n_estimators': [3, 10, 30], 'max_features': [2, 4, 6, 8]},
    {'bootstrap': [False], 'n_estimators': [3, 10], 'max_features': [2, 3, 4]},
]

forest_reg = RandomForestRegressor()

grid_search = GridSearchCV(forest_reg, param_grid, cv=5,
                           scoring='neg_mean_squared_error',
                           return_train_score=True)

grid_search.fit(housing_prepared, housing_labels)
```

6.2 Examine the Results of Your Grid Search

- Can examine the best hyperparameters using:

```
>>> grid_search.best_params_  
{'max_features': 8, 'n_estimators': 30}
```

- Can examine all search results using:

```
>>> cvres = grid_search.cv_results_  
>>> for mean_score, params in zip(cvres["mean_test_score"], cvres["params"]):  
...     print(np.sqrt(-mean_score), params)  
...  
63669.05791727153 {'max_features': 2, 'n_estimators': 3}  
55627.16171305252 {'max_features': 2, 'n_estimators': 10}  
...  
49682.25345942335 {'max_features': 8, 'n_estimators': 30}
```



Best Tuned Accuracy

6.2 Evaluate Your System on the Test Set

- The final model is the best estimator found by the grid search.
- To evaluate it on the test set, transform the test features, predict using transformed features, and evaluate accuracy.

```
final_model = grid_search.best_estimator_  
X_test = strat_test_set.drop("median_house_value", axis=1)  
y_test = strat_test_set["median_house_value"].copy()  
X_test_prepared = full_pipeline.transform(X_test)  
final_predictions = final_model.predict(X_test_prepared)  
final_mse = mean_squared_error(y_test, final_predictions)  
final_rmse = np.sqrt(final_mse) # => evaluates to 48,209.6
```

Better than train set!



6.3 Save Your Best Model for the Production System

```
from sklearn.externals import joblib

joblib.dump(my_model, "my_model.pkl")
# and later...
my_model_loaded = joblib.load("my_model.pkl")
```

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7. Present Your Solution

- Present your solution highlighting:
 - What you have learned
 - What worked and what did not
 - What assumptions were made
 - What your system's limitations are
- Document everything, and create nice presentations with:
 - Clear visualizations
 - Easy-to-remember statements, e.g., “the median income is the number one predictor of housing prices”.

8. Launch, Monitor, and Maintain Your System

- Prepare your production program that uses your best trained model and launch it.
- Monitor the accuracy of your system. Also monitor the input data.
- Retrain your system periodically using fresh data.

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9. Exercises

Exercise

- Try a Support Vector Machine regressor (`sklearn.svm.SVR`), with various hyperparameters such as `kernel="linear"` (with various values for the `C` hyperparameter) or `kernel="rbf"` (with various values for the `C` and `gamma` hyperparameters). Don't worry about what these hyperparameters mean for now. How does the best SVR predictor perform?