

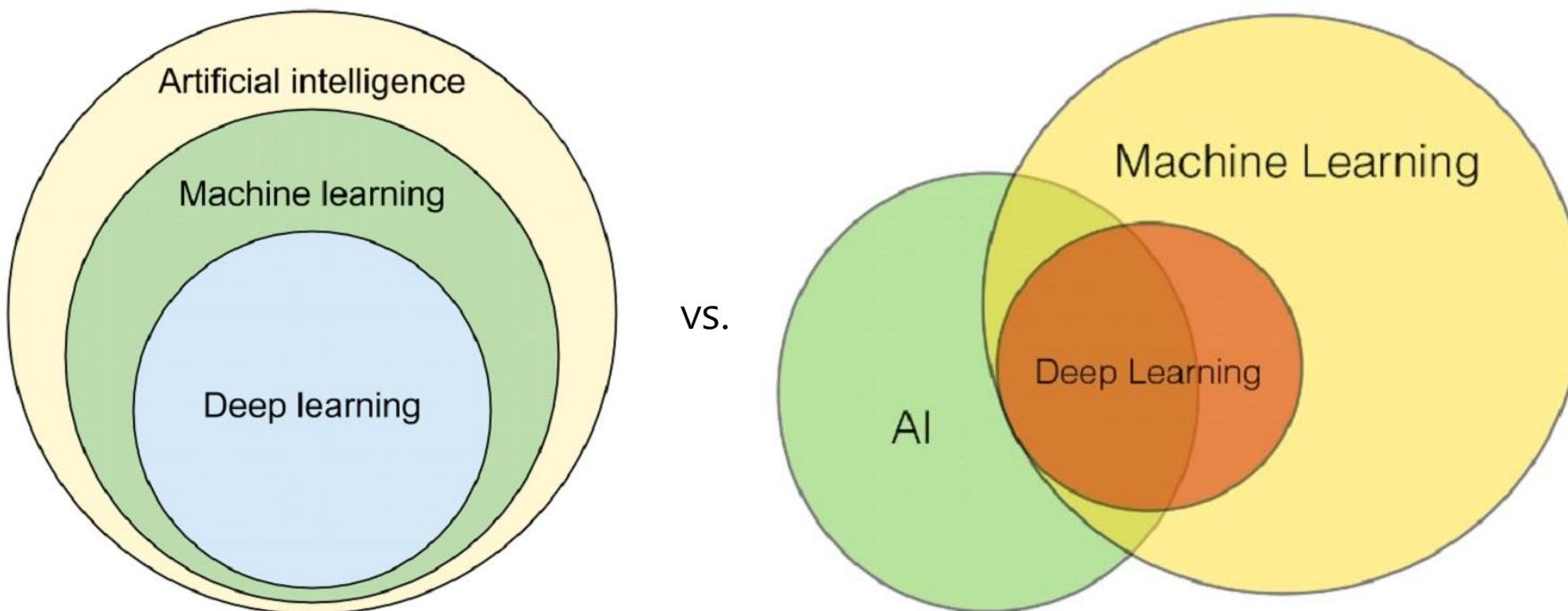
Machine Learning Tutorial with scikit-learn

Sunglok Choi, Assistant Professor, Ph.D.
Dept. of Computer Science and Engineering, SEOULTECH
sunglok@seoultech.ac.kr | <https://mint-lab.github.io/>

Machine Learning

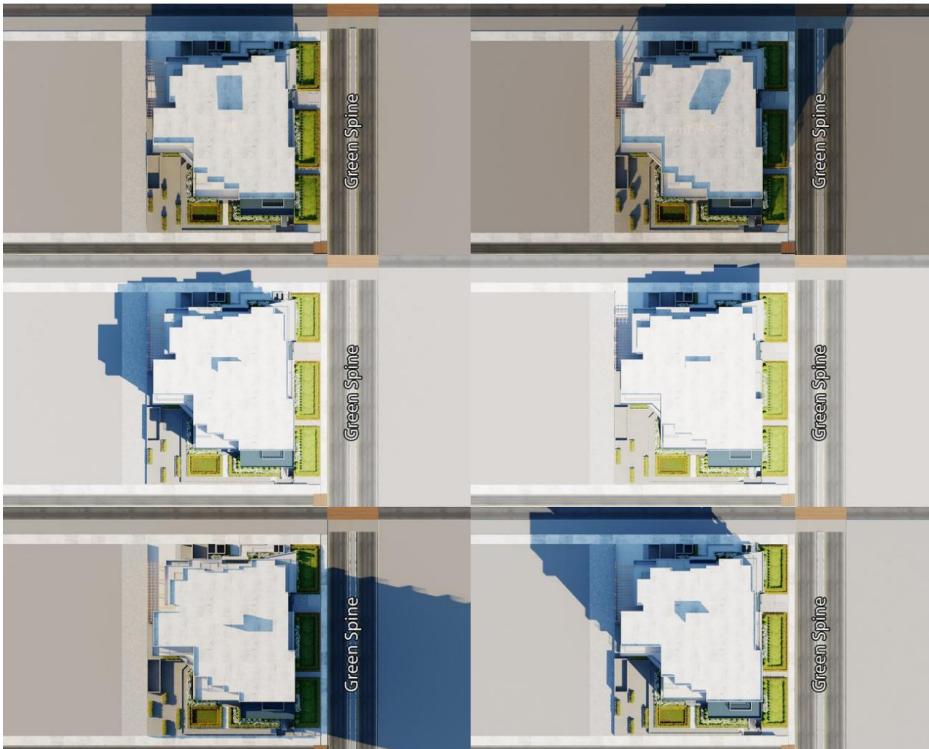
- **Machine learning** (shortly *ML*)

- A type of computer algorithms that achieve tasks (or build models) **automatically through the use of data**
- **Data-driven approaches** vs. rule-based approaches
- **Induction** (귀납법 in Korean) vs. **deduction** (연역법 in Korean)
- Artificial intelligence vs. **machine learning** vs. deep (neural network) learning

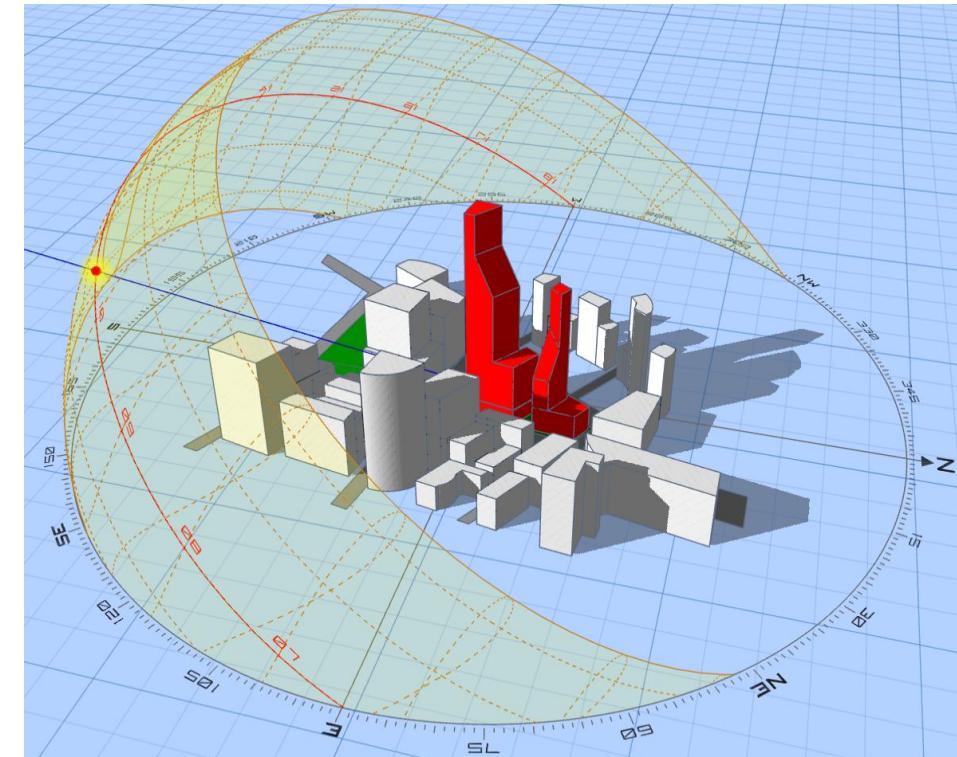


Machine Learning

- **Machine learning** (shortly *ML*)
 - **Data-driven approaches** vs. rule-based approaches
 - Example) Selecting a parking spot while avoiding strong sunshine

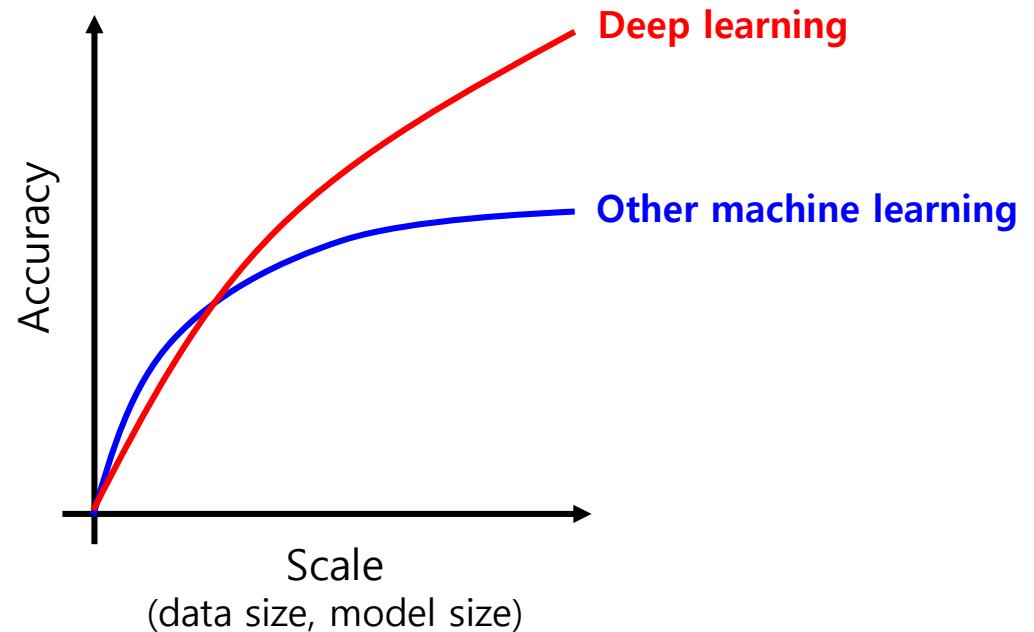


Data-driven approaches (shadow record)



Rule-based approaches (sun path, ray casting, ...)

Why Machine Learning? (vs. Deep Learning)

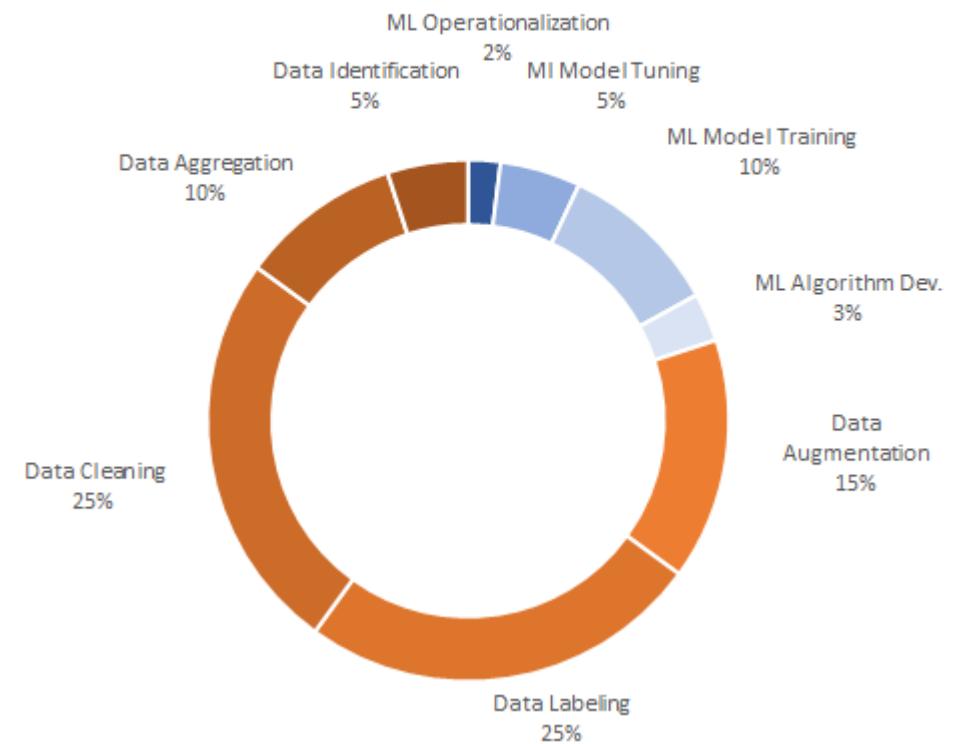


Machine Learning

- **ML procedure** (~ trial and error; 시행착오 in Korean)

- 1. **Data acquisition**
- 2. Data preprocessing (e.g. labeling)
- 3. Feature selection and extraction
- 4. **Model** and **cost function** selection (or design)
- 5. **Hyperparameter** selection (e.g. optimizer, learning rate)
- 6. Model **training**
- 7. Model **testing**
- 8. Model **deployment**

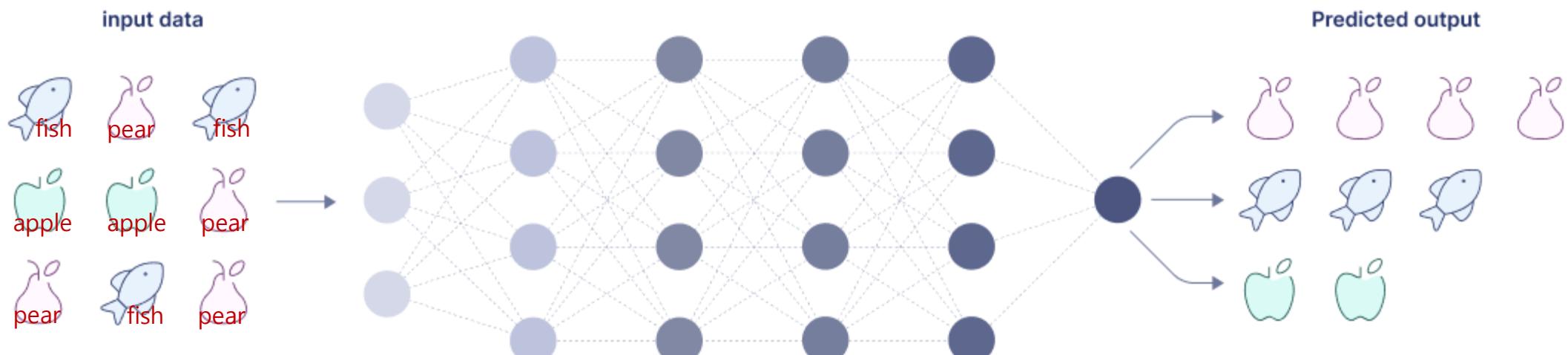
80% of time spent for Machine Learning Projects is allocated to Data related tasks



Machine Learning

- **ML approaches** (with respect to the given data)

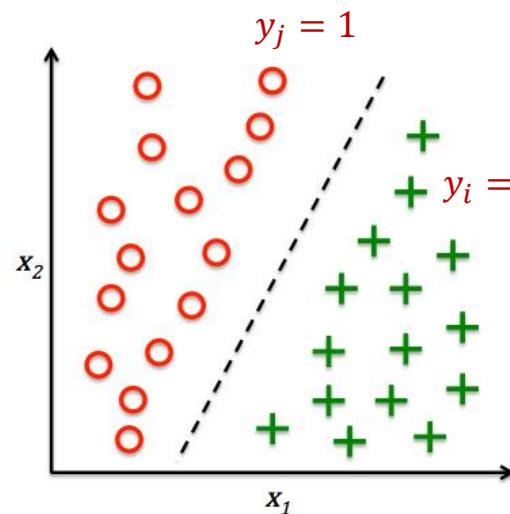
- Supervised learning (지도학습 in Korean): Given example inputs and their desired targets
 - Note) Self-supervised learning, weakly supervised learning, semi-supervised learning, few-shot learning, ...
- Unsupervised learning (비지도학습 in Korean): Given only example inputs (without their targets)
 - Note) It is sometimes used for feature learning (a.k.a. representation learning).
- Reinforcement learning (강화학습 in Korean): Given current input and intermediate feedback (reward/penalty)
after executing the current action



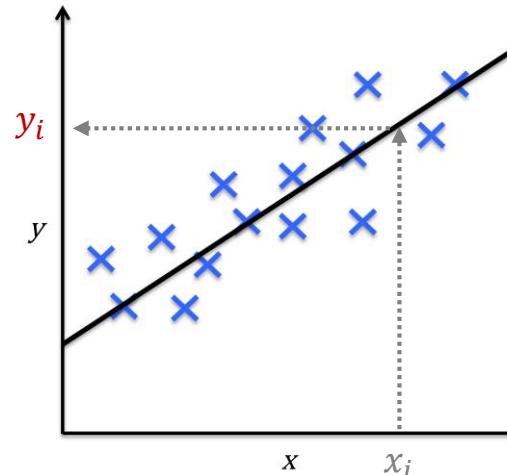
Machine Learning

- **ML problem formulations** (with respect to the targets)

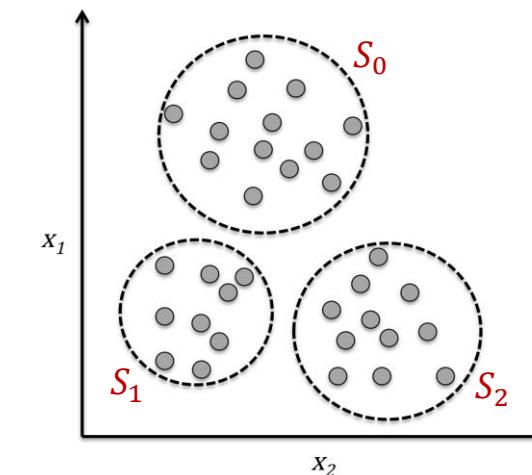
- **Classification**: Identifying which category (discrete) an observation belongs to
- **Regression**: Predicting dependent variables (continuous) corresponding to independent variables
- **Clustering**: Grouping similar data into sets (discrete)
- **Dimensionality reduction**: Transforming the given high-dimensional data to their low-dimensional representation
- **Model selection**: Choosing a model type and its parameters well-associated with the given data
- **Reinforcement learning**: Finding an optimal policy for achieving a goal (more cumulative reward)



Classification



Regression



Clustering

[scikit-learn](#): A Machine Learning Library in Python

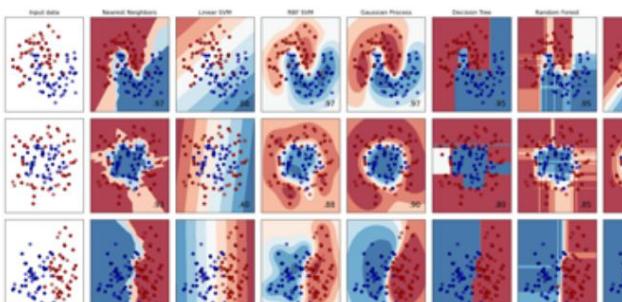
- [**scikit-learn**](#) (a.k.a. *sklearn*) is a Python-based open-source machine learning library.
 - It is built on NumPy, SciPy, and matplotlib (and included in [Anaconda](#) by default).
 - Its name *sci* stands for *science*.
- References ([Documentation](#)): [User guide](#) (~ ML book), [API reference](#), [tutorials](#), and [examples](#)
 - [Example datasets](#) for education and algorithm evaluation.
 - Note) [Machine Learning Repository](#), UCI

Classification

Identifying which category an object belongs to.

Applications: Spam detection, image recognition.

Algorithms: SVM, nearest neighbors, random forest, and [more...](#)

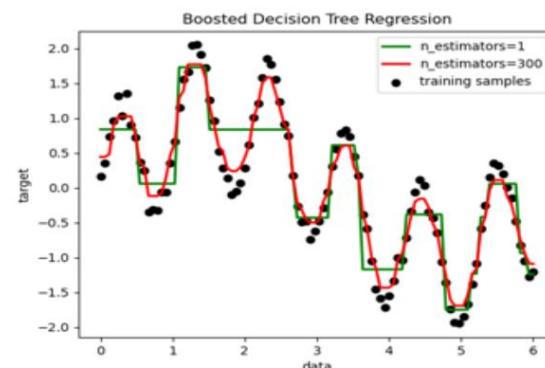


Regression

Predicting a continuous-valued attribute associated with an object.

Applications: Drug response, Stock prices.

Algorithms: SVR, nearest neighbors, random forest, and [more...](#)

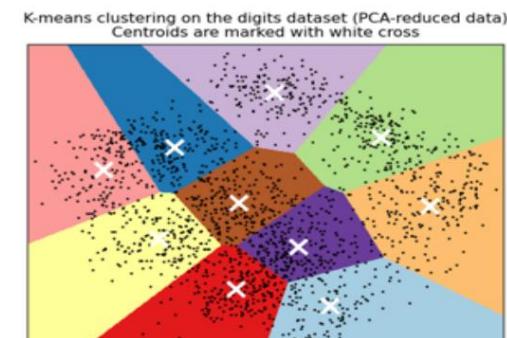


Clustering

Automatic grouping of similar objects into sets.

Applications: Customer segmentation, Grouping experiment outcomes

Algorithms: k-Means, spectral clustering, mean-shift, and [more...](#)



scikit-learn:

- [scikit-learn](#)
 - It is built on top of NumPy and SciPy.
 - Its name is lowercase.
- [References](#)
 - [Example](#)
 - Note: scikit-learn is a Python library.

Python For Data Science Cheat Sheet

Scikit-Learn

Learn Python for data science interactively at www.DataCamp.com



Scikit-learn

Scikit-learn is an open source Python library that implements a range of machine learning, preprocessing, cross-validation and visualization algorithms using a unified interface.



A Basic Example

```
>>> from sklearn import neighbors, datasets, preprocessing
>>> from sklearn.model_selection import train_test_split
>>> from sklearn.metrics import accuracy_score
>>> iris = datasets.load_iris()
>>> X, y = iris.data[:, :2], iris.target
>>> X_train, X_test, y_train, y_test = train_test_split(X, y, random_state=33)
>>> scaler = preprocessing.StandardScaler().fit(X_train)
>>> X_train = scaler.transform(X_train)
>>> X_test = scaler.transform(X_test)
>>> knn = neighbors.KNeighborsClassifier(n_neighbors=5)
>>> knn.fit(X_train, y_train)
>>> y_pred = knn.predict(X_test)
>>> accuracy_score(y_test, y_pred)
```

Loading The Data

Also see NumPy & Pandas

Your data needs to be numeric and stored as NumPy arrays or SciPy sparse matrices. Other types that are convertible to numeric arrays, such as Pandas DataFrame, are also acceptable.

```
>>> import numpy as np
>>> X = np.random.random((10,5))
>>> y = np.array(['M','M','F','F','M','F','M','F','F'])
>>> X[X < 0.7] = 0
```

Training And Test Data

```
>>> from sklearn.model_selection import train_test_split
>>> X_train, X_test, y_train, y_test = train_test_split(X,
>>> y,
>>> random_state=0)
```

Preprocessing The Data

Standardization

```
>>> from sklearn.preprocessing import StandardScaler
>>> scaler = StandardScaler().fit(X_train)
>>> standardized_X = scaler.transform(X_train)
>>> standardized_X_test = scaler.transform(X_test)
```

Normalization

```
>>> from sklearn.preprocessing import Normalizer
>>> scaler = Normalizer().fit(X_train)
>>> normalized_X = scaler.transform(X_train)
>>> normalized_X_test = scaler.transform(X_test)
```

Binarization

```
>>> from sklearn.preprocessing import Binarizer
>>> binarizer = Binarizer(threshold=0.0).fit(X)
>>> binary_X = binarizer.transform(X)
```

Create Your Model

Supervised Learning Estimators

Linear Regression

```
>>> from sklearn.linear_model import LinearRegression
>>> lr = LinearRegression(normalize=True)
```

Support Vector Machines (SVM)

```
>>> from sklearn.svm import SVC
>>> svc = SVC(kernel='linear')
```

Naive Bayes

```
>>> from sklearn.naive_bayes import GaussianNB
>>> gnb = GaussianNB()
```

KNN

```
>>> from sklearn import neighbors
>>> knn = neighbors.KNeighborsClassifier(n_neighbors=5)
```

Unsupervised Learning Estimators

Principal Component Analysis (PCA)

```
>>> from sklearn.decomposition import PCA
>>> pca = PCA(n_components=0.95)
```

K Means

```
>>> from sklearn.cluster import KMeans
>>> k_means = KMeans(n_clusters=3, random_state=0)
```

Model Fitting

Supervised learning

```
>>> lr.fit(X, y)
>>> knn.fit(X_train, y_train)
>>> svc.fit(X_train, y_train)
```

Unsupervised Learning

```
>>> k_means.fit(X_train)
>>> pca_model = pca.fit_transform(X_train)
```

Fit the model to the data

Fit the model to the data
Fit to data, then transform it

Prediction

Supervised Estimators

```
>>> y_pred = svc.predict(np.random.random(2,5))
>>> y_pred = lr.predict(X_test)
>>> y_pred = knn.predict_proba(X_test)
```

Unsupervised Estimators

```
>>> y_pred = k_means.predict(X_test)
```

Predict labels

Predict labels
Estimate probability of a label
Predict labels in clustering algos

Encoding Categorical Features

```
>>> from sklearn.preprocessing import LabelEncoder
>>> enc = LabelEncoder()
>>> y = enc.fit_transform(y)
```

Imputing Missing Values

```
>>> from sklearn.preprocessing import Imputer
>>> imp = Imputer(missing_values=0, strategy='mean', axis=0)
>>> imp.fit_transform(X_train)
```

Generating Polynomial Features

```
>>> from sklearn.preprocessing import PolynomialFeatures
>>> poly = PolynomialFeatures(5)
>>> poly.fit_transform(X)
```

Evaluate Your Model's Performance

Classification Metrics

Accuracy Score

```
>>> knn.score(X_test, y_test)
>>> from sklearn.metrics import accuracy_score
>>> accuracy_score(y_test, y_pred)
```

Estimator score method
Metric scoring functions

Classification Report

```
>>> from sklearn.metrics import classification_report
>>> print(classification_report(y_test, y_pred))
```

Precision, recall, f1-score
and support

Confusion Matrix

```
>>> from sklearn.metrics import confusion_matrix
>>> print(confusion_matrix(y_test, y_pred))
```

Regression Metrics

Mean Absolute Error

```
>>> from sklearn.metrics import mean_absolute_error
>>> y_true = [3, -0.5, 2]
>>> mean_absolute_error(y_true, y_pred)
```

Mean Squared Error

```
>>> from sklearn.metrics import mean_squared_error
>>> mean_squared_error(y_test, y_pred)
```

R² Score

```
>>> from sklearn.metrics import r2_score
```

Clustering Metrics

Adjusted Rand Index

```
>>> from sklearn.metrics import adjusted_rand_score
>>> adjusted_rand_score(y_true, y_pred)
```

Homogeneity

```
>>> from sklearn.metrics import homogeneity_score
>>> homogeneity_score(y_true, y_pred)
```

V-measure

```
>>> from sklearn.metrics import v_measure_score
>>> metrics.v_measure_score(y_true, y_pred)
```

Cross-Validation

```
>>> from sklearn.cross_validation import cross_val_score
>>> print(cross_val_score(knn, X_train, y_train, cv=4))
>>> print(cross_val_score(lr, X, y, cv=2))
```

Tune Your Model

Grid Search

```
>>> from sklearn.grid_search import GridSearchCV
>>> params = {"n_neighbors": np.arange(1,3),
>>> "metric": ["euclidean", "cityblock"]}
>>> grid = GridSearchCV(estimator=knn,
>>> param_grid=params)
>>> grid.fit(X_train, y_train)
>>> print(grid.best_score_)
>>> print(grid.best_estimator_.n_neighbors)
```

Randomized Parameter Optimization

```
>>> from sklearn.grid_search import RandomizedSearchCV
>>> params = {"n_neighbors": range(1,5),
>>> "weights": ["uniform", "distance"]}
>>> rsearch = RandomizedSearchCV(estimator=knn,
>>> param_distributions=params,
>>> cv=4,
>>> n_iter=8,
>>> random_state=5)
>>> rsearch.fit(X_train, y_train)
>>> print(rsearch.best_score_)
```



scikit-learn: A Machine Learning Library in Python

- Iris flower dataset [UCI ML Repository] [scikit-learn] [API]

- Classes (#: 3): *Iris setosa*, *Iris versicolor*, and *Iris virginica*
- Attributes: **4** real numbers
 - Sepal length (unit: cm), sepal width (unit: cm)
 - Petal length (unit: cm), petal width (unit: cm)
 - Note) The values are quantized in the unit of 0.1 cm.
 - Note) In Korean, Iris - 붓꽃, Sepal - 꽃받침, and Petal - 꽃잎
- The number of data: **150** (50 for each class)
- Example) Loading the *iris* flower dataset

```
from sklearn import datasets
```

```
iris = datasets.load_iris()
```

```
print(iris.target_names) # ['setosa' 'versicolor' 'virginica']
print(iris.feature_names) # ['sepal length (cm)', ...]
print(iris.data.shape) # (150, 4)
print(iris.target.shape) # (150,)
```



scikit-learn: A Machine Learning Library in Python

- **How to use (3 steps):** Instantiation → training (fit) → inference/testing (predict)
- Example) Iris flower classification using support vector machine (SVM)
 - Accuracy with 4 attributes: **0.973** (146/150)
 - Accuracy with 2 attributes (sepal width and length): **0.820** (123/150)

```
import numpy as np
import matplotlib.pyplot as plt
from sklearn import (datasets, svm)
from matplotlib.lines import Line2D # For the custom legend

# Load a dataset
iris = datasets.load_iris()

# Train a model
model = svm.SVC()                      # Accuracy: 0.973 (146/150)
model.fit(iris.data, iris.target)        # Try 'iris.data[:,0:2]' (Accuracy: 0.820)

# Test the model
predict = model.predict(iris.data) # Try 'iris.data[:,0:2]' (Accuracy: 0.820)
n_correct = sum(predict == iris.target)
accuracy = n_correct / len(iris.data)
```

scikit-learn: A Machine Learning Library in Python

- Example) Iris flower classification using support vector machine (SVM)

```
# Visualize testing results
cmap = np.array([(1, 0, 0), (0, 1, 0), (0, 0, 1)])
clabel = [Line2D([0], [0], marker='o', lw=0, label=iris.target_names[i], color=cmap[i]) for i in range(len(cmap))]
for (x, y) in [(0, 1), (2, 3)]:
    plt.figure()
    plt.title(f'svm.SVC ({n_correct}/{len(iris.data)})={accuracy:.3f}')
    plt.scatter(iris.data[:,x], iris.data[:,y], c=cmap[iris.target], edgecolors=cmap[predict])
    plt.xlabel(iris.feature_names[x])
    plt.ylabel(iris.feature_names[y])
    plt.legend(handles=clabel, framealpha=0.5)
plt.show()
```

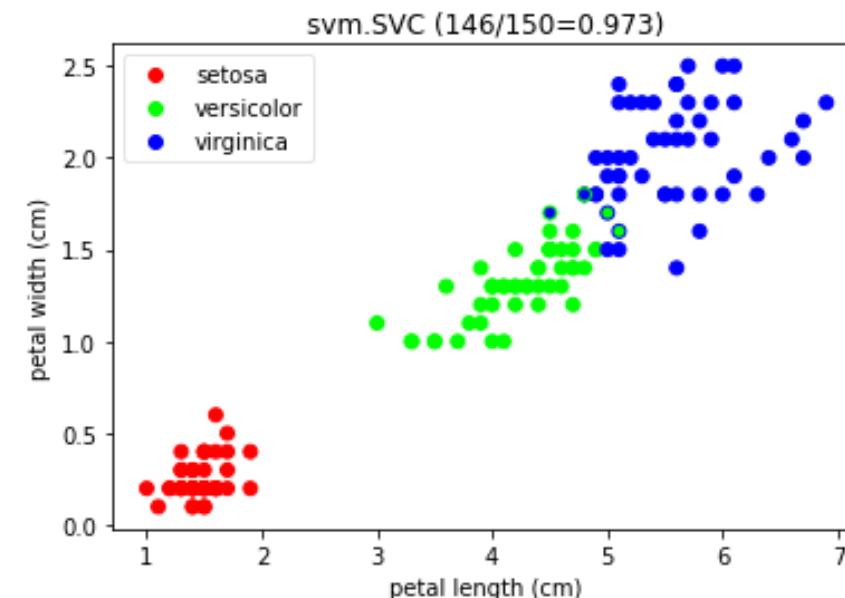
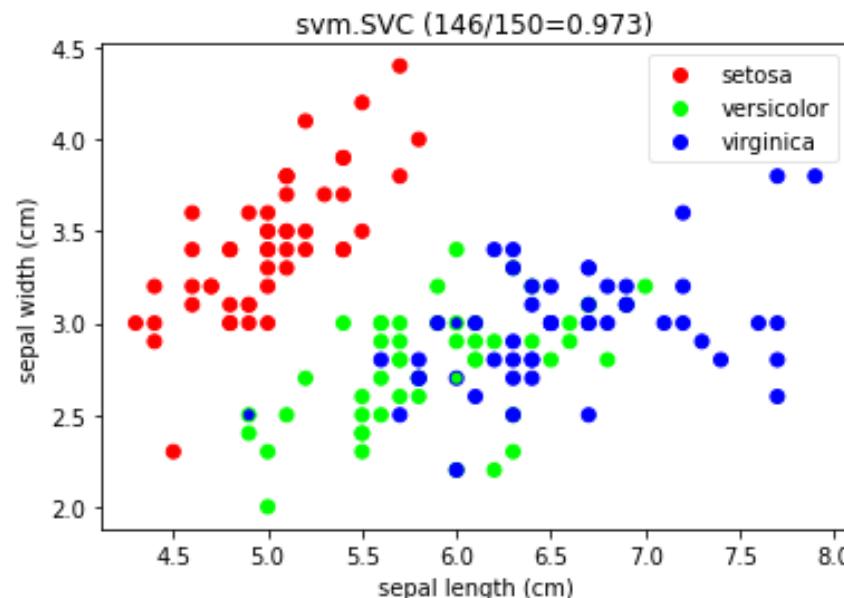


Table of Contents

- Machine Learning
- scikit-learn
- Classification
- Regression
- Clustering
- Machine Learning FAQ

Classification

▪ Binary classification

- Classifying observations into one of two groups (1 or 0; True or False; positive or negative)
- e.g. Detecting spam e-mails
 - (Determining whether an e-mail is *spam* or *normal*)
- **Accuracy:** # of correct answers / # of data
 - e.g. Accuracy of spam detection with 100 e-mails (spam: 10, normal: 90)

```
def is_spam_always_true(text):
    return True # Accuracy: 0.1 (10/100)

def is_spam_always_false(text):
    return False # Accuracy: 0.9 (90/100)
```

- Accuracy is not a good measure for imbalanced data (T: 10, F: 90).

Classification

▪ Binary classification

- **Confusion matrix**: 2D representation of correctness per classes

		Predicted class	
		+	-
Actual class	P	TP true positive	FN false negative (type II error)
	N	FP false positive (type I error)	TN true negative

Note) $P = TP + FN$

$N = FP + TN$

$$ACC = \frac{TP + TN}{P + N}$$

Accuracy

$$BA = \frac{1}{2} \left(\frac{TP}{P} + \frac{TN}{N} \right)$$

Balanced accuracy

$$RE = \frac{TP}{P} = \frac{TP}{TP + FN}$$

Recall, hit rate, sensitivity,
true positive rate

$$PR = \frac{TP}{TP + FP}$$

Precision,
positive predictive rate

$$F1 = 2 \cdot \frac{RE \cdot PR}{RE + PR}$$

F1-measure

harmonic mean of precision and recall

$$FPR = \frac{FP}{N} = \frac{FP}{FP + TN}$$

Fall-out*,
false positive rate*

Note) higher* is worse.

Classification

▪ Binary classification

- **Confusion matrix**: 2D representation of correctness per classes

		Predicted class	
		+	-
Actual class	P	TP true positive	FN false negative (type II error)
	N	FP false positive (type I error)	TN true negative

Note) $P = TP + FN$

$N = FP + TN$

e.g. Accuracy of spam detection with 100 e-mails (spam: 10, normal: 90)

Predicted		Predicted	
		T	F
Actual	S	10	0
	N	90	0

Always True Always False

$$ACC = \frac{TP + TN}{P + N}$$

Accuracy

0.1 vs. 0.9

$$BA = \frac{1}{2} \left(\frac{TP}{P} + \frac{TN}{N} \right)$$

Balanced accuracy

0.5 vs. 0.5

$$RE = \frac{TP}{P} = \frac{TP}{TP + FN}$$

Recall, hit rate, sensitivity,
true positive rate

1.0 vs. 0.0

$$PR = \frac{TP}{TP + FP}$$

Precision,
positive predictive rate

0.1 vs. 0.0

$$F1 = 2 \cdot \frac{RE \cdot PR}{RE + PR}$$

F1-measure

harmonic mean of precision and recall

0.18 vs. 0.0

$$FPR = \frac{FP}{N} = \frac{FP}{FP + TN}$$

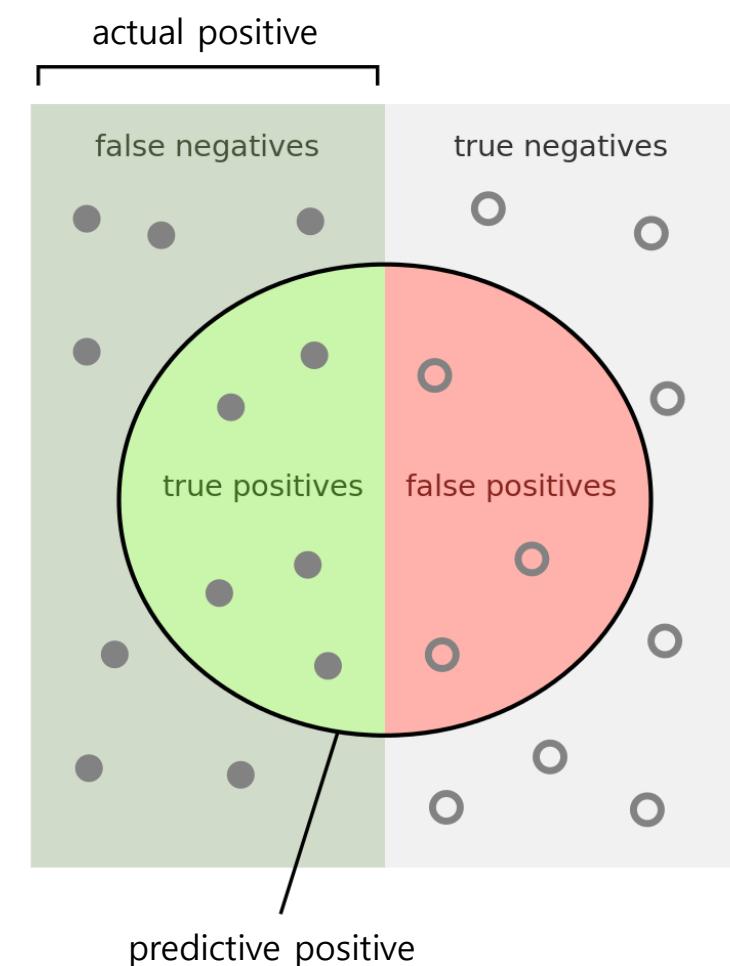
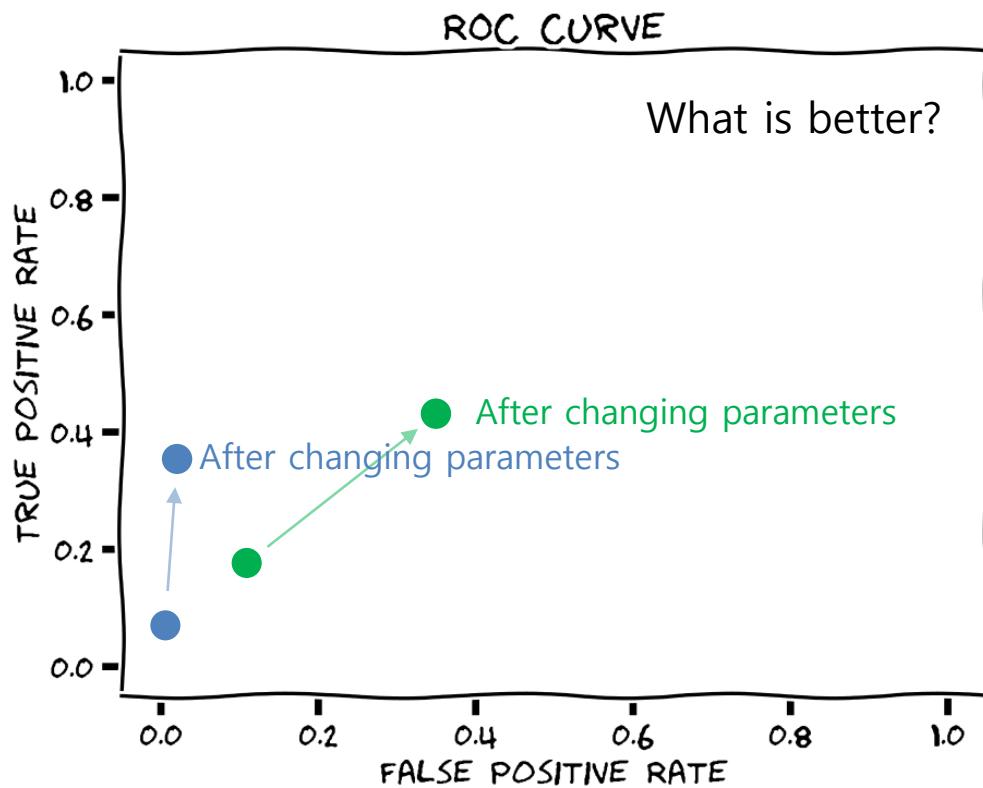
Fall-out*,
false positive rate*

1.0 vs. 0.0

Note) higher* is worse.

Classification

- **Binary classification**
 - Precision and recall
 - ROC curve (Receiver Operating Characteristic curve)
 - A 2D performance plot for varying internal parameters



How many selected items are relevant?

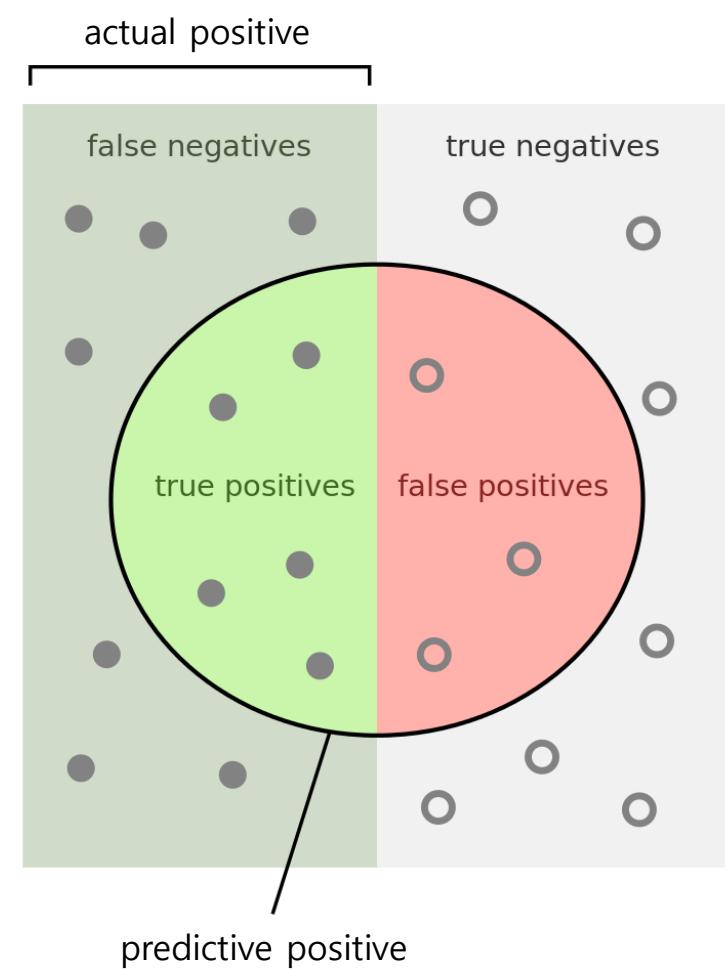
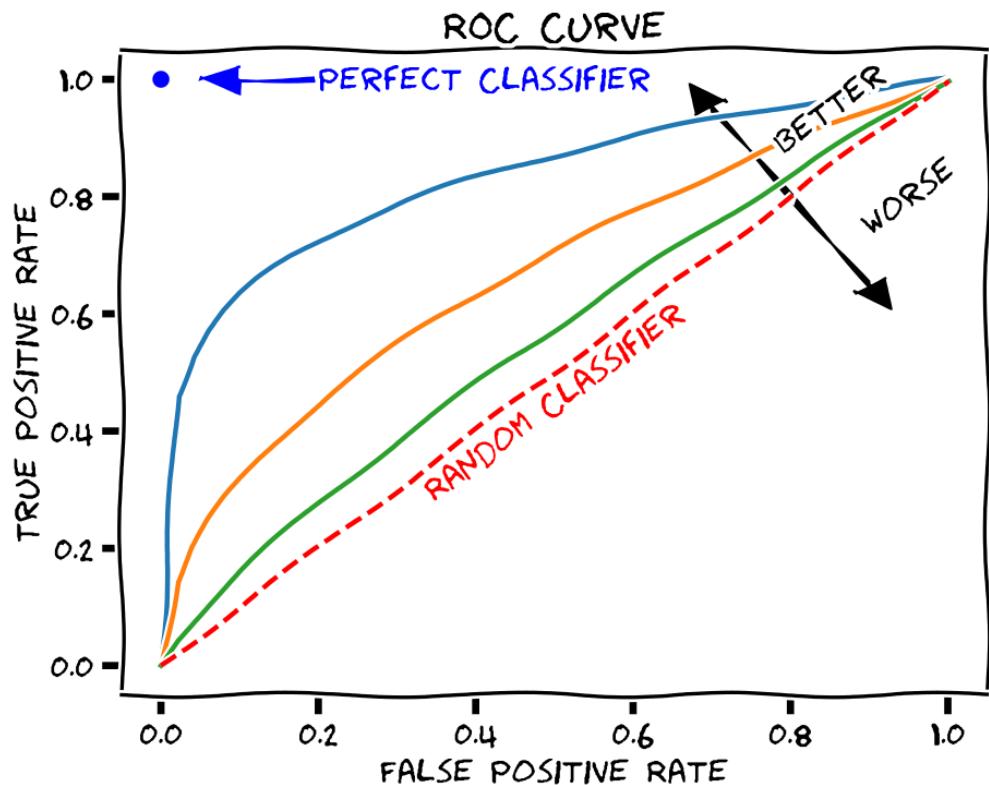
$$\text{Precision} = \frac{\text{true positives}}{\text{predicted positives}}$$

How many relevant items are selected?

$$\text{Recall} = \frac{\text{true positives}}{\text{actual positives}}$$

Classification

- **Binary classification**
 - Precision and recall
 - ROC curve (Receiver Operating Characteristic curve)
 - 2D performance plot for varying internal parameters



How many selected items are relevant?

$$\text{Precision} = \frac{\text{True Positives}}{\text{True Positives} + \text{False Positives}}$$

How many relevant items are selected?

$$\text{Recall} = \frac{\text{True Positives}}{\text{True Positives} + \text{False Negatives}}$$

Classification

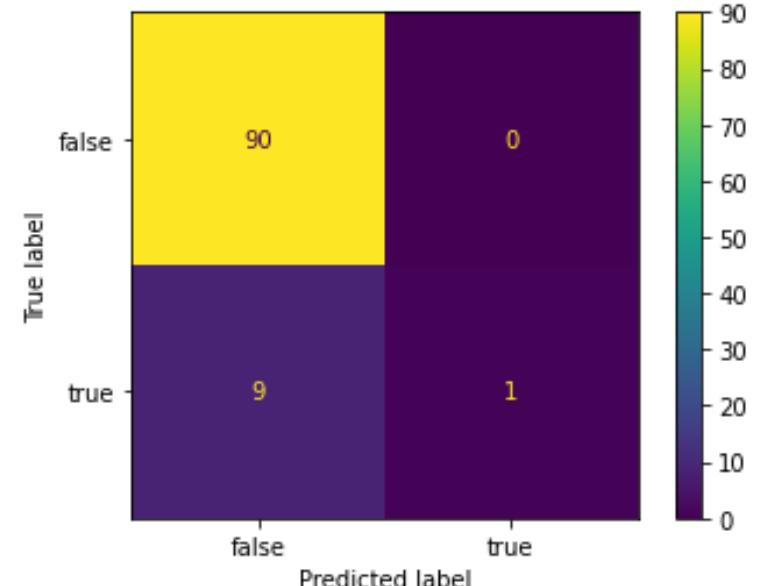
▪ Binary classification

- Example) Evaluating binary classification

```
from sklearn import metrics

# Example ground truth and its prediction
y_true = [False] * 90 + [True] * 10 # True labels
y_pred = [False] * 99 + [True] * 1 # Predicted labels

print(metrics.accuracy_score(y_true, y_pred)) # 0.91
print(metrics.balanced_accuracy_score(y_true, y_pred)) # 0.55
print(metrics.precision_score(y_true, y_pred)) # 1.0 = 1 / 1
print(metrics.recall_score(y_true, y_pred)) # 0.1 = 1 / 10
print(metrics.f1_score(y_true, y_pred)) # 0.18 = 2 * (1.0*0.1) / (1.0+0.1)
print(metrics.precision_recall_fscore_support(y_true, y_pred)) # ...
print(metrics.classification_report(y_true, y_pred))
#          precision    recall  f1-score   support
#     False       0.91      1.00      0.95      90
#     True        1.00      0.10      0.18      10
#   accuracy         -         -      0.91     100
#   macro avg       0.95      0.55      0.57     100
# weighted avg     0.92      0.91      0.88     100
conf_matx = metrics.confusion_matrix(y_true, y_pred) # np.array([[90, 0], [9, 1]], dtype=int64)
conf_disp = metrics.ConfusionMatrixDisplay(conf_matx, display_labels=['false', 'true'])
conf_disp.plot()
```



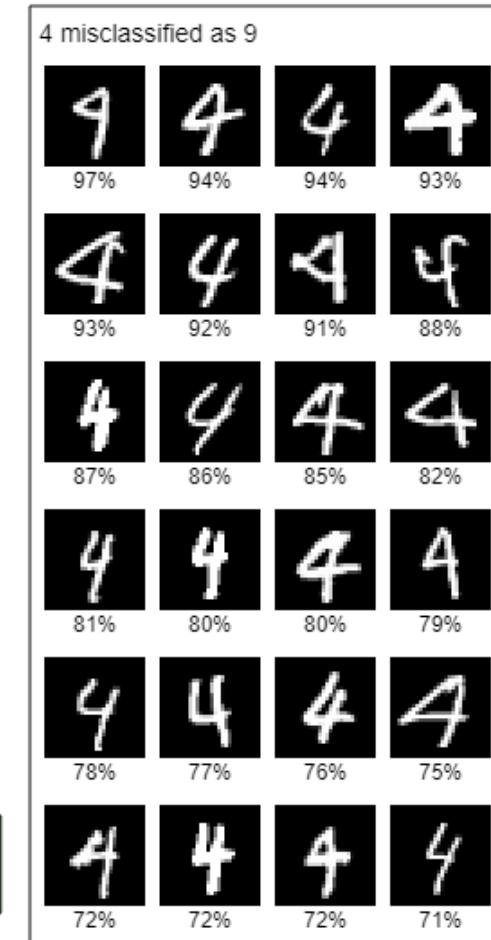
Classification

▪ Multiclass classification

- Classifying observations into one of three or more classes
- e.g. Confusion matrix of visual digit classification

	predicted 0	predicted 1	predicted 2	predicted 3	predicted 4	predicted 5	predicted 6	predicted 7	predicted 8	predicted 9	recall
actual 0	954	0	0	7	1	10	6	3	7	3	96%
actual 1	0	1031	4	3	1	4	1	2	16	2	97%
actual 2	12	21	852	18	11	8	14	20	29	5	86%
actual 3	2	5	9	899	1	71	0	12	23	7	87%
actual 4	2	8	2	2	861	7	7	1	4	89	88%
actual 5	7	5	9	24	3	833	12	8	12	2	91%
actual 6	11	6	2	0	6	31	902	0	8	1	93%
actual 7	3	10	5	3	7	7	1	1041	0	14	95%
actual 8	2	28	4	29	2	31	1	9	882	21	87%
actual 9	7	3	1	7	10	11	1	44	4	873	91%

precision 95% 92% 96% 91% 95% 82% 95% 91% 90% 86% accuracy 91%



Classification

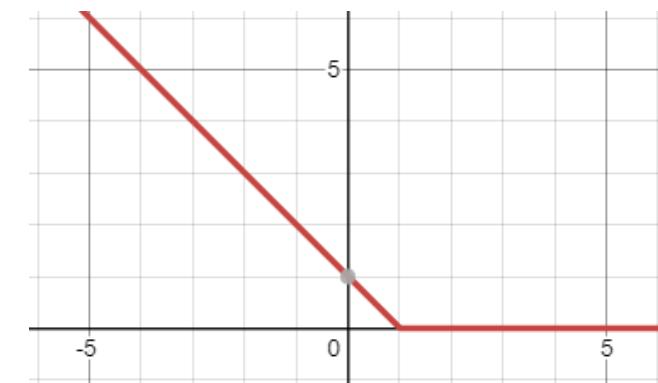
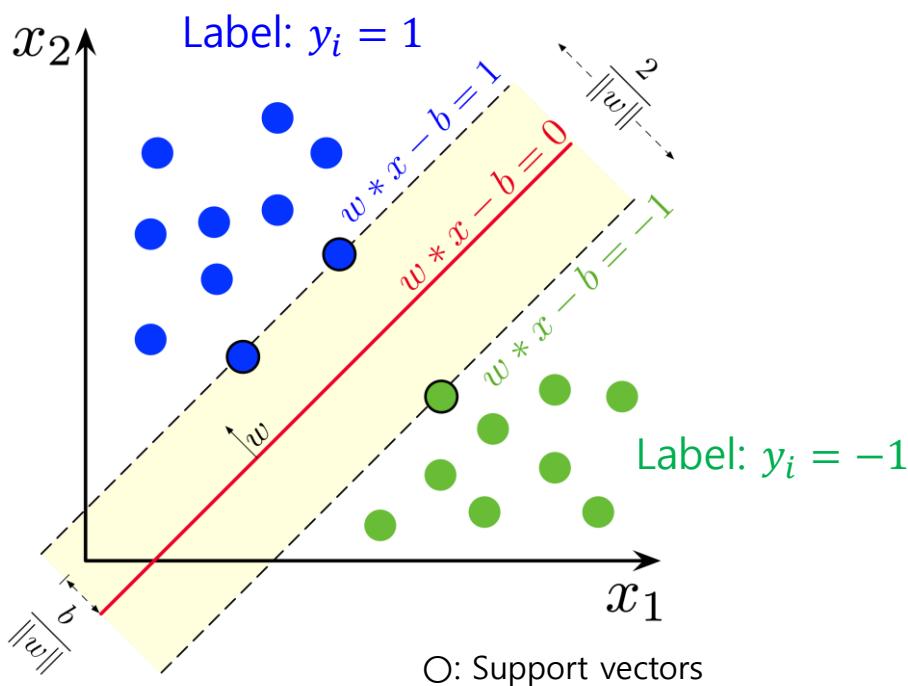
- **Support vector machine (SVM)** [\[scikit-learn\]](#) [\[API\]](#)

- Supervised learning models (usually for classification and regression)
- A non-probabilistic (deterministic) binary linear classifier

- Finding the maximum-margin **hyperplane** (~ boundary; line in 2D, plane in 3D)

$$\mathbf{w}^\top \mathbf{x}_i - b = 0 \text{ (signed distance)} \rightarrow y_i(\mathbf{w}^\top \mathbf{x}_i - b) \text{ (per-class signed distance)}$$

- Optimization: $\operatorname{argmin}_{\mathbf{w}, b} \frac{1}{n} \sum_{i=0}^n h(y_i(\mathbf{w}^\top \mathbf{x}_i - b)) + \lambda \|\mathbf{w}\|^2$ where $h(x) = \max(0, 1 - x)$

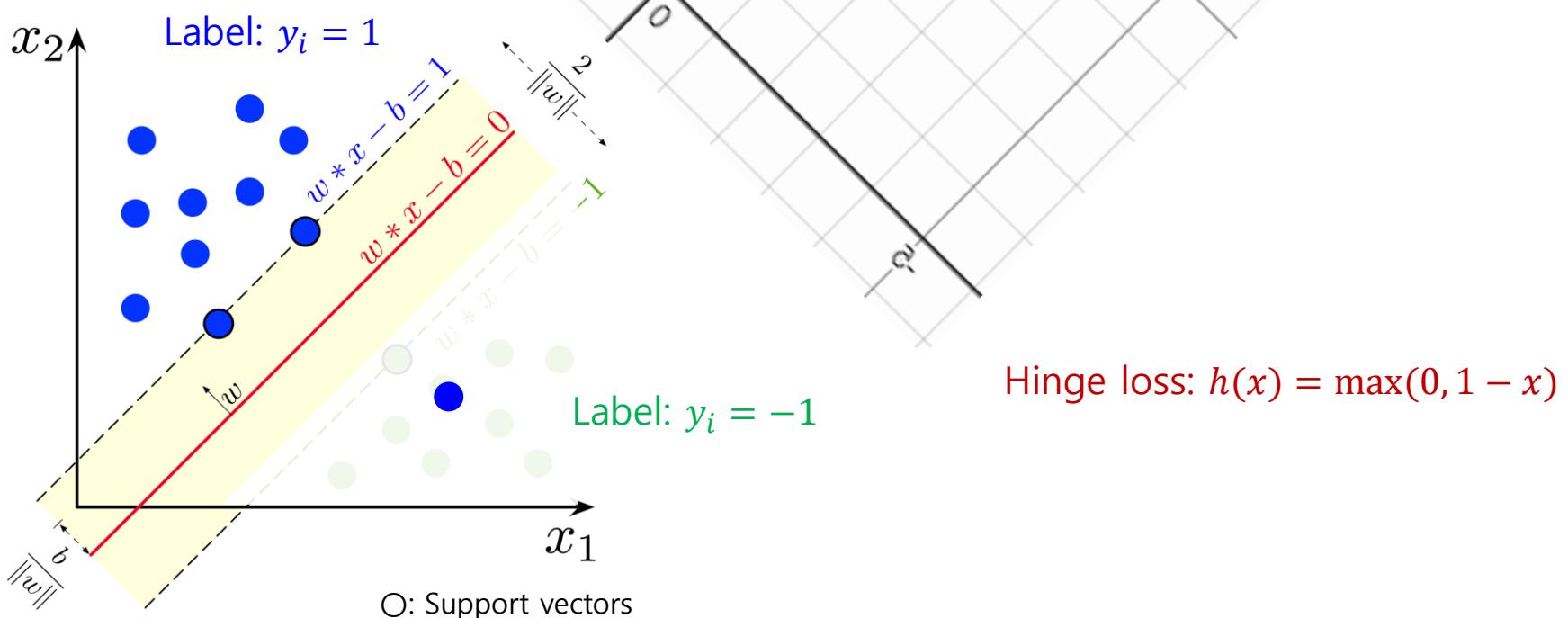


Classification

- **Support vector machine (SVM)** [scikit-learn]

- Supervised learning models (usually binary)
- A non-probabilistic (deterministic) classifier
- Finding the maximum-margins

- Optimization) $\operatorname{argmin}_{\mathbf{w}, b} \frac{1}{n} \sum_{i=0}^n h(y_i (\mathbf{w}^\top \mathbf{x}_i + b))$

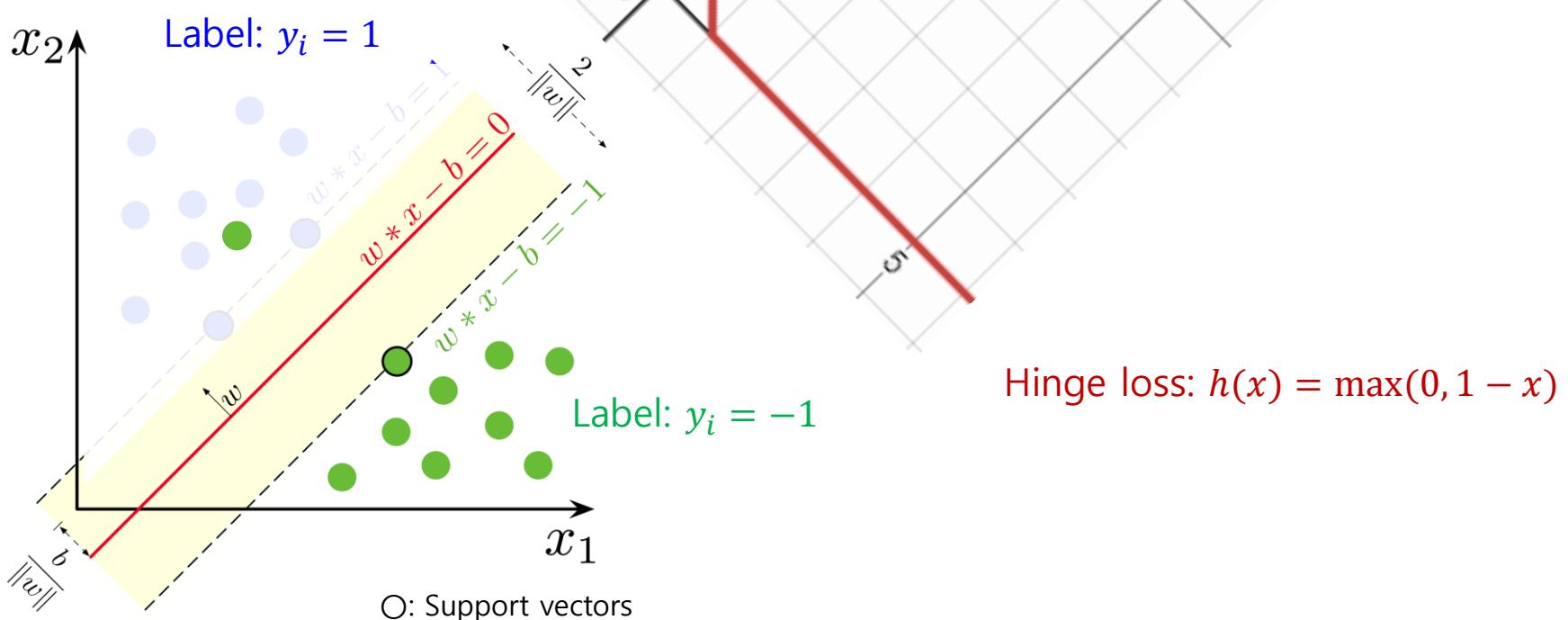


Classification

▪ Support vector machine (SVM) [scikit-learn]

- Supervised learning models (usually binary)
- A non-probabilistic (deterministic) classifier
- Finding the maximum-margin hyperplane

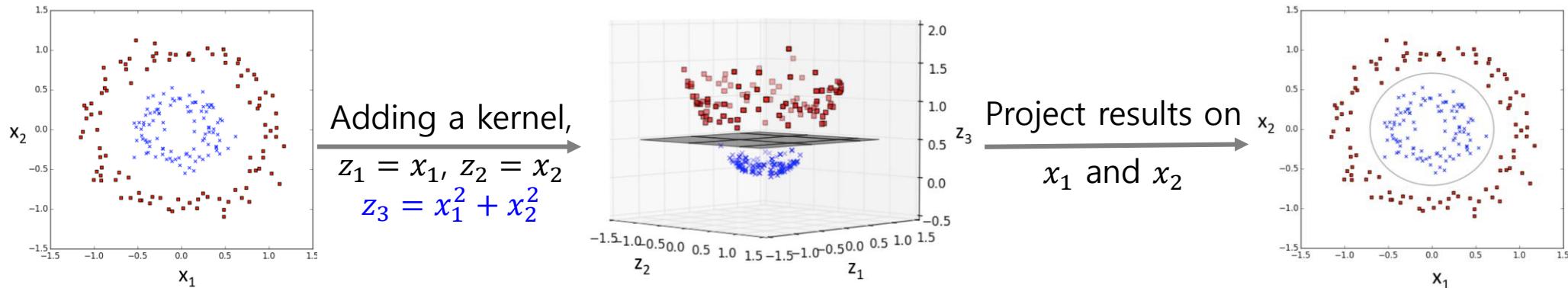
- Optimization) $\operatorname{argmin}_{\mathbf{w}, b} \frac{1}{n} \sum_{i=0}^n h(y_i(\mathbf{w}^\top \mathbf{x}_i + b))$



Classification

- **Support vector machine (SVM)** [\[scikit-learn\]](#) [\[API\]](#)

- The [kernel trick](#) enables *non-linear* classification.

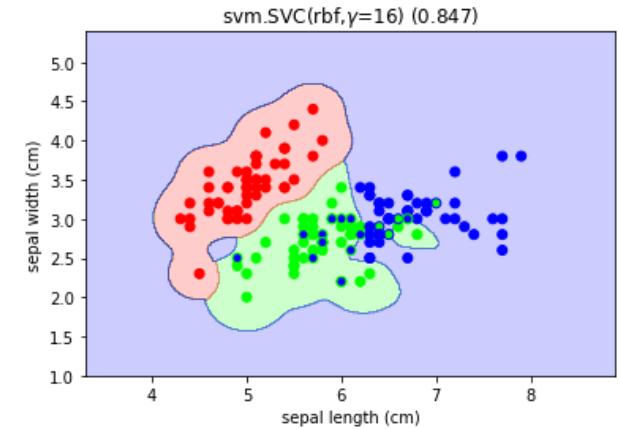
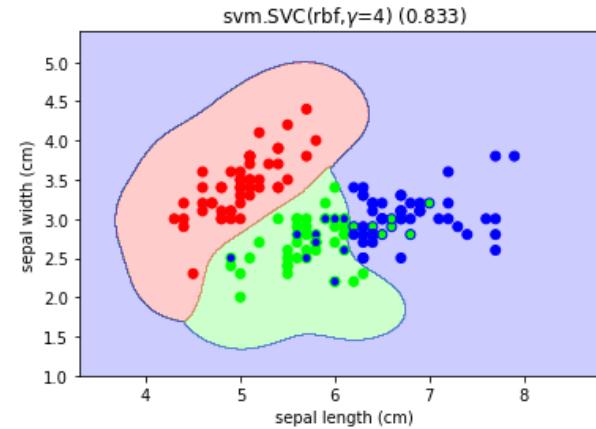
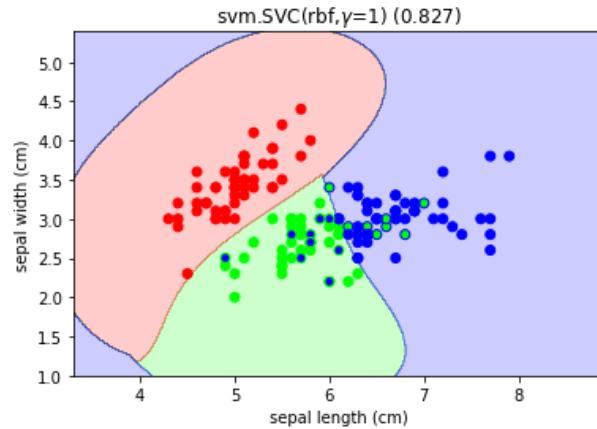
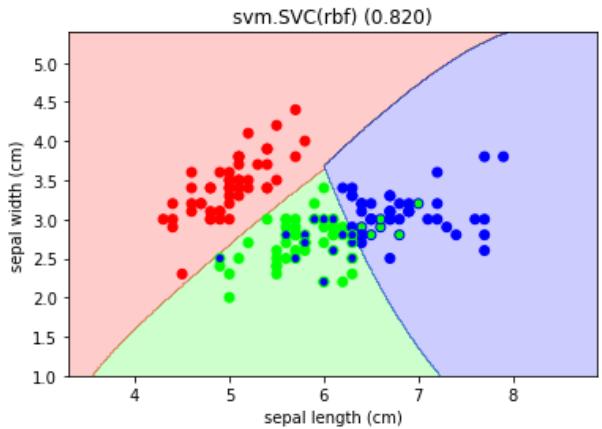
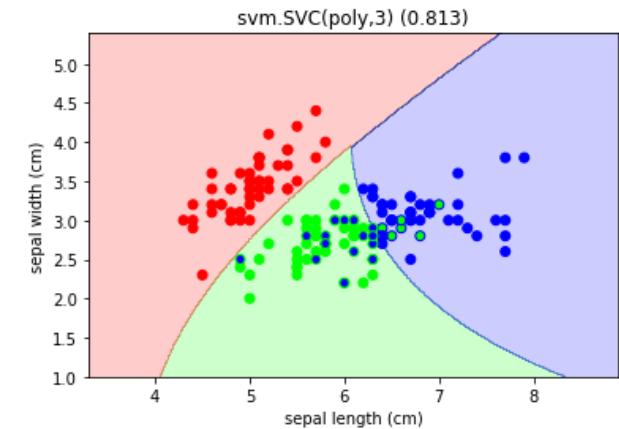
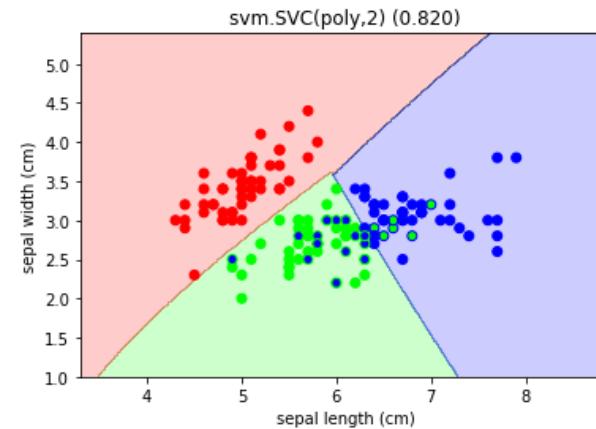
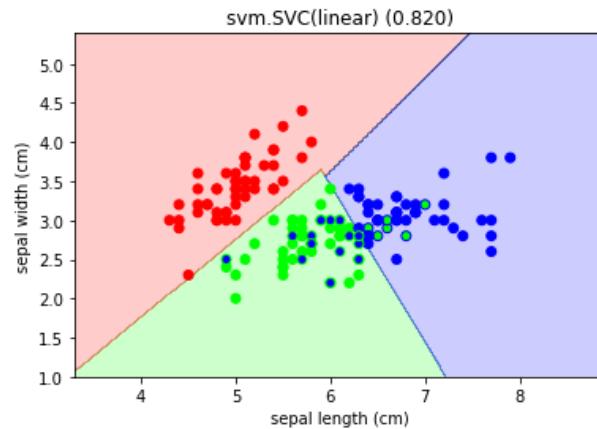
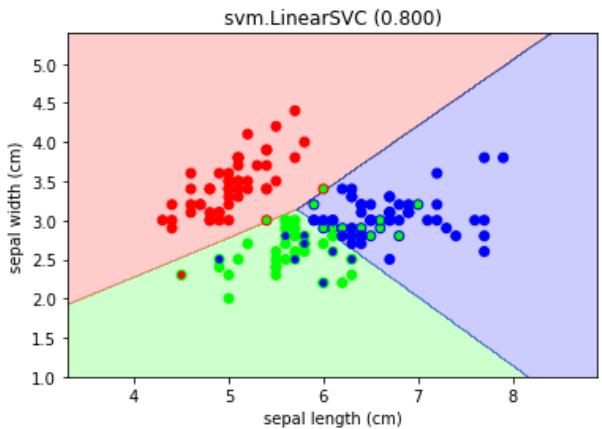


- Advantages
 - Effective in high-dimensional spaces
 - Still effective in cases where # of dimensions > # of samples
 - Memory-efficient because it uses a subset of data (called support vectors) in training
 - Customizable by specifying kernel functions
 - Disadvantages
 - Does not directly provide probabilistic estimates
 - Often fails in highly noisy data and large-scale data

Classification

- **Support vector machine (SVM)** [\[scikit-learn\]](#) [\[API\]](#)

- Example) SVM classifiers with various kernels (1/3)



▪ Support vector machine (SVM) [scikit-learn] [API]

- Example) SVM classifiers with various kernels (2/3)

```
import numpy as np
import matplotlib.pyplot as plt
from sklearn import (datasets, svm, metrics)
from matplotlib.colors import ListedColormap

# Load a dataset partially
iris = datasets.load_iris()
iris.data = iris.data[:,0:2]
iris.feature_names = iris.feature_names[0:2]
iris.color = np.array([(1, 0, 0), (0, 1, 0), (0, 0, 1)])

# Instantiate classification models
models = [
    {'name': 'svm.LinearSVC',
     'obj': svm.LinearSVC()},
    {'name': 'svm.SVC(linear)',
     'obj': svm.SVC(kernel='linear')},
    {'name': 'svm.SVC(poly,2)',
     'obj': svm.SVC(kernel='poly', degree=2)},
    {'name': 'svm.SVC(poly,3)',
     'obj': svm.SVC(kernel='poly')},
    {'name': 'svm.SVC(poly,4)',
     'obj': svm.SVC(kernel='poly', degree=4)},
    {'name': 'svm.SVC(rbf)',
     'obj': svm.SVC(kernel='rbf')},
    {'name': 'svm.SVC(rbf,$\gamma=1)',
     'obj': svm.SVC(kernel='rbf', gamma=1)},
    {'name': 'svm.SVC(rbf,$\gamma=4)',
     'obj': svm.SVC(kernel='rbf', gamma=4)},
    {'name': 'svm.SVC(rbf,$\gamma=16)',
     'obj': svm.SVC(kernel='rbf', gamma=16)},
    {'name': 'svm.SVC(rbf,$\gamma=64)',
     'obj': svm.SVC(kernel='rbf', gamma=64)},
    {'name': 'svm.SVC(sigmoid)',
     'obj': svm.SVC(kernel='sigmoid')},
]
```

- **[Support vector machine \(SVM\)](#)** [\[scikit-learn\]](#) [\[API\]](#)

- Example) SVM classifiers with various kernels (2/3)

```
x_min, x_max = iris.data[:, 0].min() - 1, iris.data[:, 0].max() + 1
y_min, y_max = iris.data[:, 1].min() - 1, iris.data[:, 1].max() + 1
xx, yy = np.meshgrid(np.arange(x_min, x_max, 0.01), np.arange(y_min, y_max, 0.01))
xy = np.vstack((xx.flatten(), yy.flatten())).T

for model in models:
    # Train a model
    model['obj'].fit(iris.data, iris.target)

    # Test the model
    predict = model['obj'].predict(iris.data)
    model['acc'] = metrics.balanced_accuracy_score(iris.target, predict)

    # Visualize training results (decision boundaries)
    zz = model['obj'].predict(xy)
    plt.figure()
    plt.contourf(xx, yy, zz.reshape(xx.shape), cmap=ListedColormap(iris.color), alpha=0.2)

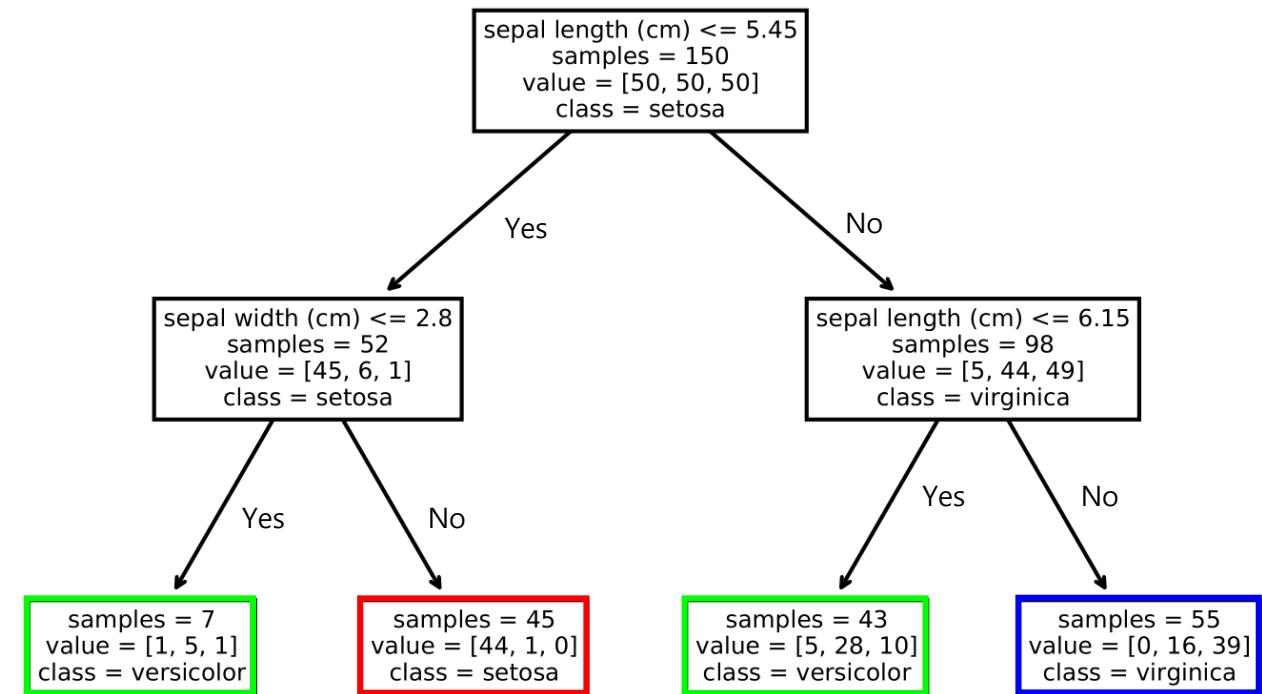
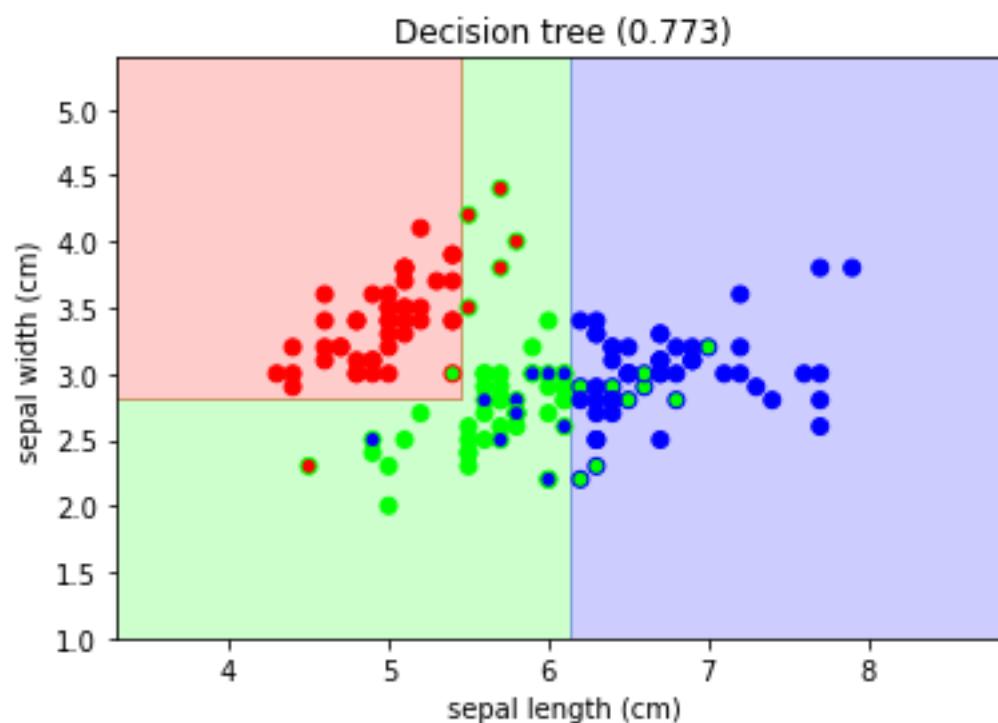
    # Visualize testing results
    plt.title(model['name'] + f' ({model["acc"]:.3f})')
    plt.scatter(iris.data[:,0], iris.data[:,1], c=iris.color[iris.target], edgecolors=iris.color[predict])
    plt.xlabel(iris.feature_names[0])
    plt.ylabel(iris.feature_names[1])

plt.show()
```

Classification

- **Decision tree** [scikit-learn] [API]

- A tree-like model for decision with rules and outcomes (~ a if-then-else flowchart)
- Example) Decision tree classifier training and visualization (1/2)



```

import numpy as np
import matplotlib.pyplot as plt
from sklearn import (datasets, tree, metrics)
from matplotlib.colors import ListedColormap

# Load a dataset partially
iris = datasets.load_iris()
iris.data = iris.data[:,0:2]
iris.feature_names = iris.feature_names[0:2]
iris.color = np.array([(1, 0, 0), (0, 1, 0), (0, 0, 1)])

# Train a model
model = tree.DecisionTreeClassifier(max_depth=2) # Try deeper
model.fit(iris.data, iris.target)

# Visualize training results (decision boundaries)
x_min, x_max = iris.data[:, 0].min() - 1, iris.data[:, 0].max() + 1
y_min, y_max = iris.data[:, 1].min() - 1, iris.data[:, 1].max() + 1
xx, yy = np.meshgrid(np.arange(x_min, x_max, 0.01), np.arange(y_min, y_max, 0.01))
xy = np.vstack((xx.flatten(), yy.flatten())).T
zz = model.predict(xy)

# Test the model
predict = model.predict(iris.data)
accuracy = metrics.balanced_accuracy_score(iris.target, predict)

# Visualize testing results
plt.figure()
plt.title(f'Decision tree ({accuracy:.3f})')
plt.contourf(xx, yy, zz.reshape(xx.shape), cmap=ListedColormap(iris.color), alpha=0.2)
plt.scatter(iris.data[:,0], iris.data[:,1], c=iris.color[iris.target], edgecolors=iris.color[predict])
plt.xlabel(iris.feature_names[0])
plt.ylabel(iris.feature_names[1])

# Visualize training results (the trained tree)
plt.figure()
tree.plot_tree(model, feature_names=iris.feature_names, class_names=iris.target_names, impurity=False)
plt.show()

```

Classification

- **Decision tree** [\[scikit-learn\]](#) [\[API\]](#)

- A [tree](#)-like model for decision with rules and outcomes (~ a if-then-else [flowchart](#))
- Advantages (because it is a [white box](#) model)
 - Simple to understand, interpret, and visualize
 - Easy to modify the trained tree
 - Easy to be combined with other decision methods
- Disadvantages
 - Unstable and sensitive
 - A small change in the data can lead a large change in the structure of the optimal decision tree.
 - Prone to fall in overfitting
 - Discontinuous prediction
 - Relatively inaccurate
 - This disadvantage was improved by [random forest](#), a ensemble of decision trees.

Classification

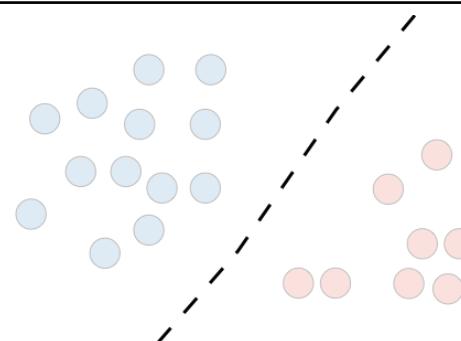
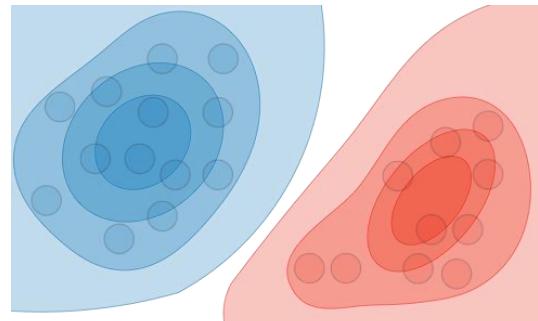
- **Naïve Bayes classifiers** [\[scikit-learn\]](#) [\[API\]](#)

- A classifier based on Bayes' theorem under the Naïve assumption

$$P(y|x_1, \dots, x_n) = \frac{P(y) P(x_1, \dots, x_n|y)}{P(x_1, \dots, x_n)} = \frac{P(y) \prod_{i=1}^n p(x_i|y)}{P(x_1, \dots, x_n)}$$

(posterior, likelihood, prior, and marginalization; y : class, x : data)

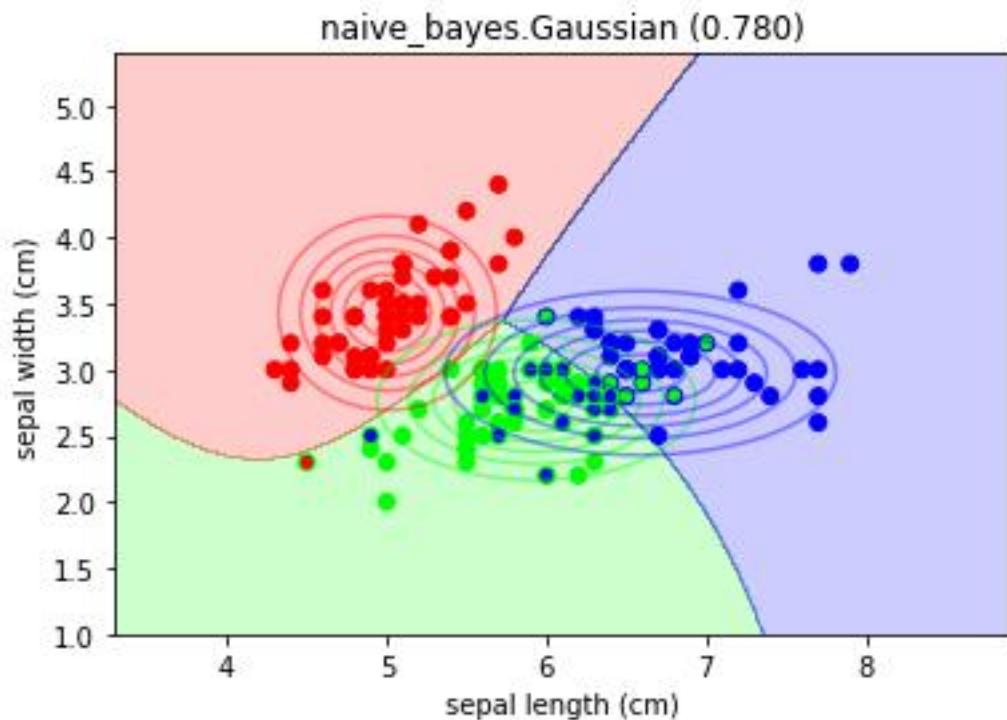
- Gaussian Naïve Bayes classifier if we assume $p(x|y) = \frac{1}{\sigma_y \sqrt{2\pi}} \exp\left(-\frac{1}{2}\left(\frac{x - \mu_y}{\sigma_y}\right)^2\right)$

	Discriminative model	Generative model
Goal	Directly estimate $P(y x)$	Estimate $P(x y)$, then deduce $P(y x)$
Trained	Decision boundaries	Probability distributions of the data
Illustration		
Examples	SVM, decision tree, regression, NN	Naïve Bayes , GMM, VAE, GAN

Classification

- **Naïve Bayes classifiers** [\[scikit-learn\]](#) [\[API\]](#)

- Example) Naïve Bayes classifier training and visualization (1/3)



```
## Class 0
* Trained prior      = 0.333
* Manual prior       = 0.333
* Trained mean       = [5.006 3.428]
* Manual mean        = [5.006 3.428]
* Trained variance   = [0.122 0.141]
* Manual variance    = [0.122 0.141]

## Class 1
* Trained prior      = 0.333
* Manual prior       = 0.333
* Trained mean       = [5.936 2.77 ]
* Manual mean        = [5.936 2.77 ]
* Trained variance   = [0.261 0.097]
* Manual variance    = [0.261 0.097]

## Class 2
* Trained prior      = 0.333
* Manual prior       = 0.333
* Trained mean       = [6.588 2.974]
* Manual mean        = [6.588 2.974]
* Trained variance   = [0.396 0.102]
* Manual variance    = [0.396 0.102]
```

- [Naïve Bayes classifiers](#) [scikit-learn] [API]

- Example) Naïve Bayes classifier training and visualization (2/3)

```
import numpy as np
import matplotlib.pyplot as plt
from sklearn import (datasets, naive_bayes, metrics)
from matplotlib.colors import ListedColormap
from scipy.stats import multivariate_normal

# Load a dataset partially
iris = datasets.load_iris()
iris.data = iris.data[:,0:2]
iris.feature_names = iris.feature_names[0:2]
iris.color = np.array([(1, 0, 0), (0, 1, 0), (0, 0, 1)])

# Train a model
model = naive_bayes.GaussianNB()
model.fit(iris.data, iris.target)
#model.class_prior_ = [0.1, 0.6, 0.3] # Try this to give manual prior

# Validate training
for c in range(len(model.classes_)):
    data = iris.data[iris.target == c,:]
    print(f'## Class {c}')
    print(' * Trained prior    = ' + np.array2string(model.class_prior_[c], precision=3))
    print(' * Manual prior     = ' + '{:.3f}'.format(len(data) / len(iris.data)))
    print(' * Trained mean     = ' + np.array2string(model.theta_[c], precision=3))
    print(' * Manual mean      = ' + np.array2string(np.mean(data, axis=0), precision=3))
    print(' * Trained variance = ' + np.array2string(model.sigma_[c], precision=3))
    print(' * Manual variance  = ' + np.array2string(np.var(data, axis=0), precision=3))
```

- [Naïve Bayes classifiers](#) [scikit-learn] [API]

- Example) Naïve Bayes classifier training and visualization (3/3)

```
# Visualize training results (decision boundaries)
x_min, x_max = iris.data[:, 0].min() - 1, iris.data[:, 0].max() + 1
y_min, y_max = iris.data[:, 1].min() - 1, iris.data[:, 1].max() + 1
xx, yy = np.meshgrid(np.arange(x_min, x_max, 0.01), np.arange(y_min, y_max, 0.01))
xy = np.vstack((xx.flatten(), yy.flatten())).T
zz = model.predict(xy)
plt.contourf(xx, yy, zz.reshape(xx.shape), cmap=ListedColormap(iris.color), alpha=0.2)

# Visualize training results (trained Gaussians)
for c in range(len(model.classes_)):
    likelihood = multivariate_normal(model.theta_[c], np.diag(model.sigma_[c]))
    zz = model.class_prior_[c] * likelihood.pdf(xy)
    plt.contour(xx, yy, zz.reshape(xx.shape), cmap=ListedColormap(iris.color[c]), alpha=0.4)

# Test the model
predict = model.predict(iris.data)
accuracy = metrics.balanced_accuracy_score(iris.target, predict)

# Visualize testing results
plt.title(f'naive_bayes.Gaussian ({accuracy:.3f})')
plt.scatter(iris.data[:,0], iris.data[:,1], c=iris.color[iris.target], edgecolors=iris.color[predict])
plt.xlabel(iris.feature_names[0])
plt.ylabel(iris.feature_names[1])
plt.show()
```

Classification

■ Example) More classifiers

```
# Instantiate classification models
models = [
    {'name': 'linear_model.SGD',
     'obj': linear_model.SGDClassifier()},
    {'name': 'naive_bayes.Gaussian',
     'obj': naive_bayes.GaussianNB()},
    {'name': 'neural_network.MLP',
     'obj': neural_network.MLPClassifier()},
    {'name': 'neighbors.KNN',
     'obj': neighbors.KNeighborsClassifier()},

    {'name': 'svm.LinearSVC',
     'obj': svm.LinearSVC()},
    {'name': 'svm.SVC(linear)',
     'obj': svm.SVC(kernel='linear')},
    {'name': 'svm.SVC(poly,2)',
     'obj': svm.SVC(kernel='poly', degree=2)},
    {'name': 'svm.SVC(poly,3)',
     'obj': svm.SVC(kernel='poly')},
    {'name': 'svm.SVC(poly,4)',
     'obj': svm.SVC(kernel='poly', degree=4)},
    {'name': 'svm.SVC(rbf)',
     'obj': svm.SVC(kernel='rbf')},
    {'name': 'svm.SVC(rbf,$\gamma=1)',
     'obj': svm.SVC(kernel='rbf', gamma=1)},
    {'name': 'svm.SVC(rbf,$\gamma=4)',
     'obj': svm.SVC(kernel='rbf', gamma=4)},
    {'name': 'svm.SVC(rbf,$\gamma=16)',
     'obj': svm.SVC(kernel='rbf', gamma=16)},
    {'name': 'svm.SVC(rbf,$\gamma=64)',
     'obj': svm.SVC(kernel='rbf', gamma=64)},
    {'name': 'svm.SVC(sigmoid)',
     'obj': svm.SVC(kernel='sigmoid')},

    {'name': 'tree.DecisionTree(2)',
     'obj': tree.DecisionTreeClassifier(max_depth=2)},
    {'name': 'tree.DecisionTree(4)',
     'obj': tree.DecisionTreeClassifier(max_depth=4)},
    {'name': 'tree.DecisionTree(N)',
     'obj': tree.DecisionTreeClassifier()},
    {'name': 'tree.ExtraTree',
     'obj': tree.ExtraTreeClassifier()},

    {'name': 'ensemble.RandomForest(10)',
     'obj': ensemble.RandomForestClassifier(n_estimators=10)},
    {'name': 'ensemble.RandomForest(100)',
     'obj': ensemble.RandomForestClassifier()},
    {'name': 'ensemble.ExtraTrees(10)',
     'obj': ensemble.ExtraTreesClassifier(n_estimators=10)},
    {'name': 'ensemble.ExtraTrees(100)',
     'obj': ensemble.ExtraTreesClassifier()},
    {'name': 'ensemble.AdaBoost(DTree)',
     'obj': ensemble.AdaBoostClassifier(tree.DecisionTreeClassifier())},
```

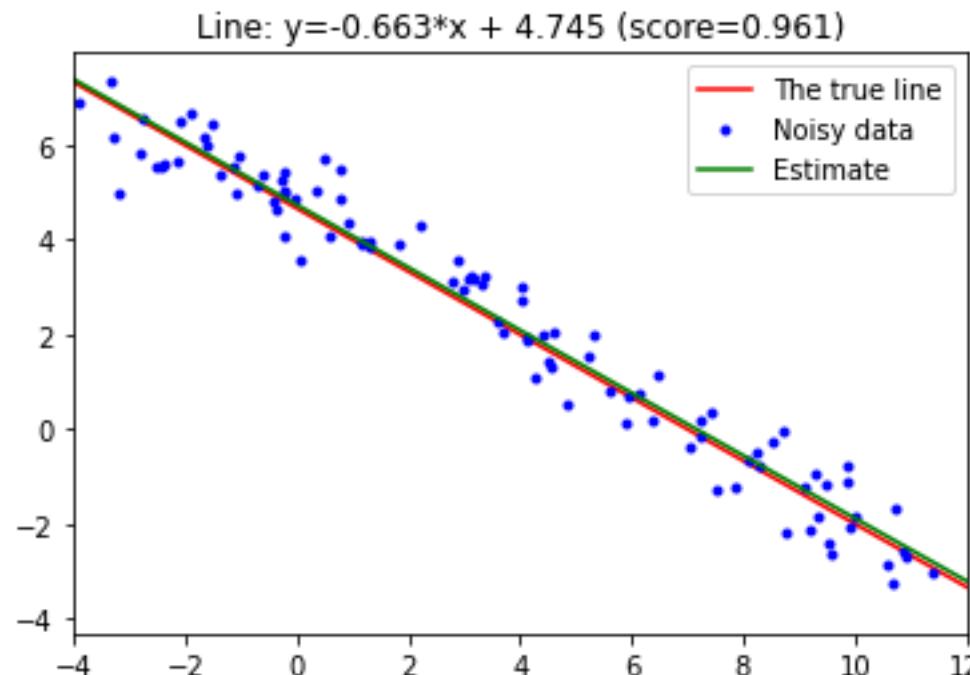
Regression

- [Linear regression](#) [\[scikit-learn\]](#) [\[API\]](#)

- A linear modeling for the relationship between a scalar response (y) and one or more observed variables (x_i)

$$y = \mathbf{b} + \mathbf{a}_1 x_1 + \cdots + \mathbf{a}_n x_n$$

- e.g. 2D line fitting: $y = \mathbf{b} + \mathbf{a}x$
 - Example) Line fitting with scikit-learn (1/2)



```

import numpy as np
import matplotlib.pyplot as plt
from sklearn import (linear_model, metrics)

true_line = lambda x: -2/3*x + 14/3
data_range = np.array([-4, 12])
data_num = 100
noise_std = 0.5

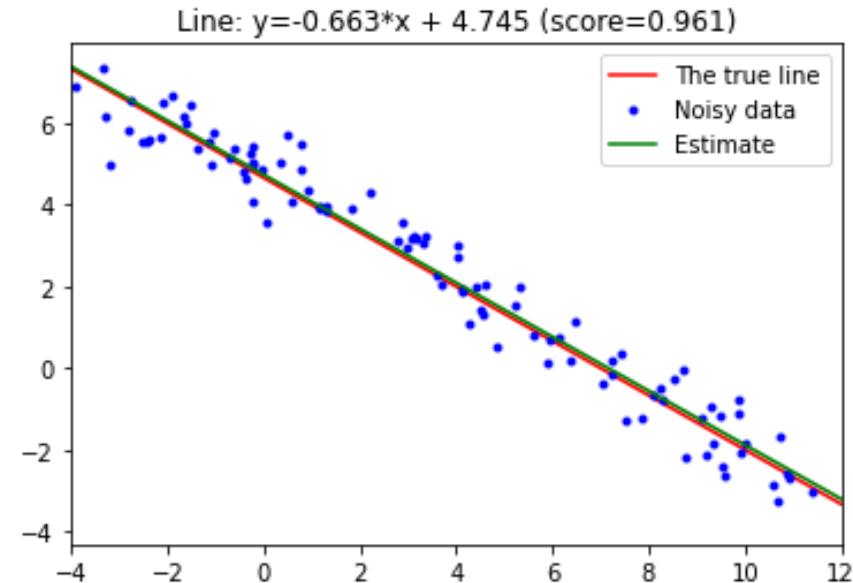
# Generate the true data
x = np.random.uniform(data_range[0], data_range[1], size=data_num)
y = true_line(x) #  $y = -\frac{2}{3}x + \frac{14}{3}$ 

# Add Gaussian noise
xn = x + np.random.normal(scale=noise_std, size=x.shape)
yn = y + np.random.normal(scale=noise_std, size=y.shape)

# Train a model
model = linear_model.LinearRegression()
model.fit(xn.reshape(-1, 1), yn)
score = model.score(xn.reshape(-1, 1), yn)

# Plot the data and result
plt.title(f'Line: y={model.coef_[0]:.3f}*x + {model.intercept_:.3f} (score={score:.3f})')
plt.plot(data_range, true_line(data_range), 'r-', label='The true line')
plt.plot(xn, yn, 'b.', label='Noisy data')
plt.plot(data_range, model.coef_[0]*data_range + model.intercept_, 'g-', label='Estimate')
plt.xlim(data_range)
plt.legend()
plt.show()

```



Regression

- **Support vector machine regression (SVR)** [\[scikit-learn\]](#) [\[API\]](#)

- Example) Final exam score prediction with SVR (1/2)

- The given data (file: data/class_score_en.csv)

```
# midterm (max 125), final (max 100)
```

113, 86

104, 83

110, 78

101, 79

101, 77

103, 76

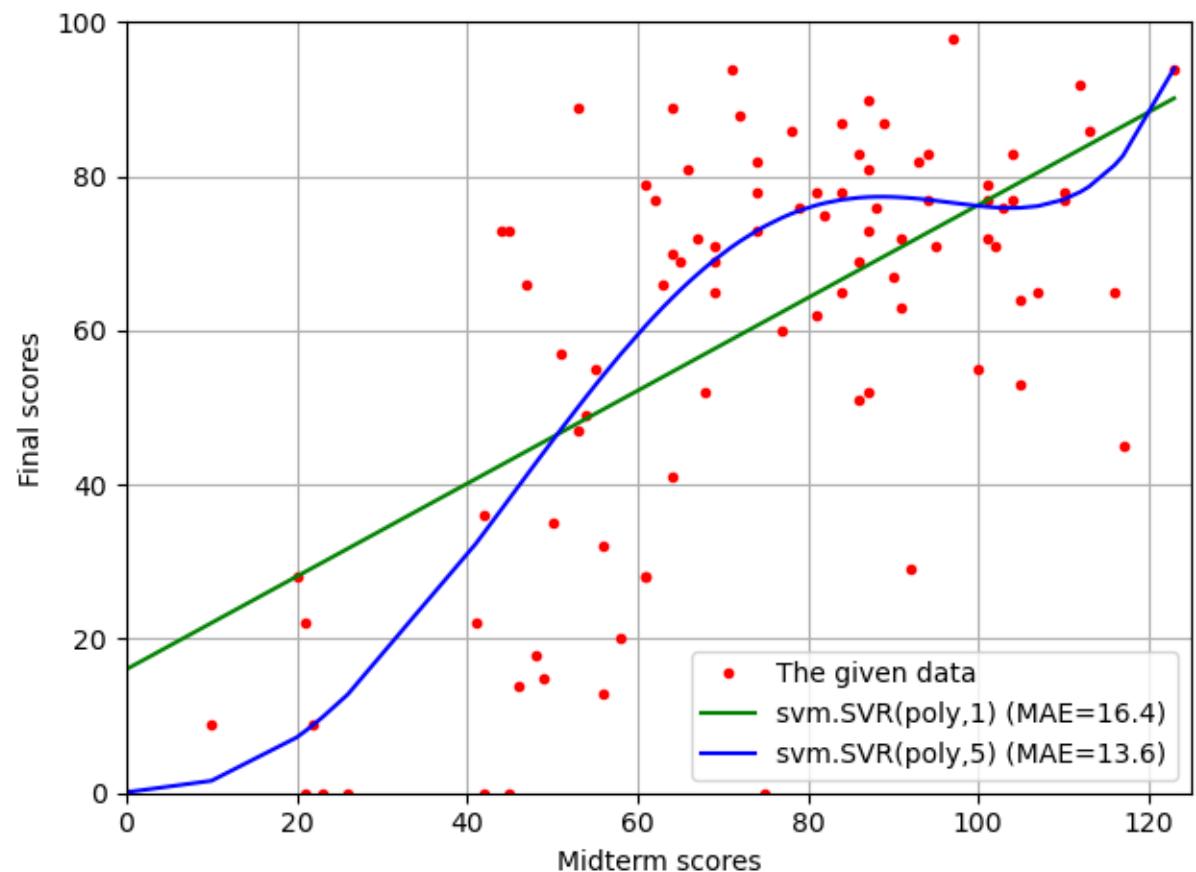
71, 94

102, 71

88, 76

101, 72

... .



```

import numpy as np
import matplotlib.pyplot as plt
from sklearn import svm

midterm_range = np.array([0, 125])
final_range = np.array([0, 100])

# Load score data
class_kr = np.loadtxt('data/class_score_kr.csv', delimiter=',')
class_en = np.loadtxt('data/class_score_en.csv', delimiter=',')
data = np.vstack((class_kr, class_en))
x = data[:,0].reshape(-1, 1)
y = data[:,1]

# Instantiate regression models
models = [
    {'name': 'svm.SVR(poly,1)', 'obj': svm.SVR(kernel='poly', degree=1, coef0=1), 'color': 'g'},
    {'name': 'svm.SVR(poly,5)', 'obj': svm.SVR(kernel='poly', degree=5, coef0=1), 'color': 'b'},
]

```

Prepare for plotting

```

plt.figure()
plt.plot(data[:,0], data[:,1], 'r.', label='The given data')
idx_sort = np.argsort(data[:,0])

```

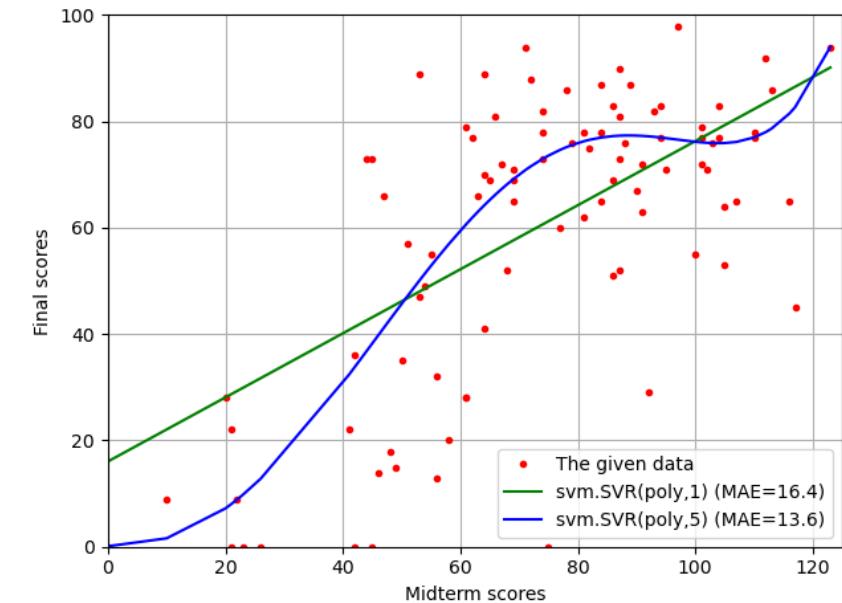
for model in models:

```

    # Train a model
    model['obj'].fit(x, y)

    # Visualize regression results (the estimated line)
    y_pred = model['obj'].predict(x)
    model['mae'] = np.mean(np.abs(y_pred - y))
    plt.plot(x[idx_sort,0], y_pred[idx_sort], label=f'{model["name"]} (MAE={model["mae"]:.1f})', color=model['color'])

```



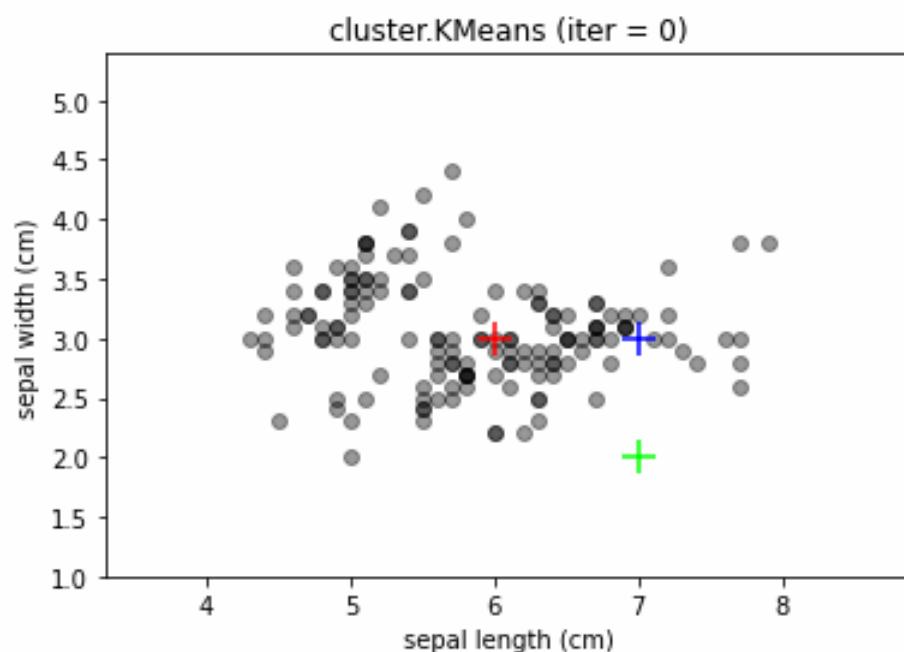
Note) Mean Absolute Error (MAE)

$$\text{MAE}(Y, \hat{Y}) = \frac{1}{N} \sum_{i=1}^N |\hat{y}_i - y_i|$$

Clustering

- **k-means clustering** [\[scikit-learn\]](#) [\[API\]](#)

- k-means algorithm moves centroids to minimize the within-cluster sum of squares (WCSS; a.k.a. variance)
 - Initialization: Randomly select the initial centroids
 - Iterative update: Recalculate each centroid as the mean of its assigned data points
- Example) k-means clustering with Iris flower dataset



```

import numpy as np
import matplotlib.pyplot as plt
from sklearn import (datasets, cluster)
from matplotlib.colors import ListedColormap

# Load a dataset partially
iris = datasets.load_iris()
iris.data = iris.data[:,0:2] # Try [ :,2:4]
iris.feature_names = iris.feature_names[0:2] # Try [ :,2:4]
iris.color = np.array([(1, 0, 0), (0, 1, 0), (0, 0, 1)])

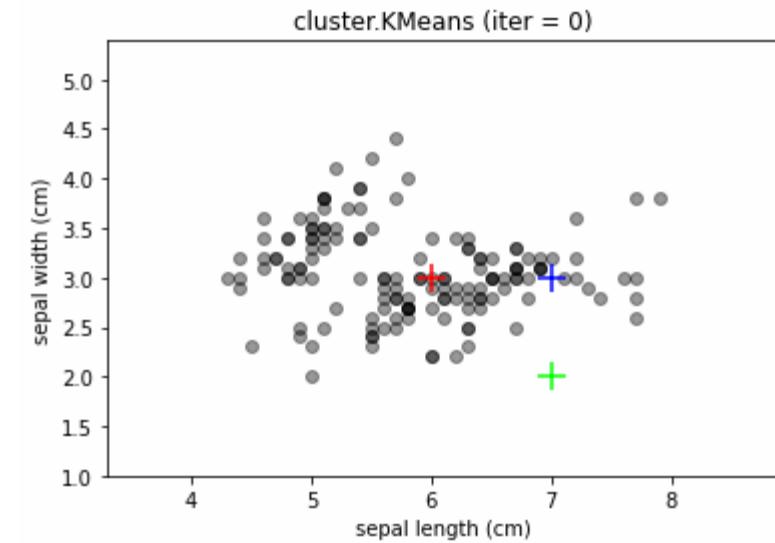
# Train a model
model = cluster.KMeans(n_clusters=3)
model.fit(iris.data)

# Visualize training results (decision boundaries)
x_min, x_max = iris.data[:, 0].min() - 1, iris.data[:, 0].max() + 1
y_min, y_max = iris.data[:, 1].min() - 1, iris.data[:, 1].max() + 1
xx, yy = np.meshgrid(np.arange(x_min, x_max, 0.01), np.arange(y_min, y_max, 0.01))
xy = np.vstack((xx.flatten(), yy.flatten())).T
zz = model.predict(xy)
plt.contourf(xx, yy, zz.reshape(xx.shape), cmap=ListedColormap(iris.color), alpha=0.2)

# Visualize testing results
plt.title('cluster.KMeans')
plt.scatter(iris.data[:,0], iris.data[:,1], c=iris.color[iris.target])
plt.xlabel(iris.feature_names[0])
plt.ylabel(iris.feature_names[1])

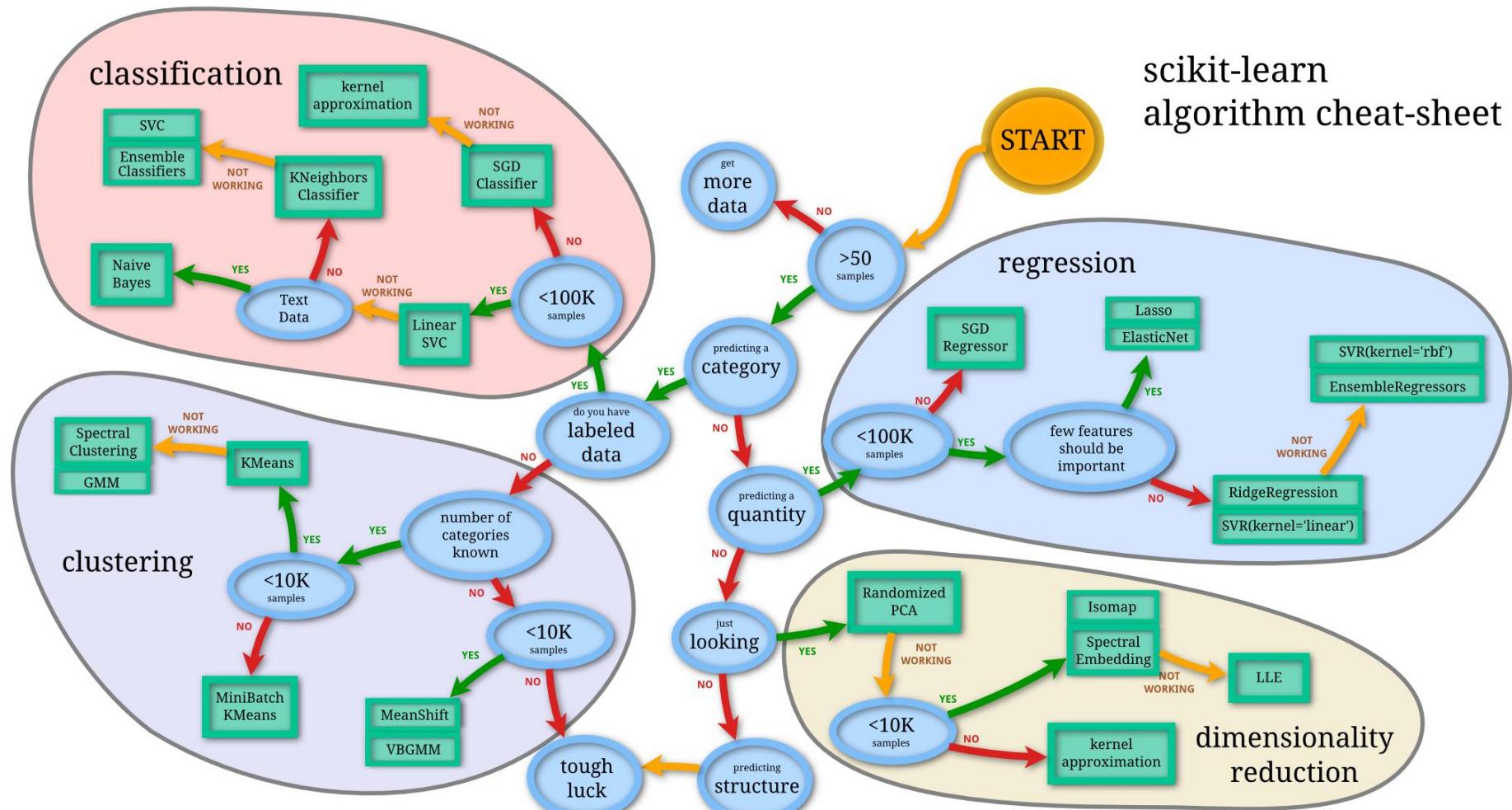
# Visualize training results (mean values)
for c in range(model.n_clusters):
    plt.scatter(*model.cluster_centers_[c], marker='+', s=200, color='k')
plt.show()

```



Machine Learning FAQ

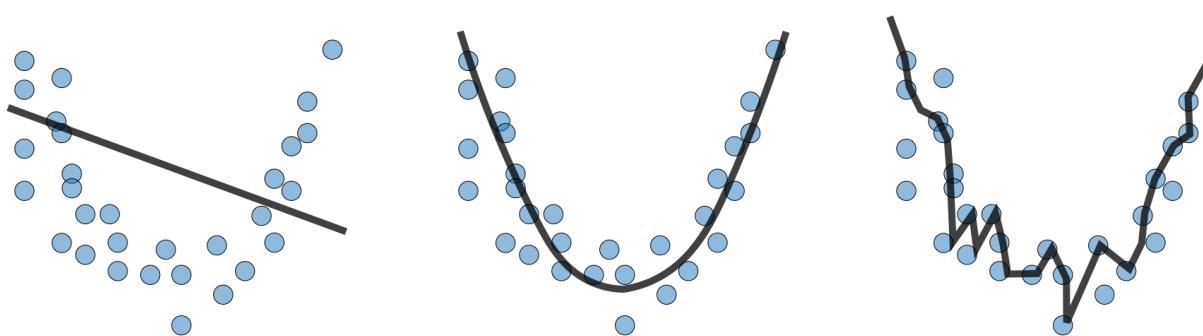
- Q) How to select a good ML algorithm or model?
- A) Mostly deep learning (if enough data are available), but not always



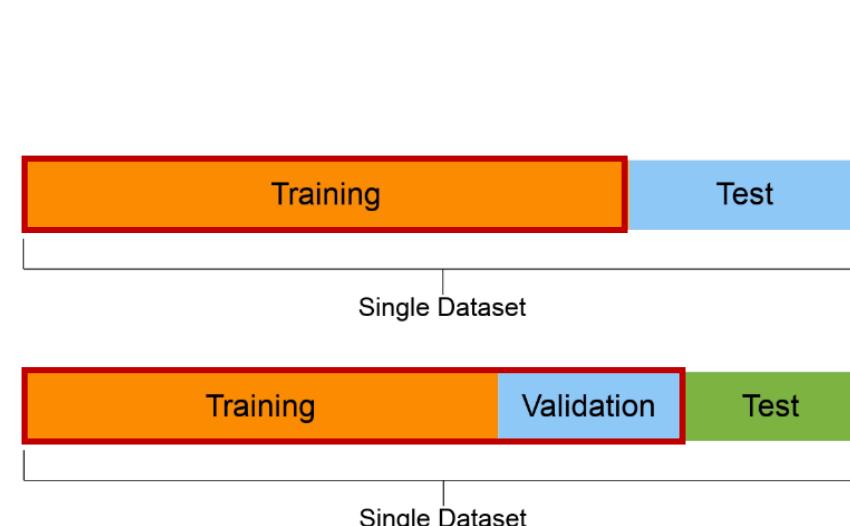
Machine Learning FAQ

- **Q) How to achieve a good result (good training)?**
- **A) More trials (more data/computing power), but your intuition and experience are important.**

- Good hyperparameter values?
 - [Grid search](#) (~ try all combinations, often on a log-scale) or your intuition and experience
- Enough model complexity? Enough training?
 - Observing test results: [Underfitting](#) or [overfitting](#)



- [Training, validation, and test data separation](#)
 - Note) **Validation data:** Test data for intermediate trained models
- Enough data?
 - More data are always good if possible.
 - Please think about the dimension of data and the number of model parameters.

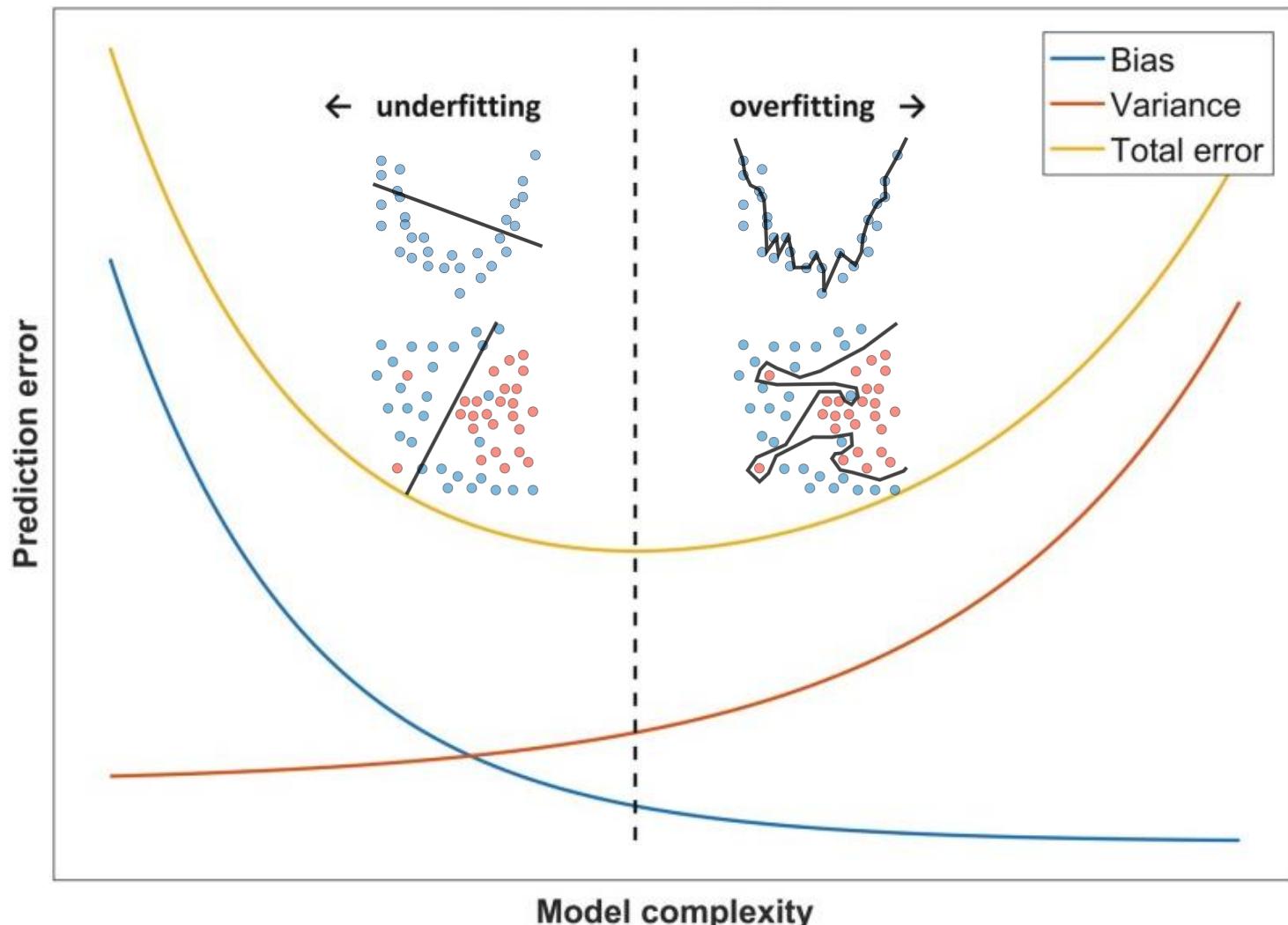


Underfitting vs. Overfitting

	Underfitting	Just fit	Overfitting
Symptoms	<ul style="list-style-type: none"> ▪ High training error ▪ Training error close to test error ▪ High bias 	<ul style="list-style-type: none"> ▪ Training error slightly lower than test error 	<ul style="list-style-type: none"> ▪ Very low training error ▪ Training error much lower than test error ▪ High variance
Regression Illustration			
Classification Illustration			
Learning Curve			
Possible Remedies	<ul style="list-style-type: none"> ▪ Increase model complexity ▪ Add more features ▪ Train longer 		<ul style="list-style-type: none"> ▪ Simplify your model ▪ Add regularization ▪ Get more data

Underfitting vs. Overfitting

- Bias-variance tradeoff



Training and Test Data Separation

- **Holdout method**: A simple training and test data separation

- Holdout method separates training and test data in the given ratio (e.g. 7:3 or 9:1) and does not shuffle them.
- Holdout method has danger of **overfitting to the fixed test data**.
- Example) Holdout validation with scikit-learn

```
from sklearn import (datasets, svm, model_selection, metrics)

# Load a dataset
iris = datasets.load_iris()
iris.data = iris.data[:,0:2]
iris.feature_names = iris.feature_names[0:2]
X_train, X_test, y_train, y_test = model_selection.train_test_split(iris.data, iris.target, test_size=0.3)

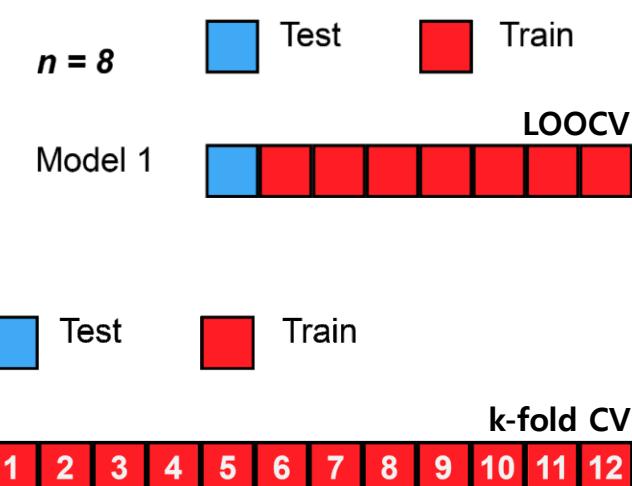
# Train a model
model = svm.SVC()
model.fit(X_train, y_train)

# Evaluate the model
acc_train = metrics.balanced_accuracy_score(y_train, model.predict(X_train))
acc_test = metrics.balanced_accuracy_score(y_test, model.predict(X_test))
print(f'* Accuracy @ training data: {acc_train:.3f}')
print(f'* Accuracy @ test data: {acc_test:.3f}')
```

Training and Test Data Separation

▪ Cross-validation (a.k.a. rotation estimation, out-of-sample testing)

- Cross-validation is a model validation technique to assess how the trained model will generalize to an independent data set (e.g. unseen dataset from the real world).
 - It *was* common for academic researches (with *small-size* datasets).
 - It utilizes the whole data more effectively for training and testing a model (compared to holdout method).
- Exhaustive cross-validation → Usually not feasible
 - **Leave-p-out cross-validation (LpOCV)**
 - Training $n - p$ data and test p data for *all possible combinations*
 - C_p^n times of trainings (e.g. $C_{30}^{100} \approx 3 \times 10^{25}$)
 - **Leave-one-out cross-validation (LOOCV)**
 - Training $n - 1$ data and test a single datum for n *possible combinations*
 - n times of trainings ($p = 1$)
- Non-exhaustive cross-validation
 - **k-fold cross-validation**
 - LOOCV on k equal sized subsamples: k times of trainings



Machine Learning FAQ

▪ Cross-validation

- Example) k-fold cross-validation with scikit-learn

```
import numpy as np
from sklearn import (datasets, svm, model_selection)

# Load a dataset
iris = datasets.load_iris()
iris.data = iris.data[:,0:2]
iris.feature_names = iris.feature_names[0:2]

# Train a model
model = svm.SVC()
cv_results = model_selection.cross_validate(model, iris.data, iris.target, cv=5, return_train_score=True)

# Evaluate the model
acc_train = np.mean(cv_results['train_score'])
acc_test = np.mean(cv_results['test_score'])
print(f'* Accuracy @ training data: {acc_train:.3f}')
print(f'* Accuracy @ test data: {acc_test:.3f}')
```

Summary

- **Machine Learning**

- In short, data-driven approaches, inductive approaches
- Problem formulation: [Classification](#), [regression](#), [clustering](#), ...

- [**scikit-learn**](#)

- Usage (3 steps): Instantiation → training (fit) → inference/testing (predict)

- **Classification**

- Performance measures
 - Accuracy
 - [Confusion matrix](#) (balanced accuracy, [precision/recall](#), F1-measure)
 - [ROC curve](#)
- [**Support vector machine \(SVM\)**](#) [\[scikit-learn\]](#) [\[API\]](#)
- [**Decision tree**](#) [\[scikit-learn\]](#) [\[API\]](#)
- [**Naïve Bayes classifiers**](#) [\[scikit-learn\]](#) [\[API\]](#)
- Example) Iris flower data classification

Summary

▪ Regression

- [Linear regression](#) [scikit-learn] [API]
- Example) Line fitting with scikit-learn
- [Support vector regression \(SVR\)](#) [scikit-learn] [API]
- Example) Final exam score prediction with SVR

▪ Clustering

- [k-means clustering](#) [scikit-learn] [API]
- Example) Iris flower data clustering

▪ Machine Learning FAQ

- Good algorithm or model?
 - Mostly deep learning, but not always
- Enough model complexity? Enough training?
 - Learning curve
 - [Overfitting](#) vs. [underfitting](#)
 - [Early stopping](#)
 - Data separation: [Train, validation, and test data](#)
 - [Holdout method](#) vs. [Cross-validation](#)