lecture1-introduction

September 15, 2020

1 Lecture 1: Introduction to Machine Learning

1.0.1 Applied Machine Learning

Volodymyr Kuleshov Cornell Tech

2 Welcome to Applied Machine Learning!

Machine learning is one of today's most exciting emerging technologies.

In this course, you will learn what machine learning is, what are the most important techniques in machine learning, and how to apply them to solve problems in the real world.

3 Part 1: What is Machine Learning?

We hear a lot about machine learning (or ML for short) in the news.

But what is it, really?

4 ML in Everyday Life: Search Engines

You use machine learninng every day when you run a search engine query.

5 ML in Everyday Life: Personal Assitants

Machine learning also powers the speech recognition, question answering and other intelligent capabilities of smartphone assistants like Apple Siri.

6 ML in Everyday Life: Spam/Fraud Detection

Machine learning is used in every spam filter, such as in Gmail.

ML systems are also used by credit card companies and banks to automatically detect fraudulent behavior.

7 ML in Everyday Life: Self-Driving Cars

One of the most exciting and cutting-edge uses of machine learning algorithms are in autonomous vehicles.

8 A Definition of Machine Learning

In 1959, Arthur Samuel defined machine learning as follows.

> Machine learning is a field of study that gives computers the ability to learn without being explicitly programmed.

What does "learn" and "explicitly programmed" mean here? Let's look at an example.

9 An Example: Self Driving Cars

A self-driving car system uses dozens of components that include detection of cars, pedestrians, and other objects.

10 Self Driving Cars: A Rule-Based Algorithm

One way to build a detection system is to write down rules.

```
[2]:  # pseudocode example for a rule-based classification system
      object = camera.get_object()
      if object.has_wheels(): # does the object have wheels?
          if len(object.wheels) == 4: return "Car" # four wheels => car
          elif len(object.wheels) == 2:,
              if object.seen_from_back():
                  return "Car" # viewed from back, car has 2 wheels
              else:
                  return "Bicycle" # normally, 2 wheels => bicycle
      return "Unknown" # no wheels? we don't know what it is
```

In practice, it's almost impossible for a human to specify all the edge cases.

11   Self Driving Cars: An ML Approach

The machine learning approach is to teach a computer how to do detection by showing it many examples of different objects.

No manual programming is needed: the computer learns what defines a pedestrian or a car on its own!

12   Revisiting Our Definition of ML

> Machine learning is a field of study that gives computers the ability to learn without being explicitly programmed. (Arthur Samuel, 1959.)

This principle can be applied to countless domains: medical diagnosis, factory automation, machine translation, and many more!

13   Why Machine Learning?

Why is this approach to building software interesting?

- It allows building practical systems for real-world applications that couldn't be solved otherwise.
- Learning is wildly regarded as a key approach towards building general-purpose artificial intelligence systems.
- The science and engineering of machine learning offers insights into human intelligence.

Part 2: Three Approaches to Machine Learning

Machine learning is broadly defined as the science of building software that has the ability to learn without being explicitly programmed.

How might we enable machines to learn? Let's look at a few examples.

14   Supervised Learning

The most common approach to machine learning is supervised learning.

1. First, we collect a dataset of labeled training examples.
2. We train a model to output accurate predictions on this dataset.
3. When the model sees new, similar data, it will also be accurate.
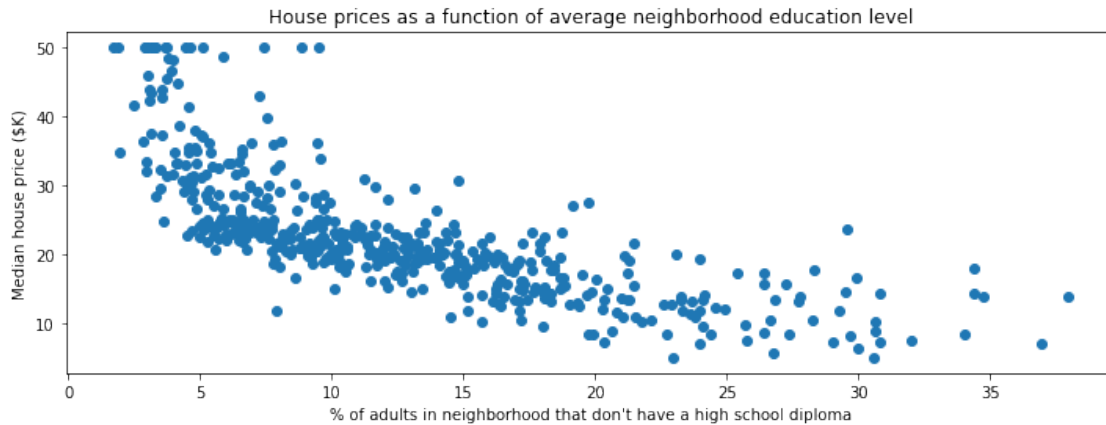
15   A Supervised Learning Dataset

Consider a simple dataset for supervised learning: house prices in Boston. * Each datapoint is a house. * We know its price, neighborhood, size, etc.

```
[13]: # We will load the dataset from the sklearn ML library
      from sklearn import datasets
      boston = datasets.load_boston()
```

We will visualize two variables in this dataset: house price and the education level in the neighbor-
hood.

```
[14]: import matplotlib.pyplot as plt
      plt.rcParams['figure.figsize'] = [12, 4]
      plt.scatter(boston.data[:,12], boston.target)
      plt.ylabel("Median house price ($K)")
      plt.xlabel("% of adults in neighborhood that don't have a high school diploma")
      plt.title("House prices as a function of average neighborhood education level")
```

```
[14]: Text(0.5, 1.0, 'House prices as a function of average neighborhood education
      level')
```


16 A Supervised Learning Algorithm

We can use this dataset of examples to fit a supervised learning model.

- The model maps input x (the education level) to output a y (the house price).
- It learns the mapping from our dataset of examples (x, y).

```
[15]: import numpy as np
      from sklearn.kernel_ridge import KernelRidge

      # Apply a supervised learning algorithm
      model = KernelRidge(alpha=1, kernel='poly')
      model.fit(boston.data[:,[12]], boston.target.flatten())
      predictions = model.predict(np.linspace(2, 35)[:, np.newaxis])
```

```python
# Visualize the results
plt.scatter(boston.data[:,[12]], boston.target, alpha=0.25)
plt.plot(np.linspace(2, 35), predictions, c='red')
plt.ylabel("Median house price ($K)")
plt.xlabel("% of adults in neighborhood that don't have a high school diploma")
plt.title("House prices as a function of average neighborhood education level")
```

[15]: Text(0.5, 1.0, 'House prices as a function of average neighborhood education level')
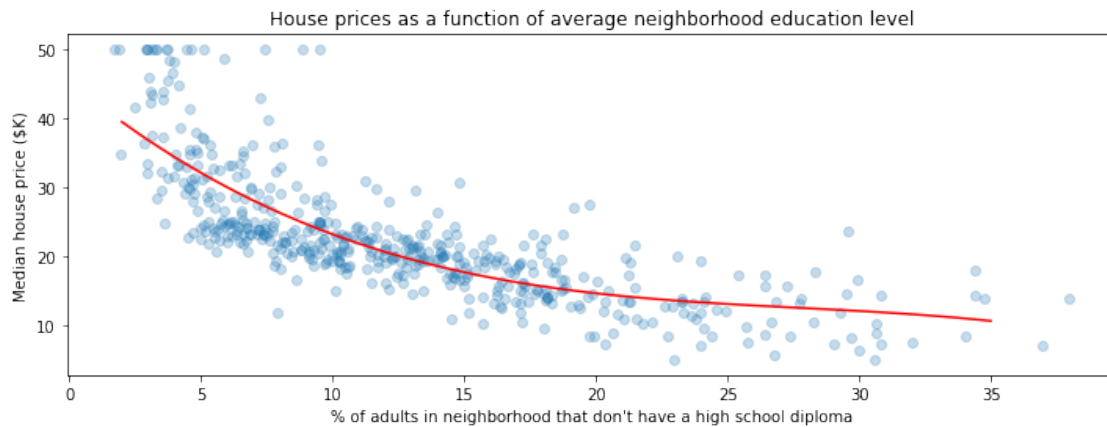
17 Applications of Supervised Learning

Many of the most important applications of machine learning are supervised: * Classifying medical images. * Translating between pairs of languages. * Detecting objects in a self-driving car.

18 Unsupervised Learning

Here, we have a dataset *without* labels. Our goal is to learn something interesting about the structure of the data: * Clusters hidden in the dataset. * Outliers: particularly unusual and/or interesting datapoints. * Useful signal hidden in noise, e.g. human speech over a noisy phone.
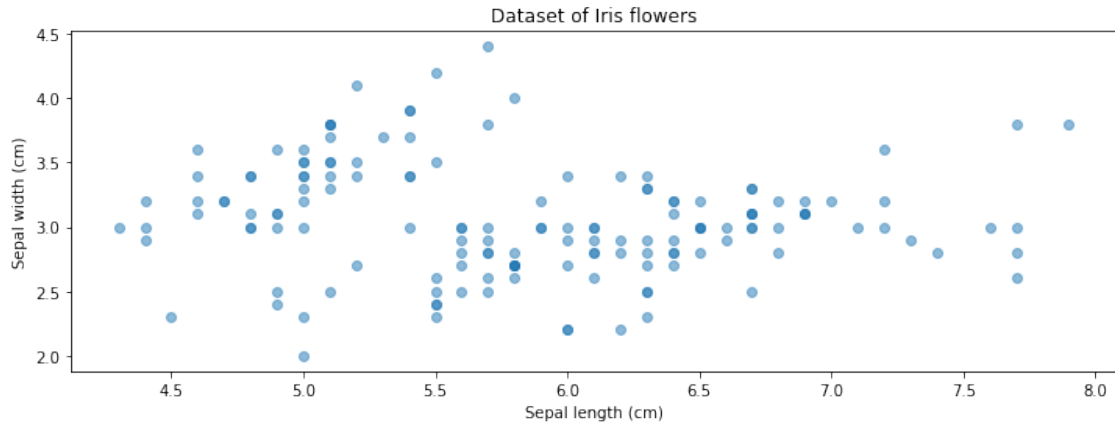
19 An Unsupervised Learning Dataset

Here is a simple example of an unsupervised learning dataset: Iris flowers.

```python
# Load and visualize the Iris flower dataset
iris = datasets.load_iris()
```

```python
plt.scatter(iris.data[:,0], iris.data[:,1], alpha=0.5)
plt.ylabel("Sepal width (cm)")
plt.xlabel("Sepal length (cm)")
plt.title("Dataset of Iris flowers")
```

[20]: Text(0.5, 1.0, 'Dataset of Iris flowers')

20 An Unsupervised Learning Algorithm

We can use this dataset of examples to fit an unsupervised learning model. * The model defines a probability distribution over the inputs. * The probability distribution identifies multiple components (multiple peaks). * The components indicate structure in the data.

```python
[21]: # fit a Gaussian Mixture Model with three components
from sklearn import mixture
model = mixture.GaussianMixture(n_components=3, covariance_type='full')
model.fit(iris.data[:,[0,1]])
```

[21]: GaussianMixture(n_components=3)

```python
[22]: # display learned probabilities as a contour plot
x, y = np.linspace(4.0, 8.0), np.linspace(2.0, 4.5)
X, Y = np.meshgrid(x, y)
Z = -model.score_samples(np.array([X.ravel(), Y.ravel()]).T).reshape(X.shape)
plt.contour(X, Y, Z, levels=np.logspace(0, 10, 1), cmap="gray", alpha=0.5)
plt.scatter(iris.data[:,0], iris.data[:,1], alpha=0.5)
plt.scatter(model.means_[:,0], model.means_[:,1], marker='D', c='r')
plt.ylabel("Sepal width (cm)")
plt.xlabel("Sepal length (cm)")
plt.title("Dataset of Iris flowers")
```

```
plt.legend(['Datapoints', 'Probability peaks'])
```

[22]: <matplotlib.legend.Legend at 0x12293ad68>
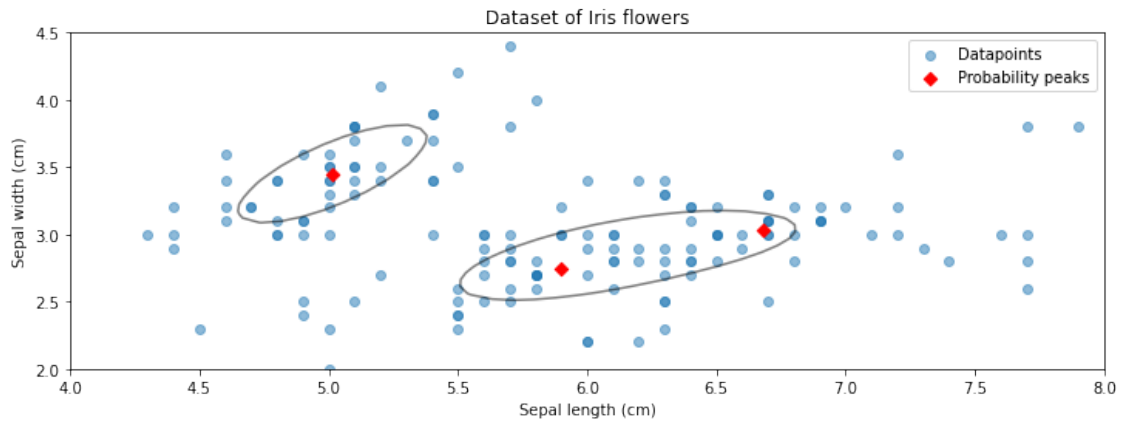
[28]:
```
CS = plt.contour(X, Y, Z, levels=np.logspace(0, 30, 1), cmap='gray', alpha=0.5)
p1 = plt.scatter(iris.data[:,0], iris.data[:,1], alpha=1, c=iris.target,␣
 ↪cmap='Paired')
plt.scatter(model.means_[:,0], model.means_[:,1], marker='D', c='r')
plt.ylabel("Sepal width (cm)")
plt.xlabel("Sepal length (cm)")
plt.title("Dataset of Iris flowers")
plt.legend(handles=p1.legend_elements()[0], labels=['Iris Setosa', 'Iris␣
 ↪Versicolour', 'Iris Virginica'])
```

[28]: <matplotlib.legend.Legend at 0x1229d3668>
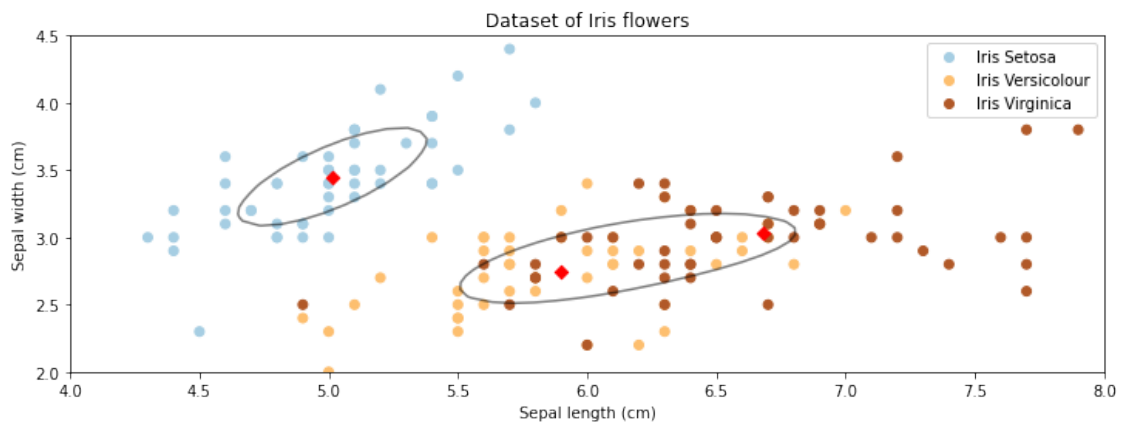
21 Applications of Unsupervised Learning

Unsupervised learning also has numerous applications: * Recommendation systems: suggesting movies on Netflix. * Anomaly detection: identifying factory components that are likely to break soon. * Signal denoising: extracting human speech from a noisy recording.

22 Reinforcement Learning

In reinforcement learning, an agent is interacting with the world over time. We teach it good behavior by providing it with rewards.

Image by Lily Weng

23 Applications of Reinforcement Learning

Applications of reinforcement learning include: * Creating agents that play games such as Chess or Go. * Controling the cooling systems of datacenters to use energy more efficiently. * Designing new drug compounds.

24 Artificial Intelligence and Deep Learning

Machine learning is often discussed in the context of these two fields. * AI is about building machines that exhibit intelligence. * ML enables machines to learn from experience, a useful tool for AI. * Deep learning focuses on a family of learning algorithms loosely inspired by the brain.

Image source.

Part 3: About the Course

Next, let's look at the machine learning topics that we will cover.

25 Teaching Approach

The focus of this course is on applied machine learning. * We will cover a broad toolset of core algorithms from many different subfields of ML. * We will emphasize applications and show how to implement and apply algorithms via examples and exercises.

Why are we following this approach? * Applying machine learning is among the most in demand industry skills right now. * There can be a gap between theory and practice, especially in modern machine learning. * Often, the best way of understanding how an algorithm works is to implement it.

26   What You Will Learn

- What are the core algorithms of ML and how to define them in mathematical language.
- How to implement algorithms from scratch as well as using ML libraries and apply them to problems in computer vision, language processing, medical analysis, and more.
- Why machine learning algorithms work and how to use that knowledge to debug and improve them.

27   Software You Will Use

You will use Python and popular machine learning libraries such as: * `scikit-learn`. It implements most classical machine learning algorithms. * `tensorflow`, `keras`, `pytorch`. Standard libraries for modern deep learning. * `numpy`, `pandas`. Linear algebra and data processing libraries used to implement algorithms from scratch.

28   Executable Course Materials

The core materials for this course (including the slides!) are created using Jupyter notebooks. * We are going to embed an execute code directly in the slides and use that to demonstrate algorithms. * These slides can be downloaded locally and all the code can be reproduced.

```
[29]: import numpy as np
      import matplotlib.pyplot as plt
      from sklearn import datasets, neural_network
      plt.rcParams['figure.figsize'] = [12, 4]
```

We can use these libraries to load a simple datasets of handwritten digits.

```
[7]: # https://scikit-learn.org/stable/auto_examples/classification/
     ↪plot_digits_classification.html
     # load the digits dataset
     digits = datasets.load_digits()

     # The data that we are interested in is made of 8x8 images of digits, let's
     # have a look at the first 4 images.
     _, axes = plt.subplots(1, 4)
     images_and_labels = list(zip(digits.images, digits.target))
     for ax, (image, label) in zip(axes, images_and_labels[:4]):
         ax.set_axis_off()
         ax.imshow(image, cmap=plt.cm.gray_r, interpolation='nearest')
         ax.set_title('Label: %i' % label)
```
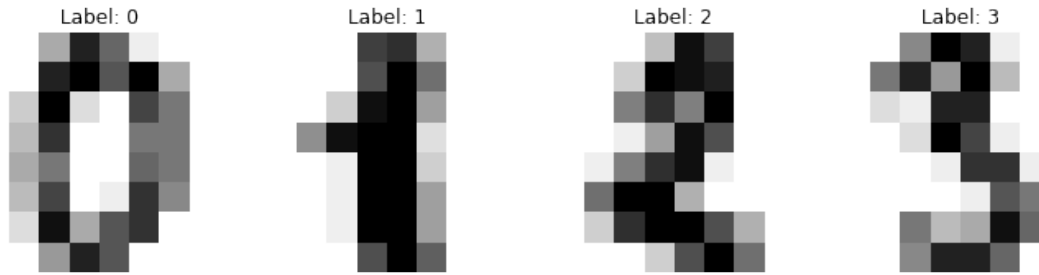
We can now load and train this algorithm inside the slides.

```
[30]: np.random.seed(0)
      # To apply a classifier on this data, we need to flatten the image, to
      # turn the data in a (samples, feature) matrix:
      data = digits.images.reshape((len(digits.images), -1))

      # create a small neural network classifier
      from sklearn.neural_network import MLPClassifier
      classifier = MLPClassifier(alpha=1e-3)

      # Split data into train and test subsets
      X_train, X_test, y_train, y_test = sk.model_selection.train_test_split(data,
       →digits.target, test_size=0.5, shuffle=False)

      # We learn the digits on the first half of the digits
      classifier.fit(X_train, y_train)

      # Now predict the value of the digit on the second half:
      predicted = classifier.predict(X_test)
```
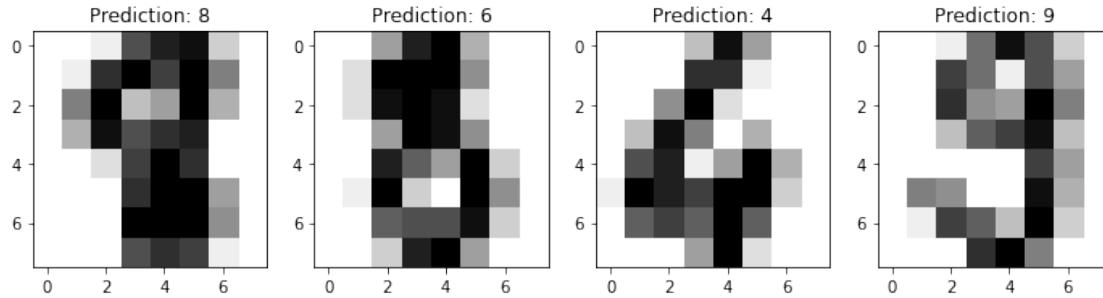
We can now visualize the results.

```
[31]: _, axes = plt.subplots(1, 4)
      images_and_predictions = list(zip(digits.images[n_samples // 2:], predicted))
      for ax, (image, prediction) in zip(axes, images_and_predictions[:4]):
          ax.imshow(image, cmap=plt.cm.gray_r, interpolation='nearest')
          ax.set_title('Prediction: %i' % prediction)
```

Prediction: 8   Prediction: 6   Prediction: 4   Prediction: 9

Part 4: Logistics and Other Information

We will go over some practical bits of information.

29 Course Format: Reverse Classrom

The format of this course will be that of the "reverse classroom". * Pre-recorded lecture videos will be made available online ahead of time. You should watch them ahead of each weekly lecture. * In-class discussions will focus on answering student questions, going over homework problems, doing tutorials.

30 Course Content

The course spans about 25 lectures approximately divided up into a set of blocks: 1. Supervised and unsupervised algorithms. 2. Foundations of machine learning. 4. Applying machine learning in practice. 5. Advanced topics and guest lectures.

31 Machine Learning Algorithms

- Supervised learning algorithms: linear models and extensions, kernel machines, tree-based algorithms.
- Unsupervised learning algorithms: density estimation, clustering, dimensionality reduction
- Introduction to deep learning models.

32 Foundations of Machine Learning

- The basic language of machine learning: datasets, features, models, objective functions.
- Tools for machine learning: optimization, probability, linear algebra.
- Why do algorithms work in practice? Probabilistic and statistical foundations.

33 Applying Machine Learning

- Evaluating machine learning algorithms.
- Diagnosing and debugging performance.
- Analyzing errors and improving models.
- Deploying and debugging pipelines.

34 Advanced Machine Learning Topics

- Introduction to reinforcement learning
- Guest lectures from industry

35 Course Assignments

There are two main types of assignments. 1. Supervised and unsupervised algorithms. 2. Foundations of machine learning. 4. Applying machine learning in practice. 5. Advanced topics and guest lectures.

36 Prerequisites. Is This Course For You?

This course is designed to aimed at a very general technical audience. Main requirements are: * Programming experience (at least 1 year), preferably in Python. * College-level linear algebra. Matrix operations, the SVD decomposition, etc. * College-level probability. Probability distributions, random variables, Bayes' rule, etc.

37 Other Logistics

- The majority of course materials will be accessible online.
- Grading will be based on a combination of homework assignments and course projects. See website for more details.
- There is no required textbook, but we recommend Elements of Statistical Learning by Hastie, Tibshirani, and Friedman.

37.0.1 Again, Welcome to Applied Machine Learning!