Machine Learning – Learning, Reasoning, and Training

15-110 – Friday 11/14

Announcements

- **Check6-1** is due Monday
  - Don't forget to fill out the project survey! Link: https://forms.gle/sZYocmdGMfC2Ptxe9
  - Remember that Check6-1 also has a written component

Learning Goals

- Identify the three major categories of learning (**supervised**, **unsupervised**, and **reinforcement**) and the three major categories of reasoning (**classification**, **regression**, and **clustering**)

- Decide which combination of **learning** and **reasoning** categories are best used to solve a stated problem

Machine Learning and Models

Machine Learning Creates Models

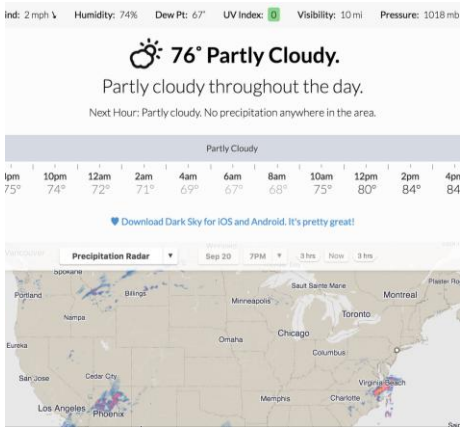
In data analysis and simulation, we designed algorithms and models to explore specific datasets.

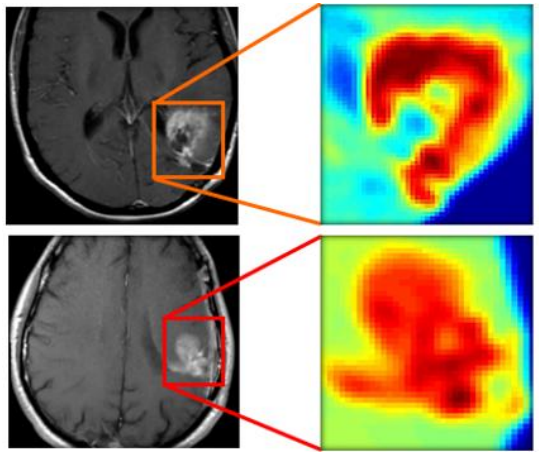
Machine learning (ML) goes one step further. Instead of designing a model for a dataset, we apply a general machine learning algorithm to the data. This identifies patterns in the data and **generates the model automatically**. It's like outsourcing the work to the computer!

The special part of this process is that the programmer doesn't teach the algorithm the pattern to create a specific model; the programmer teaches the algorithm how to find patterns generally. This means that the computer can generate many different models on its own, given the right data.

Machine Learning in Many Contexts

Machine Learning generates models that are used in thousands of contexts across the world, including speech recognition, weather prediction, and medical diagnosis.





We'll start by discussing the most common types of machine learning and how it works, then show examples of real-world machine learning used today.

Models

The **model** generated by a machine learning algorithm is used to perform reasoning tasks.

Once a model has been generated, we can analyze it to gain insights about the original dataset. For example, we might build a model to group open-ended feedback provided in a country-wide survey, then use those groups to identify common trends among answers.

We can also apply a model to new data to make predictions. A model trained on market behavior could make a prediction about which products produced by a business might be most popular in an upcoming quarter.

Models are Based on Data

To train a model using machine learning, we must start with a large amount of **data**. The algorithm will try to find patterns and correlations in that data. A model is only as good as its dataset!

Each data entry must be broken down into a set of **features** so the machine learning algorithm can analyze features separately or in groups. If you have a table of data, the features would be the **columns**; if you have a set of text, the features would be **words** or **groups of words**.

You can create and add new features the same way you would add new columns in data analysis.

Learning Categories

Many Machine Learning Algorithms

There are a very large number of machine learning algorithms that computer scientists have designed which all generate models using different approaches. How do we choose which one to use?

We can break algorithms into groups based on how they **learn** and on how they perform **reasoning**.

Three Ways to Learn

There are three primary ways that machine learning algorithms learn patterns from data. Which type you use depends on what type of problem you're trying to solve.

The three categories are **supervised learning**, **unsupervised learning**, and **reinforcement learning**.

Supervised Learning

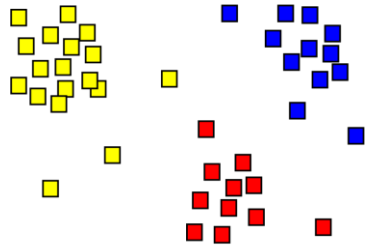
Supervised learning algorithms train models to predict outputs based on inputs. A data entry in the dataset is the input, and a **label** or a **score** is the output.

Example: to train a model to predict a person's favorite ice cream based on other desert preferences, each data entry (set of desert preferences) must be accompanied by a label (that person's favorite ice cream).

Once the model is fully trained, it can be used to make predictions about unlabeled data.

This is like when you learn by completing a homework assignment. You're trying to predict a correct answer (label) which is known by the teacher. This means the teacher (ML algorithm) can check your work. Later, you'll apply your knowledge to new problems where the answer is unknown.

Unsupervised Learning



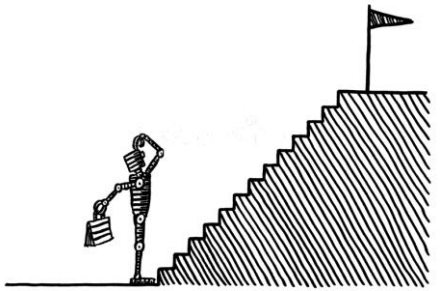
Unsupervised learning algorithms train models that infer the natural structure of a dataset. Which data entries are most similar to each other?

Example: identify common categories of favorite ice cream flavors by grouping together people who have similar desert preferences.

Unsupervised learning is often used when the data is **not** labeled – no true answer is known. That means that a human being will need to look over the model's results to see if they make sense or seem random.

This is like how researchers come up with theories to explain how the world works. Theories are based on data and may make sense, but might be changed of disproven later on.

Reinforcement Learning



Reinforcement learning algorithms train models that help an **artificial intelligence agent** approach an overall goal. Usually this involves taking a sequence of actions to bring the agent closer to the endpoint and giving feedback on those actions.

Example: train a robot to make ice cream by constantly changing the temperature and speed of an ice cream machine and measuring the consistency of the product until it's just right.

This is like playing a guessing game where the person with the secret word tells you if your guesses are hot or cold. You adjust your guesses and questions based on the person's feedback until you've gotten to the correct word.

We'll talk more about how AIs work later in the unit.

Demo: Supervised Learning

We can build an image-recognition model using supervised learning by labeling a bunch of pictures as belonging to specific classes.

Try it out here: https://teachablemachine.withgoogle.com/train/image

Reasoning Categories

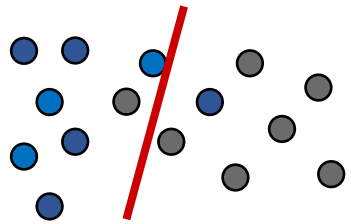
Many Ways to Reason

Once you've identified what type of learning you need to do, there are still lots of options for what type of algorithm you can use! One way to narrow the options down further is to ask what type of **reasoning** the algorithm will need to do.

For supervised learning, common reasoning approaches include **classification** and **regression** algorithms.

For unsupervised learning, common reasoning approaches include **clustering**.

Classification Algorithms

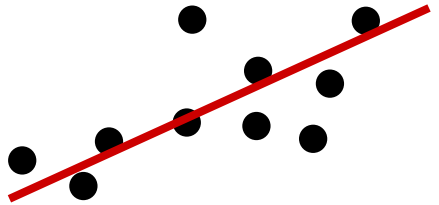


A **classification** algorithm takes labeled data of any type and produces a **model** (called a classifier) which determines which **category** a given data entry most likely belongs to. In other words, it produces a **categorical** (discrete) result.

For example, a classifier might take in data about an email (the sender, title, message content) and classify it as SPAM or NOT SPAM

Classification is commonly used in image recognition. Examples of classification algorithms include Naive Bayes, Decision Trees, and Support Vector Machines (SVMs).

Regression Algorithms

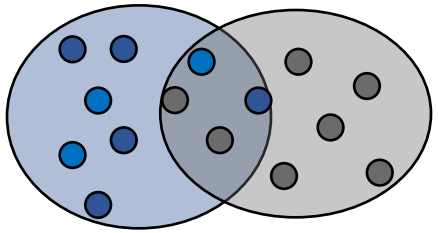


A **regression** algorithm takes numerically-labeled data and produces a function that maps data entries to **numerical** (continuous) results. Instead of predicting a specific category, it gives each data entry a **score**.

For example, a regression algorithm might take information about a house (GPS location, previous sell date, previous sell price, average price of nearby houses) and use it to predict its market value (a price).

Regression algorithms are used to predict things like stock market prices and weather temperatures. A linear regression is one kind of regression algorithm.

Clustering Algorithms



A **clustering** algorithm takes a set of data and produces a model that breaks the data into some number of **clusters** by identifying data entries that are similar to each other. We don't actually know the true categories or scores of the provided data, so it's hard to 'test' the resulting model, as we aren't sure what the actual result should look like.

For example, a clustering algorithm could recommend a new set of plant species by finding similarities between plant features in a given region.

Clustering is used in consumer analysis, data compression, and bioinformatics. K-means clustering is one kind of clustering algorithm.

Activity: Choose How to Reason

When you want to apply machine learning to a problem, investigate the type of problem and feature types to choose a method of reasoning.

You do: what combination of learning category + reasoning category would you use to...

- ... predict someone's favorite sport based on their job?
- ... investigate potential groupings of people based on their favorite restaurants?
- ... estimate how many meters a person walks per day based on their demographics?

Many Other Algorithms

Classification, regression, and clustering are just the most common types of reasoning algorithms. There are plenty of others that we don't have time to discuss in this class.

To make a model, though, you just need one algorithm- the best fit for the problem you're trying to solve.

Let's dive a bit deeper into how we can apply machine learning with supervised algorithms specifically.

Training a Model

ML Process: Decide, Train, then Test

To apply machine learning to a supervised task, follow a simple process

First: **decide** which learning algorithm you'll use, what it should produce and which features you'll train on. Make sure the algorithm matches the feature types!

Second: **train** a model created by the algorithm by providing it with the data. The algorithm will 'learn' from the data the same way a student learns by going over worked examples.

Third: **test** the model on a different set of data. This helps determine how accurate the model actually is.

Training Identifies Key Features

During the training process the algorithm identifies which features contribute the most to the underlying pattern. It does this by picking features that reduce the **error** that results from running the model on known data.

It's rare for a machine learning algorithm to identify a single feature that can definitively be used to answer a question. Usually, the algorithm uses a **combination of several features** which are weighted based on how well they correlate with the correct answer.

The algorithm needs to learn from a **lot** of examples to get a good sense of what the real pattern is.

Example: Is It a Dog?

Let's use a very simplified example to demonstrate how a machine learning algorithm might learn which features best match a label.

We want to train a model to recognize pictures of dogs. What kinds of features might it identify?

(The features we describe here are far too high-level, but the general idea is about right).

Example: Is It a Dog?

Guess: 

Answer: 

Prior knowledge:

???

Updated knowledge:

- Has Pointy Ears
- Has Fur
- Screen in background

Example: Is It a Dog?

Guess:  Answer: 

Prior knowledge:

- Has Pointy Ears
- Has Fur
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Updated knowledge:

- Has Pointy Ears
- Has Fur
- Grey/Black Coloring

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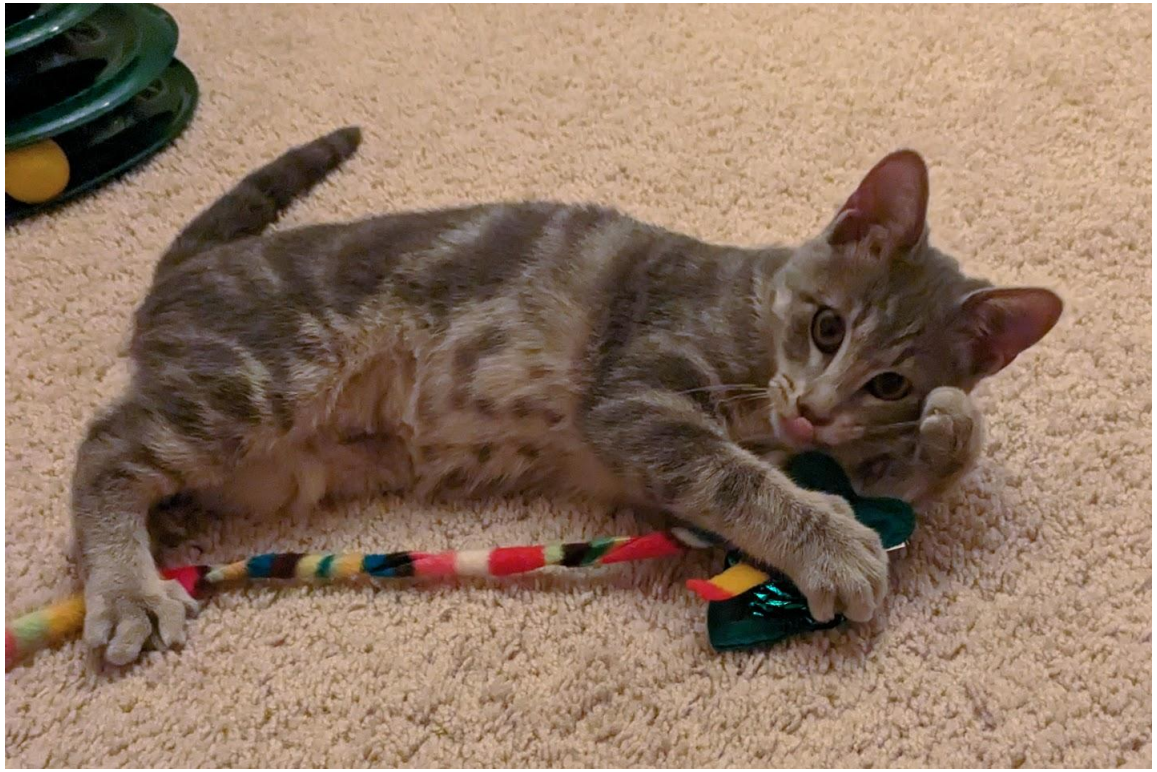

Real-World Example: ChatGPT

Let's consider the popular LLM ChatGPT. How was this system trained?

ChatGPT was trained to generate sequences of text using a HUGE dataset based on the internet and a large corpus of books. This taught the model which words most often go together and allowed it to **generate new text**.

ChatGPT was trained in how to communicate using an advanced algorithm that combined **supervised learning** and **reinforcement learning**.

- For supervised learning, the programmers created example conversations with human and chatbot participants to serve as training data
- For reinforcement learning, ChatGPT generated several possible responses and humans ranked them

Next Time: Testing the Model

Once we've built a model, how can we know how well it will perform?

We need to **test** the model on reserved test data. We'll talk about how to do that in the next machine learning lecture!

Learning Goals

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Machine Learning with sklearn

Bonus material

Real Example: Favorite Ice Cream Model

Now let's try building a real model with machine learning!

We'll use our ice cream data from the Data Analysis lecture. Our goal is to predict a person's 3rd favorite ice cream based on their 1st and 2nd preferences.

There are a ton of possible flavors, so we'll **hand code** the data to group similar flavors together and reduce the number of options to predict. This results in 6 possible categories: chocolate, coffee/tea, cookie, fruit, vanilla, and other.

Our approach is **supervised** (we already know what people's favorites are) and predicts a **categorical** result (an ice cream flavor). We need to use a classification algorithm.

Machine Learning Libraries

You can implement a machine learning algorithm yourself, but it isn't usually necessary. There are lots of great **external libraries** that have already implemented machine learning algorithms for you. All you have to do is plug in data!

We'll use the library **scikit-learn** here. You can install it in Thonny by going to Manage Packages and searching 'sklearn', or by running `pip` with:

```
pip install sklearn
```

We won't expect you to write code with `sklearn` this semester; these slides are just here in case you're curious about what coding with machine learning truly looks like.

Naive Bayes Classifier

Naive Bayes is a classification algorithm. The classifier it creates uses **conditional probabilities** to predict categories.

$$P(\mathrm{A}|\mathrm{B}) = \frac{P(\mathrm{B}|A) \cdot P(A)}{P(B)}$$

When Naive Bayes is given a new data entry X, it uses the data it has already collected to determine the **probability** that X belongs to each possible category.

For each category C, it checks how **probable** it is that each feature in X occurs with C by checking how often it occurred in past data entries. By multiplying these probabilities together, it can form a general probability that the data entry belongs in that category.

$$P(C|X) = P(X_1|C) * P(X_2|C) * P(X_3|C) * P(C)$$

The category with the highest probability wins!

Naive Bayes Example

Say we've collected the following data:

- #1: Chocolate
  #2: Cookie
  #3: Chocolate
- #1: Chocolate
  #2: Coffee/Tea
  #3: Vanilla
- #1: Cookie
  #2: Cookie
  #3: Vanilla
- #1: Coffee/Tea
  #2: Vanilla
  #3: Chocolate
- #1: Cookie
  #2: Vanilla
  #3: Chocolate
- #1: Coffee/Tea
  #2: Vanilla
  #3: Vanilla

If we encounter a new data point where the #1 favorite is Chocolate and the #2 favorite is Vanilla, we'd calculate the odds of each class as follows:

- P(#3 Chocolate | #1 Chocolate, #2 Vanilla) = P(#1 Chocolate | #3 Chocolate) * P(#2 Vanilla | #3 Chocolate) * P(#3 Chocolate) =
  1/3 * 2/3 * 1/2 = 1/9
- P(#3 Vanilla | #1 Chocolate, #2 Vanilla) = P(#1 Chocolate | #3 Vanilla) * P(#2 Vanilla | #3 Vanilla) * P(#3 Vanilla) =
  1/3 * 1/3 * 1/2 = 1/18

Chocolate has a higher probability than Vanilla, so Naive Bayes would predict that classification for the entry.

Naive Bayes in sklearn

In `sklearn`, we can employ Naive Bayes with the function `sklearn.naive_bayes.CategoricalNB()`.

This will create an 'empty' model. We can then train that model on data using `model.fit(data, labels)`, and run it on new data using `model.predict(newData)`.

However, we'll need to rearrange our data to make it fit into `sklearn`'s expectations! `CategoricalNB` wants integers, not strings. We can solve this by mapping each category to a number; in fact, this has been done already in the code posted to the course website.

0: chocolate	1: coffee/tea	2: cookie
3: fruit	4: vanilla	5: other

Setting Aside Test Data

Before training, we need to split our data into two groups- **training** data and **testing** data. That will make it possible for us to check our work later on.

We have information about when the data was collected, so let's just test on the most recent semester for now.

```
...
trainInput = []
trainLabels = []
testInput = []
testLabels = []
# allData = [ [ sem, #1, #2, #3 ] ]
for point in allData:
    semester = point[0]
    inputValues = point[1:3]
    outputValue = point[3]
    if semester == "F22":
        testInput.append(inputValues)
        testLabels.append(outputValue)
    else:
        trainInput.append(inputValues)
        trainLabels.append(outputValue)
```

Training the Model

Once the data is organized, training the model is easy. Just generate a new instance of the model using `CategoricalNB`, then call the `fit` method on that model using the data.

We can use the trained model to make predictions on new data points. For example, let's say we want to predict someone's 3rd favorite if their 1st favorite is chocolate and 2nd favorite is cookie. Create a list of the two category numbers (0 and 2), put that in another list, and call the `predict` method on the model.

The function returns 4, which corresponds to the vanilla category! A reasonable guess.

```
from sklearn.naive_bayes import CategoricalNB

model = CategoricalNB()
model.fit(trainInput, trainLabels)

print(model.predict([ [0, 2] ])) # [4]
```

Testing the Model

We'll talk about testing models next time. To test our model in the code example, we just need to call the `score` method on the model using the test data we set aside earlier.

The result will be an accuracy between [0, 1]. We get an accuracy of 24.6% - not great, but also not terrible considering the amount of variety in the possible answers.

Note that we had to set aside the test data first for this to work! If we trained on the test data, we'd get a faulty result.

```
accuracy = model.score(testInput, testLabels)

print(accuracy) # 0.24550898203592814
```