Practical Neural Networks From Scratch

Concepts, Techniques and Tools to Build Intelligent Systems

Module 1

Introduction to Data science, Artificial Intelligence and Machine Learning

Ali Samanipour

May. 2023

“The laws of Nature are written in the language of mathematics.”

<u>Galileo Galilei</u>

1 Data Science, AI and ML

2 ML Applications and Use cases

3 Why We Should Use Machine Learning

4 ML vs Traditional Approaches

5 Types of ML Systems

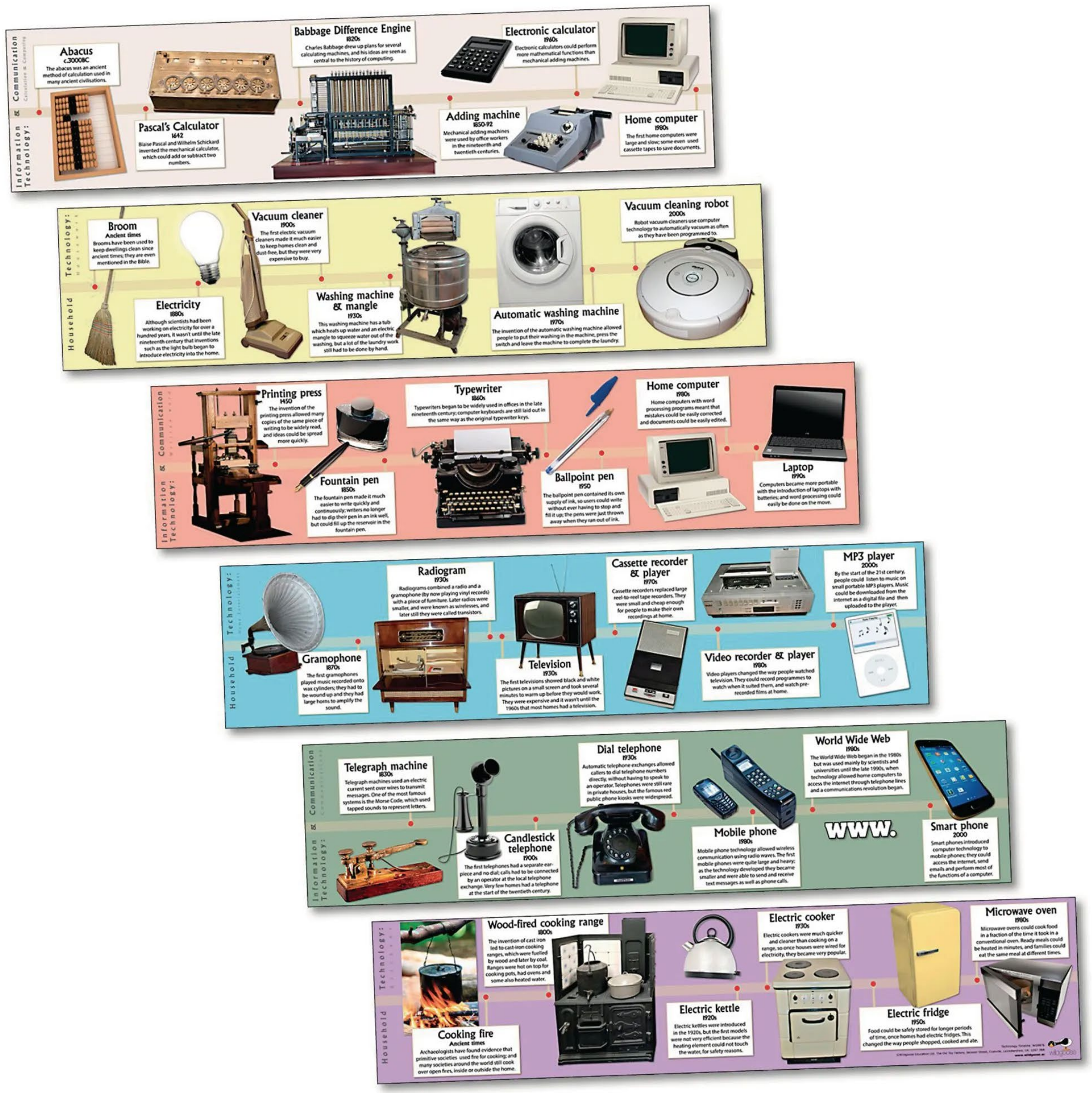
6 ML SDLC (How To Develop ML Models)

What is not Artificial Intelligence (AI)

AI is not exactly what you have seen in Sci-Fi Movies.

Today, The world is full of machines

Machines cultivate and harvest our crops, make our houses, fly our planes, assemble our cars, control traffic, cook and pack food, entertain us, and even take care of us when we are sick.



Thinking Vs Following Predefined Rules

Most machines work by following predefined steps required to complete a task successfully.

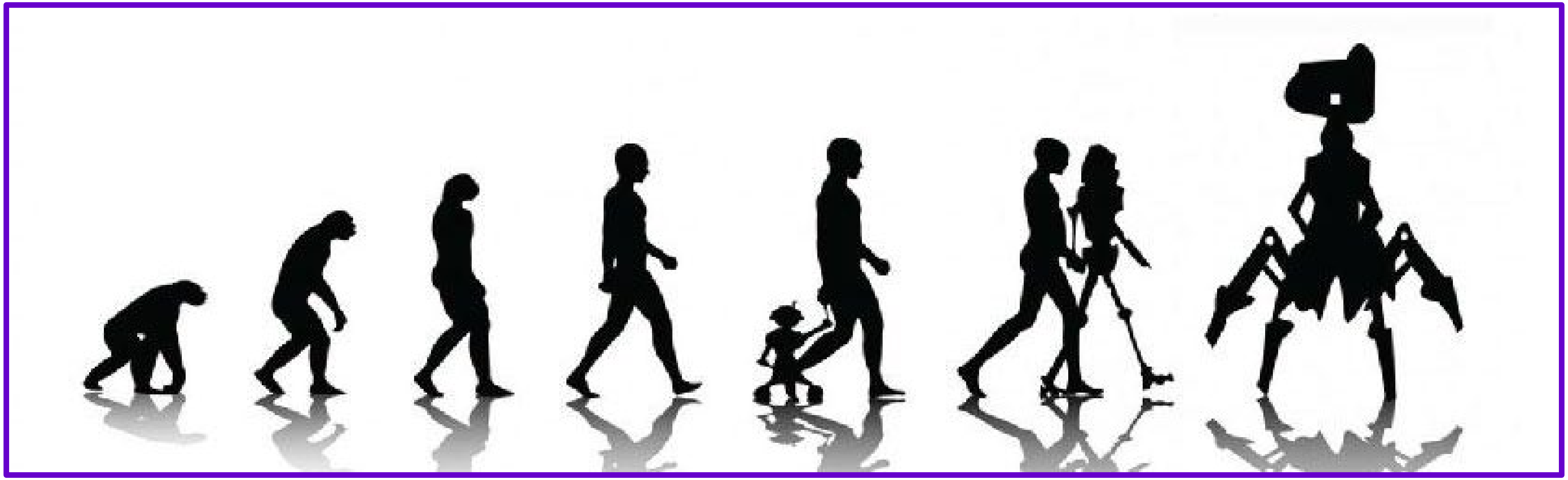
Courtesy of https://museum.mmu.ac.ke/

Human Intelligence

For the past few decades, we have been trying to build intelligent machines.

Artificial Intelligence

The field of algorithms that strive to impart human intelligence to machines is called Artificial Intelligence (AI).



AI Systems Vs Humans

AI is a multidisciplinary field of research with a goal to create technology that can enable machines to function like humans.

Human mind consists of memories, intellect, thoughts (emotions), and a sense of identity.

Human intellect is the discriminative faculty of the mind that determines whether an action is right or wrong.

How a Human Work?!

1. The sense organs present the current situation someone is in, to their intellect.
2. Then, intellect consults the memory, past experiences, present thoughts, and emotions
3. Then decides the action. the actions can be speaking, running, smiling, crying, fighting and so on.

How AI Systems Expected to Work?

Machines may not have emotions to influence their decisions! But machines ***must learn from past experiences, and these experiences must influence their decisions***.

1. A machine should have the sense organs by which it can digitally map and record our physical world.
2. It must have the ability to learn from the mistakes it makes.

AI Systems Classifications

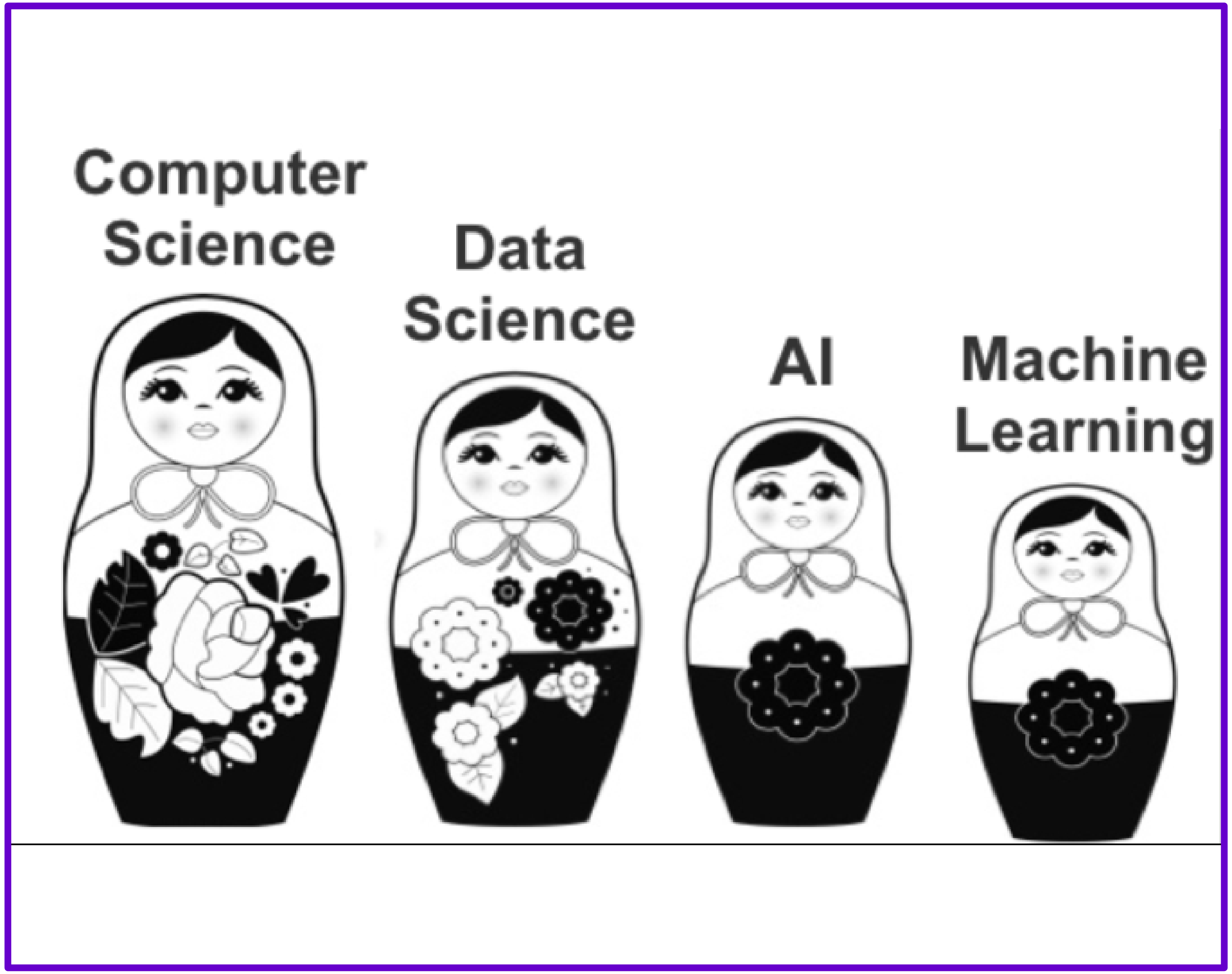
Artificial narrow intelligence (**ANI** or narrow AI) refers to a computer’s ability to perform a single task extremely well.

Artificial general intelligence (**AGI** or strong AI) is when a computer program can perform any intellectual task exactly like a human, that is, machines exhibit human intelligence.

Artificial super intelligence (**ASI**) is an AI system that surpasses human intellect, that is, machines having greater problem solving and decision-making capabilities that are far superior to human beings.

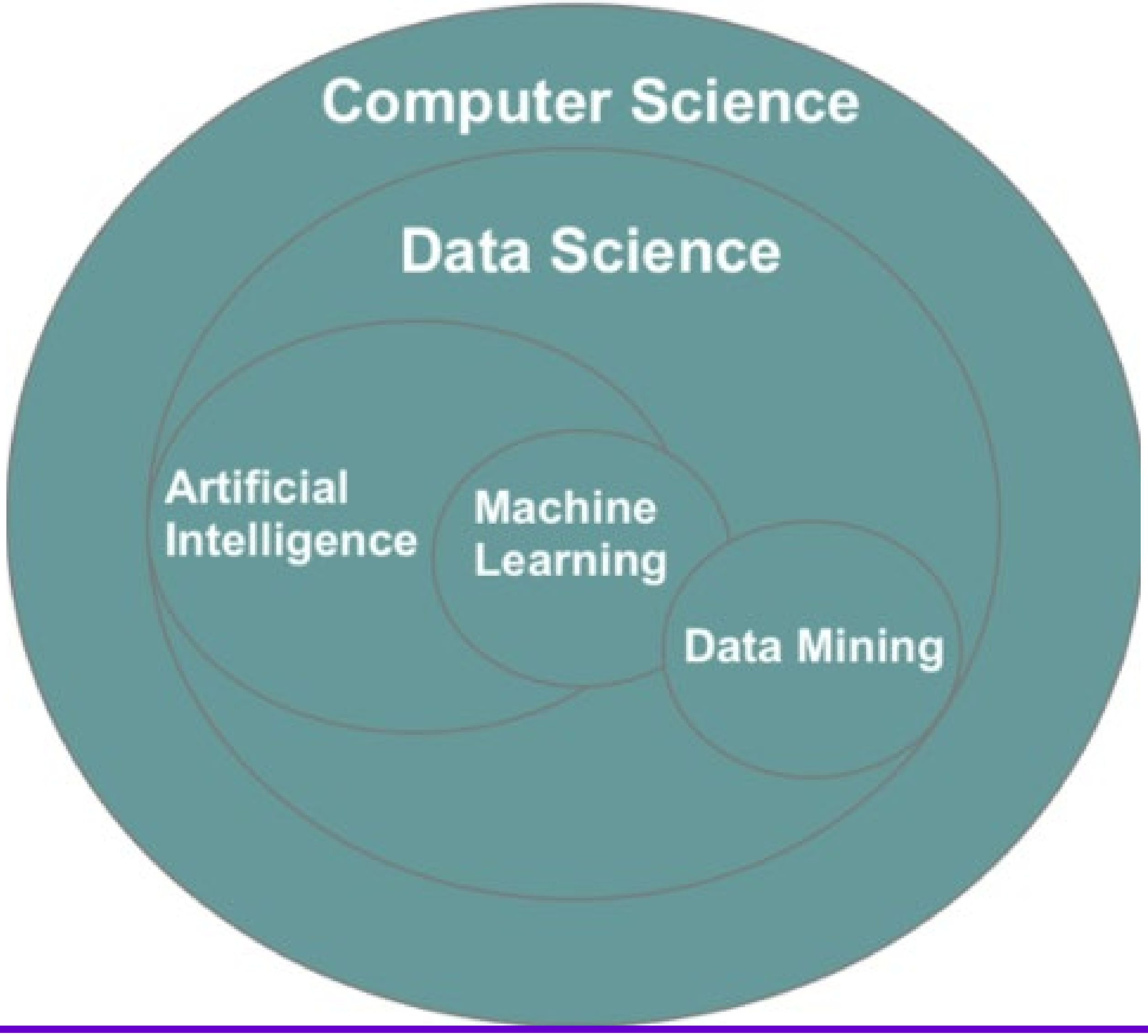
CS, DS, AI and ML

AI is actually is sub field of Data Science



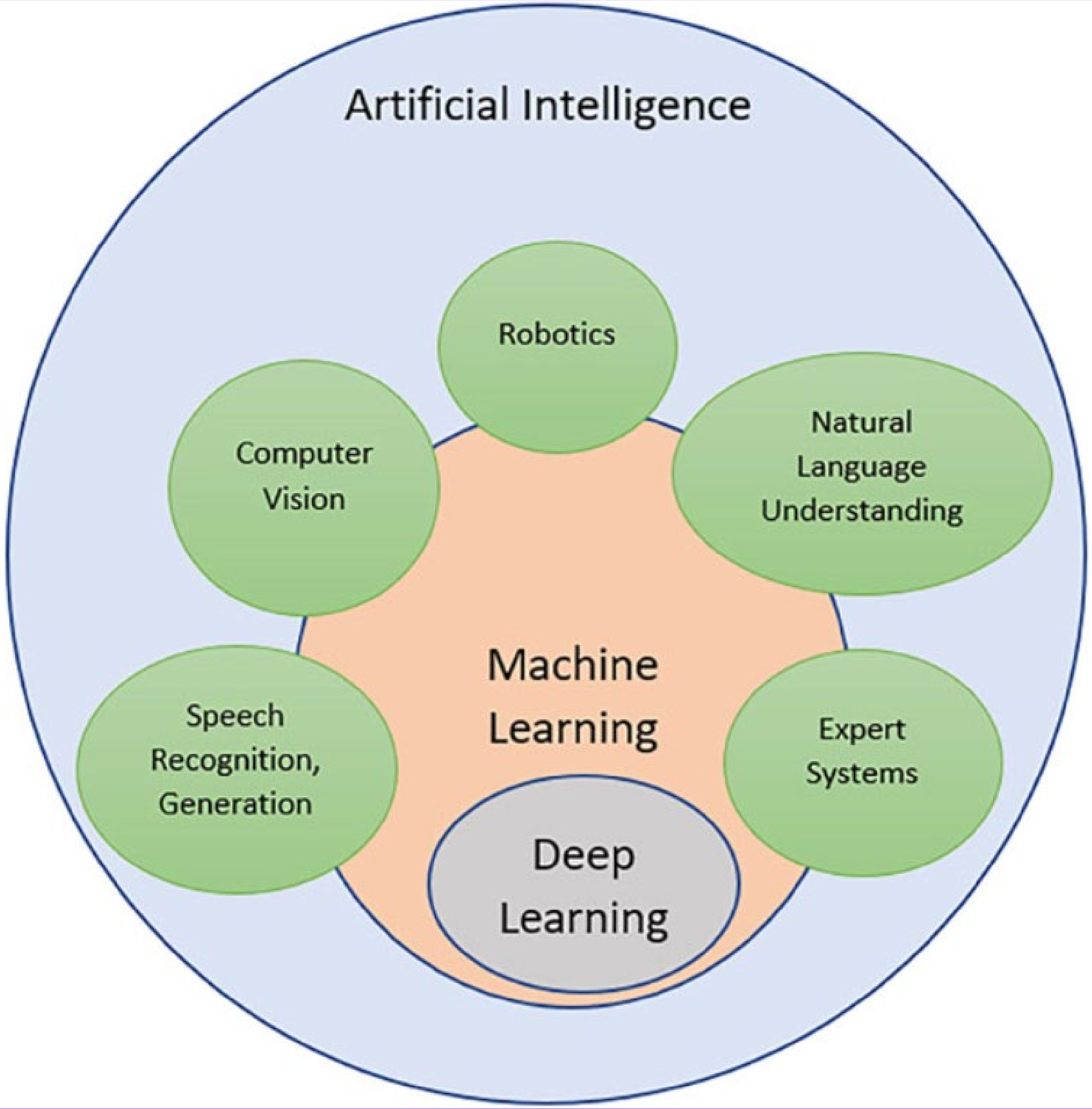
Relationship Between Data-related Fields

AI is actually is sub field of Data Science and Really closed fields like Data Mining



AI Subcomponents

Machine learning (ML) is a broad class of algorithms that is used to build components of an AI system.



What Is Machine Learning?

Machine learning is the science (and art) of programming computers so they can learn from data.

“Machine learning is the] field of study that gives computers the ability to learn without being explicitly programmed”

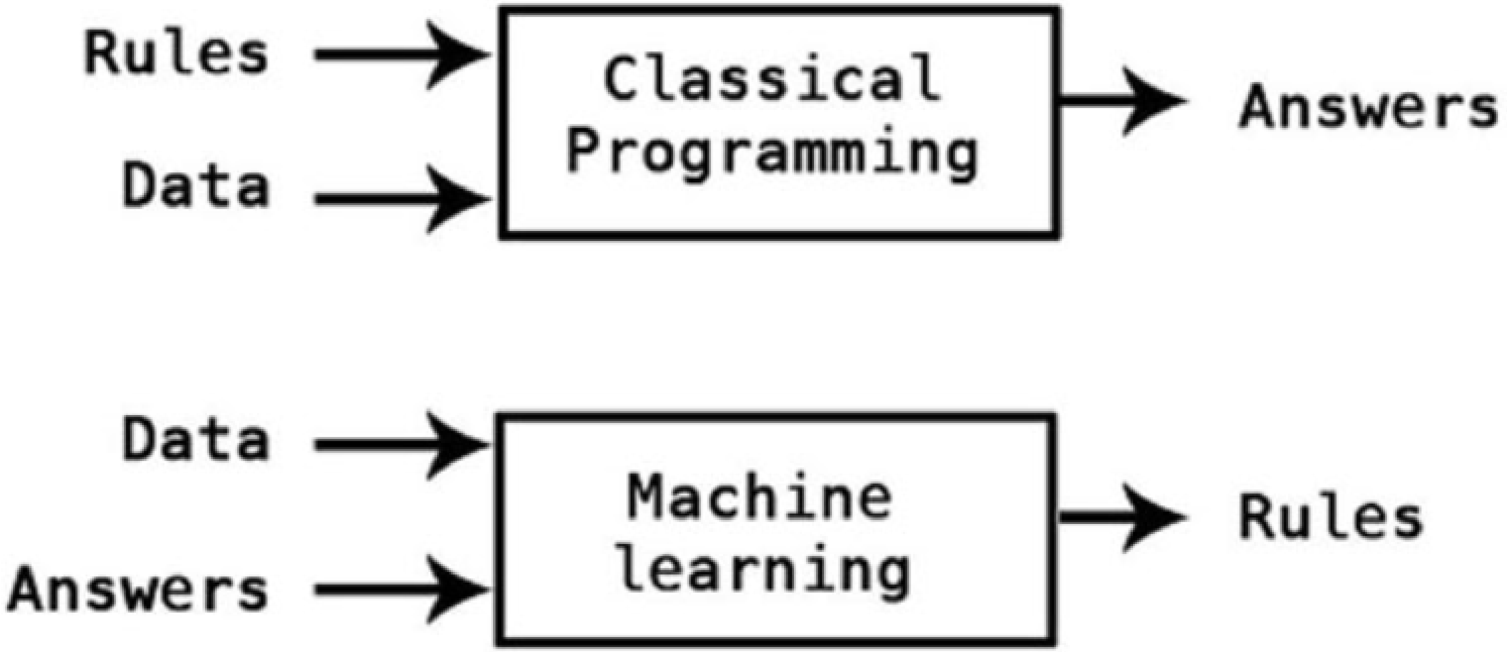
Arthur Samuel, 1959

“A computer program is said to learn from experience E with respect to some task T and some performance measure P , if its performance on T , as measured by P , improves with experience E”

Tom Mitchell, 1997

What Is Machine Learning?

Machine Learning (ML) includes the study, design, and development of algorithms to **give computers the capability to learn from data instead of requiring explicit programming of hard-coded rules**.



What ML is great for ? (1)

Problems for which existing solutions require a lot of fine-tuning or long lists of rules (a machine learning model can often simplify code and perform better than the traditional approach)

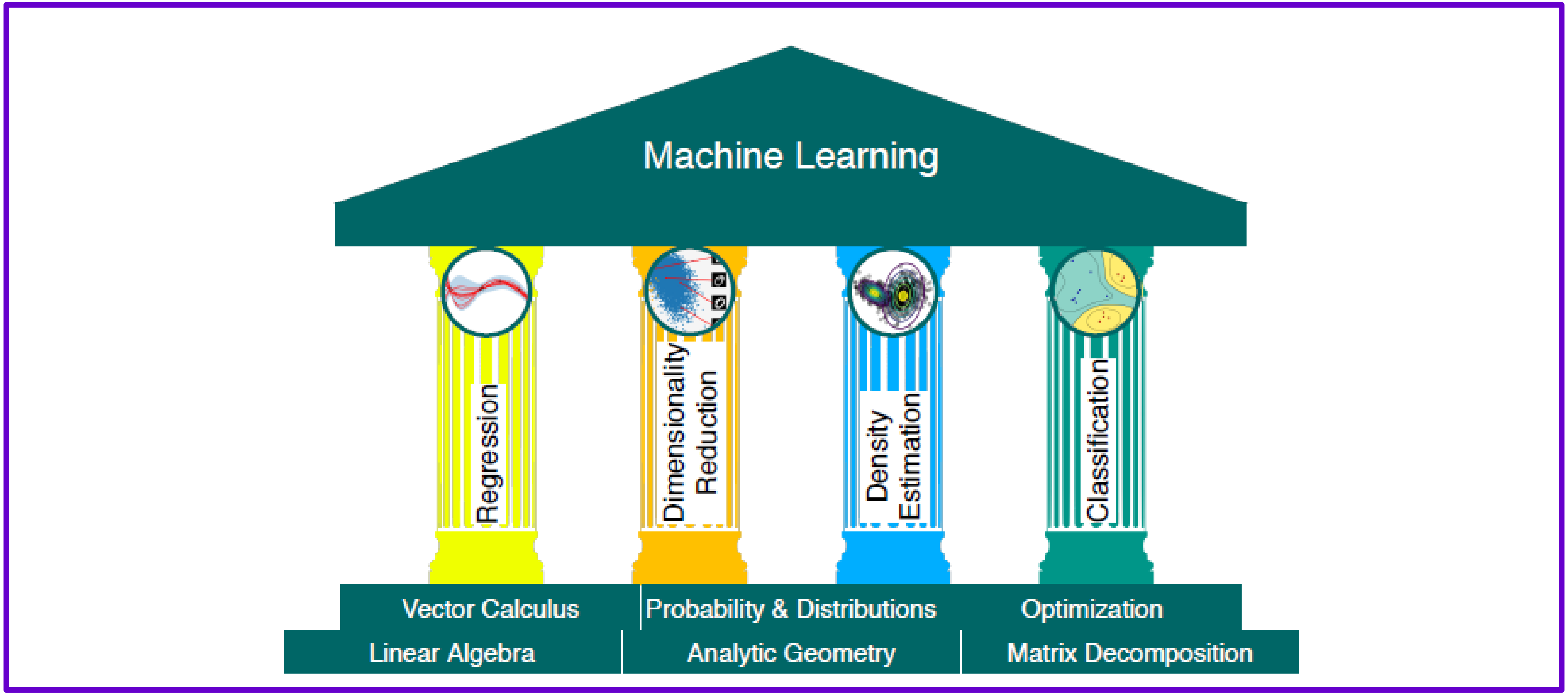
What ML is great for ? (2)

Complex problems for which using a traditional approach yields no good solution (the best machine learning techniques can perhaps find a solution)

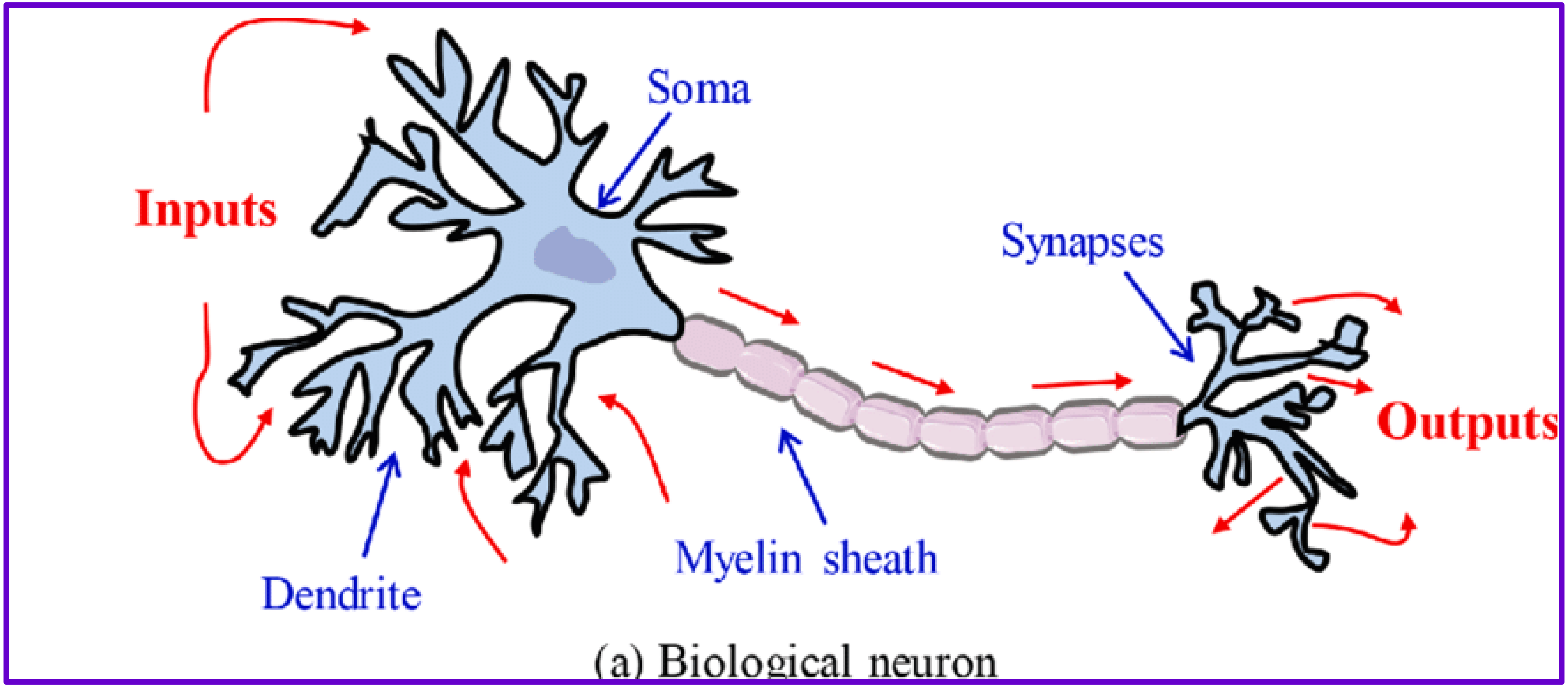
What ML is great for ? (3)

Getting insights about complex problems and large amounts of data

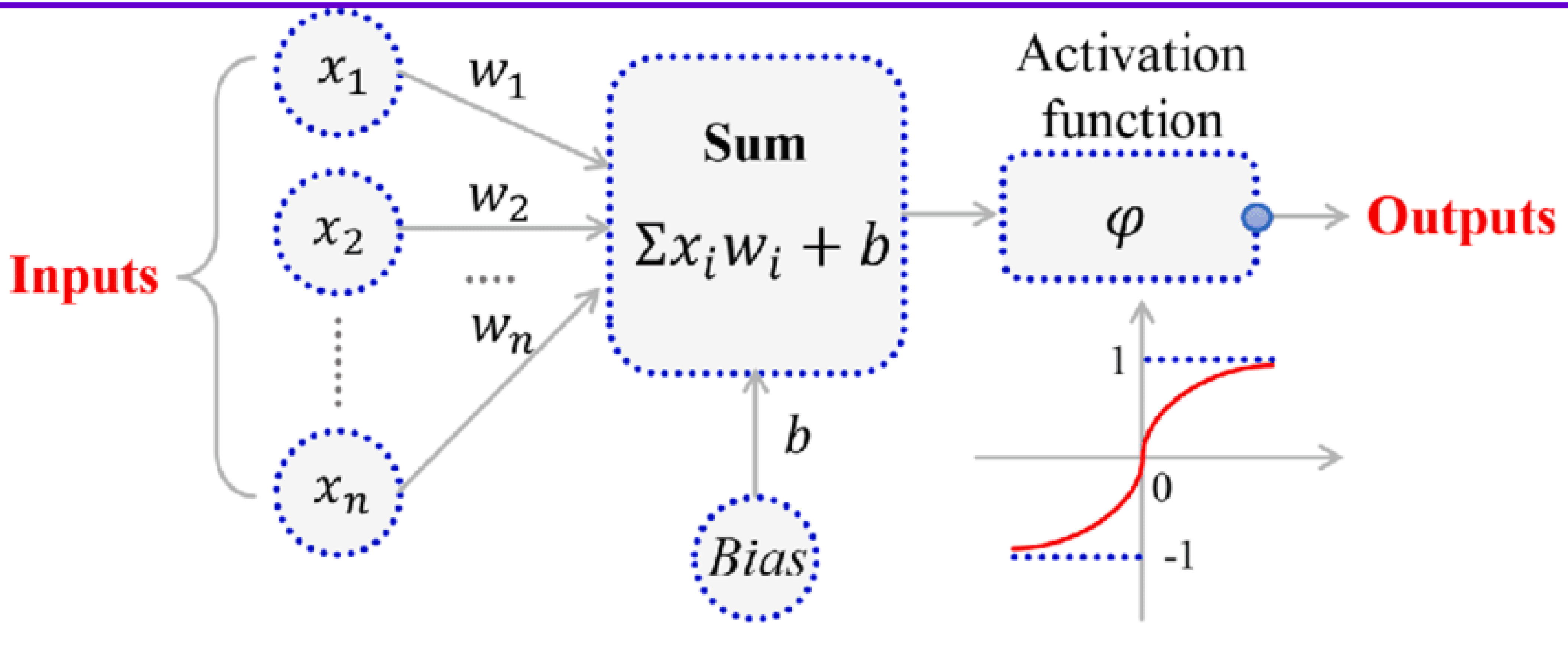
Show we know Math?!(for Machine Learning)



How Humans Learn and Think vs How Computers dose (An Example)

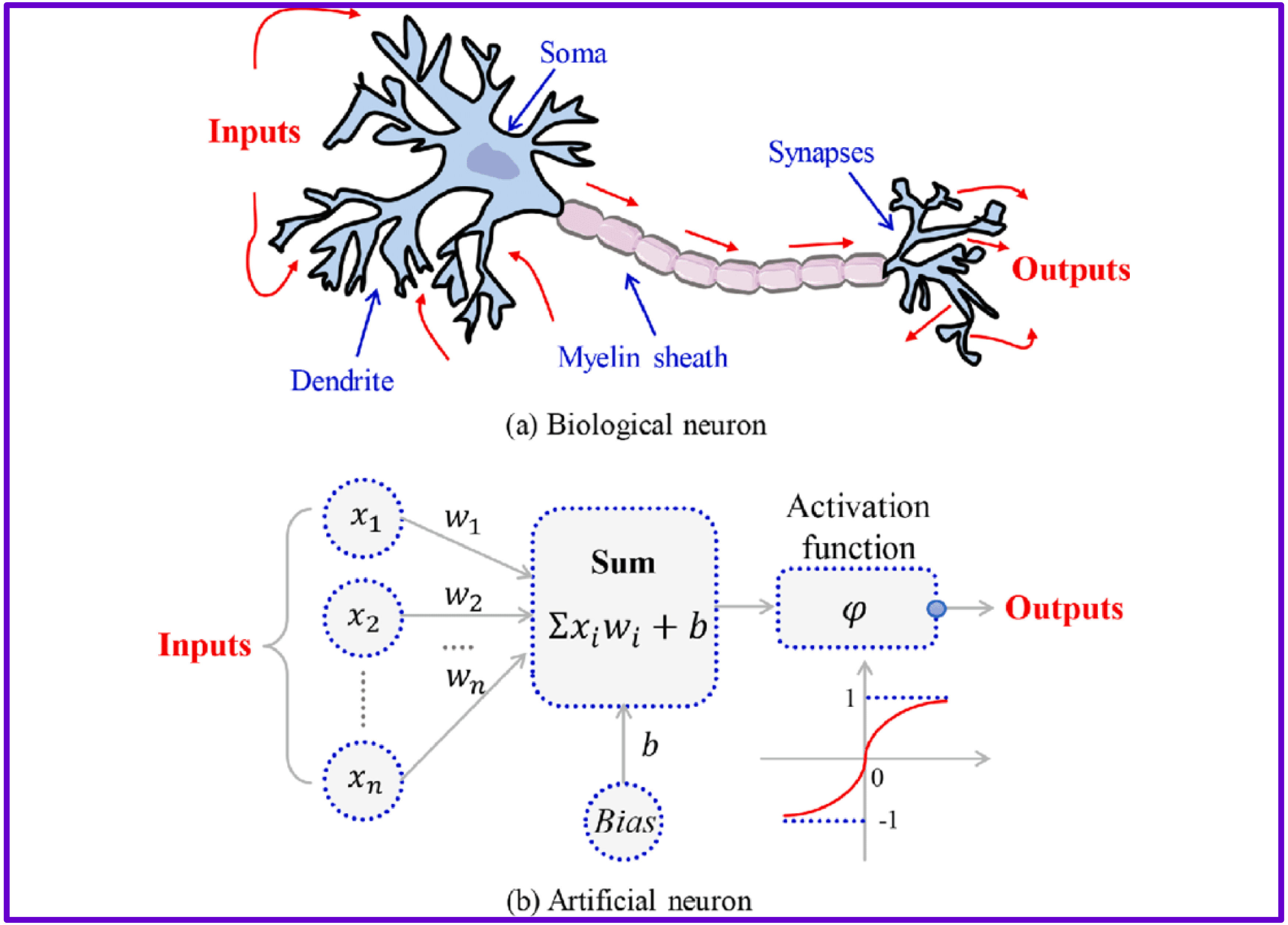


How Humans Learn and Think vs How Computers dose (An Example) …



(b) Artificial neuron

How Humans Learn and Think vs How Computers dose (An Example) …



1. Data Science, AI and ML
2. ML Applications and Use cases
3. Why We Should Use Machine Learning
4. ML vs Traditional Approaches
5. Types of ML Systems
6. ML SDLC (How To Develop ML Models)

Application areas of ML

Financial services

Predictions are made by applying appropriate machine learning algorithms to identify two important factors: determining insights into data for identifying investment opportunities or helping investors to know when to trade. Additionally, various data mining and machine learning algorithms are utilized to perform cyber surveillance to prevent frauds from occurring, and to identify clients with high-risk profiles in banking sector and other businesses in the financial industry.

Application areas of ML

Government

For a government organization, there is a huge collection of data obtained from multiple sources, and records are maintained over years. Such data forms the prime source from where data can be mined, and insights generated to improve public safety and provide utilities for the welfare of the society. Machine learning can play an important role in determining such services. It can also help detect fraud and minimize identity theft.

Application areas of ML

Health care

Due to the advent of wearable devices, sensor technology incorporated in the healthcare sector can provide access to a patient’s health in real time. This data accumulation can help medical experts analyze the data, and identify trends and critical areas, which can lead to improved diagnosis and treatment. Machine learning models can be developed and trained to provide insights into the patient’s health

Application areas of ML

Health care

Due to the advent of wearable devices, sensor technology incorporated in the healthcare sector can provide access to a patient’s health in real time. This data accumulation can help medical experts analyze the data, and identify trends and critical areas, which can lead to improved diagnosis and treatment. Machine learning models can be developed and trained to provide insights into the patient’s health

Application areas of ML

Retail

Online shopping is the trend these days. Business organizations are providing services like recommending products and their combinations that have been previously purchased based on the buying history. Retailers rely on machine learning to capture data, analyze it and use it to personalize a shopping experience and provide customer insights along with price optimization.

Application areas of ML

Oil and gas

Machine learning models are being trained to determine new energy sources, analyze minerals in the ground, predict refinery sensor failure, and streamline oil distribution to make the refineries more efficient and cost-effective.

Application areas of ML

Transportation

The transportation industry majorly relies on making routes more efficient and predicting potential problems. So, machine learning algorithms to be developed have to analyze, the incoming data needs to be modeled. This can further be used to identify patterns and trends to generate optimized routes. Thus, machine learning is an important tool for various transportation organizations

Application areas of ML

Customer Relationship Management (CRM)

Machine learning utilizes learning models to analyze the emails and informs the sales team members about the most important mails to respond to first.

Application areas of ML

Human resource (HR)

Human resource (HR) systems use machine learning models to identify the characteristics of effective employees and use this to find the best applicants for open positions.

Application areas of ML

Self-driving cars

Machine learning uses deep learning neural networks to identify objects and determine optimal actions for safely steering a vehicle.

Application areas of ML

Virtual assistant

In order to interpret natural speech, personal schedules or previously defined preferences and take action, smart assistants utilize machine learning technology through several deep learning models.

Real World Use-Cases of ML

Analyzing images of products on a production line to automatically classify them

This is image classification, typically performed using convolutional neural networks (CNNs) or sometimes transformers.

Real World Use-Cases of ML

Detecting tumors in brain scans

This is semantic image segmentation, where each pixel in the image is classified (as we want to determine the exact location and shape of tumors), typically using CNNs or transformers.

Real World Use-Cases of ML

Automatically classifying news articles

This is natural language processing (NLP), and more specifically text classification, which can be tackled using recurrent neural networks (RNNs) and CNNs, but transformers work even better.

Real World Use-Cases of ML

Automatically flagging offensive comments on discussion forums

This is also text classification, using the same NLP tools.

Real World Use-Cases of ML

Summarizing long documents automatically

This is a branch of NLP called text summarization, again using the same tools.

Real World Use-Cases of ML

Creating a chatbot or a personal assistant

This involves many NLP components, including natural language understanding (NLU) and question-answering modules.

Real World Use-Cases of ML

Forecasting your company's revenue next year, based on many performance metrics

This is a regression task (i.e., predicting values) that may be tackled using any regression model, such as a linear regression or polynomial regression model, a regression support vector machine, a regression random forest, or an artificial artificial neural network. If you want to take into account sequences of past performance metrics, you may want to use RNNs, CNNs, or transformers.

Real World Use-Cases of ML

Making your app react to voice commands

This is speech recognition, which requires processing audio samples: since they are long and complex sequences, they are typically processed using RNNs, CNNs, or transformers.

Real World Use-Cases of ML

Detecting credit card fraud

This is anomaly detection, which can be tackled using isolation forests, Gaussian mixture models, or autoencoders.

Real World Use-Cases of ML

Segmenting clients based on their purchases so that you can design a different marketing strategy for each segment

This is clustering, which can be achieved using k - means, DBSCAN, and more.

Real World Use-Cases of ML

Representing a complex, high-dimensional dataset in a clear and insightful diagram

This is data visualization, often involving dimensionality reduction techniques.

Real World Use-Cases of ML

Recommending a product that a client may be interested in, based on past purchases

This is a recommender system. One approach is to feed past purchases (and other information about the client) to an artificial neural network, and get it to output the most likely next purchase. This neural net would typically be trained on past sequences of purchases across all clients.

Real World Use-Cases of ML

Building an intelligent bot for a game

This is often tackled using reinforcement learning (RL; see Chapter 18), which is a branch of machine learning that trains agents (such as bots) to pick the actions that will maximize their rewards over time (e.g., a bot may get a reward every time the player loses some life points), within a given environment (such as the game). The famous AlphaGo program that beat the world champion at the game of Go was built using RL.

Real World Use-Cases of ML

Building an intelligent bot for a game

This is often tackled using reinforcement learning (RL; see Chapter 18), which is a branch of machine learning that trains agents (such as bots) to pick the actions that will maximize their rewards over time (e.g., a bot may get a reward every time the player loses some life points), within a given environment (such as the game). The famous AlphaGo program that beat the world champion at the game of Go was built using RL.

1. Data Science, AI and ML
2. ML Applications and Use cases
3. Why We Should Use Machine Learning
4. ML vs Traditional Approaches
5. Types of ML Systems
6. ML SDLC (How To Develop ML Models)

Problem of classifying flowers

Consider a huge basket of flowers, and assume that there are three categories of flowers

Problem of classifying flowers
Solution: Step 0

Flowers vary in size, color, texture, and shape. We want to build an algorithm than can classify the flowers to a type

Features — **Class/Target**

sepal length (cm)	sepal width (cm)	petal length (cm)	petal width (cm)	type
7.1	3.0	5.9	2.1	virginica
6.2	2.9	4.3	1.3	versicolor
5.6	3.0	4.1	1.3	versicolor
5.4	3.4	1.7	0.2	setosa
5.0	3.6	1.4	0.2	setosa

Sample Observations

Independent Variables — **Dependent Variable**

Problem of classifying flowers
Solution: Step 1

The first step is to select the properties or features of flowers that will be useful to identify flower species. Once selected, these features are represented with a numerical value that an algorithm can take as input.

Features **Class/Target**

sepal length (cm)	sepal width (cm)	petal length (cm)	petal width (cm)	type
7.1	3.0	5.9	2.1	virginica
6.2	2.9	4.3	1.3	versicolor
5.6	3.0	4.1	1.3	versicolor
5.4	3.4	1.7	0.2	setosa
5.0	3.6	1.4	0.2	setosa

Sample Observations

Independent Variables **Dependent Variable**

Problem of classifying flowers
Solution: Step 2

Once features are identified, we must define set of rules to classify a flower. Here, our output or target variable is the category of flower.

Features | **Class/Target**

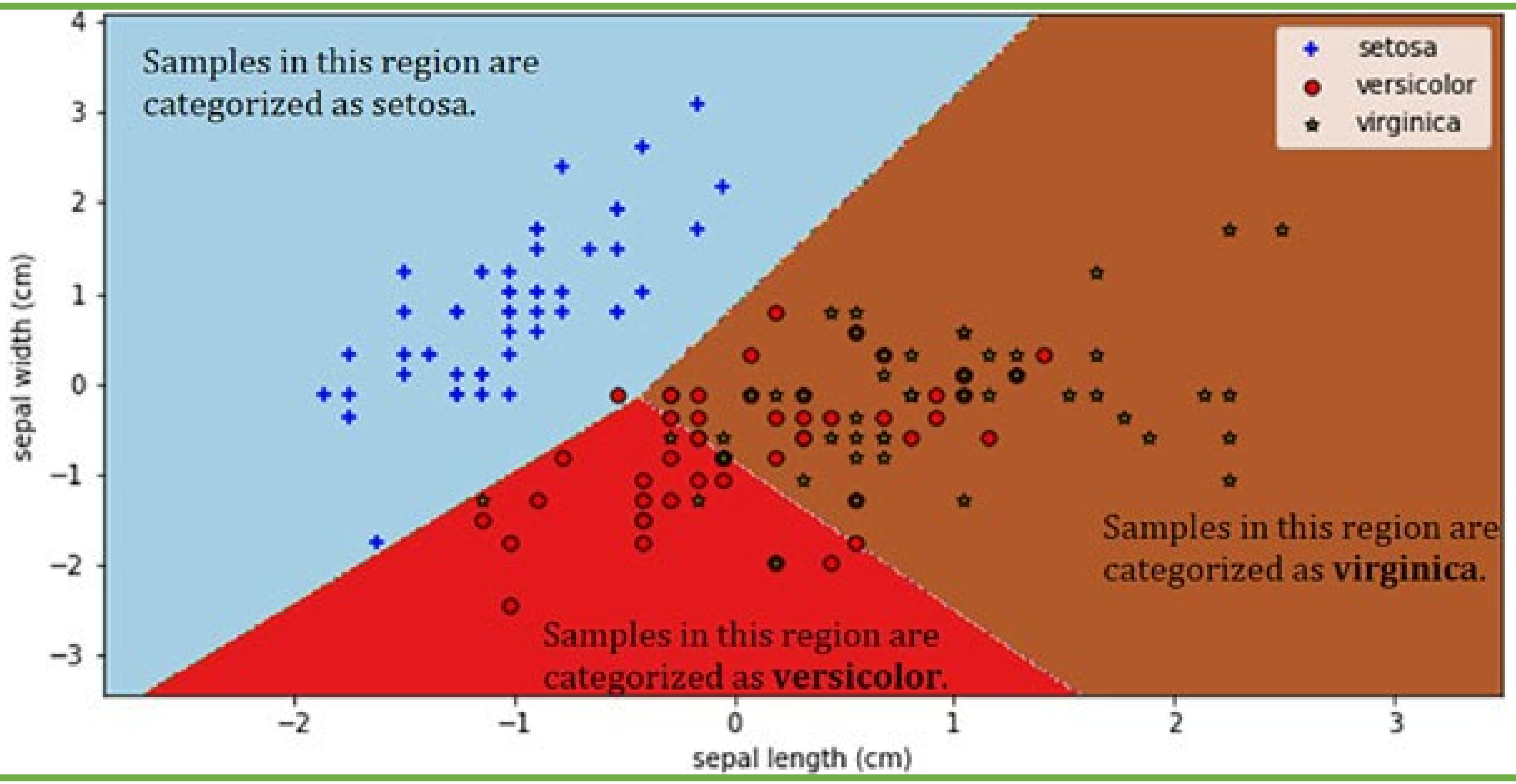
sepal length (cm)	sepal width (cm)	petal length (cm)	petal width (cm)	type
7.1	3.0	5.9	2.1	virginica
6.2	2.9	4.3	1.3	versicolor
5.6	3.0	4.1	1.3	versicolor
5.4	3.4	1.7	0.2	setosa
5.0	3.6	1.4	0.2	setosa

Sample Observations

Independent Variables | **Dependent Variable**

Problem of classifying flowers
Solution: Step 2 ...

Identifying the Iris species using first two features



Problem of classifying flowers
Solution: Step 3(**Model**)

Simple rules(**Model**) to classify the flowers into the respective categories by observing only two features are:

1. If the normalized sepal length < 0 and normalized sepal width > 0, then it’s setosa.
2. If the sepal length and width fall in the lower triangular region, it’s versicolor with a high chance. This triangular region can be defined by three straight line equations.
3. Otherwise, its virginica.

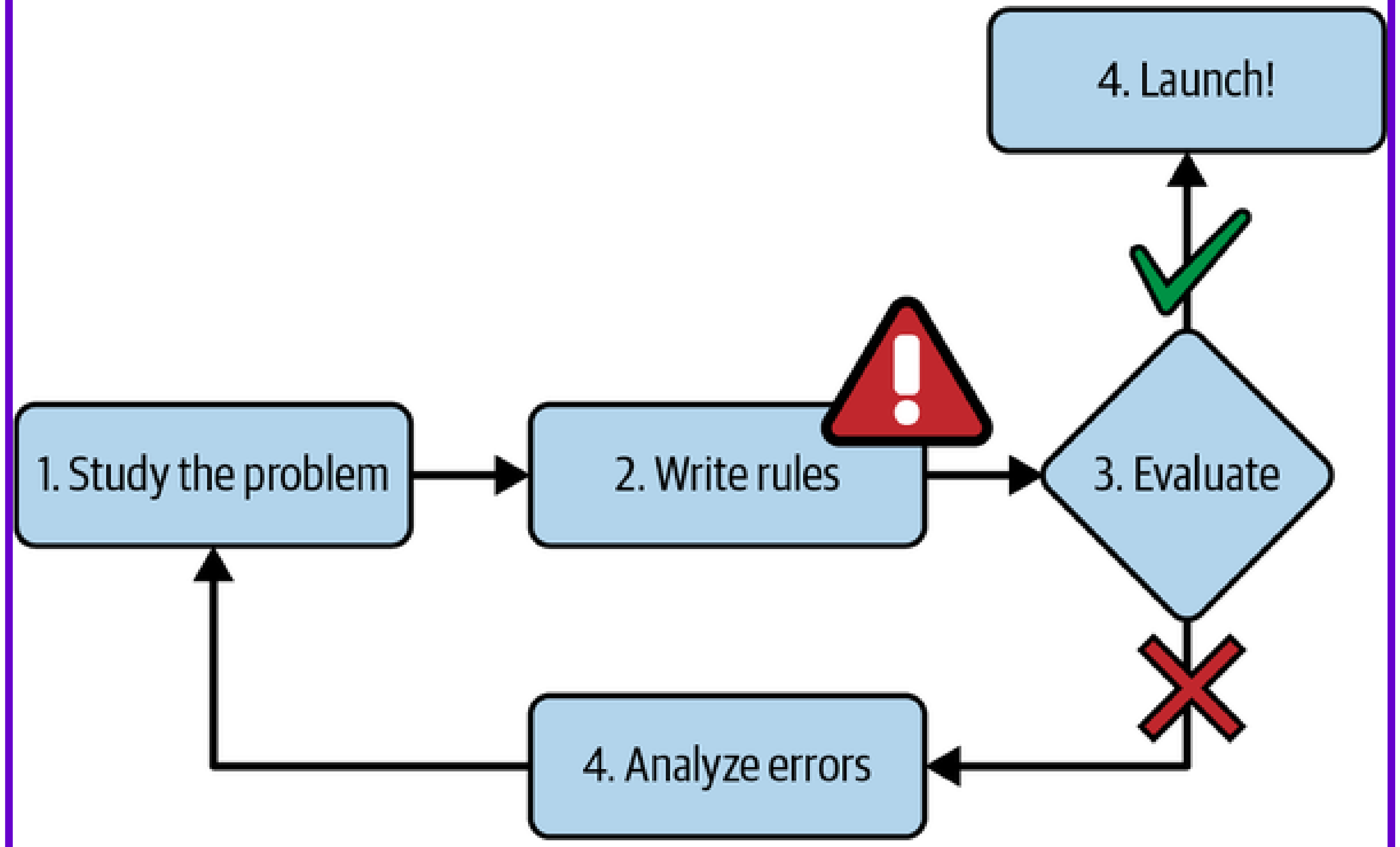
Problem of filtering spam emails

1. First you would examine what spam typically looks like. You might notice that some words or phrases (such as “4U”, “credit card”, “free”, and “amazing”) tend to come up a lot in the subject line. Perhaps you would also notice a few other patterns in the sender’s name, the email’s body, and other parts of the email.
2. You would write a detection algorithm for each of the patterns that you noticed, and your program would flag emails as spam if a number of these patterns were detected.
3. You would test your program and repeat steps 1 and 2 until it was good enough to launch.

1. Data Science, AI and ML
2. ML Applications and Use cases
3. Why We Should Use Machine Learning
4. ML vs Traditional Approaches
5. Types of ML Systems
6. ML SDLC (How To Develop ML Models)

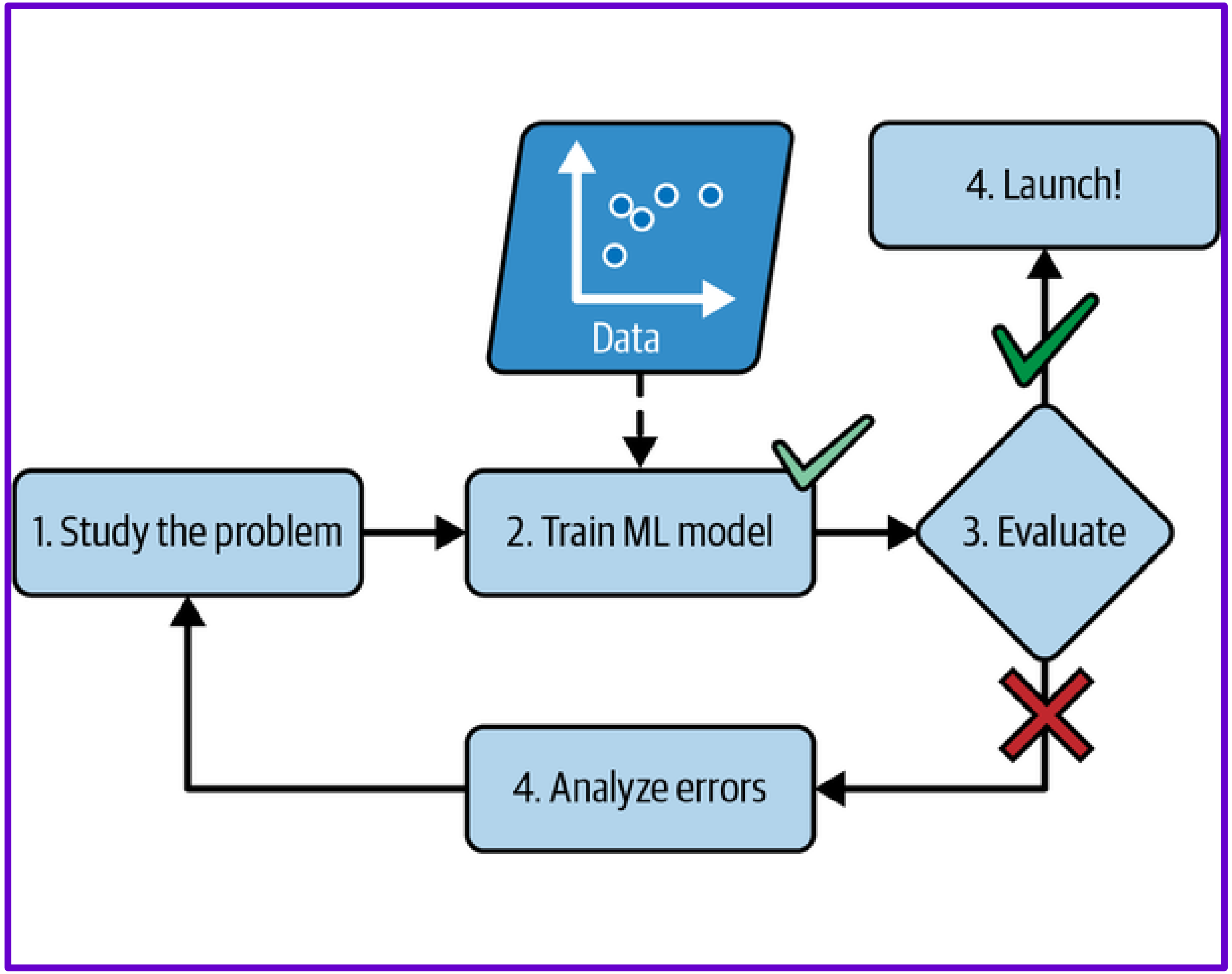
The traditional approach

Since the problem is difficult, your program will likely become a long list of complex rules—pretty hard to maintain.



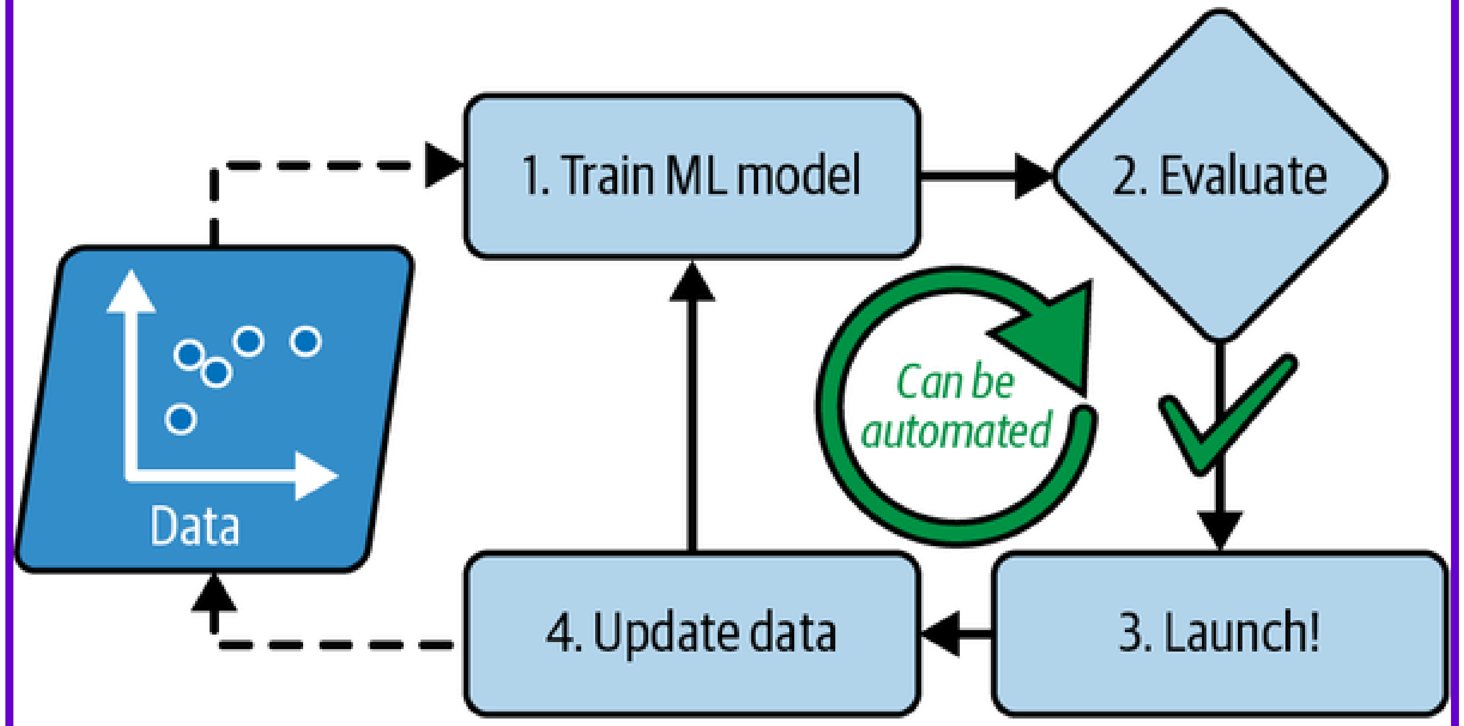
The machine learning approach

In contrast, a spam filter based on machine learning techniques automatically learns which words and phrases are good predictors of spam by detecting unusually frequent patterns of words in the spam examples compared to the ham examples



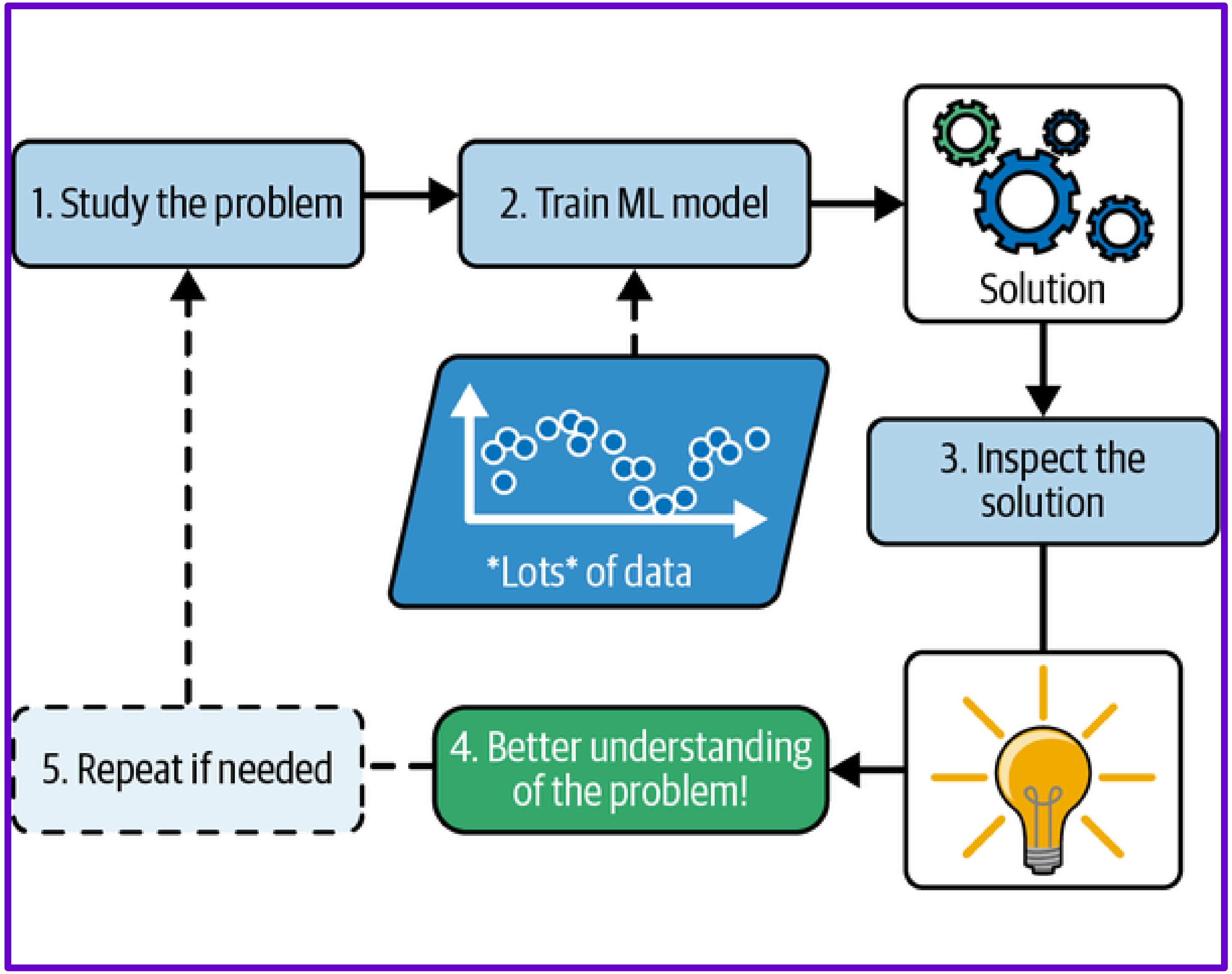
Automatically adapting to change

Machine learning algorithms try to automate the process by learning rules or decision boundaries or a mathematical function



Machine learning can help humans learn

Sometimes this will reveal unsuspected correlations or new trends, and thereby lead to a better understanding of the problem



1 Data Science, AI and ML

2 ML Applications and Use cases

3 Why We Should Use Machine Learning

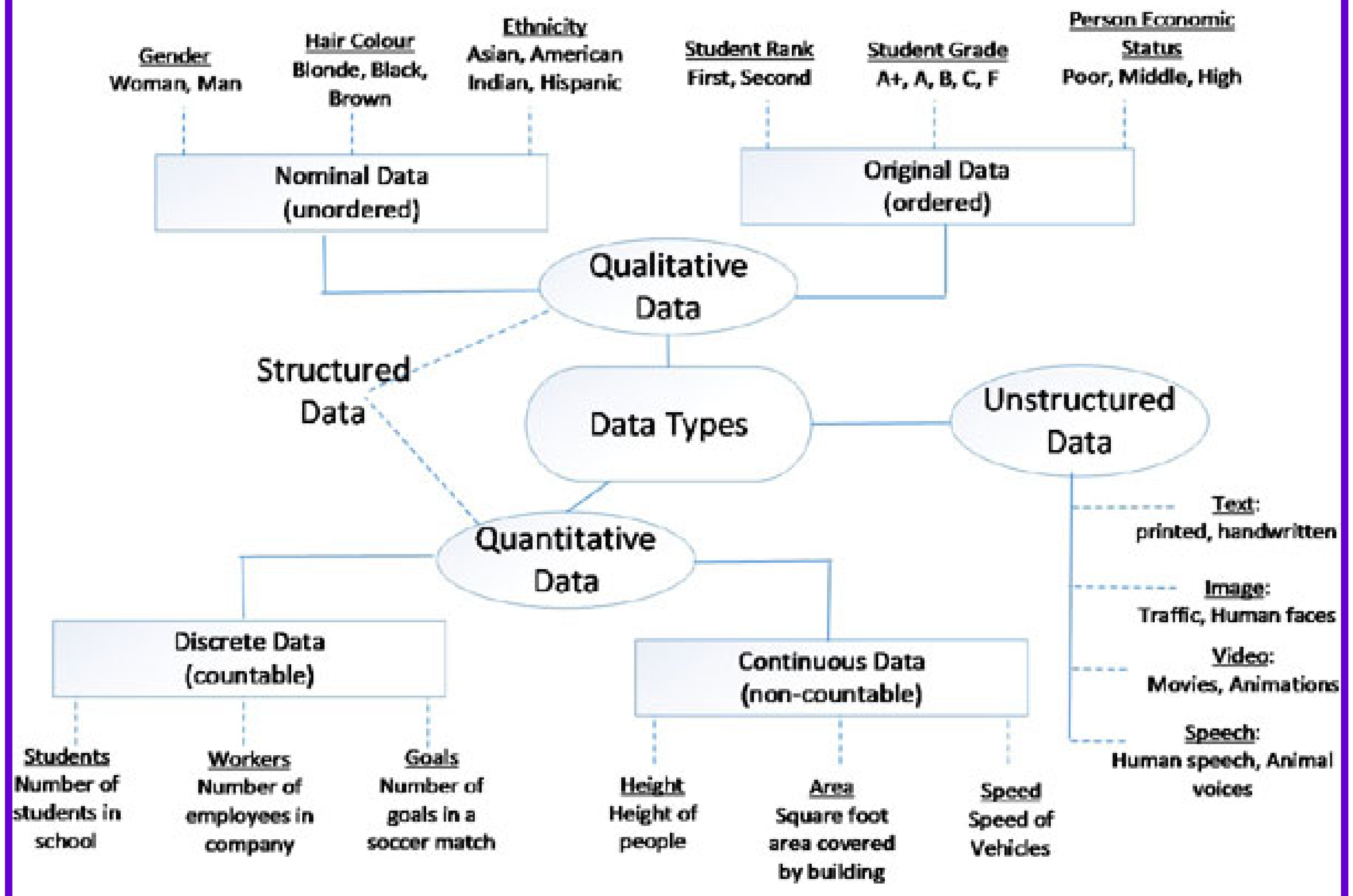
4 ML vs Traditional Approaches

5 Types of ML Systems

6 ML SDLC (How To Develop ML Models)

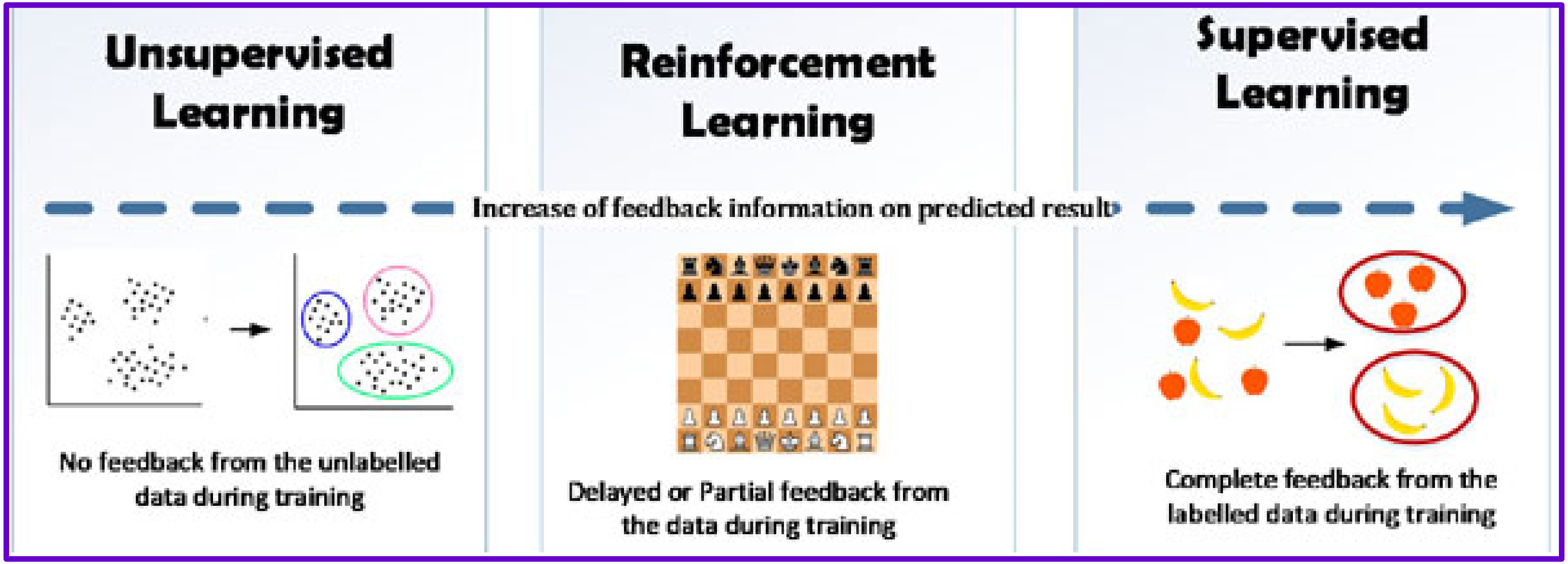
Data types

All data types must be converted to numerical form before feeding them into machine learning model. This is done in the feature extraction phase of ML model building.



Types of ML Systems: Overview

We can categorize machine learning model types based on the level of the feedback that algorithms receive during its learning phase.



Types of ML Systems: Categorization Criteria

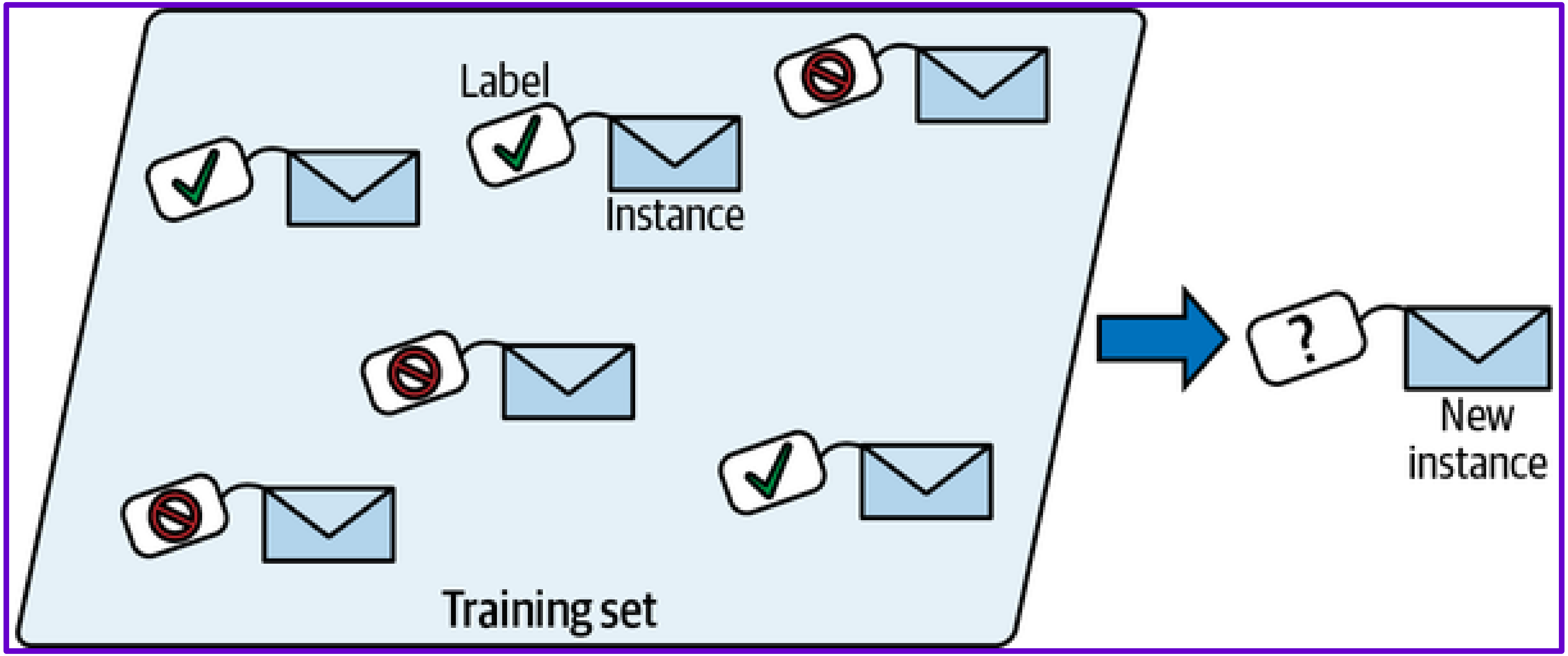
How they are supervised during training (supervised, unsupervised, semi-supervised, self-supervised, and others)

Whether or not they can learn incrementally on the fly (online versus batch learning)

Whether they work by simply comparing new data points to known data points, or instead by detecting patterns in the training data and building a predictive model, much like scientists do (instance-based versus model-based learning)

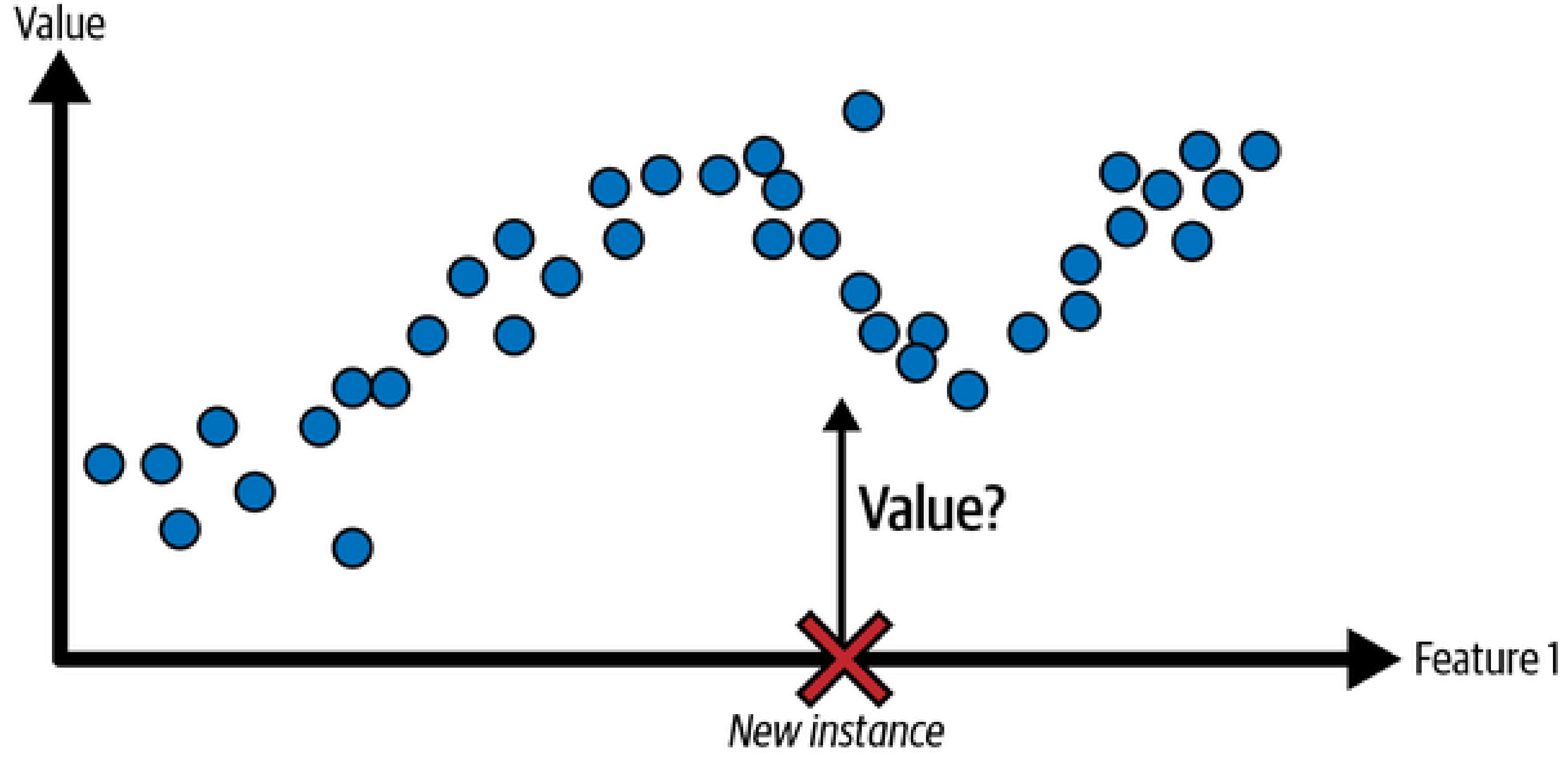
Supervised learning: Classifciation

In supervised learning , the training set you feed to the algorithm includes the desired solutions, called labels. and it must learn how to classify.



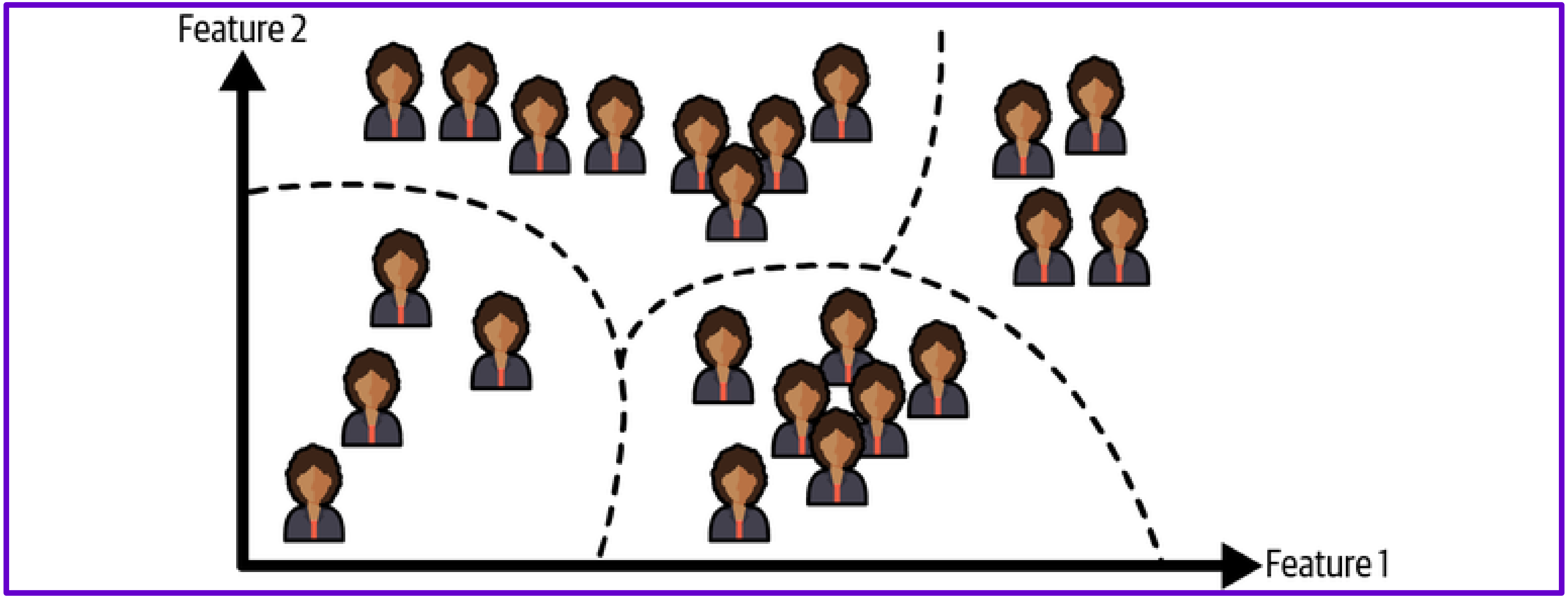
Supervised learning : Regression

Predict a target numeric value, such as the price of a car, given a set of features



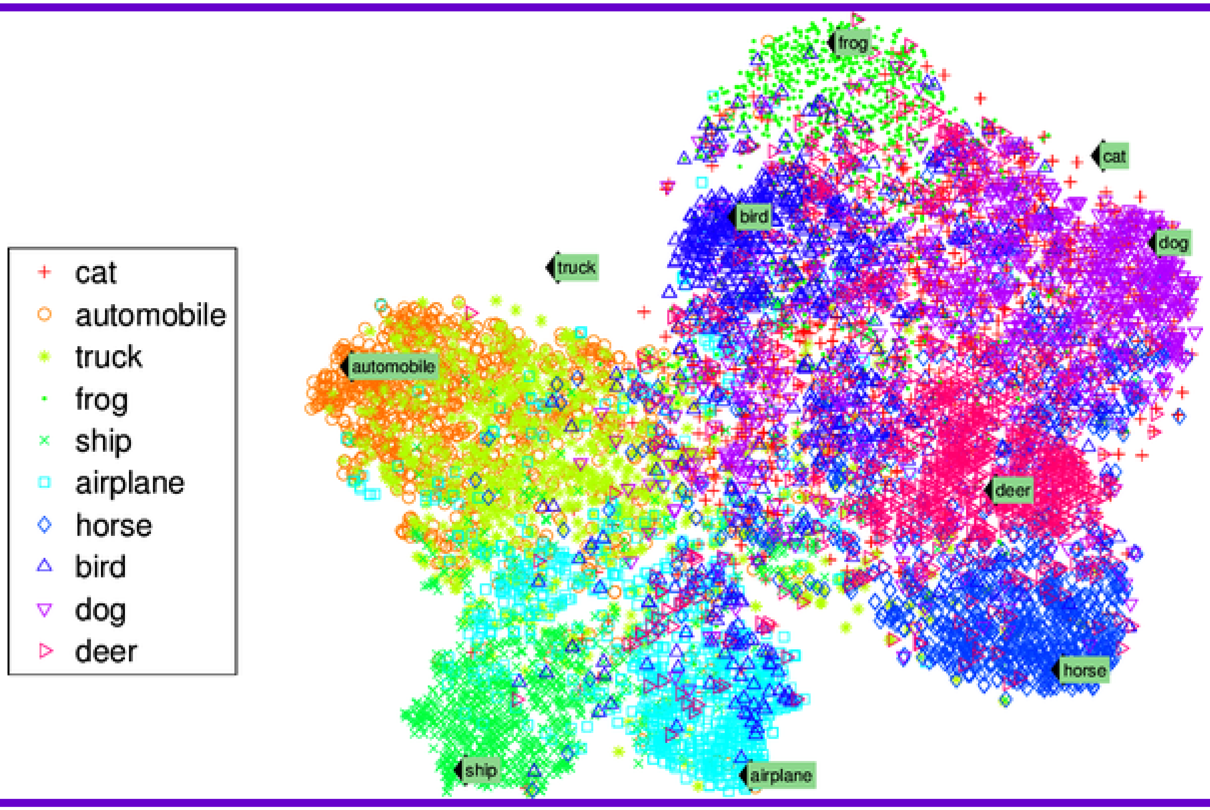
Unsupervised learning: Clustering

In unsupervised learning , as you might guess, the training data is unlabeled. The system tries to learn without a teacher.



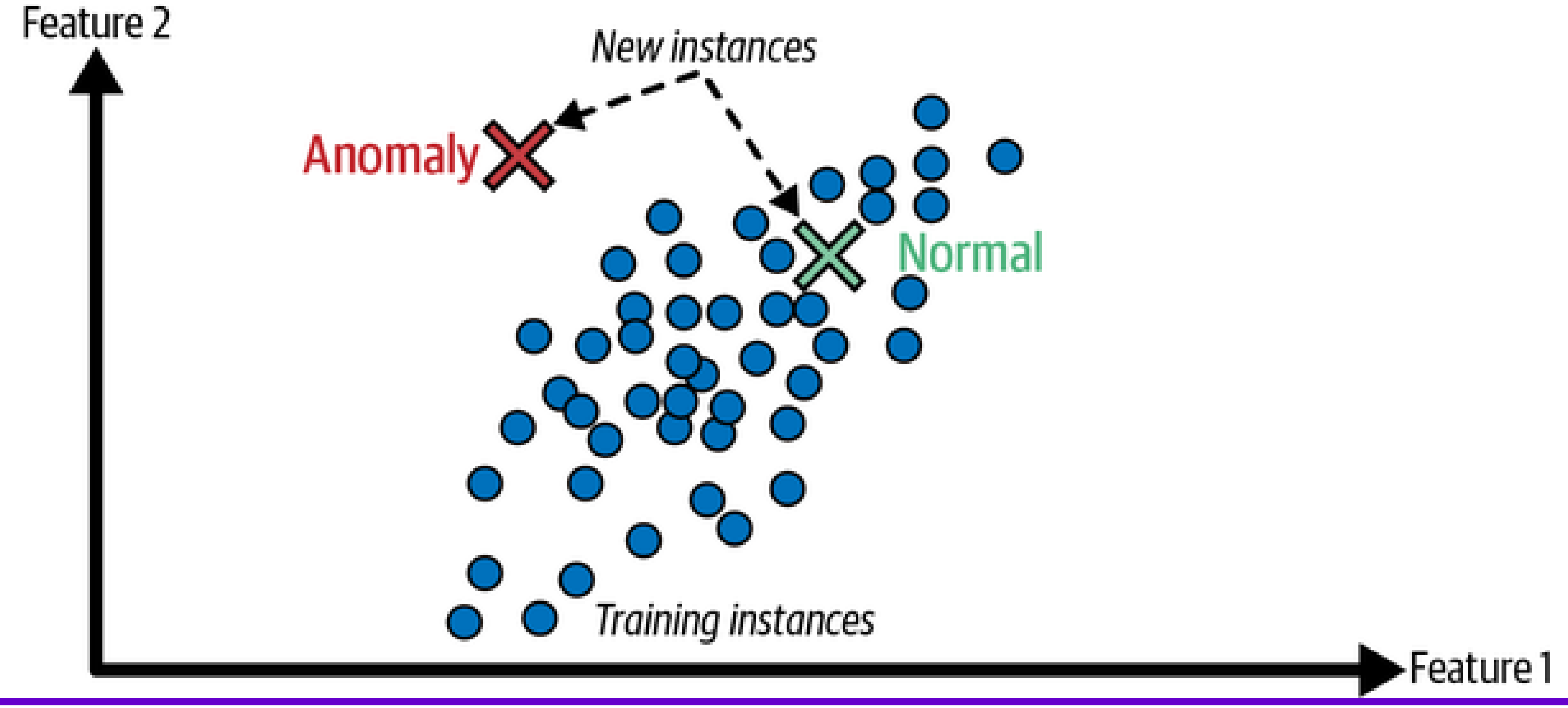
Unsupervised learning: Visualization

You feed them a lot of complex and unlabeled data, and they output a 2D or 3D representation of your data that can easily be plotted.



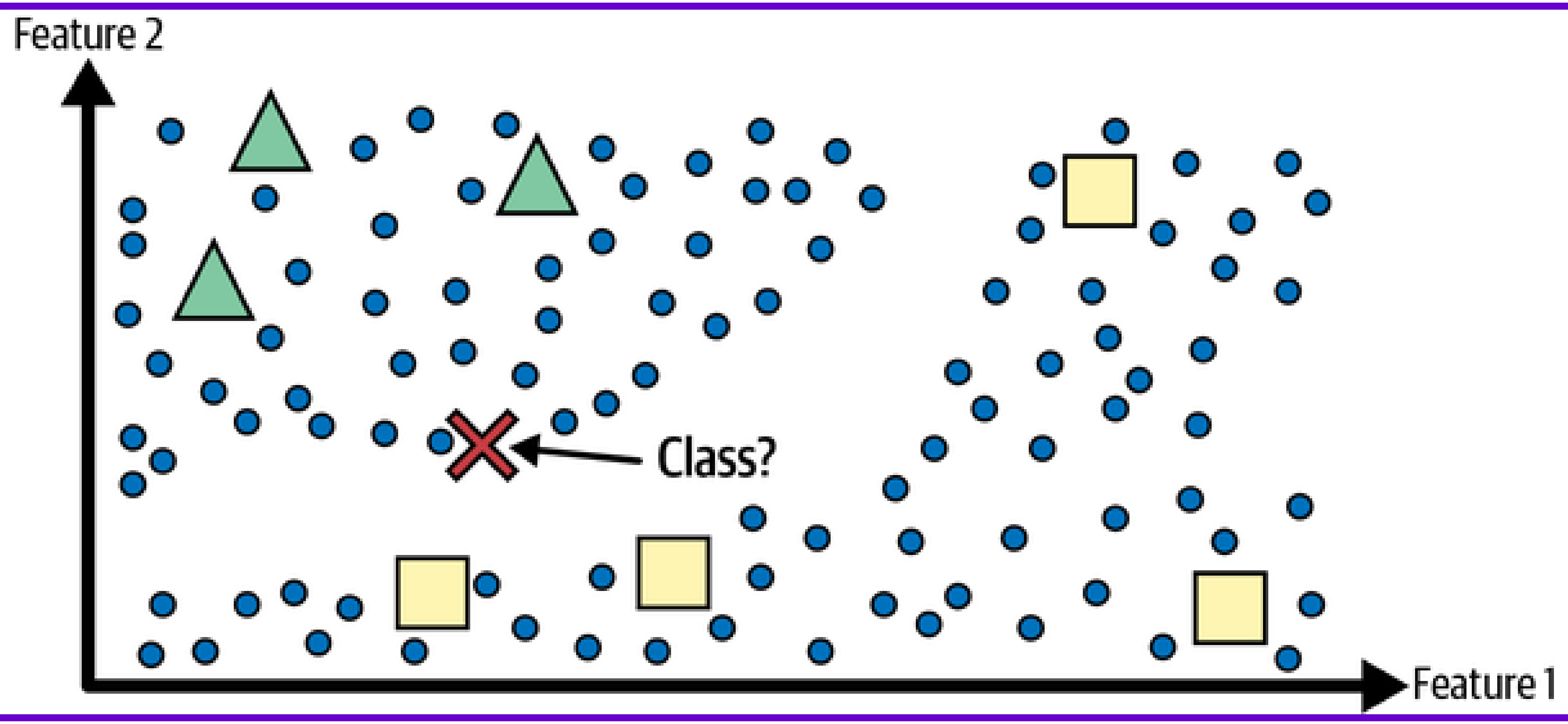
Unsupervised learning: Anomaly detection

The system is shown mostly normal instances during training, so it learns to recognize them; then, when it sees a new instance, it can tell whether it looks like a normal one or whether it is likely an anomaly



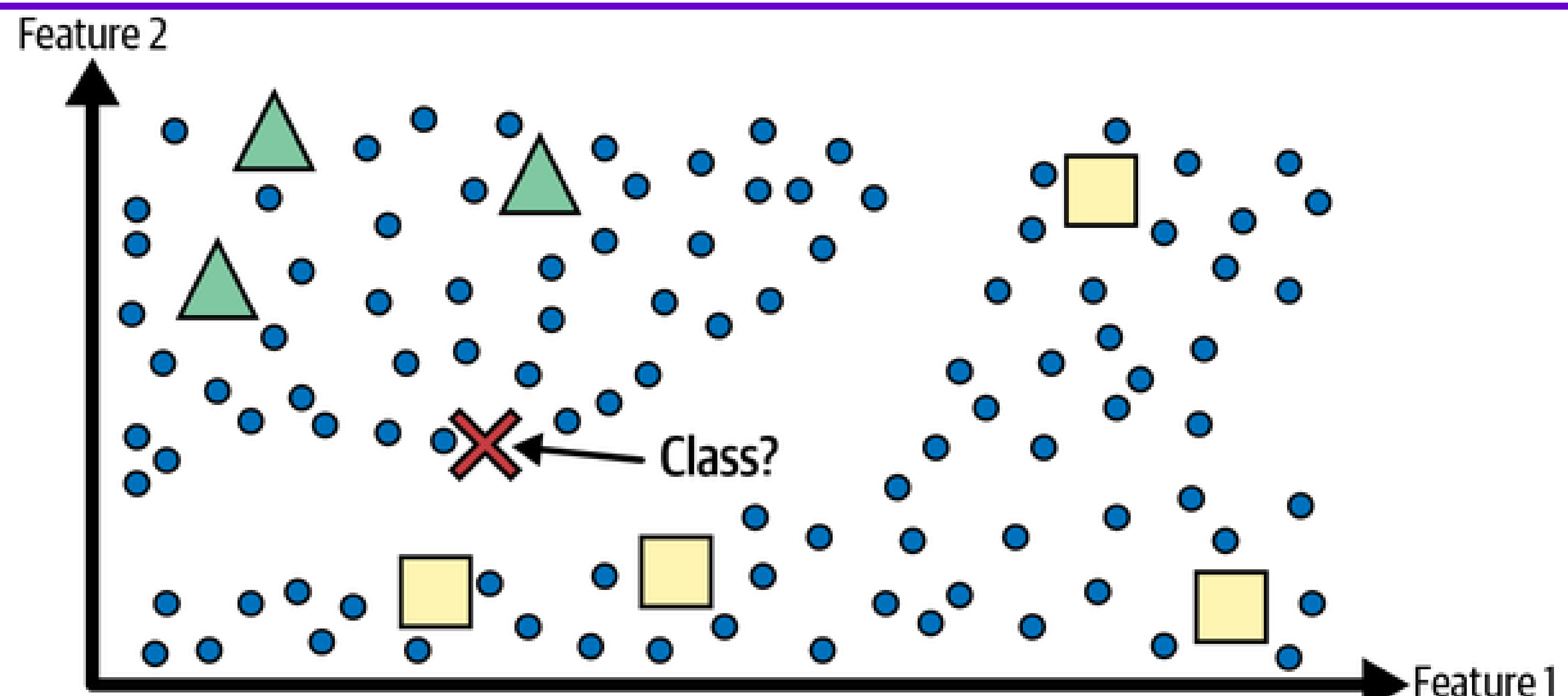
Semi-supervised learning

Since labeling data is usually time-consuming and costly, you will often have plenty of unlabeled instances, and few labeled instances. Some algorithms can deal with data that's partially labeled.



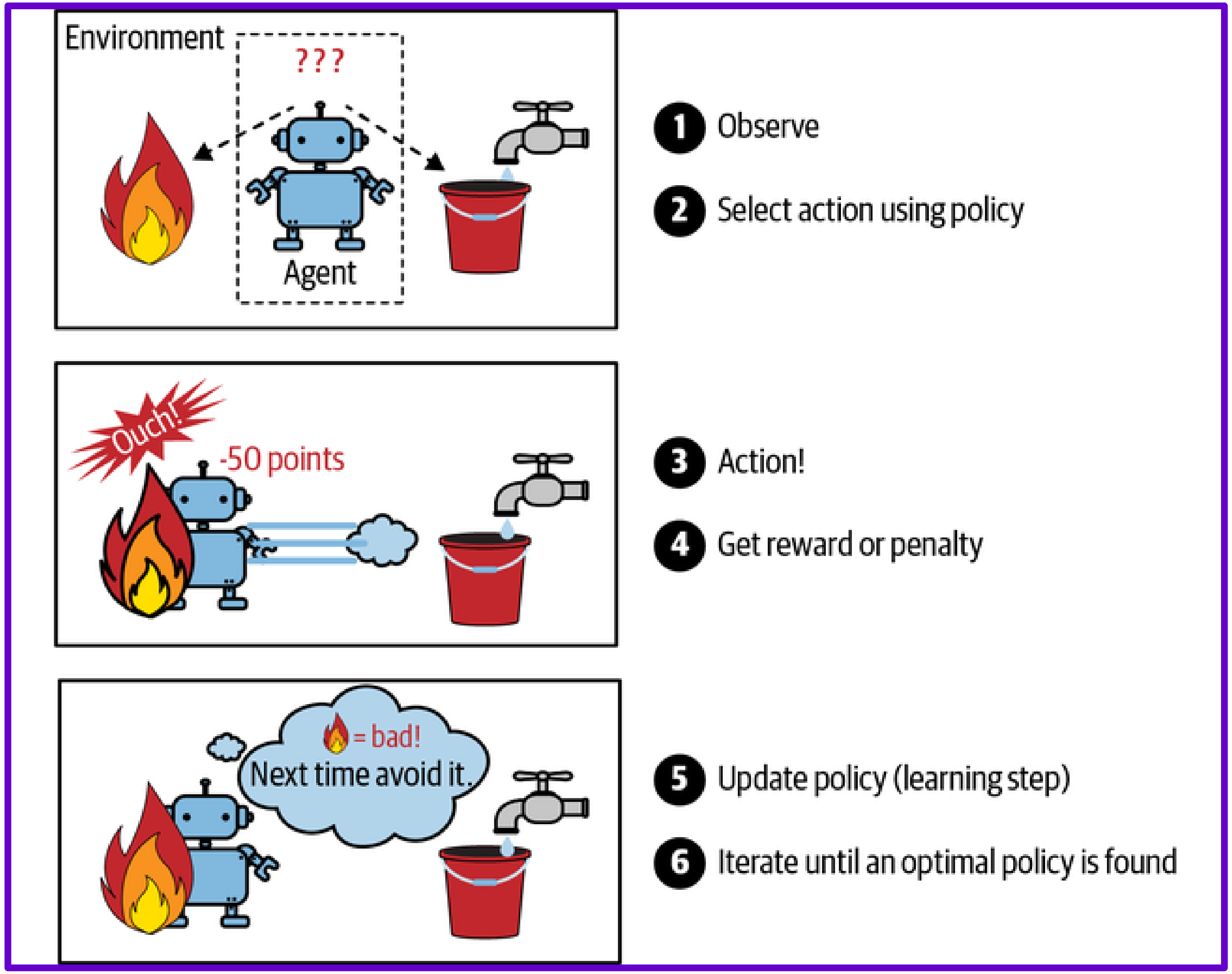
Self-supervised learning

actually generating a fully labeled dataset from a fully unlabeled one.



Reinforcement learning

The learning system, called an agent in this context, can observe the environment, select and perform actions, and get rewards in return It must then learn by itself what is the best strategy, called a policy , to get the most reward over time.



Batch Versus Online Learning

First the system is trained, and then it is launched into production and runs without learning anymore; it just applies what it has learned.

Unfortunately, a model's performance tends to decay slowly over time, simply because the world continues to evolve while the model remains unchanged.(model rot or data drift)

If the model deals with fast-evolving systems, for example making predictions on the financial market, then it is likely to decay quite fast.

Online learning

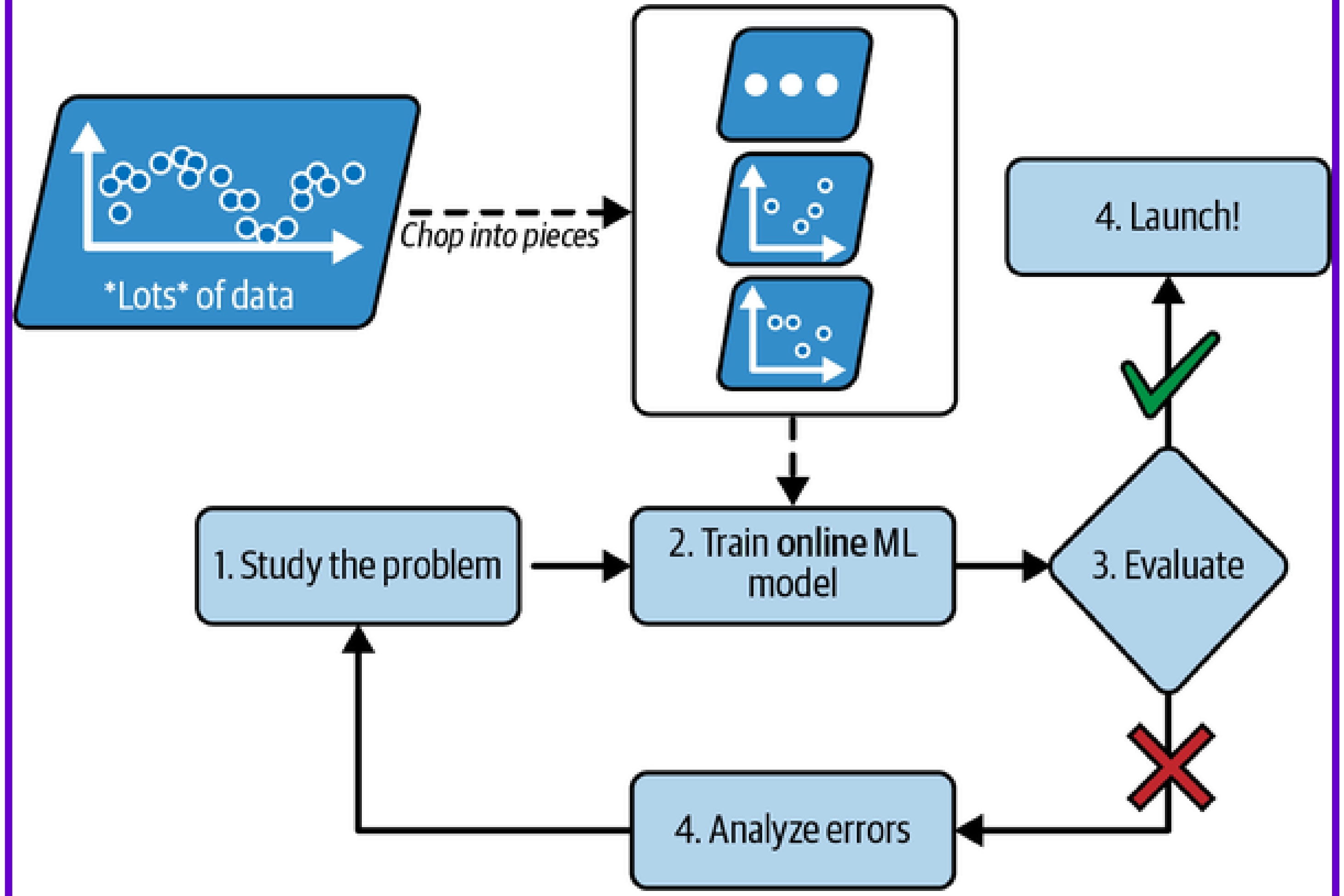
First the system is trained, and then it is launched into production and runs without learning anymore; it just applies what it has learned.

Unfortunately, a model's performance tends to decay slowly over time, simply because the world continues to evolve while the model remains unchanged.(model rot or data drift)

If the model deals with fast-evolving systems, for example making predictions on the financial market, then it is likely to decay quite fast.

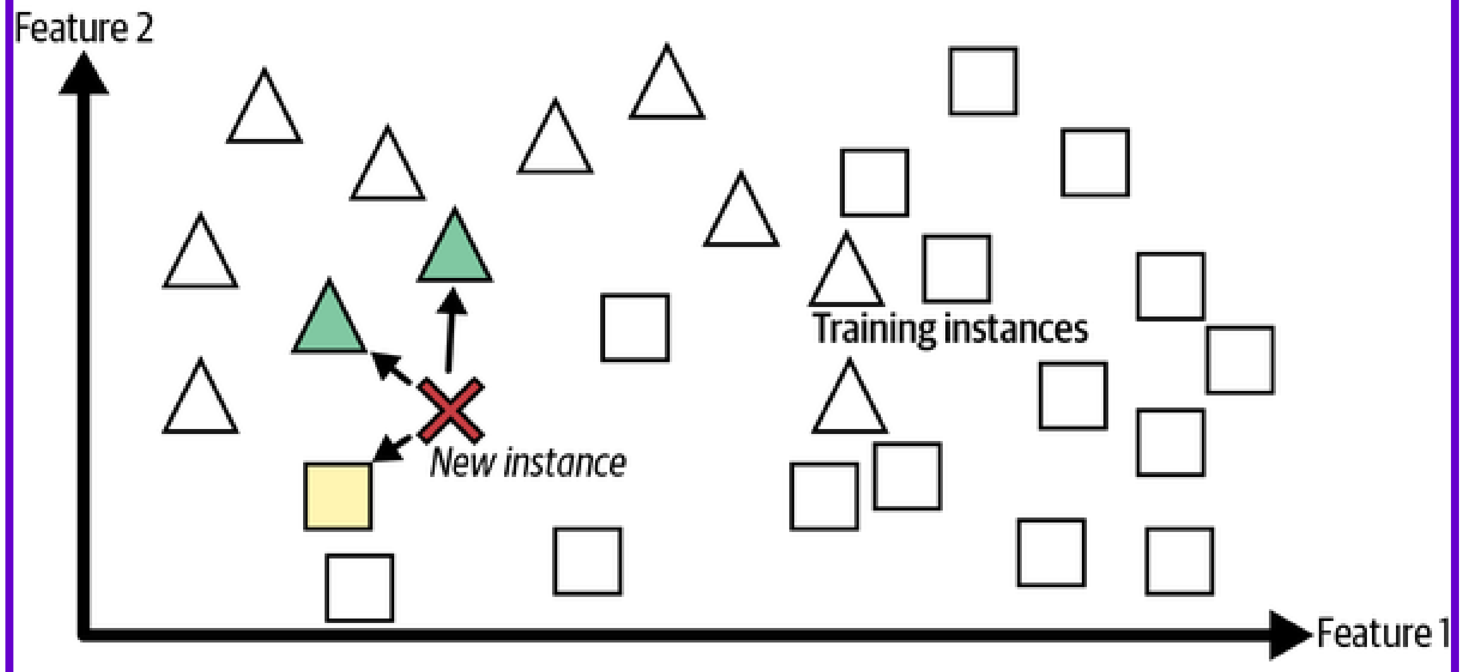
Online learning

You train the system incrementally by feeding it data instances sequentially, either individually or in small groups called mini-batches .so the system can learn about new data on the fly



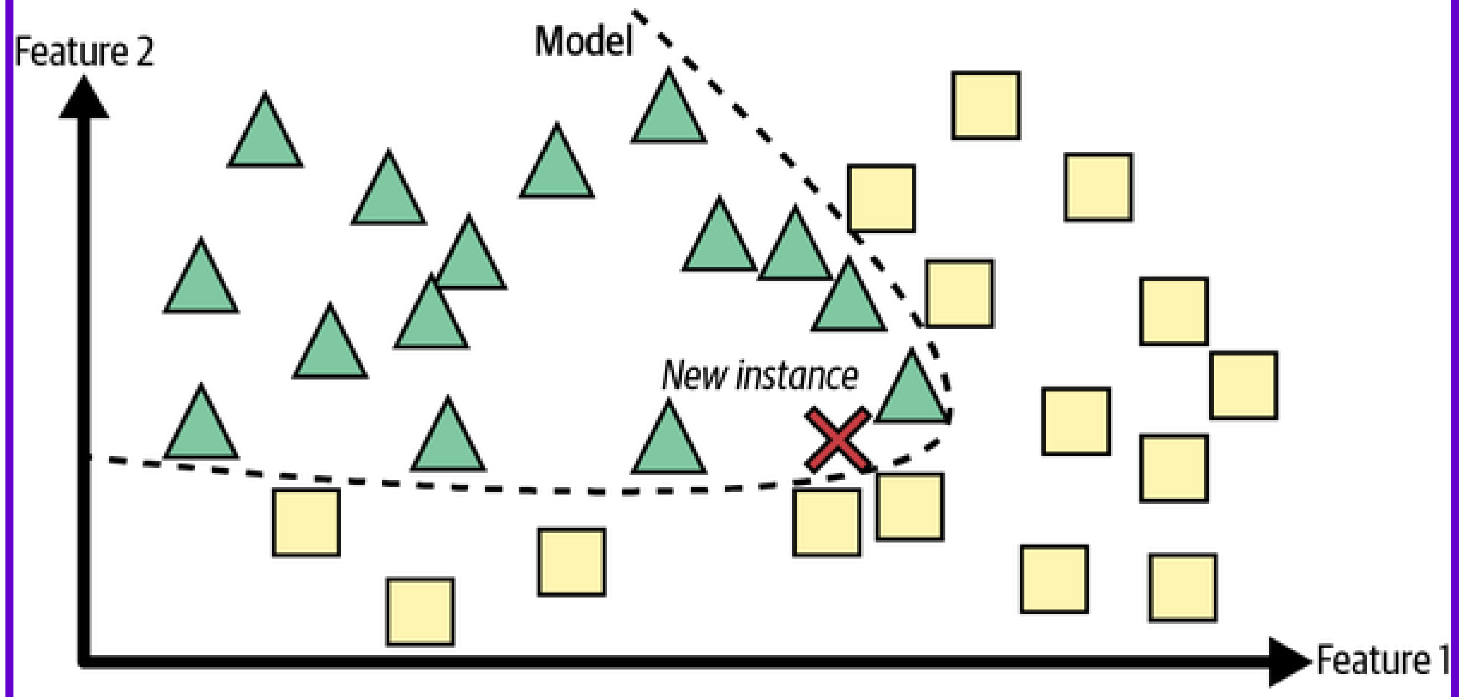
Instance-Based Versus Model-Based Learning

The system learns the examples by heart, then generalizes to new cases by using a similarity measure to compare them to the learned examples.



Model-Based Learning

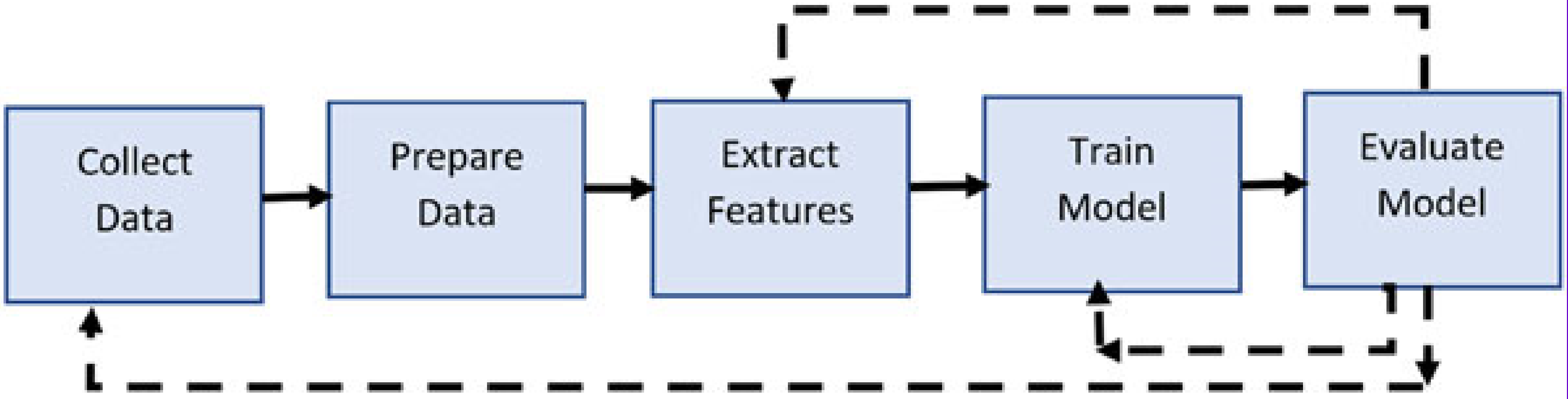
Another way to generalize from a set of examples is to build a model of these examples and then use that model to make predictions.



1. Data Science, AI and ML
2. ML Applications and Use cases
3. Why We Should Use Machine Learning
4. ML vs Traditional Approaches
5. Types of ML Systems
6. ML SDLC (How To Develop ML Models)

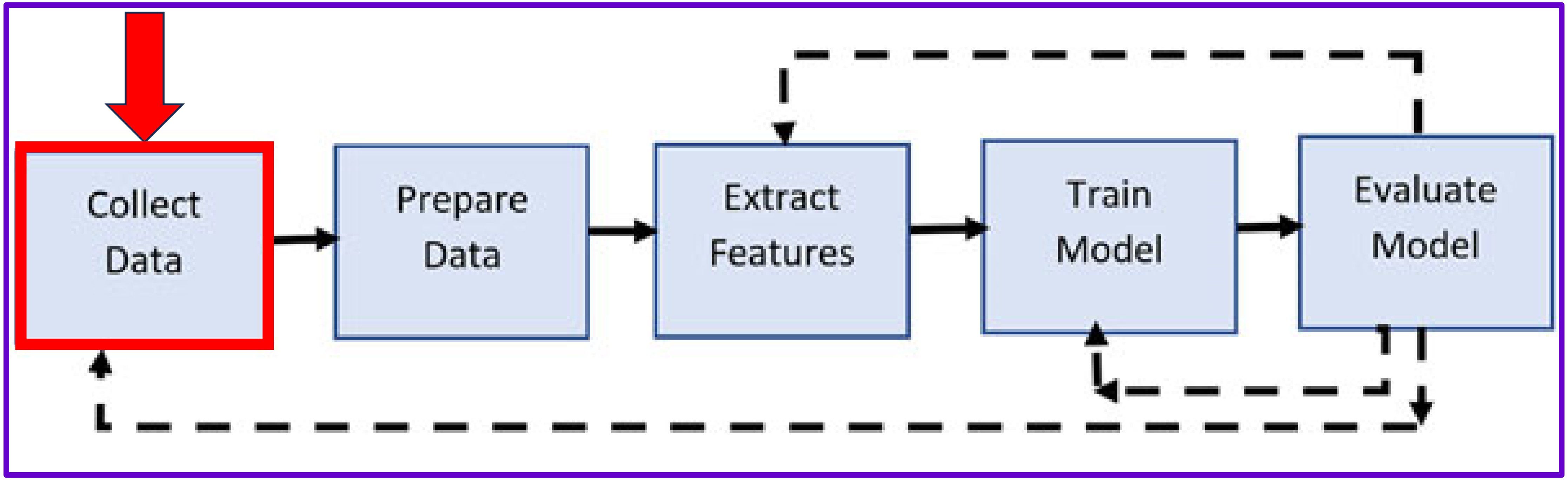
How are ML Models created?

Building a ML model is an iterative process. It starts with understanding the business problem and then collecting data related to the problem domain. Then, this data is processed, cleaned, and prepared for modelling.



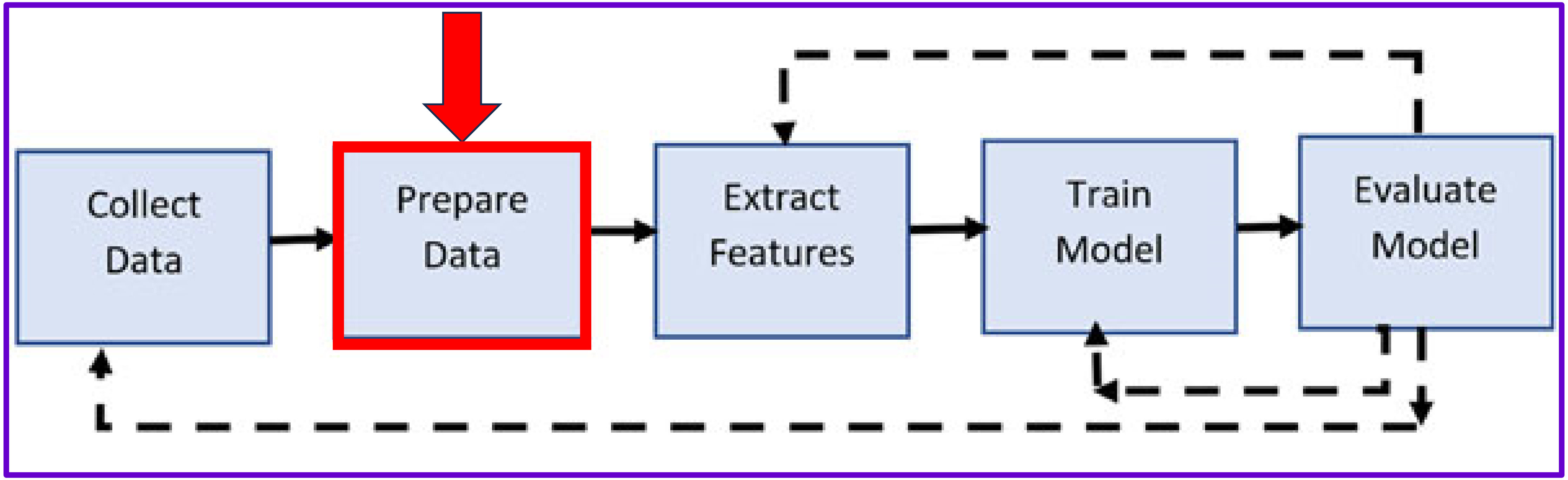
How are ML Models created?
Step 1: Data collection

The process of collecting observations or data related to the problem is called data collection.



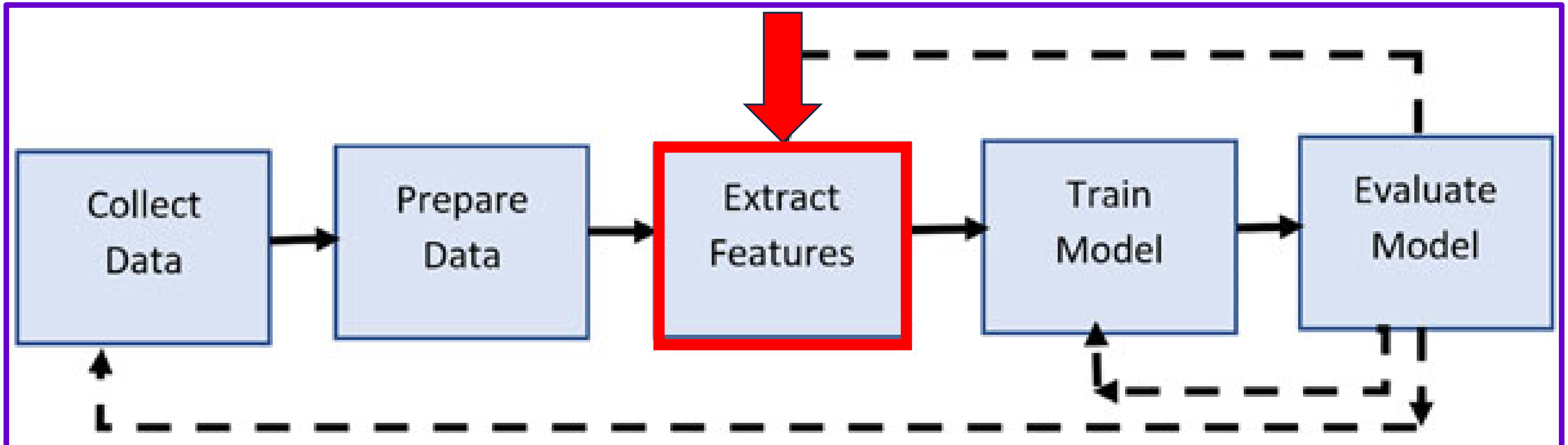
How are ML Models created?
Step 2: Data preparation

In this step, the observations are analyzed to check whether there are any missing values, any error in data collection like an abnormal value of observation, and if so, those must be corrected or removed from dataset.



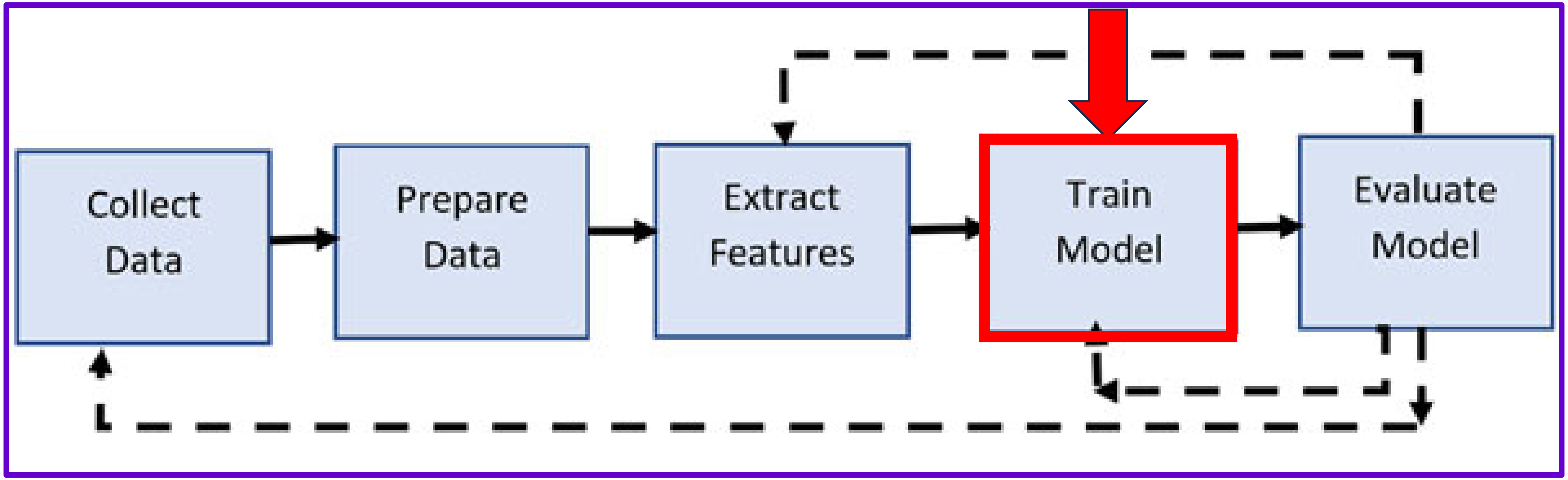
How are ML Models created?
Step 3: Feature extraction/selection

The features of the cleaned data are further analyzed for obvious intercorrelations. This step is also called feature engineering .



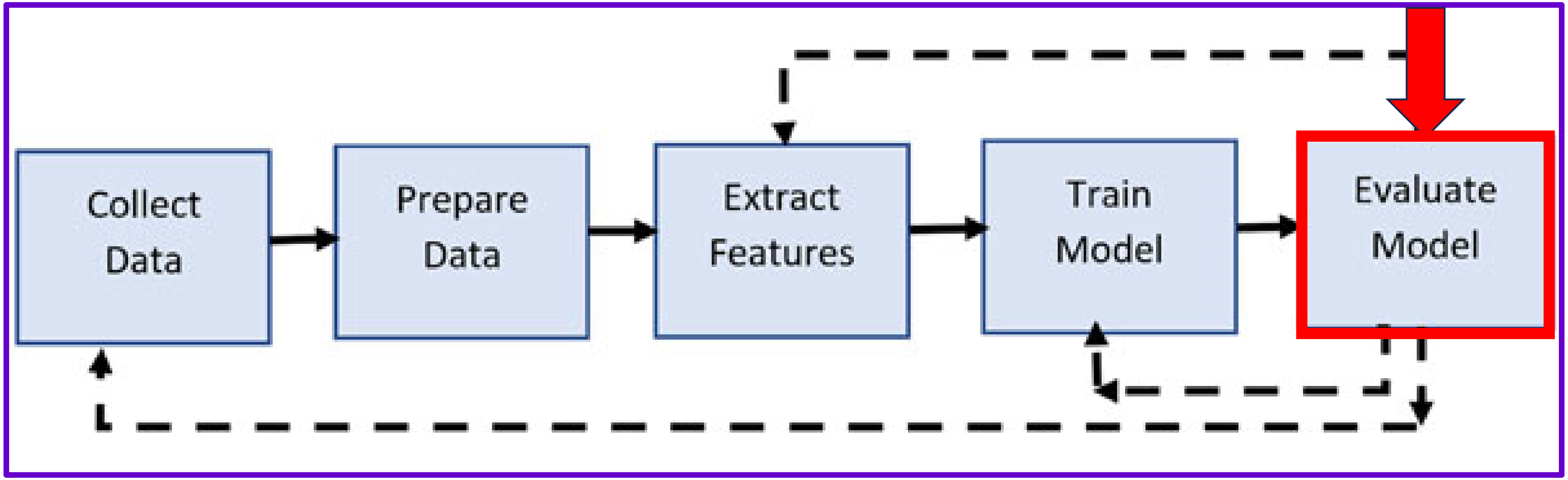
How are ML Models created?
Step 4:Train model

Choosing a mathematical function that accepts selected features and outputs desired result: Model selection



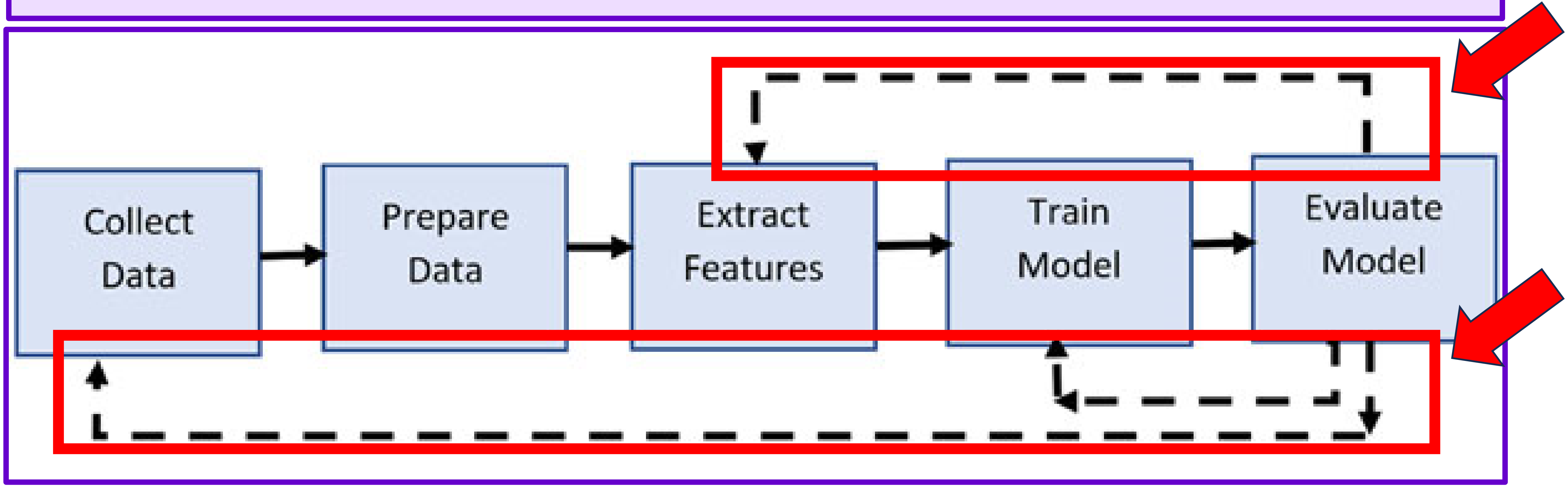
How are ML Models created?
Step 5: Model evaluation

Various metrices are designed to access the quality of the models created in the previous step.



How are ML Models created?
Step 6: Model Correction

If it's found that the model quality is not acceptable, then various ways of improving the models are tried.



Main Challenges of Machine Learning

In short, since your main task is to select a model and train it on some data, the **two things that can go wrong** are "bad model" and "bad data". Let's start with examples of bad data.

Main Challenges of Machine Learning

- Insufficient Quantity of Training Data
- Nonrepresentative Training Data
- Poor-Quality Data Obviously
- Irrelevant Features
- Overfitting the Training Data
- Underfitting the Training Data

Course References

[1] S. J. Russell and P. Norvig, *Artificial Intelligence: A Modern Approach*. Pearson, 2021.
[2] T. Ghosh and S. K. B. Math, *Practical Mathematics for AI and Deep Learning: A Concise yet In-Depth Guide on Fundamentals of Computer Vision, NLP, Complex Deep Neural Networks and Machine Learning (English Edition)*. BPB Publications, 2022.
[3] M. P. Deisenroth, A. A. Faisal, and C. S. Ong, *Mathematics for Machine Learning*. Cambridge University Press, 2020.
[4] T. V. Geetha and S. Sendhilkumar, *Machine Learning: Concepts, Techniques and Applications*. CRC Press LLC, 2023.
[5] A. Géron, *Hands-On Machine Learning with Scikit-Learn, Keras, and TensorFlow: Concepts, Tools, and Techniques to Build Intelligent Systems*. O'Reilly Media, 2023.
[6] O. Theobald, *Machine Learning for Absolute Beginners: A Plain English Introduction (Third Edition)*. Scatterplot Press, 2021.

Accessing Course Resource

linkedin.com/in/Samanipour

t.me/SamaniGroup

github.com/Samanipour