# Point Cloud Classification and Machine Learning

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# 1. What is Point Cloud Classification?

Before explaining Point Cloud Classification, dissecting the term and explaining the underlying concepts is imperative. These underlying concepts are 'Point Cloud' and 'Classification.'

## a. Point Cloud


*Figure 1: 'Human Face Made up of Point Clouds' SEO Test Image*

A Point Cloud is the most basic form of digital reality. It is a collection of points over a physical object's surface that can completely describe and represent it. When you view an object's point cloud collection in a software application (digitally), you can see the object manifested as a cloud of points (Andersen, Chapman, and Wilcox, 2003).

Alternatively, we can describe Point Clouds as an unordered set of points possessing unique X, Y, and Z coordinates. So, from a Machine Learning (ML) perspective, Point Clouds are rudimentary elements comprised of spatial measurements, forming a dataset representing a complete three-dimensional (3D) physical object. Experts often employ Point Clouds in 3D scanning, which involves analyzing physical objects to gather shape-related data (Thompson, 2019).

Point Clouds can hold wealthy spatial information and are highly efficient in processing large-scale data sets (Wen, Cheng, and Yu, 2021). These attributes allow them to effectively express an object's shape, size, position, and direction. Therefore, making them very beneficial in terms of high spatial utilization and, in turn, a critical three-dimensional (3D) data type. Point Clouds have many real-life applications across many realms, including large-scale scene reconstruction, virtual reality, digital elevation model production, and many other technology-intensive fields (Zhang *et al.*, 2021).

## b. Classification

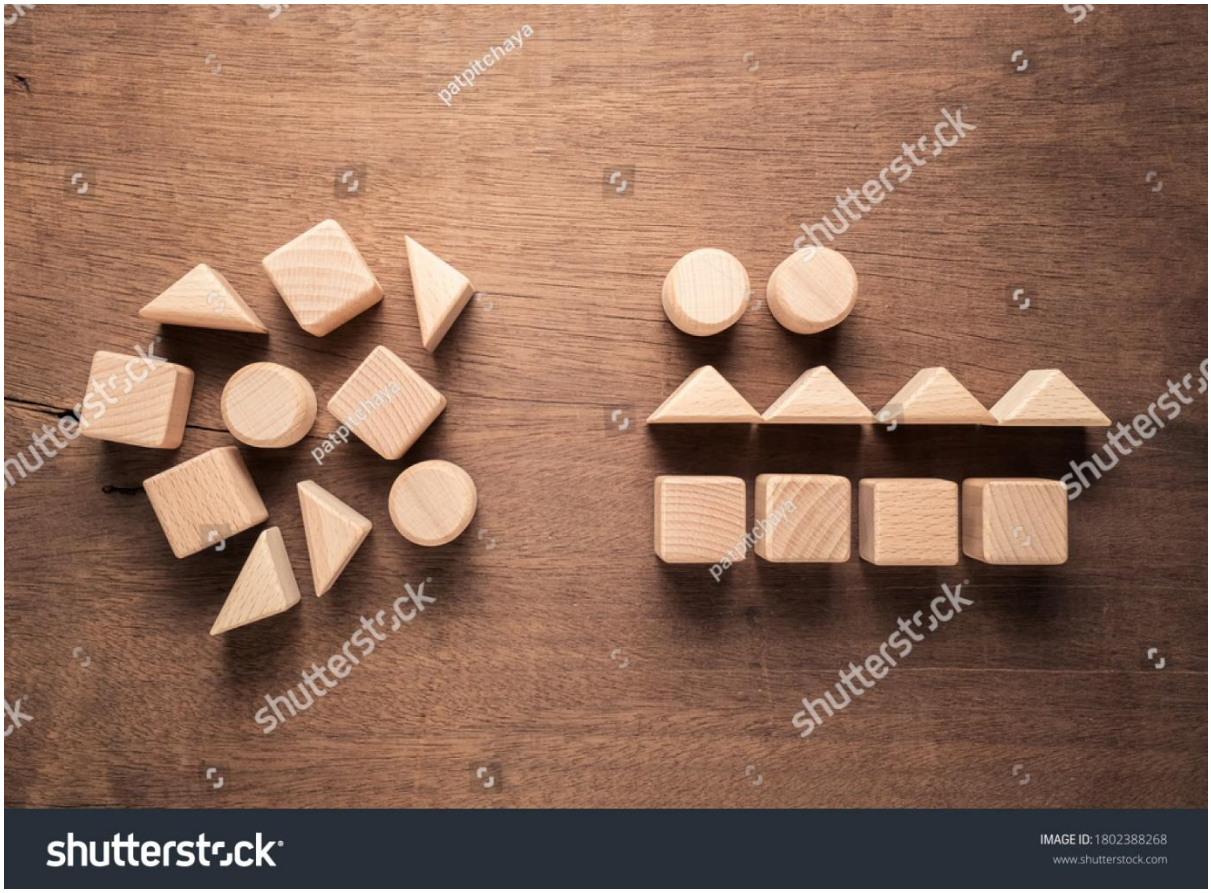


*Figure 2: 'Classification' SEO Test Image*

Classification is an ML task involving classifying objects under distinct categories like 'True' or 'False' or other pre-defined labels like 'Dog' or 'Cat' (Simplilearn, 2021). For example, given a large consisting of dog and cat images, we can use ML techniques (Classification) to determine and categorize whether each image is that of a dog or a cat.

### c. Point Cloud Classification

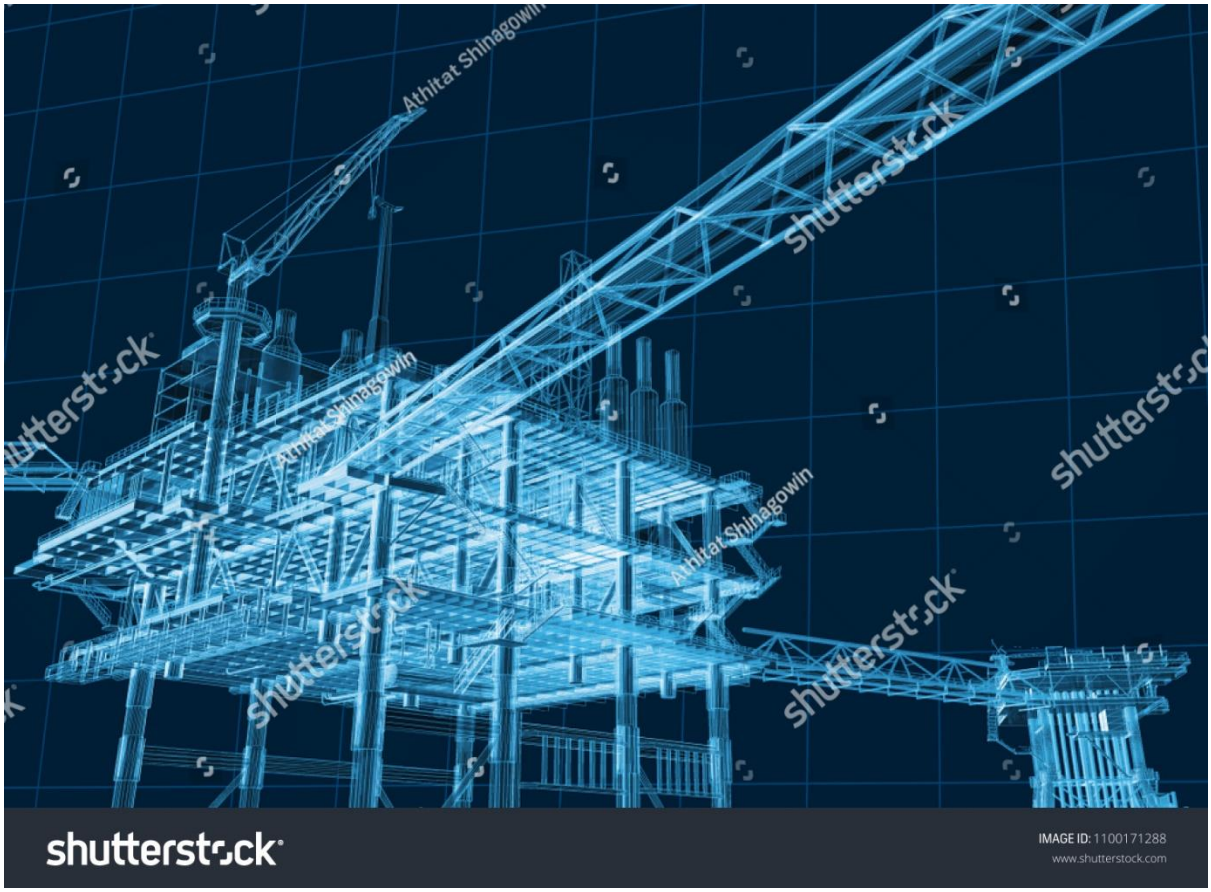


*Figure 3: '3D Render of an Oil Rig' SEO Test Image*

The two concepts above yield Point Cloud Classification. Given a collection of Point Clouds, Point Cloud Classification refers to the task of assigning a pre-defined category label to each point cloud (Dai, Zhang, and Lin 2020). Say we have Point Clouds representing an aerial view of a parking lot. We can classify these Point Clouds under different categories. The categories can include cars, buildings, trees, concrete ground, and other captured objects.

## 2. Machine Learning Explained

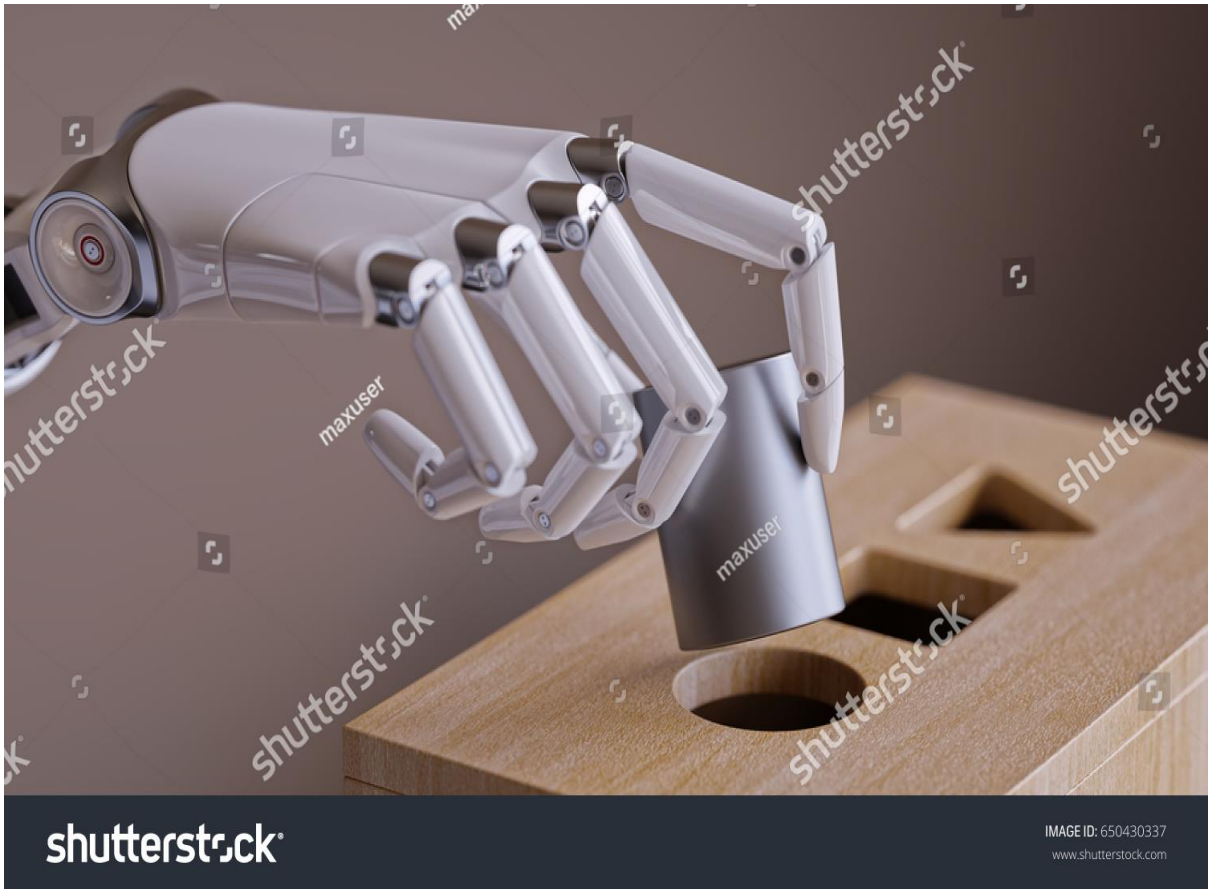


*Figure 4: 'Machine Learning' Test SEO Image*

The recurrence of the term 'ML' in the previous section implies a strong correlation between Point Cloud Classification and ML. So, we will shed more light on ML to help paint a more wholesome picture of Point Cloud Classification.

## a. Traditional Computer Programming vs. Machine Learning

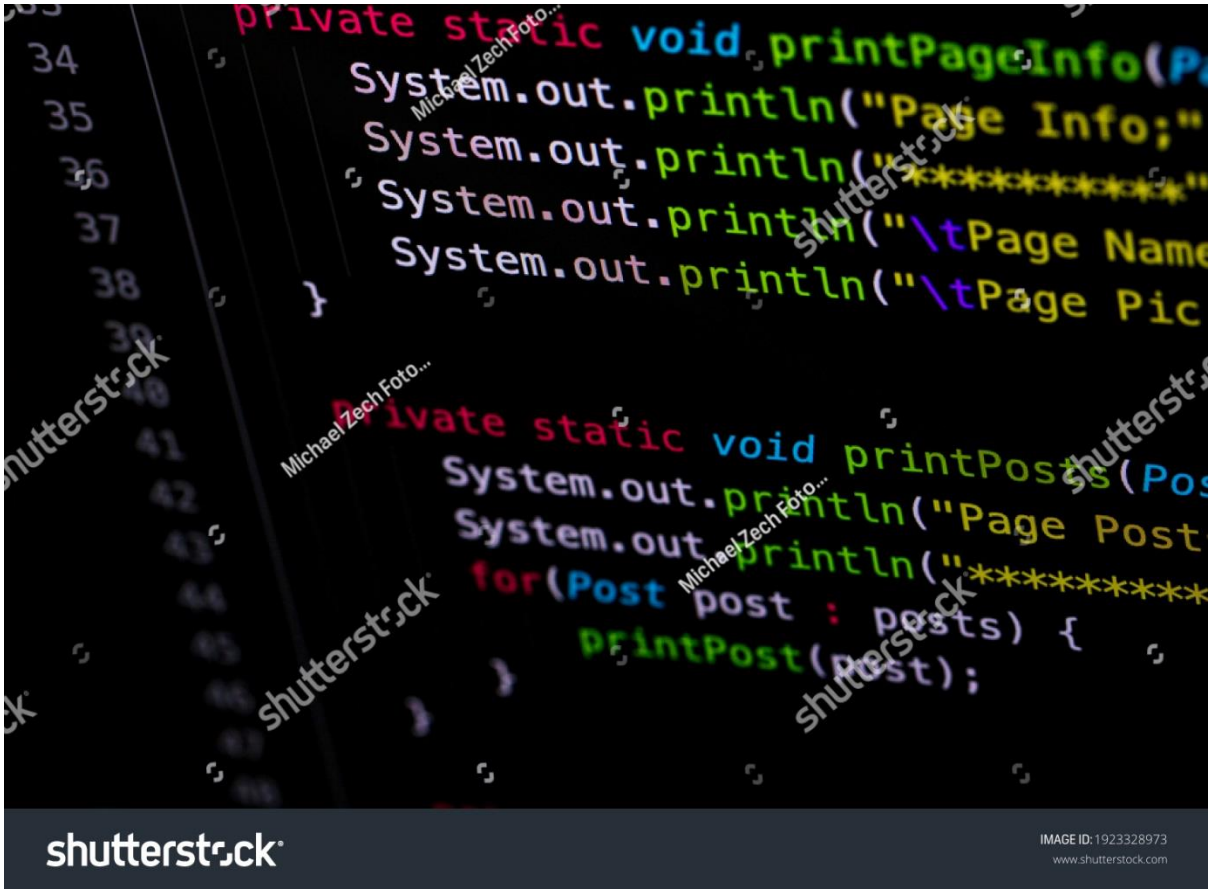


*Figure 5: 'Java Code' SEO Test Image*

To get a computer to complete a task, you usually have to use a programming language to communicate the instructions. The act of writing these instructions (code) is called computer programming. A programmer must be semantically and syntactically exact with their code because computers do not infer a programmer's intent when interpreting code; they execute code as-is.

Contrastingly, ML provides a means to get computers to accomplish tasks without explicitly programming them. It allows computers to 'learn' from relevant data to achieve a particular task. Even better, the ML systems can perform the said task better the more they do it.

## b. Ideal Problem Scenarios for Machine Learning

ML is ideal situations where existing solutions achieved via traditional programming require a lot of fine-tuning or a long list of rules. It also comes in handy in fluctuating environments. It is easier for an ML system to adapt to new data than for a programmer to continually modify their code to suit an ever-changing environment. Lastly, it also proves helpful in instances where we want to gain insights from a large amount of data to understand complex issues (Géron, 2019).

This last sentence in the preceding paragraph is exceptionally compatible with the earlier parking lot aerial view example. In that scenario, the 'data' refer to the point clouds of the parking lot. The 'complex issue' refers to the physical object(s) in the image we want to analyze. The 'insights' we are trying to gain would refer to our intention to pick apart the 'complex issue' by making out the different objects (cars, buildings, trees, concrete ground, etc.) in the aerial view image.

### c. The Three Most Common Types of Machine Learning

There are three main approaches to ML. These include Supervised Learning, Unsupervised Learning, and Semi-supervised Learning (Géron, 2019).

#### i. Supervised Learning

Supervised Learning involves using data (training data) comprising the desired solutions (labels) to train an ML algorithm (model). So that the model may recognize previously seen patterns when presented with new data. If this description sounds familiar, it is because you have just read a more ML-*esque* description of the Classification concept. So, to clarify, the Dogs and Cats images example from earlier and the Point Cloud Classification concept both fall under Supervised Learning. In Point Cloud Classification, an ML system learns from previous example point clouds (training data). It then uses this knowledge to classify new point clouds.

#### ii. Unsupervised Learning

An ML system attempts to learn without seeing any examples (training data) in Unsupervised Learning. This kind of learning often comes in handy when a programmer wants an ML system to discover hidden patterns in data autonomously. A relatable real-life application is in credit card fraud detection. In this scenario, an ML system monitors transactions in real-time, looking to flag anomalous (unusual) transactions that could indicate fraudulent activity.

#### iii. Semi-supervised Learning

As deducible from the name, Semi-supervised Learning, this learning approach combines the ideas of the first two learning approaches. A real-life application is language translation. A Semi-supervised ML system can translate words from one language without access to complete dictionaries in both languages (Burns, 2021).

# 3. Security Within Point Cloud Classification


*Figure 6: 'Cybersecurity' SEO Test Image*

As discussed before, Point Clouds has many real-life applications, from simple 3D scanning to more involved applications such as robotics and safety-critical systems like autonomous driving. The two latter application areas (robotics and safety-critical systems) adequately highlight the need for assured security in Point Cloud Classification. Robots are helpful across many sectors, including construction, manufacturing, agriculture, medicine, etc. On the other hand, safety-critical systems refer to systems that can cause death or serious injury should they malfunction. These include inventions like nuclear reactors, amusement park infrastructure, ambulance control systems, and, as stated before, autonomous vehicles. A medical robot relying on a compromised Point Cloud Classifier module as part of its optical setup may overdose a patient by issuing a wrong prescription. Similarly, a driverless car depending on a malfunctioning Point Cloud Classifier to make out objects on the road is nothing short of a mobile killing machine. So again, it is not difficult to see why security is vital in Point Cloud Classification.

## a. Most Common Point Cloud Classification-Related Security Attacks

However, like almost every technology, Point Clouds are susceptible to attacks. There are primarily four attack types in Point Cloud Classification. These include point modification, addition, deletion, and perturbation attacks. An attacker can modify, add, or delete a small number of points, causing a Point Cloud Classifier to misclassify Point Clouds. They may also execute a perturbation attack for the same nefarious end goal by combining modification, addition, deletion actions (Jia and Gong 2021).

### b. Approaches to Security Attack Mitigation

There have been many proposals and innovations towards mitigating security attacks in Point Cloud Classification. These solutions generally fall into two broad categories. The first category is solutions meant for attack detection in Point Cloud Classifiers. The second category is solutions that aim to train more robust Point Cloud Classifiers that can withstand security attacks. However, there is always a possibility that an adversary may employ advanced attacks to overcome many of these attack mitigation solutions (Jia and Gong 2021).

# 4. How Point Cloud Classification and Machine Learning Can Help You


*Figure 7: 'Industries' SEO Test Image*

Our earlier discussions have already acquainted us with some benefits that Point Cloud Classification and ML can offer various industries. However, how you leverage Point Cloud Classification and ML depends on what you do. While many sectors use Point Cloud Classification to achieve highly technological feats, it also benefits less technology-intensive industries. For example, the Agriculture and Forestry and Mining and Aggregates industries. So, we will briefly review the lesser-known benefits and applications of Point Cloud Classification and ML for a well-rounded showcase of the capabilities of these two concepts.

Point Cloud Classification plays a crucial role in modern agriculture, specifically Remote Sensing and Precision Agriculture. Remote Sensing is a method of gathering information about an object or a physical area of the natural world (in this context, a farm) from a distance without direct physical contact with the object or area under study. Remote Sensing plays a significant role in Precision Agriculture (Shanmugapriya *et al.*, 2019). Precision agriculture involves collecting and using large amounts of crop-related georeferenced data to support managerial decision-making and optimize agricultural inputs (Mesas-Carrascosa *et al.*, 2020). So, Point Cloud Classification empowers agriculturists to more effectively classify, monitor crops, and assess their yields.

Mining experts use Unmanned Aerial Vehicles (UAVs) to obtain all kinds of aerial data on mining sites. These data could be orthophotos, Digital Surface Models (DSMs), and Point Clouds. Then by employing ML techniques to classify these point clouds, they can fulfill various 3D modeling needs. 3D modeling plays a vital role in mining, including asset management, volume calculation, blast-induced ground

vibration operations, open-pit mine mapping, stockpile computation, and pollution monitoring (Bui *et al*., 2020).

# 5. Frequently Asked Questions


*Figure 8: 'FAQs' Test Image*

We have now introduced Point Clouds and what it means to classify them using ML techniques. We have also explored why security is paramount in Point Cloud Classification and the very many applications of Point Cloud Classification. As a final note, we will now consider some of the frequently asked questions on the topic in this last section.

## a. How do you classify Light Detection and Ranging (LiDAR) Points?

LiDAR is a modern, cost-effective remote sensing approach often employed in airborne mapping tasks that uses laser light to sample the earth's surface densely. The dense sampling capability enables the technique to yield accurate X, Y, Z coordinate measurements (Esri, 2019b). LiDAR Points refer to the X, Y, Z coordinate measurements obtained from mapping objects. After collecting these measurements (points), it is now time to classify the points to group them under the object associated with each point. To classify the points, we define the different categories (classes) in an industry-standard file format called LAS files with a (.las) extension. These files store and manage LiDAR data. We then assign the points to the different categories until every point is classified (Esri, 2019a).

## b. What is a Point Cloud Image?

A point cloud image (or point cloud model) is a 3D structure of a physical object generated with millions of points obtained by a 3D scanning device (Chu *et al*., 2020) (Rana, 2015).

### c. What is Pointly?

Pointly is an AI-driven cloud-based Software-as-a-service (SaaS) solution developed by Supper & Supper GmbH for managing and classifying Point Clouds, including LiDAR Point clouds, Photogrammetric, Sonar Point Clouds, and other types of Point Clouds (Pointly, 2021).

### d. What is an Organized Point Cloud?

Organized Point Clouds follow a grid-like structure similar to image pixels in a matrix structure (Hung *et al*., 2017). They are 3D Point Clouds sampled from a regular 2D grid (Holzer, 2012). Besides possessing the basic X, Y, Z coordinates, they also describe the neighborhood relationships between the individual points (Schaefer, 2020).

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