A Comparison of Common Map Area Classification Methods Using Machine Learning With ArcGIS

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1 Project Overview

In this project, comparisons were made between different learning algorithms for mapping land-use types in GIS software. Specifically, this project made use of Esri's ArcGIS - a popular, free, open-source GIS software used by both students and professionals in the fields of cartography, urban planning, geology, and the defense and intelligence industries.

We attempted to analyze and compare four different algorithms: supervised pixel-based learning, unsupervised pixel-based learning, supervised object-based learning, and unsupervised object-based learning. When testing these algorithms, we found that unsupervised object-based learning produced unusable output, and was by far the least functional of the algorithms. The two algorithms that best classified the land types were the unsupervised pixel-based and supervised object-based classification algorithms.

We then outlined a design to apply this algorithm to a consumer application. Our design is for a game similar to GeoGuesser, a game developed by Anton Wallén which presents users with a street-view image of a location and asks the users to guess where in the world they are looking at. Our application design would present users with a land-use map of an area and ask the users to guess where in the world the map area is located.

2 ArcGIS

2.1 Geographic Information System Overview

A geographic information system (GIS) "analyzes and displays geographically referenced information" [2.1]. GISs use location references to categorize areas of land by any number of parameters, including land type, level of development, elevation, area boundaries, hydrography, structures, and transportation. Each of these categories can be subdivided, refined, and layered atop one another to generate a feature map of an area.

There are a number of software options for GISs, commercial, proprietary, and open-source. For this project, ArcGIS Pro 2.5 was used. ArcGIS Pro is a desktop GIS software developed by the Environmental Systems Research Institute (Esri), one of the most globally popular suppliers of GIS software and geodatabase management applications. ArcGIS also happens to be the GIS software of choice for many Cartography and other GIS minor classes at Virginia Tech.

2.2 ArcGIS Pro

This project made use of ArcGIS Pro, a combined data management application, geospatial data and map creator GUI, geoprocessing and analysis tool, and command-line interface. ArcGIS Pro includes powerful geospatial image analysis tools, including those that make use of artificial intelligence and machine learning. These tools are integrated into an Image Classification Wizard within the application and are what is being analyzed in this project.

2.3 Professional Use & Goals of Research

GIS software is widely used in multiple fields, including environmental research, urban planning, defense, and healthcare. The included analysis tools streamline the use of GIS software across all of these fields. A look into how the analysis tools use machine learning could lead to methods of improvement or the ability to translate the analysis process to another application.

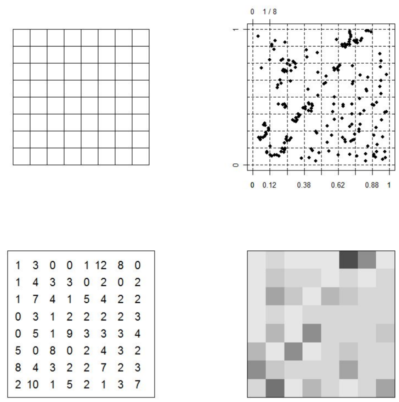
3 Unsupervised Pixel-Based Image Classification

3.1 Explanation

Unsupervised classification involves using a clustering algorithm to classify data points based on their identifying properties. In this case, the identifying property is pixel color. The clustering algorithm, given a user-specified number of classes and an image, will classify each pixel in the image.

The best way to visualize this, for this use case, is in a three-dimensional graph space, with each axis representing the red, green, and blue values of each pixel. Each pixel in an image will be graphed to this space, and clusters will be formed to group the pixels such that the feature traits within each cluster are as similar as possible, while the feature traits between clusters are as dissimilar as possible.

However, this project does not rely on typical image data. In this project, the feature data is raster images generated from lidar mapping data. Numerous federal agencies use satellites, unmanned aerial vehicles, and drones to map the entire planet, and many of the generated raster files are publicly available. Below is an example showing how raster representations correspond to images. As can be seen, data points (in this case generated by data gathered from lidar sensors) are mapped to a grid, then each grid value is colored according to how many data points lie within it - the more data points, the darker the pixel.



In the image [Image 3.1, left], the top-left grid is a blank pixel grid. The top right shows raw data points. The bottom left shows the number of data points per grid space, which leads to the bottom right - the final pixel set.

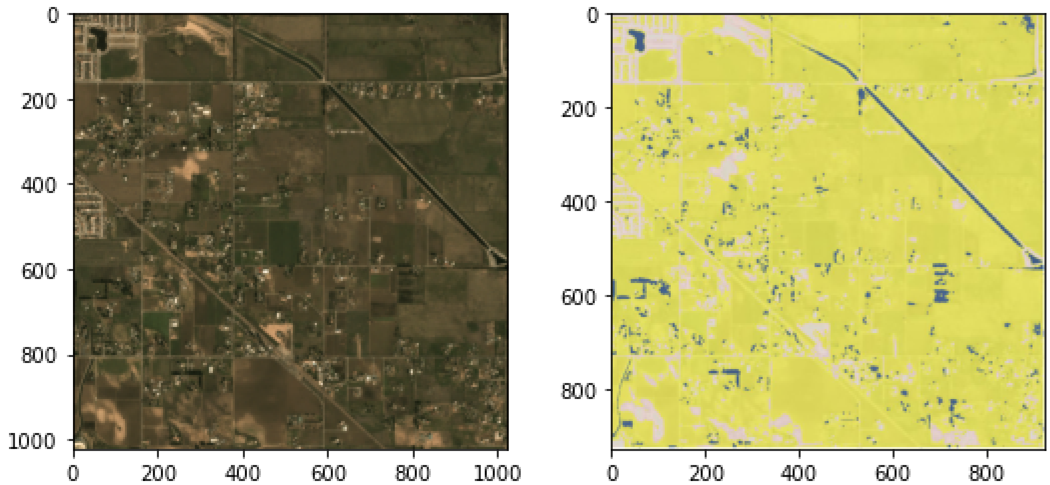
The advantages of this classification method include being relatively quick to run and easy to understand. In ArcGIS, specifically, the relative quickness in performing this classification is incredibly apparent when compared to other pixel classification methods.

There are disadvantages to this method. Unsupervised classification categorizes the data into simple clusters - it does not tell the user what those clusters represent. Labeling the clusters can become very time consuming for the user, as it requires examining the original data manually. Another disadvantage is the possibility of being unable to utilize a single set of clusters across all datasets. This issue is especially prevalent in GIS, as map pixel colors of even a single area can change drastically depending on the season, time of day, weather, and development or reversion to nature over time.

3.2 Algorithm

ArcGIS uses the k-means algorithm, below, to generate clusters [3.1]. For this algorithm, the greyscale-coded raster data pixels are arranged in a sample space based on the darkness of each pixel, then n data points are chosen as starting mean points, where n is the user-specified number of clusters. Then, each data point is assigned to whichever mean point it is closest to, using a specified distance algorithm. In the case of ArcGIS, this algorithm is the Euclidean distance algorithm. After that, new mean points are chosen by taking the average values of each of the feature traits, and the process is repeated for a specified number of iterations.

3.3 ArcGIS Classification Output Over The Sample Map



4 Supervised Object-Based Image Classification

4.1 Explanation

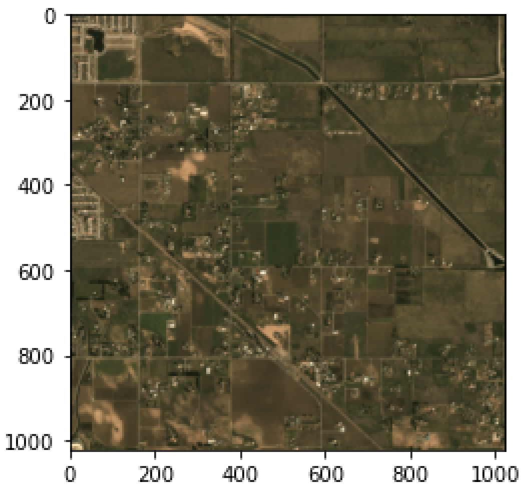
For this application, supervised object-based classification works somewhat similarly to unsupervised pixel-based classification, in that it classifies raster data pixels by analyzing the pixel color and clustering appropriately. However, this method is object-based, not pixel-based. What this means is that the algorithm will take into account a user-specified object size, quantified by a length of pixels, and will attempt to generate clusters that highlight entire objects in the image, rather than running the chance of one object having multiple classifications depending on the color of pixels within the object. The algorithm will attempt to define objects to be a minimum pixel width of the user-defined width value.

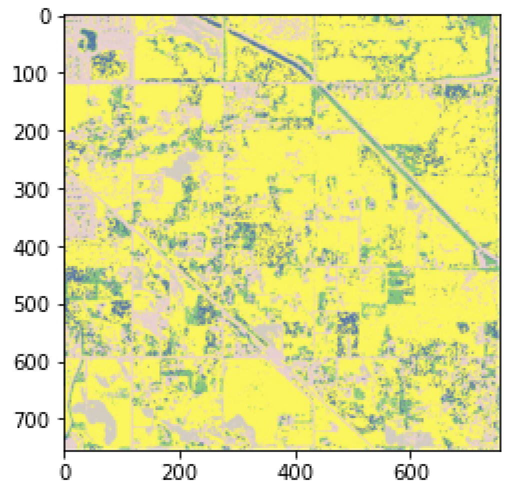
The key difference between supervised and unsupervised classification is in the name - supervised classification is “supervised”, or takes user input as an initial parameter. The algorithm begins with the user selecting groups of pixels that represent an object, then uses that initial data as a parameter in classifying the rest of the pixels.

4.2 Algorithm

After determining object borders, ArcGIS uses the k-means algorithm to generate clusters of objects. This works exactly like the k-means algorithm described in section 3.2 but classifies the entire objects by the values of the pixels contained within them, rather than individual pixels.

4.3 ArcGIS Classification Output Over The Sample Map





5 Training Results

As can be seen above, the supervised object-based classification creates a much more detailed result than the unsupervised pixel-based classification and is also more accurate. The unsupervised pixel-based classification was still very accurate, but it did not reach the level of detail achieved by the object-based classifier.

The object-based classifier took much more time to run per location than the pixel-based classifier but achieved more detailed results.

6 Result Analysis

The object-based classifier was able to achieve more detail than the pixel-based classifier due to user input regarding object definitions. However, the additional calculations necessary in object-based classification resulted in a noticeably longer computation time.

Both classifiers categorized the land types present in each tested map area fairly accurately. However, the pixel-based classifier struggled to differentiate between similarly-colored land types, such as forests and farmland, or barren areas and some developed areas, like parking lots.

However, accuracy is not the only factor to consider. The noticeably longer run time of the object-based classifier is not desirable in a web application, as it could cause severe latency issues. Since a location on the globe will be picked at random, a database of locations and corresponding classified map images would be incredibly memory-intensive, so the algorithm will instead be run in real-time for each location. This requires a quicker algorithm run time in order to better the user experience.

The lower detail of the pixel-based algorithm is, in our opinion, inconsequential for our use case. The major points in each location area are still visible, such as roads and major land type borders. Landmarks, such as waterways and major developed areas, are also plainly visible in the pixel-based classification. The lower detail of the pixel-based classifier only causes minute land type differences to be unapparent. For these reasons, we drew up our application plan to use the pixel-based classifier.

A more in-depth analysis of each location and algorithm output can be found in the attached Jupyter Notebook file.

7 Application Plan

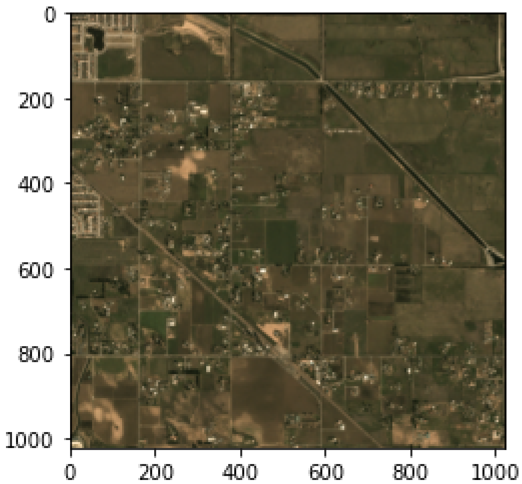
It would be relatively simple to build a network application that presents a user with a map image colored by land type categorizations and allows for a user to click on a map of the world to guess where the map shows. Points would be awarded based on the distance between the coordinates clicked by the user and the coordinates of the center of the map. This would be the core functionality of our application.

The game would determine a random location from the set of satellite images in any one of NASA's Landsat image collections, then run the land type classification algorithm to build the classified image to present to the user. There will be a time limit given for the user to guess the location, and the user will have the option to unveil a series of hints to narrow their searches, such as the location hemisphere, location continent, and location country, with the score decreasing with each hint.

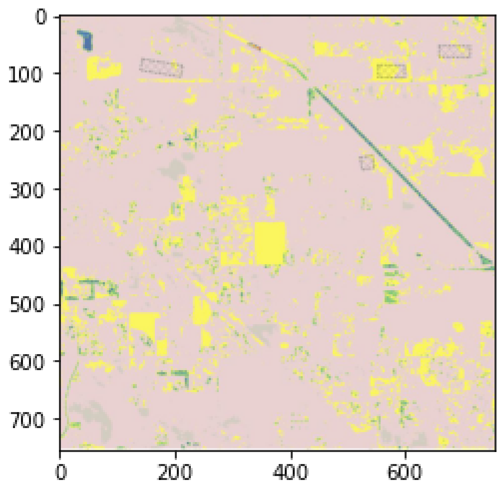
If this were a two-semester project, we would spend the second-semester building this application. However, given that this is a single-semester project, and we spent the majority of our time researching and learning to use ArcGIS, the application did not get built.

8 Example Maps

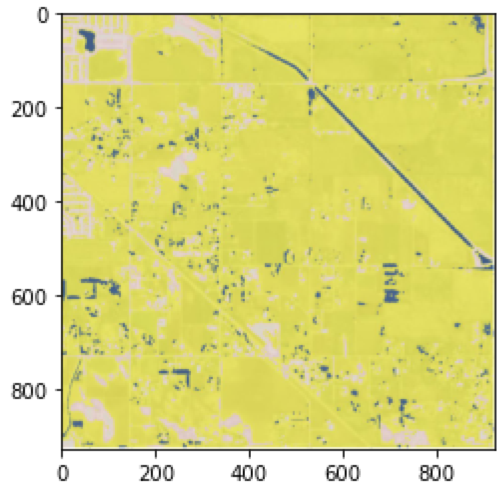
Location 1:



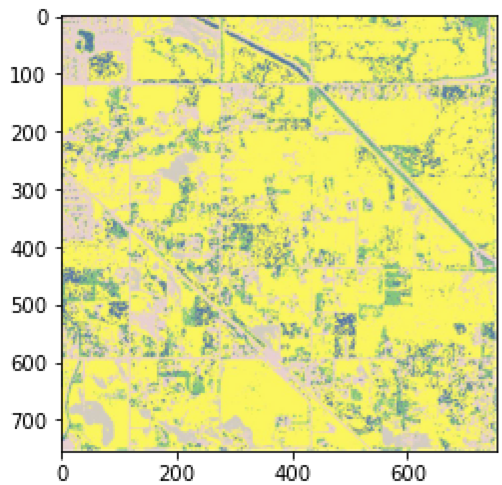
Satellite image



Supervised pixel-based algorithm output

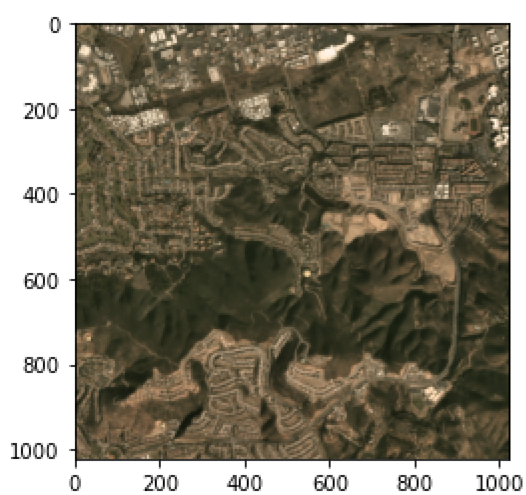


Unsupervised pixel-based algorithm output

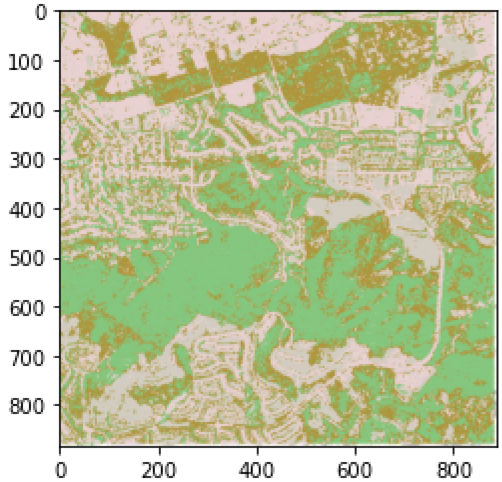


Supervised object-based algorithm output

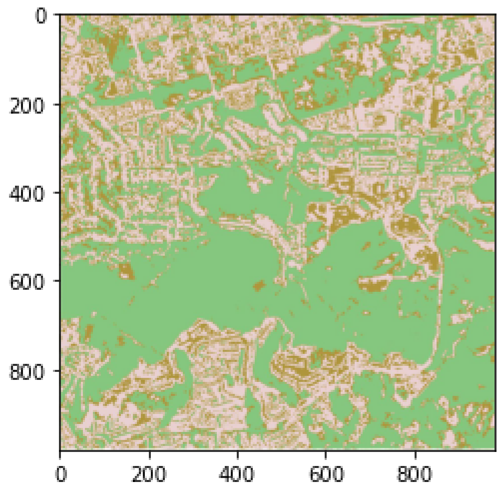
Location 2:



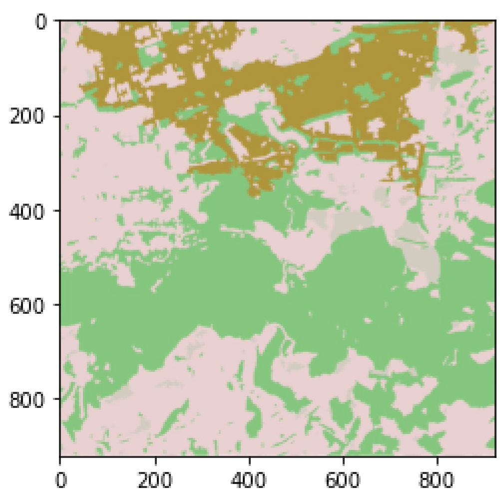
Satellite image



Supervised pixel-based algorithm output

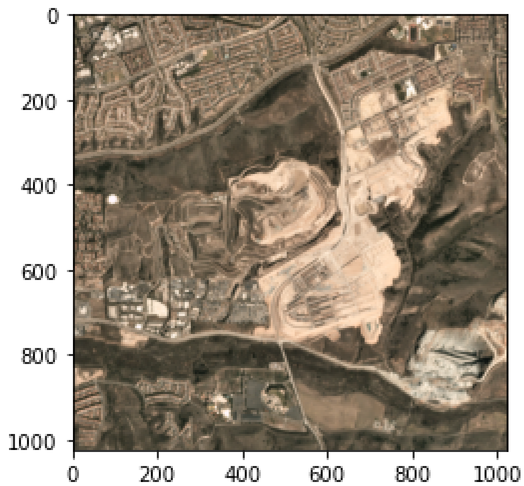


Unsupervised pixel-based algorithm output

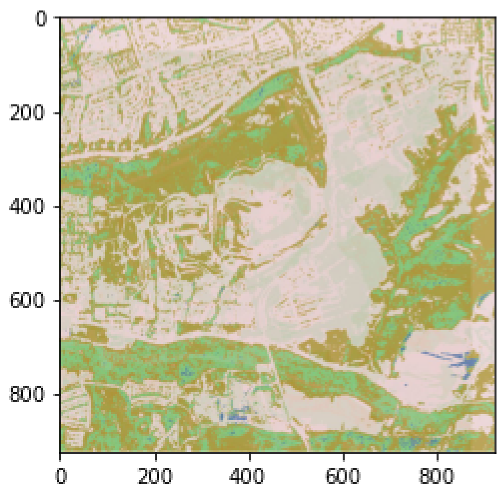


Supervised object-based algorithm output

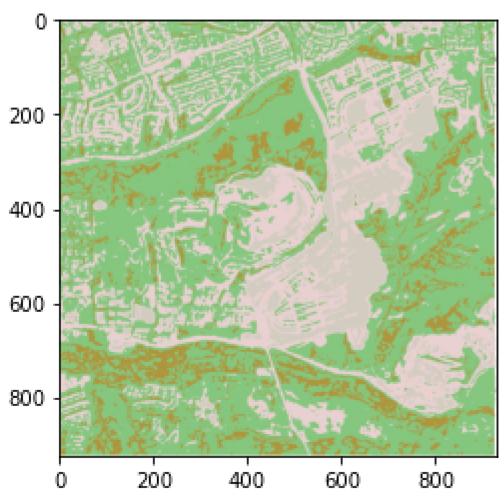
Location 3:



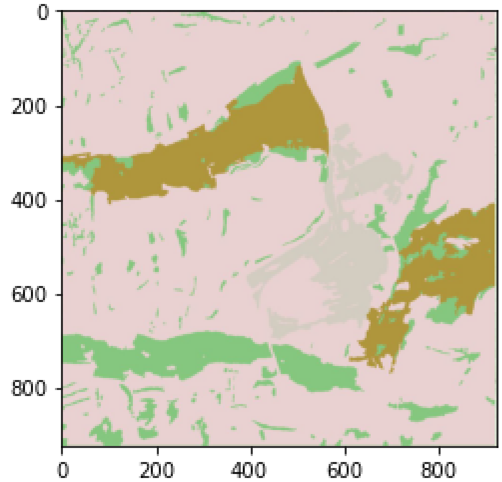
Satellite image



Supervised pixel-based algorithm output



Unsupervised pixel-based algorithm output



Supervised object-based algorithm output

Sources

[2.1] “What is a geographic information system (GIS)?” [Online]. Available: https://www.usgs.gov/faqs/what-a-geographic-information-system-gis?qt-news_science__products=0&qt-news_science_products=0#qt-news_science_products. [Accessed: 11-Dec-2020].

[3.1] “How Multivariate Clustering works—ArcGIS Pro | Documentation.” [Online]. Available: https://pro.arcgis.com/en/pro-app/tool-reference/spatial-statistics/how-multivariate-clustering-works.htm. [Accessed: 11-Dec-2020].

Images

[3.1] By Ldecola - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=17099141