Introduction

Organizations across the globe have long relied on geographic information system (GIS) technology to manage and analyze data through the powerful lens of location, helping them tackle some of the toughest business and societal challenges. GeoAI—GIS enriched with artificial intelligence (AI)—is already helping organizations get better, faster answers.

What is AI?

Simply stated, AI is the simulation of human intelligence in machines, training computers to recognize and detect patterns, extract information and meaning from data, and to solve problems and help make decisions through artificial learning.

Machine learning, deep learning, and generative AI are the categories of AI that are most relevant to GIS.

Machine learning is an application of AI that allows machines to learn without being specifically programmed to do so. It uncovers insights from data through methods incorporating decision trees or cluster analysis.

Deep learning is a type of machine learning based on artificial neural networks, which progressively uses multiple layers of information to extract higher-level features from the raw input. It uses more advanced methods and helps solve complex problems across large data volumes, with a focus on automated data extraction and pattern recognition.

Generative AI is a subset of deep learning that creates new data, such as text, images, videos, audio, and 3D models. Generative AI models learn patterns from existing data and use this knowledge to generate new and possibly unique outputs.

GeoAI: AI in GIS

GeoAI advances the science of GIS by using AI tools and models to automate data extraction and perform analysis on imagery, video, text, 3D, vector/tabular, time series, and other data. It extracts and classifies features from unstructured text or imagery sourced from satellites, drones, aircraft, video feeds, and even mobile phones. GeoAI is also used to detect patterns, clusters, and anomalies in data, and to make predictions and forecasts.

A key impact of GeoAI across all sectors is democratization—making feature extraction and spatial analysis available across an organization and to all organizations. This means better-informed decisions, more efficient operations, and the ability to tackle complex spatial problems that could have been previously out of reach for some organizations.

Also, organizations that already use GIS extensively will benefit from the ability to tackle complex problems by combining human GIS expertise with AI capabilities. This could lead to entirely new applications and insights that weren't possible before.

How can GeoAI help GIS professionals?

- **Automated data extraction:** AI helps GIS professionals by automating processes to extract useful GIS information from data. Object detection in aerial imagery and named-entity recognition from unstructured text are two examples. Object detection in imagery helps emergency response teams quickly map locations of debris. Named-entity recognition helps law enforcement officers process text documents in search references to events, people, and the like. Such tasks involve repetitive work; AI lets the machine do this work so that humans can focus their energy and expertise on more complex problem solving that the machine can't do. And AI does this work more quickly and at scale.

- **Deeper insights:** ArcGIS includes many tools to perform analysis of geospatial information. With AI techniques, Esri® is adding even more tools, providing GIS analysts with new options to identify patterns, make predictions, and ultimately gain better insights from data. AI brings together more powerful tools that, when used correctly, allow GIS users to do things we could not do before. Good examples include state-of-the-art machine learning tools for creating predictions using large, multivariate datasets and for making forecasts based on complex time series patterns. Multimodal analysis is also enhanced with AI, enabling analysis across unstructured text, images, and other data modalities not supported by traditional tools.

Using GeoAI

The combination of AI and GIS has already changed how leading organizations manage operations. GeoAI enables new levels of sustainability, efficiency, and growth. The next section of this book presents an overview of current GeoAI capabilities, followed by stories illustrating how organizations are already using GeoAI in the public, private, and NGO/nonprofit sectors. The book concludes with a section about the next steps you can take to learn more about getting started with GeoAI.

Learn more about GeoAI by visiting:

go.esri.com/geoai_book

Part 1

GeoAI Technology Overview

GeoAI integrates artificial intelligence, or AI, with geospatial data, science, and technology to increase understanding and solve spatial problems. AI is the ability of computers to perform tasks that typically require some level of human intelligence and reasoning—through programming that continually adapts, infers patterns, generalizes, and improves output over time. We can use GeoAI for applications such as detecting and categorizing objects in imagery and lidar, identifying clusters and anomalies in data, and making predictions and forecasts. The intersection of GIS, AI, machine learning, and deep learning creates opportunities that weren't available before.

GeoAI offers new ways to evaluate numerous solutions to difficult spatial problems. Spatially explicit models incorporate an aspect of geography, such as location, shape, or proximity, into an algorithm, making the models more efficient, accurate, and representative of the reality we want to model. With these techniques, we can allocate resources based on meaningful spatial patterns and relationships, find trends and anomalies in space and time, and incorporate spatial relationships into predictions and forecasts.

Machine learning in ArcGIS

Machine learning is a branch of AI in which computers learn patterns within data, and then use what they've learned to predict outcomes or make decisions. Machine learning algorithms are data-driven and operate with minimal human intervention. As machines process more and more data, they are trained so that they automatically "learn" how to adjust their behavior and improve their performance based on previous experience.

Machine learning shows up everywhere in our daily lives and across many industries. Product recommendations, traffic alerts, social media ads, health-care diagnoses, fraud detection, predictive maintenance—all use machine learning in some way, shape, or form. Irrespective of the specific industry or application, the types of problems solved by machine learning generally fall into three main categories: clustering, prediction (which includes regression and classification problems), and forecasting.

Machine learning in ArcGIS Pro

In the context of ArcGIS technology, machine learning is far from new. In fact, machine learning algorithms have been incorporated within ArcGIS and used in geographic applications of these three categories for many years. For example, you can classify pixels within remotely sensed data using K-Nearest Neighbor or Support Vector Machine algorithms. Or you can apply decision tree ensembles, machine learning techniques that combine multiple decision trees to improve predictive accuracy, to classification problems with vector and tabular data using the Forest-Based and Boosted Classification and Regression tool. You can also take advantage of logistic regression and maximum entropy (Presence-Only Prediction—MaxEnt) approaches for predicting binary classification outcomes.

For clustering problems, you have access to algorithms that group spatial data based solely on the data attributes (Multivariate

Clustering), their locations (Density-Based Clustering), or based on both the attributes and locations of the data (Build Balanced Zones). You also have access to a family of global regression models and decision tree ensembles for regression tasks, as well as the ability to apply decision tree ensembles to time series forecasts. Lastly, you can use Causal Inference Analysis to go beyond prediction and uncover the true causal relationships between variables. Behind the scenes, the algorithm uses machine learning to isolate the effect of a true exposure on an outcome from other confounding variables. An example would be isolating the effect of fertilizer (cause) on corn yield (effect) in the presence of other related variables, such as soil type, farming techniques, and environmental variables.

Although all these algorithms are considered machine learning, there is a fundamental difference between applying a traditional, nonspatial machine learning method to spatial data (such as, Forest-Based and Boosted Classification and Regression) and using true spatial machine learning. In the latter case, geography is incorporated directly into the mathematics of the machine learning algorithm through notions of shape, adjacency, orientation, contiguity, proximity, density, spatial distribution, and so on. Examples of spatially explicit machine learning algorithms include spatial autoregression and different types of geographically weighted regression, as well as spatially constrained multivariate clustering. Your choice of machine learning algorithm should always depend on the underlying problem you are trying to solve, the structure of your data, and your desired goals and deliverables.

AutoML

In the past decade, machine learning has experienced rapid growth in both the range of applications it is used for and the amount of new research produced. Some of the driving forces behind this growth are the maturity of the machine learning algorithms and methods, the generation and proliferation of volumes of data for the algorithms to learn from, the inexpensive computers to run the algorithms, and the increasing awareness among businesses that machine learning algorithms can address complex data structures and problems.

Many organizations want to use machine learning to take advantage of their data and derive insights, but there is an imbalance between the number of potential machine learning applications and the number of trained, expert machine learning practitioners to address them. As a result, there is an increasing demand to standardize machine learning across organizations by creating tools that make machine learning widely accessible throughout and can be used off the shelf by nonexperts in machine learning, as well as by domain experts.

Recently, automated machine learning (AutoML) has emerged as an approach to address the demand for machine learning in organizations across all experience and skill levels. AutoML aims to create a single system to automate (in other words, remove human input from) as much of the machine learning workflow as possible, including data preparation, data engineering, model selection, hyperparameter tuning, and model evaluation. In doing so, it can be beneficial to nonexperts by lowering the barrier of entry into machine learning but also to trained machine learning practitioners by eliminating some of the most tedious and time-consuming steps in the machine learning workflow.

Deep learning in ArcGIS

Deep learning is available in different formats across the ArcGIS ecosystem, making it increasingly accessible for users of varying skill sets. Whether you're interested in using ArcGIS Online to test a pretrained model or using the ArcGIS API for Python to create a custom model, there is an ArcGIS option for you. Whichever platform you choose, ArcGIS has the tools to help you accomplish your deep learning tasks.

Pretrained deep learning models

Training AI models is a time- and resource-intensive process, but ready-made pretrained GeoAI models automate the task of digitizing and extracting geographic features from imagery, point cloud, and text datasets.

Manually extracting features from raw data, such as digitizing building footprints or generating land-cover maps, is time consuming. Deep learning automates the process and minimizes the manual interaction necessary to complete these tasks. However, training a deep learning model can be complicated because it requires large quantities of data, computing resources, and knowledge of how deep learning works.

With pretrained models, analysts do not need to invest time and effort in training a deep learning model. The models have been trained on data from a variety of geographies. As new imagery becomes available, we can extract features and produce layers of GIS datasets for mapping, visualization, and analysis. Pretrained models can be accessed from ArcGIS Living Atlas of the World and other online repositories.

More than 100 pretrained models are already available, and even more are being developed every day, including the following:

- **Image feature extraction and detection:** extract features, such as buildings, vehicles, swimming pools, and solar panels, from aerial and satellite imagery.
- **Pixel classification:** classify land-cover satellite imagery.
- **Point cloud classification:** classify power lines and tree points using point cloud data.
- **Image redaction:** blur sensitive areas from imagery to comply with privacy policies.