

- » Breaking down the basics of GIS
- » Understanding how the pieces of GIS combine to form a complete system
- » Practicing how to think spatially like a geographer
- » Exploring real-world applications of GIS

Chapter **1**

Understanding GIS

Everything you experience from day to day happens somewhere in geographic space. As a result, you can represent your world and your experiences in it by using maps. You use those maps to navigate to a restaurant, track a package, decide where to locate a store, guide conservation efforts, and satisfy hundreds of other applications where location matters. Whenever location plays a role in decision-making, GIS helps you understand patterns, relationships, and trends that shape the world around you.

GIS is a powerful tool for analyzing, visualizing, and understanding spatial relationships. It helps businesses find ideal store locations, urban planners design smarter cities, scientists track climate change, and emergency responders map disaster-relief efforts.

In today's digital world, GIS has evolved far beyond paper maps. It's interactive, dynamic, and integrated with real-time data, enabling you to analyze everything from traffic patterns to weather conditions. If you're an aspiring GIS professional, a student, or just curious about how maps shape decisions, this book will help you understand how GIS works and why it's an essential tool in so many fields.

This chapter offers you a view of the GIS landscape (ahem!) to give you a sense of what GIS encompasses, how its components work together, and how thinking spatially can help you uncover useful patterns and meaningful insights.

Grasping the Power of GIS

GIS has come a long way since its inception in the 1960s as an innovative tool for land-use management. Today's GIS bridges geography and technology, giving resource managers and decision makers the ability to harness geographic data to solve real-world problems.

Beyond creating maps, GIS is also a tool for analyzing and visualizing data. It helps you find patterns, relationships, and trends that you'd never spot in a spreadsheet. What started as a tool for land-use planning and resource management has grown into a powerhouse of new capabilities and advanced techniques, ranging from 3D visualization to real-time data analysis and artificial intelligence (AI). The evolution of GIS continues to be driven by faster computers, bigger data-sets, and new ways to apply GIS across all industries.

Evolving from land-use tracking to spatial data science

GIS didn't begin with simple mapmaking but was created to solve practical problems. GIS was developed in the 1960s by Roger Tomlinson for Canada's national land-use inventory. Through his work, Tomlinson pioneered the idea of digitally storing, layering, and analyzing geographic data.

Since then, GIS has grown into a full-fledged, spatial data science tool. No longer just for tracking land use, GIS enables you to visualize data, analyze trends, and forecast future scenarios. Forestry specialists use GIS to forecast wildfire risks; climate scientists use it to simulate sea level rise; and urban planners use it to analyze urban growth patterns. Government agencies, businesses, and nonprofit organizations rely on GIS to take on some of today's biggest challenges, like climate change and disaster response, helping to monitor, predict changes, and deploy resources. GIS even plays a role in some everyday challenges, like helping me figure out where I left my smartphone.

Collaborating in the cloud

Gone are the days when GIS was stuck on a single desktop computer. Cloud-based GIS has revolutionized storing, analyzing, and sharing geographic data, making it more accessible and collaborative than ever. Instead of relying on one powerful, stand-alone machine, you can tap into the cloud (the vast network of remote computers that store and process data on the internet) to process and share data from anywhere to anywhere.

One of the most widely used GIS cloud platforms is ArcGIS Online, from Esri, which enables you to create, analyze, and share maps entirely in the cloud. Many organizations rely on ArcGIS Online for its integrated suite of tools, spatial data, and ready-to-use apps, making it a go-to solution for professional GIS work.

But ArcGIS Online isn't the only game in town. Open-source web mapping tools like Mapbox, Leaflet, and OpenLayers provide flexible, cost-effective ways to bring GIS to the web. If you're working on a shoestring budget, these options help you bring interactive maps to the web. Although these tools don't include built-in spatial analysis like ArcGIS Online, you can pair them with open-source GIS back-ends like PostGIS (a spatial database) and GeoServer (a web-based GIS platform) to handle more advanced geospatial tasks.

Over the last decade, open-source GIS solutions have evolved rapidly, offering free and flexible alternatives to proprietary solutions. Tools like QGIS (a powerful desktop GIS) and GRASS GIS (for advanced geospatial analysis and modeling) allow individuals and organizations to perform GIS work without high costs. Add data from OpenStreetMap (OSM), which provides freely available geographic data, and you have pretty much all you need for taking on just about any GIS project.

Technology is not the only force shaping GIS. Engaged user communities are another key driving force for GIS. Open-source GIS benefits from its collaborative development environment, in which users contribute improvements and share knowledge freely. Meanwhile, even proprietary GIS platforms like ArcGIS Online evolve based on user feedback, with strong professional networks helping to drive innovation.

The shift toward cloud-based and open-source GIS puts powerful mapping and analysis tools into more hands than ever before. Whether you're collaborating on a city planning project, tracking migratory birds across the Pacific Flyway, or building interactive web maps, these platforms make it easy to work with geographic data anywhere. So what are you waiting for? A whole world of flexible, affordable, and even free GIS tools are out there, ready for you to explore!

Transforming data into action

GIS helps people make sense of the world by bringing together geography, computing, and problem-solving. With GIS, you can input, store, retrieve, edit, analyze, and visualize geographic data. But you may wonder what that looks like in the real world, which has real-world problems to solve. Here's just a taste of the many ways in which GIS can provide solutions:

- » **Data management:** Store, retrieve, and edit geographic data, from maps to live sensor feeds (like real-time traffic data)

- » **Analysis:** Count, group, classify, isolate, and measure features and their patterns across the landscape
- » **Mapping:** Overlay different datasets to uncover relationships, compare features, and make new maps
- » **Visualization:** Create and manipulate 2D and 3D visualizations, predict missing values, and model changes over time
- » **Route optimization:** Find the shortest, fastest, or most scenic path, identify potential customers, and locate businesses
- » **Topographic analysis:** Perform tasks like modeling surface flow or measuring visibility from a specific location

This list of capabilities shows the diversity and power of GIS. But its real power doesn't derive from what GIS can do but rather from how people use it. Here are some areas in which you might see GIS in action:

- » **Disaster management:** Emergency responders use GIS to map wildfire perimeters, identify evacuation routes, and prioritize relief efforts based on population density and risk factors.
- » **Urban development:** Planners analyze land-use patterns and infrastructure needs, combining geographic and demographic data to design smarter cities.
- » **Environmental conservation:** Conservationists track deforestation, predict wildlife migration patterns, and monitor water quality using GIS-based analyses.
- » **Business applications:** Retailers optimize their supply chains, identify target markets, and pinpoint ideal store locations using GIS tools.
- » **Public health:** Epidemiologists map disease outbreaks, analyze health-care access, and predict future areas of concern.

This section describes just a small slice of the capability of GIS in tackling everything from disaster response to business strategy. GIS brings together time-tested geographic methods with cutting-edge computing, allowing you to analyze places, patterns, and problems in ways that were impossible just a few decades ago.

GIS is truly transformative software, reshaping the way decisions are made around the world every day, from helping first responders save lives to giving conservationists the tools they need to protect natural habitats. Beyond the software. GIS is part of a much bigger system that connects data, technology, and people. That's what this book is all about.

Meeting the GIS Collective

If someone asks, “What is GIS?” the easy answer is that it’s software for making maps and analyzing spatial data. In reality, though, it’s a powerful system composed of multiple parts. I like to think of it as a team (see Figure 1-1), with each member playing a necessary role. Together, what they create sometimes even seems magical. Meet the five players of Team GIS:

- » **Computer hardware:** The machines and devices that process and display GIS data
- » **Geographic software:** The programs that help you analyze and visualize data
- » **Data:** The fuel that drives GIS (Without it, you have nothing to analyze!)
- » **Methods:** The techniques and workflows that turn raw data into meaningful insights
- » **People:** Professionals across countless fields to solve real-world problems

Read on to take a look at what each of these components brings to the GIS collective.



FIGURE 1-1: GIS is a collection of hardware, software, data, methods, and people.

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Computer hardware

GIS software does the heavy lifting, but hardware is what makes it all possible. Modern GIS doesn’t just run on desktops anymore; you find GIS on laptops,

tablets, mobile devices, and even cloud servers. Here's a quick look at the hardware that keeps your GIS running:

- » **Data collection devices:** These devices include GPS units, drones, satellite sensors, and even smartphones that gather geographic data. The data may come from a field scientist recording wildlife locations or a drone mapping a construction site, but GIS always starts with data collection. (See Chapter 7 for details on collecting geographic data.)
- » **Input devices:** You can enter data directly into GIS using onscreen digitizing, scanners, and even manual digitizers (if you can find one outside a museum!).
- » **Data storage and processing:** GIS deals with huge amounts of data, so having the right hard drives, cloud storage, memory, and high-performance computing makes a big difference to effective use and management of all that data.
- » **Output devices:** Monitors, printers, and plotters (large-format printers) help you visualize and share your GIS work. You can display it through an interactive map on your screen or a printed map for a presentation, but GIS results need to be seen!



TIP

Before you invest in GIS software, make sure that it's compatible with your hardware. Also, don't fall into the trap of thinking that the most expensive setup is the best; you can always upgrade as your GIS needs grow. Most GIS software includes documented minimum system requirements, and often includes recommended specifications that go beyond that. For best performance, and to avoid future frustrations, start with the recommended rather than the minimum (Future You will thank you).

Geographic software

GIS software is the engine that drives geographic analysis. Beyond just storing and displaying maps, GIS helps you uncover patterns, relationships, and trends in your data. Here are some of the capabilities that make GIS software powerful:

- » **Interactive analysis:** Say that you need to see how urban growth affects green spaces. GIS lets you layer different datasets to find hidden trends. (Chapters 5 and 15 explain working with layering.)
- » **3D Visualization:** Modern GIS offers more than just flat maps. Many tools can now display elevation models, create fly-through animations, and even create *digital twins*, or virtual replicas of cities, buildings, or entire environments that update with real-world data.

» **Real-time data integration:** Live traffic feeds, weather updates, and satellite imagery can all be integrated into GIS, giving you up-to-the-minute insights.

Following are just some of the ways people use GIS software:

» **An environmental scientist** overlays vegetation data on a 3D terrain model to study how elevation affects plant growth.

» **A real estate agent** pulls up a map showing houses within the client's price range, complete with property details and virtual tours.

» **A city planner** presents an animated time-lapse video showing how urban sprawl has changed over the past 30 years.

» **A national park visitor** uses an interactive GIS app, taking a virtual fly-through tour of a hiking trail before visiting.

GIS software offers myriad possibilities to help you understand the world around you in new ways.

Geographic data

Hardware and software are the driving forces behind GIS analysis and products, but data provide the fuel. No data, no GIS. GIS works with many types of data, but they're easier to understand when grouped into two basic categories:

» **Primary data:** Data you collect yourself. This is data gathered firsthand for a specific purpose. Because you're in control, this data is often the most reliable and tailored to your needs. Examples include:

- **GPS field surveys:** Mapping roads, trails, or invasive plant species
- **Drone imagery:** Capturing high-resolution aerial views of construction sites, crops, or coastlines
- **Sensor readings:** Recording environmental conditions, like temperature, air quality, or water levels
- **Crowd-sourced data:** Using data contributions from citizen science projects like iNaturalist or tapping into real-time updates like OpenStreetMap contributions

» **Secondary data:** Data collected by others for unrelated tasks. Although these data are collected by someone else, they're still incredibly valuable. Examples include:

- **Census data:** Government-collected population, housing, and economic statistics
- **Satellite imagery:** Preexisting earth observation data from agencies like NASA or commercial providers
- **Weather and climate data:** Temperature trends, precipitation patterns, and severe weather events
- **Business and economic data:** Real estate prices, market trends, or customer demographics
- **Historical maps:** Old survey maps or digitized archives for land-use changes

GIS data can come from a variety of sources, including government agencies, open-source projects, private companies, or even your own organization's records. If you're not sure where to start, check out Chapter 21 for ten data sources that can get you started.

Most GIS data you collect, whether from a primary or secondary data source, will need some sort of preparation (or "cleaning") before you can use it. Here are the basic steps for getting data into your GIS:

1. **Decide what you need.**

Your project goals will help you figure out the best data to use. For instance, determine whether you're working with existing datasets, collecting new field data, or using remote sensing (satellite or aerial imagery).

2. **Gather the data.**

Gathering data may involve surveying using GPS or mobile GIS apps, downloading government datasets, flying a drone (uncrewed aircraft system, or UAS) to capture high-resolution imagery, or accessing satellite imagery from providers like Landsat or Sentinel.

3. **Format the data for GIS.**

Data often needs to be converted, formatted, or cleaned up before you can use it in GIS. You need to perform some QA/QC checks on the data, clean up any errors or extraneous data items, and then save or export the data file to a compatible format. Common GIS data formats include:

- **Shapefiles and GeoJSON:** Used for vector data (points, lines, and polygons)

- **Raster images (TIFF, JPEG2000):** Used for satellite or elevation data
- **Tabular data (CSV, Excel, database formats):** Used for attribute information

I can't include a section about data in this chapter without mentioning metadata. *Metadata* is data about data. It tells you where the data came from, how and when it was collected, how accurate it is, and other important details that let you and others know that it came from an authoritative source. If you don't know where your data came from or how old it is, be cautious, especially if you're using it for decision-making. See Chapter 7 for more about metadata.



REMEMBER

Good data equals good GIS analysis. If your data is outdated, messy, or inaccurate, your GIS results will be, too (garbage in, garbage out). So be sure to always review the metadata for the data you gather from other sources. Likewise, be sure to always include metadata with any data you create.

Methods

Methods comprise the “how” of GIS. With GIS, it's not just about *what* you analyze, it's about *how* you analyze it. The methods you use can reveal patterns, relationships, and trends that might not be obvious when looking at the raw data.

Here are some of the most common methods and how GIS users employ them:

- » **Overlay analysis:** Used to stack multiple datasets (like land use, soil type, and flood zones) to see how they interact. For example, if you want to find the best place to build a school, overlay population density, zoning laws, and flood risk maps can narrow down your options.
- » **Network analysis:** Good for finding the shortest route, optimizing delivery schedules, or modeling transportation systems. For instance, when you need to map the fastest emergency response routes for ambulances, network analysis enables you to factor in traffic conditions and road closures to give you the best paths.
- » **Spatial interpolation:** Helpful for estimating unknown values based on surrounding data points. For example, by analyzing nearby sensor data, meteorologists use spatial interpolation to estimate temperature and rainfall in areas without weather stations.
- » **Geostatistics and machine learning:** These are advanced methods that help predict patterns and trends. For example, you can use these techniques to model wildlife migration patterns, analyze crime hotspots, and predict fire risk.



REMEMBER

Understanding how these methods work will help you figure out the right questions to ask when you're analyzing data. The right questions lead to meaningful results. You can discover much more about GIS methods in the chapters in Part 4.

People

GIS is made and used by people to help people. Across industries like business, government, military, education, nonprofits, and healthcare, GIS helps people do their work effectively. In doing so, it also enhances the way organizations work and decisions are made.

Behind every great GIS-powered decision is a system that needs to be built, maintained, and integrated into daily workflows. To be successful, organizations can't just install software and then sit back and hope for the best; they need the right people to implement it. GIS professionals serve this purpose, and depending on the organization, GIS implementation may involve these roles:

- » **GIS administrators or IT specialists** who set up enterprise GIS systems
- » **GIS analysts and consultants** who determine how GIS fits into the business processes and building an implementation plan around those processes
- » **Geospatial architects** who design scalable solutions, often using a combination of networked workstations and cloud-based solutions



TIP

If your organization is new to GIS, working with an experienced GIS consultant or enterprise GIS specialist can help ensure a smooth transition and long-term success. Be sure to always plan and budget for training. Well-trained staff keep the whole system running smoothly, from implementation to ongoing operations and future upgrades.

Thinking Spatially: Why Geography Matters

Every tool is designed to solve a problem. Sharp things cut, heavy things hammer, and pointy things hold stuff together. GIS is a tool with a problem-solving purpose as well: to solve geographic problems.

Geographers needed a way to analyze and solve location-based problems, so they created GIS as a problem-solving toolkit to address geographic questions. Today, many different fields use GIS, but the questions that it helps answer are still fundamentally geographic. So, to get the most out of your GIS, think like a geographer.



REMEMBER

Thinking like a geographer doesn't mean memorizing capital cities or knowing Wisconsin's best-selling cheese. Those tidbits of knowledge may come in handy on Trivia Night, but they can't help you think like a geographer. On the contrary, thinking like a geographer means seeing the world through a spatial lens, recognizing patterns, relationships, and connections based on location. When you start to see (or imagine) maps in everything, you're thinking like a geographer.

Geography affects you every single day. It encompasses the logistics that bring you cereal for breakfast, the sensors that tell you when to grab an umbrella, and the real-time traffic updates that help you steer clear of traffic jams. Think about how often you make decisions based on location. Geography plays a role in answering questions like these:

- » What's the fastest way to get downtown during rush hour?
- » Where's the best place to open a new clothing store?
- » What restaurants are within walking distance of my hotel?
- » Which neighborhood has the best schools?
- » Why is cancer mortality higher in some neighborhoods than others?
- » How is climate change contributing to the distribution of this bird species?
- » Where will traffic congestion be worse in ten years based on population trends?

Geographers and GIS professionals ask these kinds of spatial questions every day. GIS helps them figure out the answers by enabling them to identify, characterize, question, analyze, visualize, explain, and finally apply their knowledge of patterns, distributions, and relationships.



REMEMBER

You don't need to be a geographer to think like one. But you do need to think spatially to take full advantage of GIS.

Recognizing the spatial nature of analysis

Geographers recognize that the world is interconnected, but a core principle of geography is that places and features that are closer together tend to be more related to one another than those that are farther apart. This idea helps explain why location matters in business, transportation, public health, and more.

When analyzing problems with GIS, several spatial factors come into play. Here are a few key factors to help you start thinking spatially:

- » **Density:** If you're an urban planner, the more houses an area has (the greater density), the more potential riders a public transit system has.

- » **Sinuosity:** Maybe you've noticed how winding streets force you to drive slowly. Urban planners design curvy subdivisions to reduce speeding and create safer pedestrian areas.
- » **Connectivity:** Remote towns with poor road access often struggle with economic growth because goods, services, and people have a harder time moving in and out.
- » **Pattern change:** As farmland and open space turn into housing developments and warehouses, local food production and wildlife habitat may pay a price.
- » **Movement:** Hurricanes, migration patterns, and traffic all depend on movement over time. For example, meteorologists track hurricane paths to predict where the storms will go next, potentially saving lives.
- » **Shape:** A developer looking to build a house may prefer a square-shaped lot over an awkwardly shaped one for easier construction and design.
- » **Size:** Large farms need bigger parcels of land for efficient production. Plus, large farm equipment doesn't work well on tiny fields.
- » **Isolation:** A store surrounded by vacant businesses may struggle because of a lack of foot traffic.
- » **Adjacency:** If a large industrial data center is built next to your house, your property value may take a hit.

All these factors have one thing in common: They require you to see, acknowledge, and question spatial locations, patterns, and distributions. Thinking spatially helps you ask better GIS questions and get more meaningful answers.

Getting better at spotting spatial patterns takes practice. Here are some tips to get you started:

- » **Look at maps.** The more you study maps, the easier it is to spot patterns.
- » **Notice how traffic flows.** Be aware of which roads get backed up at certain times of day.
- » **Study aerial and satellite images.** These images give you a bird's-eye view of landscapes and how they change over time.



TIP

Seeing spatial patterns takes practice. You need to read maps, study satellite images, and most important, practice creating, querying, and analyzing spatial data with GIS. The more you do, the sooner you'll become a very spatial person. (See what I did there?)