If system architecture design were a step-by-step process, the first step would be to review all your options before committing to any one of them. In other words, managers should focus on understanding all the pieces of the puzzle before making critical technology choices. A system is like a puzzle: it contains several interacting parts, each related to the other in a very special way. Each of those parts is also made up of components that carry on a special relationship with each other. Software technology is a good place to begin to understand these interacting parts and special relationships.

Software technology selection is a critical step in building a GIS. Within the past 15 years especially, GIS technology has grown tremendously, from serving a small group of users in a local office environment to integrating operations distributed on a global scale. Now the ArcGIS 9.3 release provides a new range of simple user methods for deploying a variety of mapping services, sharing GIS tools and information with Google and Microsoft Web2.0 commercial and public users, and leveraging ArcGIS Explorer as a window to access information provided from every part of the world. All this promotes a growing level of information exchange and collaboration based in spatial thinking. What this means for your future and how can you use geography to make a difference in your organization will be a large factor in your decision making.

The GIS technologies you’ll be choosing among include a variety of GIS data sources, ArcGIS Desktop applications for GIS power users, ArcGIS Server for supporting GIS business workflows and Web services, mobile client applications integrated with corporate business operations through wireless communications, and a variety of network services. Examining your GIS technology options is the first phase in building a GIS.

This chapter provides an overview of ESRI’s GIS technology, past and present. Software solutions to serve your GIS needs could come from ArcGIS Desktop and ArcGIS Server technology, both of which serve a variety of GIS operations, involving local workstations, remote desktops and Web browsers, and mobile clients. Data can be accessed either from a centralized data center or in a distributed geodatabase architecture or in some combination of both. Understanding available technology options, in order to identify candidates that may satisfy your operational needs, establishes a baseline for making the best technology decision. Right now you’re not buying, you’re just window shopping; in other words, you’re looking at the pieces of the puzzle, and your focus is on understanding the relationships between them, all of which will inform your decision making.

The histories of the various technologies reveal how they have influenced each other, another aspect of relationship to consider in designing a system that will accommodate change. Changes in platform processing performance and network communication bandwidth have already influenced the evolution of GIS technology, and are likely to continue to do so. Wireless communications has already opened a new frontier, enabling mobile users to be more tightly coupled with primary business workflow operations. GIS deployment strategies are changing from traditional department- and enterprise-level operations to emerging federated and service-oriented operations.

Selecting the right software is a primary system design task, as is choosing the most effective deployment architecture for that software. You should know there are many alternatives for both GIS software technology and architecture solutions. This chapter describes them (using ESRI examples) and what they may be good for, but you must make the decision as to what’s best for your organization. As in all things GIS, you begin system architecture design by thinking about what you want to get out of the GIS. How will GIS optimize your organization’s workflows? By understanding what you need a GIS to do, you are ready to
identify the functions that will get it done. Software is the system component that provides this functionality. So, by defining the required functions, you have narrowed your software choices to those products that perform them.

You are likely to find the functionalities you need in the software available now—or in the near future—because traditionally their invention follows closely on the heels of the expressed user need. Historically, developers have responded to users’ needs by creating software technology that meets the functional requirements identified by the GIS community. The history of GIS software products developed by ESRI follows the evolution of computer technology in general and the growing populations of GIS users in particular.
Understanding where the technology has been helps in anticipating where it is going. Over four decades, ESRI has developed GIS software to provide the functionality required by the GIS user community. Much has been learned over the years as technology has changed and deployment strategies have evolved to support user needs. Software development trends and enterprise architecture strategies provide clues about how GIS technology is changing.

This chapter begins with an overview of the ESRI software evolution as illustrated in figure 2-1. Understanding the target market for each member of the ESRI software family will help you identify your technology needs and develop a road map for migration to successful enterprise GIS operations.

ESRI software evolution

ARC/INFO software was installed on the Prime mainframe computer in 1982, offering developers and GIS professionals a rich toolkit for the geospatial query and analysis that would soon demonstrate the value of GIS technology. Most GIS work was performed by GIS professionals with extensive software training and programming experience. These GIS professionals developed information products (useful results of GIS applications), usually providing them in paper form, to support operational user needs. Then ArcView was introduced in 1992, an offering of easy-to-use commercial off-the-shelf (COTS) software that operational—not necessarily professional—GIS users could use directly. Thanks to ArcView, for the first time many kinds of GIS users could do their own project analysis and build their own information products without depending on a GIS professional to do their thinking for them. First-year ArcView sales totaled more than all the ARC/INFO sales over the previous 10 years put together. GIS users liked doing their own work, so an easy-to-use desktop software with which to perform GIS analysis and make basic geographic information products was a big hit. Early on in ESRI software's evolution, end users were looking toward simple software technology to provide access to and control of GIS data resources.

Since the 1980s, ESRI had been partnering with other businesses in using ARC/INFO technology to build applications for industry. This became the ESRI Business Partner (BP) program, a simple way to introduce a geographic representation into existing vertical market solutions. Using ArcView to better manage and display spatial relationships, this program grew in the 1990s. (There are many examples of BP ArcView applications still being used today in crime...
analysis, emergency dispatch, and forestry, to name a few.) Developers found ArcView easy to integrate with existing applications, but they wanted the option of creating business solutions—and their accompanying geographic displays—without the ESRI user interface, so a new product, MapObjects, was introduced in 1996. Developed specifically for the ESRI Business Partner needs, MapObjects provided developers with a simple way to integrate map displays into their own application environments (the common standard desktop Visual Basic), without the ESRI user interface. Early on, developers were looking for standard software components that could be easily integrated with their own software solution.

Electric utility companies were using GIS in the early 1990s to manage their electrical power line infrastructure. Utility maintenance workflows were complex and required specialized power-flow and asset-management applications to buttress their distributed electrical facilities (telephone poles, capacitors, and power lines). GIS solutions were provided to support these operations. Compute-intensive GIS desktop software was used for the work management applications, and spatial data was integrated with enterprise facility and customer database solutions to support the operational workflow.

At the time, engineers located at remote field offices performed most of the facility maintenance tasks. To provide these field engineers with remote user access to centrally managed GIS desktop applications, centralized Unix Application Servers/Windows Terminal Servers were introduced. A relatively complex ArcStorm spatial database solution was introduced, to provide a scalable way to tightly integrate file-based spatial data with the tabular database systems of the facility. Soon enough, with enterprise GIS maintenance needs on the rise, simpler solutions for data management and application administration were needed. In response, ESRI worked with Oracle to develop the Spatial Database Engine (SDE). Deployed in 1997 as ArcSDE, it offered the first fully integrated, database-management solution at the enterprise level for the geographic database.

What about Web services? Initially, custom implementations of ArcView and MapObjects Internet mapping services handled the first GIS Web services. ArcIMS was introduced in 1997, providing a framework for publishing GIS information products to Web browser clients. Web technology introduced GIS information products to new users throughout the organization and to the public, rapidly expanding the population that uses GIS information products.

A boost from hardware
New opportunities for the advance of software technology came from computer hardware performance improve-ments in the late 1990s. In effect, faster hardware came along to compensate for the bigger processing loads incumbent with increasing software functionality. This is a story significant for system architects who need to be aware of the effect hardware can have on software, and vice versa. For ESRI, it happened this way: In the 1990s, ESRI software developers began to change the way they wrote the processing instructions or code underlying the software, moving from the traditional scripted subroutine coding methods to object component coding techniques. Using common object interface standards, they could develop higher level code functions in a much more adaptable and expandable way. Component object functions could be used in many different software solutions, and could be combined with third-party components to enable much more rapid development. Exploring several of the new software object models (CORBA, JAVA, and COM), ESRI found the Microsoft Common Object Model libraries to be the most effective environment for the compute-intensive GIS application code. ESRI released the ARC/INFO GIS functions in the new ArcObject code base in 1999, for the ArcGIS Desktop software release.

This code base came to be known simply as ArcObjects, a library of software components that make up the foundation of ArcGIS. (ArcGIS Desktop, ArcGIS Engine, and ArcGIS Server are all built using the ArcObjects libraries. ArcGIS Desktop software provides the full set of ArcObjects technology, while focused subsets of the same ArcObjects support the ArcEditor, ArcView, ArcReader, and ArcExplorer desktop software solutions. See ESRI product family, page 23.)

ArcGIS Desktop software, providing GIS users with a simple and very powerful user interface supporting a full spectrum of standard GIS operations, came to be ESRI’s flagship product. It started to lead the GIS industry with the most extensive set of geospatial functionality, with each release expanding that functionality. From the beginning, professional GIS users sought out the best tools available to advance GIS technology. Moving from the legacy ARC/INFO software to the new ArcObjects component development accelerated the advance of GIS software technology by orders of magnitude. Before the ArcObject code base, around the mid-1990s, GIS user requirements had been expanding faster than the ARC/INFO software release schedule could keep up with—new releases would fall short of what customers wanted. Yet within a couple of years after the ArcGIS Desktop release in 1999 (with its ArcObjects technology underpinnings), customers were asking developers to slow down—technology was advancing well beyond their needs and what they could absorb. There was a performance cost introduced with the new technology—ArcObjects applications required twice the processing resources as the older ARC/INFO.
code to produce the same information display. Computer hardware advances made up the difference the same year (1999), which made trading performance for much better technology a worthwhile exchange.

A period of adjustment
ArcGIS Server and ArcGIS Engine came along to provide GIS developers with access to the same rich ArcObjects software components available in the rest of ArcGIS Desktop software. ArcObjects—the library of software components that make up the foundation of ArcGIS—is now available as a desktop and server development framework, offering the full range of GIS functions for custom application development and deployment. Somewhere within that range of functionality, you can find the solutions that best fit your user needs; in system architecture design, it’s important to know what those needs are before selecting the software, and that requires understanding your organization’s users.

Not all GIS software users are looking for the same thing. Professional GIS users (geographers, scientists, architects, etc.) are looking for a simple, powerful, productive user interface they can use as a tool to support their work. ArcGIS Desktop provides these users with an open user interface to explore, build, study, analyze, and discover new things about the world, which in turn become tools that move GIS technology forward. GIS programmers and business partners are looking for software development environments that allow them to include ArcObjects functionality as part of their focused customer solutions, because it models the real world better. Many GIS users are not analysts or programmers; they want simple access to GIS information products and services—GIS makes their work more structured and productive. ArcGIS Server provides an optimum platform for professional GIS users to share information and services to these people along with colleagues worldwide who use GIS information in their work. IT professionals seek enterprise solutions that are stable, easy to support, dependable, scalable, and secure. Centralized application and data management—ArcSDE, geodatabase, distributed geodatabase synchronization, open standards and interoperability, data automation, ease of implementation, simple license management, data integrity, backup and disaster recovery, security—are primary concerns that affect supportability and maintainability, the cost factors managed by IT professionals. Because all the types of users have always been important to GIS, ArcGIS technology has grown and evolved to accommodate their varying needs.

Meanwhile, as we’ve seen, hardware technology has been evolving too, affecting software technology’s own evolution. A maturing GIS technology took advantage of hardware performance gains to allow for more software functionality and adaptability. Faster hardware encouraged software migration from the tightly scripted code of the 1980s and 1990s to the object relational ArcObjects code underlying ArcGIS software technology now. What this means to system architects is significant to know: ArcGIS Desktop generates twice the processing load of the older ARC/INFO scripted code to produce the same map display. In exchange for this performance cost, GIS technology has advanced at a much more rapid pace—with the functional benefits now far exceeding the performance trade-off.

We are seeing the same performance trade-off moving from ArcIMS to ArcGIS Server technology. In 1999, hardware technology performance gains absorbed the ArcGIS Desktop software performance cost in just one year. This pattern is repeating itself as customers migrate to ArcGIS Server technology. Any change requires a period of adjustment, but by recognizing a pattern of history repeating itself, the system architect can design to accommodate such change.

The factors of growth and change bring into play special considerations when designing a system specifically for GIS. As a data-intensive technology, GIS is a big consumer of server processing resources. It can generate a high level of network traffic as applications use large quantities of data from shared database-, file-, or Web-based data sources. If you don’t get the hardware and network capacity right, GIS users will not be able to perform their work. If you get the technology wrong, you could end up with a solution that will not work in your deployed environment. If you do get it right, you can experience the geographic advantage many others have enjoyed over the past few decades.

Web-based service-oriented architecture solutions promise to move technology ahead at an even faster rate. The building of applications from Web services expands the benefits of a component development architecture and virtualization to a higher level—beyond vendor control and into the open marketplace. There will be a software performance cost in that too: more processing required to support the same information product. Nonetheless, many customers are choosing to take a chance once more, exchanging performance for a more adaptive application development environment.

Organizational GIS evolution
GIS’s long history with users has informed its software development every step of the way. Organizations count among the user population, as you will see in this chapter. The more you know about how user needs have evolved, both on an individual and organizational level, the better you can prepare for the future and the opportunities it holds, even as you plan a system design to meet your current needs.
In today’s world there are many configurations to choose from, thanks to the rapidly expanding GIS evolution. GIS implementations grew in size and complexity throughout the 1990s, and its evolution continues to flourish throughout the world today. It’s still the case that many organizations begin with a single ArcGIS Desktop user and over time expand the use of GIS technology to provide department-level operations. In turn, as multiple departments use GIS in their work, data sharing between departments expands GIS to even newer levels. Such enterprise GIS operations offer more opportunities for data sharing and for leveraging geospatial resources to meet cross-department business needs. Mature GIS operations are expanding to integrate on a community and national level, and even globally.

Department-level GIS
As we’ve seen, GIS technology was initially introduced as a desktop application (ARC/INFO, in 1982), and geographic analysis and mapping work moved from data represented on paper and Mylar (clear plastic) sheets to digital datasets run by computer technology. As multiple GIS desktop users began working together, they found that sharing digital data allowed them to be more productive and provide better GIS information products. A department’s local area network (LAN) was used to share data between desktops, as department managers saw the advantage in maintaining shared data on department file servers, with common user access to the shared data files. A majority of the GIS community today is still at the department-level. Figure 2-2 provides a simple overview of department-level GIS architecture.

In a typical scenario, as GIS data resources grow and mature at the department level, more users throughout the organization are able to take advantage of GIS technology. Many departments develop their own local GIS operations that benefit from data resources developed and maintained by other departments. Then the organization’s wide area network (WAN) becomes a way of sharing data between department servers. Data standardization and concurrency issues can become a challenge as data is developed and managed by different department-level sources, and organizations soon recognize a need for enterprise-level management of the shared spatial data resources.

The initial Spatial Database Engine release in the mid-1990s enabled the creation of this early enterprise-level GIS management in the form of data warehouse operations. Many organizations began sharing GIS data resources from a central ArcSDE data warehouse. IT departments hired GIS managers or geographic information officers to integrate shared enterprise GIS data resources and establish common data standards, to benefit operations throughout all departments and support enterprise management needs. The enterprise data warehouse provided a reliable, shared GIS data source for departments throughout the organization. This was a very common GIS technology evolution experienced by many local governments, and even today many smaller communities are growing together in the same way.

Enterprise-level GIS
Figure 2-3 provides an overview of the organization-level GIS architecture alternatives. Departments initially share data across the WAN until an enterprise-level data warehouse can be established to maintain and share common GIS data resources. The central IT GIS team can leverage the centralized GIS database by publishing a variety of GIS Web services. These services can support users throughout the organization, and provide a platform for using GIS technology to support enterprise-level operations.

In the early 1990s, when the electric and gas utilities began using company-wide GIS for work order management of power distribution facilities, most implementations were served by a central database. Remote users had terminal access to application compute servers (terminal servers) located in the central computer facility with the GIS database.

Many organizations today are moving their geospatial data to a common, central, enterprise geodatabase like this, shifting from a department-file-based GIS in favor of one that provides terminal client access to centrally managed server environments. In this scenario, departments retain responsibility for their data resources, updating and maintaining data through terminal access to central ArcGIS Desktop applications. The central IT computer center handles the general administration tasks of data backups, operating system upgrades, platform administration, and so forth. Users throughout the organization enjoy browser access to published Web services over the intranet.
The complexity and sophistication of the geodatabase, made possible by such central administration, has rendered centralized servers a more productive alternative for most organizations, from local municipalities to national-level government agencies. Most enterprise GIS operations today are supported by systems (application and data servers) maintained in a centralized data center.

Community GIS evolution
By the beginning of this century, a growing Internet was demonstrating the tremendous value of sharing information between communities, states, and organizations around the world. Internet access was extended from the workplace to the home, rapidly expanding the GIS user community. On the next page, figure 2-4 shows how communities and companies developed and deployed services to users and customers over the Internet. Because of the Internet, organizations could share data and exchange services while users, in turn, gained access to data and services from a multitude of organizations.

ESRI introduced the Geography Network, providing a metadata search engine that published information about GIS data services and provided direct Internet links between the ArcGIS Desktop application and the data or service provider. ArcIMS introduced a way for organizations throughout the world to share GIS data and services. The Geography Network established a framework to bring GIS data and services together, which helped foster a rapidly expanding infrastructure of communities everywhere sharing information worldwide. Promotion of data standards and improved data collection technologies continue to unlock enormous possibilities for sharing geospatial information, which should help us better understand and improve our world.
GIS data resources are expanding exponentially. In the 1990s, GIS data servers seldom held (or had a need for) a database that was more than 25 to 50 gigabytes (GB) in size. Today it is common for organizations to operate geodatabase servers handling several terabytes to petabytes of GIS data (one petabyte is equal to eight quadrillion bits of data). Community-level data marts are being established to consolidate GIS data resources and provide Internet data sharing to organizations throughout county and state regional areas. State and national agencies are consolidating data and sharing it with each other and with communities and municipalities everywhere.

Many organizations are outsourcing their IT operations to commercial Internet service providers (ISPs). Application service providers (ASPs) support organizations with IT administration, providing opportunities for smaller organizations to take advantage of high-end GIS database and application solutions to serve their business needs. State governments are hosting applications and data for smaller municipalities throughout their state so that the smaller communities can take advantage of GIS technology to help their local operations.

Regional geography network (g.net) sites allow for the sharing of data throughout the region and within large state and federal agencies. Web portal software provides a metadata search engine that can be used by organizations to share their data and bolster their community operations. Cities can establish metadata sites to promote local commercial and public interests. States can consolidate metadata search engines for sharing data and services with municipalities throughout the state. Law enforcement can establish search engines to feed and use national datasets. Businesses can establish metadata search engines to support distributed operational environments. Web services enable community data sharing and integrated workflows.

Deployment of ArcGIS Server with ArcGIS 9 expanded Web services technology to include geoprocessing and a broad range of service-oriented Web operations. GIS technology, in conjunction with Web standards and open systems architecture, has opened new opportunities for improving business operations. GIS software and computer infrastructure technology continue to expand GIS capabilities and introduce new business opportunities. Improved availability and capacity of wireless technology enables mobile communication connectivity for a growing number of GIS users.

The growth of both the technology and the sharing of it through data and services is establishing GIS as an integral part of community. The technology provides real-time access to geographic information, which means it’s rapidly becoming a primary technology for understanding not only business opportunities but the world itself. With technology changing more rapidly today than ever before, national and global geospatial initiatives are bringing communities and people together to understand and solve the world’s problems in ways we only dreamed possible just 10 years ago.
English is becoming a common second language for many people throughout the world, allowing many to share technology and work together like never before. Geography provides a common language for understanding our world, and brings people of different nations and cultures together to understand and solve common problems.

In my work I have had the pleasure to travel throughout the world and meet people from many different nationalities and backgrounds. My ability to communicate was limited by language barriers in the 1970s, 1980s, 1990s—I would communicate through interpreters, facial expressions, and sign language. It was a very big world, and there was much we did not understand. Today I share my understanding of GIS technology with our international distributors, business partners, and GIS customers all over the globe. We communicate ideas, problems, and solutions through a shared language, which is some combination of computerese and our common interest in geography. The language barrier is falling, perhaps because of some of the things we’re doing with GIS:

- Working with global energy companies to better manage their geographic information resources
- Working with scientists throughout Europe to build a common geospatial data infrastructure for the European community
- Training United Nations staff responsible for peacekeeping operations, disaster relief support, and support for troubled nations throughout the world
- Working with people in national parks in Canada and the United States using GIS to better manage our natural resources
- Working with customers in Hong Kong who use GIS to better manage land resources and support services for one of the world’s most complex metropolitan environments

In other words, GIS is working; the technology is making a difference in our world, by employing geography to bring nations together in a very special way to better understand and solve the problems we share. From this perspective, the GIS community is as extensive as the world, and sometimes the software product options to choose from can seem just as wide-ranging. All this functionality is within reach, however; it’s just a matter of assessing what you need to serve your own organization’s mission. All the ESRI products available now have been developed over the years in response to user need. So looking more closely at what the software does, in the section that follows, becomes something of a journey through not only what is possible for you to do with it but also what your fellow users may already be doing.

**ESRI product family**

The ESRI product family, illustrated in figure 2-5, includes a mix of software developed to fulfill a wide range of GIS user requirements. ArcGIS software supports desktop, server, and mobile applications. Data management solutions support a variety of file-,
geodatabase-, and Extensible Markup Language (XML)-based formats.

GIS Web services support a variety of managed, hosted, and shared GIS Internet services. ArcGIS Server provides technology for publishing GIS services that can be consumed by ArcGIS Desktop, mobile GIS, and standard Web browsers. ESRI Developer Network (EDN) offers a range of technical services to the ESRI Engine, a desktop development environment that provides a complete set of ArcGIS ArcObjects components for custom desktop application development.

Desktop GIS: ArcGIS Desktop software is focused on providing the professional GIS user with direct access to all GIS data resources, all published geodata services, and tools for geographic analysis and visualization that will lead toward advancement of GIS technology. Desktop GIS is divided into four licensed solutions based on user functional needs. These include ArcGIS Desktop (ArcInfo, ArcEditor, ArcView) and ArcGIS Engine, a desktop development environment that provides a complete set of ArcGIS ArcObjects components for custom desktop application development.

ArcGIS Desktop software is licensed at different software levels based on user needs. ArcReader is free desktop software for viewing and sharing a variety of dynamic geographic data. ArcView includes all the functionality of ArcReader and adds geographic data visualization, query, analysis, and integration capabilities. ArcEditor includes all the functionality of ArcView and adds the power to create and edit data in an ArcSDE geodatabase. ArcInfo is the complete GIS data creation, update, query, mapping, and analysis system.

A range of desktop extension licenses are available that provide enhanced functionality for supporting more focused GIS operations. Desktop extensions operate with the foundation ArcGIS Desktop license and expand functions for geospatial analysis, productivity, solution-based, Web services, and a range of no-cost add-ons to address a variety of focused user needs. (For more detailed information on this and all ESRI software products, see www.esri.com.)

Server GIS: Server GIS is used for a variety of centrally hosted GIS services. Use of server-based GIS technology is expanding rapidly as more and more customers leverage Web-based enterprise technology. GIS technology can be managed on central application servers to deliver GIS capabilities to large numbers of users over local and wide area networks. Enterprise GIS users connect to central GIS servers using traditional desktop GIS as well as Web browsers, mobile computing devices, and digital appliances.

ArcGIS Server software (figure 2-6) is divided into three licensed solutions based on available functionality and system capacity. ArcGIS Server Basic includes geodatabase management (ArcSDE technology), geodatabase check-in/checkout, and geodatabase replication services. ArcGIS Server Standard includes all the
functionality of ArcGIS Server Basic plus standard map publishing, ArcGlobe services (ArcGIS Explorer), and standard geoprocessing. ArcGIS Explorer is a free, lightweight, ArcGIS Server desktop client that can be used to access, integrate, and use GIS services, geographic content, and other Web services. ArcGIS Server Advanced includes all the functionality of ArcGIS Server Standard plus Web editing, mobile client application development framework (mobile ADF), advanced geoprocessing, and support for ArcGIS Server extensions.

**Developer GIS:** EDN is an annual subscription-based program designed to provide developers with comprehensive tools that increase productivity and reduce the cost of GIS development. EDN provides a comprehensive library of developer software, a documentation library, and a collaborative online Web site that offers an easy way to share up-to-the-minute information.

**GIS Web services:** GIS Web services offer a cost-effective way to access up-to-date GIS content and capabilities on demand. With ArcWeb Services, data storage, maintenance, and updates are handled by ESRI, eliminating the need for users to purchase and maintain the data. Users can access data and GIS capabilities directly using ArcGIS Desktop or use ArcWeb Services to build unique Web-based applications. An ArcWeb Services subscription provides instant and reliable access to terabytes (TB) of data, including street maps, live weather and traffic information, extensive demographic data, topographic maps, and high-resolution imagery from an extensive list of world-class data providers.

ArcGIS Online provides access to terabytes of cached map services. With ArcGIS Online you can access 2D maps, 3D globes, reference layers, and functional tasks via the Web to support your GIS work. You can contribute your own data for publishing through ArcGIS Online and make it broadly available to other users. You can also purchase data you see in ArcGIS Online and publish it on your own server.

Software vendors do modify pricing strategies when necessary to account for technology change. Prices normally go down over time, so building a solution from current technology and establishing your project budget based on current pricing models is a conservative management strategy. In any case, it is important to understand pricing and factor this in to your technology decision. (For example, the price of Web services has changed from ArcIMS to ArcGIS Server, which has affected how we design these systems.)

Customers are often aware of the basic core software, but many times they do not see what is really under the covers—what will make a difference in user performance and supportability. ArcGIS software includes a variety of ways to deploy GIS. Several technology options are available for ArcGIS Desktop users, Web users, and for Mobile users. There is an optimum architecture solution for each of the different types of user workflows. Understanding the choices available is a first step in finding it and putting the right pieces together for your environment.

**Desktop operations:** Figure 2-7 provides an overview of the various ArcGIS Desktop client choices you can make for your environment. Applications can use different levels of software (ArcInfo, ArcEditor, ArcView), any of the ArcGIS Desktop extensions, or custom ArcGIS Engine clients.

![Desktop operations](image-url)
Stand-alone desktop applications can use a Microsoft SQL Server Express personal geodatabase (PGDB), providing up to 4 GB (per database server) of capacity for local user editing and viewing operations. The file geodatabase (FGDB), which was introduced with ArcGIS 9.2, supports 1 TB of geospatial data per table in a file format (can be configured to 256 TB). FGDB can be used as reference data or a single-user editing environment. Standard shapefiles can also be used for a local data source.

The same ArcGIS Desktop applications can be deployed in a connected LAN environment (with access to network data sources and Web services). Or, they can be deployed from a central data center on Windows Terminal Server platforms, which support remote WAN clients over lower bandwidth WAN environments, and still maintain full access to local LAN network data sources.

All of the ArcGIS Desktop applications can take advantage of the high performance of cached data sources, such as those provided over the Internet from ArcGIS Online. ArcGIS Online data is streamed to the client and cached locally, providing high performance reference data for local client applications.

Web operations: Figure 2-8 provides an overview of the various ArcGIS Server Web client choices you can make for your environment. Potential Web client candidates include ArcGIS Desktop, ArcGIS Engine, and ArcGIS Explorer. Also, standard Web browser applications can be client applications using a variety of Web applications and services.

ArcGIS Server can provide Simple Object Access Protocol (SOAP)/XML-based data services (published reference images) and geoprocessing services to ArcGIS Desktop and ArcGIS Engine client applications. It also provides a 3D globe, cached file data source for ArcGIS 3D Analyst and ArcGIS Explorer clients. ArcGIS Server also hosts a full range of map view and edit applications for Web HTML browser clients supported by out-of-the-box .NET and Java Web map and editor Server development kit components.

ArcIMS is a popular solution for delivering dynamic maps and GIS data and services via the Web. It provides a highly scalable framework for GIS Web publishing that meets the needs of corporate intranets and the demands of worldwide Internet access. ArcIMS customers are rapidly moving to ArcGIS Server software to leverage the rich functionality available with the new ArcGIS Server software release.

ArcGIS Image Server changes how imagery is managed, processed, and distributed. Image Server provides fast access and visualization of large quantities of file-based imagery, processed on the fly and on demand. It provides rapid display of imagery for a number of users working simultaneously, without the need to pre-process the data and load it into a database management system (DBMS). ArcGIS Image Server can be used as a data source for ArcGIS Desktop, ArcGIS Server, and ArcIMS operations. Additional support is provided for AutoCAD and MicroStation CAD clients. On-the-fly processing can include image enhancement, orthorectification, pan sharpening, and complex image mosaicking. Understanding these options and how they might best support your GIS needs is an important first step in selecting the right solution for your environment.

### Mobile GIS
Mobile GIS supports a range of mobile systems from lightweight devices to PDAs, laptops, and Tablet PCs. ArcPad is software for mobile GIS and field-mapping applications. All ArcGIS Desktop products—
ArcReader, ArcView, ArcEditor, and ArcInfo—and custom applications can be used on high-end mobile systems, such as laptops and Tablet PCs. Figure 2-9 provides an overview of the primary connected mobile workflow alternatives.

The ArcGIS Server 9.2 Basic license supports distributed geodatabase replication. Geodatabase replication provides loosely connected synchronization services for distributed geodatabase versions maintained in supported database platforms. Web-based disconnected check-in and checkout services are also provided. Distributed geodatabase replication is discussed later in chapter 6.

ArcGIS 9.2 also provides geodatabase support in a Microsoft SQL Server Express personal geodatabase. Microsoft SQL Server Express is bundled with each ArcGIS Desktop software license. ArcGIS Desktop clients (including custom ArcGIS Engine runtime deployments) can support a distributed geodatabase client replica and synchronize changes with the central parent geodatabase. The SQL Server Express database has a data capacity of 4 GB.

ArcGIS 9.2 also supports a file-based geodatabase. ArcGIS Server 9.3 enables Web-based data checkout/check-in and one-way geodatabase replication to distributed file geodatabase clients.

ArcGIS Server 9.2 Advanced license comes with the ArcGIS mobile software development kit. ArcGIS Mobile lets developers create centrally managed, high-performance, GIS-focused applications for mobile clients. Mobile applications powered by ArcGIS Server contribute to increased field productivity and more informed personnel.

**Expanding GIS technology trends**

Advances in GIS software and computer infrastructure technology fuel a continuous expansion in GIS capabilities and new business opportunities. At the same time, the increasing availability and capacity of wireless technology is providing improvements in mobile communication connectivity for a growing number of GIS users. Wireless technology is changing both how we work now and the types of architecture strategies available for generations to come.

Mobile devices are available for work when and where you need them, and now it’s possible to manage their work wirelessly, too. Integrating loosely coupled mobile workers into enterprise workflows, mobile technology has become one of the most appealing ways to improve business operations. Traditionally, mobile data collection and management were set apart from the internal business workflow, but now they’re embedded.

This is just one example of how enterprise architecture strategies are changing. The list of common ArcGIS deployment alternatives is growing. It started with traditional GIS workstations, expanded to the more centralized, enterprise GIS option, and now includes the newly emerging federated and service-oriented architectures. In looking for ways to improve access and data sharing with other organizations, traditional department-level
GIS client/server operations are shifting to a federated GIS architecture. In seeking ways to integrate GIS with other centrally managed business operations, some traditional enterprise GIS organizations are finding the integrated business solutions they're looking for within a service-oriented architecture (SOA).

**Federated GIS technology**

Database and Web technology standards provide new opportunities to better manage and support user access to a rapidly growing volume of geospatial data resources. Web services and rich XML communication protocols enable efficient data migration between distributed databases and centralized storage locations. Web search engines and standard Web mapping services provide a means to discover and consume integrated geospatial information products published from a common portal environment with data provided from a variety of distributed service locations. Federated architectures identified in figure 2-10 promote better data management by integrating community and national GIS operations. Geodatabase replication services and managed extract, transform, and load (ETL) processes support loosely coupled distributed geodatabase environments.

Federated systems are composed of parties that share networked applications and data resources. GIS is all about sharing. Many local government, state, and federal agencies share GIS data to support community operations. Data resources owned by each party are brought together to provide community-level information products. Data maintenance responsibilities are distributed between different groups, with databases configured to share GIS resources between the different sites on a scheduled basis. Web portals provide applications supported by a variety of Web services and act as a broker to connect users with published community-wide data services.

**Service-oriented architecture**

Service-oriented architecture is the next computer frontier, if indeed Web services is our future. It's possible that at some point we may no longer have applications on our desktop, and IT expenses (which consume as much as half of the operational budget today) may go away. Changes of that magnitude have come to seem like a regular feature of this age of technology in which we live. Moving to a component-based software architecture in the late 1990s accelerated the growth of software vendor technology—software upgrades that happened once a year in the 1990s are released as quarterly service packs with today's software technology. Software upgrades that would happen once a year are now streamed to your computer for download and install on a daily basis. One can only imagine what might happen if these functional application components were replaced by Web services. A good guess is that the acceleration of technology change is just getting started—we've seen nothing yet. Yet we've seen enough to compel organizations to search for more effective ways to manage technology change.

Obviously, business environments are influenced by the rate of technology change and because change introduces risk, contributing to business success or failure. Selecting the right technology investment is
critical. Service-oriented architecture deployment strategies reduce business risk through diversification and reduced vendor dependence. Open standards reduce the time and effort involved in developing integrated business systems, providing integrated information products (common operating picture) that support more informed business decisions. Advantages of a service-oriented architecture are highlighted in figure 2-11.

**Advantages of an SOA**

- Technology change ➤ Component architecture
- Business continuance ➤ Reduce vendor dependence
- Leverage investments ➤ Reuseable components
- Customer flexibility ➤ More vendor choices
- Business integration ➤ Open system communications

- Building applications from component Web services will accelerate technology change.
- Supporting business functions from multiple vendor sources can reduce vendor dependence and improve options for business continuance when others fail.
- Service architectures can support reusable components—the same published services can be used by several business applications.
- Web services can be abstracted from the vendor technology providing the service—this opens the door for more choices among the vendor products that can support the same business application.
- Business systems can interface through a services architecture; services from each business function can be integrated by an enterprise application.

**Figure 2-11**

Advantages of service-oriented architecture.

Basically, SOA is an approach for building distributed computing systems based on encapsulating business functions as services, services that can be easily accessed in a loosely coupled fashion. Business functions are encapsulated as Web services that can be consumed by Web clients and desktop applications. The core components that make up a service-oriented architecture include service providers, service consumers, and implementation of a service directory. The SOA infrastructure connects service consumers with service providers and may be used to communicate with service directories.

From a business perspective, new business functions are provided as Web services, which are IT assets that correspond to real-world business activities or recognizable business functions; accessibility is based on service policies established to support enterprise operations (loosely coupled to the business applications).

From a technical perspective with SOA, services are coarse-grained, reusable IT assets. (Course-grained indicates that the components provide a complete service rather than bits and pieces—functions—pulled together to support a service. The ArcGIS Server ADF components are course-grained reusable IT assets, for example. A service published by the ADF would be even more course-grained or at a higher level of function). SOA services have well-defined interfaces (service contracts) with the software technology providing the service abstracted from the external accessible service interface. The trend is to support SOA through Web services based on SOAP, XML, and KML protocols.

Common Web protocols and network connectivity are essential to support this type of architecture. The SOA infrastructure may be implemented using a variety of technologies, of which ESRI’s software, with its support of open standards, can be a part. ESRI embraced open standards during the 1990s and has actively participated in the Open GIS Consortium and a variety of other standards bodies in an effort to promote open GIS technology. The initial ArcIMS Web services, Geography Network metadata search engines, Geospatial One-Stop, and the ESRI Portal Toolkit technology are all examples of the service-oriented solutions characterizing ESRI’s current customer implementations. Figure 2-12 provides a view of how current ESRI software supports the evolving SOA enterprise by fitting in with its standard IT infrastructure.

The service-oriented architecture (SOA) framework includes multiple access layers connecting producers and consumers, based on current client/server technology and incorporating Web application and service communication tiers. Consumers connect to producers through a variety of communication paths. This framework supports a presentation tier of viewers with access to available published services, a serving/publishing tier of services, and an authoring tier of professional ArcGIS Desktop users. This framework supports current client/server connections (client applications),
Web applications, and Web services—all available today with current technology. Future vendor compliance and maturity of Web interface standards are expected to gradually migrate business applications from tightly coupled proprietary client/server environments to a more loosely coupled SOA. The ideal environment would separate business services and workflows from the underlying software technology, providing an adaptive business environment in which to effectively manage and take advantage of rapid technology change.

GIS is by nature a service-oriented technology with inherent fundamental characteristics that bring diverse information systems together to support real-world decisions. GIS technology flourishes in a data-rich environment, and ArcGIS technology can help ease the transition from existing “stovepipe” GIS environments. The geodatabase technology provides a spatial framework for establishing and managing integrated business operations. Many spatial data resources are available to support organizations as they shift their operations to take advantage of GIS technology.

Migration to a service-oriented architecture is more a change in attitude than a change in technology. Moving a business from high-risk, tightly coupled, monolithic stovepipe operations to a more integrated, responsive SOA will take time. Figure 2-13 provides some basic guidelines for moving existing systems to a more dynamic and supportable SOA environment.

Understanding SOA and how it enables business process integration and helps control and manage technology change is important. Organizations must build an infrastructure that can effectively take advantage of new technology to stay competitive and productive in today's rapidly changing environment.

With this overview of how GIS-related technology has evolved over the last 20 years, it becomes apparent that geography is making a difference in how people think. GIS software provides tools with which to under-
stand the world better. Selecting the right software and configuring it properly can make a big difference in how well you are able to support your needs.

GIS technology today

Current GIS technology is available to support a rapidly expanding spectrum of GIS user needs as depicted in figure 2-14. Solutions are supported by ESRI products integrated with a variety of vendor technologies. In fact, this integration or “playing well together” is more important today than it ever was, as users and their organizations are becoming more and more focused on integrating commercial-off-the-shelf solutions than on building customized applications. Of course, there will always be a need for the latter, but in the past, most applications had to be developed from scratch. Yet these days, with open standards becoming the norm, technology changing so rapidly, and solutions becoming more available at less cost, you could almost say that we are becoming more shoppers than developers.

Data storage and data management technologies are growing in importance as organizations continue to develop and maintain larger volumes of GIS data. Individual server storage solutions are being replaced by more adaptive storage area networks (SANs), enhancing the IT’s ability to respond to changing data storage needs and providing options for efficiently managing large volumes of data.

GIS data sources include file servers, geodatabase servers, and a variety of business database solutions. Desktop ArcGIS applications can be supported on local workstation clients or on centrally managed Windows Terminal Server farms.

ArcGIS Server (and legacy ArcIMS mapping services) provide Web services to Web browser clients throughout the organization and the community. ArcGIS clients are able to connect to ArcGIS Server Web products as intelligent browser clients, enabling connection to unlimited data resources through the ESRI Geography Network, and to organization resources served through a variety of ESRI customer portals. Users can access applications from the Internet or through intranet communication channels. Mobile ArcGIS users can be integrated into central workflow environments to support seamless integrated operations over wireless or remote connected communication. ArcGIS Desktop applications can include Web services as data sources integrated with local geodatabase or file data sources, expanding desktop operations to include available Internet data sources.

GIS enterprise architecture is typically supported by a combination of ArcGIS Desktop, ArcGIS Server, and geodatabase software technology. Selecting the right
combination of technology will make a big difference in the level of support for user operational needs and business productivity.

**GIS software selection**

Selecting the right software and the most effective deployment architecture is very important. ArcGIS technology provides many alternative architecture solutions and a wide variety of software, all designed to satisfy specific user workflow needs. We looked at the ESRI products earlier. Now figure 2-15 shows these GIS software technology alternatives in terms of their everyday configuration. What is the best data source? What user workflows should be supported by GIS desktop applications? What can be supported by cost-effective Web services? What business functions would be best supported by network services? Where will mobile applications improve business operations? Understanding the available technology alternatives and how each will perform and scale within the available user environment can provide the information needed to make the right technology decisions.

**GIS data source:** Data can be accessed from local disks, shared file servers, geodatabase servers, or Web data sources. Local data sources support high-performance productivity requirements with minimum network latency, while remote Web services allow connection to a variety of published data sources, with the drawback of potential bandwidth congestion and slow performance. There are, however, other more loosely connected architecture solutions that reduce potential network performance latency and support distributed data integration.

**Desktop applications:** The highest level of functionality and productivity is supported with the ArcGIS Desktop applications. Most professional GIS users and GIS power users will be more productive with the ArcGIS Desktop software. These applications can be supported on the user workstation or through terminal access to software executed on centralized Windows Terminal Server farms. Some of the more powerful ArcGIS Desktop software extensions perform best on the user workstation with a local data source, while most ArcGIS Desktop workflows can be supported efficiently on a terminal server farm. Selecting the appropriate application deployment strategy can have a significant impact on user performance, administrative support, and infrastructure implementations.

**Web services:** The ArcIMS and ArcGIS Server technologies provide efficient support for a wide variety of more focused GIS user workflows. Web services also provide a very efficient way to share data for

---

**Figure 2-15**

GIS software technology selection.
remote client workflows. ArcIMS provides an efficient way to publish standard map information products, while ArcGIS Server provides enhanced functionality to support more advanced user workflows and services. Web services are a cost-effective way to leverage GIS resources to support users throughout the organization and associated user communities.

Network services: Intranet applications can access services provided by ArcGIS Server connecting directly through the server object manager. Network services can be used to support a variety of Web and network applications.

Mobile applications: A growing number of GIS operations are including more loosely connected mobile GIS solutions. ArcGIS technology enables continuous workflow operations that include disconnected editing and remote wireless operations. A disconnected architecture solution can significantly reduce infrastructure costs and improve user productivity for some operational workflows. Leveraging mobile services can provide alternative solutions to support a variety of user workflow environments.

Selecting the proper software and architecture deployment strategy can have a significant impact on user workflow performance, system administration, user support, and infrastructure requirements.

**GIS architecture selection**

As we’ve said GIS environments commonly begin with single-user workstations at a department level. Many organizations start with one GIS team and evolve from the department level to an enterprise operation. (This was common through the early 1990s, as many organizations worked to establish digital representation of their spatial data.) Once this data is available, organizations frequently expand their GIS operations to support enterprise business needs. GIS is a very compute-intensive and data-rich technology. A typical GIS workflow can generate a remote user desktop display every 6–10 seconds; every time it does requires hundreds of sequential data requests to be sent to a shared central data server, to render each desktop display. As a result, GIS workflows can place high processing demands on central servers and generate a relatively high volume of network traffic. Selecting the right configuration strategy can make a significant impact on user productivity.

Data can be shared between users in a variety of ways. Most organizations today have user workstations connected to local area network (LAN) environments and locate shared spatial data on dedicated server platforms. However, there are configuration alternatives, as described below.

**Centralized computing architecture**

The simplest system architecture uses a single, central GIS database with one copy of the production database environment, minimizing administrative management requirements and ensuring data integrity. Standard enterprise data backup and recovery solutions can be used to manage the GIS resources.

GIS desktop applications can be supported on user workstations located on the central LAN, each with
access to central GIS data sources. Data sources can include GIS file servers, geodatabase servers, and related attribute data sources as shown in figure 2-16.

Remote user access to central data sources can be supported by central Windows Terminal Server (WTS) farms, providing low-bandwidth display and control of central application environments.

Centralized application farms minimize administration requirements and simplify application deployment and support throughout the organization. Source data is retained within the central computer facility, improving security and simplifying backup requirements.

A variety of Web mapping services can be provided to publish data to standard browser clients throughout the organization. Web mapping services allow low-bandwidth access to published GIS information products and services.

Today, centralized computing technology can support consolidated architectures at a much lower risk and cost than similar distributed environments. For this reason, many organizations are in the process of consolidating their data and server resources. GIS can benefit from consolidation for many of the same reasons experienced by other enterprise business solutions: reduced network traffic, improved security and data access, and less cost for hardware and administration. Centralized GIS architectures are generally easier to deploy, manage, and support than distributed architectures and provide the same user performance and functionality.

Distributed computing architecture
Distributed solutions are characterized by replicated copies of the data at remote locations, establishing local processing nodes that must be maintained to be consistent with the central database environment, as shown in figure 2-17. Data integrity is critical in this type of architecture, requiring controlled procedures with appropriate commit logic to ensure changes are replicated to the associated data servers.

Distributed database environments generally increase initial system complexity and cost (more hardware and database software requirements) and demand additional ongoing system administration and maintenance. There can be increased network traffic with distributed data solutions, along with somewhat higher implementation risk. Distributed solutions are provided to support specific user needs.

In many cases, standard database solutions do not allow for replication of spatial data. GIS users with distributed database requirements must modify their data models and establish procedures to administratively support data replication. The complexity of current geodatabase environments has complicated the implementation of an efficient commercial spatial replication solution. Many GIS users are interested in replicating...
regional or selected versions of a geodatabase, which is not understood by commercial replication technologies. ArcGIS software functions are available to support custom geodatabase replication solutions. ArcGIS 9.2 provides support for distributed geodatabase replication, providing alternative options for supporting distributed operational requirements. The ArcGIS 9.3 release adds one-way replication to the FGDB and PGDB data sources.

Selecting the right technical solution

Understanding the available software technology choices is critical in building effective GIS enterprise solutions. Technology is changing faster every day, and the rate of technology change has altered the way people build and maintain effective enterprise solutions. In the 1990s, many organizations hired their own programmers and developed their own technology solutions. Building enterprise GIS operations would take many years and involve hundreds of hours of planning, data collection and conversion, application development, and incremental system deployment. Today, these same systems can be deployed within months. Custom application development today focuses on the user interface, data model, and system integration—building systems from current technology components. The right technology selection and integrated solution architecture is the key to getting ahead.

Selecting the right solution starts with a clear understanding of your business needs. You are building a solution from commercial off-the-shelf technology—software that must be adaptive and play well together. Choosing the right technology at the right time can save hundreds of hours of grief—which quickly translates into success at the bottom line. Much has been learned over the last 20 years of software development: what works, what doesn’t, and what you need to be successful. Learn from the experience of others, and keep abreast of technology trends. Understand why the technology is moving in the direction that it is, and keep your eyes open to new ideas that might signal a change in direction.

Software and hardware technology trends play together to expose future business opportunities. Take advantage of every chance you get to learn about both.

The next chapter holds what you need to know about network communications. For many organizations, network communications provide the infrastructure for building and supporting enterprise GIS operations. You need to understand your network limitations to make the proper technology selections.