Part I

Understanding the technology
This book describes an approach to system architecture design specifically intended to support successful geographic information system (GIS) operations. With it in hand, you have a process—not a prescription—and a practical tool (see CD) to help you plan the infrastructure for a GIS specific to your needs. Knowing what you need is all-important to this process, and it is the assumption of this book that you have already identified what your organization requires from a GIS. This is because system architecture design defines the relationship between peak user workflow performance needs and the hardware and network infrastructure required to meet them.

The purpose of this book is to provide managers with not only the tools but also the information to help them build a successful infrastructure for GIS. A fundamental understanding of the supporting information technology, GIS performance and scalability, and the models and methods in this book fosters the type of management framework that leads to success. These fundamentals of system architecture design could help in building a system for any technology. But we consultants at ESRI have applied them to guide our customers to successful GIS deployments.

We are sharing our understanding of the technology (chapters 1–6), how the technology comes together to fulfill user performance requirements (chapters 7–9), and the process for completing a system design (chapters 10–12) in which user requirements lead to hardware specifications. If you are a system architect, you may be tempted to jump to chapter 11 where the system design process itself is spelled out step by step. Don’t do it; rather, look before you leap. Even system architects are not ready to begin until they understand the technology and the Capacity Planning Tool (CPT), within the first 10 chapters, because the technology has changed so dramatically, so recently. (We do not send our system design consultants to a customer site until they understand what’s inside the first 10 chapters of this book.)

There used to be a time when it was possible to simply define user requirements, select a software solution of choice, and then identify hardware and network specifications to fulfill system capacity needs. Nowadays it’s more complex. Selecting the right technology requires a more specific understanding of GIS user needs and system infrastructure limitations. Enterprise GIS operations today are supported by a variety of software and hardware technologies that must work together to meet user performance needs when operating at peak system capacity. Technology selection must take into consideration performance and scalability requirements and infrastructure limitations. An integrated business needs assessment—evaluating GIS user needs along with projected system performance and scalability throughout the requirements definition process—is the recommended way to ensure deployment success.

For this reason, system architecture design—better described as an integrated business needs assessment—is not at heart a step-by-step process anymore. It is more like working on a puzzle. There are procedures within the process, such as those that must be followed during a project implementation, but first, as in a puzzle, a system must be understood as a whole before it can be properly put together. Like the pieces of a puzzle, many interacting components compose the whole, each related to another in a very special way. Each special relationship emerges during the system architecture design process to reveal to you its significance to your design. The components of this puzzle are what we examine in Building a GIS, and our discussion is divided into three parts.

Part I: Understanding the technology
Chapter 1 presents the very high-level view, such as identifying the pieces of the system design puzzle (figure 1-1). The next five chapters, which complete the first section, describe these puzzle pieces, answering the following questions:
Chapter 2. Software technology—what are the software technology options?
Chapter 3. Network communications—what effect will a given technology solution exert on the existing infrastructure?
Chapter 4. GIS product architecture—what configuration options match up with your availability and scalability needs?
Chapter 5. Enterprise security—how do you adjust your architecture solution to accommodate your security needs?
Chapter 6. GIS data administration—what are your options for maintaining and providing the required GIS data resources?

Part II: Understanding the fundamentals
The relationships between the pieces of the puzzle are expressed in terms of system performance and cost. The system performance relationships are presented in the second part of the book, chapters 7–9. You can obtain information about cost from the software and hardware vendors, once you identify the right solutions for your organization.
Chapter 7. Performance fundamentals—an overview of the performance relationships between the pieces of the system design puzzle.
Chapter 8. Software performance—an overview of software performance considerations: how will your technology decisions affect system performance and scalability?
Chapter 9. Platform performance—what do the vendors have to offer, and how do you select the hardware that will provide the required processing power?

Part III: Putting it all together
Putting all the pieces together completes the puzzle. The CPT and the actual system design process itself are presented in the final three chapters.
Chapter 10. Capacity planning—a fully illustrated and detailed description of how to use the Capacity Planning Tool (a composite of several integrated information management tools that identify user workflow requirements and select the right hardware and network solution), including how to customize it for your own situation.
Chapter 11. Completing the system design—a walk through the system design process, using a case study to show how to bring the pieces of the puzzle together in the system architecture.
Chapter 12. System implementation—guidelines for implementation of the selected design solution, which take into account the maintenance and tuning that follow.

The CPT on the CD
The performance components that contribute to success are clearly defined and modeled in the CPT, which is provided on the accompanying CD and thoroughly described in the book. Templates are provided in the CPT for collecting user requirements, as are standard workflow models that translate peak user loads to selected platform processing environments. The CPT translates the peak user workflows for you as specific platform and network specifications, applying the performance models presented in chapter 7 so that you can use it to evaluate which mixes of technology will best meet your needs. In doing so, you may find the selected software technology will not support users over the available network infrastructure. You may find your favorite vendor does not provide the best hardware for your preferred solution. You may find you need to upgrade your network infrastructure, or change your business processes to conform to a more distributed architecture. As you change each piece of the puzzle, its relationship with the other pieces of the puzzle will change and the overall solution will be reevaluated. The CPT is intended to make this process of reevaluation easier for you. For each solution, the CPT takes each component into consideration and evaluates performance of the integrated system: Does the selected solution meet your organization’s needs? If not, what other alternatives will better support your needs?

Also on the CD, you’ll find teaching and learning aids, including a list of multiple-choice questions associated with each chapter. These might be useful for teachers and students, or simply for readers interested in reviewing the main points of discussion.
A system is only as strong as its weakest link. Enterprise GIS operations are supported by a large number of infrastructure components, wherein the weakest component will limit system capacity and user productivity. Selecting the right software technology, building proper applications, establishing an effective database design, and procuring the right hardware all play a critical role in fulfilling system performance and scalability expectations. Understanding your infrastructure needs before you buy can make the difference between success and failure and significantly reduce the overall system deployment cost. The key to system design success is understanding what you need, establishing measurable performance milestones, and managing incremental progress toward performance and scalability goals throughout the development and deployment process.

Computers are part of our life because they save people—and organizations—time and money. Tasks that used to take hours or weeks can now be done in minutes, even seconds. People use GIS for the same reason they use computers: because it makes them more productive, more efficient at work. Anything that can improve efficiency and productivity is welcome. System performance—how fast and reliably the components of a computer system can process an application and display the results for you—directly contributes to user productivity. You need to configure all the elements in a system—software, hardware, network communications—so that they work well and efficiently together in doing what you need to get done.

Technology is changing, and unless people take the time to understand it, they can get in over their heads and suffer performance problems. Have you ever experienced a problem with a system at point A, only to discover that the actual cause of the problem was located way over at point E, a seemingly unrelated area? Usually these realizations come after spending quite a while exploring a lot of dead-ends trying to get to the root of the matter, often settling for a temporary workaround. No one needs to tell you, these times spent chasing symptoms interrupt the workflow, and if they happen over and over again, can significantly reduce productivity. They also could be a sign that there may be something wrong with the system design.

Far and away better, of course, is to get the system right the first time around. Then you can spend your tinkering time doing serious planning and maintenance, to keep your system at the ready to adjust, as advancements in technology and organizational goals present new opportunities for growth through change. Getting the system right means achieving performance: a proper system is one that works the way you want and as fast as you need. A system able to take advantage of opportunities and grow is a scalable one.

The key to achieving both performance and scalability—the prerequisite for getting the system right and for keeping it right as the demand on it grows—is the same task: understanding the nature of each component of a system, the interrelationships between components, and how changes in one affect the other. Each component technology does have an affect on overall system performance. The reason you might not have known right away the symptomatic connection between point A and point E in the example above is no doubt due to the intricacies of these interrelationships. They seem complex, but after we’ve sorted them out, you will see how simple system design really is.

System architecture design for GIS

Computer systems were first used to automate cartographic map production in the late 1960s. Before that, geographic analysis, a method for displaying the relationship of many layers of geospatial information, relied on more time-consuming methods. Traditional methods of creating Mylar representations of each dataset and overlaying the layers of spatial data could take weeks to complete a simple information product. Early computers were able to automate the analysis process and reduce map production timelines from weeks to hours. Current computer technology can complete this same type of analysis and generate dynamic map displays in less than a second.

The term geographic information system (GIS) was introduced by Roger Tomlinson, and was later promoted by professors at Harvard University in the 1970s, inspiring several geographic consulting companies to develop and expand GIS technology. One of those companies was ESRI, beginning in 1969. Consider that its software runs on more than one million desktops in more than 300,000 organizations now, and you can see that the evolution of GIS has followed the advance of computer technology.

Local government and business started deploying large GIS operational systems in the early 1990s, and soon it became clear that the success of such distributed GIS operations was strongly connected with an understanding of GIS performance and scalability in a distributed computer environment. Distributed GIS operations were characterized by high performance computer systems coupled with a high demand on network communications. GIS deployment required several years’ investment in data migration and custom application development. That, along with the required system infrastructure investments, was expensive. An understanding of system design requirements was critical in supporting successful GIS deployments. This
is why a software company became so interested in hardware system performance early on.

My initial responsibility when I joined ESRI was to develop a team that would support successful implementation of turnkey (“out of the box”) GIS sales. Part of that was the acquisition and installation of hardware and software technology adequate to the task of supporting an organization’s GIS workflows—or, as we call them, GIS peak operational system level requirements. We established a Systems Integration Department with four specific teams (system architecture design, project management, system installation, and project control). We helped complete several hundred successful GIS turnkey project implementations between 1992 and 1998, and learned a few things along the way. The best practices developed to facilitate implementation of turnkey GIS sales were also used to address failed system implementations. We learned from our mistakes and those of our customers.

Technology has changed tremendously, but the three fundamental building blocks required for each project implementation have not changed in all this time:

1. A clear definition of the peak user workflow requirements (user requirements analysis)
2. A clear understanding of infrastructure requirements to support the peak user workflows (system architecture design)
3. An implementation strategy that provides proper systems integration management from initial contract authorization to final system acceptance (project management)

A variety of best practices were soon established to facilitate a proper user requirements analysis. It had been evident during earlier implementations in the 1970s and 1980s, and then became abundantly clear, that identifying your user requirements—knowing exactly what you need to get out of a GIS (being able to describe the information products)—was essential for a GIS implementation to be successful. Implementations without a clear goal and purpose would fail.

Distributed processing systems introduced in the 1990s required a proper platform and network infrastructure to ensure the GIS benefits identified in the user requirements analysis could be achieved in a distributed environment. Many systems were deployed without a clear understanding of the system infrastructure requirements, and many of these early systems failed to meet user performance expectations.

In the early 1990s, I began to develop a system architecture design process for ESRI that would identify the proper hardware and network infrastructure required to support successful GIS implementations. Like a system itself, this process has been developed, maintained, and fine-tuned over the years, through working with colleagues and clients who have helped make it as productive as it is today. GIS is usually integrated into an existing system, so this design process takes into consideration an organization’s infrastructure limitations. The process can be used to make specific recommendations for hardware and network solutions that are actually based on existing and projected user needs. (You’d be surprised how many projects just guess.) Based in reality, such system designs reduce implementation risk and are more likely to be approved. In any case, a system design is a prerequisite for gaining the go-ahead for your GIS project from upper management.

This system design methodology recognizes that people, application technology, and selected data sources are equally important in determining the optimum hardware solution, as shown in figure 1-1.

- **People**: Understanding user needs—information products and the procedures for making them—establishes a rationale by which to estimate peak system workflow loads.
- **Applications**: Software technology determines the processing requirements (system loads) that must be handled by the hardware solution.
- **Data**: The type of data source and what’s required to access it (data access requirements) show you how the processing load is distributed across the system architecture.

What people need; what it takes to create what people need; and how all the components of a system
work together—every day and reliably—these are the elements that comprise a balanced system design.

The ESRI system architecture design process provides specific deployment strategies and associated hardware specifications based on identified operational workflow requirements.

**Why it’s important**

Vendor computer hardware and network infrastructure expenses represent a significant percentage of the overall system cost of deploying and maintaining distributed GIS operations. For many implementations, costs for hardware procurement and information technology (IT) administration and support exceed the cost of the GIS software. These costs must be identified during the project approval process and managed throughout system deployment to ensure that resources are available for implementation of the technology.

In order to define the overall project requirements, you must understand the relationship between GIS user needs, GIS software processing requirements, and computer hardware and network infrastructure performance and capacity. Understanding the technology (both GIS software and vendor hardware) is fundamental. To meet peak user performance requirements, a distributed computer environment must be designed properly.

Standard IT best practices confirm the importance of deploying a balanced system environment. The weakest link in the design will limit system level performance. User productivity can be improved by monitoring system performance, identifying system performance bottlenecks, and spending available system resources to upgrade and expand capacity of these “weak links” in the system design. Understanding the distribution of software processing loads and the network traffic generated by GIS workflows during peak operations is essential to selecting the right hardware and network bandwidth to handle and transport these workflow loads. That’s why such understanding is the foundation for the system architecture design process.

Since 1992, ESRI has given my team the opportunity to maintain and continue to improve a system architecture design process that can provide specifications for a balanced IT solution. Investment in hardware and network components based on a balanced system load model provides the highest possible system performance at the lowest overall cost, as suggested by figure 1-2. In it, the chain represents the several factors that are linked in a system and therefore affect system performance. User workflows must be designed to optimize interactive client productivity; work request queues should be established to manage heavy batch processing loads and enhance user productivity. Some information products are slower in the making than others, so user display requirements should be carefully evaluated: do you really need such a high-quality map when a simple one would do? Simple information displays promote quicker display performance and therefore a more productive user interface. The same holds true for the geodatabase design and database selection: how can they be optimized to make the best of user performance and productivity? If complex data models are needed for data maintenance, then possibly a simple distribution database replica could balance that out by providing high-performance view and query operations. The system platform components you select (servers, client workstations, storage systems) must perform adequately and provide the capacity to fulfill peak user workflow requirements. In addressing performance needs and bandwidth constraints over distributed communication networks, the system architecture design strategy should strike a balance between power (or quality) and economy (efficiency). The technology and configuration must be selected to conserve these shared infrastructure resources.

The weakest link (performance bottleneck) in this chain will determine the final system performance and capacity. That’s why, in building a foundation for a productive operational environment, the system architecture design process must take into account every component of the system.

The primary infrastructure components contributing to system performance are identified in figure 1-3. These components include the user, application, and data source and how they are connected. What comes of their connections and relationships in the service of a system is the stuff of which performance models are made.

Almost every interrelationship can be factored in for use in your thinking about and modeling of a system. The peak number of concurrent users and their location represent the user access requirements. What’s required

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**Balanced System Design**

A balanced system load model leads to the highest system performance at the lowest overall cost.
in terms of display response time and user think time translates to the “user productivity needs.” The application workflow establishes what you need in the way of platform capacity to satisfy the display service time requirements. The data source determines the database server capacity and storage requirements. The application and data architecture, combined with peak user workflow requirements, establish the network communication requirements.

**Success with GIS**

Selecting the right technology is the first step toward deployment success. Enterprise systems are composed of a variety of vendor components that must work together effectively to be productive. Vendor technologies are constantly evolving, introducing new functionality and hardware design enhancements. Software and hardware vendors develop their technology to support what they believe is generally accepted community interface standards. Ideally, all these vendor solutions will work together as a seamless system environment. In reality, both technology and standards are constantly changing. Technology that is used most together works best together. New technology introduces risk, and in most cases must be integrated with other system components over some period of time for interface anomalies to be identified and resolved. It can seem as if, just when you figure out one, another element comes along and you must figure it out all over again. Each component introduced, whether it’s a first launch or just an upgrade, must be reevaluated in the context of the whole. So how often are you going to get lucky if you do this all by happenstance?

This is where planning comes in, as well as the obligation to keep abreast of—so that you can keep ahead of—change. Figuring out the design may be like a puzzle, but implementation should happen in stages, with careful planning.

There are several critical deployment stages that lead to a successful implementation. Understanding the importance of each stage and the key objectives within them that aim at success results in more effective enterprise implementations. Figure 1-4 shows the different stages of GIS deployment and the advantages of managing implementation risk in stages. The cost of having to make a change in course increases exponentially as the project implementation proceeds. A change or correction made toward the end of the process can cost a thousand times more than if you’d identified the problem and made the change at the beginning.

**Requirements stage**

Understanding technology alternatives, quantifying user requirements, and establishing an appropriate system architecture design deployment strategy are critical during the requirements stage. Capacity planning during this phase can establish preliminary hardware performance specifications and validate that budget and performance expectations can be achieved. This is a planning stage where “getting it right” can save considerable effort and money by making choices that will lead to a successful deployment.

**Design stage**

System development and prototype testing validate functional interfaces and performance metrics. Functions must work and performance targets must be met to enable follow-on deployment. This is where time and money are invested to build and test the selected environment. Initial prototype testing demonstrates functionality and reduces system integration risk. Preliminary software performance testing can validate initial capacity planning assumptions and confirm that performance targets can be satisfied.

**Construction stage**

A successful initial system deployment can set the stage for success. This is where the solution comes together and final operational support needs are validated. This is an important time to demonstrate performance and capacity of the deployed system and validate that the selected hardware and infrastructure will support full production deployment.

**Implementation stage**

Final system procurement and deployment demonstrate operational success. Capacity planning metrics can be used to monitor and maintain system performance.
goals and guide system performance tuning. Good planning, development, and testing will result in a smooth deployment, productive operations, and satisfied users.

In the 1990s, much of the system cost was in data migration followed by a relatively high cost for the technology (software, hardware, etc.). Systems would be deployed over several years, which would spread costs over the system life cycle. The environment today has changed. Data is much more readily available (much faster acquisition time), and still leads as the highest overall GIS investment. Hardware and software costs have dropped by orders of magnitude and are approaching commodity prices.

Technology is moving much faster these days. Implementation timelines are short, and having to make a change in deployment strategy or having to deal with delivered systems that do not perform is an opportunity cost (lost revenue and additional labor) that can be significant. Managing implementation risk continues to be a top priority.

Getting it right from the start is best done by taking the time to understand the technology, quantify user requirements, select the right software technology, and deploy the right hardware. Not getting it right from the start will cost money to make it right later, either in system cost or in labor and time. Sometimes, if repeated failures erode upper management’s confidence, the cost is that you don’t get to have a GIS at all and the potential benefits are never realized.

What is the system design process?

The traditional GIS planning process includes a GIS needs assessment and a system architecture design. The GIS needs assessment identifies what you want out of the system, and describes specific information products, data requirements, and application needs that will improve business decisions and workflow productivity. The system architecture design uses system design guidelines and platform sizing models to establish vendor hardware specifications and identify peak network traffic requirements. Platform performance specifications are calculated based on user workflow requirements pinpointed in the GIS needs assessment.

Timing is important in the decision-making process, so the most effective system design approach is one that considers user needs and system architecture constraints throughout the design process—an integrated business needs assessment. It’s a kind of holistic approach, if you want to look at it that way, but methodical nonetheless, and one intended to take into account everything that affects user productivity. Figure 1-5 provides an overview of the system design process as an integrated business needs assessment.

GIS needs assessment

The GIS needs assessment identifies how GIS technology can be leveraged to improve organizational or business operations. A fundamental objective is to clearly understand and identify what information products
you want out of the GIS. Once you understand what information you want from the GIS, you are prepared to identify GIS application and data requirements and develop an implementation strategy for meeting these identified needs. The user requirements analysis is a process that must be accomplished by the user organization (improving user workflows, identifying more efficient business practices, and setting organizational goals and objectives). A GIS professional familiar with current GIS solutions and customer business practices can help facilitate this planning effort.

System architecture design
The system architecture design is based on user requirements identified by the GIS needs assessment. You must have a clear understanding of your GIS application and data requirements before you are ready to develop system design specifications. System implementation strategies should schedule hardware purchase requisitions “just in time” to support user deployment needs.

The system design normally begins with some level of what’s called a “technology exchange”—in other words, people working together to understand and share what they need to know (the information in the first 10 chapters of this book). User participation is a key ingredient in the design process. Once the technology exchange is complete, the design process includes a review of the existing computer environment, GIS user requirements, and current GIS design alternatives.

The system design capacity planning tools translate peak user workflow requirements to specific platform specifications. An integrated implementation strategy is developed to achieve GIS deployment milestones.

Traditionally, the user needs assessment and the system architecture design were two separate efforts. But there are some key advantages in completing these efforts together. GIS software solutions should include a discussion of architecture options and system deployment strategies. The existing hardware environment and information on peak user workflows and user locations can be identified during the user needs workflow interviews. Technology selection should consider configuration options, required platforms, peak system loads for each technology option, performance and scalability, and overall system design costs. And finally the system implementation schedule must consider hardware delivery milestones. A primary goal of developing the new Capacity Planning Tool presented later in this document is to automate the system architecture design analysis in such a way that GIS professional consultants will be able to use the Capacity Planning Tool to complete an integrated business needs assessment, considering system architecture design implications throughout the user needs assessment process.

An integrated business needs assessment (user needs and system architecture design) is by far the best way to complete your planning process. You can easily integrate the system architecture design process with your user needs assessment by understanding part I and part
II of this book, and using the Capacity Planning Tool. You can use this tool—and the several modules within the tool—to document your workflow requirements and support your technology decisions during the user needs assessment process: this will be your integrated business needs assessment. In this step-by-step process for completing the integrated business needs assessment (in chapter 11), we will focus on the system architecture design steps, and touch lightly on the user requirements analysis. (Roger Tomlinson’s book, Thinking about GIS: Geographic Information System Planning for Managers, provides the more complete step-by-step process for the user requirements analysis.)

Figure 1-6 provides an overview of the information management capabilities of the CPT that are available during the planning process. Step-by-step examples of how the CPT will empower your integrated business needs assessment is provided in the City of Rome case study in chapter 11. You need to complete part I and part II of this book to take full advantage of part III during your planning process.

You can use the CPT to provide an overview of your business needs, infrastructure specifications, and to establish your hardware vendor platform requirements. The CPT shows you the expected system performance for a variety of technology options. You can identify your network and platform environment and see if the technical solution you are considering can work for you. Technology decisions can be made based on a full understanding of user workflow requirements and properly established system performance expectations. Once the system is operational in your environment, you can continue to base technology decisions on a complete understanding of your system performance and scalability. Establishing performance target milestones, based on credible information about the technology, will reduce implementation risk and build a framework to manage your implementation success.

Primary and secondary factors to consider
Distributed GIS solutions bring together a variety of vendor products. Each vendor technology is a part of the total enterprise that must be integrated into the existing system environment. Integration of any multi-vendor environment is made possible through voluntary compliance with generally accepted industry interface standards. When each new component is integrated into the system, the entire functionality, performance, and security of the system can be affected, and the following primary factors must be considered:

Functionality: Does the integrated system meet your functional workflow requirements?
Performance: Will the integrated system satisfy your performance needs during peak workflow operations?
Security: Does the final system environment support your enterprise security requirements?
The primary design factors of functionality, performance, and security often dictate the initial system architecture design strategy. In many cases, policy issues, driven by established compliance factors or other technical or nontechnical issues, limit platform technology options and restrict deployment on older software versions. At first glance, the system architecture design can appear to be preordained, requiring only a simple implementation decision.

However, there are several secondary design factors that should be reviewed, since they often dictate implementation success or failure. These factors include the following:

- Cost considerations
- Scalability (ease of handling more users or higher volumes)
- Reliability (eliminating single points of failure)
- Mobility (support field editing or viewing)
- Availability (dependence on internal and external services)
- Quality of service or data
- Software stability
- Maintainability (centralized versus distributed architecture)
- Flexibility (adaptability to change)

A review and understanding of these secondary design factors in the context of your specific implementation strategy is necessary to ensure success. A complete design process will include a review of both the primary and secondary design factors to ensure proper technology selection and appropriate deployment strategy.

What system architects do

System architects establish the target architecture during the system design process; purchase and install the hardware needed to support the design; and resolve any performance issues during final implementation. Once the design is approved and the project is funded, the system architect is responsible for a final review and update of the hardware specifications right before procurement. He or she is also responsible for scheduling the vendor installations and for participating in the monitoring and testing of system functionality and performance at each of the implementation milestones (see chapter 12).

Enterprise GIS environments include a broad spectrum of technology integrations; in other words, our systems include a lot of stuff that needs to play well together and the system architect has to make sure it does. Most environments today are composed of a variety of hardware vendor technologies, including database servers, storage area networks, Windows Terminal Servers, Web servers, map servers, and desktop clients—all connected by a broad range of local area networks, wide area networks, and Internet communications. All these technologies must function together properly to provide a balanced computing environment. So if the business did not begin with GIS, the system architect will be integrating new systems with existing business operations when you “go live” or launch a GIS. A host of software vendor technologies, including database management systems, ArcGIS Desktop, and ArcGIS Server software, Web services, and hardware operating systems—all must operate seamlessly with existing legacy applications. (Data and user applications are added to the integrated infrastructure environment to enable the final implementation.) The result is a very large, mixed bag of technology that must work together properly and efficiently to fulfill user workflow requirements.

Final purchase decisions are influenced by both operational requirements and budget limitations, introducing unique challenges for the system designer. Good leadership, qualified staff, and proven standard practices lead to successful deployments, so a wise system architect gets a team together for the GIS project from the start, to build from there. (Tomlinson's book, Thinking About GIS, describes the ideal GIS project team composition and methodology from the beginning stages of

Figure 1-7

Building blocks of the technical foundation supporting a distributed GIS environment.
planning for a GIS. The book you have in hand takes off from there.)

The building blocks
A general understanding of the fundamental technologies supporting a GIS enterprise solution provides a foundation for the system architecture design process described in this book. Figure 1-7 identifies the key technology building blocks underlying a distributed GIS environment. Each of these building blocks is a chapter in this book, which is divided into three parts, with the intention of first empowering you with the knowledge and tools to manage your own solution before you take action. The first part is comprised of chapters that describe the various components of a system. Part II describes the underlying principles of physics and engineering that determine how these pieces interact with each other. In Part III, having gained a deeper understanding of the technology relationships, we are ready to put the pieces together into a balanced system that will perform and scale, which is the goal of system architecture design for GIS.

Planning for success
As you know, technology is changing very rapidly. Most enterprise GIS deployments evolve over years of commitment, planning, and hard work. It is essential in today's world to plan for technology change and update these plans on an annual basis. GIS project planning should be scheduled to support the annual business cycle. Enterprise GIS is an evolving program that changes each year to support business objectives and keep pace with technology.

But the best plan is to understand what you're doing, every step of the way. Then, the technology won't get away from you and you won't run amok with it either. What do system architects do? They plan for success. They understand that computer systems are only as strong as their weakest link, and sometimes that weakest link is us. To understand a system as a whole, you have to know all its parts. To miss understanding any one of them is equivalent to missing more than one opportunity to save money and time. For the sake of simply making it work, you owe it to your GIS project to move forward with an intelligent plan. Planning ahead before investing in software and hardware saves money and reduces risk. GIS projects most often fail because system performance requirements are not satisfied. Setting appropriate performance targets, following development best practices, monitoring performance throughout deployment to ensure performance targets are met, and using the models and tools provided in this book increase your likelihood of success.