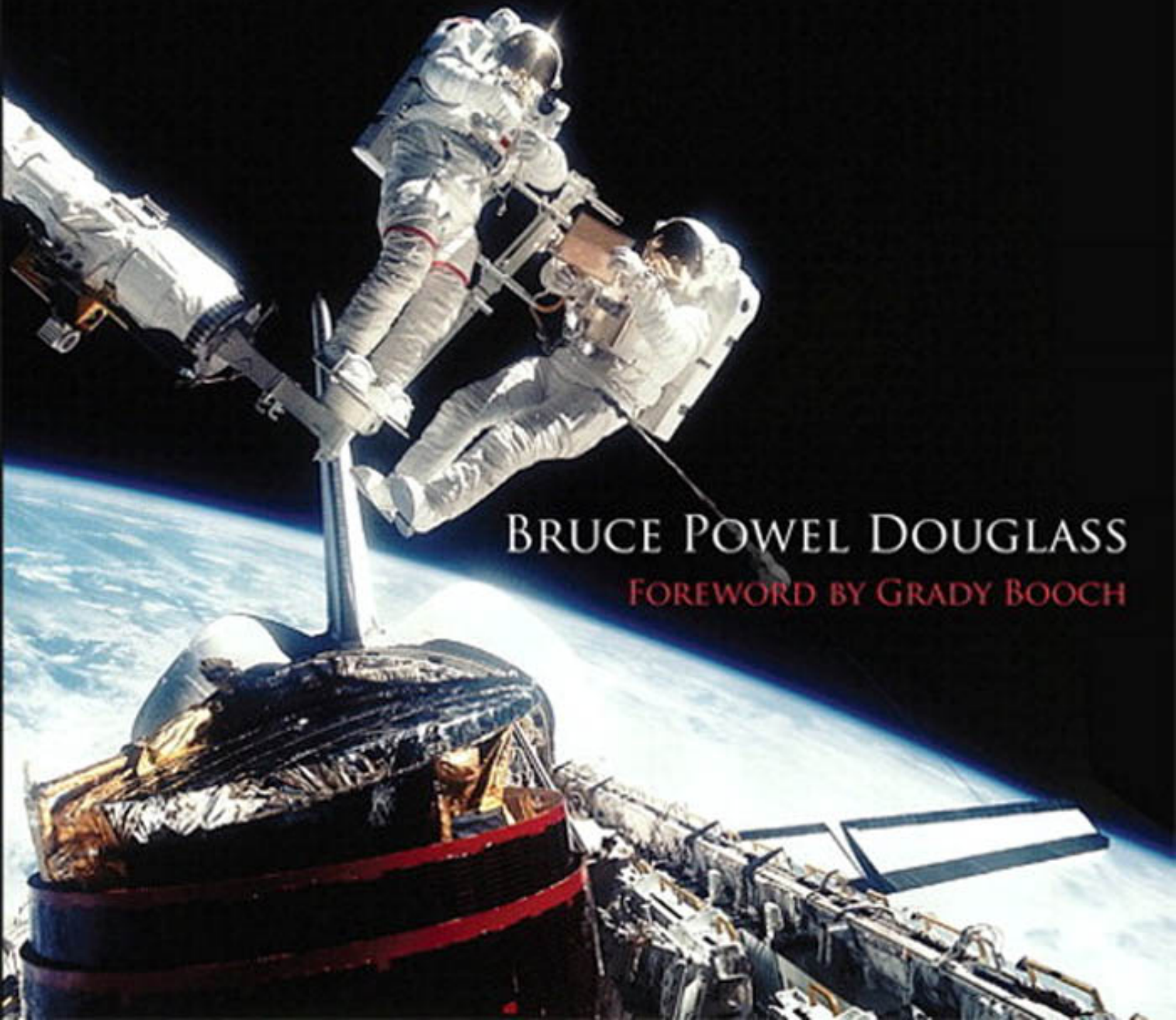
Real-Time Agility

The Harmony/ESW Method for Real-Time and Embedded Systems Development



Bruce Powel Douglass

Foreword by Grady Booch

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Foreword

One of the things I have always admired about Bruce is his ability to take a complex, potentially deadly serious topic—in this case, real-time and embedded systems development—and make it interesting, approachable, and practical.

Bruce has contributed a large and important body of work to this domain. In his previous books on developing real-time systems, Bruce has attended to the issues of an underlying theory, best practices for modeling, and the codification of design patterns. In this present work, he turns his attention to the human elements: How does one develop quality real-time and embedded systems in a repeatable, predictable, reliable fashion? To that end, Bruce weds the evolving field of agile development with real-time development. He brings to the table considerable experience in developing and delivering real systems, and thus his observations on the specific needs of embedded systems are both relevant and credible.

As you'll see by reading this book, Bruce is somewhat of a Renaissance man. You don't often see a software book that contains code, UML models, some hairy mathematical formulas, and entertaining prose all in one package, but Bruce does pull it off. In reading his work, I often found myself nodding a vigorous yes, or being pleasantly jolted by his insights. Bruce's work is methodical, complete, and pragmatic. I hope that you will enjoy it as much as I have.

For as a classically trained musician raised by wolves, Bruce has certainly made a difference in this industry.

—Grady Booch
IBM Fellow

Preface

Back in 1996, I perceived a need for guidance on the development of real-time and embedded systems. By that time, I had built many such systems in various domains, such as medical, telecommunications, consumer electronics, and military aerospace, over the previous 20-odd years. I had developed a process known as ROPES (Rapid Object-Oriented Process for Embedded Systems) based on that experience. The development projects provided a cauldron for development (adding a bit of this and a scooch of that) and evaluation of the concepts and techniques. The evaluation of the techniques in real projects turned out to be invaluable because truth is often different from theory. What worked well was kept and what didn't was culled. Over time, ROPES was integrated with systems engineering (with the help of Dr. Hans-Peter Hoffmann), resulting in the Harmony process. Later, with the acquisition of I-Logix by Telelogic, Harmony was elaborated into a family of processes of which embedded systems development was a member (Harmony/ESW).

My original thought for providing guidance included producing a set of books on the topics of real-time theory, modeling real-time systems (with a companion book providing detailed exercises), developing real-time architectures, and efficient development techniques and processes. While that vision changed a bit over the next 12 years, I dutifully proceeded to begin capturing and elaborating the ideas, creating the examples, and writing the chapters. I had written several books before, so I had an idea of the extent of the work I had undertaken (although it turns out that I seriously underestimated the effort). In parallel with this writing effort, my "day job" kept me very busy consulting to customers in a variety of embedded domains; contributing to standards such as the UML, the UML Profile for Schedulability, Performance, and Time, SysML, and others; and speaking at dozens of conferences. I believe the primary effect of these activities was to significantly improve the quality of the practices through their repeated application in real projects.

Over the years, the resulting set of books realized the vision:

- *Doing Hard Time: Developing Real-Time Systems with UML, Objects, Frameworks, and Patterns* (Reading, MA: Addison-Wesley, 1999) was the "real-time theory" book that focused on the core concepts of real-time software-intensive systems.

- The *Real-Time UML* book has gone through two revisions so far (the third edition was published by Addison-Wesley in 2004) and focuses on how to analyze and design real-time systems with the UML.
- *Real-Time Design Patterns: Robust Scalable Architectures for Real-Time Systems* (Boston: Addison-Wesley, 2002) provided a taxonomy of views for real-time system architectures and a set of architectural design patterns that could be used to construct those architectures.
- *Real-Time UML Workshop for Embedded Systems* (Burlington, MA: Elsevier Press, 2006) was meant to be the "lab book" to accompany *Real-Time UML*. It walks the reader through a progressive series of exercises for both simple (traffic-light controller) and complex (unmanned air vehicle) system examples.

This book is meant to complete that initial vision. It represents the experience I have gained more than thirty years of developing real-time and embedded systems. In my work, I emphasized early measures of correctness and just enough process to achieve the goals long before Extreme Programming and agile methods became the buzzwords they are today. This book is focuses on agility, "traveling light" along the road to software development. Doing enough with process to improve the quality of the developed systems but not so much that the workflows become a burden to the developer is the key goal for the Harmony/ESW process. I firmly believe that a good process enables you to produce high-quality software in less time with fewer defects; poor processes result in either lower quality or much higher development cost.

Why Agile?

When you embark on a trip, you want to bring enough stuff with you to provide the necessities, comfort, and support for the trip and its intended purpose. However, you live within constraints about how much you can bring. Not only do the airlines limit the number of bags you can bring; they also limit the weight and size of each. Plus, you have to somehow get your luggage to the airport and from the airport to your destination. You must carefully select the items you bring so that you don't overburden yourself. When packing for a trip, you must carefully weigh the convenience of having more stuff against the cost and risk of carrying it around with you. Lots of people will give you advice, but the best advice will come from people who travel extensively for the same purposes that you do.

Developing software processes is very similar. Developing software is not about entering in the CPU operation codes in hexadecimal. It's not about writing the assembly, or even the high-level source code. It is about creating the software that meets the customer's needs and fits within the various constraints imposed by financial and technological limitations. It is about discovering the best way to organize and orchestrate the machine op codes to achieve the system's mission. It is about analysis and design. That is not to say that source or assembly code isn't important, but these are really sidebars to the fundamental concerns.

It turns out that software development is difficult. It requires invention on a daily basis. It is very hard to develop software that consistently does the right thing at the right time and does not have unintended side effects. Software development brings its own baggage, such as written documentation, review processes, change management processes, software development processes, testing processes, various work products, and tools.

Like the airline traveler, you must decide what baggage you need to bring along during the trip and what you can (and perhaps should) do without.

There are many software development processes from which to choose. The best of these are developed by thoughtful, smart, and *experienced* people. Far too many processes are defined by people who don't have the experience and won't have to develop software using the techniques and workflows that they come up with. The resulting processes are often incredibly cumbersome, bloated by extra documentation and ancillary work that is included "for completeness." It's like travel policies created and managed by people who don't actually travel, and therefore don't feel the pain that their policies entail. Such policies are rarely appreciated by the people who actually have to plan and travel.

Does this mean what many software developers have come to believe—that processes are at best burdens to be borne and at worst, impediments to the actual development of software? No; I believe process adds value. A good process provides guidance for the efficient development of high-quality software that meets the needs of the customer. Sadly, too many processes don't meet this need. They often require you to carry too much baggage along the way. Even worse, they often require you to carry items in your bags that don't aid you at all in achieving your goals.

Agile methods are a reaction to these heavyweight approaches to software development. Just as the efficient traveler needs just enough baggage, the effective software developer needs just enough process. Agile methods promote "traveling light"—using enough process to make you efficient and to create great software without spending extra effort performing tasks that don't add much value.

This book is about agile methods and how they can be applied to the development of real-time embedded-software-intensive systems. Many of these systems are large in scale and rigorous in their need for quality. Others are small and can be developed by a single person or a small team. Agile methods apply well to all such systems. The trick is to decide how much baggage you need to carry the elements you really need for the trip.

The delivery process detailed in this book is known as Harmony/ESW (for Embedded SoftWare). It is a member of the Harmony process family—a collection of best practices for software and systems development. Harmony/ESW uses a spiral development approach, incrementally developing the system with continuous execution, which provides immediate feedback as to the correctness and quality of the software being developed. It has been successfully applied to projects both small (3 people or fewer) and large (more than 100 people). It emphasizes the development of working software over the creation of documentation. It emphasizes correctness over paperwork and efficiency over artificial measures of completeness.

I hope you enjoy your trip.

Audience

The book is oriented toward the practicing professional software developer, the computer science major in the junior or senior year, project and technical leads, and software managers. The audience is assumed to have familiarity with the UML and basic software development and an interest in effective development of real-time and embedded software. Readers who need more information about UML or real-time concepts are referred to my other books, listed previously.

Goals

The primary goal of this book is to provide guidance for the efficient and effective development of real-time and embedded software. To this end, the first two chapters focus on the introduction of the basic concepts of agility, model-based development, and real-time systems. The next two chapters highlight the key principles and practices that enable rapid development of high-quality software and provide an overview of the Harmony/ESW process concepts. The remaining chapters take you through the process, providing detailed workflows, work product descriptions, and techniques.

About This Book

It should be noted that this book is about applying agile methods to the development of real-time and embedded systems. These systems, as discussed above, have some special characteristics and properties not found in traditional IT or desktop software. For that reason, some of the practices and implementation approaches will be a bit different from those recommended by some other authors.

In addition to being agile, the processes presented in this book also take advantage of other standards and techniques. One such is model-driven development (MDD). Model-driven development is the generic term for Model-Driven Architecture (MDA), an OMG[1] standard for developing reusable software assets that is being applied very effectively in aerospace and defense systems.

Applying agile methods to modeling is not new. Scott Ambler's excellent book on agile modeling[2] provides a good discussion of agile methods in the context of using UML and the Rational Unified Process (RUP). This book differs in a couple of ways. First and foremost, this book applies both agile and MDD to the development of real-time and embedded systems. Many of these systems have special concerns about safety and reliability, and I will talk about how to address those concerns with agility. Second, this book uses the Harmony/ESW process as its basis, rather than the Unified Process. The processes are superficially similar, but the former focuses heavily on the special needs of real-time and embedded systems, particularly on quality of service, safety, and reliability and how they can be effectively managed. The third and final primary difference is the emphasis on the use of technology to automate certain aspects of development, especially in the use of highly capable modeling and testing tools. The process doesn't require high-end tools but takes advantage of them when it can.

In addition to standards, this book emphasizes the use of technology to make your development life better and easier. Just as few people insist on coding in assembler, today's modeling technology allows us to "raise the bar" in productivity by using tools to validate the correctness of models, generate application code, provide "automatic" documentation, enable trade-off analysis, and so on.

1. Object Management Group, not "Oh, my God," as some people believe.
2. Scott Ambler, *Agile Modeling: Effective Practices for eXtreme Programming and the Unified Process* (New York: John Wiley & Sons, 2002).

The value proposition of agile methods is significantly enhanced when it is used in conjunction with such standards and technologies. To be clear, the practices and process workflows presented in this book *are* agile and adhere to the basic goals and principles of agile methods, but they also embrace advances in processes and technologies to leverage that agility. The guidance in this book is both practical and proven and is the culmination of decades of personal experience developing, managing, or consulting to projects in this space. As a side note, most of the analysis and design examples in this book are of a Star Trek transporter system. Although I had to invent some physics for this, my son (a physics major himself) kept me from being too fast and loose with the laws of the universe. It was a fun design to create. Appendix A contains the requirement specifications for the system in case you want to implement it yourself.

Accessing the Harmony/ESW Process Content

This book discusses in detail the Harmony/ESW process content and how it can be used to implement agile methods for real-time and embedded systems development. By the time you read this, the Harmony/ESW process content should be integrated into the Rational Method Composer (RMC) content, available at www-01.ibm.com/software/awdtools/rmc/.

RMC is a flexible process management platform for authoring, managing, and publishing process content. It comes with an extensive library of best practices including the Rational Unified Process (RUP). It is used by companies and project teams needing to manage their development approaches to realize consistent, high-quality product development. The Web site includes the ability to download a trial copy or purchase the tool and related content.

Note: All process content on the above-mentioned Web site is the property of IBM.

Chapter 1

Introduction to Agile and Real-Time Concepts

Different people mean different things when they use the term **agile.** The term was first used to describe a lightweight approach to performing project development after the original term, **Extreme Programming** (XP),[1] failed to inspire legions of managers entrusted to oversee development projects. Basically, agile refers to a loosely integrated set of principles and practices focused on getting the software development job done in an economical and efficient fashion.

This chapter begins by considering why we need agile approaches to software development and then discusses agile in the context of real-time and embedded systems. It then turns to the advantages of agile development processes as compared to more traditional approaches.

The Agile Manifesto

A good place to start to understand agile methods is with the agile manifesto.[2] The manifesto is a public declaration of intent by the Agile Alliance, consisting of 17 signatories including Kent Beck, Martin Fowler, Ron Jeffries, Robert Martin, and others. Originally drafted in 2001, this manifesto is summed up in four key priorities:

- *Individuals and interactions* over processes and tools
- *Working software* over comprehensive documentation

1. Note that important acronyms and terms are defined in the Glossary.
2. http://agilemanifesto.org. Martin Fowler gives an interesting history of the drafting at http://martinfowler.com/articles/agileStory.html.

- *Customer collaboration* over contract negotiation
- *Responding to change* over following a plan

To support these statements, they give a set of 12 principles. I'll state them here to set the context of the following discussion:

- Our highest priority is to satisfy the customer through early and continuous delivery of valuable software.
- Welcome changing requirements, even late in development. Agile processes harness change for the customer's competitive advantage.
- Deliver working software frequently, from a couple of weeks to a couple of months, with a preference to the shorter timescale.
- Business people and developers must work together daily throughout the project.
- Build projects around motivated individuals. Give them the environment and support they need, and trust them to get the job done.
- The most efficient and effective method of conveying information to and within a development team is face-to-face conversation.
- Working software is the primary measure of progress.
- Agile processes promote sustainable development. The sponsors, developers, and users should be able to maintain a constant pace indefinitely.
- Continuous attention to technical excellence and good design enhances agility.
- Simplicity—the art of maximizing the amount of work not done—is essential.
- The best architectures, requirements, and designs emerge from self-organizing teams.
- At regular intervals, the team reflects on how to become more effective, then tunes and adjusts its behavior accordingly.

Agile methods have their roots in the XP (Extreme Programming[3]) movement based largely on the work of Kent Beck and Ward Cunningham. Both

3. See www.xprogramming.com/what_is_xp.htm or Kent Beck's *Extreme Programming Explained* (Boston: Addison-Wesley, 2000) for an overview.

agile and XP have been mostly concerned with IT systems and are heavily code-based. In this book, I will focus on how to effectively harness the manifesto's statements and principles in a different vertical market—namely, real-time and embedded—and how to combine them with modeling to gain the synergistic benefits of model-driven development (MDD) approaches.[4]

Note

Agility isn't limited to small projects. Agile@Scale is an IBM initiative to bring the benefits of agility to larger-scale systems and projects. This initiative includes agile project tool environments such as Rational Team Concert (RTC; based on the Jazz technology platform). Interested readers are referred to www-01.ibm.com/software/rational/agile and www-01.ibm.com/software/rational/jazz/features.

Why Agile?

But why the need for a concept such as "agile" to describe software development? Aren't current software development processes good enough?

No, not really.

A process, in this context, can be defined as "a planned set of work tasks performed by workers in specific roles resulting in changes of attributes, state, or other characteristics of one or more work products." The underlying assumptions are the following:

- The results of using the process are repeatable, resulting in a product with expected properties (e.g., functionality and quality).
- The production of the goal state of the work products is highly predictable when executing the process in terms of the project (e.g., cost, effort, calendar time) and product (e.g., functionality, timeliness, and robustness) properties.
- People can be treated as anonymous, largely interchangeable resources.
- The problems of software development are infinitely scalable—that is, doubling the resources will always result in halving the calendar time.

4. A good place for more information about agile modeling is Scott Ambler's agile modeling Web site, www.agilemodeling.com.

As it turns out, software is *hard* to develop. Most existing development processes are most certainly not repeatable or predictable in the sense above. There are many reasons proposed for why that is. For myself, I think software is *fundamentally complex*—that is, it embodies the "stuff" of complexity. That's what software is best at—capturing how algorithms and state machines manipulate multitudes of data within vast ranges to achieve a set of computational results. It's "thought stuff," and that's hard.

The best story I've heard about software predictability is from a blog on the SlickEdit Web site by Scott Westfall called the "The Parable of the Cave" (see sidebar).[5] Estimating software projects turns out to be remarkably similar to estimating how long it will take to explore an unknown cave, yet managers often insist on being given highly precise estimates.

The Parable of the Cave

Two people stand before a cave. One is the sagely manager of a cave exploring company whose wisdom is only exceeded by his wit, charm, and humility. Let's call him, oh, "Scott." The other is a cave explorer of indeterminate gender who bears no resemblance to any programmers past or present that this author may have worked with and whose size may be big or little. Let's call him/her "Endian."

"Endian," said Scott in a sagely voice that was both commanding and compassionate, "I need you to explore this cave. But before you do, I need to know how long you think it will take, so that I may build a schedule and tell the sales team when the cave will be ready."

"Great Scott," replied Endian using the title bestowed upon Scott by his admiring employees, "how can I give you an answer when surely you know I have never been in this cave before? The cave may be vast, with deep chasms. It may contain a labyrinth of underwater passages. It may contain fearsome creatures that must first be vanquished. How can I say how long it will take to explore?"

Scott pondered Endian's words and after a thorough analysis that might have taken days for others but was completed in but a moment for him, he replied, "Surely this is not the first cave you explored. Are there no other caves in this district? Use your knowledge of those caves to form an estimate."

5. Used with permission of the author, Scott Westfall. The SlickEdit Web site can be found at http://blog.slickedit.com/?p207.

Endian heard these words and still his doubt prevailed. "Your words are truly wise," said Endian, "but even within a district the caves may vary, one from another. Surely, an estimate based on the size of another cave cannot be deemed accurate."

"You have spoken truly, good Endian," replied Scott in a fatherly, supporting tone that lacked any trace of being patronizing as certain cynical readers may think. "Here, take from me this torch and this assortment of cheeses that you may explore the cave briefly. Return ere the morrow and report what you have learned."

The parable continues like this for pages, as parables are known to do. Let's see, Endian enters the cave . . . something about a wretched beast of surpassing foulness . . . he continues on . . . hmm, that's what the assortment of cheeses were for. Ah! Here we go.

Endian returns to Scott, his t-shirt ripped and his jeans covered in mud. Being always concerned with the well-being of his employees, Scott offers Endian a cool drink, then asks, "Endian, what news of the cave? Have you an estimate that I can use for my schedule? What shall I tell the sales team?"

Endian considers all that he has seen and builds a decomposition containing the many tasks necessary to explore the cave based on his earlier reconnoitering. He factors in variables for risk and unknowns, and then he responds, "Two weeks."

In addition, the scope of software is increasing rapidly. Compared to the scope of the software functionality in decades past, software these days does orders of magnitude more. Back in the day,[6] my first IBM PC had 64kB of memory and ran a basic disk operating system called DOS. DOS fit on a single 360kB floppy disk. Windows XP weighs in at well over 30 million lines of code; drives hundreds of different printers, disks, displays, and other peripherals; and needs a gigabyte of memory to run comfortably. These software-intensive systems deliver far more functionality than the electronic-only devices they replace. Compare, for example, a traditional phone handset with a modern cell phone. Or compare a traditional electrocardiogram (ECG) that drove a paper recorder like the one I used in medical school with a modern ECG machine—the difference is remarkable. The modern machine can do everything the old

6. I know I'm dating myself, but my IBM PC was my fifth computer. I still remember fondly the days of my TRS-80 model I computer with its 4kB of memory . . .

machine did, plus detect a wide range of arrhythmias, track patient data, produce reports, and measure noninvasive blood pressure, blood oxygen concentration, a variety of temperatures, and even cardiac output.

Last, software development is really invention, and invention is not a highly predictable thing. In electronic and mechanical engineering, a great deal of the work is conceptually simply putting pieces together to achieve a desired goal, but in software those pieces are most often invented (or reinvented) for every project. This is not to oversimplify the problems of electronic or mechanical design but merely to point out that the underlying physics of those disciplines is far more mature and well understood than that of software.

But it doesn't really matter if you believe my explanations; the empirical results of decades of software development are available. Most products are late.[7] Most products are delivered with numerous and often significant defects. Most products don't deliver all the planned functionality. We have become used to rebooting our devices, but 30 years ago it would have been unthinkable that we would have to turn our phones off, remove the batteries, count to 30, reinsert the batteries, and reboot our phones.[8] Unfortunately, that is the "state of the art" today.

To this end, many bright people have proposed processes as a means of combating the problem, reasoning that if people *engineered* software rather than hacked away at it, the results would be better. And they have, to a large degree, been better. Nevertheless, these approaches have been based on the premise that software development can be treated the same as an industrial manufacturing process and achieve the same results. Industrial automation problems are highly predictable, and so this approach makes a great deal of sense when the underlying mechanisms driving the process are very well understood and are inherently linear (i.e., a small change in input results in an equally small change in output). It makes less sense when the underlying mechanisms are not fully understood or the process is highly nonlinear. Unfortunately, software development is neither fully understood nor even remotely linear.

It is like the difference in the application of fuzzy logic and neural networks to nonlinear control systems. Fuzzy logic systems work by applying the concept of partial membership and using a centroid computation to determine outputs.

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7. See, for example, Michiel van Genuchten, "Why Is Software Late? An Empirical Study of Reasons for Delay in Software Development," *IEEE Transactions on Software Engineering* 17, no. 6 (June 1991).

8. Much as I love my BlackBerry, I was amazed that a customer service representative recommended removing the battery to reboot the device *daily*.

The partial membership of different sets (mapping to different equations) is defined by set membership rules, so fuzzy logic systems are best applied when the rules are known and understood, such as in speed control systems.

Neural networks, on the other hand, don't know or care about rules. They work by training clusters of simple but deeply interconnected processing units (neurons). The training involves applying known inputs ("exemplars") and adjusting the weights of the connections until you get the expected outputs. Once trained, the neural network can produce results from previously unseen data input sets and produce control outputs. The neural network learns the effects of the underlying mechanisms from actual data, but it doesn't in any significant way "understand" those mechanisms. Neural networks are best used when the underlying mechanisms are not well understood because they can learn the data transformations inherent in the mechanisms.

Rigorously planned processes are akin to fuzzy logic—they make a priori assumptions about the underlying mechanisms. When they are right, a highly predictable scheme results. However, if those a priori assumptions are either wrong or missing, then they yield less successful results. In this case, the approach must be tuned with empirical data. To this end, most traditional processes do "extra" work and produce "extra" products to help manage the process. These typically include

- Schedules
- Management plans
- Metrics (e.g., source lines of code [SLOC] or defect density)
- Peer and management reviews and walk-throughs
- Progress reports

And so on.

The idea is that the execution of these tasks and the production of the work products correlate closely with project timeliness and product functionality and quality. However, many of the tasks and measures used don't correlate very well, even if they are easy to measure. Even when they do correlate well, they incur extra cost and time.

Agile methods are a reaction in the developer community to the high cost and effort of these industrial approaches to software development. The mechanisms by which we invent software are not so well understood as to be highly predictable. Further, small changes in requirements or architecture can result in huge differences in development approach and effort. Because of this, empiricism, discipline,

quality focus, and stakeholder focus must all be present in our development processes. To this end, agile methods are not about hacking code but instead are about focusing effort on the things that demonstrably add value and defocusing on efforts that do not.

Properties of Real-Time Embedded Systems

Of course, software development is hard. Embedded software development is harder. Real-time embedded software is even harder than that. This is not to minimize the difficulty in reliably developing application software, but there are a host of concerns with real-time and embedded systems that don't appear in the production of typical applications.

An embedded system is one that contains at least one CPU but does not provide general computing services to the end users. A cell phone is considered an embedded computing platform because it contains one or more CPUs but provides a dedicated set of services (although the distinction is blurred in many contemporary cell phones). Our modern society is filled with embedded computing devices: clothes washers, air traffic control computers, laser printers, televisions, patient ventilators, cardiac pacemakers, missiles, global positioning systems (GPS), and even automobiles—the list is virtually endless.

The issues that appear in real-time embedded systems manifest themselves on four primary fronts. First, the optimization required to effectively run in highly resource-constrained environments makes embedded systems more challenging to create. It is true that embedded systems run the gamut from 8-bit processes in dishwashers and similar machinery up to collaborating sets of 64-bit computers. Nevertheless, most (but not all) embedded systems are constrained in terms of processor speed, memory, and user interface (UI). This means that many of the standard approaches to application development are inadequate alone and must be optimized to fit into the computing environment and perform their tasks. Thus embedded systems typically require far more optimization than standard desktop applications. I remember writing a real-time operating system (RTOS) for a cardiac pacemaker that had 32kB of static memory for what amounted to an embedded 6502 processor.[9] Now *that's* an embedded system!

Along with the highly constrained environments, there is usually a need to write more device-driver-level software for embedded systems than for standard application development. This is because these systems are more likely to have

9. It even had a small file system to manage different pacing and monitoring applications.

custom hardware for which drivers do not exist, but even when they do exist, they often do not meet the platform constraints. This means that not only must the primary functionality be developed, but the low-level device drivers must be written as well.

The real-time nature of many embedded systems means that predictability and schedulability affect the correctness of the application. In addition, many such systems have high reliability and safety requirements. These characteristics require additional analyses, such as schedulability (e.g., rate monotonic analysis, or RMA), reliability (e.g., failure modes and effects analysis, or FMEA), and safety (e.g., fault tree analysis, or FTA) analysis. In addition to "doing the math," effort must be made to ensure that these additional requirements are met.

Last, a big difference between embedded and traditional applications is the nature of the so-called target environment—that is, the computing platform on which the application will run. Most desktop applications are "hosted" (written) on the same standard desktop computer that serves as the target platform. This means that a rich set of testing and debugging tools is available for verifying and validating the application. In contrast, most embedded systems are "cross-compiled" from a desktop host to an embedded target. The embedded target lacks the visibility and control of the program execution found on the host, and most of the desktop tools are useless for debugging or testing the application on its embedded target. The debugging tools used in embedded systems development are almost always more primitive and less powerful than their desktop counterparts. Not only are the embedded applications more complex (due to the optimization), and not only do they have to drive low-level devices, and not only must they meet additional sets of quality-of-service (QoS) requirements, but the debugging tools are far less capable as well.

It should be noted that another difference exists between embedded and "IT" software development. IT systems are often maintained systems that constantly provide services, and software work, for the most part, consists of small incremental efforts to remove defects and add functionality. Embedded systems differ in that they are released at an instant in time and provide functionality at that instant. It is a larger effort to update embedded systems, so that they are often, in fact, replaced rather than being "maintained" in the IT sense. This means that IT software can be maintained in smaller incremental pieces than can embedded systems, and "releases" have more significance in embedded software development.

A "real-time system" is one in which timeliness is important to correctness. Many developers incorrectly assume that "real-time" means "real fast." It clearly does not. Real-time systems are "predictably fast enough" to perform their tasks.

If processing your eBay order takes an extra couple of seconds, the server application can still perform its job. Such systems are not usually considered real-time, although they may be optimized to handle thousands of transactions per second, because if the system slows down, it doesn't affect the system's *correctness*. Real-time systems are different. If a cardiac pacemaker fails to induce current through the heart muscle at the right time, the patient's heart can go into fibrillation. If the missile guidance system fails to make timely corrections to its attitude, it can hit the wrong target. If the GPS satellite doesn't keep a highly precise measure of time, position calculations based on its signal will simply be *wrong*.

Real-time systems are categorized in many ways. The most common is the broad grouping into "hard" and "soft." "Hard" real-time systems exhibit significant failure if every single action doesn't execute within its time frame. The measure of timeliness is called a **deadline**—the time after action initiation by which the action must be complete. Not all deadlines must be in the microsecond time frame to be real-time. The **F2T2EA** (**F**ind, **F**ix, **T**rack, **T**arget, **E**ngage, **A**ssess) **Kill Chain** is a fundamental aspect of almost all combat systems; the end-to-end deadline for this compound action might be on the order of 10 minutes, but pilots absolutely must achieve these deadlines for combat effectiveness.

The value of the completion of an action as a function of time is an important concept in real-time systems and is expressed as a "utility function" as shown in Figure 1.1. This figure expresses the value of the completion of an action to the user of the system. In reality, utility functions are smooth curves but are most often

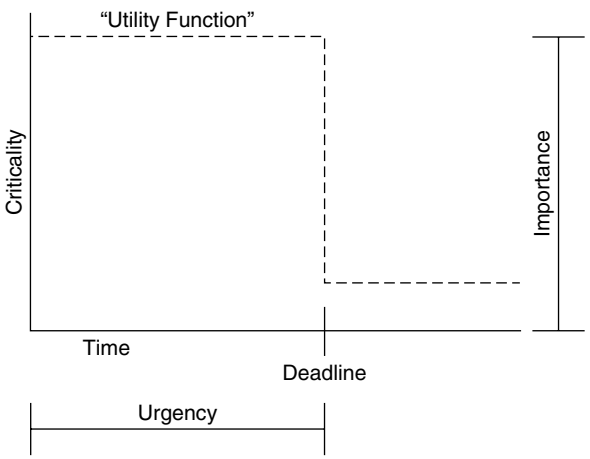

Figure 1.1 *Utility function*

modeled as discontinuous step functions because this eases their mathematical analysis. In the figure, the value of the completion of an action is high until an instant in time, known as the deadline; at this point, the value of the completion of the action is zero. The length of time from the current time to the deadline is a measure of the urgency of the action. The height of the function is a measure of the criticality or importance of the completion of the action. Criticality and urgency are important orthogonal properties of actions in any real-time system. Different scheduling schemas optimize urgency, others optimize importance, and still others support a fairness (all actions move forward at about the same rate) doctrine.

Actions are the primitive building blocks of concurrency units, such as tasks or threads. A **concurrency unit** is a sequence of actions in which the order is known; the concurrency unit may have branch points, but the sequence of actions within a set of branches is fully deterministic. This is not true for the actions between concurrency units. Between concurrency units, the sequence of actions is *not* known, or cared about, except at explicit synchronization points.

Figure 1.2 illustrates this point. The flow in each of the three tasks (shown on a UML activity diagram) is fully specified. In Task 1, for example, the sequence is that Action A occurs first, followed by Action B and then either Action C or Action D. Similarly, the sequence for the other two tasks is fully defined. What is not defined is the sequence between the tasks. Does Action C occur before or after Action W or Action Gamma? The answer is *You don't know and you don't care*. However, we know that before Action F, Action X, and Action Zeta can occur, Action E, Action Z, and Action Gamma have all occurred. This is what is meant by a task synchronization point.

Because in real-time systems synchronization points, as well as resource sharing, are common, they require special attention in real-time systems not often found in the development of IT systems.

Within a task, several different properties are important and must be modeled and understood for the task to operate correctly (see Figure 1.3). Tasks that are time-based occur with a certain frequency, called the **period.** The period is the time between invocations of the task. The variation around the period is called **jitter.** For event-based task initiation, the time between task invocations is called the **interarrival time.** For most schedulability analyses, the shortest such time, called the **minimum interarrival time,** is used for analysis. The time from the initiation of the task to the point at which its set of actions must be complete is known as the **deadline.** When tasks share resources, it is possible that a needed resource isn't available. When a necessary resource is locked by a lower-priority task, the current task must **block** and allow the lower-priority task to complete its use of the resource before the original task can run. The length of time the

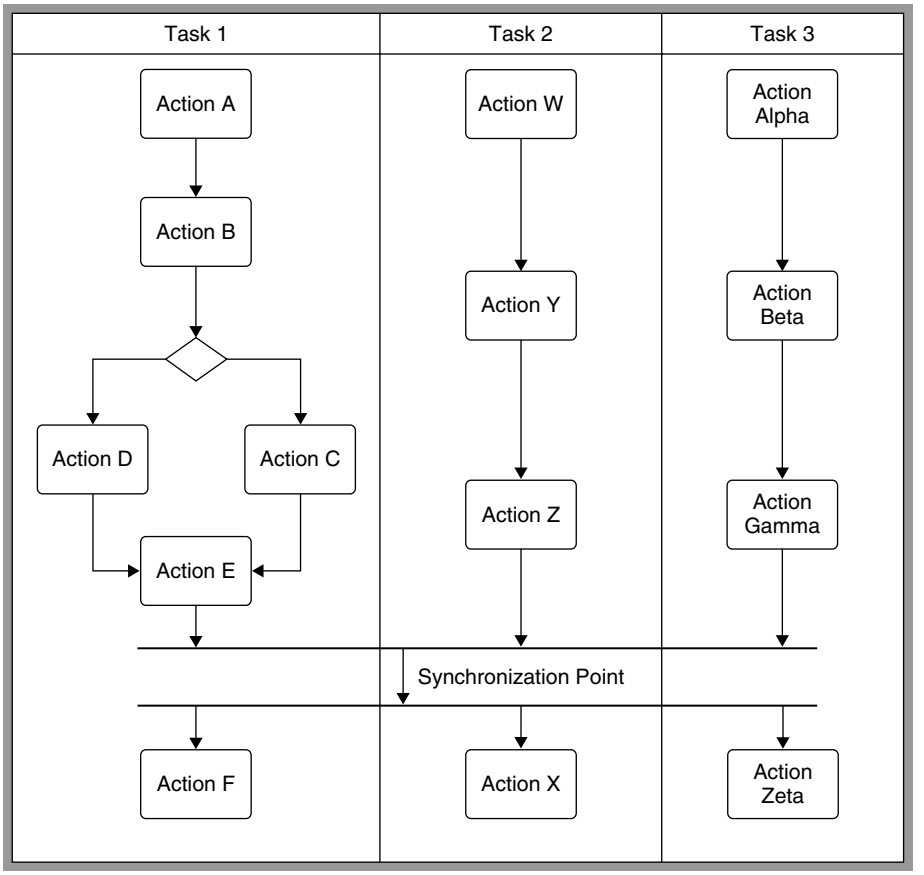

Figure 1.2 *Concurrency units*

higher-priority task is prevented from running is known as the **blocking time.** The fact that a lower-priority task must run even though a higher-priority task is ready to run is known as **priority inversion** and is a property of all priority-scheduled systems that share resources among task threads. Priority inversion is unavoidable when tasks share resources, but when uncontrolled, it can lead to missed deadlines. One of the things real-time systems must do is bound priority inversion (e.g., limit blocking to the depth of a single task) to ensure system timeliness. The period of time that a task requires to perform its actions, including any potential blocking time, is called the **task execution time.** For analysis, it is common to use the longest such time period, the **worst-case execution time,** to ensure that the system can always meet its deadlines. Finally, the time

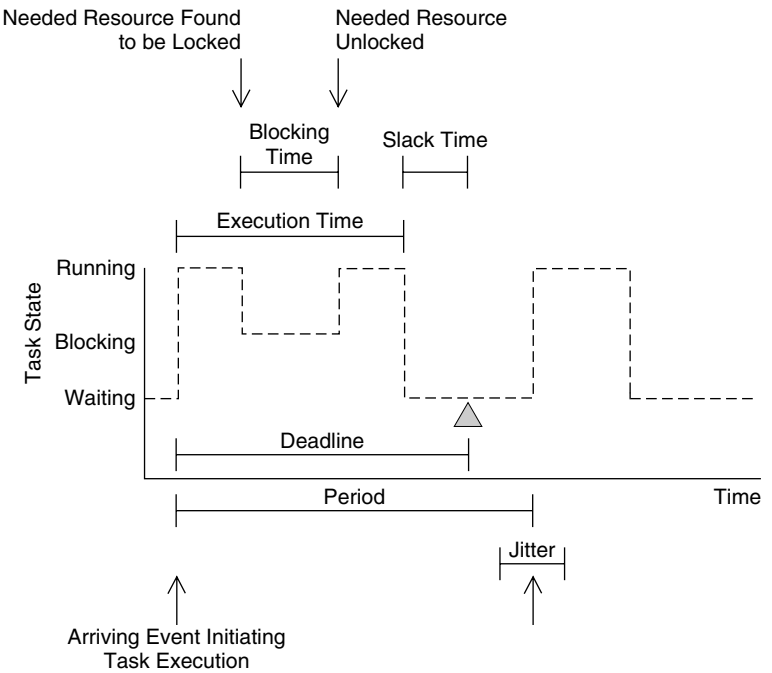

Figure 1.3 *Task time*

between the end of the execution and the deadline is known as the **slack time.** In real-time systems, it is important to capture, characterize, and manage all these task properties.

Real-time systems are most often embedded systems as well and carry those burdens of development. In addition, real-time systems have timeliness and schedulability constraints. Real-time systems must be **timely**—that is, they must meet their task completion time constraints. The entire set of tasks is said to be **schedulable** if all the tasks are timely. Real-time systems are not necessarily (or even usually) deterministic, but they must be predictably bounded in time. Methods exist to mathematically analyze systems for schedulability,[10] and there are tools[11] to support that analysis.

10. See *Doing Hard Time: Developing Real-Time Systems with UML, Objects, Frameworks, and Patterns* and *Real-Time UML: Advances in the UML for Real-Time Systems,* both written by me and published by Addison-Wesley (1999 and 2004, respectively).

11. For example, see www.tripac.com for information about the RapidRMA tool.

Safety-critical and high-reliability systems are special cases of real-time and embedded systems. The term **safety** means "freedom from accidents or losses"[12] and is usually concerned with safety in the absence of faults as well as in the presence of single-point faults. **Reliability** is usually a stochastic measure of the percentage of the time the system delivers services.

Safety-critical systems are real-time systems because safety analysis includes the property of **fault tolerance time**—the length of time a fault can be tolerated before it leads to an accident. They are almost always embedded systems as well and provide critical services such as life support, flight management for aircraft, medical monitoring, and so on. Safety and reliability are assured through the use of additional analysis, such as FTA, FMEA, failure mode, effects, and criticality analysis (FMECA), and often result in a document called the hazard analysis that combines fault likelihood, fault severity, risk (the product of the previous two), hazardous conditions, fault protection means, fault tolerance time, fault detection time, and fault protection action time together. Safety-critical and high-reliability systems require additional analysis and documentation to achieve approval from regulatory agencies such as the FAA and FDA.

It is not at all uncommon for companies and projects to specify very heavyweight processes for the development of these kinds of systems—safety-critical, high-reliability, real-time, or embedded—as a way of injecting quality into those systems. And it works, to a degree. However, it works at a very high cost. Agile methods provide an alternative perspective on the development of these kinds of systems that is lighter-weight but does not sacrifice quality.

Benefits of Agile Methods

The primary goal of an agile project is to develop working software that meets the needs of the stakeholders. It isn't to produce documentation (although documentation will be part of the delivered system). It isn't to attend meetings (although meetings will be held). It isn't to create schedules (but a schedule is a critical planning tool for all agile projects). It isn't to create productivity metrics (although they will help the team identify problems and barriers to success).[13] You may do all of these things during the pursuit of your

12. Nancy Leveson, *Safeware: System Safety and Computers* (Reading, MA: Addison-Wesley, 1995).

13. See Scott Ambler's discussion of acceleration metrics at www.ibm.com/developerworks/blogs/page/ambler?tag=Metrics.

primary goal, but it is key to remember that those activities are secondary and performed only as a means of achieving your primary goal. Too often, both managers and developers forget this and lose focus. Many projects spend significant effort without even bothering to assess whether that effort aids in the pursuit of the development of the software.

The second most important goal of an agile project is to enable follow-on software development. This means that the previously developed software must have an architecture that enables the next set of features or extensions, documentation so that the follow-on team can understand and modify that software, support to understand and manage the risks of the development, and an infrastructure for change and configuration management (CM).

The benefits of agile methods usually discussed are:

- Rapid learning about the project requirements and technologies used to realize them
- Early return on investment (ROI)
- Satisfied stakeholders
- Increased control
- Responsiveness to change
- Earlier and greater reduction in project risk[14]
- Efficient high-quality development

These are real, if sometimes intangible, benefits that properly applied agile methods bring to the project, the developers, their company, the customer, and the ultimate user.

Rapid Learning

Rapid learning means that the development team learns about the project earlier because *they are paying attention*. Specifically, agile methods focus on early feedback, enabling dynamic planning. This is in contrast to traditional approaches that involve ballistic planning. Ballistic planning is all done up front with the expectation that physics will guide the (silver) bullet unerringly to its target

14. See, for example, www.agileadvice.com.

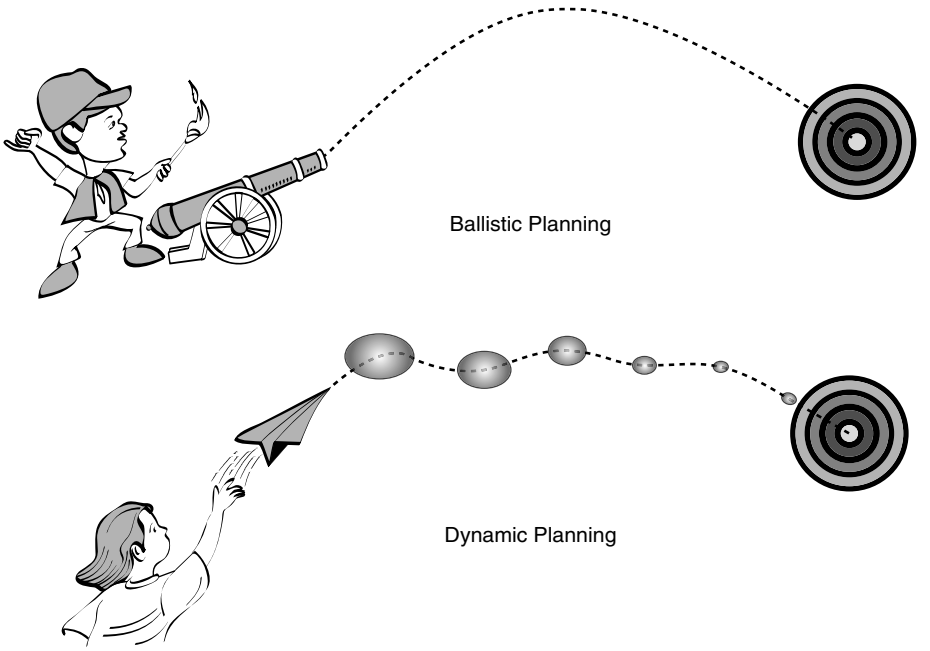

Figure 1.4 *Ballistic versus dynamic planning*

(see Figure 1.4). Agile's dynamic planning can be thought of as "planning to replan." It's not that agile developers don't make plans; it's just that they don't believe their own marketing hype and are willing to improve their plans as more information becomes available.

Since software development is relatively unpredictable, ballistic planning, for all its popularity, is infeasible. The advantage of early feedback is that it enables dynamic planning. A Law of Douglass[15] is "The more you know, the more you know." This perhaps obvious syllogism means that as you work through the project, you learn. This deeper understanding of the project enables more accurate predictions about when the project will be complete and the effort the project will require. As shown in Figure 1.5, the ongoing course corrections result in decreasing the zone of uncertainty.

Early Return on Investment

Early return on investment means that with an agile approach, partial functionality is provided far sooner than in a traditional waterfall process. The latter

15. Unpublished work found in the Douglass crypt . . .

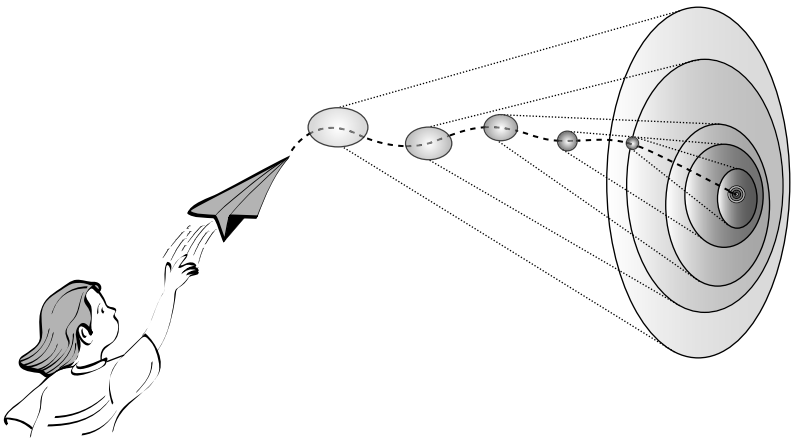

Figure 1.5 *Reduction in uncertainty*

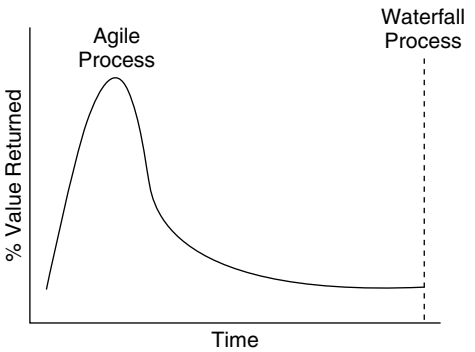

Figure 1.6 *Percent value returned over time*

delivers all-or-none functionality at the end point, and the former delivers incremental functionality frequently throughout the duration of the development. As you can see in Figure 1.6, agile delivers high value early, with less incremental value as the system becomes increasingly complete, whereas the waterfall process delivers nothing until the end.

Another way to view this is by looking at incremental value over time, as shown in Figure 1.7. We see that an agile process delivers increasing value over time, whereas the waterfall process delivers no value until the end.

Delivering value early is good for a couple of reasons. First, if the funding is removed or the project must end early, something of value exists at the point of termination. This is not true for the waterfall process, but it is a primary value in an agile process. Additionally, delivering validated, if partial, functionality early

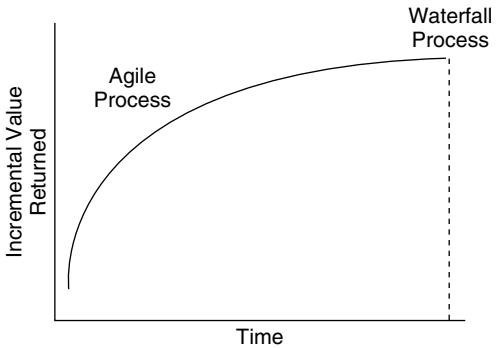

Figure 1.7 *Incremental value*

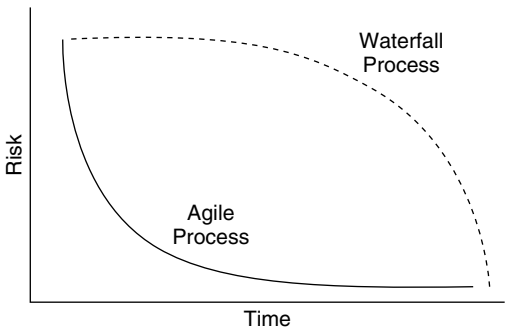

Figure 1.8 *Risk over time*

reduces risk, as we see in Figure 1.8. Exactly how early deliveries do this is a topic we will discuss in more detail later, but let us say for now that because we validate each incremental build and we tend to do high-risk things early, we significantly and quickly reduce the project risk. The waterfall process reduces risk slowly at first because you only really know about the quality and correctness of things that you validate, and validation comes only at the end in a waterfall process.

How can we return incremental value for a system that is delivered externally, such as a cell phone or a missile? Every increment period (which the Harmony/ESW[16] process refers to as a **microcycle**), a system is designed, implemented, and validated in accordance with its mission statement. This mission statement identifies the functionality, target platform, architectural intent, and defect repairs to be included. The incremental functionality is organized

16. Harmony/Embedded Software. This is one of the members of the IBM Rational Harmony family of processes and is the basis of the content of this book. The process basics will be discussed at some length in Chapter 3.

around a small set of use cases running on an identified (but not necessarily final) target environment. Through the use of good engineering practice, we can encapsulate away the platform details and ensure that the delivered functionality is correct, given the current target. For example, for one tracking system, our team originally targeted laptops with simulated radars and created actual validated functionality on that environment. Over the course of the project, as hardware became available, we migrated to target hardware of the actual military systems. Through this approach, we had high-quality, testable software earlier than expected.

Satisfied Stakeholders

Stakeholders are simply people who have a stake in the successful outcome of a project. Projects have all kinds of stakeholders. Customers and marketers are focused on the functional benefits of the system and are willing to invest real money to make it happen. Their focus is on specifying to the developers the needs of the users in a realistic and effective fashion. Managers are stakeholders who manage that (real or potential) investment for the company to achieve a timely, cost-effective delivery of said functionality. Their job is to plan and schedule the project so that it can be produced to satisfy the customer and meet the users' needs. The users are the ones who use the system in their work environment and need high-quality functionality that enables their workflow to be correct, accurate, and efficient. All these stakeholders care about the product but differ in the focus of their concern. The customers care how much they pay for the system and the degree to which it improves the users' work. The managers primarily care how much the system costs to develop and how long that effort takes. The users primarily care about the (positive) impact the system makes on their work.

Agile methods provide early visibility to validated functionality. This functionality can be demonstrated to the stakeholders and even delivered. This is in stark contrast to traditional preliminary design review (PDR) and critical design review (CDR) milestones in which text is delivered that describes promised functionality in technological terms. Customers can—and should—be involved in reviewing the functionality of the validated incremental versions of the system. Indeed, the functionality can be implemented using a number of different strategies, depending on what the process optimization criterion is. Possible criteria include the following:

- Highest-risk first
- Most critical first

- Infrastructure first
- Available information first

All other things being equal, we prefer to deliver high-risk first, because this optimizes early risk reduction. However, if the users are to deploy early versions of the system, then criticality-first makes more sense. In some cases, we deploy architectural infrastructure early to enable more complex functionality or product variations. And sometimes we don't have all the necessary information at our fingertips before we must begin, so the things we don't know can be put off until the necessary information becomes available.

Improved Control

Many, if not most, software projects are out of control, to some degree or another. This is largely because although projects are planned in detail, they aren't tracked with any rigor. Even for those projects that are tracked, tracking is usually done on the wrong things, such as SLOC delivered. Thus most projects are either not tracked or track the wrong project properties.

Project tracking requires the answers to three questions:

- Why track?
- What should be tracked?
- How should projects be tracked?

Why track? Project teams that don't know exactly *why* they are tracking project properties rarely do a good job. Only by identifying the goals of tracking can you decide what measures should be tracked and how to implement the tracking procedures.

The biggest single reason for project tracking is that plans are *always* made in the presence of incomplete knowledge and are therefore inaccurate to some degree. Tracking enables the project deviance from plan to be identified early enough to effectively do something about it. Projects should be tracked so that they can be effectively managed, replanned as appropriate, and even scrapped if necessary. You can effectively replan only when you know more than you did when the original plan was made, and that information can come from tracking the right things. Put another way, the fundamental purpose of tracking is to reduce uncertainty and thereby improve project control.

What should be tracked? Ideally, tracking should directly reduce uncertainty in the key project characteristics that relate to the cost, time, effort, and quality of the product; that is, tracking should directly measure cost, time to completion, effort to completion, and defect rates. The problem is that these quantities are not directly measurable.

So projects typically evaluate metrics that are measurable with the expectation that they correlate with the desired project quantities. Hence, people measure properties such as lines of code or defects repaired. The flaw in those measures is that they *do not* correlate strongly with the project criteria. If, at the end of the project, you remove lines of code during optimization, are you performing negative work and reducing the time, cost, or effort? If I don't know exactly how many lines of code I'm going to end up with, what does writing another 10,000 lines of code mean in terms of percent completeness? If I measure cyclomatic complexity, am I demonstrating that the system is correct? The answer is an emphatic *no*.

The problem with many of the common metrics is that while they are easy to measure, they don't correlate well with the desired information. This is because those metrics track against the project implementation rather than the project goal. If you want to measure completeness, measure the number of requirements validated, not the number of lines of code written. If you want to measure quality, measure defect rates, not cyclomatic complexity. The other measures do add incremental value, but the project team needs to focus on achievement of the ultimate goal, not weak correlates.

Agile methods provide the best metrics of all—working, validated functionality—and they provide those metrics early and often. Agile focuses on delivering correct functionality constantly, providing natural metrics as to the quality and completeness of the system over time. This in turn provides improved project control because true problems become visible much earlier and in a much more precise fashion.

Responsiveness to Change

Life happens, often in ways that directly conflict with our opinions about how it ought to happen. We make plans using the best available knowledge, but that knowledge is imprecise and incomplete and in some cases just wrong. The imprecision means that small incremental errors due to fuzziness in the data can add up to huge errors by the end of the project—the so-called butterfly effect in chaos theory.[17] Chaos theory is little more than the statement that most systems are

17. See Edward N. Lorenz, *The Essence of Chaos (The Jessie and John Danz Lecture Series)* (Seattle: University of Washington Press, 1996).

actually nonlinear; by **nonlinear** we mean that small causes generate effects that are not proportional to their size. That sums up software development in a nutshell: a highly nonlinear transfer function of user needs into executable software.

The incompleteness problem means that not only do we not know things very precisely, but some things we don't know at all. I remember one project in which I was working on a handheld pacemaker program meant to be used by physicians to monitor and configure cardiac pacemakers. It was a based on a Z-80-based embedded microcomputer with a very nice form factor and touch screen. The early devices from the Japanese manufacturer provided a BIOS to form the basis of the computing environment. However, once the project began and plans were all made, it became apparent that the BIOS would have to be rewritten for a variety of technically inobvious reasons. Documentation for the BIOS was available from the manufacturer—but only in Japanese. The technical support staff was based in Tokyo and spoke only—you guessed it—Japanese. This little bit of missing information put the project months behind schedule because we had to reverse-engineer the documentation from decompiling the BIOS. It wouldn't be so bad if that was the only time issues like that came up, but such things seem to come up in every project. There's always something that wasn't planned on—a manufacturer canceling a design, a tool vendor going out of business, a key person being attracted away by the competition, a change in company focus, defects in an existing product sucking up all the development resources, . . . the list goes on and on.

Worst, in some way, is that knowledge you have about which you are both convinced and incorrect. This can be as varied as delivery dates, effort to perform tasks, and availability of target platforms. We all make assumptions, and the law of averages dictates that when we make 100 guesses, each of which is 90% certain, 10 are still likely to be wrong.

Despite these effects of nonlinearity, incompleteness, and incorrectness, we still have to develop systems to meet the stakeholders' needs at a cost they're willing to pay within the time frames that meet the company's schedules. So in spite of the nonlinearity, we do our best to plan projects as accurately as possible. And how well do we do that? The answer, from an industry standpoint, is "not very well at all."

The alternative to plan-and-pray is to plan-track-replan. Agile methods accept that development plans are wrong at some level and that you'll need to adjust them. Agile methods provide a framework in which you can capture the change, adjust the plans, and redirect the project at a minimal cost and effort. The particular agile approach outlined in this book, known as the Harmony/ESW process, deals with work at three levels of abstraction, as shown in Figure 1.9.

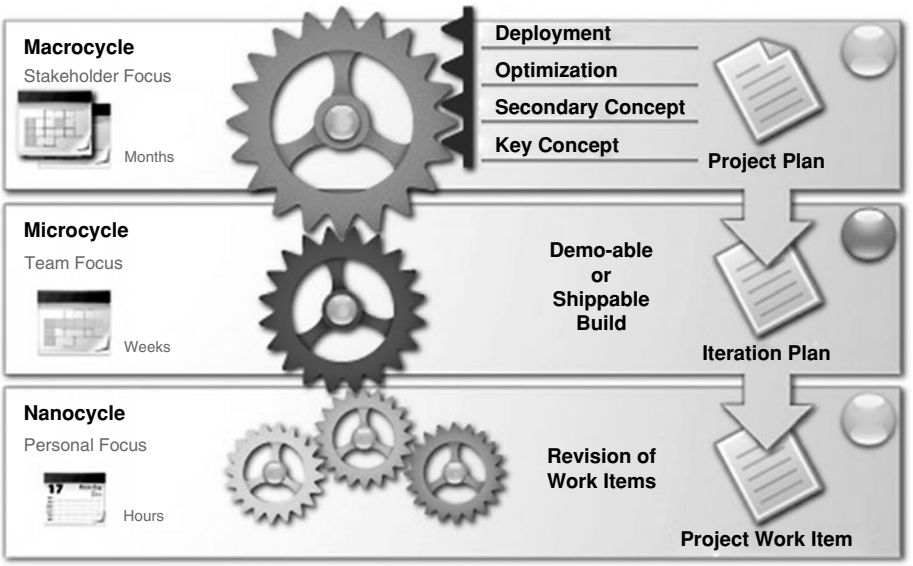

Figure 1.9 *Harmony/ESW timescales*

The smallest timescale, known as the **nanocycle,** is about creation in the hour-to-day time frame. In the nanocycle, the developer works off of the work items list, performs small incremental tasks, and verifies that they were done properly via execution. In this time frame, small changes with local scope can be effectively dealt with in the context of a few minutes or hours.

The middle time frame is called the **microcycle** and focuses on the development of a single integrated validated build of the system with specified functionality. The microcycle time frame is on the order of four to six weeks and delivers formally validated, although perhaps limited, functionality. Changes with medium scope are dealt with in the formal increment review[18] and in the prototype mission statement that identifies the scope for the microcycle iteration.

The largest time frame is called the **macrocycle.** The macrocycle concerns itself with the beginning and end of the project and primary milestones within that context. The macrocycle is usually 12 to 24 months long and represents a final, or at least significant, customer delivery. At this scope, large-scale changes are managed that may result in significant project replanning.

18. Also known as the "party phase" because it is not only a review, but also a "celebration of ongoing success"—as opposed to a postmortem, which is an analysis designed to discover why the patient died.

Earlier and Greater Reduction in Project Risk

The last of the benefits we will discuss in this section has to do with reduction of project risks. In my experience, the leading cause of project failure is simply ignoring risk. Risk is unavoidable, and attempts to ignore it are rarely successful. I am reminded of a company I consulted to that wanted help. The development staff of this medical device company had been working 55 to 60 hours per week *for 10 years* and had never made a project deadline. They asked that I come and see if I could identify why they were having such problems. As it happens, they did develop high-quality machines but at a higher-than-desirable development cost and in a longer-than-desirable time frame. They consistently ignored risks and had a (informal) policy of refusing to learn from their mistakes. For example, they had a history of projects for fairly similar devices, and it had always taken them five months to validate the machines. However, they, just as always, scheduled one month for validation. They refused to look at why projects were late and adjust future plans to be more reasonable.

In this context, risk means the same thing as it did in the earlier discussion of safety. It is the product of the severity of an undesirable situation and its likelihood. For a project, it is undesirable to be late or over budget or to have critical defects. We can reduce project risks by *managing them*. We manage them by identifying the key project risks and their properties so that we can reduce them. Risks are managed in a document called either a **risk list** or a **risk management plan.** As we will learn later, this risk list contains an ordered list of conditions, severities, likelihoods, and corrective actions known as **risk mitigation activities** (RMAs). These activities are scheduled into the iterations primarily in order of degree of risk (highest-risk first).

For example, if the risk is that CORBA[19] is too slow to handle the throughput required, an early prototype[20] should include some high-bandwidth data exchange and the performance can be measured. If it is found that CORBA does, in fact, provide inadequate performance, other technical solutions can be explored. Because the problem was discovered early, the amount of rework in that

19. Common Object Request Broker Architecture, an OMG standard.

20. A **prototype** is a validated build of the system produced at the end of an iteration microcycle. It contains a subset (but usually not all) of the real code that will ship in the system. Unless specifically described as such, we do not mean a **throwaway** prototype, which is an executable produced to answer a specific set of questions but will not be shipped in the final product.

case will be less than in a traditional "Oh, God, I hope this works" development approach. In agile methods this kind of an experiment is known as a **spike.**[21]

The risk list is a dynamic document that is reviewed at least every iteration (during the party phase[22]). It is updated as risks are reduced, mitigated, or discovered. Because we're focusing attention on risk, we can head off an undesirable situation before it surprises us.

Efficient High-Quality Development

High quality is achieved by the proper application of agile methods but in a different way from traditional industrial processes. This is again a dynamic, rather than a ballistic, approach. Agile achieves high quality through continuous execution, continuous integration, and continuous testing—begun as early as possible. Agile holds that the best way not to have defects in a system is not to systematically test them out but to not introduce them into the software in the first place (a topic I will address in more detail in upcoming chapters).

Efficiency is why most people in my experience turn to agile methods. In fact, agile methods have sometimes been thought to sacrifice quality and correctness in the pursuit of development efficiency. It is true that agile methods are a response to so-called heavyweight processes that emphasize paper analysis and ballistic planning over early execution and risk reduction. Nevertheless, agile emphasizes efficiency because it is a universal truth that software costs too much to develop and takes too long. A good agile process is *as efficient as possible* while achieving the necessary functionality and quality. Agile often recommends lighter-weight approaches to achieve a process workflow.

Agile Methods and Traditional Processes

Agile methods differ from traditional industrial processes in a couple of ways. Agile planning differs from traditional planning because agile planning is—to use the words of Captain Barbossa[23]—"more what you'd call a guideline." Agile development tends to follow a depth-first approach rather

21. In agile-speak, a spike is a time-boxed experiment that enables developers to learn enough about an unknown to enable progress to continue. See www.extremeprogramming.org/rules/spike.html.

22. See Chapter 9.

23. *Pirates of the Caribbean: The Curse of the Black Pearl* (Walt Disney Pictures, 2003).

than the breadth-first approach of traditional methods. Another key agile practice is test-driven development (TDD), which pushes testing as far up front in the process as possible. Finally, agile embraces change rather than fearing it.

Planning

It is a common and well-known problem in numerical analysis that the precision of a computational result cannot be better than that of the elements used within the computation.[24] I have seen schedules for complex system development projects that stretch on for years yet identify the completion time *to the minute*. Clearly, the level of knowledge doesn't support such a precise conclusion. In addition (pun intended ☺), errors accumulate during computations; that is, a long computation *compounds* the errors of its individual terms.

If you are used to working in a traditional plan-based approach, agile methods may seem chaotic and intimidating. The problem with the standard waterfall style is that although plans may be highly detailed and ostensibly more complete, that detail is *wrong* and the computed costs and end dates are *in error*.

Further, not only is the information you have about estimates fuzzy at best, it is also usually systematically biased toward the low end. This is often a result of management pressure for a lower number, with the misguided intention of providing a "sense of urgency" to the developers. Sometimes this comes from engineers with an overdeveloped sense of optimism. Maybe it comes from the marketing staff who require a systematic reduction of the schedule by 20%, regardless of the facts of the matter. In any event, a systematic but uncorrected bias in the estimates doesn't do anything but further degrade the accuracy of the plan.

Beyond the lack of precision in the estimates and the systematic bias, there is also the problem of *stuff you don't know and don't know that you don't know.* Things go wrong on projects—*all* projects. Not all things. Not even most things. But you can bet money that *something* unexpected will go wrong. Perhaps a team member will leave to work for a competitor. Perhaps a supplier will stop producing a crucial part and you'll have to search for a replacement. Maybe as-yet-unknown errors in your compiler itself will cause you to waste precious weeks trying to find the problem. Perhaps the office assistant is really a KGB[25] agent carefully placed to

24. Assuming certain stochastic properties of the error distribution, of course.

25. Excuse me, that should be *FSB* now.

bring down the Western economy by single-handedly intercepting and losing your office memo.

It is important to understand, deep within your hindbrain, that planning the unknown entails inherent inaccuracy. This doesn't mean that you shouldn't plan software development or that the plans you come up with shouldn't be as accurate as is needed. But it does mean that you need to be aware that they contain errors.

Because software plans contain errors that cannot be entirely removed, schedules need to be tracked and maintained frequently to take into account the "facts on the ground." This is what we mean by the term **dynamic planning**—it is planning to track and replan when and as necessary.

Depth-First Development

If you look at a traditional waterfall approach, such as is shown in Figure 1.10, the process can be viewed as a sequential movement through a set of layers. In the traditional view, each layer (or "phase") is worked to completion before moving on. This is a "breadth-first" approach. It has the advantage that the phase and the artifacts that it creates are complete before moving on. It has the significant *dis*advantage that the basic assumption of the waterfall approach—that the work within a single phase can be completed without significant error—has been shown to be incorrect. *Most* projects are late and/or over budget, and at least part of the fault can be laid at the feet of the waterfall lifecycle.

An incremental approach is more "depth-first," as shown in Figure 1.11. This is a "depth-first" approach (also known as spiral development) because only a small part of the overall requirements are dealt with at a time; these are detailed, analyzed, designed, and validated before the next set of requirements is examined in detail.[26] The result of this approach is that any defects in the requirements, through their initial examination or their subsequent implementation, are uncovered at a much earlier stage. Requirements can be selected on the basis of risk (high-risk first), thus leading to an earlier reduction in project risk. In essence, a large, complex project is sequenced into a series of small, simple projects. The resulting incremental prototypes (also known as **builds**) are validated and provide a robust starting point for the next set of requirements.

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26. The astute reader will notice that the "implementation" phase has gone away. This is because code is produced throughout the analysis and design activities—a topic we will discuss in much more detail in the coming chapters.

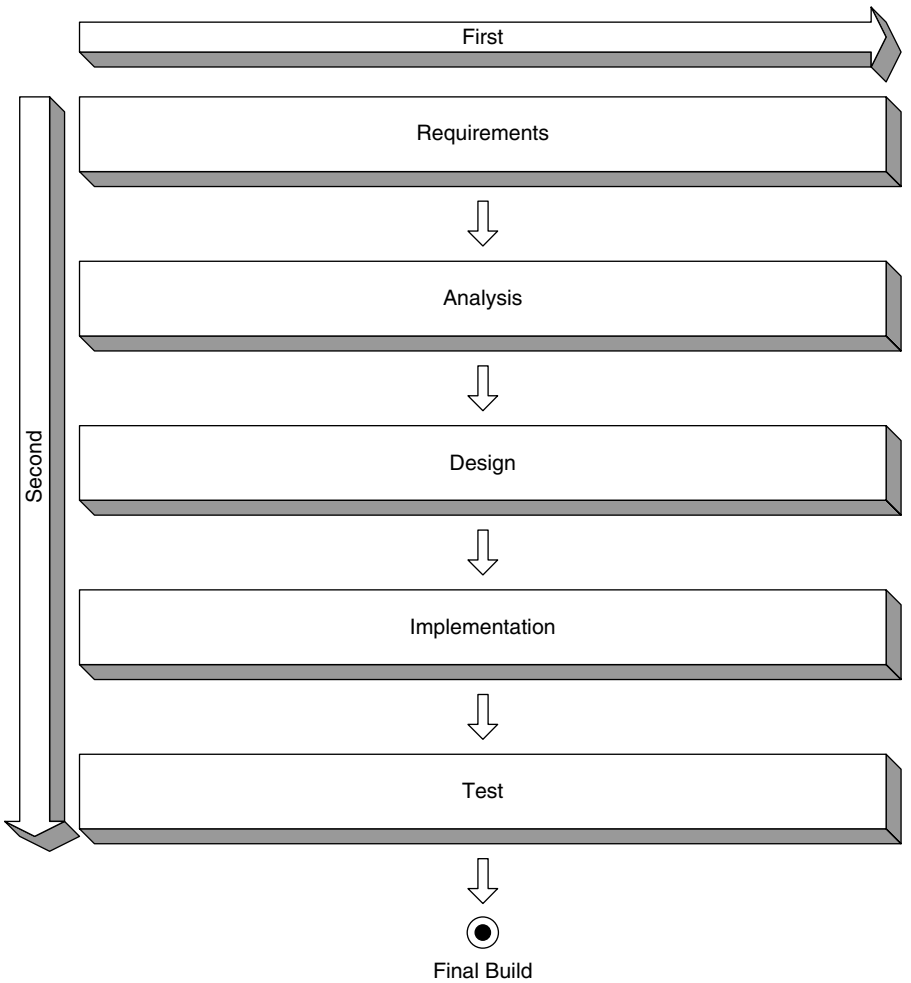

Figure 1.10 *Waterfall lifecycle*

Put another way, we can "unroll" the spiral approach and show its progress over linear time. The resulting figure is a sawtooth curve (see Figure 1.12) that shows the flow of the phases within each spiral and the delivery at the end of each iteration. This release contains "real code" that will be shipped to the customer. The prototype becomes increasingly complete over time as more requirements and functionality are added to it during each microcycle. This means not only

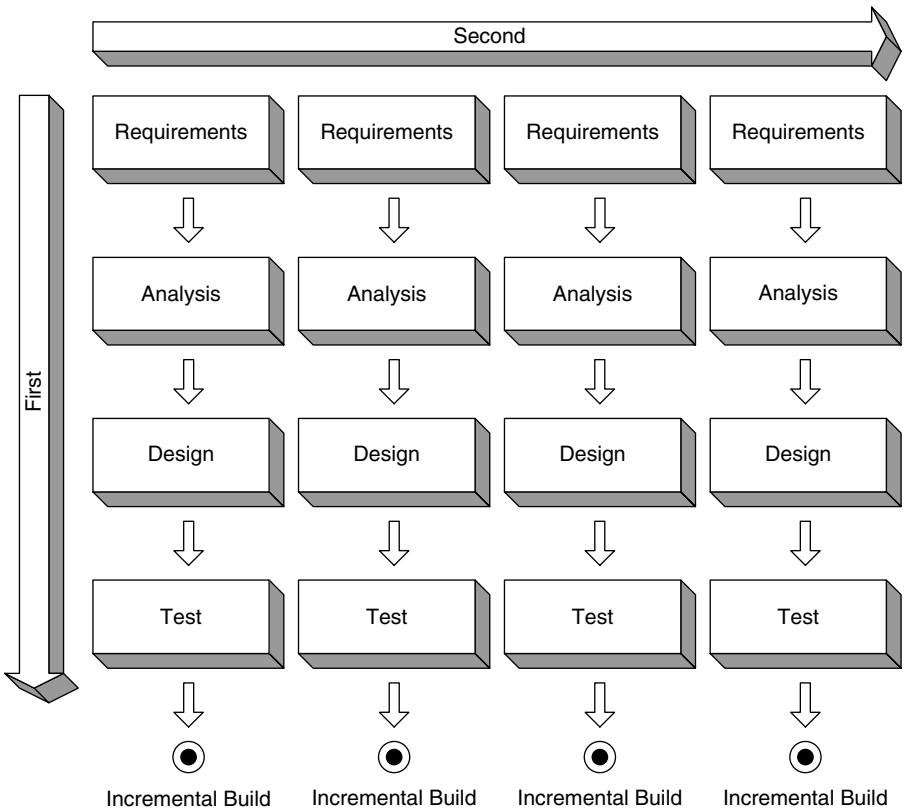

Figure 1.11 *Incremental spiral lifecycle*

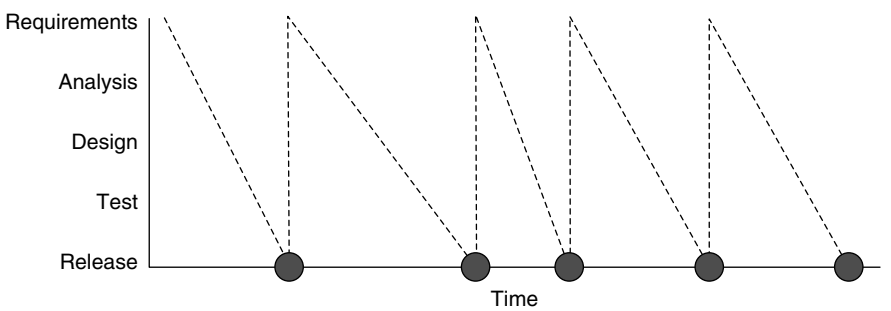

Figure 1.12 *Unrolling the spiral*

that some, presumably the high-risk or most critical requirements, are tested first, but also that they are tested more often than low-risk or less crucial requirements.

Test-Driven Development

In agile approaches, testing is the "stuff of life." Testing is *not* something done at the end of the project to mark a check box, but an integral part of daily work. In the best case, requirements are delivered as a set of executable test cases, so it is clear whether or not the requirements are met. As development proceeds, it is common for the developer to write the test cases before writing the software. Certainly, before a function or class is complete, the test cases exist and have been executed. As much as possible, we want to automate this testing and use tools that can assist in creating coverage tests. Chapter 8 deals with the concepts and techniques for agile testing.

Embracing Change

Unplanned change in a project can occur either because of the imprecision of knowledge early in the project or because something, well, *changed*. Market conditions change. Technology changes. Competitors' products change. Development tools change. We live in a churning sea of chaotic change, yet we cope. Remember when real estate was a fantastic investment that could double your money in a few months? If you counted on that being true forever and built long-range inflexible plans based on that assumption, then you're probably reading this while pushing your shopping cart down Market Street in San Francisco looking for sandwiches left on the curb. We cope in our daily lives because we know that things will change and we adapt. This doesn't mean that we don't have goals and plans but that we adjust those goals and plans to take change into account.

Embracing change isn't just a slogan or a mantra. Specific practices enable that embracement, such as making plans that specify a range of successful states, means by which changing conditions can be identified, analyzed, and adapted to, and methods for adapting what we do and how we do it to become as nimble and, well, *agile,* as possible.

In the final analysis, if you can adapt to change better than your competitors, then evolution favors *you*.[27]

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27. As the saying goes, "Chance favors the prepared mind." I forget who said it first, but my first exposure to it was Eric Bogosian in *Under Siege 2: Dark Territory* (Warner Bros., 1995).

Coming Up

This chapter provided some basic background information to prepare you for the rest of the book. Agile approaches are important because of the increasing burden of complexity and quality and the formidable constraint of a decreasing time to market. Following the discussion of the need for agility, the context of real-time systems was presented. The basic concepts of timeliness, such as execution time, deadline, blocking time, concurrency unit, criticality, and urgency, are fundamental to real-time systems. Understanding them is a prerequisite to understanding how agile methods can be applied to the development of such systems. The discussion went on to the actual benefits of agile methods, such as lowered cost of development, improved project control, better responsiveness to change, and improved quality. Finally, agile and traditional methods were briefly compared and contrasted. Agile methods provide a depth-first approach that embraces change and provides a continual focus on product quality.

The next chapter will introduce the concepts of model-driven development. Although not normally considered "agile," MDD provides very real benefits in terms of conceptualizing, developing, and validating systems. MDD and agile methods work synergistically to create a state-of-the-art development environment far more powerful than either is alone.

Chapter 3 introduces the core principles and practices of the Harmony/ESW process. These concepts form the repeated themes that help define and understand the actual roles, workflows, tasks, and work products found in the process.

Then, in Chapter 4, the Harmony/ESW process itself is elaborated, including the roles, workflows, and work products. Subsequent chapters detail the phases in the Harmony/ESW microcycle and provide detailed guidance on the implementation of those workflows.

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