



# TRILLIONS

THRIVING IN THE EMERGING  
INFORMATION ECOLOGY

PETER LUCAS    JOE BALLAY    MICKEY McMANUS



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WILEY

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*To Diana, Sue, and Lynn*



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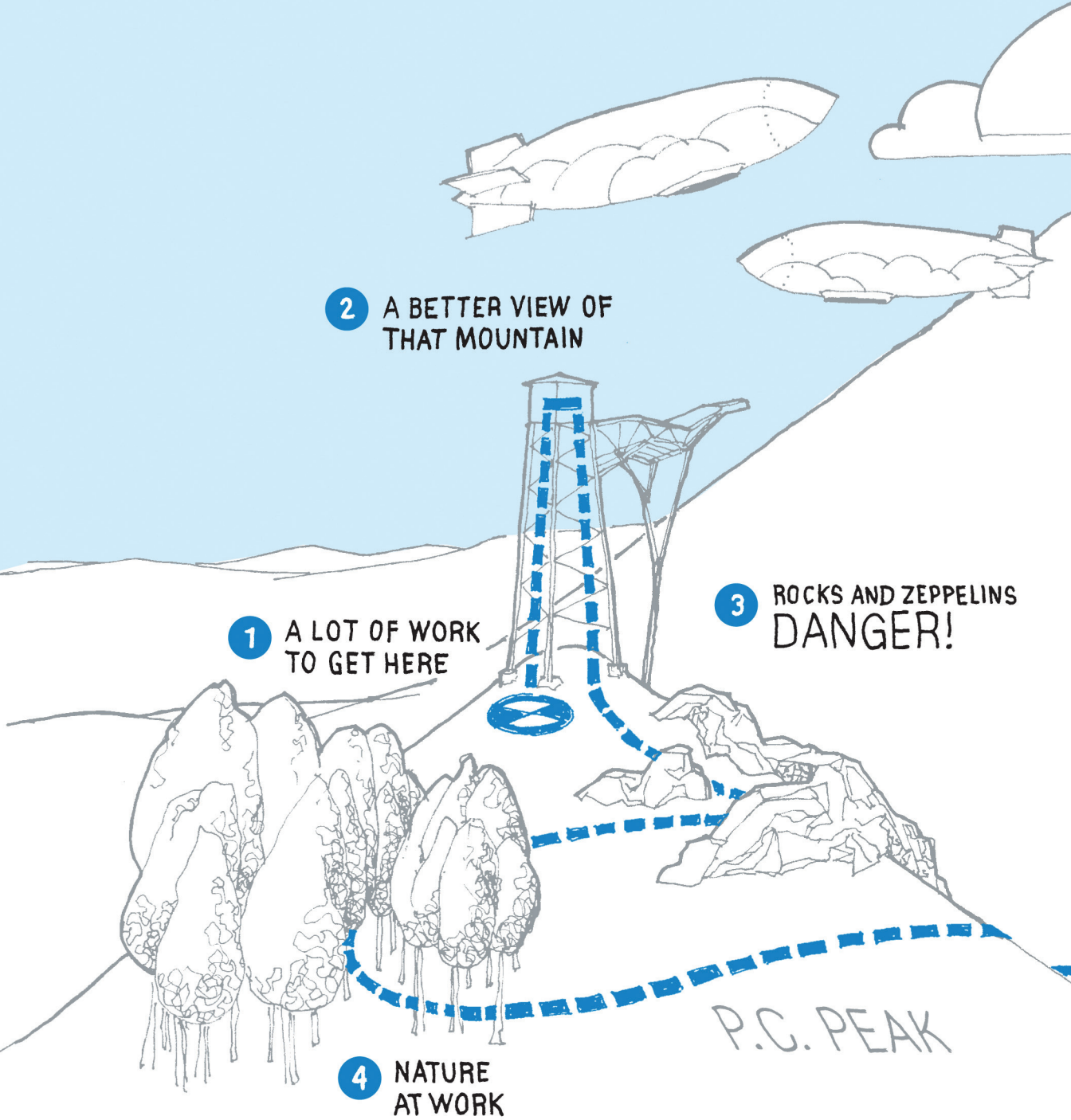
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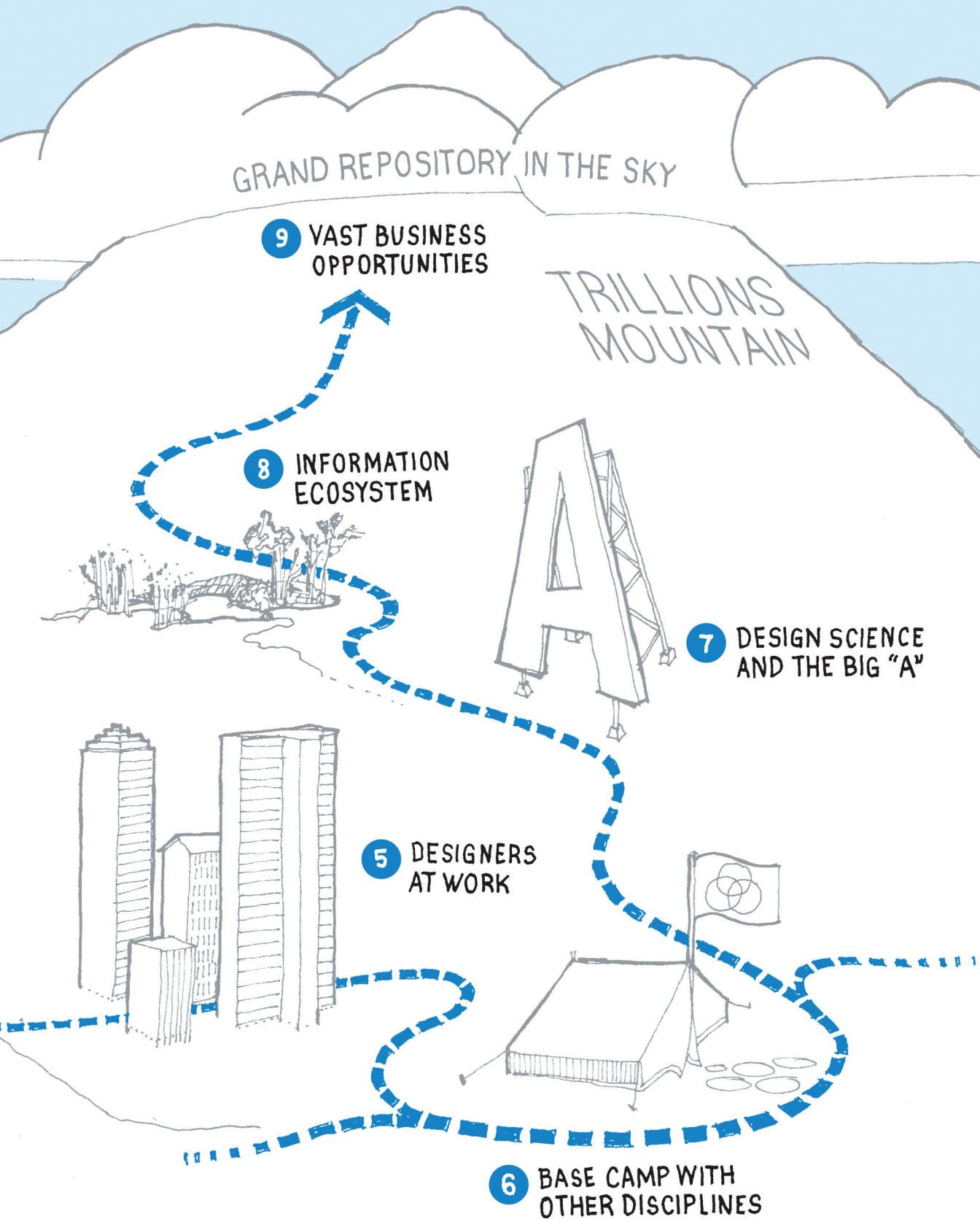
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# Preface

## TWO MOUNTAINS

The ruling metaphor for technological change is that of successive waves of innovation. We envision each paradigm shift and its corresponding rearrangement of the way we live as a wave that comes crashing down on our beach just as the tumult of the previous one begins to recede. This book is about two such waves—the rise of mass-market computing and the age of pervasive computing that is about to supplant it. For reasons that will become clear, we have chosen a slightly different metaphor to describe this particular sequence: that of climbing two adjacent mountains.<sup>1</sup>

Anyone who has climbed a real mountain (at least if they did so in the days before GPS) knows the experience of a long slog through the forest, during which one's exact position (and thus the status of the climb) can be known only vaguely. But then suddenly the timberline is reached and the accompanying long, clear sight lines produce an abrupt sense of orientation and perspective, after which one's relationship to the summit is correspondingly clear. When we started MAYA Design in 1989, we, and the industry we proposed to serve, had not yet reached the timberline of PC Peak. (This was an era in which the most complex technology to be found in the average home was a VCR, with its flashing "12:00" serving as a taunting harbinger of usability nightmares to come.) Our plan was to offer our services as a kind of mountain guide for the many industries that suddenly found themselves in the complexity business. Nobody quite knew what we were climbing toward or how long it would take to get there. But everybody knew that climb we must. It did not take long for the view to clarify. By the mid-1990s the Internet had gone mainstream, more or less everybody had a PC, and the agenda for the next decade or so was pretty much set. The path to the summit was suddenly obvious.

But, there was more to this newly clear view than most people noticed. While most eyes were (and remain today) firmly fixed on the summit, those who cast their gaze more widely discerned a surprise. PC Peak, which we have been climbing since the 1970s does not stand alone in the technological landscape. It has an adjacent companion—one with a much higher summit. This second peak is called Trillions Mountain, and it towers far over our current perch.

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<sup>1</sup>The metaphor isn't actually all that different, mountains merely being waves in an unusually viscous medium.

For many years, the only important computing device in a typical home or business was the personal computer (PC), first on the desktop and then on the laptop. In only the past few years, this has suddenly changed, with smartphones and tablet computers well on the way toward eclipsing the PC for most purposes. The term *pervasive computing*<sup>2</sup> refers to the assumption—now widely held by people who pay attention to such trends—that this transition, dramatic though it is, is just the first step in a far more fundamental change. Rather than moving computation out of one kind of box into other—smaller and more portable—boxes, by the end of this transition computing will for all practical purposes be confined to no box at all. Computation (and thus data) will all but literally have escaped into the ambient environment. We already put microprocessors into nearly every significant thing that we manufacture, and we are quickly figuring out how to make those processors usefully communicate with each other, and with us. Moreover, the cost of routine computing and storage is rapidly becoming negligible. We are, as we shall see, well on our way to a world with trillions of computers. Once these trends get past their initial chaotic stage, they will quickly coalesce into something new and disruptive: an *environment* of computation. Not computation that we *use*, but computation that we *live in*.

We are by no means the first to make this observation. As we have said, these trends are widely recognized. But most of what has been written on the topic comes in one of two forms. The first of these comprise world of tomorrow gee-whiz stories about the wonders to come—how houses will cater to our whims; power grids will become intelligent; and tractors will drive themselves through fields sown not just with seeds, but also with millions of “smart dust” moisture and nutrient sensors. The second form is written by and for computer scientists, dealing with tricky nuts-and-bolts issues such as distributed databases, self-configuring mesh networks, and “device discovery” protocols.

This book is neither of these. Although we do present examples, and at places verge on the technical, neither represents our main point. The book is really about *people*—how we might arrange for them to live well in this new kind of built environment, and how we might botch the job. In other words, it is about *design*. Exactly what that means, and what it takes to be an effective designer is a topic that needs a fresh look in each technological epoch. What it takes in the present era and the profound impact of this new mode of design on the business world are the major themes of this work.

The occasion for the book is the upcoming twenty-fifth anniversary of our company, MAYA Design. However, it is not intended as a self-congratulatory

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<sup>2</sup>Academics love to fight about names. The term *pervasive computing* has a major competitor in the literature: *ubiquitous computing*. As far as we can tell, the terms are synonymous. However, there seem to be sensitivities attached to the use of one or the other term, apparently having to do with concerns over whom history will recognize as the founders of the discipline. We have no dog in that fight. We use *pervasive computing* because we think it sounds better than the awkward *ubiquitous computing* and especially its common but hideous contraction *ubicomp*. Such things matter.

*festschrift*. We will keep our personal war stories to a minimum, and those we do tell are offered more in the spirit of a foot soldier's diary than a general's memoir. But they are, we think, worth the telling. For, they were culled from almost a quarter-century of intimate collaboration with engineers and marketing professionals from many of the world's most successful and advanced organizations.

As a business, MAYA is uniquely structured. In many ways, we reflect the tradition of the great industrial design consultancies of the 1940s and 1950s.<sup>3</sup> The majority of our work involves long-term consulting relationships with firms that develop and market technological products and services. But we also have many of the attributes of an industrial R&D lab, performing applied research in areas of relevance to our commercial work. In any given week, a designer at MAYA might spend time helping a new tech startup launch a tablet-based pervasive computing service; working on a project with one of our Fortune 500 clients developing a long-term product architecture; and exploring a DARPA-funded technology that will not be commercially viable for a decade. The hybrid nature of this project mix is virtuous in both directions: It lets us help our commercial clients see past the pressures of the next quarter and thus avoid the often-fatal pitfalls of local hill climbing, and it encourages us to focus our research efforts toward practical issues that are likely to really matter to the humans that are always at the center of our attention.

This is a book with three authors, a fact that would be blatantly obvious even absent the names on the cover. We have tried to even out the voices, at least in the main body of the text. But truth be known, we have not tried all that hard. The presence of three very different voices, and several others that show up from time to time, is an essential part of our story. They reflect a belief—at the very heart of MAYA's approach to design—that the problems we and our clients now face are beyond the ken of any one disciplinary tradition. From the day we opened our doors, we have brought together engineers, human scientists, and visual designers in the conviction that triangulating from all three of these disciplinary perspectives represents our best hope for getting the future right. We have never looked back.

We created MAYA at a time when the practice of interdisciplinary design was rare and the idea of human-centered design in computing and information systems was nascent. We maintain a belief that the hard problems that people, organizations, communities, and cultures will face in the coming years can only be solved at the intersection of how people think, how technology works, and what form and function the desired solution takes.

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<sup>3</sup>Our name, "MAYA"—an acronym standing for "Most Advanced Yet Acceptable"—is an homage to Raymond Loewy, one of several role models from among this group, who often spoke of his goal for a design to reach "the MAYA stage."

## A FIELD GUIDE TO TRILLIONS MOUNTAIN

And so, we find ourselves at the very apex of PC Peak. It was a long, tough climb, but we made it. We desperately want to go even higher, so we have taken to building fire towers, and extensions upon those. But the skills that got us to this eminence don't help much here at the top, so the towers are rickety and dangerous. Everybody sees Trillions Mountain out there across the valley, rising far above us into the clouds. But most people avert their eyes. We climb up, not down; and down appears to be the only way to get over there. Plus, we don't even know how to climb that kind of a mountain. So, it's back to the fire towers. Others busy themselves trying to cantilever a bridge out in the new mountain's direction. That isn't going too well, either.

But a few of us are ready to bite the bullet and start the trip, even if it means reversing some hard-won progress and then mapping a whole new territory. If you're up for the journey, we hope that this book will be of some assistance.

We begin with an overview of what we can see of Trillions Mountain from our present viewpoint. Most of the prerequisites to the emergence of pervasive computing are already in place, and many of the remaining developments are well underway. Although these claims are not really controversial, their implications are not well-known to many people, even within the industry, so Chapter 1 is intended as a kind of executive summary of progress to date. Chapter 2, while a bit more speculative, explores a set of possibilities that are certainly possible and in our judgment both likely and desirable.

Chapter 3 concerns itself with those rickety fire towers. As the industry climbed upward from the spacious foothills of the current mountain to the crowded heights, increased competition for a dwindling set of opportunities has led to some pretty risky behaviors. Here we will explore some of the less-than-healthy aspects of today's computing scene, with special emphasis on those that represent significant threats to the unfolding of a safe and sane technological future.

We then begin to plan our climb up Trillions Mountain. There are many novel challenges ahead, but most of them share a common basis. That basis is *complexity*. More than anything else, what will distinguish computing in the future from computing in the past are sheer scale and the complexity that comes with it. Devices will exist in unprecedented numbers, as will occasions for human-machine interactions. The design techniques that have served us well on PC Peak will be wholly inadequate for the problems of scale that we will soon face.

These are unfamiliar issues to the computing world, but they are not without precedent. The next section of the book examines some of these precedents and what we might learn from them. Chapter 4 examines the ultimate master of distributed complexity: Nature herself. We explore the basic self-organizational patterns of natural systems and how they inform steps toward

the creation of an ecology of information devices. Chapter 5 looks at the design process itself, both from an historical and contemporary perspective. Finally, Chapters 6 and 7 bring science into the story, examining the thesis that the notions of *design* and *science* are not, as is often assumed, disjoint activities. We pay special attention to the generalization of the concept of architecture as the basis for a scientific approach to the design process.

The last two chapters, Chapters 8 and 9, attempt to pull this material together into a coherent, if fuzzy, image of life in the foothills of Trillions Mountain. We know better than to be too specific here, but it is possible to discern the broad strokes of how the story of pervasive computing is likely to unfold, and in these chapters we lay them out in as much specificity as we dare.

Finally, scattered throughout is a fair amount of supplementary material, which we hope will support and reinforce the main thread of the text. Each of us indulges in a bit of first-person storytelling, as do a few of our MAYA colleagues. Included here are a number of case studies describing both examples of our research activities and commercial work done in collaboration with our clients. You will also encounter references to various audio, video, and interactive material, which can be found at the book's website: [TRILLIONS.MAYA.COM](http://TRILLIONS.MAYA.COM).

There are also two “interludes” — minichapters whose purpose is to place examples of these trends into their historical context. We end the book with an epilogue containing material specifically aimed toward members of the business community as they face the challenges raised by the advent of pervasive technologies.

Some topics that are discussed in *Trillions* really deserve dedicated books in their own right. Much of the research work that has been done by our small band and by others is still very much in progress as this book goes to print. However, where possible, we have included pointers in the end pages to where you can drill deeper into the topics we have touched.



# *Acknowledgments*

It is customary for authors of works of nonfiction to whine to their readers about the impossibility of thanking everyone that they should. We certainly have no cause to break with this tradition. Indeed, our situation is worse than most. The contents of this book are not the results of a bounded research project. Rather, they are the collective product of a quarter-century collaboration, not only among the authors, or even among the hundreds of design professionals who have worked at MAYA over the years. Rather, the circle of credit extends in a most fundamental way to include the many extraordinary clients with whom we have been privileged to work. The countless intimate collaborations with our clients' engineers, designers, marketers, and managers are the wellspring of whatever insights we may have to offer. To mention even a few would be a disservice to many others of equal importance, so we can only acknowledge the depth and breadth of our debt here. And, of course, the collective contribution of everyone in the MAYA family—past and present—is vast beyond calculation.

In thanking those with a direct hand in the creation of the book itself, we must begin with Ralph Lombreglia. Whatever success we have had in making unfamiliar and complex topics accessible to the general reader has benefited greatly from his fine rhetorical sensibilities and his unfailing good advice throughout the project. A number of longtime MAYAnS have also been direct contributors to the text: Jeff Senn—a genuine polymath who has been a core member of the MAYA family since the day we opened our doors—has made countless contributions both to the ideas and to the words themselves. Bill Lucas (no relation to Pete) and David Bishop have each taken the time to write essays that we have gratefully included in the text.

Nearly everyone in the MAYA companies has read early drafts of the manuscript, and many have provided valuable feedback. Special recognition must go to Dutch MacDonald, who has regularly provided detailed feedback on all aspects of the project while also managing to keep the business on an even keel during our frequent bouts of book-driven inattention. Lori Paul, our treasured executive assistant (a title that vastly understates her value), has been characteristically masterful at keeping the process moving forward amidst the background chaos of a busy consultancy. Thanks are also due to Chris DeMarco for technical support and Christen Adels for attending to legal matters.

This is a book of significant breadth and deceptive complexity, and the brunt of our compulsion for fact-checking and general rigor has fallen on Susan Salis and Susan Zelicoff (collectively referred to as “the Susi”). Their diligence and care in managing the minutiae of the project were frequently the only things standing between us and chaos.

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Finally, we are profoundly grateful for the patience, support, and love of our spouses Diana Dee-Lucas, Sue Ballay, and Lynn Lofton.

**TRILLIONS**



CHAPTER 1

# The Future, So Far

*Behind all the great material inventions of  
the last century and a half was not merely  
a long internal development of technics:  
There was also a change of mind.*

—LEWIS MUMFORD

There is a point of view—generally called “technological determinism”—that essentially says that each technological breakthrough inexorably leads to the next. Once we have light bulbs, we will inevitably stumble upon vacuum tubes. When we see what they can do, we will rapidly be led to transistors, and integrated circuits and microprocessors will not be far behind. This process—goes the argument—is essentially automatic, with each domino inevitably knocking down the next, as we careen toward some unknown but predetermined future.

We are not sure we would go that far, but it is certainly the case that each technological era sets the stage for the next. The future may or may not be determined, but a discerning observer can do a credible job of paring down the alternatives. All but the shallowest of technological decisions are necessarily made far in advance of their appearance in the market, and by the time we read about an advance on the cover of *Time* magazine, the die has long since been cast. Indeed, although designers of all stripes take justifiable pride in their role of “inventing the future,” a large part of their day-to-day jobs involves reading the currents and eddies of the flowing river of science and technology in order to help their clients navigate.

Although we are prepared to go out on a limb or two, it won't be in this chapter. Many foundational aspects of the pervasive-computing future have already been determined, and many others will follow all but inevitably from well-understood technical, economic, and social processes. In this chapter, we will make predictions about the future, some of which may not be immediately obvious. But we will try to limit these predictions to those that most well-informed professionals would agree with. If you are one of these professionals (that is to say, if you find the term *pervasive computing* and its many synonyms commonplace), you may find this chapter tedious, and you should feel free to skip ahead. But if the sudden appearance of the iPad took you by surprise, or if you have difficulty imagining a future without laptops or web browsers, then please read on.

## TRILLIONS IS A DONE DEAL

To begin with, there is this: There are now more computers in the world than there are people. Lots more. In fact, there are now more computers, in the form of microprocessors, manufactured *each year* than there are living people. If you step down a level and count the building blocks of computing—transistors—you find an even more startling statistic. As early as 2002 the semiconductor industry touted that the world produces more transistors than grains of rice, and cheaper. But counting microprocessors is eye-opening enough. Accurate production numbers are hard to come by, but a reasonable estimate is ten billion processors per year. And the number is growing rapidly.

Many people find this number implausible. Where could all these computers be going? Many American families have a few PCs or laptops—you

probably know some geeks that have maybe eight or ten. But many households still have none. Cell phones and iPads count, too. But *ten billion a year*? Where could they all possibly be going?

The answer is *everywhere*. Only a tiny percentage of processors find their way into anything that we would recognize as a computer. Every modern microwave oven has at least one; as do washing machines, stoves, vacuum cleaners, wrist watches, and so on. Indeed, it is becoming increasingly difficult to find a recently designed electrical device of any kind that does not employ microprocessor technology.

Why would one put a computer in a washing machine? There are some quite interesting answers to this question that we will get to later. But for present purposes, let's just stick to the least interesting answer: It saves money. If you own a washer more than ten years old, it most likely has one of those big, clunky knobs that you pull and turn in order to set the cycle. A physical pointer turns with it, showing at a glance which cycle you have chosen and how far into that cycle the machine has progressed. This is actually a pretty good bit of human-centered design. The pointer is clear and intuitive, and the act of physically moving the pointer to where you want it to be is satisfyingly literal. However, if you have a recently designed washer, this knob has probably been replaced with a bunch of buttons and a digital display, which, quite possibly, is not as easy to use.

So why the step backward? Well, let's think for a second about that knob and pointer. They are the tip of an engineering iceberg. Behind them is a complex and expensive series of cams, clockwork, and switch contacts whose purpose is to turn on and off all the different valves, lights, buzzers, and motors throughout the machine. It even has a motor of its own, needed to keep things moving forward. That knob is the most complex single part in the appliance. A major theme of twentieth-century industrialization involved learning how to build such mechanically complex devices cheaply and reliably. The analogous theme of the early twenty-first century is the replacement of such components with mechanically trivial microprocessor-based controllers. This process is now ubiquitous in the manufacturing world.

In essence, the complexity that formerly resided in intricate electro-mechanical systems has almost completely migrated to the ethereal realm of software. Now, you might think that complexity is complexity and we will pay for it one way or another. There is truth in this statement, as we will see. However, there is a fundamental economic difference between complexity-as-mechanism and complexity-as-software. The former represents a unit cost, and the latter is what is known as a nonrecurring engineering expense (NRE). That is to say, the manufacturing costs of mechanical complexity recur for every unit made, whereas the replication cost of a piece of software—no matter how complex—approaches zero.

This process of substituting “free” software for expensive mechanism repeats itself in product after product, and industry after industry. It is in

itself a powerful driver in our climb towards Trillions. As manufacturing costs increase and computing costs decrease, the process works its way down the scale of complexity. It is long-since complete in critical and subtle applications such as automotive engine control and industrial automation. It is nearly done in middling applications such as washing machines and blenders, and has made significant inroads in low-end devices such as light switches and air-freshener dispensers.

Money-saving is a powerful engine for change. As the generalization from these few examples makes clear, even if computerized products had no functional advantage whatsoever over their mechanical forebears, the rapid computerization of the built world would be assured. But this is just the beginning of the story. So far, we have been considering only the use of new technology to do old things. The range of products and services that were not practical before computerization is far larger. For every opportunity to replace some existing mechanism with a processor, there are hundreds of new products that were either impossible or prohibitively expensive in the precomputer era. Some of these are obvious: smartphones, GPS devices, DVD players, and all the other signature products of our age. But many others go essentially unnoticed, often written off as trivialities or gimmicks. Audio birthday cards are old news, even cards that can record the voice of the sender. Sneakers that send runners' stride data to mobile devices are now commonplace. Electronic tags sewn into hotel towels that guard against pilferage, and capture new forms of revenue from souvenirs, are becoming common. The list is nearly endless.

Automotive applications deserve a category of their own. Every modern automobile contains many dozens of processors. High-end cars contain hundreds. Obvious examples include engine-control computers and GPS screens. Less visible are the controllers inside each door that implement a local network for controlling and monitoring the various motors, actuators, and sensors inside the door—thus saving the expense and weight of running bulky cables throughout the vehicle. Similar networks direct data from accelerometers and speed sensors, not only to the vehicle's GPS system, but also to advanced braking and stability control units, each with its own suite of processors. Drilling further down into the minutiae of modern vehicle design, one finds intelligent airbag systems that deploy with a force determined by the weight of the occupant of each seat. How do they know that weight? Because the bolts holding the seats in place each contain a strain sensor and a microprocessor. The eight front-seat bolts plus the airbag controller form yet another local area network dedicated to the unlikely event of an airbag deployment.

We will not belabor the point, but such lists of examples could go on indefinitely. Computerization of almost literally everything is a simple economic imperative. Clearly, ten billion processors per year is not the least bit implausible. And that means that a near-future world containing trillions of computers is simply a done-deal. Again, we wish to emphasize that the argument so

far in no way depends upon a shift to an information economy or a desire for a smarter planet. It depends only on simple economics and basic market forces. We are building the trillion-node network, not because we can but because it makes economic sense. In this light, a world containing a trillion processors is no more surprising than a world containing a trillion nuts and bolts. But, of course, the implications are very different.

## CONNECTIVITY WILL BE THE SEED OF CHANGE

In his 1989 book *Disappearing through the Skylight*, O. B. Hardison draws a distinction between two modes in the introduction of new technologies—what he calls “classic” versus “expressive”:

To review types of computer music is to be reminded of an important fact about the way technology enters culture and influences it. Some computer composers write music that uses synthesized organ pipe sounds, the wave forms of Stradivarius violins, and onstage Bösendorf grands in order to sound like traditional music. In this case the technology is being used to do more easily or efficiently or better what is already being done without it. This can be called “classic” use of the technology. The alternative is to use the capacities of the new technology to do previously impossible things, and this second use can be called “expressive.” . . .

It should be added that the distinction between classic and expressive is provisional because whenever a truly new technology appears, it subverts all efforts to use it in a classic way. . . . For example, although Gutenberg tried to make his famous Bible look as much like a manuscript as possible and even provided for hand-illuminated capitals, it was a printed book. What it demonstrated in spite of Gutenberg—and what alert observers throughout Europe immediately understood—was that the age of manuscripts was over. Within fifty years after Gutenberg’s Bible, printing had spread everywhere in Europe and the making of fancy manuscripts was an anachronism. In twenty more years, the Reformation had brought into existence a new phenomenon—the cheap, mass-produced pamphlet-book.

Adopting Hardison’s terminology, we may state that the substitution of software for physical mechanism, no matter how many billions of times we do it, is an essentially classic use of computer technology. That is to say, it is not particularly disruptive. The new washing machines may be cheaper, quieter, more reliable, and conceivably even easier to use than the old ones, but they are still just washing machines and hold essentially the same position in our homes and lives as their more mechanical predecessors. Cars with computers instead of carburetors are still just cars. At the end of the day, a world in which every