TRILLIONS

THRIVING IN THE EMERGING
INFORMATION ECOLOGY

PETER LUCAS   JOE BALLAY   MICKEY McMANUS

Contents

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WILEY

JOHN WILEY & SONS, INC.

Published by John Wiley & Sons, Inc., Hoboken, New Jersey.
Published simultaneously in Canada.

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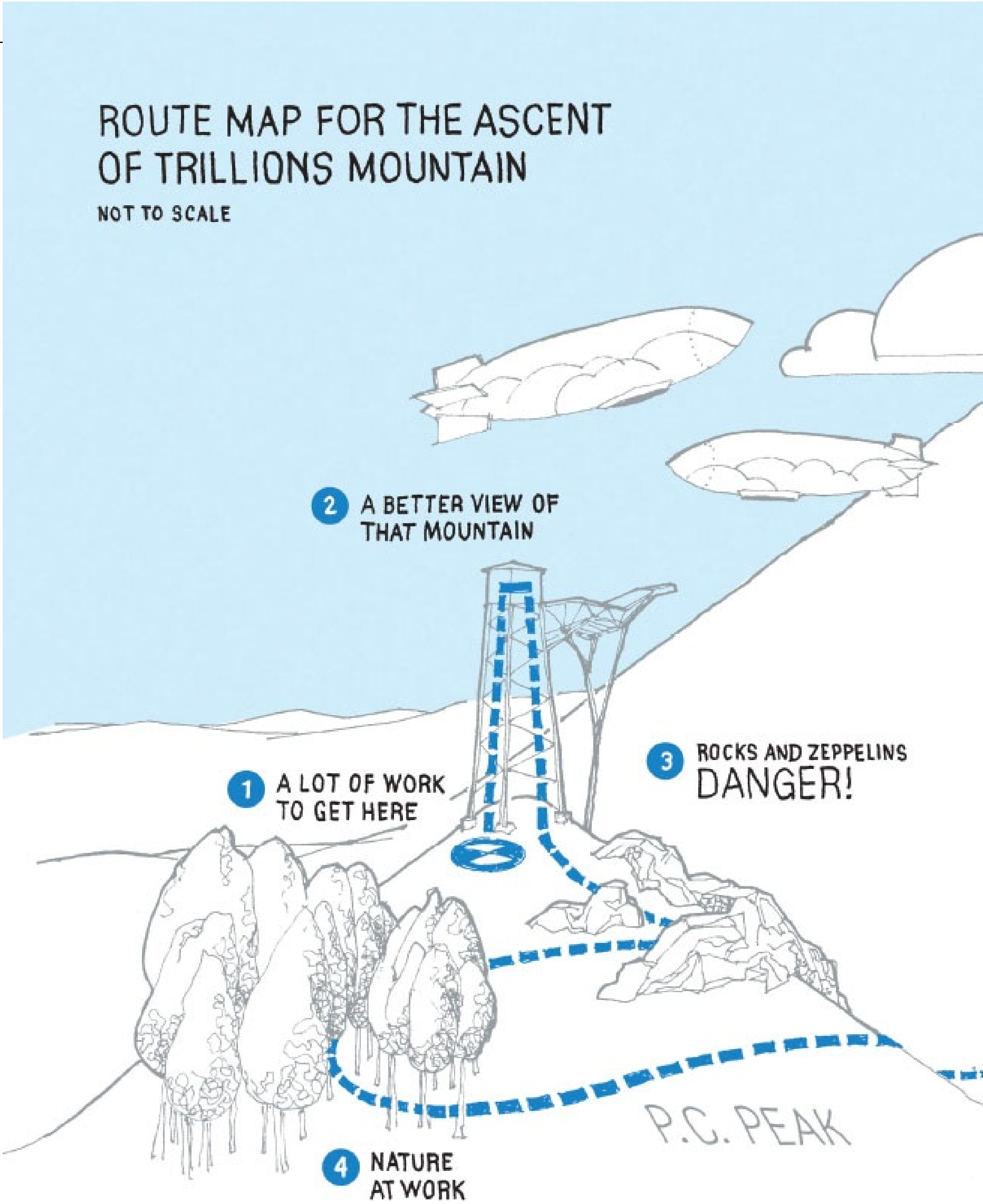
Library of Congress Cataloging-in-Publication Data:

Lucas, Peter,
Trillions : thriving in the emerging information ecology / Peter Lucas, Joe Ballay, Michael McManu
— 1st ed.
p. cm.
Includes index.
ISBN 978-1-118-17607-8 (hardback); 978-1-118-22715-2 (ebk.);
978-1-118-24006-9 (ebk.); 978-1-118-26478-2 (ebk.)
1. Information technology. 2. Information society. I. Ballay, Joe, II. McManus, Michael, III. Title.
T58.5.L835 2012
303.48’33—dc23
2012012395

To Diana, Sue, and Lynn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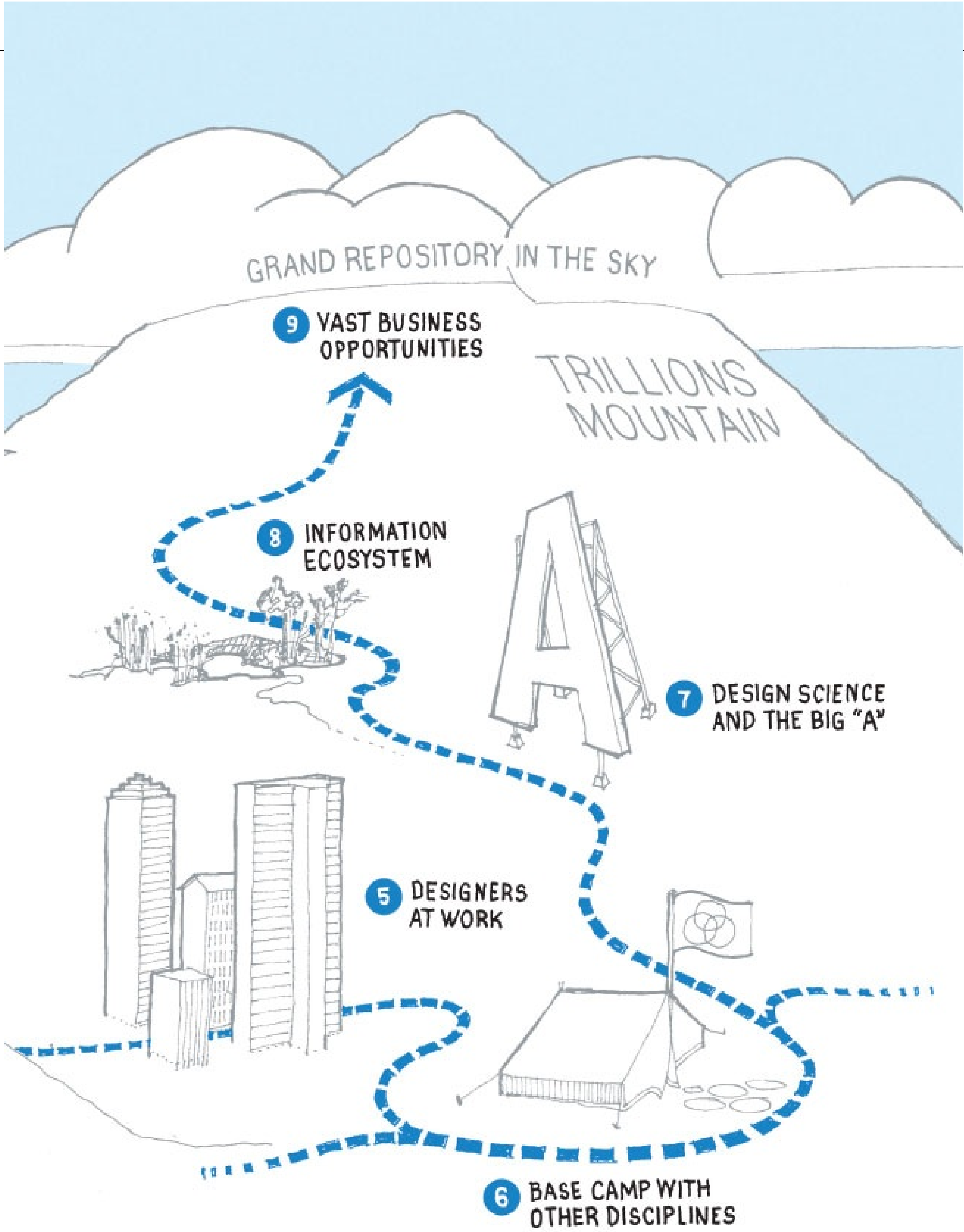

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Preface

TWO MOUNTAINS

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

Anyone who has climbed a real mountain (at least if they did so in the days before GPS) knows th experience of a long slog through the forest, during which one's exact position (and thus the status the climb) can be known only vaguely. But then suddenly the timberline is reached and th accompanying long, clear sight lines produce an abrupt sense of orientation and perspective, aft which one's relationship to the summit is correspondingly clear. When we started MAYA Design i 1989, we, and the industry we proposed to serve, had not yet reached the timberline of PC Peak. (Th was an era in which the most complex technology to be found in the average home was a VCR, wi its flashing "12:00" serving as a taunting harbinger of usability nightmares to come.) Our plan was offer our services as a kind of mountain guide for the many industries that suddenly found themselv in the complexity business. Nobody quite knew what we were climbing toward or how long it wou take to get there. But everybody knew that climb we must. It did not take long for the view to clarif By the mid-1990s the Internet had gone mainstream, more or less everybody had a PC, and the agen 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 (an remain today) firmly fixed on the summit, those who cast their gaze more widely discerned a surpris PC Peak, which we have been climbing since the 1970s does not stand alone in the technologic landscape. It has an adjacent companion—one with a much higher summit. This second peak is calle Trillions Mountain, and it towers far over our current perch.

For many years, the only important computing device in a typical home or business was the person computer (PC), first on the desktop and then on the laptop. In only the past few years, this h suddenly changed, with smartphones and tablet computers well on the way toward eclipsing the PC f most purposes. The term *pervasive computing*[2] refers to the assumption—now widely held by peop who pay attention to such trends—that this transition, dramatic though it is, is just the first step in 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 practic purposes be confined to no box at all. Computation (and thus data) will all but literally have escap into the ambient environment. We already put microprocessors into nearly every significant thing th we manufacture, and we are quickly figuring out how to make those processors usefully communica with each other, and with us. Moreover, the cost of routine computing and storage is rapidly becomin negligible. We are, as we shall see, well on our way to a world with trillions of computers. Once thes trends get past their initial chaotic stage, they will quickly coalesce into something new an disruptive: an *environment* of computation. Not computation that we *use*, but computation that we *li* *in.*

We are by no means the first to make this observation. As we have said, these trends are widel recognized. But most of what has been written on the topic comes in one of two forms. The first these comprise world of tomorrow gee-whiz stories about the wonders to come—how houses w cater to our whims; power grids will become intelligent; and tractors will drive themselves throug fields sown not just with seeds, but also with millions of "smart dust"moisture and nutrient sensor The second form is written by and for computer scientists, dealing with tricky nuts-and-bolts issu 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 technica neither represents our main point. The book is really about *people*—how we might arrange for them live well in this new kind of built environment, and how we might botch the job. In other words, it about *design*. Exactly what that means, and what it takes to be an effective designer is a topic th needs a fresh look in each technological epoch. What it takes in the present era and the profoun 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 *festschrift*. We will keep our personal war storie to a minimum, and those we do tell are offered more in the spirit of a foot soldier's diary than general's memoir. But they are, we think, worth the telling. For, they were culled from almost quarter-century of intimate collaboration with engineers and marketing professionals from many the world's most successful and advanced organizations.

As a business, MAYA is uniquely structured. In many ways, we reflect the tradition of the grea industrial design consultancies of the 1940s and 1950s.[3] The majority of our work involves long-ter consulting relationships with firms that develop and market technological products and services. B we also have many of the attributes of an industrial R&D lab, performing applied research in areas relevance to our commercial work. In any given week, a designer at MAYA might spend time helpin a new tech startup launch a tablet-based pervasive computing service; working on a project with o 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 proje mix is virtuous in both directions: It lets us help our commercial clients see past the pressures of t next quarter and thus avoid the often-fatal pitfalls of local hill climbing, and it encourages us to foc our research efforts toward practical issues that are likely to really matter to the humans that a 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 the cover. We have tried to even out the voices, at least in the main body of the text. But truth b known, we have not tried all that hard. The presence of three very different voices, and several othe that show up from time to time, is an essential part of our story. They reflect a belief—at the ver heart of MAYA's approach to design—that the problems we and our clients now face are beyond th ken of any one disciplinary tradition. From the day we opened our doors, we have brought togeth engineers, human scientists, and visual designers in the conviction that triangulating from all three these disciplinary perspectives represents our best hope for getting the future right. We have nev looked back.

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

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. W desperately want to go even higher, so we have taken to building fire towers, and extensions upo those. But the skills that got us to this eminence don't help much here at the top, so the towers a rickety and dangerous. Everybody sees Trillions Mountain out there across the valley, rising far abov us into the clouds. But most people avert their eyes. We climb up, not down; and down appears to b the only way to get over there. Plus, we don't even know how to climb that kind of a mountain. So, it back to the fire towers. Others busy themselves trying to cantilever a bridge out in the new mountain 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 har won progress and then mapping a whole new territory. If you're up for the journey, we hope that th book will be of some assistance.

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

Chapter 3 concerns itself with those rickety fire towers. As the industry climbed upward from th spacious foothills of the current mountain to the crowded heights, increased competition for dwindling set of opportunities has led to some pretty risky behaviors. Here we will explore some the less-than-healthy aspects of today's computing scene, with special emphasis on those th 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, bu most of them share a common basis. That basis is *complexity*. More than anything else, what wi distinguish computing in the future from computing in the past are sheer scale and the complexity th comes with it. Devices will exist in unprecedented numbers, as will occasions for human–machi interactions. The design techniques that have served us well on PC Peak will be wholly inadequate f the problems of scale that we will soon face.

These are unfamiliar issues to the computing world, but they are not without precedent. The ne section of the book examines some of these precedents and what we might learn from them. Chapter examines the ultimate master of distributed complexity: Nature herself. We explore the basic sel organizational patterns of natural systems and how they inform steps toward the creation of a ecology of information devices. Chapter 5 looks at the design process itself, both from an historic and contemporary perspective. Finally, Chapters 6 and 7 bring science into the story, examining th thesis that the notions of *design* and *science* are not, as is often assumed, disjoint activities. We pa special attention to the generalization of the concept of architecture as the basis for a scientif approach to the design process.

The last two chapters, Chapters 8 and 9, attempt to pull this material together into a coherent, fuzzy, image of life in the foothills of Trillions Mountain. We know better than to be too specific her but it is possible to discern the broad strokes of how the story of pervasive computing is likely 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 wi support and reinforce the main thread of the text. Each of us indulges in a bit of first-perso storytelling, as do a few of our MAYA colleagues. Included here are a number of case studie describing both examples of our research activities and commercial work done in collaboration wi our clients. You will also encounter references to various audio, video, and interactive material, whic can be found at the book's website: TRILLIONS.MAYA.COM.

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

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

[1] The metaphor isn't actually all that different, mountains merely being waves in an unusual viscous medium.

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

[3] Our name, "MAYA"—an acronym standing for "Most Advanced Yet Acceptable"—is an homag to Raymond Loewy, one of several role models from among this group, who often spoke of his go for a design to reach "the MAYA stage."

Acknowledgments

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

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

Nearly everyone in the MAYA companies has read early drafts of the manuscript, and many hav provided valuable feedback. Special recognition must go to Dutch MacDonald, who has regular provided detailed feedback on all aspects of the project while also managing to keep the business o an even keel during our frequent bouts of book-driven inattention. Lori Paul, our treasured executiv assistant (a title that vastly understates her value), has been characteristically masterful at keeping th process moving forward amidst the background chaos of a busy consultancy. Thanks are also due t 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 fo fact-checking and general rigor has fallen on Susan Salis and Susan Zelicoff (collectively referred as "the Susi"). Their diligence and care in managing the minutiae of the project were frequently th only things standing between us and chaos.

Nearly all the members of MAYA's visual design group have contributed their fine talents to th project. Special recognition is due to Greg Gibilisco, who is responsible for the bulk of the graphic and also So-Eun Ahn and Daniel Szecket for valuable contributions. Matt Ross, our amazin filmmaker, is largely responsible for the films and animations found in the supplementary material.

We offer our grateful thanks to the entire editorial team at John Wiley & Sons. In particular, we wi always be indebted to acquisitions editor Tim Burgard for getting excited about our idea at a tim when everybody else was giving us blank stares. We also thank our development editor Stacy River and our production editor Todd Tedesco for their skill in balancing our sometimes-wacky visio against the realities of getting a real book onto the shelves and into the current chaos of the eBoo realm.

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

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 MUMFOR

There is a point of view—generally called “technological determinism”—that essentially says th each technological breakthrough inexorably leads to the next. Once we have light bulbs, we w inevitably stumble upon vacuum tubes. When we see what they can do, we will rapidly be led transistors, and integrated circuits and microprocessors will not be far behind. This process—goes th argument—is essentially automatic, with each domino inevitably knocking down the next, as 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 th stage for the next. The future may or may not be determined, but a discerning observer can do credible job of paring down the alternatives. All but the shallowest of technological decisions a necessarily made far in advance of their appearance in the market, and by the time we read about a advance on the cover of *Time* magazine, the die has long since been cast. Indeed, although designers all stripes take justifiable pride in their role of “inventing the future,” a large part of their day-to-da jobs involves reading the currents and eddies of the flowing river of science and technology in order help their clients navigate.

Although we are prepared to go out on a limb or two, it won’t be in this chapter. Many foundation aspects of the pervasive-computing future have already been determined, and many others will follo all but inevitably from well-understood technical, economic, and social processes. In this chapter, w will make predictions about the future, some of which may not be immediately obvious. But we wi try to limit these predictions to those that most well-informed professionals would agree with. If yo are one of these professionals (that is to say, if you find the term *pervasive computing* and its ma synonyms commonplace), you may find this chapter tedious, and you should feel free to skip ahea But if the sudden appearance of the iPad took you by surprise, or if you have difficulty imagining 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. Lo more. In fact, there are now more computers, in the form of microprocessors, manufactured *each ye* 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 indust touted that the world produces more transistors than grains of rice, and cheaper. But countin microprocessors is eye-opening enough. Accurate production numbers are hard to come by, but 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? Mar American families have a few PCs or laptops—you probably know some geeks that have maybe eig or ten. But many households still have none. Cell phones and iPads count, too. But *ten billion a yea* Where could they all possibly be going?

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

Why would one put a computer in a washing machine? There are some quite interesting answers this question that we will get to later. But for present purposes, let's just stick to the least interestir answer: It saves money. If you own a washer more than ten years old, it most likely has one of thos big, clunky knobs that you pull and turn in order to set the cycle. A physical pointer turns with i showing at a glance which cycle you have chosen and how far into that cycle the machine h progressed. This is actually a pretty good bit of human-centered design. The pointer is clear ar intuitive, and the act of physically moving the pointer to where you want it to be is satisfyingly liter However, if you have a recently designed washer, this knob has probably been replaced with a bun 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 th tip of an engineering iceberg. Behind them is a complex and expensive series of cams, clockwork, ar switch contacts whose purpose is to turn on and off all the different valves, lights, buzzers, and moto throughout the machine. It even has a motor of its own, needed to keep things moving forward. Th knob is the most complex single part in the appliance. A major theme of twentieth-centu industrialization involved learning how to build such mechanically complex devices cheaply ar reliably. The analogous theme of the early twenty-first century is the replacement of such componen with mechanically trivial microprocessor-based controllers. This process is now ubiquitous in th manufacturing world.

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

This process of substituting "free" software for expensive mechanism repeats itself in product aft product, and industry after industry. It is in itself a powerful driver in our climb towards Trillions. A manufacturing costs increase and computing costs decrease, the process works its way down the sca of complexity. It is long-since complete in critical and subtle applications such as automotive engi control and industrial automation. It is nearly done in middling applications such as washing machin and blenders, and has made significant inroads in low-end devices such as light switches and ai freshener dispensers.

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

Automotive applications deserve a category of their own. Every modern automobile contains ma dozens of processors. High-end cars contain hundreds. Obvious examples include engine-contr computers and GPS screens. Less visible are the controllers inside each door that implement a loc 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 networ direct data from accelerometers and speed sensors, not only to the vehicle's GPS system, but also advanced braking and stability control units, each with its own suite of processors. Drilling furth down into the minutiae of modern vehicle design, one finds intelligent airbag systems that deploy wi a force determined by the weight of the occupant of each seat. How do they know that weigh Because the bolts holding the seats in place each contain a strain sensor and a microprocessor. Th eight front-seat bolts plus the airbag controller form yet another local area network dedicated to th unlikely event of an airbag deployment.

We will not belabor the point, but such lists of examples could go on indefinitely. Computerizatio of almost literally everything is a simple economic imperative. Clearly, ten billion processors per ye is not the least bit implausible. And that means that a near-future world containing trillions computers is simply a done-deal. Again, we wish to emphasize that the argument so far in no wa depends upon a shift to an information economy or a desire for a smarter planet. It depends only simple economics and basic market forces. We are building the trillion-node network, not because w can but because it makes economic sense. In this light, a world containing a trillion processors is more surprising than a world containing a trillion nuts and bolts. But, of course, the implications a very different.

CONNECTIVITY WILL BE THE SEED OF CHANGE

In his 1989 book *Disappearing through the Skylight*, O. B. Hardison draws a distinction between tw 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 technolog enters culture and influences it. Some computer composers write music that uses synthesized orga pipe sounds, the wave forms of Stradivarius violins, and onstage Bösendorf grands in order to sou like traditional music. In this case the technology is being used to do more easily or efficiently better what is already being done without it. This can be called "classic" use of the technology. Th alternative is to use the capacities of the new technology to do previously impossible things, a this second use can be called "expressive." . . .

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

Adopting Hardison's terminology, we may state that the substitution of software for physic mechanism, no matter how many billions of times we do it, is an essentially classic use of comput technology. That is to say, it is not particularly disruptive. The new washing machines may b cheaper, quieter, more reliable, and conceivably even easier to use than the old ones, but they are sti just washing machines and hold essentially the same position in our homes and lives as their mo mechanical predecessors. Cars with computers instead of carburetors are still just cars. At the end o the day, a world in which every piece of clockwork has experienced a one-to-one replacement by a embedded processor is a world that has not undergone fundamental change.

But, this is not the important part of the story. Saving money is the proximal cause of th microprocessor revolution, but its ultimate significance lies elsewhere. A world with billions o isolated processors is a world in a kind of supersaturation—a vapor of potential waiting only for a appropriate seed to suddenly trigger a condensation into something very new. The nature of this see is clear, and as we write it is in the process of being introduced. That seed is *connectivity*. A computing is about data-in and data-out. So, in some sense, all computing is connected computing- we shovel raw information in and shovel processed information out. One of the most important thing that differentiates classic from expressive uses of computers is who or what is doing the shoveling. the case of isolated processors such as our washing-machine controller, the shoveler is the *huma being turning that pointer*. Much of the story of early twenty-first century computing is a story human beings spending their time acquiring information from one electronic venue and re-entering into another. We read credit card numbers from our cell phone screens, only to immediately speak o type them back into some other computer. So we already have a network. But as long as the domina transport mechanism of that network involves human attention and effort, the revolution will b deferred.

Things are changing fast, however. Just as the advent of cheap, fast modems very rapid transformed the PC from a fancy typewriter/calculator into the end nodes of the modern Internet, s too are a new generation of data-transport technologies rapidly transforming a trillion fanc clockwork-equivalents into the trillion-node network.

An early essay in such expressive networking can be found in a once wildly popular but now large forgotten product from the 1990s. It was called the Palm Pilot. This device was revolutionary n because it was the first personal digital assistant (PDA)—it was not. It was revolutionary because was designed from the bottom up with the free flow of information across devices in mind. The ve first Palm Pilot came with "HotSync" capabilities. Unlike previous PDAs, the Pilot was designed seamlessly share data with a PC. It came with a docking station having a single, inviting button. On push, and your contact and calendar data flowed effortlessly to your desktop—no stupid questions inscrutable fiddling involved. Later versions of the Palm also included infrared beaming capabiliti —allowing two Palm owners to exchange contact information almost as easily as they could exchan physical business cards.

In this day—only a decade later—of always-connected smartphones, these capabilities seem mode —even quaint. But they deserve our attention. It is one thing to shrink a full-blown PC with all i complexity down to the size of a bar of soap and then put it onto the Internet. It is quite another to d the same for a device no more complex than a fancy pocket calculator. The former is an impressiv achievement indeed. But, it is an essentially classic application of traditional client-server networkir technology. The iPhone truly is magical, but in most ways, it stands in the same relation to th Internet as the PC, which it is rapidly supplanting—namely it is a terminal for e-mail and web acce and a platform for the execution of discrete apps. It is true that some of those apps give the appearan of direct phone-phone communications. (Indeed, a few really do work that way, and Apple has begu to introduce new technologies to facilitate such communication). But it is fair to say that the iPhone it was originally introduced—the one that swept the world—was essentially a client-server device. I utility was almost completely dependent upon frequent (and for many purposes, constant) connectio to fixed network infrastructure.

The Palm Pilot, in its modest way, was different. It communicated with its associated PC or anoth Palm Pilot in a true peer-to-peer way, with no centralized "service" intervening. Its significance is th it hinted at a swarm of relatively simple devices directly intercommunicating where no single point failure can bring down the whole system. It pointed the way toward a new, radically decentralize ecology of computational devices.

The Pilot turned out to be a false start, rapidly overtaken by the vastly greater, but essentially class capabilities of the PC-in-a-pocket. But the true seeds of expressive connectivity are being sown. design engineer would be hard-pressed to select a current-production microprocessor that did not hav some kind of communications capability built-in, being thus essentially free. Simple serial ports a trivial, and adequate for many purposes. USB, Ethernet, and even the higher-level protocols f connecting to the Internet are not uncommon. Wireless ports such as Bluetooth, ZigBee, and Wi currently require extra chips, but they are increasingly trivial to add. Although these capabilities ofte go unused, they are there, beckoning to be employed. And the demand is growing. It is the ra manufacturer who does not have a connectivity task force. What CEOs are not asking their CTC when their products will be controllable via a mobile "app?" Much of MAYA's business in the las decade has involved helping our clients understand their place in this future information ecolog Whether they are manufacturers of kitchen appliances or medical devices or garage-door openers, whether they are providers of financial services or medical insurance, the assumption of univers connectivity is implicit in their medium-term business planning. We won't just have trillions computers; we will have a trillion-node network. Done deal. The unanswered question is how, and ho well, we will make it work.

COMPUTING TURNED INSIDE OUT

As consumer products go, the personal computer has had quite a run. From its origins in the 1970s as slightly silly geek toy with sales in the thousands, PC sales figures sustained a classic exponenti growth curve for more than 35 years. Cumulative sales exceeded one billion units quite some tin ago. In 2008 it was reported that there were in excess of one billion computers in use worldwide. comparison, after 100 years of production, there are an estimated 600 million automobiles in u worldwide. For the postindustrial world, the PC is the gift that keeps on giving.

After all these years of consistent growth, it is difficult to imagine a world without PCs. But th phrase *post-PC era* has entered the lexicon. The precipitous collapse of an entire industry is the kin of thing—like a serious economic recession—that happens only a few times per career. As a resul many midcareer professionals have never actually witnessed one and therefore lack a viscer understanding of what such an event is like.

Fall of the Minicomputer

By Pete

In 1987, I received an invitation to attend something called "DECWorld '87." This was a one-company event sponsored by a computer manufacturer called Digital Equipment Corporation (DEC). It was part trade show, part technical conference, and all party. It was by far the most opulent business event of any kind that I have attended, before or since. DEC was a company that was making more money than it knew what to do with, and they were determined to entertain their friends in style. As part of the celebration, they chartered the *Queen Elizabeth II* and brought it to Boston Harbor. A decade later, DEC was out of business.

Sandwiched between the IBM-dominated mainframe era of the 1950s and 1960s and the PC age of the past three decades was a nearly forgotten period during which most of the underlying technologies of modern computing were introduced and perfected. This was the era of the minicomputer, and it was when I came of age as a technologist. The first computer I ever touched was an exotic machine called an Adage Graphics Terminal. Despite its name, it wasn't just a terminal. It was a full-fledged computer. Being only the size of a few refrigerators, it was marvelously compact for a 1970 computer. And, most amazingly, it was a single-user device. When you signed up for an hour on this machine in a windowless upstairs room at the Penn State Computation Center, you were signing up for an up-close-and-personal experience in which it was just you and the computer. It is difficult to capture just how unique an experience this was in an age in which the closest typical users ever came to a computer was when they passed a deck of punched cards over a counter to be submitted, along with many other such decks, into the input queue of some back-room mainframe. Just to put things into perspective: The Penn State Science Fiction Club once attempted to commission the Adage for an evening in order to hold a *SpaceWar* tournament. (*SpaceWar* was the first real graphical computer game, and the Adage was the only machine on campus capable of running it.) Although the sci-fi fans were willing to pay the relevant fee (which, if I recall, was something like $100 1970 dollars per hour), their request was denied by University officials as an "inappropriate use of University facilities."

Within a few years, machines faster, cheaper, and smaller than the Adage had become the mainstay of industrial and scientific computing. The trajectory of the minicomputer industry represents a microcosm of the coming PC revolution. Smaller in scale and a bit shorter in duration, to those who lived through it the era nonetheless had all the same feeling of inevitably and seeming permanence as our current turn of the screw—right up to the time when it suddenly collapsed.

That collapse was truly stunning. In a 1986 article, *Fortune* magazine called DEC's founder Ken Olsen "America's most successful entrepreneur," saying:

> In 29 years he has taken Digital Equipment Corp. from nothing to $7.6 billion in annual revenues. DEC today is bigger, even adjusting for inflation, than Ford Motor Co. when death

claimed Henry Ford, than U.S. Steel when Andrew Carnegie sold out, than Standard Oil when John D. Rockefeller stepped aside.

DEC's revenues peaked the very next year, and then it promptly entered its death spiral. As things turned out, when we founded MAYA in 1990, Digital was our first client. More on this in Chapter 6. My point here is that we had an insider's view of how a truly great company could have been so utterly insensitive to the implications of the PC revolution, a revolution that by that time nobody —certainly not DEC—doubted was coming. As the screw prepares to turn again, I can think of no story more relevant.

But, as a consumer product, the PC is dead—as dead as the eight-track tape cartridge. In anoth decade, a desktop PC will look as anachronistic in a home office as a CRT terminal looks today. You parent's Dell tower over in the corner will remind you of your grandparent's doily-covered conso record player. The laptop form-factor will survive longer—maybe even indefinitely. But suc machines will increasingly be seen as outliers—ultra–high power, ultra-flexible machines tuned to th needs of an ever-dwindling number of professionals who think of themselves as computer workers, opposed to information workers.

We are not saying that keyboards, mice, or large-format displays are going away. This may well b the case, but this chapter is about sure things, not speculations, and our guess is that more or le conventional input/output devices will linger for quite some time. But the Windows-based PC h seen its day. There are many ways to measure such things, and the details vary by methodology, bu generally speaking, PC revenues peaked almost a decade ago. Unit sales in the developed world hav recently peaked as well.

The nearly complete transition from desktop to laptop PCs represents a mere evolution of forr factor. The modes of usage remain fundamentally unchanged. The same cannot be said about th transition to the post-PC era. The functions that were once centralized in a single device a increasingly being dispersed into a much broader digital environment. People who write a lot ar people who spend their days crunching numbers still reach for their laptops, and they probably will f a while. But surfing the web is no longer a PC thing. People may still like the experience of viewi web pages on a spacious screen using a tangible mouse, but they like getting information when ar where it is needed even more, even if it involves poking fat fingers at a pocket-sized screen. E-mail no longer something kept in a PC—it is something floating around in the sky, to be plucked dow using any convenient device. And, of course, in many circles e-mail itself is something of a quai formalism—rather like a handwritten letter—appropriate for thank-you notes to grandma and mas mailing party invitations, but a poor, slow-speed substitute for phone-to-phone texting or tweeting f everyday communication.

Figure 1.1 *Datamation* Magazine, March 15, 1991. Just 20 years ago, the very idea of television playing on a computer was fodder for absurdist humor. Today, no one would get the joke.

Source: Courtesy of the artist.

The important point in all of this is not the specific patterns of what has been substituted for wha but rather the larger point that, for the first time, all of these patterns are in play. During th hegemony of the PC, it was difficult for most people to see the distinction between medium an message. If cyberspace was a place, it was a place that was found inside a computer. But, th proliferation of devices has had the effect of bringing about a gradual but pervasive change perspective: The data are no longer in the computers. We have come to see that *the computers are the data*. In essence, the idea of computing is being turned inside out. This is a new game. It is not game that we are yet playing particularly well, but the game is afoot.

THE POWER OF DIGITAL LITERACY

There is one more topic that belongs in this chapter—one that is rarely discussed. It does not direct relate to evolving technologies per se, but rather about the evolving relationship between tho technologies and nonprofessional users. Put simply, people aren't afraid of computers anymor Computers today are part of the air we breathe. It is thus difficult to recapture the emotional baggag associated with the word *computer* during the 1960s and 1970s. This was a generation whose paren watched Walter Cronkite standing in front of a room-sized UNIVAC computer as it "predicted Eisenhower's 1952 presidential election victory (Figure 1.2). Phone bills arrived on punched card whose printed admonitions not to "spindle, fold, or mutilate" became a metaphor for the mutilation humanity by these mindless, omnipotent machines. The trend toward uniformity of language an thought that began with the printing press would surely be forced to closure by these power tools conformity.

Figure 1.2 1952: Walter Cronkite watches UNIVAC predict the electoral victory of Dwight Eisenhower.

Source: U.S. Census Bureau.