Preface

This book explores the future of science and technology, and their implications for human beings. It is based on the insights of hundreds of scientists and engineers working at the cutting edge of research, as seen through the eyes of a social scientist who worked alongside them to organize, write, and edit a series of influential government-sponsored and independent reports. Although I have made every effort to be balanced and comprehensive, this book is not a sterile exercise in abstraction and objectivity. Rather, it seeks to provide information that will be both fascinating and useful for students, entrepreneurs, investors, fellow scientists or engineers, and people in many walks of life who want to understand how their work and their world will change in coming decades.

One of the scariest questions for young people is this: "What will you be when you grow up?" Sometimes people nearing retirement age joke, "I still don't know what I'm going to be when I grow up!" Often *be* means *do,* and the question really refers to selecting a career and finding a job. More broadly, the question might refer to what kind of person you or I might become, in whatever span of life is left to us on this spinning planet. However the question is defined, it cannot be answered in isolation. A person cannot simply decide to become a blacksmith, elevator operator, or spaceship pilot. The economy and the technological culture must provide such jobs, or no one can get them. Contrary to predictions, the trade of blacksmithing did not completely disappear, although its role in society has been greatly diminished. I suppose elevator operators became security guards—and I wonder if they considered that change to be a demotion or a promotion. I don't know what happened to all of the prospective spaceship pilots. My point is that the nature of technical work, and the nature of the world in which we all live, will change radically in the future, because science and technology have entered an era of fundamental transformation.

At the time of the "dot-com crash" nearly a decade ago, computer professionals used to joke, "Now we'll find out how many computer programmers

the world really needs." The implication was that data processing had been going through a technological revolution, but after the guns had fallen silent, there might not be much action anymore. Everyone in the field had noticed that big companies and government agencies had been producing their own electronic data systems, often at great cost and with dismal results. Soon, it was believed, they would admit that the desire to have their own proprietary systems was a dysfunctional status obsession and begin to buy their software off the shelf—just as everyone else was already doing. In the early 1980s, very small companies could succeed while writing software for the consumer market, but since then a shakeout had occurred in small business and home office software. By way of analogy, in the beginning of the twentieth century, scores of small companies set out to make automobiles, but within half a century the overwhelming majority had ceased to exist. Perhaps by 2010, every business on the face of the Earth could make do with Microsoft Office.

This issue raises two questions very germane to the topic of this book: "What is computer science?" and "How can it continue to progress?" Computer science is not simply programming, nor is it the more exalted profession of software engineering, although both entities depend on it. Nor is computer science merely a branch of electrical engineering, although many people who call themselves computer scientists have a degree in "EE." Rather, computer science is an incomplete convergence of mutually supportive fields that cooperate to produce the hardware, software, and management systems required to process information, including in consumer areas such as the World Wide Web and online games, as well as in service of corporations and government agencies. As "comp-sci" matures, it draws more and more fields into it. Early on, it attracted many mathematicians; today, it needs the expertise of members of the cognitive science field and the social sciences. As this unification progresses, the field should probably be renamed simply *information science.* Indeed, this term is already in wide circulation, where it is used to encompass all forms of communication, whether or not they are supported by electronic devices.

We cannot be sure how much longer the electronic hardware will continue to progress. In the past, hardware advances both permitted and demanded software advances, and the evolution of the two together enabled entirely new applications. When I entered Yale University as a physics major in 1958, it was widely believed that two prominent application areas, nuclear technology and space rocketry, would rise still further to transform the world. This proved to be a miscalculation: Within 15 years, both areas had largely stalled. We still need nuclear and aerospace engineers, but now they work primarily as the paid minions of corporate executives, with very limited scope

for personal innovation. The same is true for most computer professionals in large organizations. Even so, the information area has kept lively because individual entrepreneurs and small companies have continued to develop new approaches and applications. "A revolution every five minutes" is a slight exaggeration, but this period of growth and discovery could end at any time.

So what is a person to do? What I did, when I was young, was stumble from field to field for a few years, before realizing that as a social scientist I could keep innovating by applying my growing professional experience to a series of different topics, each appropriate for the decade in which I was working on it. At a recent computer science convention, a couple of corporate recruiters told me they were looking for students who knew exactly what specialty they wanted to work in, and who were gaining the precise expertise required for that niche. I was horrified to hear this. What will these companies do with these people when their specialties are no longer needed in a few years? Fire them, probably.

A young person seeking a career in science or engineering today should start from the hopeful premise that the fundamental things he or she is really interested in will remain important decades later. But such a person cannot assume that particular narrow technical fields or job classifications will still exist even one decade in the future. The fact that many of the best opportunities will exist at the boundaries of fields does not mean that a student should avoid exploring one field deeply. For many, a "T-shaped" expertise will be best—that is, deep in one area but also covering adjacent areas. Often, a corporation or other technical organization will value highly a person who has solid expertise in a field central to its work, but who also possesses enough expertise in adjacent areas to contribute to a multidisciplinary team, or even to promote transfer of new ideas from one field to another. Opportunities for such a person become especially great when an entire new field is opening up.

Many physicists who happened to be mathematically inclined became computer scientists simply by redefining the expertise they already had. Others, who were better with chemistry than math, became materials scientists, and more recently redefined their expertise as nanoscience. As this book will demonstrate, nanotechnology is converging with biotechnology and information technology. Great opportunities exist for people who are prepared to build the bridges between those fields today.

Does this transdisciplinary philosophy place unreasonable demands on students, asking them to add extra work to the full-time job of learning one field well? Not necessarily, if their teachers also evolve with the changing conditions in science and technology. Much of the "expertise" in many fields consists of brute, dumb facts, often in the form of unnecessary nomenclatures. The

unification of the sciences and branches of engineering requires a transformation of their styles and cultures. Part of that transition will be achieved by easy-to-use information technology systems that replace the arcane technical handbooks of the past. Part of it will be achieved by new terminology and analytic or design procedures that can be applied broadly across fields. And part of it will be achieved by the development of new professions specifically designed to bridge between specialized branches of expertise.

When I earned my doctorate in sociology from Harvard University in 1975, with a dissertation on the social history of the space program, I was lucky to get a job in the tenth-ranked sociology department in the country, because the job market was in the process of crashing. Enthusiasm for the social sciences began to dwindle at that time, and today the social sciences (except economics, if you want to count that "rich" field among the social sciences) have less influence than they did in the 1950s and 1960s. Coincidentally, 1975 also marked the end of the remarkably vigorous post-war growth of U.S. universities. Put bluntly, it is hard to name any clear-cut discoveries achieved in the social sciences comparable to the feats achieved in genetics, for example, over the same period. And yet, public confidence in political leaders is justifiably low at the present time, and advanced societies face many policy decisions, including some concerning which technologies to promote or prohibit. We would be better off today if the social sciences were more influential, and if they had earned that position on the basis of solid achievements based on actual scientific discovery. Ultimately, winning such respect will require the social sciences to become integrated with the cognitive sciences, on the basis of a shared understanding of human behavior.

This book has two themes. One is clearly stated in the title: *Nanoconvergence.* Today, nanotechnology is converging on the one side with information technology, and on the other side with biotechnology. The convergence of information technology with biotechnology is making it possible to build new technologies on the basis of cognitive science, all enabled by nanotechnology. The second theme is perhaps less clearly stated in the identity of the author of the book, a social scientist who became an information or computer scientist and worked with the National Nanotechnology Initiative. Technological convergence requires a social awareness if it is to benefit people, and that awareness can best be achieved by reviving social science on the basis of its convergence with the other fields.

While useful for students who face career choices, this book is not narrowly aimed at people who are deciding what they want to be when they grow up, except in the sense that we all must negotiate shifts in our identity in this changing world, hoping we all grow intellectually so long as we live. Whether

as investors, managers, consumers, or citizens, we will all face choices related to science and technology. This book is intended to be a resource for people who are contemplating many kinds of choices, and for people who are interested in understanding the world around them. It seeks to put the reader into communication with hundreds of scientists and engineers, and with the hundreds of social scientists and philosophers who have collaborated with them, so as to share their excitement and wisdom about the coming convergence.