Eric Roberts March 7, 2016

A History of Capacity Challenges in Computer Science

Those who cannot remember the past are condemned to repeat it.

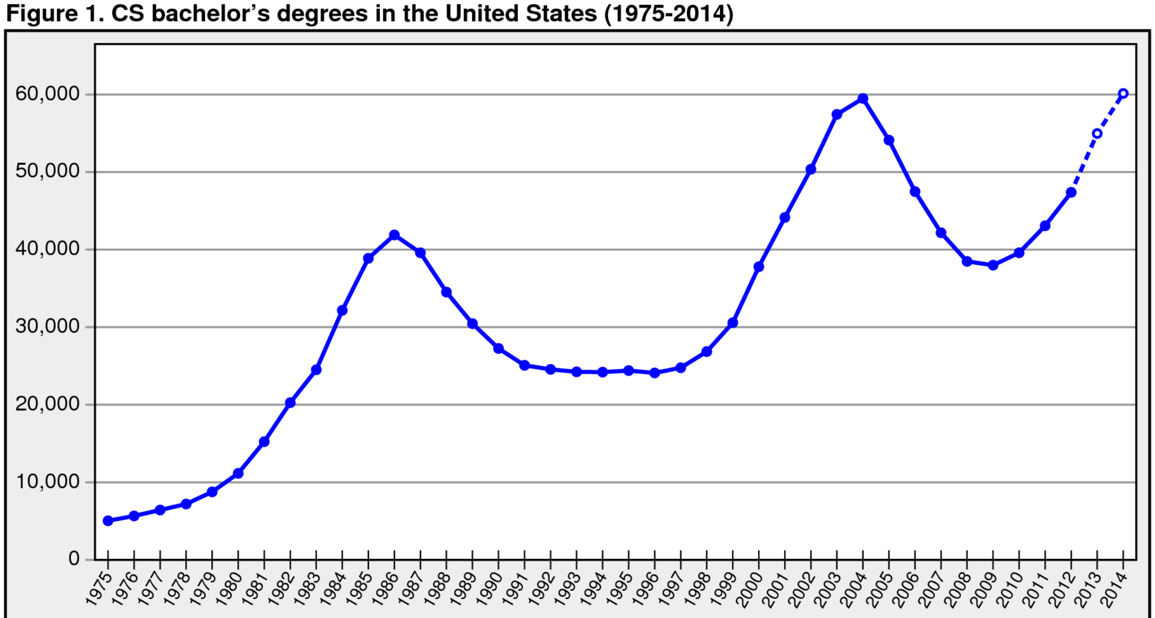
—George Santayana, *Reason in Common Sense,* 1905

Since the 1970s, the number of students graduating with bachelor's degrees in computer science has fluctuated significantly. As shown in Figure 1, computer science degree production in the United States has experienced two episodes of rapid increase followed in each case by a precipitous collapse. The first peak occurred in 1986, the second in 2005, and we are once again on a steep upward trajectory, which began in 2009.[1]

It is important to keep in mind that the number of bachelor's degrees produced in a year inevitably lags in comparison to enrollment data. As students reach their junior and senior years, switching fields becomes less likely. Thus, the peaks in degree production in 1986 and 2004 reflect changes in student enrollment patterns that occurred two to three years earlier.

If you look at the graph in Figure 1, the first conclusion that jumps to mind is that student interest in computer science is cyclical. That interpretation, however, is insufficient. Most importantly, it fails to recognize the fact that the downturns in the mid

Figure 1. CS bachelor's degrees in the United States (1975-2014)



Source: National Center for Education Statistics (2013 and 2014 data estimated from CRA Taulbee survey)

[1] Unfortunately, the most recent digest from the National Center for Education Statistics includes data only through 2012. To offer a more informative picture of the current situation, Figure 1 uses growth rates recorded in the Computing Research Association's Taulbee surveys to estimate the broader numbers for 2013 and 2014.

1980s and the early 2000s happened for different reasons. The more recent downturn was clearly caused by the dot-com collapse. After the tech bubble burst in 2001, student interest in computer science waned throughout the United States, a downturn exacerbated by a popular mythology suggesting—entirely contrary to fact—that all jobs in technology were about to be shipped offshore to low-wage countries like India and China.

The earlier collapse in the mid 1980s was very different in its origins. The cause of that decline was the inability of universities to attract enough faculty to meet growing student demand. Beginning around 1984, most computer science departments were forced to limit course enrollments and to restrict admission to the computer science major. These actions led in turn to a steep decline in degree production a few years later.

In order to make any useful predictions about the likely outcome of the current expansion, it is essential to undertake a more detailed analysis of the reasons for the variations in degree production that computer science has experienced in the past. To understand the history from a national perspective, it makes sense to analyze the three peak periods independently, which gives rise to the following three questions:

- What happened during the downturn in the 1980s?
- What happened during the downturn in the 2000s?
- What is the nature of the enrollment expansion today?

What happened during the downturn in the 1980s?

Who controls the past controls the future; who controls the present controls the past.

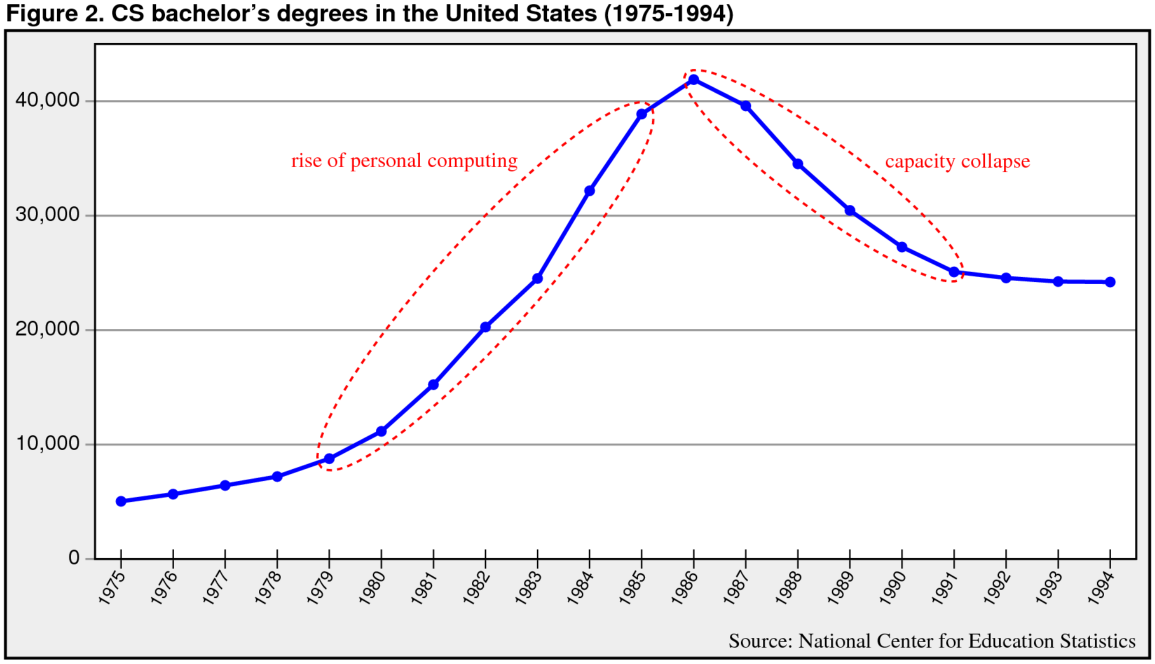
—George Orwell, *Nineteen Eighty-Four,* 1949

The first boom-and-bust cycle in academic computer science began with a steady rise in bachelor's degrees throughout the 1970s, which became more rapid at the end of the decade. This dramatic rate of increase continued until sometime around 1984, when the number of students entering the field reached its peak. The peak was followed by a decline in degree production that eventually flattened out in 1994, when degree production was down by 42 percent from its earlier high. These statistics are illustrated in Figure 2, which extracts the relevant years from Figure 1 and adds labels showing the most likely explanations for the changes in direction.

The rapid increase in student demand at the beginning of the cycle is easy to explain. The late 1970s and early 1980s saw the introduction of the personal computer, which brought many more people into contact with computing. With the release of the Apple II in 1977 and the IBM PC in 1981, a large number of prospective college students had access to computing for the first time in history. The excitement associated with the advent of personal computers coupled with the widespread availability of well-paying jobs in computing drew many students into the field.

The cause of the decline in student numbers that began in 1984 is more difficult to explain. The excitement that fueled the boom was, after all, still growing. January 1984, for example, marked the release of the Macintosh, heralded in Apple's Super Bowl

Figure 2. CS bachelor's degrees in the United States (1975-1994)



commercial as "the reason that 1984 won't be like *1984.*" Although the overall U.S. economy experienced a small recession beginning in 1981, that downturn had a minor effect on the technology sector. In an article published by the Bureau of Labor Statistics in 1985, economist John Burgan noted that "employment declines in high-tech industries were not as deep as those in manufacturing" and that, in particular, those companies with the largest concentration of highly skilled technical workers were the only ones that outperformed the rest of the economy.[2] There seem to be no economic or technical reasons to explain a collapse of student interest beginning in 1984.

If one looks closely at the downturn of the 1980s, however, it quickly becomes clear that the reasons for the collapse in student enrollments had nothing at all to do with student interest. Student demand for computer science courses and degrees remained high throughout that period. Students in the mid 1980s did not *decide* against majoring in computer science but were instead *prohibited* from doing so by departments that lacked the resources to accommodate them.

I believe that what happened in the 1980s is best described as a *capacity collapse* in which universities and colleges were simply unable to satisfy the growing level of student demand. Departments tried a number of strategies to increase their teaching capacity, including retraining faculty from other disciplines and hiring adjunct faculty from industry. In the end, however, demand overwhelmed capacity, and colleges and universities were forced to restrict admission to the computer science major, which gave rise to the subsequent downturn.

The sections that follow examine the history of this capacity collapse in more detail.

The capacity collapse of the mid 1980s

The first capacity collapse in computer science occurred around 1984, now more than 30 years ago. The passage of time, coupled with the fact that a more recent collapse occurred for different reasons, means that few people today understand the pressures that departments of computer science experienced during those years. That loss of historical understanding is particularly unfortunate because the problems we see in computer science education today closely resemble those from the beginning of the 1980s.

The challenges facing computer science in the 1980s were widely recognized at the time. Rising enrollments and the shortage of qualified faculty were a central focus of the fourth Snowbird Conference in 1980.[3] The discussions at Snowbird led to a report entitled *A Discipline in Crisis,* which was published in the June 1981 issue of *Communications of the ACM.* That report begins with the following sentences, which offer a succinct review of the problem:

---

[2] John Burgan, "Cyclical behavior of high-tech industries," *Monthly Labor Review,* May 1985.

[3] The Snowbird Conferences are a biennial gathering for the chairs of computer science departments in research universities. These conferences are sponsored by the Computing Research Association, which was called the Computer Science Board prior to 1990.

> There is a severe manpower crisis in Computer Science. There are acute shortages of well-trained computer people at all levels, especially the Ph.D. level. The Ph.D. shortage is especially serious because it threatens our ability to conduct basic research in Computer Science and to train the next generation of computer experts.

The report goes on to outline the problems faced by the 83 Ph.D.-granting institutions included in the Taulbee surveys. All participants agreed that finding faculty to satisfy the growing demand was a critical challenge. In 1979, for example, American and Canadian universities produced only 248 Ph.D.s in computer science. The report then noted that "fewer than 100 of these Ph.D.s chose academic careers, and they had over 650 academic positions from which to choose." In other words, there was approximately one applicant for every seven advertised positions, at least in terms of the new-Ph.D. pipeline. Six of those seven positions would either go unfilled or be offered to a candidate with less educational preparation or a degree in another field.

In a later section, *A Discipline in Crisis* offers the following description of the pressures on existing faculty:

> Pressures on faculty are intense. In the United States, Ph.D. Computer Science faculty have grown from 805 in 1975 to 837 in 1979—virtually no growth. The undergraduate student demand for Computer Science has risen at 15 percent to 20 percent annually during the same period.
>
> Thus overburdened, faculty cannot find adequate time to conduct research or to supervise graduate students in research. This atmosphere is a strong incentive for research-oriented faculty to seek positions in industrial research groups. Departments must find ways to give faculty more time for exploring new ideas with their graduate students while continuing to fulfill teaching commitments. Limiting or cutting back enrollments would be counterproductive given the societal need manifested in the rising enrollments. The only way in the long term to meet this need is to train, hire, and retain new faculty.

Although the numbers today are of course much higher, reading this assessment from the early 1980s creates a clear impression of *déjà vu.*

In addition to the report on *A Discipline in Crisis,* the June 1981 issue of *Communications of the ACM* included a letter from ACM President Peter Denning entitled "Eating our seed corn." Although Denning did not introduce the seed-corn metaphor—and indeed says in his President's letter that "the phrase 'eating our seed corn' appears everywhere"—he certainly helped to popularize it and bring the issue before a larger audience. He cites in particular an article in the *Business Week* issue of November 17, 1980, which charges that

> Industry is eating some of its own seed corn. Not only are they taking students who would become faculty, they are recruiting faculty.

The community's awareness of the looming capacity crisis deepened over the next few years. The Snowbird Conference in 1982 led to the preparation of a new report entitled *Meeting the Crisis in Computer Science,* which appeared in *Communications of the ACM* in December 1983. Although this follow-on report identified some encouraging signs, it concluded that "the basic critical situation had not yet been ameliorated. Ph.D.s in computer science are still being produced at about 250 per year, while the demand is still about five times that. The number of undergraduates entering computer science departments continues to increase, and the number of unfilled computer science faculty positions is greater than in 1980."

Response from governmental agencies

One of the encouraging signs identified in the report from the 1982 Snowbird Conference was increased awareness by government agencies of the problems facing academic computer science. In October 1980, the Department of Education and the National Science Foundation released a report entitled *Science and Engineering Education for the 1980s and Beyond,* which highlighted the faculty shortfall throughout engineering and computing fields.

> There are, today, severe shortages of qualified faculty members in most fields of engineering, as well as in the computer professions. Industries have expanded their research and development efforts and have increased the rate at which new, sophisticated products are introduced. To effect this, they are luring faculty members away from the universities into challenging well-paid positions. At the same time, they are making such attractive job offers to bachelor's degree recipients that many who would once have gone to graduate school now opt for positions in industry. The net effect has been a reduction in the ability of universities to provide education in engineering and the computer professions, although undergraduate demand for these areas is more intense than ever. Unless the problem of faculty erosion is alleviated, it is possible that many engineering schools and departments that educate computer professionals may have to reduce their enrollments during this decade, thereby reducing the numbers of trained people in these fields that the Nation's future requires.

The last sentence of this paragraph raises the specter of precisely the sort of enrollment caps that computer science departments were forced to institute beginning around 1984.

In addition to focusing government attention on the problem of faculty shortages in computer science and other applied fields, one of the important contributions of the DoE/NSF report was that it introduced economic analysis into the debate. As the report notes, it is usually possible to allow market forces to correct labor imbalances, given that an increase in job opportunities attracts more people to that sector. The report argues against that course of action as a strategy for correcting the imbalances in technical fields, saying:

> While market forces may ultimately relieve current and future shortages, we believe that the innovative capacity of American industry will be severely hampered in the interim. We simply cannot afford to wait for the slow workings of the marketplace.

Over the next few years, the National Science Foundation continued to assess the problem of shortages in key technical specialties, including computer science. In 1982, NSF staffer Kent Curtis presented a report to a meeting of the Computing Research Board on the labor shortages facing computer science. I believe that the insights Curtis's report offers for the situation in the 1980s are of such direct relevance today that I have scanned his report (previously available only in an extremely poor photocopy) and made it available on my web site under its original title, *Computer Manpower—Is There a Crisis?* Curtis's report argues that academic computer science faces special challenges.

> Let us consider the conundrum facing the computer field in higher education first. It is experiencing an exponentially increasing demand for its product with an inelastic labor supply. How has it reacted? . . . 80% of the universities are responding by increasing teaching loads, 50% by decreasing course offerings and concentrating their available faculty on larger but fewer courses, and 66% are using more graduate-student teaching assistants or part-time faculty. 35% report reduced research opportunities for faculty as a result. In brief, they are using a combination of rational management measures to adjust as well as they can to the severe manpower constraints under which they must operate. However, these measures make the universities' environments less attractive for employment and are exactly counterproductive to their need to maintain and expand their labor supply. They are also counterproductive to producing more new faculty since the image graduate students get of academic careers is one of harassment, frustration, and too few rewards.

Public perceptions of the challenges

The problem of faculty shortages in computer science also received coverage in the media. In February 1981, *The Chronicle of Higher Education* ran an article entitled "As students flock to computer science courses, colleges scramble to find professors."[4] The article quotes Joe Turner (still a leader in the computer science education community) as follows:

> "It's an impossibility to fill faculty positions," says A. Joseph Turner, head of the computer science department at Clemson University. He says he has to compete with other universities, as well as industry—but the industrial competition is by far the toughest.

A month later, *The Chronicle of Higher Education* followed up the earlier article with an essay by Stanley Pogrow at the University of Arizona in which he points out that the situation facing several applied disciplines is new in the history of academia.[5]

> In previous times, fields that were experiencing rapid expansion of knowledge generally found it easy to attract new faculty members, and fields where jobs were plentiful found it easy to attract graduate students. This is no longer true. A number of fields in applied science, such as computer science, physics, and electrical engineering, where knowledge frontiers are being rapidly extended, are experiencing increasing numbers of unfilled faculty positions, a reduced aging faculty, and declining graduate enrollment.

The response from academia

Faced with the extraordinary challenge of finding faculty in a labor market in which the number of positions exceeded the number of applicants by as much as a factor of seven,

---

[4] Jack Margarrell, "As students flock to computer science courses, colleges scramble to find professors," *The Chronicle of Higher Education,* February 9, 1981, page 3.

[5] Stanley Pogrow, "In an information economy, universities and business compete for workers," *The Chronicle of Higher Education,* March 16, 1981, page 64.

universities and colleges were forced to adopt other strategies to build their teaching capacity. These strategies included

- Increasing teaching loads and class sizes
- Hiring more part-time and adjunct faculty
- Retraining faculty from other disciplines
- Limiting enrollments and access to the major

All these strategies are described in papers presented at the leading conferences in computer science education at the time. The strategy of increasing teaching loads is self-defeating, as indicated in Kent Curtis's admonition that such measures "make the universities' environments less attractive for employment and are exactly counterproductive to their need to maintain and expand their labor supply." Hiring part-time and adjunct faculty was at best a short-term solution that proved difficult to implement. Given the shortage of computing talent in the industry, adjunct faculty were also in short supply.

The strategy that had the most significant long-term effect on computer science education was faculty retraining. Starting in the early 1980s, a number of universities including the University of Massachusetts, the University of South Carolina, Ohio State University, Kent State University, the University of Evansville, Brooklyn College, Clarkson University, California State University at Fresno, Central State University in Oklahoma, Memphis State University, and James Madison University began to offer programs to retrain faculty from other disciplines to teach computer science, at least at the introductory level. These programs are described in an article that appeared in *The Chronicle of Higher Education* in July 1984, which begins as follows:[6]

> Nearly 400 faculty members in mathematics, physics, chemistry, and a host of other disciplines—scientific and nonscientific—are going to colleges and universities this summer to learn to teach computing.
>
> Some of them see retraining in computer science as an opportunity to move into an exciting, growing field. Others are getting formal training in courses they already teach. Still others are going because they recognize—or have been told—that the future in their present fields is bleak.

The *Chronicle* article found that the length of the faculty training programs varied from a high of three part-time years to a low of two weeks. The latter figure "raised eyebrows" and prompted the author of the article to ask the question, "Can two weeks be as effective as three years in training a faculty member to teach a computer course?" William Weber, chairman of the computer science department at Southeast Missouri State University, admitted that such short programs could of course not be as complete but added that universities faced no other choice. As the article describes,

> None of the 13 faculty members in his department have a doctorate in computer science. "We couldn't afford them if they did," he says. Instead, the university made a commitment to retraining.

[6] Judith Axel Turner, "Growing demand for computer courses spurs retraining of college teachers," *The Chronicle of Higher Education,* July 11, 1984, page 23.

Although faculty with formal training in computer science remained dominant at the research universities, faculty members from outside the field, often with minimal training in computer science, soon filled most of the positions in less prestigious universities and liberal arts colleges. As I wrote in an article that appeared during the enrollment boom of the late 1990s (and which reviews the strategies used during the 1980s in more detail than I do in this section), I am convinced that "academic computer science could not have survived were it not for the willingness of some faculty to move to a new field. For the most part, those who migrated to computer science were extremely conscientious about acquiring the expertise they needed to teach in their adopted discipline. Their efforts sustained computer science education at many institutions and helped reduce the impact of the earlier crisis."[7] Even so, the fact that so many computer science faculty came from outside the field had profound implications for academic computer science that continued through the next enrollment cycle.

The collapse and its aftermath

Even though institutions tried many strategies to expand their teaching capacity, they were eventually overrun by the relentless increase in student demand. Although the report from Snowbird 1980 had warned that "limiting or cutting back enrollments would be counterproductive given the societal need manifested in the rising enrollments," universities and colleges were forced to do just that. Most of those limitations were based on academic performance and were extremely restrictive. At Berkeley in the mid 1980s, for example, only students with a 4.0 GPA were admitted to the major in Electrical Engineering and Computer Science.

During these years, I was chairing the newly formed Department of Computer Science at Wellesley College. Although we were more fortunate than many colleges in that we were able to attract a few applicants in response to our searches, making actual appointments remained a near impossibility. In 1982-83, Wellesley made six offers before finding someone who would take the position. Most of our candidates accepted competing offers elsewhere at higher salaries, both from industry and academia. Unfortunately, hiring one person in that year was insufficient to keep up with the increasing student interest in the computer science major. In 1983, Wellesley decided to restrict access to the major, accepting only students who met a minimum GPA threshold.

Although limiting access to the major did reduce class sizes, it was not effective in meeting the more general goal of improving working conditions for the faculty. Enrollment limitations are, naturally enough, unpopular with students—and with their parents. Imposing such restrictions makes the relationship between faculty and students adversarial, causing students to become more competitive and, in many cases, angry. Teaching became considerably less enjoyable, and I ended up leaving Wellesley for a research lab.

---

[7] Eric Roberts, "Conserving the seed corn: reflections on the academic hiring crisis," *SIGCSE Bulletin,* December 1999, page 4.

The imposition of GPA thresholds and other strategies to reduce enrollment led naturally to a change in how students perceived computer science. In the 1970s, students were welcomed eagerly into this new and exciting field. Around 1984, everything changed. Instead of welcoming students, departments began trying to push them away. Students got that message and concluded that they weren't wanted. Over the next few years, the idea that computer science was competitive and unwelcoming became widespread and started to have an impact even at institutions that had not imposed limitations on the major.

What happened during the downturn in the 2000s?

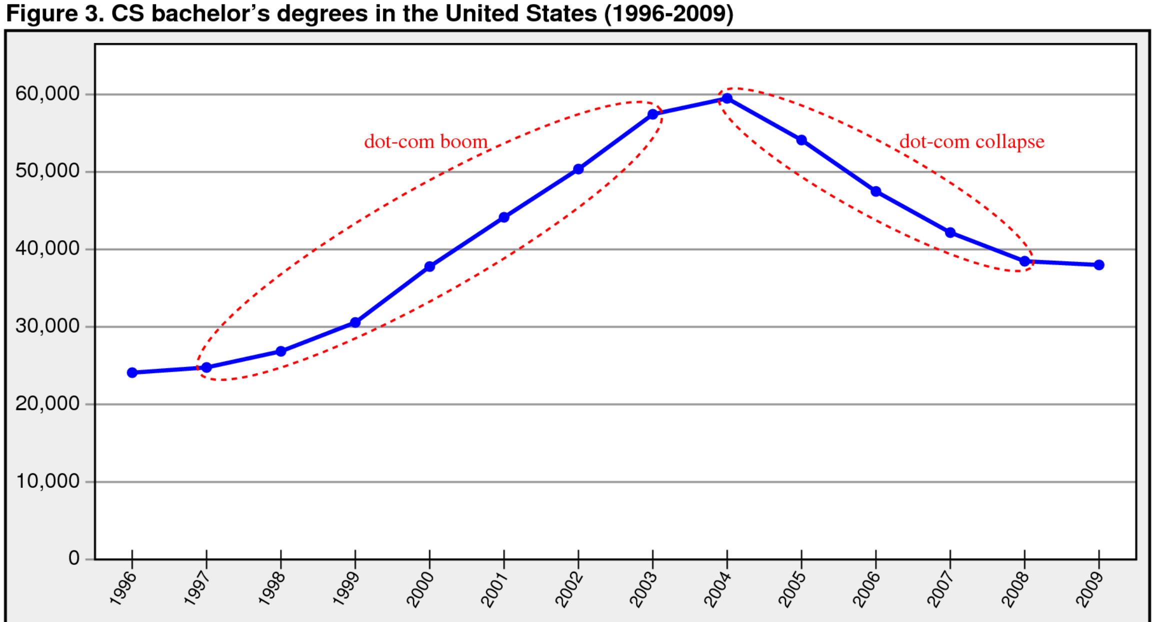
Please God, just one more bubble.

—Popular Silicon Valley bumper sticker, 2003

In many ways, the second installment in the boom-and-bust history of computer science is easier to explain than the first. The growth in interest that began in the mid 1990s coincided with the advent of the web and the elimination of commercial restrictions from the Internet. These developments ushered in a period of frenetic growth in the computing industry generally referred to as the *dot-com boom* or, when it is important to emphasize its ephemeral nature, the *dot-com bubble.* The excitement generated by both the new technologies and the opportunities provided by the startup culture attracted many students back to the field. In the years of flat enrollments between 1991 and 1996, departments had been able to rebuild their faculties, which meant that there was capacity—at least at the beginning—to accommodate a rise in student numbers. When the tech bubble burst in 2001, students began to move away from computer science, which led in turn to a multiyear decline. Figure 3 shows the rise and fall during this cycle of history.

Even though the causes of both phases of this cycle are easy to identify, it is still worth considering this period of history in more detail. From 1997 to 2003, the number of computer science graduates rose by an average of 15 percent per year, with many institutions seeing considerably larger increases. That rapid rate of growth raised echoes of the expansion of the early 1980s. Several committees were formed to study the problem in the hope that academic computer science could avoid the meltdown it had suffered a decade and a half before.

Figure 3. CS bachelor's degrees in the United States (1996-2009)



Source: National Center for Education Statistics

In 2000, academic computer science did avoid a meltdown, but not for any reason one would like to repeat. In a perverse sense, academia got lucky. The industry collapsed first. Had it not done so, it seems likely that capacity limitations would have forced universities to restrict enrollment, with all the negative consequences that the field endured in the late 1980s.

The aspect of the collapse in the early 2000s that seems hardest to explain is why things took so long for student interest to recover. The industry bounced back very quickly and was hiring at the pre-crash rate by 2004. The student numbers, however, did not start to rise substantially until after the subprime mortgage crisis in 2007. Somehow, a meme arose in the public consciousness in the form of a widespread belief that computing jobs were in danger of imminent collapse, either because they would be automated out of existence or because all software development jobs would be shipped offshore. Although there was no evidence to justify those fears—and ample data to refute them—that mythology kept students out of computer science until disaster struck in a different sector of the economy.

The sections that follow look more closely at the effect of the dot-com expansion on academic capacity and the failure of student interest to recover even after the dot-com collapse had passed.

The effect of the dot-com boom on enrollments

The frenzy of excitement around the dot-com explosion in the mid 1990s generated enormous student interest in computer science. As Figure 3 illustrates, the number of bachelor's degrees in computer science rose steadily from 1997 to 2003. Those numbers therefore reflect the decisions that students made about their major field approximately two years earlier, which aligns with the years of the dot-com boom.

During those years, the situation facing computer science departments corresponded closely to the rapid expansion of the early 1980s and generated a similar set of pressures. Along with the double-digit annual growth in student numbers, departments faced a shortage of available faculty. In the December 1998 issue of the *SIGCSE Bulletin,* Paul Myers and Henry Walker published a review of academic hiring, which concluded that there was "a very serious shortage of new Ph.D.s in computer science," to the point that in 1997-98 "only about half of the open tenure-track positions were filled."[8] While that level of undersupply falls far short of the seven-positions-for-every-applicant crisis of the 1980s, it nonetheless generated considerable concern, not only in university departments, but also in the media, industry, and government.

In 1999, the Computing Research Association published a report entitled *The Supply of Information Technology Workers in the United States,* detailing the shortage of workers in both industry and academia. The report observed that academic institutions faced a

---

8 Paul Myers and Henry Walker, "The state of academic hiring in computer science: an interim review," *SIGCSE Bulletin,* December 1998, page 32.

special problem, invoking the "seed-corn problem" popularized by Peter Denning a decade earlier.[9]

> Many educators, industrial laboratory leaders, and government science officials are concerned that the high industrial demand for information technology (IT) workers will siphon out of the educational systems many students who would otherwise pursue an advanced degree. This diminishes [the] pool of people who will join the university faculties that perform basic research and teach the next generation of students. This problem is compounded when industry also successfully recruits current faculty members, including junior faculty who would become the academic leaders of the profession in the coming decades. This is known as the "seed-corn" problem—an analogy to those who consume too much of this year's crop, reserving too little for next year's planting.

As was true in the mid 1980s, the problems of faculty recruitment were noted by the media. In September 1999, *The Chronicle of Higher Education* included a news story entitled "Computer scientists flee academe for industry's greener pastures" that begins with the following evocative paragraphs:[10]

> Just as he prepared to leave Cornell University last spring to help start a new high-technology company, Thorsten von Eicken got word that the computer-science department at Cornell had voted to grant him tenure.
>
> He left anyway.
>
> Mr. von Eicken is part of a stampede of bright, young Ph.D.s in computer science who are abandoning academe for the corporate world.
>
> High-paying, fast-paced jobs in the computer industry are attracting both seasoned academics and newly minted Ph.D.s who, in the past, would have opted for careers in higher education. The upshot: Computer-science and computer-engineering departments are suffering a serious shortage of professors at a time when undergraduate enrollments are booming.
>
> Many departments are losing professors faster than they can hire them. The University of Illinois at Urbana-Champaign recruited five new professors in electrical and computer engineering to start this fall, but lost five others who were already on its faculty. The University of Washington recruited four scholars to its department of computer science and engineering but lost five. Cornell hired three but lost six.

The difficulty of faculty recruitment was also picked up by *The New York Times,* which ran an article entitled "Computer science departments are depleted as more professors test entrepreneurial waters" on August 9, 2000.[11] The article quotes Ed Lazowska, then chair of the Computer Science and Engineering Department at the University of Washington, as follows:

> It is difficult to hold a computer science department together these days. You'd like to keep a lot of that entrepreneurial energy here. Faculty recruiting and retention are difficult. Ten years ago, industrial research labs were the enemy; now it's the lure of startups.

---

[9] Peter Denning, "Eating our seed corn," *Communications of the ACM,* June 1981, page 341.

[10] Robin Wilson, "Computer scientists flee academe for industry's greener pastures," *Chronicle of Higher Education,* September 24, 1999, page A16.

[11] Rebecca S. Weiner, "Computer science departments are depleted as more professors test entrepreneurial waters," *The New York Times,* August 9, 2000.

In 2001, the National Academies released a major study entitled *Building a Workforce for the Information Economy* that looked broadly at the questions of the computing and information-technology workforce, including several issues concerning education. At the request of the study panel for the National Academies and with the endorsement of the ACM Education Board, I submitted a white paper that focused on how the shortage of faculty candidates was making it impossible for universities and colleges to meet the demand from employers for graduates with the necessary level of expertise.[12] That white paper was cited several times in the final report, which issued the following conclusion with respect to higher education:

> The academic research enterprise in IT continues to be strong, but industry and academia are competing for the same small pool of highly productive, creative individuals. Ph.D. production and faculty recruitment and retention are both threatened by the lure of the commercial sector. Some faculty and graduate students are leaving academia for better-compensated positions in industry; others leave because only industry (especially start-ups supported by venture capital) offers them the opportunity to pursue their intellectual and research interests. . . . Compared to the benefits to be found in industry and start-ups, academic life—with the attendant burdens of low salaries, teaching, and the need to obtain grant support—is increasingly seen as unattractive to many graduate students. The long-term significance of these perceptions is at present unclear, but they do not bode well for the long-term health of the IT field.

Although many of the discussions that led to the National Academies report took place in 1999 and 2000, the final version was not released until 2001. By that time, the situation in the computing industry had changed entirely. The speculative bubble that had fueled the growth of a vast array of dot-com companies collapsed, and the industry went into a tailspin. The NASDAQ composite index—which had risen from 740.47 at the beginning of 1995 to a high of 5,132.52 on March 10, 2000—collapsed to 1,108.49 by October 10, 2002. With that collapse, investors lost trillions of dollars, the wide-open job market of the late 1990s disappeared (if only for a couple of years), and students who had been lining up to major in computer science, like many faculty members and graduate students before them, started to look for greener pastures.

The slowness of the recovery after the dot-com collapse

On one level, the decline in computer science enrollments after the dot-com collapse is easy to understand. At the time, the news was full of stories of the demise of Internet startups, so recently the darlings of Wall Street, many of which lost their entire value overnight. As startups collapsed and large companies started downsizing, the high-tech industry did not seem like a good bet for stable employment over the long term. Students headed off in other directions.

What is paradoxical about the downturn in student interest is that it persisted for many years after the industry had fully recovered. While there was a small dip in overall employment in the information-technology sector between 2000 and 2002, employment

---

[12] Eric Roberts, "Computing education and the information technology workforce," *SIGCSE Bulletin,* June 2000, page 83.

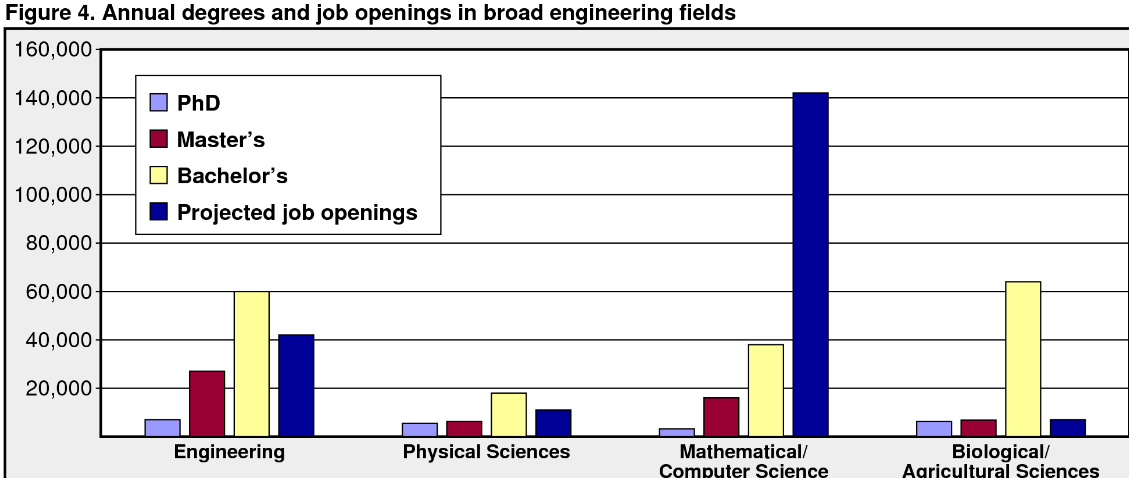
numbers quickly surpassed their pre-crash levels. By 2005, employment prospects for students completing a bachelor's degree in computer science and other specialties in information technology were considerably better than they were for students in any other discipline. That conclusion is underscored in the following excerpt from a December 2005 publication from the National Science Foundation:[13]

> Continuing a pattern that has been evident for decades, recent bachelor's and master's engineering graduates and computer science graduates at the bachelor's level are more likely than graduates in other fields to be employed full time after graduation, and upon entering the workforce, they are rewarded with higher salaries.

These conclusions from the Bureau of Labor Statistics were echoed in the popular press. In May 2006, *Money* magazine rated "software engineer" as the best job in America on the basis of a combination of factors including salary, job availability, potential for growth, flexibility, and creativity.[14]

One of the best analyses about the shortage of software professionals appears in a talk by John Sargent, Senior Policy Analyst at the Department of Commerce, which he presented at the CRA Computing Research Summit in February 2004.[15] Although the entire presentation is worth viewing—in part because it is striking how little things have changed over the past decade—the talk is particularly memorable for the slide that appears in Figure 4, which combines data on degree production from the Department of Education with job projections from the Bureau of Labor Statistics.

Figure 4. Annual degrees and job openings in broad engineering fields



SOURCES: Tabulated by National Science Foundation/Division of Science Resources Statistics; degree data from Department of Education/National Center for Education Statistics, Integrated Postsecondary Education Data Systems Completion Survey, and NSF/SRS Survey of Earned Doctorates; Projected Annual Average Job Openings derived from Department of Commerce (Office of Technology Policy) analysis of Bureau of Labor Statistics 2002-2012 projections.

---

13 National Science Foundation, "Recent engineering and computer science graduates continue to earn the highest salaries," *InfoBrief,* December 2005.

14 *Money* magazine, "Best jobs in America," May 2006.

15 John Sargent, "The adequacy of the U.S. science and engineering workforce," CRA Computing Research Summit, February 23, 2004.

Because of its unusual effectiveness, several people have updated this slide as new releases of the relevant data become available. The most recent version I'm aware of was created by my colleague Phil Levis and is available from `http://csl.stanford.edu/~pal/ed/`. The take-home message of the graph, however, has remained constant over the past decade: universities are producing far too few graduates in computer science to meet industry demand.

The bar that towers over the other data points in Figure 4 makes it immediately clear that the number of jobs in computing-related disciplines far exceeds the number of students trained in those fields. If students were responding to market forces, the imbalance between degree production and job growth would have sparked a stampede toward computer science. That stampede did not happen. Despite the many economic advantages available to those with computer science degrees, students shied away from the field until after the subprime mortgage crash in 2007.

The reasons behind the lingering unpopularity of computer science during the 2000s are complex. The factors certainly included memories of the pain associated with the collapse of the dot-com bubble and a widespread fear that computing jobs would soon be shipped offshore to low-wage countries. The fear of offshoring was particularly intense, even though a 2006 ACM report entitled *Globalization and Offshoring of Software* found no evidence that software jobs were disappearing in developed countries. In fact, the report found that "despite a significant increase in offshoring over the past five years, more IT jobs are available today in the U.S. than at the height of the dot-com boom" and, moreover, that "IT jobs are predicted to be among the fastest-growing occupations over the next decade."[16]

An interesting illustration of the disconnect between the available economic data and popular perception appears in the online response to a keynote address at the CIO Leadership Conference by Maria Klawe, then Dean of Engineering at Princeton University, with the title "Blue skies ahead for IT jobs."[17] The abstract for Klawe's talk reads as follows:

> Contrary to popular belief, career opportunities in computer science are at an all-time high. We've got to spread that message among students from a rainbow of backgrounds, or risk becoming a technological backwater.

The comments that Klawe's talk elicited—which have, unfortunately, vanished along with the original website at *CIO Magazine*—ran at least ten-to-one *against* her assessment of the sunny outlook for the field. Here are a few typical reactions that I downloaded at the time:

---

[16] William Aspray, Frank Mayadas, and Moshe Y. Vardi (editors), *Globalization and Offshoring of Software: A Report of the ACM Job Migration Task Force,* Association for Computing Machinery, February 2006.

[17] Maria Klawe, "Blue skies ahead for IT jobs," CIO Leadership Conference, Boston, MA, May 8–10, 2006.

- All this talk about "Blue Skies" ahead just can't hide the stark fact that Americans who don't wish to migrate to India and/or some other offshore haven are going to have a difficult career.
- Why would any smart American undergrad go into IT when companies like IBM and HP are talking of stepping up their offshoring efforts in the coming years? They want cheap labor, no matter the real cost.
- I think the latest figures from the U.S. Department of Labor are not correct.

The last of these comments, which is quoted in its entirety, seems particularly telling. The reader offers no alternative data, just a deeply seated belief that the optimistic forecasts of the Labor Department must be wrong. Evidence counted for little in this debate.

Ironically, popular fears about the tenuous future of the discipline were in some cases encouraged by comments from within the academic community. In July 2008, *Communications of the ACM* published a debate about future directions for the technology curriculum.[18] Professor Stephen Andriole at Villanova University predicted that the need for programmers would soon diminish:

> Of course there will be programming jobs for our students. But the number of those jobs will decline, become more specialized, and distributed across the globe. . . . Today, Fortune 1000 companies have far fewer programmers than they did because of the rise of packaged applications and the labor-rate-driven sourcing options they now have. This trend will accelerate resulting in fewer programming jobs for our students. Should we continue to produce more programmers?

In my response, I argued that Andriole was looking only at one sector of the technology industry and that the number of jobs across the industry as a whole would continue to rise, in line with the predictions from the Bureau of Labor Statistics. In recent years, the sustained increase in the number of software jobs makes it clear that my analysis was closer to the mark.

Although I never published an analysis of the reasons why students continued to stay away from computer science long after the industry recovered, I did prepare a report for the ACM Education Board, which considers this paradox in more detail.[19]

---

[18] Stephen J. Andriole and Eric Roberts, "Point/counterpoint: Technology curriculum for the early 21st century," *Communications of the ACM*, July 2008, page 27.

[19] Eric Roberts, "Understanding the paradox: strategies to rebuild student interest in computing," presentation to the ACM Education Board, August 22, 2008.

What is the nature of the enrollment expansion today?

It's like déjà vu all over again.

—attributed to Yogi Berra

Since 2007, the number of students taking computer science courses and declaring computer science majors has been rising rapidly. To a large extent, the expansion mirrors the earlier expansionary periods that occurred from 1979 to 1984 and from 1994 to 2001, in the years just before the preceding crashes. In particular, the factors fueling the increase in student interest are similar. The last seven years have been an extremely exciting time in computer science, with the proliferation of computing into ever more facets of everyday life. The ubiquity of smart phones and the applications that run on them, the enormous successes in machine learning, the rise of big data, and so many other advances all make computer science extremely attractive. Moreover, the seemingly boundless opportunities for employment that computing careers offer—particularly when coupled with the enormous uncertainty facing other aspects of the economy—are certain to draw more students into computer science, just as those same factors have in the past.

The sections that follow trace the dimensions of the current expansion and its likely consequences, exploring both the similarities and the differences from the earlier cycles.

The dimensions of the current expansion

Over the last four years, several members of the field who remember the history of the two previous cycles, including myself, have sought to raise awareness of the danger of rapid expansion in enrollment with no commensurate increase in teaching capacity. In 2011, I published an editorial entitled "Meeting the challenges of rising enrollments" in ACM's *Inroads* magazine.[20] In that piece, I review the history of the earlier crises and end with the following warning:

> In the 1980s, the inability to hire new faculty made it impossible for most departments to satisfy the increased student demand. As a result, institutions were forced to discourage student interest by adopting such strategies as limiting the size of the computer science major or staffing courses with inadequately trained outsiders. . . .
>
> As a nation, we cannot afford to repeat the failures of the early 1980s. As we emerge from a decade in which far too few students chose to major in computer science, it makes no sense to frustrate the renewed student enthusiasm by turning yet another generation away because of a lack of resources. The economy needs more people with computer science training, and we have a collective responsibility to prepare students for those positions.

More recently, Ed Lazowska from the University of Washington, Jim Kurose at the National Science Foundation (on leave from the University of Massachusetts), and I have

[20] Eric Roberts, "Meeting the challenges of rising enrollments," ACM *Inroads* magazine, September 2011, page 4.

given joint talks in various venues about the growing capacity problem, including the NSF Future Directions in Computer Science Education summit in January 2014, the National Center for Women in Information Technology summit in May 2014, and the Computing Research Association's biennial conference at Snowbird in July 2014. The slides from our presentation, entitled "Tsunami or sea change?: Responding to the explosion of student interest in computer science," offer an overview of the capacity crisis and are available from `http://lazowska.cs.washington.edu/NCWIT.pdf`. The slides document the rapid growth in the number of computer science majors at several leading research institutions, both public and private, as shown in Figure 5.

The expansion seen at these institutions is even more rapid than aggregate statistics show because many universities insulate themselves from changes in demand by controlling admissions to the major. For example, institutions like Carnegie Mellon and the University of Washington experience lower variability because those institutions admit students directly into the computer science program. The number of applicants changes along with the national pattern of student interest, but the number of students actually admitted remains much more stable.

The slides also document the continued strength of the job market for graduates with strong computational backgrounds. Figure 6, for example, shows the projections from the Bureau of Labor Statistics for job growth and job openings (job growth plus replacement) for the STEM (science, technology, engineering, and mathematics) sectors of the economy from 2012-22. By both measures, most of the employment growth over the decade is in the computing disciplines, which account for 71 percent of job creation and 57 percent of job openings in STEM.

Figure 5. Increasing demand for the computer science major

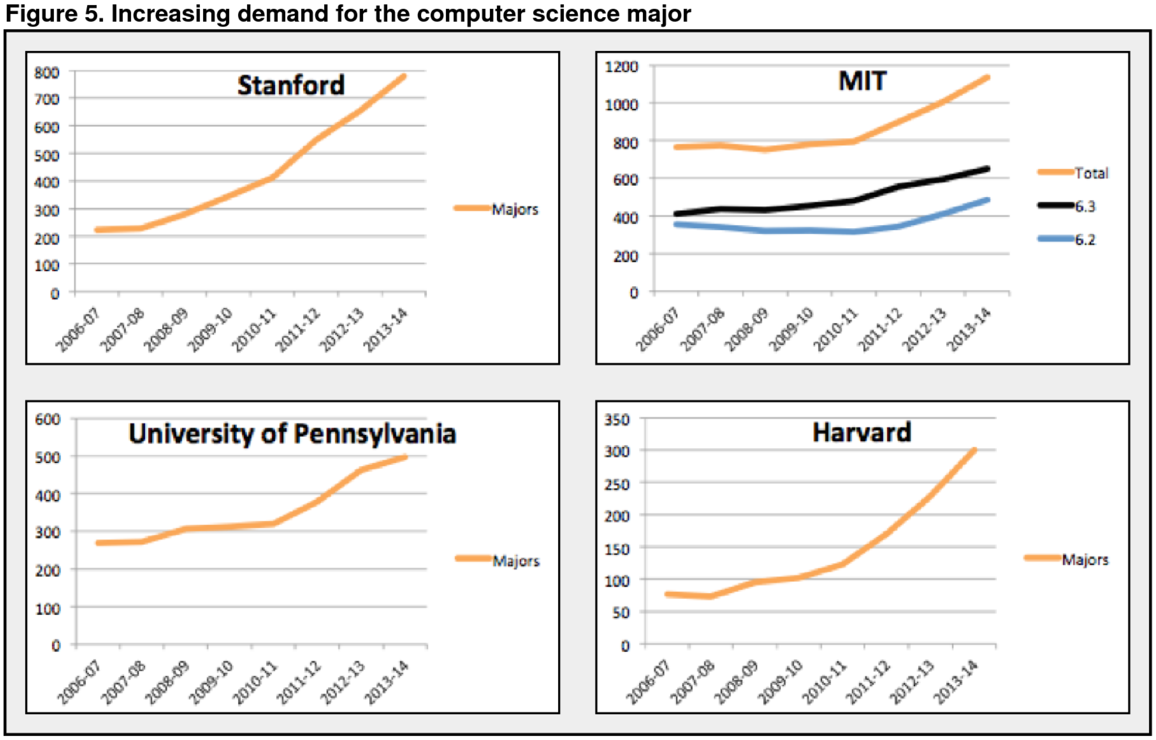
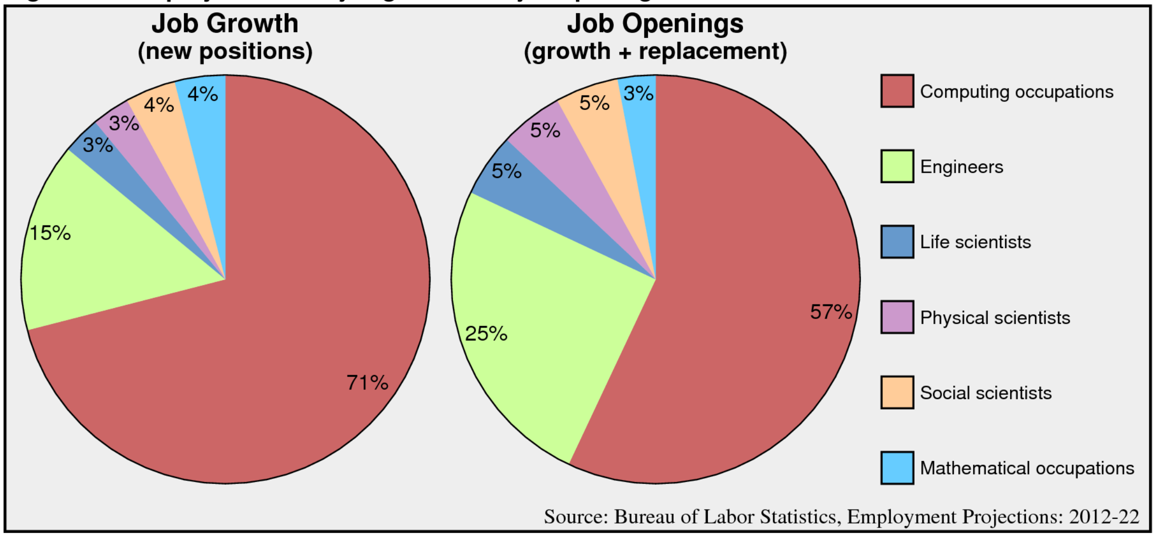


Figure 6. BLS projections for job growth and job openings for 2012-22



The "Tsunami or sea change" presentation ends with the warning that "we have seen this movie before, and it wasn't pretty." In previous cycles, "universities did not respond adequately," increasing the importance of doing a better job this time around.

Today—as in past years in which student enrollments in computer science increased rapidly—faculty openings exceed the number of applicants for those positions. From July 2014 through June 2015, more than 700 distinct advertisements of computer science faculty positions at North American universities and colleges were posted on the ACM employment web site. Many of these ads listed multiple searches (sometimes as many as five) at the same institution, so the total number of open positions is larger than the number of advertisements. Although the precise number is impossible to determine because many of the listings use imprecise phrases like "several positions" or "multiple positions," it appears that the number of open computer science faculty positions in 2014-15 was around 1000.

According to the Computing Research Association's most recent Taulbee survey, North American institutions produced 1,651 computer science Ph.D.s in 2014.[21] Of this number, 244 (15 percent) accepted faculty positions at North American institutions. By this calculation, the current rate of Ph.D. production is sufficient to fill about one of every four open positions.

Although the ratio of applicants to open positions is less than the one-in-seven shortfall of the early 1980s, the number of unfilled positions is significantly larger in absolute terms. If the number of Ph.D.s is sufficient to fill only a quarter of the open positions, then the number of positions that cannot be filled from this pool is around 750. Unlike other fields, computer science has no reserve labor force in the form of Ph.D.s who received their degrees in prior years but who have been unable to find positions. Some

---

[21] Stuart Zweben and Betsy Bizot, "2014 Taulbee survey," *Computing Research News,* May 2015.

positions, of course, will attract faculty members from lower-ranked institutions who "trade up" to more prestigious employment. That flow of existing faculty up the ladder of institutional prestige, which is usually referred to as *churn* in discussions of the academic labor market, means that some of the 750 open positions will indeed be filled, but only in a way that leaves vacancies in other institutions that will have to be filled in future years. The only way to ensure stability is for the number of new faculty entering the workforce to keep pace with the rate of departures and the growth of the field.

Where are we heading?

Figuring out how to respond to the current expansion is complicated by the fact that history does not provide us with a clear sense of how the situation will evolve from here. The two expansionary periods we have seen before—which were quite similar in form—were followed by collapses that were qualitatively different. Are we heading for another capacity collapse similar to the one the field experienced in 1984, or will we be saved by a downturn in the high-tech industry that sends students scurrying away to other fields? And, perhaps more importantly, is there any way to predict the actual outcome?

Given the uncertainties of economics, it is clear that the answer to the second question is no: there is no way to predict with confidence exactly how economic forces will play out in the high-tech industry and how those forces will affect enrollment patterns. Many analysts believe that the situation in the technology sector is substantially different from the "irrational exuberance" of the dot-com bubble. As *The Economist* reported on July 25,[22]

> Greed, profligacy, tiny companies with outlandish valuations: it is not hard to detect echoes of the turn of the century, when the dotcom bubble burst spectacularly and America's economy stumbled as a result. But to see history as about to repeat itself is to miss how deeply things have changed. Today's technology businesses are selling services and products from which they already generate income, rather than just saying that one day they might. And the group of people doing the investing is much smaller now than it was then. The risks are on fewer shoulders.

This assessment, of course, is by no means authoritative. The important point is that there is certainly no evidence to suggest that there *will* be a downturn in the high-tech industry that doesn't affect the economy as a whole. More importantly, it is foolhardy to assume that there will be such a downturn and that academic computer science will be saved thereby. We don't know what is going to happen, and it is therefore important to prepare for what might well be a capacity collapse similar to that of the 1980s.

There is, however, a reasonable interpretation of history that makes the differences in the mid 1980s and the early 2000s less important. Rather than looking at the character of the downturns, I believe it is more productive to focus on the pace of the enrollment increases that preceded those periods of collapse. In the early 1980s, the late 1990s, and again today, computer science departments face a rate of expansion that is much faster

---

[22] "To fly, to fall, to fly again," *The Economist,* July 25, 2015.

than university departments ordinarily sustain. Those periods of expansion, moreover, coincide with extremely tight labor markets for faculty, which makes it difficult to respond to the increase in student load, even if the institutional will to do so is there. In the absence of extraordinary measures that most universities have been unwilling to undertake in the past, the rates of increase during the boom years are simply unsustainable. And, in a marvelously succinct principle generally attributed to Herbert Stein, economics tells us that

> If something is unsustainable, it will stop.

Stein's principle does not tell us *how* an unsustainable phenomenon will stop, only that it *will.* The unsustainable buildup of the early 1980s ended with a capacity collapse. The unsustainable expansion of the dot-com era ended with the collapse of the dot-com bubble, and with it, the enrollment crisis that had threatened to overwhelm academic departments.

The current rise looks very much like the previous ones and exists against a backdrop of faculty shortages that bears all the hallmarks of past expansions. Unless new strategies are implemented at a scale that has not been attempted in the past, this expansion too will stop. Our foresight may not permit us to understand the precise mechanism of the collapse, but those details will matter very little to those who suffer from its effects.

What strategies are currently in progress?

As the effects of increasing enrollments become more evident, professional societies have undertaken several initiatives to address the capacity problems. These initiatives include the following:

- The Computing Research Association has launched a "Booming Enrollments" committee chaired by Tracy Camp at the Colorado School of Mines. As of late 2015, that committee is beginning its data-gathering phase.
- The ACM Education Council has created a working group on the capacity crisis that I am chairing. This document is intended primarily as input to that working group.
- The National Science Foundation and the National Academies are considering the formation of a study panel to address broader issues with respect to the information-technology workforce. I have spoken with staff members who are working on the project, but do not know its current status and schedule.

Why has a concerted response from the community been so slow in coming?

Despite being several years into the latest period of skyrocketing enrollments, efforts to address the problems are just now getting off the ground. For those of us who have lived through past crises, this delay reflects an unfortunate change in the community's understanding of the problems. In the early 1980s, academic computer scientists had a solid appreciation of the dangers they faced from massive increases in enrollment. The same was true in the late 1990s—an understanding all the more vivid because memories were still fresh from the capacity collapse of the mid 1980s. This time around, however, it has been much harder to get universities, departments, and individual faculty to recognize the risks, despite the accumulation of additional historical experience.

In my view, the failure in this cycle to benefit from the lessons of history arises from a confluence of several factors:

- *Historical clarity is obscured by memories of the dot-com collapse.* For computer science departments today, and particularly for those staffed by faculty who are too young to remember the earlier peaks and valleys of computer science enrollment, the dominant memory is of the enrollment downturn that followed the collapse of the dot-com bubble. For a little over a decade, computer science educators have been working to increase student interest in the field. Once a movement like that gets going, it is difficult to change gears, even when the number of students we serve clearly threatens to overwhelm existing resources. Given the demand for people with those skills, it is clear that we still need to attract more students to computing. To work on building demand without also working to increase capacity strikes me as suicidal.
- *History has convinced many people that student demand is cyclical.* When you look at the variation in degree production over the last several decades, it is easy to conclude that student interest varies in a cyclical fashion. As Jim Kurose said when he spoke at Stanford's computer science faculty lunch earlier in the year, he often meets administrators who are convinced that they can predict the cyclical period and know when students will next lose interest. That attitude, however, is inconsistent with history. Students did not turn away from computer science in the 1980s by choice but instead from a lack of teaching resources within the institutions. What's worse is that the assumption of cyclicity is self-fulfilling. If administrators decide not to support computer science departments because of a belief that those enrollments will inevitably fall, that very decision ensures a capacity collapse.
- *There was a widespread conviction that technology would solve the problems.* The early years of the current enrollment increase coincided with the birth of MOOCs (massive open online courses) and the excitement they generated in their early years. To many people in academia, MOOCs held forth the promise of allowing universities to reach larger communities of students at lower cost, thereby enabling an increase in productivity. Although that vision failed to materialize, the widespread enthusiasm for using technology to solve the capacity problem in computer science made it difficult to consider other options.
- *Teaching large computer science courses has become a more specialized endeavor.* Computer science enrollments and major counts are much larger today than they were at the height of previous enrollment expansions. As a result, many departments have, entirely appropriately, hired people specifically tasked with teaching the lower-division courses that have seen the greatest increases in enrollment. The downside of this approach is that much of the faculty is insulated from the pressures of increased student interest until the enrollment bubble reaches the upper-division courses.

- *Much of the early history lies beyond the Google "event horizon."* In putting together this history, I was interested to discover that several relevant articles I remembered from the early 1980s were invisible online because they predate digital archiving for the journals in which they appear. Looking for evidence about faculty shortages in the 1980s becomes much harder when none of the references from, for example, *The Chronicle of Higher Education,* show up in Google searches.

The fact that people who are responsible for making decisions that affect the future of computer science education are less aware of the problems of the past makes it harder for the field to act with a common purpose. That historical myopia, however, in no way reduces the importance of finding a way to forestall a repeat of the capacity collapse of the 1980s that cut the number of qualified computer scientists nearly in half. Our society cannot afford to repeat that mistake.