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The Coevolution of Technologies and Institutions: Silicon Valley as the Iconic High-Technology Cluster

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In the 1990s Silicon Valley achieved iconic status for economic development planners globally. But how did Silicon Valley come into being? We demonstrate that its rise was a social process of bricolage in which actor's fashioned solutions for various problems that they confronted with what they found at hand (Garud and Karnoe 2003). Frequently, these solutions AQ1 were adapted from existing forms and then applied to new purposes. For the most part, they were responses to immediate problems, rather than wisely considered, far-sighted solutions by prescient economic actors maximizing their utility functions. Those solutions that appeared to work were diffused, repeated, and adjusted, gradually evolving into routines and institutions (Nelson and Winter 1982). These routines and institutions enabled further experimentation even as a stable repertoire of actions came into being. Borrowing from Spender's notion (1989) of industrial recipes, we argue that through an unplanned iterated learning process Silicon Valley actors developed regional recipes for creating and nurturing start-ups. This chapter examines how technology and institutions coevolved to create an ecosystem within which entrepreneurs were able to encapsulate many of the new innovations in separate firms, as opposed to all of the innovations being commercialized by existing firms.

The information/computer/electronics (ICE) and, to a far lesser degree, biomedical technologies have formed the core of the venture capital-financed start-up economy. For the last five decades, the ICE technologies have experienced exponential rates of improvement in cost and functionality combined with extremely large intellectual property content. Also, the ICE technologies have frequently experienced (or, alternatively, entrepreneurs have created) moments when entry barriers have been lowered sufficiently to allow nimble well-placed entrepreneurs to enter new market niches. Thus, on one dimension, understanding Silicon Valley is predicated upon tracing the evolution of technologies and the industries based on them, and, on the other dimension, the evolution of the institutions, practices, and cultural understandings that orient action.

The chapter examines the building of the entrepreneurial support infrastructure and its co-evolution with the local high-tech industries. In our discussion we highlight the way Silicon Valley entrepreneurs developed new business models and often combined different technologies to create new business opportunities. We also consider the importance of culture as an explanatory variable arguing that culture particularly is as much a dependent variable as it is an independent variable. In our estimation, it is better to consider culture as having coevolved with the regional business activity—and in the case of Silicon Valley might better be seen as a learned set of guides to action, rather than as something emanating from a Gold Rush mentality or a set of personal attributes. In the conclusion, we reflect upon the implications of our findings for an evolutionary theory of the development of entrepreneurial, high-technology regions.

The Formation of Silicon Valley

Entrepreneurship in Silicon Valley involves two separate sets of organizations (Kenney and Burg 1999). The first set of organizations are the ones AQ2 from which the entrepreneurs emerge and the second are the organizations that specialize in supporting the entrepreneurial process. The primary source of entrepreneurs for Silicon Valley start-ups has been other firms (Gompers, Lerner, and Scharfstein 2003). Though Gordon Moore, a founder of Intel, believes that university research institutions contributed little to the evolution of the semiconductor industry (Moore and Davis 2001), generalizing from the semiconductor industry he underestimates the role of universities and corporate research laboratories in providing the support and intellectual space within which the seeds of new industries could develop (National Research Council 1999*a*, 1999*b*). A number of the defining firms in individual industries can be attributed to universities and corporate research laboratories. For example, 3Com, Cisco, Yahoo!, Seagate, Google, Sun Microsystems, and Cadence are directly linked to Bay Area corporate research institutes and universities (Kenney and Goe 2004).

Having a rich source of entrepreneurs is very important, but it is the institutions that nurture the firms they create which give Silicon Valley a powerful advantage over other regions. Silicon Valley hosts a set of interdependent institutions specialized in supporting firms, particularly technology firms capable of extremely rapid growth. These institutions form what observers termed an ecosystem, a social structure of innovation, or an incubator region (Bahrami and Evans 2000; Eisenhardt and Schoonhoven 1990; Florida and Kenney 1990; Lee et al. 2000; Todtling 1994). However, this ecosystem was not *sui generic*, but rather formed over time in tandem with the industries that were formed in the region.

Establishing when Silicon Valley was formed is not simple. Conventionally, it might be dated to the decision by William Shockley to establish Shockley Semiconductor in Silicon Valley. This was a defining moment and there was an element of serendipity in the choice of Palo Alto for the firm. Shockley also had considered the Boston area where there were already a number of transistor firms using germanium as their substrate, MIT was producing numerous technically capable personnel, and a group of early technology adopters (the minicomputer firms) were on the verge of being established. On reflection, there seems little doubt that a number of other regions, such as Los Angeles, Long Island, or northern New Jersey would have had sufficient technical personnel, lead customers, and other institutional supports to allow an industry to take root. For example, the germanium-based transistor firms on the East Coast particularly Boston might have switched to silicon, which ultimately became the substrate of choice for the most important technology of the late twentieth century as the silicon semiconductor became the ubiquitous enabling technology for digitization. Or, alternatively, Texas Instruments (TI) in Texas might have begun to spin-off firms. Fortunately or unfortunately, TI was not as badly managed as Shockley Semiconductors and it never experienced the mass resignations that led to the creation of Fairchild Semiconductor. It was Fairchild Semiconductor that began leaking people and contributed the start-ups that eventually transformed the region into what the editor of the *Electronic News* first described in 1973 as the Silicon Valley.

If Shockley Semiconductor was the bad seed that soon failed, Fairchild was the most fecund of all. However, in some sense, fecundity is also a function of the environment and the environment into which Fairchild was born was significant. To illustrate, it is convenient to explore what existed in the prehistory of Silicon Valley not as a theological exercise, but as a partial explanation of why the semiconductor industry would find the region such a conducive environment. There was an existing electronics industry that could be traced back as far as Lee De Forest and the invention of the vacuum tube (Sturgeon 2000). Also, other entrepreneur-based, high-tech electronics firms, the most salient of which were Hewlett-Packard and Varian, were located in the region. Though these firms were not semiconductor firms, they were electronics firms and HP was especially important because it was building the basic equipment that all electronic firms needed.

Shockley was not the first person or firm to decide to locate in the South Bay. In 1952 IBM decided to establish a branch of its Yorktown Heights research laboratory in San Jose to tap the skilled personnel in the area.[1] Approximately eighteen years later Xerox established its West Coast research facility in Palo Alto to access the skilled labor pool. Already in 1958 there were real business reasons to establish a new high-technology electronics firm in the region.

Shockley's relocation to Palo Alto was serendipitous and, at least, partially motivated by his desire to live close to his mother. However, the history of Silicon Valley also includes the role of Frederick Terman initially Dean of Engineering and then Provost at Stanford (Sturgeon 2000). A professor of electrical engineering, Terman admired the MIT model of university interaction with business. He was also a fervent believer in the economic potential of electronics, championing the establishment of electronics firms in the region and assiduously working to both attract them and support entrepreneurs including those on his faculty wishing to establish firms. Terman urged Shockley to establish his firm in Palo Alto. Serendipity brought Shockley to Silicon Valley, but Fredrick Terman was a centrally located actor actively trying to manipulate fate.

The entrepreneurial support system would also evolve with the development of new firms. Yet it would be incorrect to attribute the creation of the VC industry directly to Fairchild. History shows that the capital required to start Fairchild was raised by Arthur Rock, who, at the time, was a manager at the New York investment bank Hayden Stone. And yet there were already a number of informal investors in the region that were willing to invest in new electronics start-ups. Thus even though the capital to establish Fairchild was raised in New York, there was already a group of proto-venture capitalists in formation at the time of Fairchild's establishment. In fact, there was a history of Stanford professors and administrators investing in start-ups that can be traced back to the early investors in

Federal Telegraph (Sturgeon 2000). Though it is difficult to be certain, there is anecdotal evidence that the Bay Area was already one of the national centers for angel investors in electronics.[2] The Bay Area VC industry grew with the semiconductor industry, but it is important to note that semiconductors were only one of a number of industries funded.

Whether Fairchild should be considered irreplaceable in the formation of the Silicon Valley high-technology cluster is probably unanswerable. Leslie (2000) argues that a microwave technology cluster was established in the region at roughly the same time (1950s) on the basis of defense department research. From 1955 through the early 1960s, there was a high-technology electronics boom and many firms were formed in the region with funding from informal investors. There is reason to believe that a high-technology cluster of some sort was evolving and would have continued to evolve. However, the region is termed Silicon Valley with good reason. To return to our earlier statement, the semiconductor was the most important technology of the twentieth century, and it was a critical input that made new industries such as work stations, personal computers, and computer networking possible. There can be little doubt that the semiconductor is at the heart of the dominance Silicon Valley has shown for the last three decades.

Entrepreneurs, Technologies, Firms, and Industries in Silicon Valley

The evolution of Silicon Valley is based on its entrepreneurs, the technologies they commercialize, and the firms they create. Figure 3.1 is a chronology of the most significant technologies that have fueled the region's growth. In some cases, a technology was developed in Silicon Valley, but eventually shifted out of the region entirely. Of course, the sources are not always local as the semiconductor technology was imported from Bell Laboratories in New Jersey.

The level of employment is a good measure of which industries were most important. Figure 3.2 shows that software currently employs the greatest numbers in the region having overtaken components (semiconductors) in 1996. It continued to grow very rapidly in the late 1990s fueled by the dot-com boom. The aerospace sector represented by guided missiles has been largely steady at 20,000 through the entire period with the exception of the 1980s when it doubled due to Reagan's Star Wars plans. The growth of computer and peripherals' employment is interesting

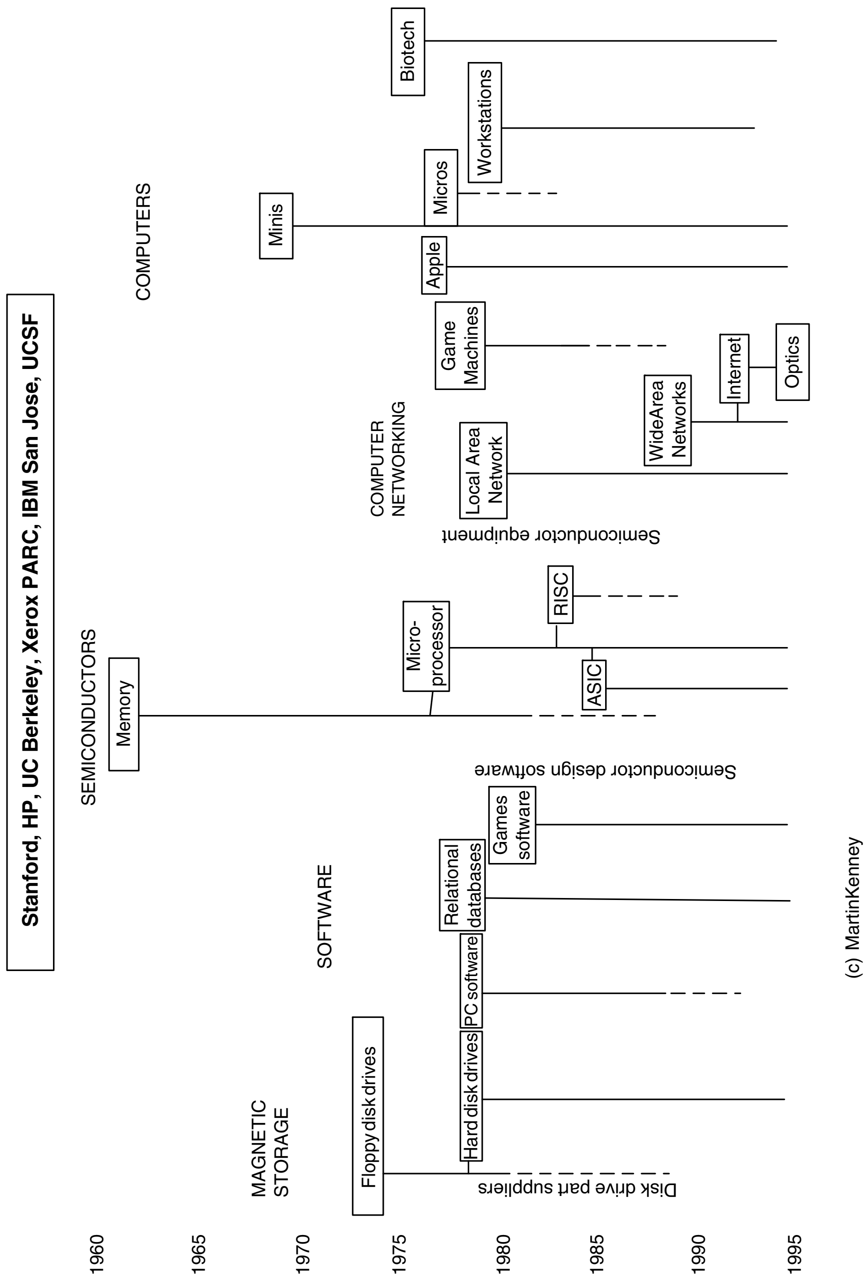

Figure 3.1. Genealogy of Silicon Valley technologies

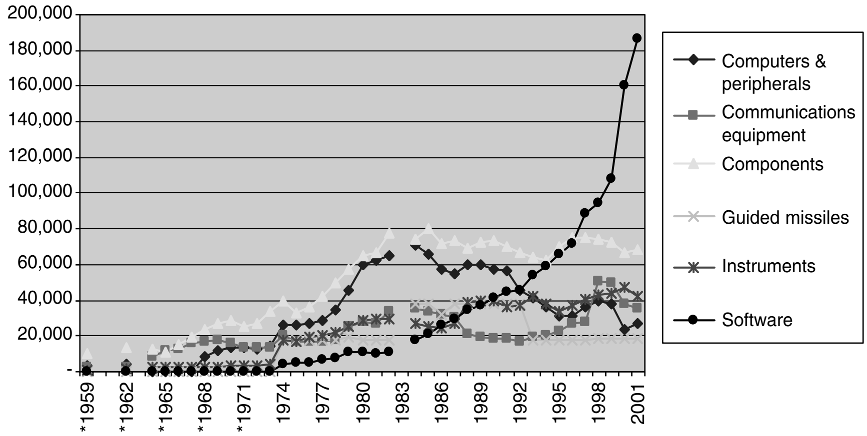

Figure 3.2. Employment in four Bay Area counties, 1959–2001

Note: Data before 1998 was collected by SIC code. For 1998–2001 data was not available in SIC codes. Therefore data was collected in NAIC codes that approximate SIC codes.

because it peaked in the early 1980s and then decreased to approximately 25,000 in 2001. Benefiting from the dot-com boom, communication equipment employment grew from approximately 20,000 in the 1980s to over 50,000 in the late 1990s. Scientific instruments also have been an important contributor to Bay Area employment since the 1970s. However, the overwhelming growth has been in software, an industry that did not even merit a separate category until the early 1970s; a few years after IBM signed the consent decree unbundling software and hardware.

Employment provides one perspective on the structure of the Bay Area high-technology industries. Figure 3.3 indicates the number of establishments in each industry, and this provides a different perspective. The number of establishments in each industry differs so radically that a logarithmic scale was required to present the data. Notice that during the entire period there were no more than six establishments in guided missiles. In the case of components, instruments, communication equipment, and computer and peripherals, the number of firms was in the hundreds, though obviously there was much churn during the entire period. In absolute terms, the number of computer establishments declined since its high in the 1980s. This corresponds with the proliferation and later shakeout of microcomputer and workstation manufacturers. The one industry showing a continuing high rate of entry is software, which, with a few exceptions of which the most notable was the collapse of the

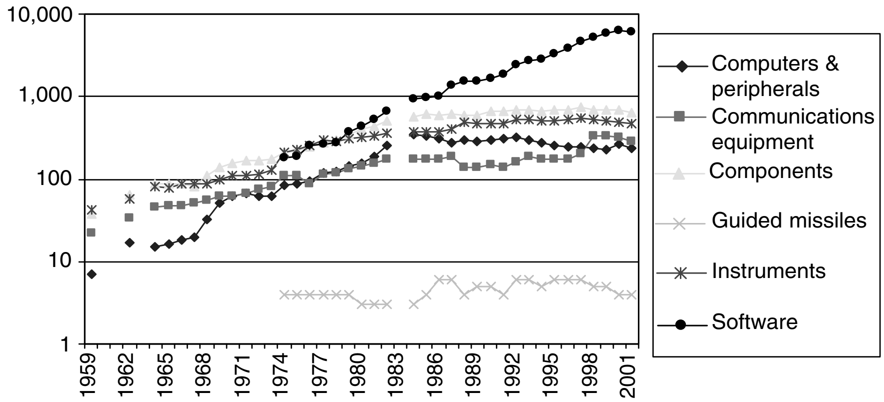

Figure 3.3. Establishments in four Bay Area counties, 1959–2001

Note: Data before 1998 was collected by SIC code. For 1998–2001 data was not available in SIC codes. Therefore data was collected in NAIC codes that approximate SIC codes.

dot-com bubble in 2001, has continually grown in the number of establishments and employment since the Census of Manufacturing first began collecting data in 1974.

The quantitative indicators and the figure provide an overview of the development of the region. In the following sections, we examine the development of the most salient industries and firms providing a richer description of the coevolution of the region, technologies, and industries.

Semiconductors and Ancillary Industries

Over the last four decades, semiconductor technology has been characterized by one overwhelming dynamic, namely Moore's law, which has correctly predicted that the areal density of transistors would double every eighteen months, and since the cost of a semiconductor device is roughly comparable to the chip's dimensions, either performance increases for the same price or price drops accordingly. What this means is that each new generation of semiconductor devices is able to process more information than the previous generation, providing the opportunity to increase the speed and capability of any artifact containing semiconductors. As a result, products containing ICs experience constant improvements in functionality, and functionality that formerly was too expensive or even impossible to undertake continually becomes less expensive and enters the realm of the possible.

Semiconductor technology was so fecund in opening new economic spaces that new business opportunities repeatedly emerged, and the cognoscenti had opportunities to create their own firms. This fecundity is illustrated by the fact that Fairchild and its successor firms experienced 134 spin-offs by 1986 (SEMI 1986), and there have been more since then. In tandem with the increase in areal density-making integrated circuits less expensive per transistor, the cost of a fabrication facility doubled every four years (Leachman and Leachman 2004). When Fairchild began producing chips, converted pizza ovens were used for the baking process. By 1975, a fabrication facility cost approximately $50 million (OhUallachain 1997: 220) and in keeping with what product life-cycle theory would predict, entry costs increased to the point at which there were far fewer entrants.[3] According to SEMI's genealogy, from 1974 to 1980 inclusive there were 21 entrants in Silicon Valley (or an average of three per year). In the seven prior years 1967–73 inclusive, there were forty-three start-ups (an average of 6.1 per year). Yet in the following six years from 1981 through 1986 inclusive, forty-six firms were established (an average of $7.7 = 46/6$ firms per year). AQ3

The increased rate of entry after 1981 was the result of a collective action solution to increasing cost of fabrication. Beginning in the early 1980s, a number of start-ups were established to design and market new ICs. However, they contracted for manufacturing from the integrated producers that had spare capacity. This circumvented the entry barrier created by the capital cost of fabrication. The integrated producers benefited, because their expensive fabrication facilities could be fully utilized. The difficulty with this solution was that during semiconductor market booms, the integrated manufacturers reclaimed their capacity, and the fabless firms often lost their access to the fabrication capacity. A market-based solution was the silicon foundry specialized in contract manufacturing. These foundries, which were established in Taiwan, were pure contractors that did not compete with their customers. As specialists they had to be willing to invest, provide excellent service, and rapid turnaround (Leachman and Leachman 2004). Soon, a number of Taiwanese firms were established to produce chips designed by other firms. This developed into a symbiotic relationship eliminating the high cost of manufacturing as an entry barrier and unleashing a plethora of new Silicon Valley semiconductor start-ups that specialized in design and marketing.

Semiconductor devices were the foundational industry for the region, and Fairchild was the ideal typical Silicon Valley start-up. However, the key to continuing entrepreneurship in the semiconductor industry has been the ability to create new business models. When the cost of a fab became an entry barrier in the early 1970s, a collective action solution was fashioned that reopened the industry to start-ups and the pace of start-up formation, once again, accelerated. Developing this solution was only possible because the actors in the support infrastructure were willing to back start-ups pioneering new business models.

Frequently, an industrial cluster will both attract and spawn supplier firms for the core industry (Porter 1998). The roots of the semiconductor AQ4 equipment industry can also be traced to Fairchild. Fairchild initially built its equipment internally, but soon decided to divest these activities and assisted the spin-off of firms like Electroglass, Kasper, and Micro Tech (Moore and Davis 2001; von Hippel 1988: 173). The most significant surviving Fairchild-linked firms are Applied Materials (established in 1967), which is the largest semiconductor equipment maker in the world; KLA (established in 1976); Tencor (established in 1976); Lam Research (established in 1980); and Novellus (established in 1984); all of which are located in Silicon Valley. Though very few ICs are made in Silicon Valley, it shares with Japan the distinction of being the global center for semiconductor production equipment design and manufacturing. In fact, the headquarters of the Semiconductor Equipment and Materials Industry Association is in San Jose.

In the last three decades, a merchant IC design automation software industry emerged. This software was a response to the fact that the increasingly complex IC designs could no longer be done on paper without an unacceptable number of errors. Thus, in the late 1960s the integrated semiconductor firms began developing software tools for design automation. Fairchild was an early leader as its engineers developed Computer-Aided Design (CAD) software (Walker 1998). At the beginning of the 1980s, a number of IC design software start-ups were established. Many of the advances were made at UC Berkeley and certain UCB professors participated in forming start-ups. For example, in 1982 Solomon Design Associates was established by Jim Solomon who was assisted by a number of UCB professors. SDA merged with ECAD, a start-up that was publicly traded, to form Cadence Design Systems (Solomon 1988). AQ5 Today, Cadence is the world's largest supplier of electronic design technologies, methodology services, and design services. In 1986, Synopsys, a major competitor, was founded in North Carolina, as a spinout from a General Electric acquisition, Calma. However, at the suggestion of its VC investors moved it to Silicon Valley (de Geus 1988). As the software AQ6 improved, an ever-greater number of the IC firms abandoned their in-house software and purchased software from the design software vendors. The standardization of the design software facilitated the rise of the fabless semiconductor firms as they could purchase their design tools, releasing them from the onerous task of creating their own software. The software also allowed the foundries to stipulate their manufacturing parameters in the software to be used by the designers. In other words, the design software became the interface between the designers and the manufacturers.

The development of a supplier industry enriched the semiconductor industry ecosystem. A number of these firms were very successful and thus also enriched the venture capitalists investing in them, thereby contributing to VC industry growth. Each further development of the division of labor reinforced not only the semiconductor industry, but also the institutions supporting the entrepreneurial infrastructure.

The semiconductor industry was important for a number of reasons beyond its technological fecundity. First, the large number of spin-offs in the 1960s encouraged the already existent entrepreneurial culture. Second, the semiconductor industry provided significant investment opportunities for venture capital. Third, it attracted attention to the region and many of the region's entrepreneurs including Robert Noyce, Gordon Moore, and Jerry Sanders, became iconic figures, even as the region became Silicon Valley.

Computers

Silicon Valley has been the birthplace of computer firms serving a wide variety of product classes (i.e. IBM-compatible mainframes, minicomputers, work stations, personal computers, etc.), though interestingly enough, Silicon Valley only became dominant in workstations. Rather than discuss the entire history of computer producers in Silicon Valley, the greatest attention is paid to the computers based on microprocessors, a new category of integrated circuits that were pioneered by Silicon Valley semiconductor firms in the early 1970s. These small computers dedicated to individuals were central to the establishment of the networked, distributed computing paradigm that dominates contemporary computing. This period is also interesting, because in personal computing today, Silicon Valley firms produce many of the crucial components, even though Silicon Valley is no longer the center of the PC industry.

Initially, of course, the computing industry was dominated by IBM and the various other mainframe producers. It was with the minicomputer, which was so important for the building of Route 128, that Silicon Valley firms began to experience success in computing. The greatest success was HP, but many other VC-financed start-ups entered the market; some of them, such as Tandem Computer established in 1975 to offer fail-safe computing, captured unique niches while others were me-too firms. Another important firm was Amdahl, which was founded in 1970 by Eugene Amdahl, a key IBM computer designer, and offered an IBM plug-compatible computer. A number of these computing firms were successful, but they did not spawn waves of new firm creation and entirely new industries, rather they occupied niches and created large capital gains for investors.

For Silicon Valley, the great wave of new firm creation in computing would begin in the late 1970s when two technological trajectories combined to create personal computing. The first trajectory was the work at Xerox PARC, which developed an expensive workstation that was a personal computer, that is not a time-shared computer. The Xerox effort, in fact, created a workstation designed by engineers for engineers. Xerox failed to capture the market, but many start-ups entered the market to try where Xerox was failing. Very quickly, a market for workstations developed and an industry emerged led by Sun (Stanford University Network) Microsystems based in Silicon Valley, and Apollo Computers based in Route 128. Sun became the dominant workstation provider, though in the late 1980s and early 1990s, it was challenged by another Stanford spinout, Silicon Graphics, Inc., which specialized in graphics computing. Eventually, the workstation firms would morph into the computer server providers.

The other personal computing trajectory was what was then called microcomputers, and it led directly to the PC. Beginning in the mid-1970s, many hobbyists and engineers including Apple's Steve Jobs and Steve Wozniak began building computers using the newly introduced microprocessors from Silicon Valley firms, such as Intel and Zilog, and the non–Silicon Valley firm Motorola. Silicon Valley soon became a hotbed of hobbyist computer start-ups with their locus in the now famous Homebrew Computer Club that met at Stanford University (Freiberger and Swaine 1984; Langlois 1990).[4] Of all the start-ups, Apple Computer was the most strategic as Steve Jobs actively tapped the Silicon Valley entrepreneurial support structure (Young 1988: 151). By utilizing this infrastructure and conforming to its requirements, Apple was transformed as investors required the appointment of experienced management and made other changes necessary to establish a real business. This support helped tip the scales for Apple's survival and growth.

During the early 1980s microcomputer start-ups proliferated. By all measures, the region was on its way to becoming the industry center. New firms were being established to provide software (e.g. Visicalc was developed by Bay Area entrepreneurs) and components. But then in August 1981, IBM introduced its PC, which rapidly became the dominant design, and nearly all the non-IBM compatible microcomputer firms in Silicon Valley and other places disappeared. Within three short years, most Silicon Valley microcomputer firms, with the notable exception of Apple, left the business (Angel and Engstrom 1995). After the mid-1980s, Silicon Valley would not host any new PC companies with the exception of HP, which entered during this period.

The demise of the PC industry did not mean that Silicon Valley would not benefit from the diffusion of PCs. Numerous start-ups found opportunities in supplying components including microprocessors (Intel and AMD), BIOS chips (AMI, Phoenix Technologies, and Chips and Technologies), graphics chips (S3, Nvidia, and Cirrus Logic), hard disk drives (HDDs) (Seagate, Quantum, and Conner Peripherals), and even computer mice (Logitech and Kensington). The loss of the personal computer industry to IBM and then the cloners created new markets for peripherals and components that Silicon Valley firms could supply.

With the introduction of the IBM PC, with its simple architecture and the ability of low-cost cloners to enter the market, Silicon Valley's technological prowess no longer provided any particular advantage for PC assembly. Apple survived, in an ever-narrowing niche, on the basis of marketing and some desirable software features. Despite this, Silicon Valley's position as a center for computing systems firms deteriorated as the PC turned computing hardware into a commodity, and eroded the workstation market. In historic terms, with each new computing category Silicon Valley firms were early leaders, and yet, in some cases, the industry evolved in ways that prevented them from remaining in that industry.

Peripherals—Magnetic Storage

The origins of the magnetic data storage industry can be traced to research conducted in IBM's San Jose Laboratories. Beginning in the 1970s, after the IBM consent decree, which unbundled IBM's software and allowed plug-compatibility (see Amdahl above), entrepreneurs began to leave IBM's San Jose operation to establish firms to exploit the new market opportunity of supplying storage devices for the new entrants. Soon, Silicon Valley experienced a wave of spin-offs in HDDs similar to the earlier one in semiconductors. During the 1980s, in tandem with the rapid growth of the PC industry, there were many VC-financed entrants in the HDD industry (McKendrick et al. 2000). Since the integrated HDD manufacturers like IBM and DEC would not sell components to the new entrants, there was enormous demand (Christensen 1992: 95). These small independent HDD manufacturers were eager to buy components, creating opportunities for component supplier start-ups. This prompted a massive wave of start-ups as the venture capitalists initially experienced enormous returns through public stock offerings and acquisitions. However, by the mid-1980s, the HDD industry experienced a powerful shakeout of both HDD manufacturers and component suppliers (Bygrave and Timmons 1992). The collapse of AQ7 the HDD Bubble did not mean that there were no new opportunities in fields related to magnetic storage. For example, in the 1990s, a new area of VC funding was HDD arrays, which are groups of HDDs using sophisticated software working together so as to provide redundancy and back up (McKendrick, Doner, and Haggard 2000; McKendrick 2001). Still later there was a wave of start-ups commercializing storage area networks, which combined networking technology with storage technology to optimize a firm's usage of its various data storage systems.

In summary, magnetic storage exhibited similar technical and organizational characteristics to semiconductors. The technology was rapidly improving; there was a global class source of ideas and technical personnel located in Silicon Valley, and a similar entrepreneurship and spin-off dynamic. As with semiconductors, as the entry barriers in HDD manufacturing increased, the entrepreneurs found new opportunities in disk arrays and storage area networks. Despite earlier shakeouts, VC proved willing to fund storage-related start-ups with new business models.

Computer Networking[5]

The first computer networking firms in Silicon Valley were established in the early 1970s (Burg 2001). Time-sharing of minicomputer capacity was one of the earliest forms of computer networking, and a number of start-ups were established in Silicon Valley and other regions to exploit it. As a greater number of computers were installed on corporate campuses, an opportunity arose to provide technologies that would allow for faster data transfer rates through local area networks (LANs). The initial opportunity was in exchanging data between mainframes.

The proximate cause for dramatically increased interest in computer networking was an effort that began in the early 1970s to automate the office. This office of the future required a network to share files between computers and expensive peripherals such as printers and data storage devices. A pioneer in this quest was Xerox PARC, which in the mid-1970s created a system of small computers, laser printers, and data storage devices networked by what would be called Ethernet. PARC was not alone in this effort; minicomputer firms such as Wang Computers were also trying to create the future office.

At the end of the 1980s, computers were proliferating and entrepreneurs began forming firms to design and produce networking equipment, which interestingly enough was dependent on semiconductors capable of signal processing. At the time, the market was still small and there were no standards to ensure computer interoperability. The critical event that catalyzed the formation of an industry was the 1980 decision by Xerox to offer low-cost licenses for the Ethernet standard. In 1978 Robert Metcalfe left Xerox PARC and in 1979 started 3Com. In rapid succession, Zilog lost three groups of LAN entrepreneurs. As Ethernet became the de facto standard, a positive feedback loop ensued as the increasing number of users created a growing market for yet other innovations (Burg and AQ8 Kenney 2003), and venture capitalists became more confident in funding firms (Burg and Kenney 2000). The proliferation of LANs, many running different protocols, created an opportunity for an interconnection solution. A number of firms were created to solve this problem. The most successful would be Cisco Systems, a Stanford University spin-off that commercialized a multiprotocol router.

In the early 1990s, data communications traffic exploded as LANs proliferated and wide area networks were created. File-sharing and e-mail became standard business applications, and corporations began interconnecting their global operations. The increasing standardization of the datastream meant that a simpler, cheaper, and faster solution, the switch, could be deployed. In typical fashion entrepreneurs began leaving existing firms to establish switching firms with VC financing. To ensure they did not miss this new technology, the established networking firms, such as Cisco, Synoptics, and 3Com, acquired many of these switching start-ups for large premiums, encouraging greater investment and yet more spinouts.

In the 1990s, the networking firms, and especially Cisco, developed a strategy of scanning their ecosystem to identify firms developing important new technologies and markets. Start-ups that were experiencing the greatest success were then acquired. In effect firms, especially Cisco, were using the VC financing system as an integral component of their R&D strategies (Mayer and Kenney 2004). This encouraged a further proliferation of networking start-ups established in the hope that they too would be acquired. The opportunities in networking were not limited to simply increasing speed and bandwidth. The network also became more complicated, thereby providing entrepreneurial opportunities for network management, security, and other software and hardware such as specialized ICs; many of these opportunities were exploited by start-ups.

By the mid-1990s computer networking had become one of the core Silicon Valley industries. A business model emerged in which venture capitalists-funded start-ups that were established with acquisition as an exit strategy. Cisco pioneered a new corporate strategy of using the Silicon Valley start-up ecosystem to identify the new technologies that would affect its business. As firms competed and grew and yet others were formed, Silicon Valley increasingly became the knowledge center for computer networking. This deep knowledge meant that Silicon Valley firms, entrepreneurs, and venture capitalists would be uniquely positioned to see the next big thing.

The World Wide Web

The World Wide Web (WWW) protocols were not a product of Silicon Valley; in 1991–2 they were developed at CERN in Geneva (Abbate 1999; Kenney 2003). At the time, there were few start-ups aiming to exploit the Internet, which was still largely an academic operation funded and controlled by the US federal government. In 1993 entrepreneurs had not yet comprehended the opportunities that the Internet represented. There was also a delay in convincing venture capitalists that the WWW presented an investment opportunity (Ferguson 1999). However, the lag in comprehension did not last long, especially in Silicon Valley, and by early 1994, venture capitalists were receiving business plans from entrepreneurs with ideas for the commercial exploitation of the WWW. The first easy-to-use Web browser Mosaic was developed at the University of Illinois and given away for free. Mosaic formed the basis of one of the earliest Internet start-ups, Netscape, which was established in April 1994 by Jim Clark, an ex-Stanford professor and founder of Silicon Graphics Inc. He went to the University of Illinois and hired most of the key persons who had designed Mosaic and moved them to Silicon Valley. Less than one and one-half years later, Netscape had an initial stock offering in August 1995 at a valuation of nearly $1 billion. Netscape's remarkable increase in value alerted every venture capitalist and entrepreneur that the WWW was a new opportunity. Given the greater VC resources and large number of entrepreneurs, the Bay Area quickly became the center for WWW start-ups (Kenney 2003; Zook 2002).

As the number of WWW users exploded, new business ideas and opportunities proliferated. This expansion provided opportunities for yet other start-ups to develop new software and Web-based services. Businesses were built around searching and cataloging other sites, providing instant messaging, selling products online, software tools, and Web-hosting services among others. Investors were willing to fund entrepreneurs experimenting with an amazing proliferation of business models. As these firms went public or were acquired at large premiums, and as the user base grew, the high stock market valuations for Internet-related firms unleashed a frenzy of investing encouraging even greater speculation.

By mid-1999 there was what might be termed a full-scale investment panic as public investors drove the price of new issues skyward. By the time the Bubble ended in 2000, more than 370 self-identified Internet-related firms had gone public and their total valuation had reached $1.5 trillion, though they had only $40 billion in sales (Perkins 2000). Approximately, 50 percent of all the new Internet firms were headquartered in the Bay Area. In 1999, the average return for early stage VC funds was 91.2 percent, the highest in history (NVCA 2000*a*).[6] The returns for the most successful funds were astronomical—many had annual returns of 100 percent and one even had a 400 percent annualized return. The amount of VC invested in Internet-related firms grew from a nearly negligible $12 million in the first quarter of 1995 to $31 billion in 1999 (NVCA 2000*b*). In percentage terms, the increase was equally dramatic, growing from a negligible percentage in 1995 to over 60 percent of total investment in the fourth quarter of 1999 (NVCA 2000*b*: 31). Faster than anywhere else, Silicon Valley entrepreneurs glimpsed the potential of the WWW as a commercial opportunity and then mobilized the resources necessary to try to enact that future.

Software

The richness and diversity of software firms in Silicon Valley are remarkable. As mentioned earlier, the highly specialized field of semiconductor design software is almost entirely located in Silicon Valley. In 2003 software was the largest employer in Silicon Valley, and despite recent setbacks in the longer term it is expected to grow (see Figure 3.2).

In software, as has been the case with other industries, Silicon Valley has pioneered certain software sectors and then lost them. For example, it is no longer a significant producer of PC software, with certain exceptions, such as Intuit for PC financial applications and various PC game software firms. Microsoft's PC software monopoly resulted in the demise of Silicon Valley firms such as Visicalc and Borland Computer. Even when new PC software such as the Netscape browser is commercialized in Silicon Valley, Microsoft has been able to use its monopoly power to destroy them. The only major survivors have been the tax software producer, Intuit, and the utilities software firm, Symantec—and both of these are threatened by Microsoft.

Silicon Valley firms have been far more successful in business productivity software. The most significant of these are relational database software, which was pioneered roughly contemporaneously at IBM's San Jose Laboratories and UC Berkeley. All of the key independent relational database firms (with the exception of Microsoft, a late entrant) are located in Silicon Valley. The largest of these is Oracle which is the second largest independent software firm in the world. Other important firms include Sybase, Informix (purchased by IBM), and IBM. Oracle, in particular, has spawned other important business software firms including Peoplesoft and Seibel, which pioneered other niches in the business software field.

In entertainment software, Silicon Valley also experienced success. Here, the Silicon Valley pioneer was Atari, which later collapsed. Atari's demise in the 1970s permitted the control over the game boxes to move to Japan, and today Japan is the major competitor for the US game software makers. The largest entertainment software firm in Silicon Valley is Electronic Arts, which is located in Redwood City. Electronic Arts, which used to be a developer, today not only produces games but also distributes them for other producers. They are intimately connected to the cutting-edge PC graphics chipmakers also located in the region, because these graphics capabilities determine software usability. Drawing upon a similar expertise base, the Bay Area is also host to a number of leading computer film animation firms including Pixar and Lucas Arts. Producing special effects, these firms are critical for contemporary cinema and computer games.[7]

Though Silicon Valley has not proved to be as dominant in software as in some other industries, it is one of the key global software centers. Today's Silicon Valley start-ups use Linux operating system and programs such as Java as the basis of their products. In fact, the Finnish developer of

Linux moved to Silicon Valley. Open source offers them a way to outflank Microsoft's grip on software innovation. Moreover, even as this is written, Silicon Valley start-ups are integrating Indian software production capabilities into their business plans, in the same way, as the semiconductor design firms have integrated Taiwanese fabs into their business plans. In other words, new business models are still being created.

Support Infrastructures and Culture

The development of a rich and complicated support infrastructure for entrepreneurs provides important advantages to Bay Area entrepreneurs. The goal of the actors in the support infrastructure is to participate in the capital gains that accrue when one of the start-ups is successfully sold, either to the public in an initial public stock offering or through an acquisition. The entrepreneurial support network has become so resource laden that the various actors in the network are willing to fund emerging ideas in new fields as has been the case in biotechnology (see Kenney 1986; Romanelli and Feldman in this volume), superconducting, and, most recently, nanotechnology. If these investments fail, as was the case in superconducting, only a relatively small proportion of the total VC resources and, perhaps, a few venture capitalists will be lost. If the investments succeed, as was the case with biotechnology, a new investment field will be created. Ultimately, the actors are agnostic as to what constitutes a suitable field for investment the market for the firms they support informs them by providing them with capital gains.

The Silicon Valley culture benefits from interaction in many venues that contributes to cross-disciplinary information sharing and synthesis. With so many technologists, investors, and others interacting, there are ample opportunities for combining existing technologies to create new products (Hargadon 2003). One often cited example of this is the bioinformatics start-ups that combine the technologies of computing and gene-mapping. Many of these were formed in the Bay Area.

The repeated successes in establishing new firms and then being able to garner large capital gains on a significant number of them created a culture of entrepreneurship. Interestingly, this culture differs remarkably from other entrepreneurial cultures that are based on the idea of establishing and then managing and controlling one's own firm. The Silicon Valley culture is based on establishing and then selling the company to either the public or a corporate acquirer. In either case the entrepreneur loses control of the firm. The objective, then, is capital gains, which under normal conditions can only be secured by creating a viable firm (though during the last high-technology bubble many unviable firms were created and foisted on the public). It also bears mentioning that other regions such as Boston and Israel appear to have cultures that are similar.

Though we focus on identifiable institutions in this chapter, it is important to note that an entrepreneurial culture developed in Silicon Valley which, though not unique, can be characterized as extreme entrepreneurism. As Saxenian (1994) observes, during the economic boom periods changing jobs is a given part of the labor market in Silicon Valley. Over time, participating in a start-up has become a career path. This acceptance of start-ups as normal has reduced the career risk of becoming an entrepreneur. Moreover, whereas thirty years ago the entrepreneur was expected to use credit card debt and even mortgage their home as part of the process, in the last twenty years such measures are no longer necessary prior to receiving VC. It is not in the venture capitalist's interest to raise the barriers to entrepreneurship and increase the concerns of the entrepreneur. This lowering of entry barriers has culminated in the mythology that failure will not necessarily prevent an entrepreneur from receiving funding for another start-up. Given that the Silicon Valley economy is based on capital gains, a culture and ideology encouraging entrepreneurship is a prerequisite and a natural outcome.

In keeping with the capital gains-driven economy, one of the primary cultural and economic goals is to secure stock options or equity. This has led to an environment within which equity is extended to a large number of persons in the corporate hierarchy. The ownership of options elicits extraordinary effort from the employees and, if the firm is successful, creates many wealthy managers and engineers. A certain number of these experienced and now wealthy individuals will in turn be willing to invest in other entrepreneurs or even launch their own start-up, thereby perpetuating the entrepreneurial cycle.

Another aspect of the Silicon Valley culture was memorialized in Michael Lewis's book (2000) entitled *The New New Thing*, which described Jim Clark's involvement in the creation of Netscape. In this case the hero is Jim Clark who ruthlessly capitalizes on the new WWW browser technology and reaps enormous capital gains. The region has developed a corporate environment within which new technologies, a great hack, and huge capital gains are the reigning myths. In this environment a hot new firm or technology attracts attention and floods of resumes. The ability to become involved in the hottest new technologies attracts many of the best engineers in that field who desire to be involved in the newest technology. The economic incentives and culture are aligned to encourage high-risk entrepreneurship.

Reflections

An evolutionary and systemic perspective provides an appropriate means for understanding Silicon Valley, and, by extension, other entrepreneurial high-technology districts (Avnimelech, Kenney, and Teubal 2003). Often discussions omit or elide the technological trajectories that underpin such industrial districts and overemphasize cultural aspects; we explicitly argue against this. The basis of much of this romanticization of the entrepreneur is a belief that the culture is *sui generis*. A more appropriate model would treat culture as a constructed and evolving social artifact. The entrepreneurs that have benefited from the system and the actors in the support infrastructure have every reason to support a specific set of cultural beliefs. The environment evolved, though not in a conscious directed manner, as a result of individuals pursuing various goals, one of the most important of which was the capture of capital gains.

Viewed from a longer-term historic perspective, what is striking is how a number of the technologies exploited in Silicon Valley, such as semiconductors, magnetic storage, and computer networking, have had trajectories that have unfolded in such a way so as to enable yet further opportunities to establish new firms. In a number of sectors when potential for future start-ups appeared stymied by requirements such as enormous capital investments to create semiconductor fabrication facilities, new business models were developed to circumvent the entry barrier. An evolutionary perspective highlights the region's remarkable success in repurposing its intellectual assets and attracting new talent from around the world.

The constituents of the support infrastructure created their own niches and then were able to draw resources from the environment. They became actors trying to improve their processes, which by definition, included supporting and assisting the entrepreneurs. They also changed the environment by creating demand for entrepreneurs, reinforcing the cultural valuation of the entrepreneur, and routinizing the start-up process. These actions explicitly recognized that the entry barriers for entrepreneurship are not only financial but also social and psychological. The literature has treated the willingness-to-take-a-chance attitude in Silicon Valley as an innate characteristic; we see it as a communely created social norm. The support infrastructure assisted in this in a wide variety of ways from developing an understanding that it was not necessary to require that the entrepreneur invest their entire net worth into the firm, to allowing the entrepreneurs to receive the greatest attention. In other words, the agents in the support infrastructure changed the environment to be more favorable to their practice.

Institutions and routines developed in the Bay Area ensure that the region can attract the entrepreneurs of the future. For example, its global-class universities and corporate research laboratories continue to attract many of the best and brightest students, researchers, and faculty members. The many very successful high-technology firms, nearly all of which still tout their entrepreneurial origins, attract thousands more engineers and managers some of whom will become entrepreneurs and still more are willing to join start-ups. These individuals are then placed into a munificent environment that values and even glorifies entrepreneurship and, very importantly, places the resources for attempting a start-up within reach. It is a little wonder that new things emerge and attract seed funding in an environment where venture capitalists and a large community of angel investors are willing to invest to explore their business potential.

The ability of this process to discover the New Thing is remarkable. Promising technologies receive resources, both managerial and financial, for experimentation. Those technologies that show evidence of yielding significant capital gains encourage other entrepreneurs to launch firms that attract yet more VC. Successful exits can precipitate full-scale investment manias. In contrast, some technologies do not lend themselves to large gains and they are soon dropped as having no promise for this particular methodology of supporting innovation. For example, Thomas Murtha, Lenway, and Hart (2001) show Silicon Valley was the home to a number of flat panel display screen firms funded by venture capitalists, but quickly the venture capitalists came to understand that the industry provided few suitable investment opportunities and abandoned the field. Other industries, such as personal computers, superconductivity, and soon, perhaps, nanotechnology, received VC investment initially, but were later abandoned.

An entrepreneur with a new business model need only convince a few venture capitalists to gamble. Moreover, in contrast to personal investors, by the nature of the limited partnership format, the venture capitalists must invest or they cannot continue in the business. This means that they are at least willing to listen to high-risk proposals and also willing to invest in high-risk situations. For example, venture capitalists-funded firms established to exploit Linux, such as Redhat and VA Linux, despite the fact that the business models were predicated upon unseating the Microsoft monopoly through the use of a free-operating system. In other words, the infrastructural agents can support very high-risk projects as long as they have a commensurate potential for enormous rewards.

Our evolutionary treatment of organizations and technologies presents Silicon Valley as a complex tapestry replete with commensurate coevolution within which both have shaped each other and created routines and a cultural gestalt that is self-reinforcing. The organizations in the support infrastructure function as an initial selection mechanism. Firms without the perceived requisite potential for outside capital gains are not funded, while ideas that appear to be sound—by the standards of the support network—receive funding, thereby perpetuating their survival. In this ecosystem, actor, incentives, technological trajectories, and business models have coevolved and become mutually reinforcing.

Notes

1. The San Jose Laboratory would pioneer magnetic data storage media and became IBM's global center of excellence for magnetic media. Much later many key Silicon Valley disk drive entrepreneurs spun out of IBM to create new disk drive firms (McKendrick et al. 2000*a*). Later, IBM's laboratory was an important source of the relational database technology that firms such as Oracle and Sybase commercialized in the mid-1980s.
2. The historic record suggests that in Boston there were very few angels, and this, in fact, is cited as one of the reasons for forming the first formal VC firm American Research and Development (see Hsu and Kenney 2004). AQ9
3. The classic citations on industry or product life-cycle theories are Abernathy (1978), Abernathy and Utterback (1978), or, most recently, Klepper (1996).
4. Bill Gates also was far more closely related to this hobbyist stream than he was to PARC.
5. This section is largely drawn from Burg (2001).
6. The three-year compounded average annual return was a more modest 47.9 percent!
7. This may be changing as they use PC-like computers that are harnessed by sophisticated graphics software.

AUTHOR QUERY

[AQ 1] Garud and Karone 2003 is not listed.
[AQ 2] Kenney and Burg 1999 is not listed.
[AQ 3] OhUallachain 1997 is not listed.
[AQ 4] Porter 1990 is not listed.
[AQ 5] Solomon 1900 is not listed.
[AQ 6] de Geus 1900 is not listed.
[AQ 7] Bygrave and Timmons 1992 is not listed.
[AQ 8] Burg and Kenney 2003 is not listed.
[AQ 9] Hsu and Kenney 2004 is not listed.