From the Valley of Heart's Delight to the Silicon Valley:
A Study of Stanford University's Role in the Transformation

Carolyn Tajnai
Computer Forum
Stanford University
Stanford, CA 94305

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Abstract

This study examines the role of Stanford University in the transformation from the Valley of Heart's Delight to the Silicon Valley. At the dawn of the Twentieth Century, California's Santa Clara County was an agricultural paradise. Because of the benign climate and thousands of acres of fruit orchards, the area became known as the Valley of Heart's Delight.

In the early 1890's, Leland and Jane Stanford donated land in the valley to build a university in memory of their son. Thus, Leland Stanford, Jr., University was founded.

In the early 1930's, there were almost no jobs for young Stanford engineering graduates. This was about to change. Although there was no organized plan to help develop the economic base of the area around Stanford University, the concern about the lack of job opportunities for their graduates motivated Stanford faculty to begin the chain of events that led to the birth of Silicon Valley.

Stanford University's role in the transformation of the Valley of Heart's Delight into Silicon Valley is history, but it is enduring history. Stanford continues to effect the local economy by spawning new and creative ideas, dreams, and ambitions.

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Carolyn Tajnai
Stanford Computer Forum
Stanford University

Silicon Valley, located on California's San Francisco peninsula, radiates outward from Stanford University. It is bounded by the San Francisco Bay on the east, the Santa Cruz Mountains on the west, and the Coast Range to the southeast. At the turn of the century, when fruit orchards predominated, the area was known as the Valley of Heart's Delight. Since then, semiconductor chips, made of silicon, have become the principal product of the local high-technology industry. The term Silicon Valley was used occasionally—mostly by easterners, who would mention making a trip to Silicon Valley. In 1971, it was popularized in a series of articles, "Silicon Valley USA," written by Don Hoefler for *Electronic News*. But Silicon Valley's roots can be traced to the Depression years of the 1930's. Professor Frederick Terman, a man of vision, drive, and immense ability, had a dream and his dream became reality. There is no comprehensive study of Stanford University's role in the metamorphosis of the Valley of Heart's Delight into the Silicon Valley in the latter half of the Twentieth Century. This may have led to a lack of understanding on the part of the public regarding the role of Stanford in the transformation.

Terman's motive was to help create local jobs for his electrical engineering graduates. The mission of a university is teaching and research. When university research leads to new technology, it is appropriate for industry, not academia, to develop and market that technology.

Because of the location and fine weather, the Santa Clara Valley would have grown and developed over the years without the presence of Stanford University. However, because of the University's commitment to the entrepreneurial spirit, the Valley became a haven for high-technology companies. Stanford University established a stimulating environment that encouraged the proliferation of new start-up companies. Large corporations established research centers in the area, and venture capital and real estate investment companies increased the momentum. Thus, Stanford University was instrumental in transforming the Valley of Heart's Delight into the Silicon Valley.

Frederick Terman has been called the Father of Silicon Valley. He received his undergraduate and engineer degrees from Stanford University, and a PhD in 1924 from Massachusetts Institute of Technology (MIT) under the direction of his advisor, Professor Vannevar Bush. While at MIT, Terman was strongly influenced by Bush who had participated in founding the predecessor of the Raytheon Corporation, and by the close ties that MIT enjoyed with industry. William Barton, who founded MIT in 1861, had created an institution to "respect the dignity of useful work" (Roberts, 1991). From its beginning, MIT established close ties with technology-based industrialists such as Thomas Alva Edison, Alexander Bell, and Alfred P. Sloan.

Upon receiving his PhD, Terman was offered a faculty position at MIT, but because of health concerns, he chose to return to Stanford, and later accepted a faculty position there.

In the 1930's, with the country in the midst of the Great Depression, there were almost no job opportunities for young engineers graduating from Stanford's electrical engineering department. A few jobs were available in Los Angeles but to search for good employment, many graduates had to go three thousand miles to the east coast, a difficult trek in those days.

FIRST GENERATION OF COMPANIES

Although there was no organized plan to help develop the economic base of the area, the concern about the lack of job opportunities for their graduates motivated Terman and other faculty members to begin the chain of events that led to the birth of Silicon Valley.

HEWLETT-PACKARD

William Hewlett and David Packard were electrical engineering students who spent a lot of time in the Stanford electronics laboratory talking about "someday" having their own company (Blakeslee, 1977). Upon graduation in 1934, Packard took a job at General Electric in New York. Hewlett stayed on for a year of graduate study with Professor Terman before leaving for MIT, where he received a master's degree. He returned to Stanford in 1936 to work on an engineer degree in electrical engineering.

Terman began to encourage some of his promising students to start companies near the university. When the "resistance-tuned oscillator" was discovered, Terman thought it had great commercial possibilities, and he told Hewlett that it looked like it could be used to make an instrument that would be a lot simpler and cheaper than anything on the market. However, there were some stability problems that had to be solved to make it functional. Hewlett devised an innovative solution; he designed and built an audio oscillator, a device that generates signals of varying frequencies which took advantage of the nonlinear resistance-temperature characteristic of a small light bulb to remove a serious instability. The addition of one inexpensive component turned a balky laboratory curiosity into a reliable, marketable instrument (Blakeslee, 1977).

Money was a problem, but by great effort and a bit of luck, Terman was able to get some money together for the project, including a $1,000 grant from Sperry Gyroscope (Climo, 1982); $500 was spent for materials and $500 for Packard's salary as a research assistant. In the autumn of 1938, Packard took a leave of absence from his job at GE (which paid $110 a month) to return to Stanford University (for $55 a month) (Blakeslee, 1977).

Hewlett-Packard was incorporated in January 1939. The company's first large order was from Walt Disney Productions for four oscillators to be used in making the motion picture "Fantasia." Today, Hewlett-Packard is one of the world's largest producers of computers and electronic measuring devices and equipment. The 1995 records show that Hewlett-Packard employs more than 100,000 people worldwide and has net revenue in excess of $30 billion a year.

VARIAN ASSOCIATES

In 1937, William Hansen, an assistant professor in physics, teamed with Sigurd and Russell Varian to develop the klystron tube, an electron tube in which bunching of electrons is produced by electric fields used for the generation or amplification of ultra-high frequency signals. Ed Ginzton, a PhD student under Terman, credited Terman for referring him to Hansen. Ginzton quickly became involved with Hansen and the Varians

in the klystron project. Stanford University helped by providing free use of the physics laboratories and $100 a year for materials and supplies. The group spent the war years at Sperry Gyroscope in New York. After the war, the Varians, Hansen and Ginzton returned to California; Hansen and Ginzton became Stanford faculty members.

In 1948, the Varians, Hansen and Ginzton founded Varian Associates. The 1995 records indicate that Varian employs 6,900 people worldwide and has net revenue of $1.781 billion.

SHOCKLEY TRANSISTOR CORPORATION

With Terman's encouragement, William B. Shockley, co-inventor of the transistor, returned to his hometown Palo Alto in 1956. He established the Shockley Transistor Corporation in the Stanford Industrial Park where they produced Shockley four-layer diodes, and he later joined the Stanford faculty.

In 1957, eight of Shockley's bright young electronics specialists (Gordon E. Moore, C. Sheldon Roberts, Robert N. Noyce, Eugene Kleiner, Victor H. Grinich, Julius Blank, Jean A. Hoerni, and Jay T. Last) left to establish Fairchild Semiconductor in Palo Alto. This was the beginning of the semiconductor industry. Fairchild became a corporate seedbed spawning over 38 new companies which were started by former employees. Of these, Intel is one of the most successful.

Shockley Transistor Corporation never recovered from the blow of the Fairchild spin-off (Rogers & Larsen, 1984), and was sold to Clevite in 1960, to ITT in 1965, then closed for good in 1968 (Lowood, 1994).

In 1971, Intel introduced the world's first microprocessor, which sparked a computer revolution that has changed the world. About 75 percent of the personal computers in use around the world today are based on Intel-architecture microprocessors. Today, Intel supplies the personal computing industry with the chips, boards, systems and software that are the ingredients of the most popular computing architecture. These products help create advanced computing systems for personal computer users. Intel reported annual revenue of $16 billion for 1995.

WATKINS-JOHNSON

Professor Dean Watkins, a former professor of electrical engineering, founded Watkins-Johnson in December 1957. The company produces microwave equipment and instrumentation. They use microprocessors as the controllers for measuring devices, and are working in the area of digital communications, especially secure digital communications.

In 1995, Watkins-Johnson had $387 million in revenue.

SYNTEX

Professor William S. Johnson of the University of Wisconsin was offered the Stanford chemistry department chairmanship in 1958. He asked Dr. Carl Djerassi (University of Wisconsin, Chemistry PhD'45) if he would be interested in joining him. According to Djerassi (Djerassi, 1992), Stanford's medical school had moved to the Palo Alto campus from San Francisco. "Professor Fred Terman felt that the presence of a first-rate medical school and an upgraded chemistry department would encourage biomedically or chemically oriented industrial enterprises to join the electronic and

computer companies in the Stanford Industrial Park." Professor Johnson and Dr. Djerassi agreed to come as a pair, and Professor Terman agreed on the terms.

Dr. Djerassi was vice president for research at Mexico-based Syntex Corporation, and as a result of his urging, Syntex established a US subsidiary and research branch in the Stanford Industrial Park. This set in motion a whole new chain of company formation in biology and medicine. Syntex assigned Alejandro Zaffaroni, executive vice president, to the new research laboratory, and Djerassi and Zaffaroni were responsible for the formation of Syva, Zoecon, and Alza.

Syntex became an international company with headquarters in the Stanford Industrial Park. The 1993 financial reports show employment of 10,300 and net sales of more than $2 billion per year. After 50 years as an independent company, Syntex Corporation agreed May 2, 1994, to be acquired by Roche Holding Ltd., a Swiss pharmaceutical company, in the largest takeover Silicon Valley has seen (Wolf, 1994).

STANFORD RESEARCH PARK

In 1949, Russell Varian and Ed Ginzton thought it desirable to move the research and development branch of Varian from San Carlos, ten miles north of Stanford, to a site closer to the university. Varian approached the university with a proposal for leasing land from Stanford to build a new research and development facility for Varian Associates (Lowood, 1987).

It was an opportune time. Stanford needed money to finance the university's rapid postwar growth. Leland Stanford's original bequest of his farm, consisting of over eight thousand acres prohibited the sale of this land, but there was nothing to prevent its being leased. Long-term leases were just as attractive to industry as outright ownership; thus the Stanford Industrial Park (later renamed the Stanford Research Park) was founded. The goal was to create a center of high technology close to a cooperative university. At Terman's suggestion, it became university policy that leases be limited to high-technology companies that might be beneficial to Stanford. In 1951, Varian signed the first lease. Following soon after were Eastman Kodak, General Electric, Performed Line Products, Admiral Corporation, Shockley Transistor Laboratory of Beckman Instruments, Lockheed, Hewlett-Packard and others.

TRANSITIONAL PERIOD

During the 1960's, members of the Stanford community were not as active in founding new companies in the area as were their MIT counterparts. According to Roberts (1991), a 1971 study showed that only 8 out of 243 new technical firms in Silicon Valley had their origins in Stanford University. MIT alumni founded 175 of the 243.

SECOND GENERATION OF COMPANIES

From 1971 to 1993, over 300 full-time ongoing companies had been founded by members of the Stanford University community (Leone, et al., 1993). The following are examples of new companies founded by faculty, graduates and staff of the Stanford computer science community.

PROFESSIONAL SOFTWARE

In 1977, Earl Sacerdoti (CS PhD'75) founded Professional Software, which attempted to develop an emacs editor for the Apple II. According to Sacerdoti, the company folded without completing the project—the hardware & software weren't up to it.

Machine Intelligence Corporation

In 1978, Dr. Sacerdoti founded Machine Intelligence Corporation which pioneered industrial machine vision. The company developed and marketed the first commercial vision-guided robot system together with Unimation. Sacerdoti said, "In 1988, we closed down after thirty-nine(!) consecutive losing quarters. Remaining assets were transferred to de la Rue Giori of America, which completed a project to develop a real-time money inspection system for banknote printing presses, now installed in several European sites."

Symantec Corporation

A research project begun at Machine Intelligence around 1979 with a $25,000 grant evolved into a spin-off company, Symantec, founded in 1982. Its flagship product was Q&A. Sacerdoti believes Symantec is the first success of the US Government's Small Business Innovation Research program.

Symantec develops, markets, and supports a diverse line of application and system software products designed to enhance individual and workgroup productivity as well as manage networked computing environments. The company employs more than 2,100 people, and for the fiscal year ended March 31, 1996, posted total revenue of $445.4 million.

The Copernican Group

In 1988, Dr. Sacerdoti founded The Copernican Group, a consulting organization specializing in software technology transfer. Sacerdoti maintains that software is NOT at the center of the universe! Major clients have included Apple Computer, Ashton-Tate, Bell Atlantic, Pacific Bell, Schlumberger, SEMATECH, Sun Microsystems, and Yaskawa Electric. Dr. Sacerdoti is the sole employee; affiliated consultants are brought in on specific jobs.

Tolfa

According to Dr. Sacerdoti, he began working with Tolfa in 1991 six months after it was incorporated, "So it's not truly 'my' startup in any sense." Tolfa manufactures and markets a medical device that incorporates what is essentially the only FDA-approved user interface. The device is a prosthesis that helps people with aphasia communicate, and is a commercialization of research performed at the Veterans Administration Rehabilitation Research and Development Center in Palo Alto under Larry Leifer's (Professor of Mechanical Engineering) direction. Tolfa is a privately held company with approximately a dozen employees. Dr. Sacerdoti, although still involved, is no longer an employee.

NESTAR SYSTEMS

Nestar Systems was started in Palo Alto in 1978 with the belief that the then-emerging affordable personal computers would evolve into more than toys, and that their usefulness would be multiplied many times by linking them to each other and to larger computers. Of the four founders, three of them had met at Stanford: Harry Saal (Columbia University, Physics PhD and Stanford Linear Accelerator (SLAC) researcher from 1969-1972), Leonard Shustek (CS PhD'76), and Nick Fortis (SLAC administrator, 1968-1972).

According to Shustek, "We developed and sold what might well be the first networked client-server system of small computers, called the 'Cluster/One,' initially using local-area networks of our own design. The company was a classic case in which a few academic escapees, who know a little about engineering and nothing about business, get to learn on the job by making mistakes. Unfortunately, we made enough of them so that the company, although it grew to have 125 employees by 1985, was never a success. We, of course, like to think it was because we were ahead of our time."

Network General

In 1986, Harry Saal and Leonard Shustek left Nestar and decided to try again. Shustek said, "We saw that local area networks were becoming successful but were difficult to analyze and troubleshoot. We founded Network General Corporation to make tools to manage and diagnose problems in computer communication networks. The first product was 'The Sniffer™ Network Analyzer,' a kind of microscope used to view the interactions between computers and tell you what's going on in understandable terms.

"We must have learned something from our Nestar experience—and/or gotten lucky—because Network General became an almost overnight success. We quickly dominated our tiny market niche, went public in 1989 and now, in 1996, have about 700 employees and revenue of $200M/year. And we're still, after a decade, selling the Sniffer as an important part of our product line."

3COM

Dr. Robert Metcalfe Founded 3Com in 1979. Based on Ethernet technology, 3Com derived its name from its emphasis on COMputer, COMmunication, and COMpatibility.

Metcalfe's networking started at MIT around 1970 and continued at Xerox PARC beginning in 1972. His Harvard PhD dissertation was "Packet Communication," about the Arpanet and Alohanet, from which Ethernet was derived. Ethernet was invented at PARC in 1973, and Metcalfe shares four patents on it. Dave Boggs, who joined Metcalfe's team when he was still a Stanford graduate student, is co-inventor of Ethernet.

Dr. Metcalfe held appointments as Lecturer and Consulting Associate Professor in Stanford's Computer Systems Laboratory (CSL). He offered his new course, "Introduction to Distributed Computing," on Stanford's Instructional Television network.

According to Dr. Metcalfe, "I left Xerox in January 1979 with no hard feelings for the second time (first time was for seven months 1975-76), to pursue entrepreneurial ambitions."

Dr. Metcalfe describes the founding of 3Com, "I incorporated 3Com alone on June 4, 1979, and was the only employee into the fall. Greg Shaw, who had worked in my group at Xerox after graduating from MIT, joined then and became, under SEC rules, cofounder. Ron Crane (MIT BS EE, Stanford MS EE'74, and Xerox PARC) joined after that, but to hell with the SEC, he's a 3Com founder too. We were more an MIT than Stanford company, but hey!

"I attended Vint Cerf's seminar during the summer of 1973 during which TCP/IP was fleshed out some. With Vint's encouragement (from ARPA by then), 3Com was the first company to ship a commercial version of TCP/IP, in December 1980.

"3Com went public in March 1984 and I retired in June 1990. I am now a technology journalist at the International Data Group, which publishes InfoWorld, where I am a columnist with 489,000 readers per week on average. I received the IEEE Medal of Honor for Ethernet in 1996!" Bill Krause became CEO in 1981, and in 1987, 3Com merged with Bridge Communications. Eric Benhamou became CEO in 1990.

3Com continues to be a leader and innovator, providing a wealth of local and wide area network (LAN and WAN) solutions to the global marketplace. Products and systems connect users throughout the network-in-workgroups and building/campus LANs, on WAN backbones, at remote offices, and wherever mobile users plug in and log on. In 1992, 3Com garnered much publicity when they negotiated to change the name of the home of the San Francisco Giants and the San Francisco 49ers from Candlestick Park to 3Com Park. 1995 figures indicate 3Com has over 4,500 employees; approximately 2,000 based in the Bay Area. Sales close to $1.3 billion make 3Com the second largest data networking company.

BRIDGE COMMUNICATIONS

In 1981, Judith Estrin (EE MS'77), Bill Carrico and Eric Benhamou founded Bridge Communications, one of the first LAN and Internetworking companies. Bridge was a leading supplier of high performance, general purpose local area network (LAN) systems which provide a comprehensive solution to data communications requirements of corporations, institutions and government agencies. In 1985, the company went public and in 1987 merged with 3Com. At that time annual sales were about $70 million.

NCD

According to Estrin, "In 1988, after leaving 3Com, we (Carrico and Estrin) joined a group of 5 people that had been working on a prototype of the first X-Terminal with their own money. We joined as President and Executive Vice President and raised the first round of financing." September, 1992, Estrin became CEO and Carrico became chairman. Headquartered in Mountain View, California, NCD's initial public offering was in 1992. Sales in 1993 were $144 million

NCD is dedicated to developing products that provide users access to information in network computing environments—products that truly make the network the computer. A full family of color, monochrome and gray-scale X terminals makes the full power of network computing available on the desktop. A line of PC X server products brings this same power to users whose primary desktop device is the personal computer. Electronic mail and messaging software based on established industry standards allow users to implement a common, integrated system for exchanging all types of computer-based information among multivendor systems across the network.

Precept

Judy Estrin and Bill Carrico founded Precept in 1995; Estrin is president and CEO and Carrico is Chairman of the Board. Precept is privately held and has 20 employees.

Precept Software was formed to develop and market standards-based networking software products for Windows-based PCs that will enable networks to handle the emerging demand for local- and wide-area communication of real-time multimedia information. Taking advantage of the $30 billion installed base of packet-switched networks, Precept's software will work over both the global Internet and private IP LANs and WANs based on such proven technologies as Ethernet, Fast Ethernet and FDDI. Precept products also can utilize, but will not require, new high-bandwidth network technologies such as Asynchronous Transfer Mode (ATM).

Precept management has assembled a technical team which includes experts in the fields of TCP/IP and real-time protocols, Windows software, and multimedia audio/video transmission.

IMAGEN CORPORATION

IMAGEN Corporation was a computer science spin-off that developed and marketed the earliest desktop publishing systems, though that name had not been coined yet. The staff of the Stanford Artificial Intelligence Laboratory (SAIL) had developed graphical printing using a xerographic fax machine that was loaned to them by Xerox PARC (Palo Alto Research Center) in 1971, but the computer used to drive it was a rather large DEC-10. After Canon loaned a small laser printer to the department in 1979, Luis Trabb Pardo (CS PhD'78) coupled it with a microprocessor that could do similar printing of elegant fonts at a much lower cost.

Trabb Pardo and Les Earnest, who had previously been executive officer of SAIL and who had created the first spelling checker there, licensed the new technology from Stanford and founded IMAGEN Corporation in late 1980 to develop, manufacture, and market it. They attempted to get venture capital but found that even though they had an impressive working model, the venture capital community declined to invest, saying that they had never heard of laser printing and observing that none of the large computer companies were developing such systems.

The IMAGEN principals were faced with the alternatives of trying to bootstrap or go out of business. They chose to bootstrap and over a period of four years managed to reach $20 million in annual sales with essentially no advertising and showed a profit each year. At that time some venture capitalists finally did invest, but much larger companies such as Hewlett-Packard and Apple also entered the field then and, because IMAGEN's growth had been stunted by a lack of capital, it was not large enough to compete with them effectively. In 1987, IMAGEN was finally purchased by QMS, a former competitor, and a number of the systems that it developed are still being sold by QMS (Earnest, 1994).

INTELLICORP

IntelliCorp was founded in 1980 by Edward Feigenbaum (CS Professor), Douglas Brutlag (Biochemistry Professor), Peter Friedland (CS PhD'80 and CSD Research Associate) and Larry Kedes (Medicine Professor).

IntelliCorp developed the first commercial programming development environment based on object-oriented technology. Its products are used by information technology organizations in Fortune 500 companies to streamline the development of complex commercial applications that serve the telecommunications, manufacturing, finance, utilities, transportation and government industries. They provide sophisticated, object-oriented environments for designing, developing, and delivering applications that allow organizations to reduce costs and become more competitive by gaining a great understanding of business engineering decisions through business modeling.

According to Peter Friedland, IntelliCorp was originally IntelliGenetics. The vision was to provide software solutions (both algorithmic and heuristic) to the then fledgling biotechnology industry. The plan was to grow from that domain to other industrial domains by using artificial intelligence (AI) methodologies developed at the Heuristic Programming Project (HPP), a research group in Stanford CSD.

Dr. Friedland explains, "IntelliGenetics came a full year before Teknowledge. Actually, we offered the opportunity to most of what became the Teknowledge group to join us at IntelliGenetics, but at the time, the others weren't interested. When they saw the success in starting IntelliGenetics, there was a change of heart—ergo Teknowledge."

TEKNOWLEDGE

Teknowledge arose a year later in 1981 as a broader cross-domain AI tools, training, and custom consulting company. The two became competitors in that broader space.

The founders, nearly all from Stanford and/or the HPP are: Avron Barr (CS MS'81), Jim Bennett (CS MS'79), Harold Brown (CS Research Associate), Bruce Buchanan (CS Professor), Bill Clancey (CS PhD'79 and CS Research Associate), Randy Davis (CS PhD'76), Bob Engelmore (CS Research Associate), Ed Feigenbaum (CS Professor), Peter Friedland (CS PhD'80 and Research Associate), Michael Genesereth (CS Professor), Rick Hayes-Roth, Jerry Kaplan (CS Research Associate), Ingeborg Kuhn (CS Research Associate), Douglas Lenat (CS PhD'76 and CS Professor), Penny Nii, (CS MS'73 and CS Research Associate), Tom Rindfleisch (CS Research Associate), Carli Scott (CS MS'74 and Research Programmer), Edward (Ted) Shortliffe (CS Phd'75, MD'76, Professor of Medicine), William Van Melle (CS PhD'80), and Bill White (CS MS'66 and Research Programmer).

Avron Barr said, "Ed (Feigenbaum) always cites the number of people from industry who were coming to HPP looking for information, consulting, briefings, training, tools, etc., as the reason he started Teknowledge. He wanted to cleanly separate the commercial activity in expert systems from his continuing research in the lab." Teknowledge first offered training, then custom-designed expert systems and later introduced expert system shells.

According to Allan Terry, who was an HPP research programmer for six years and is still at Teknowledge, "Buchanan, Feigenbaum, and Kuhn organized the first group meeting of 'HPP, Inc.' April 1, 1981. The name 'Teknowledge' was coined by Avron Barr and was first announced at an April 24 meeting at Buchanan's house. Meetings were held about once a week over lunch at Feigenbaum's house. The first business committee meeting was held May 13 and included Feigenbaum, Buchanan, Kuhn, Clancey, and Nii.

"The first mass meeting to discuss the idea was held in May in Tresidder (Stanford Student Union), and incorporated in July. The first shareholders' meeting was

held September 19, and they elected the Board of Directors: Feigenbaum, Lenat, Clancey, Hayes-Roth, Rindfleisch. Teknowledge went public in 1986."

Terry says, "I wasn't quite a founder but my unofficial read is that the original thinking went: 'We are a bunch of academics and we are going to commercialize AI.' What do we do well? Teach.' So they offered AI classes. This rapidly evolved into consulting on AI with emphasis in expert systems. For tools we used an in-house derivative of Emycin. Got some contracts, built some systems, did reasonably well. We later decided the way to hit it really big was products more than consulting. This resulted in the S.1 product of Teknowledge, Inc. It was a high-end expert system shell intended for knowledge engineers. It was a backward chaining expert system shell in the same general class as Emycin. An improved, extended version of it was later released as Copernicus. At the same time the M.1 product came out of a skunkworks. Tek built up a big sales force, many sales offices, went public, did everything on grand scale. We were one of the early companies to get out of Lisp and into C. We built and released Copernicus, a successor to S.1. Eventually the realization hit. Copernicus was a very nice product indeed for professional knowledge engineers but AI tools was a very hard market to make a buck in. We pulled Copernicus out of the product market and got rid of the product organization.

"For various other reasons, the consulting business was also not doing well. In 1989, Teknowledge merged with American Cimflex to form Cimflex Teknowledge in hopes of differentiating ourselves with a manufacturing focus. Unfortunately, the recession started soon after and nobody was spending on manufacturing. There were various ups and downs; we lost more money. Finally, the board noticed that only the Palo Alto Research and Development group consistently made money. They picked Rick Hayes-Roth and Neil Jacobstein to run the company. We let go unprofitable divisions after trying to turn them around, eventually got back to 'Teknowledge' and core business of lots of consulting with some product sales (M.4, the successor to M.1)."

Currently, Teknowledge Corporation provides consulting services and software products for commercial and defense applications. The principal lines of business are focused on knowledge-based systems, distributed intelligent systems, and network associate systems software. In 1996 there are 40 employees.

GO

After leaving Teknowledge, Jerry Kaplan served as Principal Technologist at Lotus Development Corporation from 1985-1987. In August 1987, he founded GO, a hand-held, pen-based computer company. In July 1991, EO (GO in Latin), an offshoot of GO was formed to build pen computers based on Penpoint. In June, 1993, AT&T bought a majority position in EO. Then in August, AT&T considered dropping GO's Penpoint for Apple's Newton. GO then agreed to sell the company to AT&T by merging with EO. January 1994, the EO-GO merger was completed and in July, AT&T closed down EO. The fascinating story is told in "Startup, A Silicon Valley Adventure," written by Dr. Kaplan. Although a new idea for another venture was brewing, he took time off to write the book before starting On Sale.

ONSALE

According to their Web Page, "ONSALE is a new type of interactive retailing. Much more than an online store, it recreates in electronic form the fun and thrill of bidding at an auction, where prices and availability change in response to customers' actions.

"ONSALE exploits the unique advantages of the online medium to create a new retailing format. By focusing on limited quantity goods, and offering them in a series of fast-action sales formats where prices and availability vary instantly in response to demand, ONSALE creates an entertaining and exciting experience."

Coherent Thought, Inc.

Dennis Brown (CS MS'77), Jim Bennett (CS MS'79), Bob Joyce (MS CSAI'83), and Michael Ann Arenas (Stanford BS) left Teknowledge and founded Coherent Thought in 1987. They made application specific client-server expert system development tools. Coherent was non-public and venture capital funded. Unfortunately, it folded in November 1990.

Key Computer Solutions

Jake Brown, a former computer science staff member and former Teknowledge employee, founded Key Computer Solutions in June of 1988. It is a sole proprietorship, self-funded company. Key offers support services on an individual basis.

Expert Support, Inc.

Expert Support was founded in October, 1990, by Dennis Brown, Jake Brown, and Jan Clayton (CS MS'82). Dennis Brown, who is married to Jake Brown, served as the associate chairman of Computer Science for five years. Expert Support is privately held and self funded. Financial information is not available; however, they are quite successful. Expert Support provides support services to vendors of advanced software products and to their users. They have 25 employees, many of whom are MS and PhD computer science graduates.

SILVAR-LISCO

Silvar-Lisco originated through a merger in 1981 of Silicon Valley Research (Silvar) and Leuven Industrial Software Company (Lisco). Silicon Valley Research, an umbrella company, began operations in 1979 and its founders were affiliated with Stanford's Linear Accelerator Center. Willem vanCleemput, a founder of both companies, was an Assistant Professor of Electrical Engineering in the Computer Systems Laboratory. Leuven Industrial Software Company began operations in 1977 and was affiliated with Leuven Research and Development, an organization with ties to the University of Leuven, Belgium.

Silvar-Lisco is a leading developer, manufacturer and marketer of advanced CAD (Computer Aided Design) software tools for the design of application specific integrated circuits (ASICs) and custom integrated circuits. The company's electronic design products are used by semiconductor and electronics systems producers to automate the physical implementation of circuit designs and accelerate the delivery of high performance chips to market.

VALID LOGIC SYSTEMS

Curt Widdoes (CS PhD'81), Tom McWilliams (CS PhD'80), Jeff Rubin, Jerry Anderson and Ray King founded Valid Logic Systems in 1981, and shortly afterward recruited Lou Scheffer. Their goal was to create tools for engineers to use in designing electronic systems, the beginning of the CAE (Computer Aided Engineering) industry. While at Stanford, Widdoes and McWilliams worked on the S-1 project under the

direction of Professor Forest Baskett. According to Dr. Widdoes, "The S-1 Project that we worked on with Forest was a project to design and build multiprocessor supercomputers at Lawrence Livermore National Laboratory. The project team built three generations of ECL supercomputers from 1975 through 1985: the S-1 Mark I, Mark IIA, and Mark IIB. A single S-1 Mark IIA CPU contained nearly 30,000 ECL-100K integrated circuits, and was designed to be connected into clusters of 16 processing elements. The project also produced the SCALD computer-aided design software, which formed the basis of Valid Logic Systems in 1981." In 1984, Widdoes and McWilliams received the IEEE McDowell Award for the development of SCALD which formed the basis of the CAE industry. Valid, Daisy, and Mentor Graphics were the first major players in the CAE industry. Daisy, which later folded, was the first to go public; Valid went public in 1983 and Mentor Graphics followed soon after. In 1987, Curt Widdoes left Valid, which was bought by Cadence in 1989.

Logic Modeling Systems

In 1987, Curt Widdoes and Steve White co-founded Logic Modeling Systems. While at Valid, Widdoes had invented hardware modeling technology and received fundamental patents covering it. He bought exclusive rights to the patents from Valid and founded Logic Modeling to bring a product to market. Logic Modeling achieved a monopoly in hardware modeling. Then in 1992, Logic Modeling Systems merged with Logic Automation, which sold software models of components. The new company was called Logic Modeling Corporation.

Logic Modeling Corporation

Widdoes was named President and later Chairman of the new company, which dominated the system level components modeling market. In 1994, Widdoes sold Logic Modeling Corporation to Synopsys for approximately $120 million, and then left Synopsys in July 1994 to pursue other interests.

0-In Design Automation

In June, 1996, Widdoes, White, David Dill, (CS Professor), Richard Ho (CS PhD'96), and Paul Estrada founded 0-In Design Automation to provide better tools for the functional validation of electronic designs, which has become the primary bottleneck in the development of large integrated circuits. Products from 0-In should be available in 1997.

LOGITECH

Founded in 1981 by Pierluigi Zappacosta (CS MS'78), Logitech is the world's largest developer and maker of computer mice. Logitech designed the first "trackball" mouse for Apple Computer's PowerBooks in 1991.

Logitech's enduring vision since its founding in 1981 has been to humanize the interface with computers through products utilizing a broad spectrum of human senses—sight, hearing and touch. Thus, Logitech pioneered the concept of "Senseware"—a broad category of affordable, easy to use products elegantly integrating both hardware and software—to make the interface between man and machine more intuitive and natural. Designed to be both stylish and comfortable, Senseware® products include professional pointing devices, such as mice, trackballs and touchpads; entertainment products, such as joysticks, gamepads, and 3D controllers for PC games and the World-Wide Web; and imaging solutions, such as personal color scanners and digital video cameras.

Logitech has established leadership in the Senseware category. The Company distributes its products through a variety of retail channels, and through strategic relationships with the world's top computer manufacturers. With a publicly-traded holding company in Switzerland, headquarters in Fremont, California, and ISO-certified manufacturing plants in Suzhou, China and Hsinchu, Taiwan, the Logitech group is both global and multi-cultural. The Logitech companies have an international management team and employ approximately 2400 people worldwide, of which about 75% are in operations.

SUN MICROSYSTEMS

Sun Microsystems was founded in 1982 by Andreas Bechtolsheim, an electrical engineering PhD student in the Computer Systems Laboratory (CSL), Scott McNealy and Vinod Khosla, roommates at Stanford's Graduate School of Business, and Bill Joy, a PhD student in computer science at the University of California, Berkeley. Sun's first product was the brainchild of Bechtolsheim. He built his first workstation out of spare parts scrounged from the Department of Computer Science and Silicon Valley supply houses. In 1982, he teamed with McNealy, Khosla and Joy to found Sun which is an acronym for Stanford University Network, the communications project for which Bechtolsheim designed his workstation.

Sun manufactures UNIX-based professional workstations and compatible software. The 1995 figures show that Sun employs 14,000 people and has revenues of almost $6 Billion. (See appendix A).

Granite Systems, Inc.

Granite was started in 1995 by Andy Bechtolsheim and David Cheriton (CS Professor). Bechtolsheim had previously co-founded Sun Microsystems, where he served as Vice President of Technology. Cheriton has done research in the field of computer networks for over 15 years.

Granite Systems is developing high-performance LAN products based on Ethernet/IEEE 802.3 standards. The company believes switching will play a large role in the future of local area networks and that Gigabit Ethernet is the simplest, most compatible and most cost-effective way to provide scalable network performance for large client/server networks.

Granite is a founding member of the Gigabit Ethernet Alliance, and is an active participant in activities such as the IEEE 802.3z working group to establish the Gigabit Ethernet standard.

September 3, 1996, it was announced that Cisco Systems agreed to buy closely held Granite Systems for $220 million in stock.

SILICON GRAPHICS

Dr. James Clark (EE Professor, Computer Systems Laboratory) learned VLSI (Very Large Scale Integration) design in a pilot course given to faculty. He worked on a geometry engine prototype in CSL with the help of Professors John Hennessy, Forest Baskett, and others. The geometry engine was a pipelined floating point unit which does the 3D translation rotation and clipping functions needed to do complex, sophisticated graphics. He built the first one in CSL, and Hennessy wrote a compiler and optimizer for

the control language which was compiled into a PLA (Programmable Logic Array). Jim Clark had the vision that there was a market for computer systems based on three-dimensional graphics. When his research was ready to be put into practice, he paid visits to established computer companies to sell his idea to them. Incredibly, not a single company understood the impact. As a result, in 1982 Clark took a leave-of-absence to start Silicon Graphics with six graduate students. Unfortunately for Stanford, he did not return to the university, but his leadership at Silicon Graphics in the development of both graphics hardware and software was instrumental in establishing that company as the leader in visual computing systems. Clark resigned from Silicon Graphics in March, 1994, to start a new software company for the coming generation of interactive television.

Silicon Graphics' headquarters are in Mountain View, California. The 1995 figures show that the company employs over 6,000 people worldwide and has revenues in excess of $2 billion per year.

Mosaic Communications Corporation

Mosaic Communications Corporation was founded in the spring of 1994 by Dr. James Clark, founder and former Chairman of Silicon Graphics, and Marc Andressen, originator of Mosaic. The mission of Mosaic Communications, a new technology company, was to provide software and services to companies and consumers for commercial activities on the Internet.

Mosaic, a state-of-the-art Internet-based hypermedia information system, took the computer world by storm. In the year after its release, it acquired a global user base of about 2 million people and was widely hailed as the "killer application" of the Internet and of data networks in general. Mosaic was developed at the National Center for Supercomputing Applications (NCSA) by the core staff of Mosaic Communications and had previously only been available in unsupported, non-commercial grade form.

Netscape Communications Corporation

On November 14, 1994, Mosaic Communications Corporation announced that it was changing its name to Netscape Communications Corporation. Netscape went public August 9, 1995, with an IPO (initial public offering) of 5 million shares. According to the *San Francisco Chronicl*e's headline, "Netscape Mania Sends Stock Soaring." After a delay in trading of ninety minutes, it quickly zoomed from $28 to $75 a share, finally closing at $58.25

Netscape develops, markets, and supports open client, server, and commercial applications software that enables information exchange and commerce over the Internet and private Internet Protocol networks. The company's products are designed to deliver high levels of performance, ease of use, and security. These products allow individuals and organizations to execute secure financial transactions across the Internet, such as the buying and selling of merchandise, publications, software, and information. Through the use of the company's software, organizations can extend their internal information systems and enterprise applications to geographically dispersed facilities, remote offices, and mobile employees.

Healtheon

Healtheon was founded in June 1996 by Jim Clark, David Schnell, and Pavan Nigam to apply the best of today's powerful communication technologies—specifically

the Internet and the World Wide Web (WWW)—and to address enormous challenges facing the health care business. In designing on-line products and services for health care information and management, Healtheon intends to revolutionize the industry and demonstrate the broader potential of the Internet. Healtheon is dedicated to making life easier and more efficient for everyone involved in health care—insurance companies, employers, employees and health care providers. The company leverages the power of the Internet to create easy-to-use interactive and secure services to let users manage health care information and benefit-related transactions more effectively.

According to the *San Jose Mercury News*, Tuesday, June 18, 1996, Healtheon's goal is to solve the paperwork and information costs of health-care providers. Healtheon will provide on-line information services for health care providers like health-maintenance organizations, doctor's offices and dentists. Dr. Clark will be Chairman of Healtheon, but will retain his title at Netscape.

MIPS

John Hennessy (EE Professor, Computer Systems Laboratory) and his graduate students had worked for seven years on a new version of an old computer architecture. During a 1984 breakfast meeting with fellow computer scientists, Edward P. Stritter (CS PhD'77), who had been on the M68000 team at Motorola, and John Moussouris, IBM 801 bipolar version designer who was visiting at Stanford, it was decided that time was ripe to move Hennessy's theories out of the laboratory and into the real world. Thus, MIPS Computer Systems, Inc., was founded. Hennessy took a leave-of-absence from his Stanford duties to be a co-founder of MIPS along with Stritter and Moussouris.

While at Stanford, Hennessy had served as project leader for the university's MIPS Project (Million Instructions Per Second) and headed an optimizing compiler project that led to a new microprocessor architectural concept known as Reduced Instruction Set Computing (RISC). In 1991, MIPS announced the first 64-bit RISC microprocessor, which could process twice as much data at a time as 32-bit chips, which had been the most advanced.

After a leave-of-absence, Hennessy returned to the university. In 1986, he was promoted to full professor and became Director of the Computer Systems Laboratory. The department of computer science moved from the School of Humanities and Sciences into the School of Engineering and Hennessy chose the new option of a joint appointment with electrical engineering and computer science. September 1994 he became Chairman of the Department of Computer Science, and June 16, 1996, he became Dean of the School of Engineering.

In 1993, MIPS Computer Systems was acquired by Silicon Graphics, and their employees and earnings are all included in the parent company's statistics.

CISCO SYSTEMS

In 1984, Sandy Lerner (Economics MS'81) and Leonard Bosack (CS MS'81) founded Cisco Systems. Bosack was Director of Computer Facilities for Stanford's Department of Computer Science, and Lerner was Director of Computer Facilities for Stanford's Graduate School of Business. Cisco was formed to commercialize the technology developed at Stanford in the late 1970's to support the campus-wide network called SUNet (Stanford University Network), and to integrate a multiplicity of local networks into a single integrated whole. Cisco shipped its first products in March 1986. Today, Cisco is the leading supplier of high-performance, multiprotocol internetworking

systems that enable its customers to build large-scale integrated networks of computers. Cisco also manufactures local-area network (LAN) interconnect devices, and multi-protocol computer peripheral equipment.

According to Ralph Gorin, who chose Len Bosack to replace him as Director of Computer Facilities, "My take (emphasis on personal interpretation) on the Cisco vision: it was a very clever way to sell software by the simple expedient of concealing the software inside hardware. They (Bosack and Lerner) were in the right place at the right time. They also are very smart, very hard working, and, incidentally, very lucky. They also had the benefit of being in an environment that was on the cutting edge of applying networking on a large scale."

Lerner confirmed Gorin's view and added the following: "I would only add that we had a highly unusual, skilled, intelligent, and motivated initial customer base which essentially directed our engineering efforts. It is the customers who are the one, key ingredient in the cisco (lowercase "c," originally) success. It's a shame companies lose sight of who they should try to please. First customers included Chuck Hedrick at Rutgers, Norm Kincl and Robert Michaels at HP Labs, and others."

Cisco is now the world's leading supplier of enterprise internetworking solutions that link geographically dispersed local-area and wide-area networks (LANs and WANs) to form a single, seamless information infrastructure. According to 1995 annual figures, Cisco employs 3800 people and has annual revenues of $1.98 billion.

CATAPULT COMMUNICATIONS

Richard A. Karp, (CS PhD'80) founded Reliability Associates in 1985. During the first year he had one software engineer working for him. In 1988, the name was changed to ISDN Technologies Corporation. Late in 1993, the name was changed to Catapult Communications.

The mission of Catapult is to provide superior telecommunications test solutions by consistently using the latest software and hardware technologies, and by offering unmatched technical support. This combination of technology and support is exactly what leading telecom companies need to meet their most demanding test challenges.

EPISTEMICS

Epistemics was founded in 1988 by Michael Genesereth (Professor, CSD), Narinder Singh (EE PhD'85) and Russ Greiner (CS PhD'85). In 1996, Singh and Greiner left the company. Arthur Keller (CS PhD'85, CS Senior Research Scientist) joined the newly reconstituted company. Epistemics licensed Infomaster from Stanford and is enhancing and commercializing it. Infomaster is an information integration system and the immediate application is to integrate heterogeneous distributed Internet-based catalogs.

RAMBUS, INC.

Rambus, Inc., was founded in March 1990 by Mike Farmwald (CS PhD'81) and Mark Horowitz (EE PhD'84 and EE Professor, Computer Systems Laboratory).

Rambus has developed a technology that solves the memory bottleneck faced by system designers. The technology is based on a very high speed, chip-to-chip interface that is incorporated on a new DRAM architecture and on conventional processors and

controllers achieving a performance rate over ten times faster than conventional DRAMs. A single Rambus™ DRAM, referred to as RDRAM™, transfers data at 500 MHz over the Rambus Channel to Rambus-compatible integrated circuits.

The Rambus technology has a major impact on improving the price/performance and size of a broad range of systems from desktop computers to portables to multimedia and consumer digital video products. Rambus' unique technology uses standard CMOS process, low cost IC packaging, and standard PC board technologies to deliver the highest performance at a low cost. In addition, the Rambus solution utilizes fewer ICs and eliminates the need for SRAM (Static Ram) caches.

In *Byte Magazine* (1992) D. L. Andrews described Rambus as follows: "The problem Rambus addresses is well known to systems designers: The data transfer rate of memory ICs lags behind a processor's ability to handle data. Although DRAM densities have increased, DRAM performance has improved marginally. Because of this, systems designers have resorted to complex workarounds of the bottleneck by using multilevel memory hierarchies, with Level 2 SCRAM caches and cache controllers. And as display resolutions increase and customers clamor for true color, costs are driven up due to the memory needed to supply pixels at a high rate for flicker-free display. Animation graphics and video also require high data transfer rates to display images in real time. All these requirements have resulted in complex architectures that use specialized multiport DRAMs or video RAMs (VRAMs) to maintain the high data transfer rates."

Rambus is a private company, and therefore does not have public investment information available. The company has been funded by a combination of license fees from its semiconductor partners and private venture equity capital. They have no current plans for additional financing, either private or public.

ENTERPRISE INTEGRATION TECHNOLOGIES (EIT)

Founded by Jay M. Tenenbaum in June 1990 the original management team comprised former executives of leading Bay Area consulting, research, and product development concerns. All were from Stanford: CEO Jay (Marty) Tenenbaum (EE PhD'70, CS Consulting Professor). President Steve Harari (Stanford MBA'81), CTO Allan M. Schiffman (CS MS'86, former Visiting Scholar in the Center for Integrated Systems (CIS) and EE Visiting Lecturer 1985), and Senior Scientists Jeff Pan and Jay Glicksman (CIS Visiting Scholars 1989/91).

According to Dr. Tenenbaum, EIT owes its start to Stanford. "We bootstrapped the company from two subcontracts on Stanford ARPA projects: the 21st century semiconductor manufacturing project at CIS, and the First-Cut project at the Center for Design Research. I will always be grateful to Stanford, in particular, to Jim Plummer, Paul Losleben, and Mark Cutkosky for their early support.

"The company had four founders, one of whom, Bruce Hitson (EE PhD'89), was a brand new Stanford CSL PhD. The company is indeed profitable and has been since its inception. Future growth is anticipated to come from joint ventures and spinoffs that commercialize our R&D."

EIT was a rapidly growing R&D and consulting company specializing in information technology for electronic commerce, collaborative engineering and agile manufacturing and a recognized leader in software and services to promote commercial use of the Internet.

EIT, a closely held private, for-profit company, was acquired in November 1995 by VeriFone and became a wholly owned subsidiary. At that time, EIT had 45 employees, eight with Stanford educations and several others with various Stanford affiliations, and $6 million in 1995 revenues. EIT had pioneered important technologies that underlie the growth of the Internet and had been responsible for two of the most important electronic commerce initiatives to date—the CommerceNet Consortium and Secure HTTP (Hypertext Transfer Protocol). EIT was instrumental in the formation of CommerceNet, an industry consortium that promotes electronic commerce. CommerceNet was spun out as a free-standing not-for-profit organization in the spring of 1996.

INTEGRATED BUSINESS SOFTWARE

Integrated Business Software was started in November 1991 by Stanford graduates Patricia Munter (English BA'90) and Jeff Loomans (CS MS'91). Both principals, as well as all of their employees, had past affiliations as lecturers or teaching assistants in the undergraduate CS106 Section Leader program.

IBS is a strategic partner for several small and medium-sized businesses in fields ranging from telecommunications to environmental consulting; it co-develops customized Windows software packages with these businesses on an equity-sharing, royalty or retainer basis. Products currently in the marketplace include: TeleMinder™, a telecommunications product for the healthcare and emergency services markets; Online Trainer™, a multimedia courseware playback system; WinRep™, an EDI (Electronic Data Interchange) front-end application for manufacturers' representatives; and SiteMap™, a hazardous waste tracking and reporting package for environmental consultants.

IBS is a privately held company, and in 1994 employed 4 Stanford graduates.

POSTMODERN COMPUTING TECHNOLOGIES, INC.

PostModern Computing Technologies, Inc., was founded in 1991 by Dr. Jens Christensen and Dr. Thane Plambeck. Christensen was a student of Nils Nilsson in AI and Plambeck was a student of Jeff Ullman in systems theory; both received their PhD degrees in 1990.

PostModern's flagship product is ORBeline, a complete implementation of the Object Management Group's (OMG) Common Object Request Broker Architecture (CORBA) standard. The CORBA standard addresses the complexities of standardizing object-oriented communication systems in networks of heterogeneous computer systems. Their end-users are advanced C++ development groups inside large companies. One customer, Fuji Capital Markets, uses PostModern's software to communicate bond prices in a financial derivatives application that links their New York, London and Tokyo offices. Mtel, the parent company of SkyTel, uses their software as the administrative networking backbone of their NWN project (Nation-Wide Network) that will deliver two-way paging to the consumer market next year. Entergy, a major utility serving seven states in the Southeastern US, uses PostModern's software to link what will become a network of 445,000 homes each equipped with an embedded 486 computer that communicates home electricity usage patterns back to the utility (no more meter-man).

PostModern has 9 employees, including several Stanford CS grads, and expects to move offices and expand again soon.

PostModern was entirely financed by their own resources and they have no outside investment. They are profitable, but do not release revenue figures. One fact they do release is that they hold a $2.5 million dollar software license agreement with First Pacific Networks, a Sunnyvale company that is working on household devices for "information highway" applications.

On April 29, 1996, Visigenic Software, Inc., announced an agreement to merge with PostModern Computing Technologies Inc., "A leading developer of distributed object-oriented communication software. The merger will position Visigenic as the premier independent provider of standards-based middleware for developing and managing distributed applications for enterprise networks and the Internet.

"The combination of Visigenic's database connectivity products, expertise, marketing and sales infrastructure with PostModern's leading edge distributed object-oriented communication technology will set a new standard in distributed applications for the Intranet and Internet. Visigenic will market, develop, service and support all PostModern products."

PostModern's entire team will join Visigenic. Jens Christensen, co-founder, CEO and president of PostModern, will take the position of Vice President and Chief Technology Officer. "We are delighted to be joining forces with Visigenic," said Jens Christensen. "Visigenic's growing marketing and sales infrastructure has the power we need to proliferate PostModern products, especially Black Widow, into the marketplace. Also, Visigenic's database expertise is an ideal complement to our distributed object technology, delivering interoperability and connectivity for database applications."

PERSISTENCE SOFTWARE

Persistence Software of San Mateo, California, was founded in 1991 by Chris Keene (Math/CS BS'83), Derek Henninger and Richard Jensen. Arthur Keller joined them as a consultant in November 1991, a few months after their founding. He is now Chief Technical Advisor and a member of their Board of Directors. Shailesh Agarwal (EE PhD'92) joined them in 1992 and Sanjai Tiwari (CE PhD'94) joined them in 1994. Gio Wiederhold (Professor CSD) is a member of the Technical Advisory Board. Persistence Software is a leader for Object-To-Relational application development systems. They address the growing challenge of corporations building large-scale object systems that must access existing business data stored in relational databases. Their products bridge the gap between relational databases and object programming.

NETWORK APPLIANCE

Network Appliance was co-founded in 1992 by Michael Malcolm (CS PhD'73). They develop and sell highly optimized data-access servers, based on custom operating software for NFS-UNIX networks. Products combine the plug-and-play simplicity of an appliance with unrivaled performance. This enables users on a network to access data faster and more efficiently. Dr. Malcolm, who left the company in March of 1995, has written an article, "The Appliance Angle," which is on their Web page.

THE MOTION FACTORY

The Motion Factory, a privately held company, was founded in May 1995 by Jean-Claude Latombe (Professor CSD), David Zhu (CS PhD'91), Yotto Koga (ME PhD'94), and Craig Becker (current CS PhD student). Prof. Latombe, the Division

Director for Artificial Intelligence, will assume the position of Chairman of the Computer Science Department January 1997.

The Motion Factory is developing the next generation of 3D animation authoring tools and products to bring life to 3D virtual worlds and to enable the creation of intelligent characters capable of real-time motion generation for 3D games. They believe that interactive 3D animation, providing rich, truly interactive and immersive experiences without the need for helmets and goggles, will become a dominant medium for multimedia-based communication and information sharing, in entertainment and in business. Enabling the creation of compelling content, interactive 3D animation will drive the future of computer gaming and the growth of the Internet.

The Motion Factory's goal is to provide the next-generation of 3D animation products that will enable game and internet content developers to bring interactive 3D animation into mainstream applications to provide rich and immersive experiences in games and 3D virtual worlds.

GIGABIT NETWORKS

Gigabit Networks, founded in 1995, specializes in the design and implementation of networked, parallel and distributed computer systems and the software necessary for putting such systems to use. Since the company is focused on the development and deployment of wide-area networks, Internet technologies, high performance computing, and multimedia technologies, the name Gigabit Networks was chosen since high-speed networking technology will become the enabling technology for information accessibility both now and in the future.

Gigabit was co-founded by James Dougherty (CS MS'95) and Ranjini Ramachandran (Statistics MS'95). Vinay Kumar R. Bannai (CS MS student) and Greg Snyder (CS MS'96) are members of the board.

SANDCASTLE

Will Harvey (CS PhD'95), Scott Roy (CS PhD'95), Chris Hondl (CS MS'94) and Oliver Goldman (CS MS'95) founded Sandcastle, a small Internet software firm, in March 1996 with seed funding from Mohr Davidow Ventures.

The mission of Sandcastle is to facilitate interaction among people on the Internet in applications like 3D chat, multiplayer games, and interactive Web sites. Sandcastle provides innovative software technology called synchronization which makes multi-participant interaction possible in a variety of markets including PC games, online advertising, online services, console games and set-top boxes, and coin-operated and location based entertainment.

YAHOO!

Yahoo! began as an idea, grew into a hobby, turned into a full-time passion, and went public in April, 1996. David Filo and Jerry Yang, Computer Systems Electrical Engineering PhD candidates started their guide in 1994 in order to keep track of their personal interests on the Internet.

During 1994, they converted Yahoo! into a customized database designed to serve the needs of the thousands of users that began to use the service through the closely

bound Internet community. They developed customized software to help them efficiently locate, identify and edit material stored on the Internet.

According to Steve Steinberg ("Seek and Ye Shall Find," *Wired*, May 1996), Yahoo! lists more than 200,000 Web sites under 20,000 different categories. He notes, "Almost 800,000 people a day use Yahoo! to search. Yahoo! has successfully exerted order on the chaotic Web."

TESSERAE INFORMATION SYSTEMS

Tesserae was started in June 1996 by Donald Geddis (CS PhD'95 and CS Research Scientist) and Narinder Singh (EE PhD'85 and CS Research Scientist). Tesserae is a database software company that does database integration on the web. According to their Web page, Tesserae provides products and services for integrating information from a variety of sources on an intranet or the Internet. In an environment composed of a mixture of monolithic legacy databases and rapidly changing new information sources, Tesserae's technology allows non-programmers to easily create a unified view of the entire corpus of information. Heterogeneous, distributed, legacy databases and software can be glued together to create a range of virtual to materialized data warehouses. The resulting system is stable and easy to reconfigure in the presence of highly dynamic information sources. Tesserae's technology provides middleware for the masses.

JUNGLEE CORPORATION

Founded June 1, 1996, Junglee Corporation focuses on applying database technology toward searching the world-wide web.

Nearly all from the CSD/CSL community, the founders are Ashish Gupta (CS PhD'94 in databases), Venky Harinarayan (CS PhD'96 in databases), Dallan Quass and Anand Rajaraman, both in the CS PhD program in databases and currently on leave, and Rakesh Mather, CEO.

Dallan Quass said, "We knew each other because we had worked together on various papers. One of the things we were interested in at Stanford was data integration. In particular, we were amazed at the amount of structured information that was embedded inside HTML documents on the World-Wide Web. We started to do research toward letting people search that information in a structured way. After a time we realized that our research had commercial potential. One of Ashish's friends (Rakesh Mather) who had previously started two companies, helped us write a business plan and get our seed round funding. He is now our CEO."

MISCELLANEOUS COMPANIES

From 1980 through 1992, approximately 200 small private companies and 30 small public companies were founded by members of the Stanford community (Leone, et al., 1993).

Because of the rapid growth of high technology in the area, opportunities for service and supplier firms also emerged. Examples of the new business opportunities are: hotels, motels, restaurants, travel, transportation, residential and commercial real estate firms, legal, medical, counseling, personal services such as cleaning services, gardeners, personal shoppers, caterers, hairdressers, nail salons, personal trainers, gymnasiums, gift wrapping, packaging and mailing services. Some of the newer ones are dog walking,

clean-up for dog poop, personal organizers, and meal delivery from restaurants. There are many opportunities for large and small businesses.

Many of the small private businesses have no plans to become large public companies. After a slump, the economy is rebounding and some of the small start-ups are becoming the new miracle companies in the Silicon Valley tradition. The entrepreneurial spirit is alive and well within the Stanford community and Silicon Valley.

CONCLUSIONS

Beginning in the mid-1930's, Stanford University has played a key role in the creation and evolution of Silicon Valley, through encouragement, technical and financial facilitation, the creation of the Stanford Research Park, and the training of excellent engineering graduates. Also, Stanford has provided an atmosphere that fosters intellectual curiosity, as well as the drive and the desire to achieve excellence.

In 1996, Santa Clara County boasts companies that lead the world in such fast-expanding fields as computers, semiconductors, lasers, fiber optics, robotics, medical instrumentation, magnetic recording, and educational and consumer electronics. Some of the companies are branches or subsidiaries of big corporations with headquarters elsewhere, which feel it is advantageous to maintain research facilities in the area. However, most of the new industry is home grown.

Stanford University's sixty-year role in the transformation of the Santa Clara Valley into Silicon Valley is history, but it is enduring history. Stanford continues to effect the local economy by spawning new and creative ideas, dreams, and ambition.

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Appendix A: The Founding of Sun Microsystems
An electronic mail message from Vaughan Pratt (1994, March 28)

Hi, Carolyn. Here's a quick rundown on events around the 79-83 period. This is all very incomplete and rushed. I have megabytes of old email messages that I've been meaning to go through to remind myself of everything that happened back then, but this is a big project that is likely to remain on the back burner for some time to come.

I'm not sure as to the exact timing of when Forest (Baskett) decided to start the Sun terminal project, but a key event precipitating its progress occurred in late 1979 when Forest and Andy [Bechtolsheim] went to Comdex, where they saw the Nu terminal, MIT's version of the (then-unborn) Sun workstation. Forest knew they could achieve the same performance and functionality in a much smaller and cheaper package, and they went back to Stanford to begin work on a Stanford version of the Nu terminal, to be called the Stanford University Network (SUN) terminal.

The principals I recall from that period were

Staff: John Seamons, Rob Poor, and Jeff Mogul (taking a year's break from being a PhD student here). John Seamons was lured away at the end of summer 1980 by an irresistible offer from newly-formed Lucasfilm. Rob Poor followed him there not too long after.

Students: Andy Bechtolsheim, Bill Nowicki, and Jeff Mogul after his one-year stint on staff. There were other students but these three were easily the most prominent on this project.

I arrived at Stanford in July 1980, on a year's sabbatical from MIT, to start a computer aided verification project with Derek Oppen. The week before I arrived Derek quit Stanford, and I went in search of another group to work with for the duration of my sabbatical. The Sun terminal project was most to my taste, and I joined up and went to work that summer writing software for the hardware that Andy had produced up to that point. In the first month I wrote a trivial window system and a graphics terminal emulator. I used this as my graphics terminal for the rest of that summer, during which I wrote a disassembler for the 68000 and made a start on a microkernel I called Sunix.

At the end of summer Forest went to Xerox PARC on leave from Stanford, from which he never returned. (A couple of years later Forest left PARC to head up DEC's new Western Research Lab. in Palo Alto, sibling to DEC's equally new Systems Research Center a few doors away. A couple of years later still he left WRL to become an SGI vice-president, where he is today.)

As a visiting associate professor, I found myself the ranking member of the project after Forest's departure. I ran the project on an informal basis, holding regular progress meetings while continuing to work on kernel and graphics software. Midway through my sabbatical I was offered a full professorship by Stanford, which I initially declined as inappropriate for someone on sabbatical. I reversed my position when MIT, citing my thin PhD supervision, declined to match Stanford's offer with the corresponding promotion.

The Sun terminal was intended to consist of three Multibus boards in an 8"x10"x14" card cage, namely a CPU board for performing the actual computation, a graphics board controlling the monitor, and an ethernet board for connection to the

embryonic Stanford network, then consisting of a 3 Mb ethernet. Prior to my arrival Andy had worked only on prototype graphics boards, while John Seamons had begun the design of an ethernet board. It was expected that someone would produce a Multibus board for the Motorola 68000 CPU imminently, so there were no plans to do this ourselves.

After Seamons left for Lucasfilm, Andy took on the ethernet design. In November 1979, having seen no sign of any manufacturer working on the expected CPU board, I suggested to Andy that he add this project to his load too. Andy felt the CPU board practically "designed itself" and hence was easy compared with the other two boards, which called for some innovations in order to be an adequate performance match to the CPU. The one question mark for the CPU board design was the memory management unit, to which Andy, Forest (who sent us a design while at PARC), and I all made significant contributions.

Andy spent the period January 1980 through July 1981 developing the three boards. My time was divided between teaching courses and working on kernel software, initially on Sunix and later helping John Seamons with a Unix port.

By August 1981 Andy had produced wirewrapped prototypes and printed-circuit-board artwork for all three boards. Through Jim Clark, Andy negotiated with CadLinc, a Detroit CAD (Computer Assisted/Aided Design) company, to manufacture Sun terminals under a non-exclusive license from Andy's company VLSI Systems Inc. (VSI), Stanford having declined this opportunity. Between that period and January 1982, VSI licensed the design to a total of eight companies, including Forward Technology, Bridge Communications, and Imagen.

At the same time Imagen was forming, under Les Earnest and Luis Trabb-Pardo, to manufacture printers based on the new Canon laser printer, which in turn was based on several years experience with laser+drum photocopying technology. Les and Luis found Andy's CPU board ideal for the Imagen printer. Luis wrote the first PROM monitor for the CPU board, subsequently rewritten by Jeff Mogul.

At about the same time we sent a prototype to John Seamons at Lucasfilm, who had been porting Version 5 Unix to the 68000. At this time I stopped work on Sunix in order to help John debug the Unix port.

In January 1982, Vinod Khosla, a recent Stanford MBA who had just left Daisy Systems, made a number of visits to our project, and eventually persuaded Andy to stop licensing the design and instead form a new company based on the Sun as its main product. Vinod persuaded his close friend Scott McNealy to join up. Plans for a company jelled in February, and Sun was officially founded at the end of February. Bill Joy came on board a month later following a visit to Berkeley in March by Andy, Vinod, Scott, and myself.

My involvement with Sun, the company, for its first year was as a consultant, during which time I designed the Sun logo, the Gallant font that one still sees today when booting a Sun workstation, the prom controller for the keyboard, and dithering software for Peter Costello's color graphics board. With John Gage I set up and took down Sun's first Siggraph booth in Boston in July 1982, and put together a suite of demos to maintain crowd interest. One evening Vinod, Andy, John, and I drove one of the Siggraph booth's Suns down to Brown University and demonstrated it to Andy van Dam's graphics group.

Later that year I started work on a C compiler for which I had some new ideas, but this proved a bigger project than I was able to squeeze into my limited consulting time and I scratched it after a quarter.

Starting April 1983, I took a two-year leave of absence from Stanford to work full time for Sun. In my first three months at Sun I designed and implemented Sun's Pixrect graphics interface, still used today as the software layer providing a uniform object-oriented interface between all Sun graphics boards and all programs writing either text or graphics to the monitor. After that I worked on developing a curve capability called Conix to be added to Pixrect, digital typography, and with Craig Taylor, on new windows algorithms. The first two of these yielded Siggraph papers, and Conix was subsequently incorporated into various graphics projects at Sun, but unfortunately never into Pixrect itself as I had intended. After returning to Stanford, I put the digital typography project on hold for two years, then put Gidi Avrahami to work on it for his PhD, which he recently completed, producing a very nice package for going all the way from ink artwork to an unhinted but otherwise nicely tuned Postscript font.

The above leaves out an awful lot. Hopefully some day I'll find the time to write at greater length on the early history of Sun. Meanwhile this will have to do.

Best,

Vaughan (Pratt), March 28, 1994

UNIFORM RESOURCE LOCATOR (URL)

3Com	http://www.3com.com
Catapult Communications	http://www.catapult.com
Cisco	http://www.cisco.com
CommerceNet	http://www.commerce.net
Enterprise Integration Technologies	http://www.eit.com
Epistemics	http://www.epistemics.com
Gigabit Networks, Inc.	http://gigabitnet.net/
Healtheon	http://www.healtheon.com
Hewlett-Packard	http://www.hp.com
Junglee	http://www.junglee.com
Logitech	http://www.logitech.com
MIPS	http://www.mips.com
Motion Factory	http://www.motion-factory.com
Netscape	http://www.netscape.com
Network Appliance	http://www.netapp.com
The Appliance Approach	http://www.netapp.com/design/index2.html
ONSALE	http://www.onsale.com
Persistence Software	http://www.persistence.com
PostModern	http://www.visigenic.com
Precept	http://www.precept.com
Rambus	http://www.rambus.com
Roche	http://www.roche.com
Verifone	http://www.verifone.com
Sandcastle	http://www.sandcastle.com
Silicon Graphics	http://www.sgi.com
Sun Microsystems	http://www.sun.com
Sun's official history	http://sunsite.math.klte.hu/sun-hung/history.html
Symantec	http://www.symantec.com
Teknowledge	http://www.teknowledge.com
Tesserae	http://www.tesserae.com
Varian	http://www.varian.com
Yahoo!	http://www.yahoo.com

GLOSSARY

ARPA	Advanced Projects Research Agency; now called DARPA, Advanced Projects Research Agency
ASIC	Application Specific Integrated circuits
ATM	Asynchronous Transfer Mode
Audio-oscillator	A device for producing alternating current; especially an audio- frequency generator.
Bootstrap	Self-help, advancement or development without outside aid. A computer becomes active and functional through a bootstrap process.
CAD	Computer Assisted/Aided Design
CMOS	Complementary Metal Oxide Semiconductor
CSL	Computer Systems Laboratory.
Diode	A 2-electrode electron tube having a cathode and an anode; a rectifier that consists of a semiconducting crystal with two terminals and that is analogous in use to an electron tube diode.
DRAM	Dynamic Random Access Memory
EDI	Electronic Data Interchange
Engineer Degree	A degree conferred on candidates who have been admitted to candidacy and who have satisfactorily completed a minimum of three full-time tuition quarters of residency and 36 units at Stanford beyond the master's degree. A thesis is required.
Ethernet	A local area network that permits computers and file servers within a given building or nearby location to communicate with each other at rates up to 100 million bits per second. When one machine has a message for another, it first checks the ethernet to see if anyone else is sending something and, if not, it begins sending. However, if two machines accidentally start "talking" at about the same time, they both detect the interference, back off and try again a little later. Message headers identify the recipient of each message and prospective recipients normally use this information to select only messages intended for them. In this way a single coaxial cable or twisted pair of wires may serve to connect a number of machines (Earnest, 1994).
FDDI	Fiber Distributed Data Interface
HTML	Hypertext Markup Language
HTTP	Hypertext Transfer Protocol
IC	Integrated Circuit
IEEE	Institute of Electrical and Electronics Engineers.
IPO	Initial Public Offering
Klystron tube	An electron tube in which bunching of electrons is produced by electric fields and which is used for the generation and amplification of ultrahigh-frequency current.
LAN	Local-area network.
MIPS	Million Instructions Per Second.
PC	Personal Computer
PLA	Programmable Logic Array
RAM	Random Access Memory

RISC	Reduced Instruction Set Computing
SAIL	Stanford Artificial Intelligence Laboratory
Silicon	A tetravalent nonmetallic element that occurs combined as the second most abundant element in the earth's crust and is used especially in alloys and electronic devices.
SCRAM	Static Random Access Memory
Skunkworks	A small R&D organization, usually physically separated from the main operation, where rapid innovation and exploration are stressed over normal processes and controls.
Silicon Valley	A geographical region southeast of San Francisco, which radiates outward from Stanford University, Stanford, California, to the adjacent cities of Palo Alto and Menlo Park, northwest to Redwood City and San Carlos, southeast to Los Altos, Mountain View, Sunnyvale, Cupertino, Santa Clara, encompassing Santa Clara County, and expanding to Alviso, Milpitas and Morgan Hill. It is contained by the San Francisco Bay on the east, Santa Cruz Mountains on the west and the Coast Range to the southeast.
SUN or SUNet	Stanford University Network
URL	Uniform Resource Locator
Valley of Heart's Delight	Limited to Santa Clara County which encompasses cities of Palo Alto and other cities to the South. The area received its name because of the benevolent climate and profusion of fruit orchards.
VLSI	Very Large Scale Integration.
WAN	Wide Area Network
WWW	World Wide Web
Xerox PARC	Xerox Palo Alto Research Center in the Stanford Research Park.