An Analysis of the Strategic Management of Technology in the Context of the Organizational Life-Cycle

by
Steven W. Klosterman

BSEE (1983), University of Cincinnati

Submitted to the System Design and Management Program
in partial fulfillment of the requirements for the degree of

Master of Science in Engineering and Management
at the
Massachusetts Institute of Technology
June 2000

Signature of Author_____
System Design and Management Program. June, 2000

Certified by_____
Thomas Kochan
George M. Bunker Professor of Management
Thesis Supervisor

Accepted by_____
Thomas Kochan
Co-Director, System Design and Management Program
Sloan School of Management

Accepted by_____
Paul A. Lagace
Co-Director, System Design and Management Program
Professor of Aeronautics and Astronautics

Acknowledgements

I would like to thank the individuals and organizations that have helped me pursue this thesis and my MIT education:

To the System Design and Management (SDM) program for providing the vision of flexible, distance learning as an enabler for mid-career engineers to study at one of the world's foremost centers of learning. To Tom Magnanti, Tom Kochan, Ed Crawley, John Williams, Margee Best, Anna Barkley, Leen Int'Veld, Dan Frey, Jon Griffith and Dennis Mahoney, I cannot sufficiently express my gratitude for being given the privilege of becoming a member of the MIT community.

To my fellow students in the SDM program for providing the support, encouragement and help, I am honored to be associated with you.

To Rick Maybury for being my impartial sounding board during the development of this thesis. Thanks for keeping me on the path!

To my colleagues at Sun Microsystems who endured undue pain, hardship and suffering to enable me to attend MIT. To Steve Doherty, Wayne Bolivar, Alex Pappas, Jon Simon, Ken Weiss, Nicholas Laplaca and Heidi Peabody, I will be forever in your debt. To Marco Riera, Willis Hendley and Ed Debarros, thank you for the encouragement. To the other members of the Workgroup Server Division at Sun, thank you for accommodating the demands of my education without complaint.

To Jonathan Propp, thank you for providing support and advice.

Especially, I would like to thank Jeff Elsmore, my manager, for taking a gamble on me and letting me try. Thanks for taking the risk. I won't let you down!

To my parents for teaching me the value of education

Finally, and most importantly, I thank my family, Lynne, Steffi and Paul. Thank you for being patient. I promise to make up for lost time!

An Analysis of the Strategic Management of Technology in the Context of the Organizational Life-Cycle

by
Steven W. Klosterman

Submitted to the System Design and Management Program on May 4, 2000
in partial fulfillment of the requirements for the degree of

Master of Science in Engineering and Management

Abstract

High-technology, new-economy firms seem to operate under different rules than their old-economy counterparts. The fast pace of disruptive invention, rapid product development cycles, short product market life and intense, frequently unanticipated competition drive technology strategies. Organizational growth and tight labor markets for talented employees influence technology capacity and capabilities. Valuation and profitability measurements seem to violate long-standing financial trends. All these reinforce a perception that these firms represent a radical departure from the stoic, traditional organization.

This thesis explores the product development and organizational history of a leading high technology firm, Sun Microsystems. Using a model based upon the organizational life cycle and principles of systems architecture, we capture the common and unique characteristics of how the firm is dealing with changing markets, technology, complexity and growth. The study tests the hypothesis that, while Sun competes in a fast-paced arena, many problems experienced during periods of rapid growth are, in fact, endemic to any organization under similar circumstances. As this hypothesis holds, we look at current technology and process initiatives in the company to assess whether they are appropriately addressing the right issues.

Thesis Supervisor: Thomas Kochan, George M. Bunker Professor of Management

Acknowledgements

I would like to thank the individuals and organizations that have helped me pursue this thesis and my MIT education:

To the System Design and Management (SDM) program for providing the vision of flexible, distance learning as an enabler for mid-career engineers to study at one of the world's foremost centers of learning. To Tom Magnanti, Tom Kochan, Ed Crawley, John Williams, Margee Best, Anna Barkley, Leen Int'Veld, Dan Frey, Jon Griffith and Dennis Mahoney, I cannot sufficiently express my gratitude for being given the privilege of becoming a member of the MIT community.

To my fellow students in the SDM program for providing the support, encouragement and help, I am honored to be associated with you.

To Rick Maybury for being my impartial sounding board during the development of this thesis. Thanks for keeping me on the path!

To my colleagues at Sun Microsystems who endured undue pain, hardship and suffering to enable me to attend MIT. To Steve Doherty, Wayne Bolivar, Alex Pappas, Jon Simon, Ken Weiss, Nicholas Laplaca and Heidi Peabody, I will be forever in your debt. To Marco Riera, Willis Hendley and Ed Debarros, thank you for the encouragement. To the other members of the Workgroup Server Division at Sun, thank you for accommodating the demands of my education without complaint.

To Jonathan Propp, thank you for providing support and advice.

Especially, I would like to thank Jeff Elsmore, my manager, for taking a gamble on me and letting me try. Thanks for taking the risk. I won't let you down!

To my parents for teaching me the value of education

Finally, and most importantly, I thank my family, Lynne, Steffi and Paul. Thank you for being patient. I promise to make up for lost time!

Table of Contents

Objective

"Those who fail to learn from history are doomed to repeat it" [1]. Is organizational and technology development in fast-moving, high-technology companies fundamentally different than what the literature has described as typical of organizational life-cycles and technology development in firms that preceded the information technology revolution?

In many firms, institutionalized arrogance blinds management to new and emerging threats to its core business. Highly successful firms frequently focus inwardly for solutions to crisis in the belief that there is little to learn from history or from other, "less successful" contemporaries. The prevalence of a "Not Invented Here" attitude can result. For example the Digital Equipment Corporation discounted the pending revolution of the personal computer[2] and failed to respond. This doomed the company. In another case, Microsoft missed the importance of the Internet and reacted, but not suffered substantial financial or potential legal consequences[3]. Even when best practices are established the fear that implementing and institutionalizing them will slow the company down. This frequently dooms well-intended attempts to initiate change.

In a company like Sun, a large number of senior managers and engineers have experienced 15 or more years of continuous, unabated success. Leadership at Sun is proud and self-confident. During this period, the company has survived crises, won numerous battles, and seen many competitors fail. Many believe that a special, flexible, unbounded culture exists that has enabled quick, dramatic invention, paradigm-shifting revolutions in technology, and the ability to turn the company "on a dime" in response to

---

[1] Attributed to George Santayana, 1863-1952

[2] "There is no reason for any individual to have a computer in their home" – quote attributed to Ken Olsen, Founder Digital Equipment Corporation, 1977

[3] Johnston, Stuart J., "Microsoft's MSN Challenge: Getting Beyond the Blind Spots", *Information Week*, July 28, 1997

emerging threats. Many are skeptical that studies of non-high tech firms or experience from other companies are relevant[4].

The objective of this thesis is to study and interpret classical organizational theory and apply it to a case study of Sun. By comparing the evolution of organization and technological forces within the company to results that theory would have predicted, we hope to confirm that Sun is not especially unique. A current initiative is then analyzed.

[4] Management invited a well-known senior vice president from a more established firm to speak at an executive offsite meeting. One director remarked, "What can we learn from these folks? Didn't their stock just tank 30%?"

Approach

The approach used in developing this thesis encompasses several tenets.

Overview of a computer system

We present the architecture, implementation and product domains of a modern computer system as a primer for the systematic influences on technological, competitive and differentiation choices made by computer makers. A decomposition strategy looks at the computer system in terms of its goals, behaviors and structure. The relationship of the organization to the technology of its products frames the organization in both the form and functional structures.

Organizational studies

We undertake a broad study of literature on the organizational life cycle, extensively using five texts for terminology and insight:

- *The Organizational Life Cycle*, edited by John H. Kimberly and Robert H. Miles
- *The Management of Innovation,* Burns and Stalker
- *Organizations: Rational, Natural and Open Systems,* W. Richard Scott
- *The Study of Organizations*, edited by Daniel Katz, Robert L. Kahn, J. Stacy Adams
- *Formal Organization*, Peter M. Blau, W. Richard Scott

Notably, these texts predate the arrival of the Internet age, hence provide a theoretical foundation untainted by recent writings on organizations. Numerous contemporary texts augment the study.

Scott gives us the strong basis for considering the organization as a system. Kimberly offers the ecological and evolutionary metaphor of birth, growth and decline. Greiner offers a comprehensive model suggesting stages of growth through creativity, direction, delegation, coordination and collaboration. Each new stage of growth is reached by negotiating crises of leadership, autonomy, control and red tape generated in the previous stage. Using these views, we develop a framework of organizational theory that addresses the phases of growth, types of organizational systems, the influence of organizational evolution and ecology, and the leading indicators of impending crises.

Case study of the history of technology development at Sun

We adopt our analytical model to a case study of technology and organizational strategies used at Sun. We examine distinct periods that emerge within this model:

- 1982-1984, Founding, growth through entrepreneurial vision
- 1985-1992, Management competence, open systems
- 1993-1998, Growth through expansion and decentralization

Within each phase, we study:

- The state of the market and competition
- Market strategy
- Technology strategy and complexity
- Organizational strategy
- Assessment of the effects of growth, crisis and response

The intent of the case study is to correlate Sun's history to the predictions of the organizational models.

Overview of current company initiatives

The paper concludes with an analysis of two ongoing initiatives within the company, dealing with process, behavior and architecture, the Product Life Cycle (PLC) and the System Hardware Architecture Council (SHAC). PLC provides a phase-gate release structure for product development. SHAC is an executive level, review board chartered to develop a process to promote greater efficiency, collaboration and cooperation between different design groups.

Tests of our hypothesis

Throughout this paper, we continuously ask these questions:

- Is Sun is unique, relative to the expected performance of any type of firm experiencing growth?
- Would past successes and failures have been predictable?
- Did corrective actions and initiatives adequate address problem?
- Do initiatives, themselves, foreshadow future problems?

We seek to move between two complementary approaches to the analysis. At one level, the process of firm growth is one that involves the independent possible identities that the organization can assume, structurally and culturally. This represents the more fundamental thrust, to transcend the influence of the actual product or engineering needs of the organization. At another level, though, what the firm produces has an important impact on structure and organization. The coupling of the changes in engineering requirements helps put the organizational choices in the proper context.

Data used in this thesis

Much of the supporting information used in developing this thesis is highly company confidential. Interview data, both in employee surveys and in conversations, was collected with the assurance that what was said would be used as background information and not to be referenced explicitly in publication. Certain data and information is masked.

- Data collected in cooperation with a consulting group, which conducted a comprehensive series of interviews with over 400 Sun employees as part of a Sun-wide self-assessment, supports several of the specific issues dealing with employee's sense of meaning, motivation and commitment. A series of meetings, telephone interviews with the lead consultant and access to interview data provided essential background and supporting arguments. Due to confidentially and promises to employees and participants, details on the consulting company, its principles and the specific remarks, summaries and conclusions reached in their report can not be included in this paper. The knowledge gained in this engagement helped confirm or refute independent work done by the author.
- Conclusions reached, based upon a survey conducted within a single engineering organization representing nearly 300 employees, in testing employee perceptions of the state of the company. This information includes supporting evidence for identifying current issues within the company from the employee point-of-view
- Interviews with leaders of two change initiatives currently underway.
- Interviews with several senior executives
- Interviews with MIT faculty members

Background

Brief history of Sun

Vinod Khosla, Andreas Becholscheim, Scott McNealy and Bill Joy launched Sun Microsystems in 1982 with the goal of making and selling high-performance computer systems. By adopting open system standards and exploiting the dynamics of network effects, they believed they could create a compelling new model for computing.

- Open systems, in 1982, meant using off-the-shelf components, industry standard interfaces, and a freely available, open operating system called UNIX. This was an exceptionally radical idea during a time when proprietary systems from IBM, Digital Equipment and Hewlett-Packard dominated high-end computing.
- According to Metcalfe's law on networking, "The power of any computing device, no matter how awesome the chip inside, will increase along with its connections to a network"[5]. Sun planned to exploit this trend and coined the phrase "The Network Is the Computer". All Sun computers included hardware and software features optimized to work in a networked environment.

Sun's high-end, desktop computer, called the workstation, targeted the technical and engineering design user, delivering high performance, superior graphics and an integrated network port. By 1989, Sun was the market leader in workstations. The company competed ferociously on price-performance and aggressive marketing.

By the late 1980's, off-the-shelf microprocessors were unable to keep pace with the increasing need for performance. Sun developed a microprocessor around a revolutionary Reduced Instruction Set Computing (RISC) architecture named the Scalable Processor ARChitecture (SPARC). Shortly thereafter, it introduced a high performance version of

---

[5] Metcalfe, Bob, inventor of Ethernet and co-founder of 3Com

the UNIX operating system named Solaris. Sun licensed SPARC and Solaris to the market in keeping with the philosophy of open-systems.

There were several types of computers and approaches to computing competing with workstations, including mainframe, minicomputer and personal computers (PC). During the mid-1990's, Sun faced increasing competition and price erosion at the low end of the workstation market due to increasing performance and plummeting prices of high-end PCs. Management made a strategic decision to stay out of the PC business and focus on emerging opportunities in commercial computing, driven by the explosive growth of the Internet.

As networking expanded, the deployment, maintenance and administration overhead of managing networks consisting of complicated PCs (fat clients) increased. Cheap, lightweight, pre-configured computers called network computers (or thin clients) were emerging as alternative end-user machines. The complex parts of a network were quickly being consolidated within a centralized network resource called a server. As the focus of computing shifted to client-server, the market in servers to provide the backbone of complex networks dramatically expanded. Sun increased its investment in servers and complementary technologies enabling the development of network-based, thin clients[6].

Sun's 1994 server business consisted of deconfigured workstations and medium-sized computers. Sun planned to augment these products by creating optimized low and mid-ranged servers for the small business and workgroup, entering the growing network/telecommunication infrastructure market and driving performance up into the traditional mainframe, supercomputer space. By September 1998, revenue for servers surpassed that of workstations.

---

[6] The most visible of these programs produced the programming framework later known as JAVA.

In fiscal year 1999, Sun Microsystems achieved nearly $12 billion in sales, continuing an almost unbroken 10-year trend of 20% annual growth and its number of employees grew to over 35,000. Major alliances with American Online, Inc and Netscape Communications augmented with Sun's stated mission to emerge from the image of a hardware equipment manufacturer to an Internet category player.

Influence of technology migration

The influence of technology innovation drives the organizational alignment and growth throughout Sun's life. Five distinct eras emerge:

- Maximizing use of common off-the-shelf parts and an open operating system
- Developing and designing new microprocessors and systems busses
- Migrating from small systems with one-processor to large systems with a couple or many processors
- Broadening the product line from a few systems to many
- Integrating new features and software into the many systems

Sun is unique in its competitive arena. Its been described as "the last standing, fully integrated computing company, adding its own value at the chip, operating system and systems level"[7]. Sun competes with Intel on microprocessors, Microsoft on operating systems and computer companies like IBM, Compaq and HP on products. Nearly 90% of the major components that go into a Sun computer, today, are custom designed. The use of SPARC makes Sun independent of the business strategy of microprocessor suppliers. The Solaris operating system is significantly more advanced and robust than virtually any

[7] Doerr, John, featured article, *Fortune*, October 13, 1997

other operating system on the market[8]. The ownership and control of key building blocks enable Sun to optimize products as a wholly integrated system.

Influence of company culture

New employee orientation, recruiting literature and press announcements portray Sun as a fun, open, entrepreneurial workplace with a minimum of formal policies and procedures. The company promotes flexibility, individual initiative and responsibility without bureaucratic shackles. Employees are expected to demonstrate increased potential for innovative, out-of-box thinking and to take advantage of an opportunity to work in a way that works best for them. Indeed, there is incidental evidence that, with more rigorous and formal company control, several revolutionary technologies may never have seen the light of day. Senior management reinforces a commitment to be aggressive, even flamboyant.

Autonomous, independent business units enable Sun to rapidly develop and deploy new and exciting products. Proliferation and expansion of the new product lines have led to substantial increases in market share in existing arenas and deep penetration into new and emerging segments.

Warning Signs

The culture of promoting individual initiative that led to substantial success also contributes to a lack of consistency, predictability and repeatability. Schedules are frequently missed and performance frequently seems to lag the market leaders[9]. Many

---

[8] Kirch, John, "Microsoft Windows NT Server 4.0 versus UNIX", http://www.unix-vs-nt.org/kirch/#stability, August 7, 1999

[9] http://www.tpc.org/New_Result/TPCC_Results.html, in recent industry standard benchmark tests, no Sun system was in the top 10 in price-performance, and in total performance, it ranked no higher than fourth

processes are not rigorously written down or reviewed and best practices are difficult to transfer or institutionalize. Groups appear to replicate or duplicate effort. Informal communication structures leave many transactions open to misinterpretation and misunderstanding, exacerbated by the sheer number of new employees and rapid expansion. There are no guidelines for decision making. The frequent lack of quantifiable metrics makes measurement, goal alignment, obligations and accountability difficult to manage. As Sun grows, these inefficiencies could slow or limit further success of the company.

Motivation for change

Solving problems motivates change. Market and technological challenges increase the urgency of doing it right. Several challenges are particularly tough.

- Sun's products are expanding both up, into higher performance, mission-critical applications, and down, into PC price-level network computers. The use of a common processor architecture and operating system is a compelling story for customers, but forces a "one size fits all" requirement on key technologies.
- Lead times in developing some technologies, especially custom microprocessors, forces fundamental technology and architectural decisions long before markets are understood and product groups have an opportunity to participate in the design. This creates solutions that are optimized at the component level, but detrimental to downstream groups integrating these components. Often, latent features of the architecture burden system developers with awkward implementation restrictions.
- Many markets served by these systems have similar, but not identical needs. Because each market, alone, can justify substantial investment in targeted products, projects developed in different business units begin to look very similar. This results in near duplication of similar products and non-optimal use of valuable engineering resources.
- The steady increase in computer performance and reduction in costs creates uneasy partitions between high-end, mid-ranged and low-end systems. Migration of products

from one market segment to another, due to the evolution of performance, compromises product family coherence. Maintaining differentiation in the product line is difficult.

- Integration continues to drive unnatural groupings of features. The accelerating aggregation of system features into fewer components increases the criticality of each part of the system. Many disassociated functions are tightly bundled in both the hardware and software, due to cost and space opportunities.
- Many of Sun's markets are maturing and competition is shifting from technology and price-performance, traditionally Sun's strengths, to service, robustness and quality leadership. "Continuous availability will be an imperative"[10] to companies providing mission critical services to their customers.
- Proliferation of brands may dilute the ability to sell Sun itself as a one-company, one-message player in the market. While the company proclaims to be "loosely coupled, tightly aligned"[11], with independent divisions autonomously working on products that contribute to a corporate vision, how aligned are they?

Recruiting and retaining talented employees are the most essential tasks facing companies in fast-growth situations. Opportunity can be lost due to insufficient resources. Hence, Sun's employees are scarce and valuable assets. Employees are highly sought after by other firms, often at greater compensation and/or other significant benefits (stock, equity, and location). Employee surveys claim that there is tangible, quantifiable retention strength in the existing company culture[12]. If sweeping changes break this tenuous hold on employees, attrition and the inability to replenish the employee pool could cripple competitiveness. Yet, these same surveys also uncover a

---

[10] McNealy, Scott, as quoted in *Sun Microsystems, Annual Report, 1999*

[11] Kunstler, Daniel, *J.P. Morgan Securities, Discussion with Scott McNealy*, May 6, 1977

[12] Sun conducts a quarterly Employee Quality Index (EQI) survey to gauge the attitudes of employees

prevalent anxiety that many processes in the company are suffering from the strain of growth.

Several initiatives are underway to interview, analyze and assess areas where improvement in process, procedures and a greater discipline can lead to higher productivity, quality and predictability, organizational learning and reduction of duplication.

Constraining the study

This thesis concentrates on a major division within Sun, the Computer Systems Division (CSD). CSD is the largest division in Sun, responsible for developing hardware, software and systems technologies used in high-performance computer systems. CSD is a reasonable proxy for Sun as a whole, sharing these attributes with other parts of the company:

- Long-tenured middle managers
- Rapidly growing and expanding engineering organizations
- Broad responsibility for both hardware and software development
- Integration challenges
- Technology leverage with other groups
- Growing, diversified customer bases
- Complexity in operations and supply chain management
- Increasing breadth and depth of product offerings
- Globalization and decentralization of product development

Other divisions within Sun may be dealing with other issues. However, since CSD currently generates over 75% of the company revenue, its influence clearly dominates.

Systems view of a computer

Sun Microsystems is major producer of high-performance computer systems. The goal of this section is to describe the subsystem and technological choices made in designing and producing computers. We explore the connection between generic system composition/design and computer system design.

- **Overview of a system** introduces the concepts of a system, subsystems, interfaces, the influence of complexity and a method for decomposing a system according goals, behavior and structure.
- **Overview of a computer system** decomposes the requirements, functions and form of a computer system and the characteristics that make it complex.
- **Glossary of computer system concepts** describes distinctions between different types of computers and different computing paradigms, including the PC, mainframe, server, workstation and network computers and centralized, time-sharing, standalone, distributed and client/server computing.

Overview of a system

What is a system?

"A system is a set of different elements so connected or related as to perform a unique function not performable by the elements alone"[13]. A system is something that is able to stand on its own within a given context. A system is a set of interacting stuff working in unison. A system is a whole thing unto itself. A system is a member of a structural hierarchy[14]:

- A *super-system* defines the external environment principles, rules, laws, and context within which a system exists. The *system* exists within the *super-system* and operates in accordance with these constraints.
- A *system* consists of a set of interrelated, interdependent component subsystems which, together, act in concert to achieve an objective. It is an independent entity.
- The *subsystems* coordinate activity within a system via interfaces and signaling, subordinate to the programmed control of the larger system. The joining of individual elements (and/or other subordinate subsystems) in a dependent manner creates subsystems.
- *Elements* represent the lowest level of the hierarchy, the individual, self-contained building blocks that make no sense to decompose.
- *Interfaces* represent the connections between elements and subsystems

The dynamic nature of a system emerges via the interactions between itself and the super-system and amongst its subsystems. The partitioning of the system into subsystems and interactions helps the individual observer understand how the system works.

---

[13] Rechtin, Eberhardt and Mark W. Maier, *The Art of Systems Architecting*, 1997

[14] Crawley, Edward, *Course Notes from Systems Architecture, Course 16.880*, 1998

Requirements

Systems exist to satisfy needs. These needs drive requirements defining the desired operational behavior, acceptance criteria, scope and scale a system is to provide. Requirements encompass several domains:

- *Inherent and explicit*: the universal objective of why the system must exist. These become the goals of the system. The end-user, consumer or customer of the system selects these.
- *Emergent and implicit*: an acceptable way of achieving the explicit goal. These define the architectural choices or functions that the system implements. The provider, in consultation with the customer, selects these requirements.
- *Preferential and distinctive*: accounting for user preferences, tastes, capabilities or needs. These define the implementation or instantiation form that the system takes when it is complete. These are constrained by the technological capacity of the producer of the system.

Complexity

Systems exist to deal with complexity. A definition of complexity would include:

- A large number of elements
- A large number of interconnections
- Interacting functions

Rechtin's definition, "Complexity: composed of interconnected or interwoven parts"[15], is inadequate when one desires to qualify levels of complexity. Iansiti[16] suggests an approach for distinguishing more-complex systems from less-complex systems:

---

[15] Rechtin

[16] Iansiti, Marco, *Technology Integration*, 1999

- Systems in which the technological base or application context is simple, the pace of technology advancement is slow or moderate, the number of different technologies needed to produce the product is small, technology choices are relatively clear and the business environment is relatively stable, are not complex.
- Complex systems emerge when the technological base is novel, changing rapidly and/or unpredictably, there are many possible applications, the number of different technologies needed is large, the number of interdependent subsystems is many, technology choices are many and the business environment is continuously changing.

Complex systems exceed the limits of a single, methodical understanding. Complexity makes it difficult for an individual to manage or understand the system.

Decomposition according to goal, behavioral and structural attributes

When confronted with complex systems, an architect can rely on a decomposition strategy in trying to break the system down into manageable chunks. Decomposition subdivides a system into constituent, less-complex subsystems, each more manageable. Approaches to decomposition partition the system in an organized fashion. Strategies include decomposition by technology, function, physical location, organizational breakdown, competence and vendor.

Koopman[17] proposes a decomposition method using goals, behavioral and structural attributes, useful in describing technical and non-technical systems, such as organizations. We will use this technique to partition and analyze the major components of a computer. Comparing this approach to needs analysis, goals are analogous to explicit requirements, behaviors to inherent functions and structure to form.

---

[17] Koopman, Philip, "A Taxonomy of Decomposition Strategies Based on Structures, Behaviors, and Goals", *Proceedings of Design Theory & Methodology Conference*, September 1995

Table 1 Koopman's Goal, Behavioral and Structural attributes

Goals	"Goals are emergent design properties that satisfy the needs which the design is intended to fulfill. Goals include any result that is not directly available as an 'off-the-shelf' building block. Goals thus include performance targets, costs and aesthetics. Goals also include emergent structures and behaviors that are too complex to be implemented without some sort of decomposition. Clearly, classification of a design attribute as a goal depends on the state of the art in the particular technology of interest as well as the design context. In particular, the goal for a component will often be to provide a structure or behavior included in a higher-level. Goals typically answer the question 'why' when trying to explain decisions made with respect to structures and behaviors."
Behaviors	"A behavior is an action, force, process, or control law that is exerted on or by a structure with respect to the structure's external environment. In the case that only a portion of a design (a subdesign) is under consideration, other subdesigns constitute a portion of the external environment for the behavior under consideration. Behaviors typically answer the questions of 'how' and 'when' in a design, and are typically described using verbs and adverbs. Behaviors encompass not only data transformation and causal relationships normally associated with the word 'function', but also processes, flows, and other temporal aspects of the design. In the computer field, functions often specifically exclude timing and sequencing aspects of the design; using the term behavior should help avoid confusion in that domain."
Structure	"Structures are physical components, logical objects, geometric attributes, fields, or arrangements of other structures within a design. Structures typically answer the question of 'what' in a design, and typically are described using nouns and adjectives. The term structure is used to encompass not only geometry and other tangible aspects of 'form', but also non-tangible entities."

Overview of a computer system

Let us examine the goals, behaviors and structure of a modern computer system.

The goals of a computer

At its most rudimentary level a computer is a machine that performs a function on a piece of data in order to create a new piece of data according to some pre-defined transform function. The explicit goals for a computer lead to these requirements.

Table 2 Goals of a computer system

Must have a way to input data
Must have a way to transform data
Must have a way to view the resulting, transformed data

Behaviors of a computer system

Several, secondary attributes distinguish a computer system from a simple computing machine[18]. These represent the emergent, implicit behaviors of the system.

Table 3 Behaviors of a computer system

A human-accessible way to input data
A human-readable way to view data
The ability to change the transform function in a programmed way
The keeping of state, so that data can be maintained and transformed through several iterative steps.
The ability to save data for use later
The ability to share data between users and/or other computers

[18] Mano, *Computer Architecture*, 1980

Structure of a computer system

Experience, preference and accepted user practice define the functions a computer system should provide, accepted and understood means of providing, manipulating, maintaining and displaying data.

Table 4 Structure of a computer system

Element	Description
Input device	An interface to a human user in the form of input devices, typically keyboards, mouse, or similar pointing devices. This satisfies the requirement to provide "A human accessible way to input data."
Output Device	An interface to the human in the form of output devices, typically a video display screen, printer, indicator lights or other visual elements. This satisfies the requirement to provide "A human readable way to view data."
Processor	The Central Processing Unit (CPU) is the central component of any computer system. It behaves as the primary transform engine for the system, where all of the operations occur. The CPU defines the base architecture and software instruction set.
Memory	Main memory is where information, quickly needed by the processor, is stored. Main memory must match CPU performance. High-speed caches hold frequently accessed data. Volatile main memory loses its data when power is off. Memory satisfies the requirement for "The keeping of state, so that data can be maintained and transformed through several iterative steps."
Storage	Storage – Because main memory is volatile, a secondary data exists in the form of non-volatile storage media such as floppy, hard drive disks or tapes. This satisfies the requirement "The ability to save data for use later"
Software	A master program or software manages all of the subsystems in a computer system. This program manages what is given to the processor to process, what type of operation the processor is to execute, what data is stored in what location, how the user interacts with the system and how the computer system identifies itself and communicates via the network. This satisfies "The ability to change the transform function in a programmed way."
Network	Computer systems pass information to other computers and devices via an interconnect known as the network. This satisfies "The ability to share data between users and/or other computers"

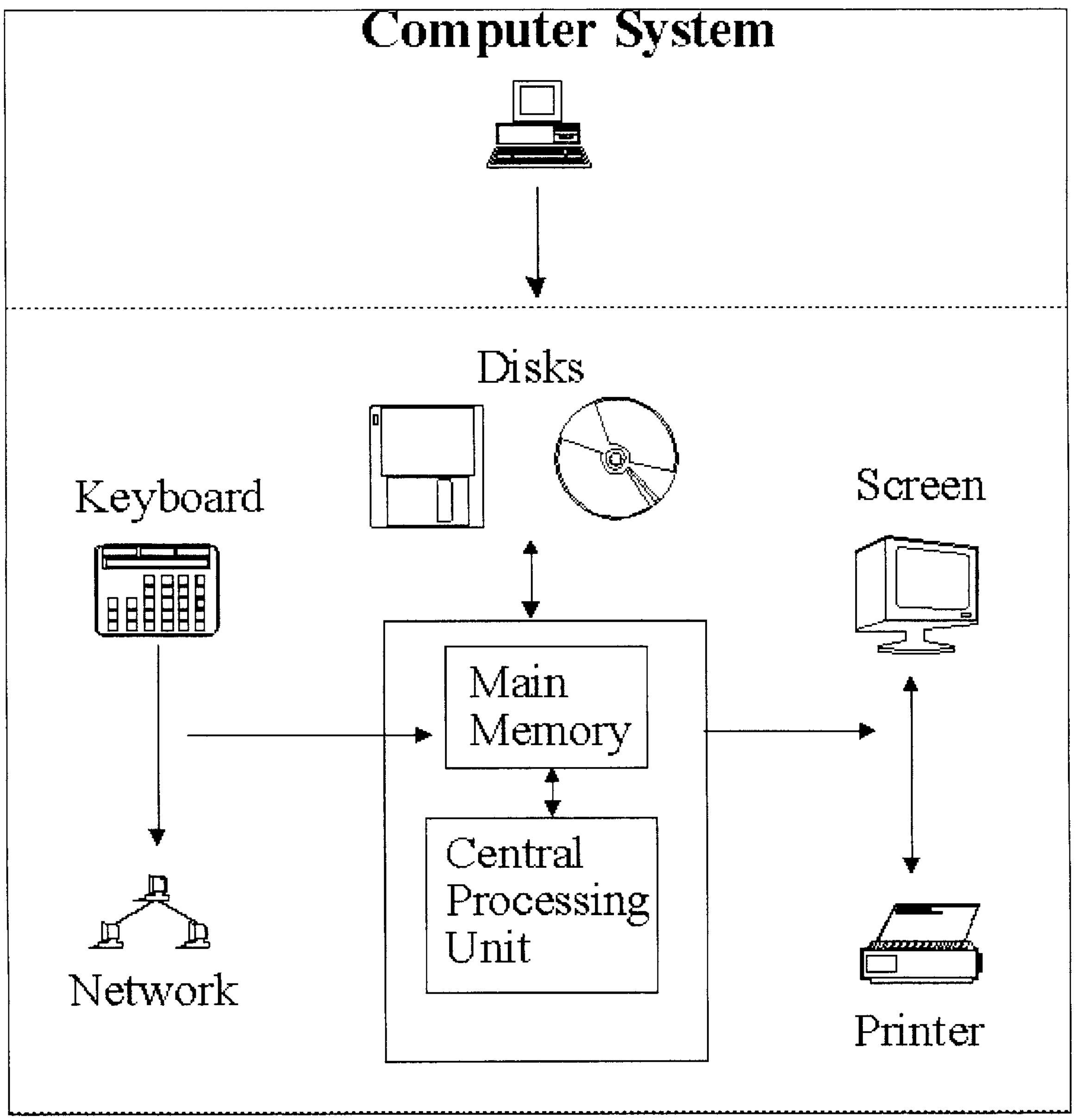


Figure 1 Basic computer system structure

Form of a computer system

The structure of modern computer systems has distinguishable and recognizable components. The form of the computer system depends upon selection of these key attributes.

Table 5 Form of a computer system

Building block	Description
Microprocessor	Defines the native "instruction set" used to program the CPU. (Today, most CPUs are integrated into a single integrated circuit (IC or chip) called a microprocessor. Hence, the term CPU, processor and microprocessor have become virtually synonymous).
Operating system	Defines the native "maintenance software" and provides the interface to higher-level application software.
System Bus	Defines the interface to which the primary system components connect and communicate. Typically, this will be what connects the microprocessor to some type of memory controller (which interfaces to memory) and some type of controller (which controls how the system interfaces to external devices)
Input/Output Bus	Defines the interface into which devices and cards providing Input/Output (I/O) connectivity to the system are attached.

These building blocks also define the nature of the computer's interfaces to the user and external environment, distinguishing one computer system from another.

Elements of a computer system

The physical implementations of component building blocks in a computer system define the indivisible elements beyond which further decomposition is unnecessary or meaningless to the customer.

Table 6 Elements of a computer system

Element	Description
Microprocessor	The Microprocessor implements in customized silicon chips.
Other VLSI chips	Other silicon chips, implemented in Very-Large-Scale-Integrated (VLSI) technology, augment system functionality.
Printed Circuit Board	Provides the electrical interconnects between chips.
Connectors/cables	Interconnects printed circuit board and other components
Enclosures	Mechanical design defines the appearance, size, weight and physical characteristics.
Power Supply	Power supply and cooling supports the proper environmental condition for electronics to operate properly
Firmware	Specialized software that initializes hardware features of the system.

The implementation approach to a computer system has a significant influence on the organization and work breakdown structure necessary to design it. Design competencies, methodologies and dependencies drive solutions.

Interactions

Many levels of interactions characterize the integrative challenges in computer systems.

Table 7 Interfaces in the hierarchy

Interface Level	Description
User Level	Determines how the user interfaces with the computer, usually mechanical keys to input and a display to read the resulting character.
Physical Layer	Influences how electronic signals pass throughout the system. The electrical quality of signals determines the speed at which the system can run. Interfaces between systems connecting to the same wires have to adhere to common specifications.
Signal level	Follows communication standards that define how signals are interpreted by each subsystem on the bus
Protocol level	Defines how combinations and streams of signals encode information.
Driver level	Specifies software readable data.
Operating system level	Interprets driver level data and puts it in proper context.
Application level	Interfaces to the operating system to allow application software to use system resources.

Each of these interfaces introduces interactions, frequently crossing from one technology space to another. The compound effects increase complexity.

Why is a computer system complex?

In addition to inherent behavior, structure and form, other computer system attributes add to complexity.

- *Pace of technology advancement.* Continuous advances in silicon technology (the doubling of speed and halving of size every 18 months[19]) drive a rapid tempo in computer system, performance improvement. This puts demands on product development teams and stresses interfaces (interconnect speed, amount of memory, electrical signal integrity, mechanical attach, power, etc).

- *Aggregation.* The amount of digital circuitry that can go into a single device now enables the implementation of many, previously decoupled, subsystems in the same physical device. Systems-on-a-chip are extremely cost effective and reliable, but increase the complexity of individual devices. Unanticipated interference between subsystems at such a small level is cause major problems.

- *Software/Hardware interfaces.* The choice of implementing a feature in software or hardware requires substantial knowledge of both domains to select the optimal partition. It is rare for a single individual to have this knowledge; hence, teams form, adding to communication and negotiation overhead.

- *Integration challenges.* Frequently different teams or even different companies provide parts of a computer system. For example, in a Dell PC, the microprocessor comes from Intel or AMD, the operating system from Microsoft and printed circuit boards from Asian manufacturers[20].

---

[19] Moore's Law, "The circuit density of semiconductors doubles every 18 months or quadruples every three years. (Circuits per chip)=$2^{(year-1975)/1.5}$", Gordon Moore, in presentation at 1975 IEEE International Electronics Device Meeting

[20] Dell, Michael, *Direct from Dell: Strategies That Revolutionized an Industry*, 1999

- *Uncertainty.* The product development times for large computer systems are long and frequently exceed the market life of the product. It is difficult to predict customer preferences at the start of a project. Product concepts often change late in the development cycle.
- *Partitioning* provides greater degrees of freedom. The availability and utility of easy to design custom chips, increases the potential size of an implementation solution set. This can lead to optimization beyond the point of diminishing returns.
- *User contexts are incompatible.* Computers are general-purpose systems. Different customers can have widely different requirements. Some want performance, some expandability, others cost. It is uneconomical to target each of the possible customers. Most computer designs are compromises.
- *Design processes developed concurrently with the design.* Because of the pace of technology, the design methodologies used to implement parts of the design are often immature or non-existent. The tools used to assist design are themselves untested. This creates a credibility gap during the early stages of a project. Is a problem with the tools or with the design?

While these attributes of a computer system are not unique, the aggregate effect supports the premise that computers are very complex.

Glossary of computer system concepts

Architectural differentiation

All computer systems share goals and functions. In the end-product space, preferential needs define market segmentation. System features satisfy these needs in terms of an application space or user base. The palate of possible user preferences in selecting a computer includes:

- Software compatibility
- Performance (CPU, OS, application)
- Quality and serviceability features
- Cost
- Ease of interfacing with other types of computer
- Portability
- Importance of graphics
- Number of microprocessors
- Amount of memory and/or storage supported
- Number and type of I/O devices supported
- Reliability
- Ability to seamlessly integrate into an existing environment
- Compatibility with old systems, promise of compatibility with future systems
- Ability to upgrade or add-on new features
- Environmental friendliness
- Robustness

Computer manufacturers compete based upon their selection and implementation of these features. The computer hardware space includes mainframes, minicomputers, personal computers, workstations, servers and thin clients.

Mainframes, centralized computing and time-sharing

Mainframes are very large computers, traditionally (and still) used to run commercial applications of big businesses and other large-scale computing tasks. Users connect to mainframe using unsophisticated display devices and software applications run on the mainframe. The operating system of a mainframe computer allocates resources to each of the attached users by managing time-slices of compute time. Mainframes also manage commonly shared resources such as printers, storage and network interconnects. The mainframe-terminal mode of computing is referred to as time-sharing. This type of computing is also called centralized, because the applications in a time-sharing environment only run on the mainframe. A minicomputer is a smaller, less expensive computer, which takes the place of a mainframe in smaller businesses or departments.

Personal computers and standalone computing

A *personal computer* (PC) is used by one person at a time. It is a sophisticated, stand-alone system, primarily administered and maintained by the end-user. Resources such as storage and printers connect directly to the PC. All applications run locally. The important characteristic of a PC is that it is fully functional on its own. The operating systems for PCs, until recently, have been optimized to efficiently run a single application at a time.

Workstations

A *workstation* is a computer intended for individual use but faster and more capable than a personal computer. It is typically used for business or professional applications, connected to, and administered as part of a network. Workstations and the applications designed for them are used by small engineering companies, architects, graphic designers, or any organization, department, or individual that requires a faster microprocessor, a large amount of memory and special features such as high-speed graphics adapters. The operating systems for workstations have evolved to run both user applications and applications over a network simultaneously, hence are called multitasking.

Servers, client/server and distributed computing

In a mode of computing referred to as the client/server model, a network of computers is linked together as clients and servers. The server is a program that awaits and fulfills requests from client programs in the same or other computers. Over time, the term *server* has also come to refer to the computer system within a network whose primary purpose to provide services to other computer programs. Similar to the mainframe, the server enables resource sharing amongst many users. In contrast with the mainframe mode of centralized computing, user applications are run on the client (usually a PC or workstation), hence the client/server mode of computing is called distributed. Today, the distinction between mainframes, minicomputers and servers is blurring since all can do both time-sharing and client/server.

Network computer (or thin-client)

A *network computer* (NC) is a low-cost PC-like device for networks configured with only essential equipment (devoid of typical PC features such as hard drives and diskettes). NCs operate via the client/server model where a server downloads an application to run on the NC. NCs are part of a class of computers called thin-clients, distinguishing them from the more feature rich fat-client PC and workstation. The operating system for a NC is typically small and easy to maintain.

Other computer terms

Multi-processor systems are those that have two or more processors. Adding processors is an economical way to improve the performance of a computer system, but it is technically challenging. The operating system, dealing with a multi-processing computer, is responsible for efficiently assigning tasks to each of the processors. When done well, multiprocessing is a highly efficient way to scale computer performance at marginal incremental cost. Larger computer systems can contain hundreds of microprocessors.

Open systems refer to use of industry standard interfaces[21]. Gradually, through the adoption of industry standard interfaces, many subsystems in a computer are becoming increasingly microprocessor-architecture independent. Exploiting standards enables storage devices, I/O devices, display tubes, network interconnects, keyboards, and main memory devices to work with many different types of microprocessor-based subsystems. Simultaneously, the standardization of key software interfaces enables operating system-independent software applications. Done correctly, software standards enable an application, written on one system, to run on other operating systems.

Summary

In this section, we reviewed the concept of a system and complexity and introduced a decomposition approach to study a computer system. We reviewed the levels of goals, behaviors and structure in developing a model for how to partition a computer. Several attributes of a computer identify it as a very complex system.

Overviews of several types of computer systems highlight the differences in meeting user needs. The distinction between workstations, PCs and NCs, servers and mainframes drives product tiers in the computer market. Open systems enable hardware and software to interoperate.

---

[21] IEEE Guide to the POSIX Open System Environment, 1003.0-1995

Theory of the organization

Organizations are social structures created by individuals to support the collaborative pursuit of specified goals. Organizations define objectives, induce participants to contribute services, control and coordinate these contributions, garner resources from the surrounding environment, dispense products or services, select, train and replace participants and arrange working accommodation with neighboring organizations[22].

The goal of this section is to present several perspectives on the organization:

- **Organization as a system** introduces several views on the organizational structure. The mechanistic, organic and open schools of organizational practice are presented. Using the perspectives we create a framework in which to analyze the evolution of organizational practices at Sun Microsystems.
- **The organizational life cycle** examines the effects of time and change on an organization. The phases of birth, maturity, decline and alternative views of the organizational life cycle are introduced along with the cause and effects of crisis during times of transition.
- **Organization and the individual** covers concepts dealing with the firm-employee relationship. The role of meaning, motivation, commitment and a social contract are explored as a basis for understanding how employees perceive their position in the system.

---

[22] Blau, Peter M., and W. Richard Scott, *Formal Organizations*, 1962

Organization as a system

Burns and Stalker, in the study of innovative organizations, observe two distinct systems of management practice[23].

- The *mechanistic* approach decomposes activities into specific, distinct tasks. The individual pursues his work in compartmentalized isolation from the organization as a whole. Someone "at the top" is responsible for making collection of tasks relevant.
- The *organic* approach distributes ownership of task definition to a hierarchy of technical specialists. Participants perform tasks according to individual aptitude and preference, within their understanding of the overall objections of the organization.

Burns and Stalker note that mechanistic systems are most often found in an organization operating under stable, repeatable conditions; organic systems under conditions of rapid change or requiring adaptability. Both approaches are frequently present in any firm, often justifiably, due to varying types of demands on different parts of the company.

The differences between the two systems ultimately resolve into differences in the kind of relationships that prevail between members of the organization, a *code of conduct.*

Scott[24] segments organization perspectives, extending the use of the system metaphor and providing a third structure:

- *rational* systems (analogous to Burns and Stalkers' mechanistic practice)
- *natural* systems (organic)
- *open* systems

---

[23] Burns and Stalker, *The Management of Innovation*, 1961

[24] Scott, W. Richard, *Organizations: Rational, Natural and Open Systems*, 1992

The organization as a rational system

As a *rational* system, "Organizations are collectivities oriented to the pursuit of relatively specific goals and exhibiting relatively highly formalized social structures."

Rational systems establish firm, quantifiable metrics that are calculated and measured with an emphasis on control systems, information, efficiency, optimization and implementation policies and procedures. Rational systems define hard constraints, authority, rules, directives, jurisdiction, performance programs and coordination guidelines. There are clear and unambiguous preference criteria for selecting among alternative activities. Goals are specific, rigidly operational and assist decision-making, bound the organization's structure and direct the types of task, personal and resources engaged.

Formalization of process dominates and rules are precisely and explicitly stated, independent of the individuals within the structure. Administrators and technical specialists supplant the entrepreneur. A strict hierarchy, with a chain of command, controls the power within the system. Leadership and innovation is routinized, regularized, and incorporated into the formal structure. Decision-making is centralized and most participants are excluded from using discretion or exercising control over their own behavior. Incentives are distributed in an impartial, impersonal manner according the economic performance against goals.

The rational system's formality increases predictability and precision at the cost of inflexibility. Pre-arranged responses and scenarios presume that the organization faces, over time, a stream of similar challenges from a stable and consistent environment. The systematic de-emphasis of individual problem solving or discretion treats employees as interchangeable cogs. The relationship of the employee to the firm is strictly economic. Employee initiative and self-confidence are insignificant. There are heavy penalties on the inability to plan for all possible contingencies. Moreover, if significant change occurs, the rational system eventually risks *trained incapacity*[25], the ability to do the wrong thing in a very efficient manner.

The organization as a natural system

As a *natural* system, "Organizations are collectivities whose participants share a common interest in the survival of the system and who engage in collective activities, informally structured, to secure this end."

Natural systems acknowledge that the stated and operational goals drive the quantifiable performance of the organization. Yet, the social nature of the organization also embeds implicit, irrational goals that exist merely to maintain its survival. Frequently, there is a disparity between these two types of goals. The natural system recognizes this and attempts to leverage the survival instinct in order to boost, rather than hinder, performance. For example, irrational decision processes that filter alternative possibilities will tend to overestimate the probability of success for an alternative that best matches the participants' expectations, eliminates conflict and molds commitment to the organization. Conversely, it may underestimate the probability of success for an alternative that threatens the existing state of the organization.

A hierarchy exists, but replaces rigid control with nurturing and persuasion as the main influence tool. Informal structures emphasizing the personal characteristics of specific individuals are tolerated with the belief that there is more to organizational structure than prescribed rules and job descriptions, i.e., the existence of a *common purpose*. Incentives and inducements include an element that recognizes individual differences and uniqueness, out-of-box thinking and loyalty.

The natural system's informality runs the risk of replacing *cost and efficiency* metrics with less quantifiable *sentimental* goals. Yet, the positive influences include increasing ease of communication, facilitating trust and correcting for inadequacies of more formal

---

[25] Veblen, Thorstein, *The Theory of Business Enterprise*, 1904

systems[26]. Natural systems account for individuals being complex, with multiple motives and values, driven as much by feelings and sentiments as by facts and interests. They rely on the worker's *willingness* to work, but recognize that they must be induced to contribute. Natural systems will frequently appear to be chaotic, unstructured and undisciplined and depend upon empowered individuals to *do the right thing*. If the *common purpose* or strategic goals are not properly communicated or aligned with the social needs of the participants, the natural organization becomes vulnerable.

The organization as an open system

As an *open* system, "Organizations are systems of interdependent activities linking shifting coalitions of participants; the systems are embedded in – dependent on continuing exchanges with and constituted by - the environments in which they operate."

The boundaries between the system and its environment blur and interfaces with external systems may become more important that those into its own subsystems. The organization acknowledges that individuals have varying interest and values, joining and leaving interactions with the system depending upon benefits they can personally gain. In contrast to the rational and natural models, participants may not share common goals or even loyalty to the survival of the organization. Thus, an open system is not strictly a formal structure but a collection of interdependent activities that must be continuously aligned, and motivated to work, in concert, according to their own interests.

Individual subsystems view themselves as autonomous, grabbing resources from the system when needed, but otherwise operating according to loose connections with other parts of the system. The emphasis shifts from the structure of the organization to the organizing of processes used to streamline coordination. The system and its subsystems behave in mutual self-interest though input, throughput, output and feedback monitoring.

[26] Gross, Edward, "Some Functional Consequences of Primary Controls in Formal Work Organizations", *American Sociological Review*, 1953

Rational, Mechanistic	Natural, Organic	Open
Rise to take advantage of production economies	Efficient	Flexibility, cooperation, empowerment and purpose dominate
Work is divided into specialties	Emerge as the embodiment of belief systems create a social imperative	Local optimization, inconsistent and difficult to measure results
Control comes down from the top	Work is divided into activities	Adaptable
Problems go up	Vision comes from the top	Depends upon "perfect market" efficiencies
Conflict between units is resolved above and outside the limits	Problems belong to the organization	Work is divided into autonomous sub-tasks
Work is highly serialized	Conflict is resolved between individuals	Sub-units are induced to cooperate based upon mutually attractive benefits
Integration is the responsibility of someone else	Work is collaborative	Contractual obligations drive interface and performance requirements
Performance is defined by standards set within each function	Integration is handled at peer levels and considered the responsibility of everyone	Problems are resolved through legal examination of the contract
Accountability is to the function	Performance is defined by that of the whole system	Work is highly parallelized
Communication is strictly through the hierarchy	Accountability is to the team	Integration is explicitly apparent in the design of the system itself
Contact with the external environment is limited to those with explicit responsibility	Communication is open and free	Accountability is to the contract
It serves itself better than its members	Contact with the external environment is at the discretion of task owners	Communication and coordination are handled by process
Predictability, regularity, repeatability and rigor dominate	It serves the customer as well as itself	Relationships are temporary
Rigidity, formality, inflexibility, lack of individual accountability lurk	The individual is empowered and free to define their own processes	

Table 8 Comparison of rational, natural, open system perspectives on the organization (inspired by Meyer[27])

[27] Meyer, Christopher, *Fast Cycle Time, How to Align Purpose Strategy and Structure for Speed*, 1999

Organizations have an inherent static structure formalizing its programmed responses to stimulus and inputs from its surrounding environment in a predetermined way to produce an intended result. When circumstances change, though, these structures also provoke implicit and, possibly, unintended responses.

The organizational life cycle

Structural inertia is an organizational tendency to maintain internal structure regardless of other factors or concerns[28]. The strength of this force determines the ability of the organization to adapt to change. Yet, an organization is also a dynamic system. It navigates through an environment subject to changes in size, politics, society, culture, competition, ecology, economics and technology. Analogies to organic processes such as birth, evolution, cycles, cause and effect, feedback, crisis, maturity, old age and death enable a perspective of the organization in terms of its organizational life. In this section, a model of the organizational life cycle, a review of a procedural planning model in developing approaches to building a new organization and the signs of decline are reviewed.

Birth – getting off the ground

A dominant theme in the birth of an organization is the potential of exploiting technological change[29]. This opportunity could arise within an existing firm that recognizes a shift in competency and designs a new organization to bring it to fruition. Alternatively, it could emerge independently, ripe for a startup venture. Both types of endeavors share common characteristics hence the use of characters such as the *entrepreneur* or *founder* is appropriate for either circumstance.

An entrepreneur identifies either a market need, new product, improvement to a process or substitute for an existing market and creates a compelling competitive advantage by the innovation of new technology. The entrepreneur develops a concept, garners

---

[28] Hannan, Michael and Freeman, John, *The Population Ecology of Organizations*

[29] Abernathy, William, and Kim B. Clark, "Innovation: Mapping the Winds of Creative Destruction", *Research Policy*, 1985

resources, produces, builds and sells the product. At some point, basic operational tasks exceed the capacity of the entrepreneur. In response, organizations are born.

Three forces, present at the founding of an organization, are significant in understanding the features it takes on throughout its life.

- *Personality of the founding team* affects attitudes towards form, structure and power.
- *Time and place of origin* place the organization within a social system and context in which resource reserves, the political and economic climate dictate certain rules of engagement.
- *Preference and prejudices exercised in building human capital* in the early organization create the foundation for myths, stories and philosophy, cultural preferences and habits that give the collective body a sense of uniqueness.

Studies show that the organizational characteristics present at the time of formation are likely to remain significant features of the organization throughout its life[30]. These influence and constrain subsequent organizational behavior and may even be incompatible with the requirements for long-term survival[31].

Growth – institutionalization

Successful passage through the birth phase ends with structures and processes that are effective and work. They may not be optimal or efficient and are often discovered as much by accident as by planning. The institutionalization of these practices moves the organization from infancy to maturity.

---

[30] Scott, W. Richard, *Organizations*, 1992

[31] Boswell, J., *The Rise and Decline of Small Firms*, 1973

Greiner's classification of the organization life cycle concentrates on fundamental characteristics of an organization as it grows. He proposes a model of evolutionary phases[32]:

- Within one phase, the organization develops inertia enabling it to optimize strategic competencies. These competencies, in a successful organization, lead to growth.
- However, efficient solutions to problems, reinforced in the current phase, can blur the ability to identify and respond to pending internal and external change agents. These agents create predictable crises.
- Response to crisis requires management adjustment for the survival of the organization. The successful negotiation of these mini-crises enables the organization to evolve to the next phase of maturity.
- The solution for the current crisis potentially becomes the seed for an impending crisis in the next stage.

The evolutionary growth model stresses the impact of internal crisis as the central theme in provoking an organization to jump to the next phase. An inadequate response to crisis leads to decline.

Note that Greiner does not suggest that a firm systematically step from one phase to the next, only that these forces are generally at work. One part of the organization may be dealing with growth due to delegation, another with growth due to creativity. Nevertheless, at an aggregate level, the growth model is valuable as a tool for assessing the broader trends that are prevalent as the larger organization changes.

---

[32] Greiner, Larry E., "Evolution and Revolution as Organizations Grow", *Harvard Business Review*, August, 1972

Growth catalyst	Characteristics of Growth	Leading indicators of crisis
1. Growth through Creativity	The founding entrepreneurs give birth to the organization. A creative epiphany gives fruit to acceptance in the marketplace and the organization begins to grow	Crisis of leadership: the organization expands beyond the capabilities of entrepreneur who appoints a manager bringing skills of coordination and administration.
2. Growth through Management	The manager introduces controls, procedures, measures, and authority and aligns the organization to a common goal	Crisis of Control: the introduction of discipline and efficiency drives continued growth stretching beyond the capabilities of the centralized manager
3. Growth through Delegation	The manager institutes a hierarchy of responsibility, decentralizing and delegating decision-making	Decentralization enables more timely and accurate response to opportunity, but can lead to duplication of effort, turf wars and inefficiency leads to a Crisis of Integration
4. Growth through Coordination	A group of management peers mandates planning procedures, reports and formal reviews to enable coordination between the different sub-organizations	Crisis of Red Tape: early success causes mechanisms to multiply and performance to adapt to the letter, not intent of process. Innovation and response time slows.
5. Growth through Collaboration	The firm purges oppressive oversight replacing it with trust and informal collaboration. Experience, instinct and intuition take over from planning, but contractual negotiation attempts to define win-win relationships.	

Table 9 Greiner's Model of Five General Evolutionary Stages

Impact of size

Another force on a firm as it grows, observed by Blau[33], is the gradual inability of subunits of the organization to change. Increasing organizational size generates structural differentiation among various subgroups at decelerating rates. The expanding organization may naturally slow its rate of innovation merely due to the inefficiencies incurred by administrative overhead dealing with divergent work habits. The inability of administrators and management to maintain and promote common, best practices could lead to ad hoc changes that inhibit collaboration.

When an organization reaches a certain size, there is the gradual influence of new employees mimicking the behavior of experienced veterans[34]. Over time, the organization loses its innovative capability, becomes insular and unable to create solutions to new problems. When a technology or market discontinuity punctuates equilibrium, it becomes difficult for the firm to react[35].

Organizational decline

Evidence of a crisis can be very elusive. An organization can fail to identify a critical problem because the initial impact is subtle. The distinction between absolute decline and a decline in performance[36] can be subtle.

---

[33] Blau, Peter, *A Formal Theory of Differentiation in Organizations*

[34] Astley, W. Graham, "The Two Ecologies: Population and Community Perspectives on Organizational Evolution", *Admin Science,* 1985

[35] Sahal, D. editor, *Information Exchange and Technological Innovation: In The Transfer and Utilization of Technical Knowledge,* 1982.

[36] Kimberly, John H. and Robert H. Miles, *The Organizational Life Cycle, 1980*

- Absolute decline, or *cutback*, occurs due to sudden loss of market share or a market getting smaller. Cutback represents an immediate and obvious threat to the very survival of the firm. These moments are intense and crystallize the need for quick and drastic corrective action.
- Less easy to detect is a gradual decline in performance, or *stagnation*, when the general climate and bureaucratic and passive behavior cause a decrease in the rate of growth. Crises in the growth model are leading indicators of stagnation.

Ironically, the institutionalization of *core competencies* can make an organization vulnerable to stagnation. Success frequently creates a false sense of security leading to complacency. Ease is confused with effort. Minor, inconsequential achievement is confused with accomplishment. Failure is excused or hidden as an embarrassing indication of incompetence. Moreover, in stable times, a firm may survive stagnation indefinitely without acting.

The environment, government policy, competition and advance of technology threaten an organization with a moving and discontinuous field of operation. Competency-destroying influences are not always apparent, even when they collide with structural inertia and comfortable stability, making it difficult for the organization to respond.

The threat of stagnation is amplified when we consider the latency of information passing through an organization. At any point in time, the structure of the organization lags behavior by one generation and behavior lags goals by one generation. This creates a perception gap between management and participants in the organization that decreases communication efficiency.

The impact of discontinuity

Tushman suggests that a method for identifying the threat of stagnation is creating *absorptive capacity* by investing in research and development of technology and processes not obviously in step with the generation of current revenue[37]. Done properly, these investments create an outward looking awareness and perspective on where potential danger may lurk, ideally before it can damage the firm. The adoption and maintenance of a healthy sense of paranoia to resist such tendencies is a contemporary theme in many modern organizations.[38]

Conceptually the notion of creating an organizational value in creating systematic look-ahead components is easy to understand. When mated with the need to compromise operational or other short-term projects with a predictable return on investment, though, these become very difficult to justify as an investment. Paradoxically, it is at the point of diminishing returns of an existing way of doing things when it is most difficult to consider alternatives[39]. Institutions that grow up with a technology become too established, too adept in their current technology to consider alternatives. For that matter, many alternatives may be outside their area of expertise. If an existing organization wants to avoid its own obsolescence, it must be willing to explore alternatives.

An illustration of this is the S-Curve, a framework that can help to identify when the organization is about to exhaust its current way of operating.

---

[37] Tushman, Michael L. and Philip Anderson, "Technological Discontinuities and Organizational Environments", *Administrative Science Quarterly*, 1986, as cited by Scott

[38] Grove, Andrew, *Only the Paranoid Survive*, 1996

[39] Foster, R, *Innovation, the Attacker's Advantage*, 1986

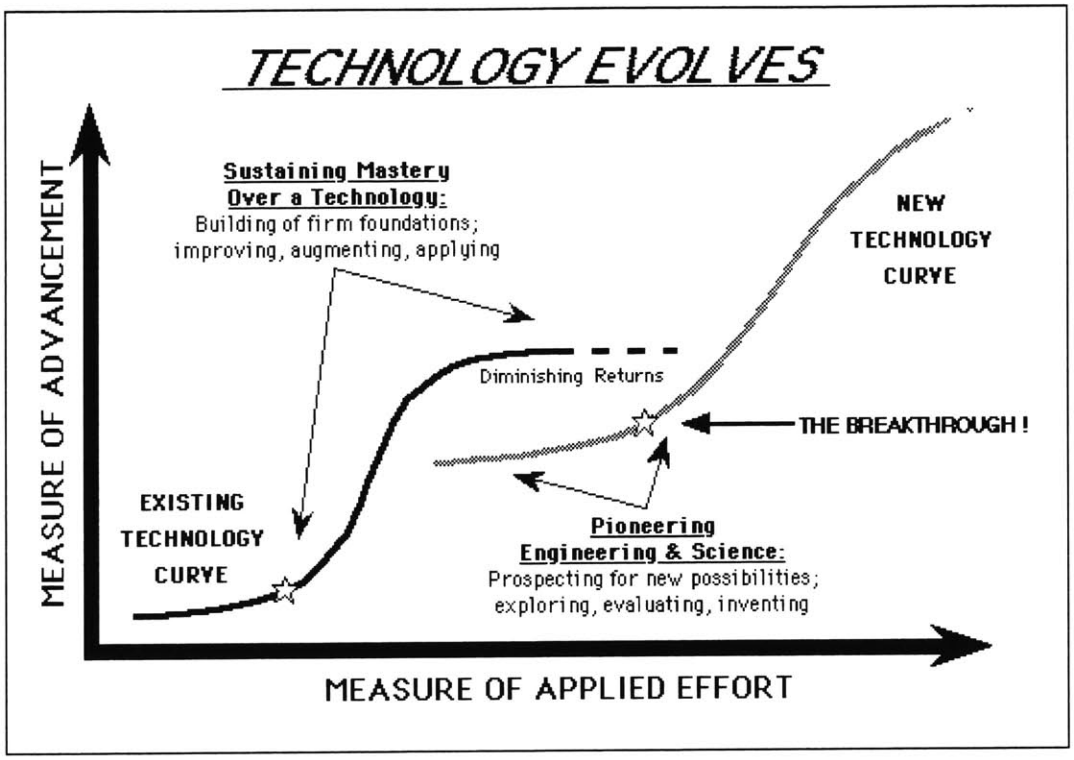


Figure 2 The S-curve

> "The S-Curve figure illustrates both the evolution of a given technology or process, and the breakthrough event when a new, superior approach becomes viable. For a given technology, the evolution is as follows: Initial efforts result in little advancement and then the technology becomes successful. This success point, at the lower knee of the curve, is where the technology has finally demonstrated its utility. After this point, significant progress and improvements are made as several embodiments are produced and the technology becomes widely established. Eventually, however, the limits of the technology are reached, and continued effort results in little additional advancement. This evolution (effort expended versus performance gains) takes the form of an S-Curve. To go beyond the limits of the top of a predecessor's S-Curve, a new alternative must be created. This new alternative will have its own S-curve and will eventually require yet another new approach to surpass its performance limits. The breakthrough event, is when the new method demonstrates its viability to exceed past the limits of its predecessor."[40]

---

[40] Millis, Marc, "Breakthrough Technologies", *NASA Archives*, 1997

We can consider the S-curve as a metaphor for how stages of organizational evolution occur. It becomes clearer that paying too much attention to the organizations current or nagging issues may drag down effort to identify the start of the next paradigm shift. Left unprepared, the organization is vulnerable.

> Robert Palmer, former CEO of the Digital Equipment Corporation, remarked, "When you are very successful, it leads you to believe you are very bright and you understand better. You must be smart—look how much money you're making! Then the environment changes and management goes into denial. It says, 'Let's keep doing what we did to make us successful, only more aggressively'. You're not allowed to talk about failure, as if it just can't happen"[41].

Sources of decline

Whetten introduces two additional sources of organizational decline. *Loss of legitimacy* occurs when the organizational successful solves a problem, but then keeps the problem-solving team intact. A self-sustaining organization emerges, maintaining canned solutions to problems, even when the problem no longer exists. *Environmental atrophy* occurs when new, market influences make the firm obsolete. The following table summarizes sources of organizational decline[42]:

---

[41] Farkas, Charles M. and Philippe De Backer, *Maximum Leadership*, 1996

[42] Whetten, David J, Sources, *Responses and Effects of Organizational Decline*, 1979

Table 10 Sources of Decline

Source	Description
Organization Atrophy (stagnation)	"Success breeds failure" Habitual use of programs to solve problems, and succeeding in solving them, causes an organization to develop patterns that gradually desensitize it to environmental change (senility). Managers, intoxicated with success, become careless. In response to crises they may just ignore it or attempt to implement mundane rules and coordination procedures that are unattractive to organization. Frequently it can be "too little, too late."
Vulnerability (cutback)	"Failure breeds more failure" A venture is most vulnerable at the very beginning of a major crisis. The absence of an early win or solution causes management to demand extreme responses to correct the perception of failure. These responses, in themselves, frequently fail due to lack of appropriate diagnosis of the root problem, amplifying organizational anxiety.
Loss of legitimacy	"Inability to move on" If an organization has survived a crisis, they've become very good at solving yesterday's problem but, once the problem is solved, the organization set up to solve the problem is difficult to dismantle. Even ineffective agencies are surprisingly resilient. It is easy to justify maintaining an organization that solved past problems as insurance, even when those problems no longer exist. Left unchecked, these organizations suck up resources and may even restrain other parts of the organization from performing.
Environmental Atrophy	"The world has passed us by" A competitor has taken over, or the environment or market has a reduced capacity to support the organization. Sometimes this leads to a response of "creative accounting". A proactive response is to use the strengths of the organization to find another niche. The reactive response is to scale down as an unfortunate victim of circumstances.

Response to decline

Decline is a symptom of a crisis. An organization is tested when it becomes aware of decline or the threat of decline. Whetten categorizes typical responses. The *Defensive* response simply ignores the problem and hopes it goes away. The *Responding* response calls for swift and dramatic action, often out of proportion to the actual source of decline. The *Preventing* response is an attempt to make the problem go away instead of correcting it. The *Generating* response has the organization treating problem solving as an opportunity to strengthen the organization.

Table 11 Responses to Decline

Response	Description
Defensive	Frequently found in bureaucratic settings Organization rules and procedures are defended as inherently important, even more important than whether it actually is achieving the objectives! No action is taken.
Responding	Call to action drives desire for swift action. But, this drives a tendency to solve symptoms rather than the problems. Frequently results in wrong solution to right problem or right solution to wrong problem. "Quick" action – relieves short-term tension ("Thank God, someone is doing something!"). But it also relaxes the motivation for long-term analysis and fixes. Failure of the response to address problems leads to capitulation when discovered.
Preventing	Manipulation, price-fixing, acquisitions, buying influence to protect the organization from external pressures (Most are either illegal or ultimately legislated against (Rockefeller, Microsoft))
Generating	Make a virtue out of responsive change This calls for a "Self-designing" organization that looks to the very act of problem solving as an opportunity. Increased tolerance for experimentation, informal communications, slack resources, loose criteria for performance evaluation, allowance for occasional failure, ad hoc jobs, frequent movement of personnel is hoped to create a higher level of innovation capacity. This could lead to a runaway innovation cycle (innovation when not needed).

For an organization motivated to sustain success, the most virtuous of the responses is *Generating* a positive, proactive approach to dealing with decline. In fact, successfully surviving a crisis creates an institutional awareness of vulnerability that, channeled, makes the firm less susceptible to decline in the future.

Dr. John Elter, VP of Strategic Development at Xerox Corporation, noted that the companies that seem to stand the test of time have, at one time or another, faced major threats and survived[43]. IBM, Xerox, Apple Computer and AT&T are examples of companies that faced major threats to a pre-existing business and were able to initiate turnarounds[44] [45] [46].

Organization disintegration and conscious choice

Augmenting Whetten's work on decline, Niv conducted several studies of non-traditional organizations in an attempt to see if stagnation is universal. In a study of communes, Niv analyzes the differences between a *model* and *pioneering* organization [47]. The model organization has institutionalized rules, methods and techniques that achieved reasonable success in the past, creating comfort, safety and routine. A common characteristic of model organizations is isolationism. Through either geographical distance or cultural bias, the model organization constrains contact with other groups. Seemingly strong and predictable, Niv observed that all model organizations eventually and gradually erode causing the system to die or making the system so unattractive that participants desert it. Niv concludes that the ability of an organization to absorb and incorporate new thinking from outside its own experience is an important attribute in achieving long-term success.

---

[43] Elter, John, interviewed as an expert in organizational robustness

[44] Carroll, Paul, *Big Blues: Unmaking of IBM*, 1994

[45] Garr, Doug, *IBM Redux : Lou Gerstner and the Business Turnaround of the Decade*, 1999

[46] Carlton, Jim, *Apple : The Inside Story of Intrigue, Egomania, and Business Blunders*, 1998

[47] Niv, Amittai, "Organizational Disintegration: Roots, Processes, and Types", as cited by Kimberly

This complements the view that organizations that have "stood the test of time" tend to be able to better survive the initial stages of decline without disintegrating.

Alternative views

Scott, Blau, Kimberly, Miles, and Greiner, as cited above, are the most frequently referenced models on organizational structure and life cycles. They are sufficient for testing the main hypothesis of this thesis. However, it would be would be remiss to fail to acknowledge a few of the dozens of contrasting or even contradictory alternative views explored. While not included in the final frameworks used in this thesis, we list them here for the reader who wishes to dig deeper into the field:

- Katz and Gartner[48] note that the size or nature of a firm population co-opts statistics and requires additional filtering when doing comparisons and selection of appropriate data. There are fundamental differences between small, medium and large companies. They propose that rather than a smooth continuum of growth, change occurs dramatically at discrete moments.
- Churchill and Lewis[49] adapt Greiner's model to deal in more detail with the problems of growth in small firms; the establishment and early growth of the firm is modeled in stages of *inception*, *survival* and *take off*.
- Stanworth and Curran[50] argue that limitations in the growth model lie in the *euphoric positivism* when formed. They propose that the impact of the founding team is even greater than Kimberly would suggest.

---

[48] Kartz and Gartner, "Properties of emerging organizations", *Academy of Management Review*, 1988

[49] Churchill, N. and Lewis, V., 'The Five Stages of Small Business Growth', *Harvard Business Review*, 1983

[50] Stanworth, M.J.K. and Curran, J., 'Growth and the Small Firm - An Alternative Perspective', *Journal of Management Studies*, 1976

- Giddens[51] refutes the assumptions of a natural science method, claiming the categories and stages produced are of ambiguous origin, and the recursive relationship between knowledge and its object ignored. The notion that the observed behavior of the organization is fitted to a pre-existing analogy is questioned as Freudian.
- Oakey, et al[52], claim subjective points of view are a significant limitation of many studies of high technology. Because of the macro level focus and the use of evolutionary metaphors, it de-emphasizes discontinuities due to revolutionary change.

---

[51] Giddens, A., *Central Problems in Social Theory*, 1979

[52] Oakey, R., R.Rothwell and S.Cooper, *The Management of Innovation in High Technology Small Firms*, 1988

Organization and the individual

"In the eyes of the employee, the carrot, the stick, and their careers are in the hands of their manager. The manager's needs always come first."[53]

An organization is both a system and a social unit made up of human beings. Hence, an understanding of what motivates key participants in a system to behave in mutually beneficial ways is important in interpreting the behavior of the system. Indeed, consistent and essential attributes of high technology firms aim at understanding the relationship between employee and employer. Recruiting, retention and attrition are particularly important topics in the era of the knowledge worker. Studies confirm that retaining an experienced employee, at almost any price, is more cost effective than trying to replace them[54]. The cost is greater when the skill sets lost are highly technical or specialized.

Employee motivation

March and Simon[55] submit that the relationship of the organization to the individual and its influence on their behavior can be classified according to three broad categories. These motivations, when mapped onto Scott's model of organizational structure sharply correlate with the characteristics of the rational, organic and open systems.

- *Members are primarily passive instruments.* They show up, do their job and go home. Any employee is interchangeable with the other; hence, there is little reason to differentiate (rational system).
- *Members bring to their organization attitudes, values and goals* and have to be motivated or induced to participate in the system. The organization must provide

---

[53] Meyer, Christopher, *Fast Cycle Time*, 1999

[54] William Drake & Associates, report on "The True Costs of Losing Knowledge Workers", 1999

[55] March, James and Simon, Herbert, *Organizations*, 1958

some type of compelling reason or coerce employees to invest their best efforts in contributing to the firm (open system).

- *Members are decision-makers and problem solvers.* Employees are self-motivated and the task of the organization is to enable initiative and independent action through appropriate support mechanisms. The identification of a *common purpose* helps align disparate activities. The primary mission of the organization is to stay out the way of the employees (organic system).

Employee commitment

Motivation creates the catalyst for employees to show up. However, unless the employee is contributing to the best of their ability, the organization does not necessary reap the full benefits. Motivation must be combined with commitment. Etzioni groups employee commitment into four levels[56], listed here in decreasing order of strength:

- *Moral* – morally correct or superior. Strongest form of commitment occurs when people organize in support of a common, moral effort. Religious fervor, total commitment and willingness to make ultimate sacrifices are characteristics of moral commitment.
- *Spontaneous, expressive* – work is enjoyable and fun. Expressive commitment comes from the members of the organization being able to fill more their economic needs in the work environment. The stereotype of this level of commitment is that "I'd be doing this even if you didn't pay me".
- *Alienate* – us against them. The bunker mentality exists in this level of commitment. A common enemy or common threat bonds participants together that, in other circumstances, may not connect.

[56] Etzioni, Amitai, *A Comparative Analysis of Complex Organizations*, 1975

- *Calculative* – purely business. Most characteristic of the open system, the calculative commitment between the individual and the organization depends upon the establishment of a mutual win-win scenario

> "The benefits of a committed workforce strategy features innovation or high quality. Studies consistently show that commitment enhances important employee role behaviors such as a high level of creative behavior, a long-term focus, and a relatively high level of cooperative behavior. High employee concern for quality is needed for organizations trying to differentiate products or services through high quality. A high degree of risk taking behavior is particularly important for organizations differentiating through innovative products and services. These critical role behaviors require flexible employees who are highly committed to the organization."[57]

The social contract

Commitment and motivation are illusive. When we remove ideological, the primary relationship between an organization and its employees is economic. Hence, regardless of the soft influences, organizations rely upon a *social contract* that explicitly links the success of the individual with that of the organization[58]. The firm depends upon the willingness to sublimate their individual goals for those of the firm, with the assurance of job security, compensation and the social benefits derived from steady employment. In recent years, though, downsizing, reengineering, restructuring, outsourcing, global competition, the emergence of a skilled, temporary workforce, and new options for

---

[57] Lucero, Margaret A., and Marion White, "Integrating Employee Benefits and Competitive Strategy", *The Journal of Business Strategies*, 1996

[58] Kochan, Thomas A., "Rebuilding the Social Contract at Work: Lessons from Leading Cases", *Task Force Working Paper #WP09* for the Task Force on Reconstructing America's Labor Market

employees outside the traditional firm, stripped bare the implicit employee-employer contract[59] [60].

Even with substantial economic prosperity and low employment in the late 1990s, the general tenor of the employee-employer relationship changes to one of accommodation. Companies continuously re-evaluate their core needs, while individuals are always on the lookout for potentially "greener pastures". It is common for a firm, even with significant revenue and profit success, to announce a layoff. It is common for a happy, well-compensated employee to resign.

In the context of motivating employees to improve their current workplace, this trend becomes a daunting hurdle. Features of a new employer-employee relationship surface through studies[61]:

- Skilled workers do not have to put up with abuse managers – they just leave
- The total employee package is becoming more crucial to obtaining and retaining the best employees
- Skills, abilities and motivation count more than experience
- Employers are demanding more accountability from employees
- Employees are becoming the competitive advantage in the business world

Aware that lifetime job security is gone, employees are more motivated to maintain critical technical skills than invest in organizational processes. The organization becomes highly tuned to short-term employee production. Both trends diminish the commitment for fundamental, long lasting, value creation in the organization.

---

[59] Pfeffer, Jeffrey, *The Human Equation: Building Profits by Putting People First*, 1998

[60] "You can have lifetime employment here if you work hard" – Employee orientation seminar at Digital Equipment Corporation, circa 1982

[61] Deal, Jack, *Deal Consulting Newsletter*

Furthermore, organizational initiatives rarely reap the rewards given to performance and operational achievement. Especially in high technology companies, few business plans go beyond a 3-year time horizon. The employee is skeptical about participating in initiatives that benefit the firm, but do not give immediate returns to the individual. Ironically, the lack of strong commitment amongst technology personnel, resulting in unusually high levels of turnover or plan apathy, is the single largest impediment for continuing success[62].

---

[62] Sethi, Viram, David Meinert, Ruch C. King, "The Multidimensional Nature of Organizational Commitment Among Information Systems Personnel", *Proceedings of the Association For Information Systems*, 1996

Structures

Effectiveness of structure in the organization is a critical part of dealing with the ability to scale or change. Most companies struggle in the design of structure, resulting in frequent, periodic reorganizations[63].

Structural soundness

Bataille discusses characteristics of an ideal, structural soundness:

- Its fit with evolving technology and human resources
- It is clearly obvious how components (technology, hr, benefits) work together
- The *rational* versus *organic* elements of the structure are clearly demarcated. At any given level of development, there is an optimal amount of rational versus organic structural attributes
- Acceptance that evolving structures represent series of *compromises*
- Careful management of *Human resource* gap at beginning – challenging and rewarding work causes exuberance and excitement
- Careful management of *Human surplus* at end – burnout, routine, magic lost
- Appreciation that at any given time, *a particular amount of difficulty is optimal* in order to keep the motivation and intensity up
- Commitment is *proactive managed* and measured, then encouraged by the structure and the meaning of incentives
- *Recruiting* the right mix of people that match the goals is important

[63] Hammer, Michael, and Steven A. Stanton, *The Reengineering Revolution*, 1995

These are daunting requirements for an organization. Structural soundness requires the participants understand how the system operates while accommodating the steady introduction of new work and opportunity. If the rate of new work is constant, the organization never fully matures because it is in a constant state of learning. The paradox of sound *structure* is that it requires continuous refreshing.

One size does not fit all

The diversity of techniques successfully employed in industrial practice suggests that there is no single, *best* structure strategy. The approaches for organizing as functional, project or matrix structures admit that all are compromises[64]. The choice of structure comes down to selecting one of these three broad areas as a primary driver.

- Technical and operational disciplines needed
- Business and strategic needs
- Ability to exploit the latest advances in technologies

Organizations aligning to one priority subtly neglect the tangible requirements of the other two. The very act of decomposing the system biases the resulting product to the disadvantage of other factors. This problem amplifies at the subsystem level as individual subteams deal with their own rationality. The resultant subsystem is optimized given the perspective of its place in the hierarchy, but not optimal when considered by the system as a whole. Misinterpretation of the big picture can cause erratic performance, confrontation and miscommunication.

Summary

We have introduced several perspectives of the organization in order to appreciate the different forces influencing both organizational choice and organizational change. They

---

[64] Eppinger, Steven D., and Karl T. Ulrich, *Product Design and Development*, 1995

represent a reasonable summary of leading thoughts on the organization backed by substantial research, study and survey.

The organization can be a rational, organic or open system.

- The *rational* system is disciplined, with a top-down, rigid hierarchy and engagement based upon fundamental rules. It is highly efficient in performing well-understood tasks. The organization exists to perform an economic purpose.
- The *organic* system is recognizable as principled, flexible, distributed, but unpredictable. The notion that the sustainability of the organization itself is a goal.
- The *open* system is one in which negotiated win-win contracts drive the obligations between individual groups. Relationships are convenient.

Organizations are in states of continuous change. In the organizational life cycle, we looked at two models.

- Organizations share evolutionary characteristics such as birth, growth, institutionalization and decline. We looked in depth at the possible sources and responses to decline
- Geiner's Growth Model gives us insight into the influence that crisis plays in forcing organizations to cope with change

The organization depends upon the meaning, motivation and commitment of its participants.

- *Motivation* can be induced by creating mutual beneficial rewards
- *Commitment* must be inspired
- Employees and employers join in an implicit social contract

The choice of structure comes down to selecting one of three broad areas as a primary driver. The appropriateness of the selection influences organizational soundness.

Case Study: The Evolution of Hardware Development at Sun Microsystems

This section consists of a case study on the evolution of hardware technology innovation during several phases in the organizational life of Sun Microsystems. We segment the 18-year history of Sun into three phases.

- **Founding, growth through entrepreneurial vision (1982-1984)** describes Sun's early years, the epiphany that led to success and Sun breaking away from the competition.
- **Management competence, open systems (1985-1992)** covers second and third generation products and maps the increasing complexity of Sun's technology and organization.
- **Growth through expansion and decentralization (1993-1998)** recounts several bold, strategy moves that opened new markets and enabled radical new products.
- **Summary** reviews key insights and conclusions.

Within each phase, we analyze:

- Background of the market and competition
- Sun's market and technology strategy
- Architecture, technology and complexity of selected products
- Organizational system, life-cycle and commitment
- Conclusion

Three books were used for the history and background on Sun, augmented by interviews with several, long-tenured employees.

- *High Noon, The Inside Story of Scott McNealy and Sun Microsystems*, Karen Southwick
- *Sunburst, The Ascent of Sun Microsystems*, Mark Hall and John Barry
- *Accidental Empires, How the Boys of Silicon Valley Make Their Millions, Battle Foreign Competition, and Still Can't Get a Date*, Robert X. Cringely

Information on the early years of Sun, especially on older products relied on the collected memory of several old-timers and two references:

- *The Sun Hardware Reference*, compiled by James W. Birdsall, an on-line reference of the Sun-1, Sun-2 and Sun-3 computers
- *Sun's Role in Redefining the PC/Workstation Boundary: Opportunities and Risk For Marketing Partners and Competitors*, Summit Strategies, 1989

Many of the features of Sun more recent products are company confidential. Specific information on performance, speeds and features of some systems is approximated. Organizational information is limited to things that are readily available in the public domain, but is kept consistent with independent research.

Characteristics that influence change

At the end of this section, we will review the history of Sun in broad, representative metrics to characterize the growth and complexity of both the systems and organization. The characteristics to keep in mind are:

- *Performance* - Speed of microprocessors - This metric is intended to be representative of general performance improvement demands on the system and is given in Megahertz (millions of cycles per second) or MIPS (millions of instructions per second). A more precise measurement of performance would reference specific benchmark applications through the Standard Performance Evaluation Corporation

(SPEC)[65]. However, because many of the benchmark applications have changed over time or, in later systems, results are still confidential, we will use microprocessor speed as a reasonable proxy.

- *Custom Complexity* - Estimates of design complexity are derived. The underlying data is also confidential, but we use the *percentage of custom design* as an approximation of amount of invention, innovation and development effort expended in developing a product line. This encompasses attributes of multiprocessing, system busses and new generation microprocessors per unit of design. For example, 0% would be completely *leveraged*, 100% completely *custom*.
- *Employee Population* – The size of the organization gives a better reading on the actual growth of the company than revenue, hence we track the employee population, over time.

[65] http://www.specbench.com/ - The SPEC consortium publishes independent performance results on a number of competitive machines.

Founding, growth through entrepreneurial vision (1982-1984)

Our first period covers the early years of Sun, the inspiration behind the founding of the company, the personalities of the entrepreneurs and the choice of technology.

Background (1980-1984)

The emergence of the workstation market

In 1980, the Apollo Computer Company released a new type of computer for the growing engineering and technical design market. The workstation would sit in an engineer's office providing a high-performance microprocessor, high-resolution graphics and an industrial strength, operating system. It replaced a graphics terminal connected to a mainframe or minicomputer in a time-sharing or standalone manner.

Apollo systems incorporated the 68000 microprocessor made by Motorola. Most of the other subsystems, including memory, I/O, graphics, storage, network interface and a sophisticated operating system, Aegis, were custom designed. Apollo distinguished itself by improving many of these technologies simultaneously and the "whole product" approach made the system extremely powerful. The Apollo series of computers was a success and workstations quickly gained an enthusiastic following.

The dawning of Sun

By 1982, Vinod Khosla, a Stanford University MBA graduate and co-founder of a computer-aided-design (CAD) software company, Daisy Systems, was coping with a rapid, growing market for software design tools. At Daisy, engineers used time-sharing systems connected to a mainframe for software development. A problem with time-sharing is that, as more users use the mainframe, the performance available per user degrades. Adding another mainframe computer helps, but is very expensive. Khosla felt the new Apollo workstation, providing distributed power to individual users was compelling. But, Daisy could not afford to equip all of its software engineers with workstations.

That same year, Andreas Bechtolsheim, Stanford University doctoral candidate, built a computer to assist his research work. Not able to afford a workstation, he pieced together components available at local electronics shop and built a computer that could connect to the Stanford computer network. Khosla met Bechtolsheim through some mutual acquaintances and came to see the new computer. He marveled at the elegance of the design and thought it would be cheap to produce. They noted that the network connection solved the awkward problem of matching the data sharing advantages of mainframe computing. Data sharing enabled engineers to collaborate on a design.

If they could mass produce this machine, and sell it at reasonable price, Khosla and Bechtolsheim were convinced that companies like Daisy would flock to the workstation. Together, they wrote a business plan and got funding to form Sun (Stanford University Network) Microsystems. Through other connections, they hired Scott McNealy as VP of manufacturing and Bill Joy, a wizard in operating systems, as software architect.

Strategy (1982-1984)

Open systems

Apollo's practice of proprietary hardware and operating system architectures followed an existing business model used by the leading computer companies of this period[66]. The rationale was to grab the customer with a compelling technology advance, enticing the customer to port and optimize its software applications and infrastructure to a new platform. With the platform explicitly designed to be incompatible with systems from other vendors, this increased the switching costs when a customer would later want to

[66]Carroll, Paul, *Big Blues: Unmaking of IBM*, 1994

move their applications to another platform. The primary purpose of this *proprietary* approach is to lock in the customer. Computer vendors could augment the base system with unique software and expansion interfaces exploiting a captive market for customized peripheral, storage and memory options and commanding premium prices[67]. Customers were aware this existed, but had no power to change it. Vendors of proprietary systems thus have a build-and-hold strategy – build a large installed base and hold it through the maintenance of a closed environment.

There were few other companies building workstations in 1982. IBM was making substantial profits from mainframe sales. Digital Equipment Corporation and Hewlett Packard were running highly profitable minicomputer businesses. Apple, IBM and Compaq were producing primitive, low-performance personal computers that ran limited numbers of applications.

The original Sun-1 computer, using off-the-shelf components, opened Bechtolsheim's and Joy's eyes to the benefits of being able to leverage cheap, commodity parts. They extended Sun's vision to provide workstation performance using industry standard hardware and software interfaces. With systems compatible with products already on the market, Sun could concentrate on core technologies as market differentiaters. In contrast to the proprietary approach, Sun marketed this design and architecture philosophy as *open systems*.

A benefit to this approach was that Sun designs were much simpler than Apollo's, but it also made them easy to copy. Hence, the strategy of open systems created a compelling need for Sun to execute designs quickly and get to market first.

[67] Pearson, Jamie P., *Digital at Work: Snapshots of the 1st 35 Years*, 1990

Technology (1982-1984)

Sun-1

The Sun-1 was the first computer produced by Sun, introduced in May 1982. Like the Apollo system, it used the Motorola 68000 microprocessor, but unlike its rival, remaining features were implemented using chips already available from vendors.

Table 12 Sun-1 Features and Product Architecture

Feature	Description
Microprocessor	Motorola 68000, 32-bit chip, running at 10Mhz. (Same chip used in Apollo's machine)
Operating System	Unisoft V7 Unix, a version of BSD Unix available to universities and corporations for a nominal license fee.
I/O Bus	Standard I/O bus, Multibus
Enclosure	Large, black box, bulky (considered relatively unattractive)
Performance	Approximately 0.5 MIPS (millions of instructions per second)
Complexity	5%

The Sun-1 was primarily a concept and demonstration machine and fewer than 200 were produced. However, it had nearly the power of the leading minicomputer of the time, the Digital VAX 11/780, for nearly one-tenth the price[68]. It rivaled the feature richness of Apollo's competitive offering at one-third the price

Nearly all Sun-1s were sold to university engineering departments[69], considered the most demanding of technical computer users. Valuable comments and suggestions came from

---

[68] Hall, Mark and John Barry, *Sunburst, The Ascent of Sun Microsystems*, 1990

[69] Birdsall noted one interesting historical. "The Sun-1 was the original computer used in the first generation of Cisco System network routers, a contemporary startup with Sun". Cisco has recently challenged Microsoft and General Electric as the highest valued corporation in the Fortune 500 (March 2000).

these early users, including recommendations for improved industrial design, more memory and a request to include the VME I/O bus to easily attach the computer to lab equipment. This community was especially pleased with the adoption of BSD UNIX.

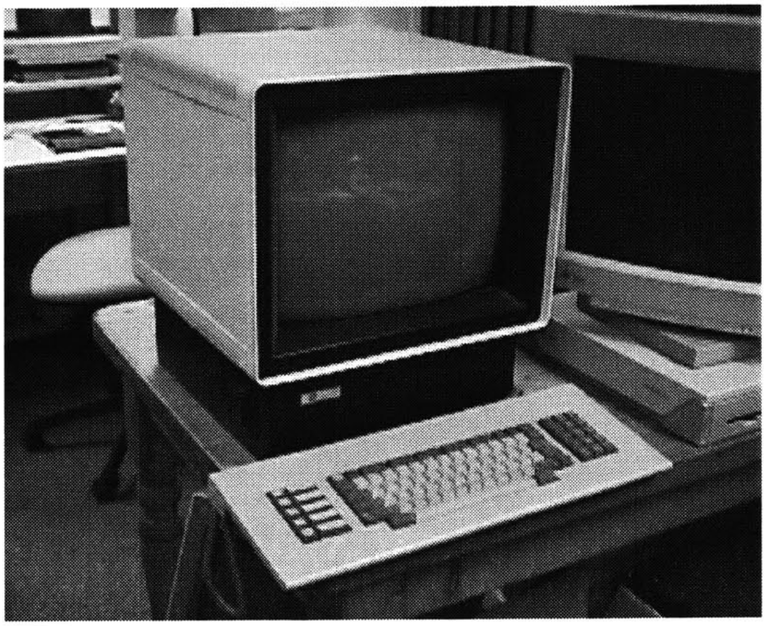


Figure 3 Sun-1 workstation

Sun-2

In November 1983, Sun released the Sun-2, "a workstation so bland that Stanford University couldn't find a basis to even demand a royalty from the startup"[70]. By this time, Motorola had released the next member of its microprocessor family. Joy solved several operating system bottlenecks and improved software features.

---

[70] Hall, *Sunburst*

Table 13 Sun-2 Features and Product Architecture

Feature	Description
Microprocessor	Motorola 68010, 32-bit chip, running at 10Mhz
Operating System	SunOS 2.0, a supercharged descendent of BSD Unix optimized by Joy to improve performance and reliability of the system (SunOS 1.0 was introduced on the Sun-1 as a prototype, but not widely distributed)
Networking	Standard Ethernet connection, NFS file services
I/O Bus	Standard I/O bus, Multibus, followed by VME in later models
Enclosure	Deskside, rackmount versions with Multibus expansion. Later VME model introduced a desktop enclosure which became known as the "wide pizza box"
Performance	approximately 0.6 MIPs
Other features	Other features: Sun developed custom video and graphics cards, significantly enhancing the graphics performance over the Sun-1.
Models	Models: Sun-2/120, Sun-2/170, Sun-2/50, Sun-2/130, and Sun-2/160. Major distinguishing differences were enclosure, number of I/O option cards allowed, and I/O bus.
Complexity	8%

Apollo's systems were technologically superior, but the Sun-2 was significantly cheaper. Unix was a major attraction for software developers and they developed new applications and ported existing software to the Sun machines.

Keeping pace with the speed of microprocessor advances is crucial for a computer systems provider. The Sun-2 exercised Sun's ability to deliver products with the latest microprocessor. The open system approach enabled a broader model line to rapidly evolve, accommodating several niche markets. Widespread acclaim over the "big pizza box" desktop system drove new directions in industrial design, for Sun and the industry.

Enhancing and Contributing to Open Standards

The Sun-2 demonstrated that adopting open standards and simple design with widely available components could produce competitive products. Nevertheless, Sun invented unique intellectual property when appropriate. Coinciding with the release of the Sun-2 and SunOS, the company expanded its standards strategy to include licensing of technologies developed internally. Sun released specifications to industry standards review boards. If the review board approved the specification as a standard, Sun would license it to the market. The earliest success of this strategy involved the development and licensing of the Network File System (NFS) in 1984.

Before 1983, most computer manufacturers provided a custom, proprietary protocol for managing and sharing data over networks. This, inherently, made file systems incompatible. As customers bought computers from multiple vendors, they increasing demanded the ability to share files across different types of computing platforms. Some type standard protocol support would need to be included in all of the various operating systems in the market. Sun software engineers developed the NFS protocol for file sharing and got it approved as an industry standard. Sun licensed NFS, but then made the extraordinary step of releasing the source code for software making it easily adaptable to any operating system. The ease in which a vendor could import NFS persuaded IBM, Digital and Hewlett Packard to adopt it. NFS became another example the value of open system architecture.

First Major Sale

A breakthrough moment occurred when Computervision, the leading supplier of CAD software for systems development, announced that they were going to change their primary develop efforts from mainframe/minicomputer time-sharing systems to workstations. This opened a bidding war between Sun and Apollo. McNealy and Khosla made a heroic effort to persuade Computervision to choose Sun[71], and landed the account, worth nearly $40 million. Apollo was severely embarrassed and the combination of compelling technology, aggressive marketing and pricing made headlines. Sun's share of the technical computing market continued to grow and an estimated 10,000 Sun-2s shipped during its first year of production.

---

[71] Hall, *Sunburst*

Organization (1982-1984)

Organizational System

Contrasting and complementary entrepreneurial styles came to play in these early years. As we recall, *the personality of the founding, team affects attitudes towards form, structure and power* [72]. Let us examine what each of the founders brings to the table.

- Khosla, the CEO, longed to run his own company and had developed the connections needed to fund a new venture. His market vision and skill, work ethic and "win against all odds" approach to business drove the company. He was blunt, quick to criticize ideas and obsessive about costs. Khosla wanted to retire by age 30.
- Bechtolsheim, the hardware architect, was a power user of computers. He knew what people like him wanted in a workstation. He had a deep understanding of how to get the most out of off-the-shelf technology and a keen sense of when to buy technology and when to invent it. His speed in designing systems was crucial for Sun to turn out competitive products.
- McNealy, the VP of Manufacturing, knew how to build, test and distribute products after three years as a middle level manager in larger organizations. If Khosla's marketing projections bore out, the ability to ship products in high volume would be crucial to fuel fast growth. McNealy brought joyful excitement, a sense of humor, loyalty, teamwork and compassion to the company. He became a catalyst for creating personal enthusiasm and motivation amongst the employees.
- Joy, the software architect, was a legend in the software world due his early work in the development Berkley Standard UNIX (BSD UNIX), a widely popular operating system with university computing centers. His academic credentials and reputation brought instant credibility to the fledgling organization. Joy's enthusiasm for

---

[72] Abernathy, William, and Kim B. Clark, "Innovation: Mapping the Winds of Creative Destruction", *Research Policy*, 1985

software standardization was a major influence in Sun's primary strategy, open systems. His appreciation of the big picture and ability to identify technology trends complemented the operational tendencies of his partners.

The organizational structure beneath senior management was flat and loose, typical of a small company in the early stages. A small team of hardware engineers under Bechtolsheim concentrated on hardware design. Joy led the software team. Khosla and McNealy dealt with the business and made sales.

Sun attracted the attention of several venture capitalists (VCs) that funded the development of the Sun-2 and encouraged the founding team to hire a seasoned executive, Owen Brown, from Digital Equipment, as President. Brown immediately worked on recruiting engineers and Bernie Lacroute, a gifted and highly respected engineering manager, joined as VP of Engineering. Together they took on the challenge of managing a rapidly growing engineering team.

Owen Brown had an easy, nurturing style and the employees liked him. However, Brown was absent (for personal reasons) during the pinnacle contract negotiation with Computervision, infuriating Khosla. This rift grew and Khosla openly questioned Brown's commitment to the young company.

Nevertheless, employees flourished in the excitement of the technology, working environment and attraction of stock options.

Growth through creativity (1982-1984)

With the drive by both Khosla and McNealy to land partnerships and customers, the Sun-2 put the company into a hypergrowth mode. McNealy demonstrated his ability to manage a delicate supply chain and deliver high-quality product in volume.

Sun improved workstation computing by aggressively controlling costs, using inexpensive components, and evangelizing "open systems" and concentration on execution. Sun achieved $39 million in sales in 1983. By 1984, the Sun-2, selling at an average selling price of about $15,000, drove Sun's yearly revenue past $150 million.

Kimberly says, "The time and place of origin place the organization within a social system and context in which resource reserves, the political and economic climate dictate certain rules of engagement"[73]. Silicon Valley, during this period, was ripe with venture capitalists eager to back fledgling high technology outfits. The existence of Stanford University, Berkeley and large companies nearby supplied a ready source of smart, competent employees. The enticement of success, embodied by the success of Apple Computer and other recent startups, made engineers tolerant of risk taking, moving from company to company and develop an attitude that they could be in control of their own destiny. (This contrasted to prevailing work ethics in other parts of the country, where loyalty, commitment, the implicit promise of lifetime still reigned). This made it possible for a company, in the valley, to move fast.

Lacroute, Bechtolsheim and Joy created an internal atmosphere that placed the engineer at the center of influence. They nurtured creative invention in the pursuit of practical application of technology, while always being aware of market and profit potential.

The aggressive sales approach used by Khosla set the tone for how Sun would attack markets. "Have lunch or be lunch" became a marching order for a take-no-prisoner approach to sales. Competitors griped that Sun did not play fair, breaking traditional rules and business practices when it ruthlessly cut profit margins to gain market share[74].

Khosla did not tolerate poor or average achievers. He insisted on hiring only the best, even leaving critical positions unfilled in the absence of an acceptable candidate. With the efforts of Brown and Lacroute, Sun's employee population grew to a few hundred.

---

[73] Kimberly and Miles, *The Organizational Life Cycle*

[74] In the Computervision deal, Computervision had already verbally awarded the contract to Apollo. When Sun was able to turn the verdict and land the sale, industry insiders decried it as Sun being a "bad loser".

McNealy was the center of fun. He chaired weekly beer blasts and embraced new employees.

Crisis of Leadership (1984)

Sun's "growth through creativity" accelerated during its first two years. Greiner's model predicts that such a period is likely to lead to a "Crisis of leadership" in which the organization expands beyond the capabilities of the founding entrepreneur. Response to such a crisis would be to augment the entrepreneur with a professional manager to being skills of coordination and administration. In mid-1984, events resembling Greiner's crisis of leadership scenario unfold.

Continued success depended upon developing long-term relationships with key customers and partners. Financial backers feared that Khosla's lack of solid people skills would soon inhibit the ability of the company to continue landing contracts. Khosla's abrupt and brutal style of management alienated employees and investors. By mid-1984, he was openly hostile to Brown, who abruptly resigned due the unrelenting scrutiny. The departure of Brown stunned many of the new employees. Rather than risk another outsider, the Board promoted McNealy to the President position. Even with this change, Khosla's demeanor did not improve. This continued to annoy the Board of Directors and, in a critical decision, it fired Vinod Khosla.

Response to Crisis

To minimize confusion and reduce employee unease, the board quickly appointed McNealy as the interim CEO. The board intended to replace McNealy as soon as it could find a suitable candidate. During the drawn-out search, McNealy landed several more contracts and sales of the Sun-2 accelerated. Employee morale improved. Lacroute's engineering team quickly added a mid-life kicker to the Sun-2 line and made steady progress in the design of new products.

Instead of drawing the executive search out, the board made a strategic gamble to give McNealy the CEO job, permanently. "Firing Vinod Khosla as CEO was the biggest decision for the company in propelling it forward", according to a Sun board member at the time[75]. Equally big, though not apparent at the time, was the choice to replace Khosla with McNealy.

Conclusion (1982-1984)

Strategy

Two dominant strategies emerge during this period. The first is the understanding that distributed, powerful computers at an engineer's desk represented a significant advantage over the time-sharing systems then in place. The benefits of cheaper costs, easier deployment, removal of a single-point-of-failure and ability incrementally scale were made possible by the maturing performance of networking interconnects.

The second strategy was to adopt an open instead of proprietary architecture. It is clear that the initial motivation for this approach was to enable the rapid development of a cheap alternative to the Apollo workstation. The revelation that open architectures were a significant benefit to the end-user, in terms of reducing proprietary lock-in, and increasing flexibility and choice became a key component of Sun's ability to differentiate it. This also forced Sun to be extremely honest and quick to implement open designs because they could not depend upon lock-in to maintain their hold on customers.

Technology

Technology was open and simple leading to a straightforward design, easy and cheap to implement. The use of off-the-shelf components and a widely available operating system enabled sun to get to market quickly with competitive machines. These technology choices, due to the ease in which they could be duplicated, drove a need for Sun to execute on designs quickly.

---

[75] Hall, *Sunburst*

Organization

Bechtolsheim and Khosla's vision of computing was solid. They correctly identified a latent market need and filled it. The organization grew through a series of rational, calculated moves. Structure was a flat and lax, *natural* system. *Open systems* created a clear common purpose. The use of stock options and incentives created mutually beneficial rewards for both the company and employees. Early success reinforced the vision proposition. Technology was balanced with sound business practice.

If Khosla was the embodiment of the entrepreneur, what happened at Sun in its third year is consistent with the Greiner model. Greiner maintains that the logical response to this type of crisis would be to hire a professional manager. However, the resident professional manager, Brown, was already gone. The burden of managing the company was now in the hands of McNealy and Lacroute. A *crisis of creativity* occurred. Greiner's *response of management* followed as the model would predict

Management competence, open systems (1985-1992)

Background (1985-1992)

Workstation competition

The success of the Sun-2 came largely at the expense of Apollo, but workstation sales were also stealing customers from the established computer firms, Digital, IBM and Hewlett-Packard. By 1985, each had workstations under development. Numerous startups, including Silicon Graphics, Ardent and Stellar, planned to enter the market.

By 1989, Digital, alone, was marketing three separate workstation families based on Intel and VAX microprocessors. One new startup, MIPS, was developing a new microprocessor, based on the principles of Reduced Instruction Set Computing (RISC), which could be a way to significantly increase performance.

In the world of standards, Sun continued to be a trendsetter with open systems, but there was increasing reluctance in the market to adopt its standards proposals. Competitors started several consortiums during this period to collaborate on alternative standards. The Open Software Foundation formed to create an alternative Unix operating system[76], other forums debated user interfaces and, other than NFS, no major vendor was licensing Sun technology.

Intel's 80386 released its first microprocessor that could compete with the performance of Motorola. IBM and other PC manufacturers were now able to build cheaper machine that could run certain applications nearly as well as the Sun-2. Apple Computer's Macintosh entered the market and caused a stir with its easy to use windowing interface.

---

[76] Salus, Peter, *A Quarter Century of UNIX*, 1994

Retail distributors, including Radio Shack and Sears were becoming alternative distribution channels for computers, driving penetration of computer usage into the home.

Importance of the applications

During this time, a wholesale movement from centralized to distributed computing occurred. Sun's operating system and software development environment was ideally suited to support this transition.

The value of a computer system ultimately resides in the base of application software that you can run on it. The firm that purchases a computer makes a substantial investment in application software, whether written in-house or purchased from a third-party independent-software-vendor (ISV). The relationship between ISVs and systems providers began to strengthen as the sales of smaller computers grew. Small companies were now able to purchase inexpensive computers capable of running programs previously only available on mainframes. A huge, untapped market for new applications and the number of ISVs began to grow.

In ISVs, software development is typically done on a "reference platform", a computer system that is either easy to write for or represents a large share of the systems being used by the software company's customers. Being designated a "reference platform" is a major, strategic advantage for a computer vendor. The first platform to support a new application gains a momentary monopoly during the time it takes to port the application to other systems.

This influence of software on customer buying habits was new.

Strategy (1985-1992)

Exploiting Open Systems

The strategy of open systems software became clear: Sun emphasized that the customer should not agonize about the hardware. Hardware continuously changes and improves.

Customers do not want to be locked-in on last year's model. The barrier to buying new hardware is the software porting effort due to incompatibility. As noted earlier, this is an artifact of the market, not technology; hence, customers were vulnerable to paying unreasonable costs. "The Open Systems environment contains the basic elements of an operating system, user interface, communication protocols, languages, database management and so on"[77]. The open systems approach lowered the barrier to porting software. Open system was Sun's religion.

Capture applications

In 1985, Sun began publishing a catalog, Catalyst, of the applications ported to its workstation. Espousing the value of its open standards as a low-risk approach for ISVs and independent hardware vendors (IHVs), Catalyst was used to persuade third party software developers to use Sun as their reference platform. In exchange for adding an application to Catalyst, Sun provided discounts on computers, joint marketing and sales campaign support. The standard software interfaces, shared with other vendors, enabled ISVs to write code with the security of knowing they could easily port their code to other platforms.

The applications available in the Catalyst catalog became an important complementary asset for Sun. As the number of applications grew, the market for Sun workstations increased. As the installed base of Sun workstations grew, ISVs selling into certain markets clamored to make sure they were included in the catalog. In a very short period of time, Sun became the leading reference platform for engineering CAD and technical applications, ensuring a major lead over the competition whenever a new software package was released.

---

[77] Levinson, John C., *Goldman Sachs Report on Computer System Market*, 1986

Match the PC

Sun's dependence on Motorola microprocessors was a concern. The ability to compete on price-performance hinged on Motorola remaining in the lead and competitive with other families of microprocessors. By 1987, Intel's 80386, its first 32-bit microprocessor, was able to compete with Motorola on price and performance. Hence, PCs with the 80386 could threaten the low-end portion of the workstation market. Sun decided to develop an Intel-based workstation that could run SunOS.

Diversify

Ninety percent of Sun's sales were into the technical and graphics-intensive space. Yet, this segment represented less than 10 percent of the total hardware market[78]. To maintain its rapid growth, Sun needed to make serious forays into the non-graphics-based commercial market. An attentive salesperson, when visiting a Wall Street investment firm, noted a trader sitting with eight dumb terminals, connected to a mainframe, monitoring transactions. The salesman convinced the information technology manager that a single, networked workstation could replace all of those terminals, while providing the same capabilities.

In a second market, General Motors, which had been using several, incompatible, proprietary systems to run its automated factories, issued a requirement that computers had to incorporate a way to interact with those from other vendors. Sun's inclusion of Ethernet, a standard networking interface, in all of its workstations enabled it to quickly demonstrate the ability to communicate and control computers from other suppliers and made it ideal for the automatic factory business.

The US Government issued a global finding that, to improve interoperability of federal computing systems, it would adopt Unix as the standard operating system for any future computer purchases. Sun, as the rising Unix proponent, was poised to exploit this.

---

[78] "Sun's Role in Redefining the PC/Workstation Boundary ", *Summit Strategies Market Report*, 1989

In the financial, industrial automation and federal markets, Sun made substantial inroads.

Meet the RISC Challenge

Sun was dependent on Motorola. At best, a switch to Intel would put Sun on par with PCs. Hence, another way of improving performance was necessary if Sun were to maintain its price-performance lead.

Intel, Motorola and most other microprocessors were based upon Complex Instruction Set Computing (CISC) architectures. CISC microprocessors are complex architectures, difficult to port to from one generation of integrated-circuit technology to the next. Hence, it is difficult for CISC to keep up with the rapid advance of circuit capabilities (recall Moore's Law).

Reduced Instruction Set Computing (RISC) was an approach to computer architecture that promised to deal with this deficiency. RISC architectures incorporate a much simpler instruction set, easier to implement in silicon. This enables RISC processors to quickly scale in performance as integrated-circuit technology advanced. The promise of RISC was compelling. HP, Digital, IBM and MIPS were experimenting with different implementations. The first to market with RISC could dramatically capture the computer performance lead.

Bill Joy began working with David Patterson, at Stanford, on the development of a new type of RISC microprocessor, the Scalable Processor ARCitecture (or SPARC). The goal of this effort was to develop an inexpensive, high-performance microprocessor architecture that could easily scale to new generations of semiconductor technology. Unlike other efforts at the time, though, SPARC was to be designed and released as an open standard.

Technology (1985-1992)

Sun-3

The Sun-3 family was introduced in January 1986. By this time, Sun had inked substantial deals with Computervision, AT&T and other large customers and partners. Its ability to provide inexpensive, high-performance systems using open standards led a shift from proprietary designs to open systems. The pull of the Catalyst program created immediate and sustained demand.

Table 14 Sun-3 Features and Product Architecture

Feature	Description
Microprocessor	Motorola 68020, 32-bit chip, running at 16.67Mhz, eventually scaling to 20Mhz and 25Mhz. Later models moved to the Motorola 68030 running at 33Mhz.
Operating system	SunOS 3.0, eventually ending with SunOS 4.1
I/O Bus	VME, for deskside systems. No I/O expansion bus for the desktop enclosures.
Enclosure	Several deskside, rackmount versions. Continued refinement of "pizza box" for desktop systems.
Performance	Starting at 0.6 MIPS, eventually topping out at nearly 4 MIPs
Other Features	All of the Sun-3 systems including an optional accelerator chip for floating point operations. Desktop systems included optional graphics expansion. Sun continued development of graphics cards.
Models	Sun-3/160, 3/75, 3/140, 3/150, 3/180, 3/110, 3/50, 3/60, 3/60LE, 3/260, 3/280, 3/80, 3/460, 3,/470, 3/480, 3/E. 3-digit model numbers represent deskside systems, two-digit the desktop "pizza box"
Complexity	10%

The use of off-the-shelf components continued the approached used in the Sun-1 and Sun-2, simplifying the design effort and enabling the quick development of the many models of the Sun-3.

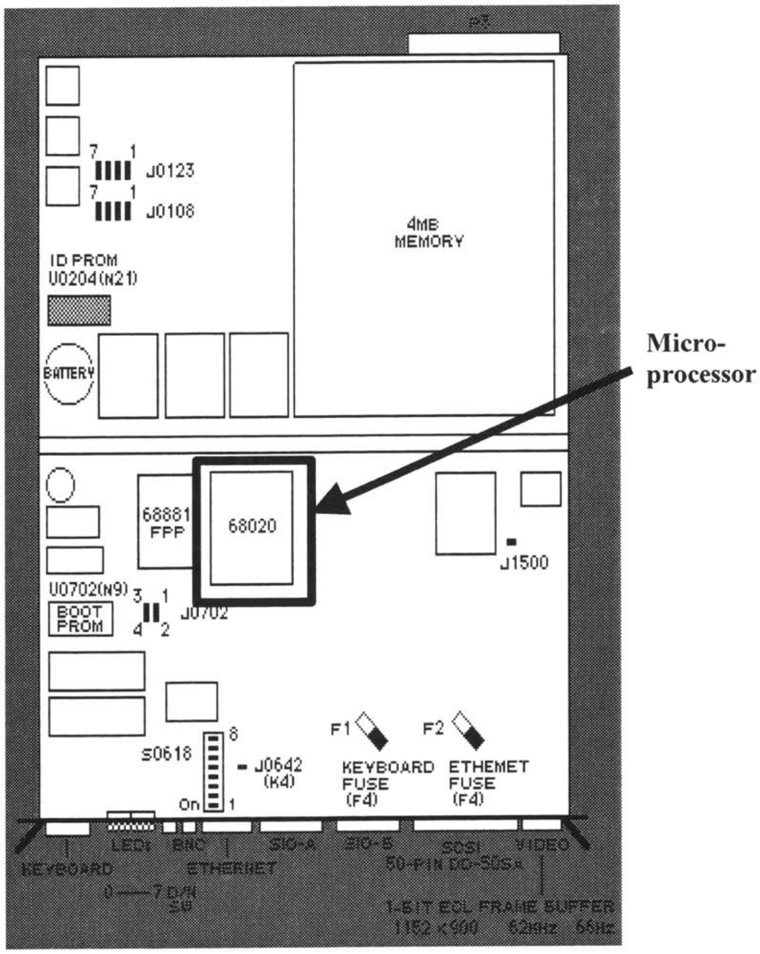


Figure 4 Sun-3 system board

The 3/50 model was a particularly aggressive product. Sun used it to drive the entry-level price of the workstation to under $5,000, less than half the price of any competitor and rivaling the price of high-end personal computers.

Sun-386i

The Sun 386i, based on the Intel 80386 processor, was introduced in 1988. The Intel processor and an ISA bus offered the ability to run MS-DOS applications in addition to Unix. Sun hoped this project would bridge the gap between personal computers and workstations[79]. The goals were to:

- Provide an attractive porting platform for software developers familiar with PCs
- Facilitate the development of new distribution channels through retail merchants
- Accommodate the vast number of I/O cards available for the PC
- Make inroads into the PC market by offering a robust, high-performance alternative

Table 15 Sun-386i Features and Product Architecture

Feature	Description
Microprocessor	Intel 80386, 32-bit chip, 20Mhz and 25Mhz. (truncated introduction of 80486-bsed system late in product life)
Operating system	SunOS 4.0.3 and MS-DOS (!)
I/O bus	ISA, standard PC bus
Enclosure	Small, tower deskside systems
Performance	Starting at 3 MIPS, eventually topping out at nearly 5 MIPs
Other features	Framebuffer for faster graphics
Models	Models: 386i/150, 386i/250, 486
Complexity	25%

The 386i was a radical departure from the Sun-1, Sun-2 and Sun-3. It introduced a version of SunOS optimized for the Intel architecture and a new graphical user-interface, and broke from the VME-bus. It was nearly half the cost of a comparable Sun-3

[79] "Sun's Role in Redefining the PC/Workstation Boundary", *Summit Strategies Market Report*, 1989

machine[80]. The 386i version of SunOS was different from the Sun-3 version with the same number. Like the Sun-3, though, most of the components in the 386i were commodity items. As shown in below, the 386i was still a simple, straightforward design.

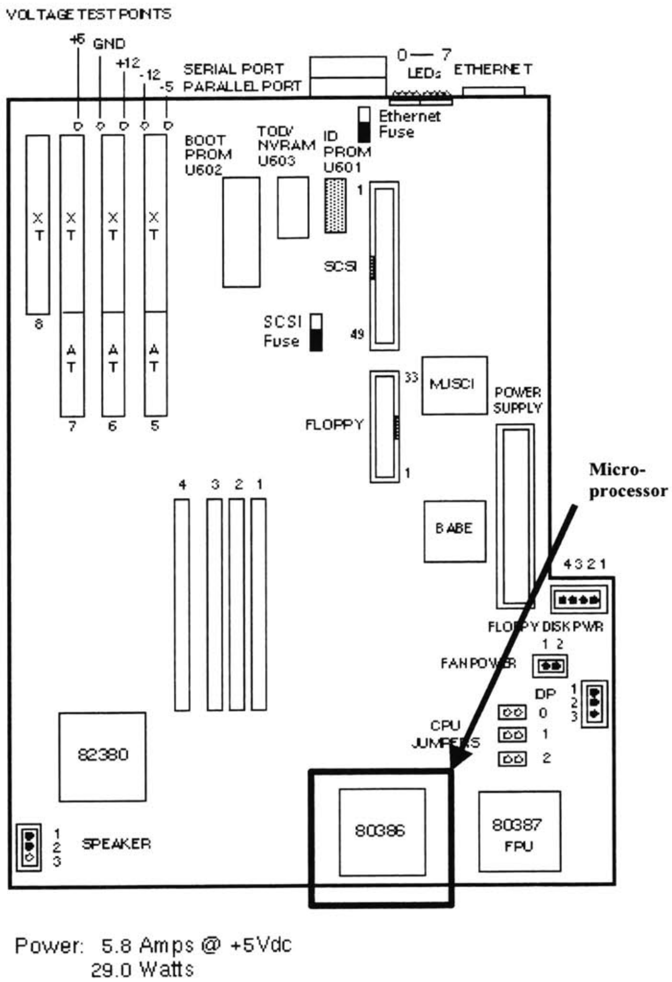


Figure 5 386i system board

[80] Microsoft's MS-DOS was the leading operating systems being used in personal computers during this period.

Sun-4, SPARCStation 1

The introduction of Sun's own RISC chip, SPARC, came with the Sun-4, in 1988. Developed with Fujitsu and Cypress as semiconductor partners, the revolutionary new architecture was implemented in a full, custom-designed chip. The first Sun-4 implementations, underengineered and overhyped in the race to get to market, did not deliver a quantum leap in performance. Nonetheless, they charted a strategic direction enabling Sun to differentiate itself from other workstation makers. SPARC promised a sustainable price-performance advantage over CISC-based computers.

The second generation of SPARC products, the SPARCStation-1, was announced in April 1989. It was a radical design and made a leap forward in price-performance and features.

Table 16 SPARCStation-1 Features and Product Architecture

Feature	Description
Microprocessor	20Mhz SPARC microprocessor, 32-bit, 64Mbytes of memory (later models up to 40Mhz)
Operating system	SunOS 4.0, 4.11
I/O bus	SBUS (A Sun designed BUS, released as a standard)
Enclosure	"Pizza box" size desktop enclosure
Performance	12.3 MIPS, later models up to 28.5 MIPS
Other features	Floating point chip important for technical applications and numerous other new features.
Models	SPARCStation 1, 1+, 2, SPARCServer, various speed improvements and packaging changes
Complexity	50%

The SPARCStation-1 system board is shown below. Note the addition of the SPARC processor and floating point unit. The SPARCStation-1 also addressed the growing problem of imbalance between microprocessor, memory and I/O performance. Processors doubled in performance every 18 months, but the rest of the system did not improve nearly as quickly. This created bottlenecks where CPU performance was throttle when it needed to access memory or I/O. This gap affected system performance.

The SPARCStation-1 introduced SBUS, a new I/O bus, which provided a significant improvement over the existing ISA bus. SPARC and SBUS were released as standards

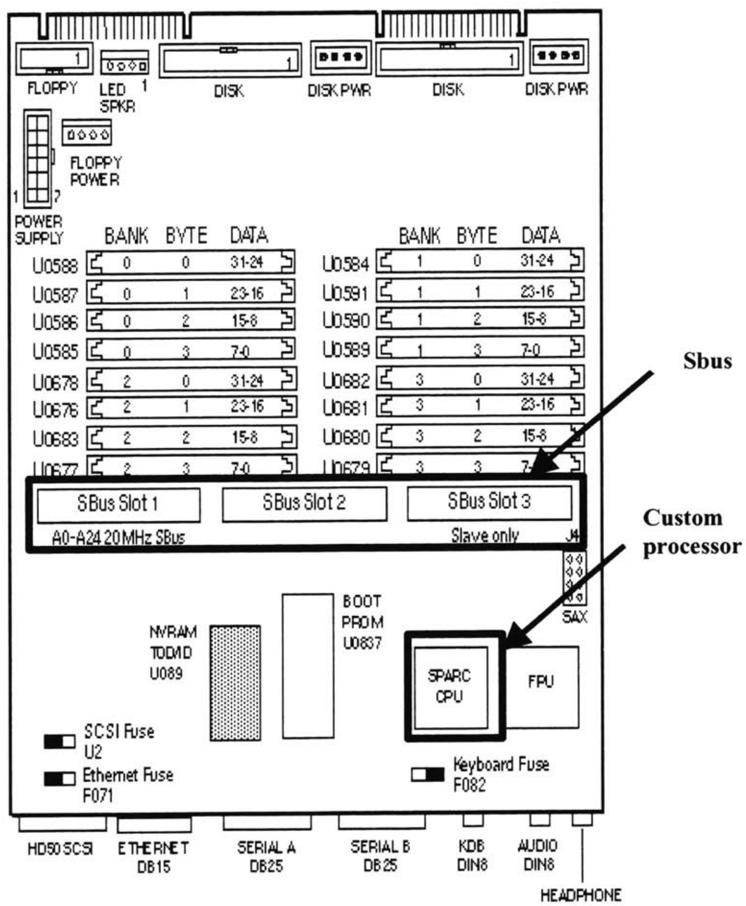


Figure 6 SPARCStation-1 system board

The industrial design of the SPARCStation-1, called the "Pizza box" was innovative. It fit nicely on the desk while still providing workstation performance.

The SPARCStation-1 established a new paradigm in design, features and costs for the technical workstation market and won several industry awards as "best product of the year"[81].

---

[81] *Byte Magazine*, December, 1989

SuperSPARC, SPARCStation-10, Multiprocessing

Following the success of the SPARCStation-1, Sun immediately worked on scaling the processor architecture to the next integrated-circuit technology. Several follow-on projects came about. A significant improvement in performance came with the introduction of the SuperSPARC microprocessor in 1992. SuperSPARC more than doubled the performance of the Sun's workstation line and introduced multiprocessing capabilities. The multiprocessing capability used in the SparcStation-10, the first product in the next generation, significantly boosted system throughput.

Table 17 SPARCStation-10 Features and Product Architecture

Feature	Description
Microprocessor	Two 50Mhz SuperSPARC microprocessors (later models up to 75 Mhz and beyond)
Operating system	SunOS, 4.1.1, Solaris 2.1
I/O bus	SBUS
Enclosure	"Pizza box" size desktop enclosure
Performance	75 MIPS, later up to 100 MIPS
Other features	MBUS, multiprocessing system bus, used to connect processors in efficient manner
Models	SPARCStation-10, 10+, 20, 20+ numerous incantations.
Complexity	65%

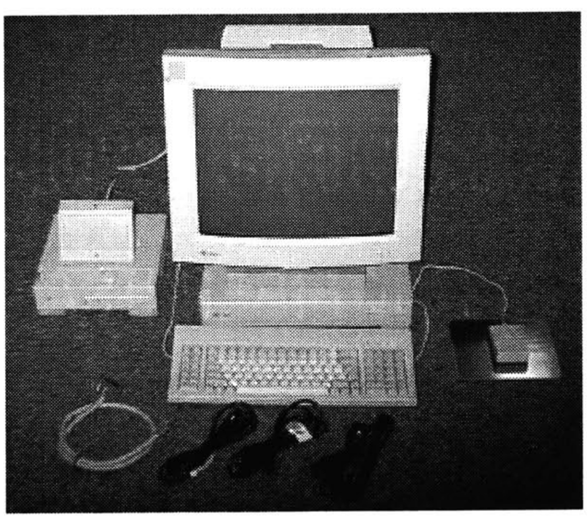


Figure 7 SPARCStation 10 "Pizza Box"

To enable the two processors, a new system bus was introduced, the MBUS. The MBUS represented yet another evolutionary step in technology.

A second feature of the SPARCStation-10 was that the microprocessors were not placed directly on the system printed circuit board, but attached to modules that plugged into the system. This allowed systems to be upgraded with new processor speeds, as they became available. MBUS was licensed as a standard and several competitors made modules.

The SPARCStation-10 was a quantum leap over the SPARCStation-1. The architecture of MBUS eventually enabled the SuperSPARC product family to scale to four, then eventually 16 microprocessors in some configurations.

The SPARCStation-10, though, was also over a year late to market. By the time it announced, in early 1992, several competitors had passed Sun in performance. SuperSPARC barely got Sun to par, despite impressive technology.

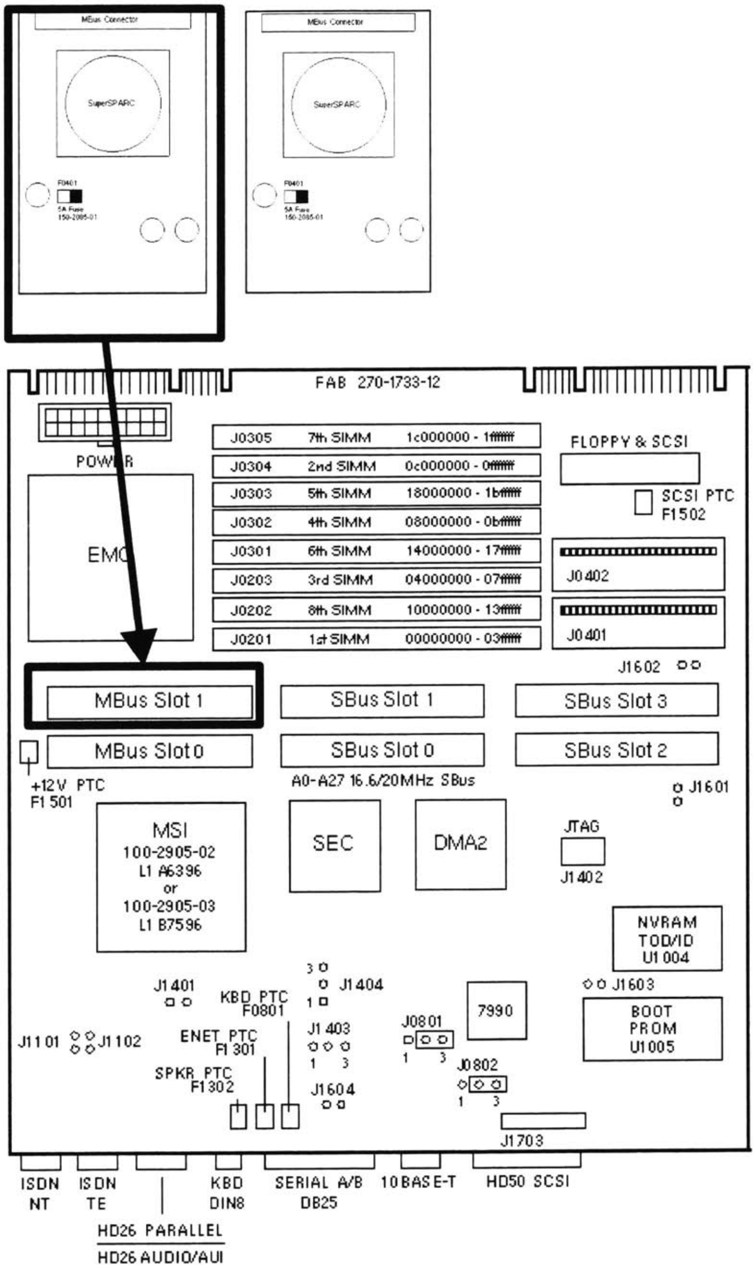


Figure 8 SPARCStation 10 system board with two SuperSPARC module

Organization (1985-1992)

Growth through Leadership

McNealy demonstrated poise, commitment and the ability to lead. His record of accomplishment, dedication, willingness to learn and likable personality convinced the board to appoint him permanent CEO.

Sun's technology direction, aggressive business practices and superb products attracted many new customers. The broadening of product lines, demands on manufacturing and the need for a substantial field sales and service presence, drove substantial growth in the number of employees. McNealy and Lacroute collaborated on technology execution, managing growth and expanding the customer base.

The Sun-3 catapulted Sun into the leadership position in the workstation market. By 1987, Sun passed Apollo in total sales and market share. The careful management of the application portfolio and execution speed complemented an aggressive sales effort.

By the end of 1988, Sun had an installed base of more than 125,000 workstations, and in 1989 surpassed the $1 billion mark in annual sales, the fastest a company had ever achieved this milestone. At the end of 1989, Sun had nearly 9,000 employees. While Sun hired several senior managers during this period, McNealy still ran the business. The absence of a hierarchy created some confusion in the management ranks.

Sun's organization remained remarkably flat. Joy and Bechtolsheim concentrated on the SPARC effort. Lacroute managed the Sun-4 design. When it became apparent that Sun-4 was not going to meet its objective, Bechtolsheim took on the task of developing the second-generation SPARCStation.

The culture at Sun early during this period was flamboyant, laid back and chaotic. The religious zeal surrounding open systems became the company's "call to arms" drew an eclectic mix of characters. However, with growth came bureaucracy and this frustrated Bechtolsheim. He prepared to leave Sun to start a company to license the technology that led to the SPARCStation-1. With funding from Khosla, now a venture capitalist, Bechtolsheim formed a 50-person company, UniSun, to develop his concept. Sun became an investor and helped fund R&D efforts. Free from distractions and growing politics, the team focused on the execution and delivery of a product. The rapid development of the SPARCStation-1 enthralled Sun and it reacquired the startup, bringing the team and product back into the fold. Employees of UniSun reaped substantial personal respect and rewards.

To develop the 386i, Sun established the East Coast Division (ESD) in Chelmsford, MA. ESD recruited many of its employees from foundering Apollo, Digital Equipment and ailing minicomputer companies in the New England area. By the introduction of the 386i, ESD had grown to over 200 people.

Crisis of Control

Sun's "growth through management" transcends this five-year period. Disciplined attention in attacking markets catapulted Sun into the Fortune 500. Greiner's model predicts that such a period is likely to lead to a "Crisis of control" in which the introduction of discipline and efficiency drives continued growth, but stretches beyond the capabilities of the centralized manager to run the show.

The investment in SPARC was extremely controversial. If Sun were to introduce a new microprocessor, ISVs would have to port to the new platform, thus eroding the strategic advantage of the Catalyst catalog. There were many in the company, including Lacroute, who were firmly against doing it. A schism between the pro-SPARC and anti-SPARC sides grew. Bechtolsheim's UniSun venture was a thinly veiled revolt. Sun's growth was causing stress in every part of its supply chain.

Then, Sun's financial performance hit a major pothole. In June 1989, Sun experienced a first quarter loss in profitability. The reasons for this were widespread demand for SPARCStation-1, inability to meet the demand and a failed attempt to move the company over to a better management information system. Four key executives resigned suddenly, including Bernie Lacroute.

Immediate problems with the financial system were addressed, but they appeared "symptomatic of a broader lack of adequate management controls and an organizational structure strained by rapid growth"[82]. According to an analyst report at the time, many factors contributed to this, among them:

- "Too many inexperienced managers with too much authority to make generally autonomous decisions and with little bottom-line accountability"
- "Inadequate attention to, and lapses in, quality assurance, shipment time, and especially customer and marketing partner support"
- "An undefined management structure that has led to dozens of autonomous, overlapping units, confusion over responsibilities, duplication of resources and efforts, infighting and repeated battles for sales to customers"
- "A reputation for arrogance and unresponsiveness that has made customers and marketing partners wary and has helped unite competitors in bids to block Sun's attempts at setting standards"

The report goes on to point out that, "Scott McNealy is spreading himself even more thinly by increasing the number of people who report to him".

A team of less than 20 engineers designed the first SPARC chip. The SuperSPARC team, staffed with seasoned veterans from Intel, Motorola and other leading microprocessor vendors, grew to over 150 engineers.

The East Cost Division added new organizational complexity and the 386i was a dismal failure. At one point, the general manager of ECD went weeks without returning telephone calls or email messages from headquarters. As a product, in comparison with rival 386-based computers, the 386i was slower, unable to operate on standard PC networks and more expensive. Less than 15,000 were ultimately sold and it created considerable confusion with customers.

---

[82] "Sun's Role in Redefining the PC/Workstation Boundary", *Summit Strategies Market Report*, 1989

Bechtolsheim continued to lead hardware development. He would frequently intervene in product decisions, even once, spending a weekend re-designing a circuit board to prove a point to a junior-level engineer. This behavior frustrated members of the technical ranks, but Andy's stature as founder, and the fact that he was frequently correct, made the consequences of confronting him significant. There were high-level resignations from the technical ranks adding to the brain drain. (A few accompanied by scathing, parting email shots).

Response to Crisis of Control

Response to such a crisis would be to organize the firm in some type of decentralized or hierarchical fashion. Before 1990, Sun's product development organization was largely functional in structure. The hardware center developed workstations and computer systems, the SPARC group designed microprocessors and a software group developed and maintained the Unix operating system. WorldWide Operations (WWOPs) facilitated the internal manufacturing of all systems designed by the company. Other areas within the company were randomly organized into hierarchical units. A fully, vertically integrated development team was now established in Massachusetts (the ECD), but nobody knew what to do with them. The former UniSun team was in a separate building, away from the main Sun campus.

The Planets

Informal relationships, amongst a small group of senior managers, enabled many business decisions to be made by consensus. Bechtolsheim believed that the job of technology and product development was in building and designing systems, not documenting, specifying or reviewing architectural direction. His own designs were lightly documented and often *willed into existence*, rather than planned. The success of the SPARCStation-1 reinforced a belief that a small group of very gifted technical people, able to make quick, autonomous decisions and depend on their gut, could innovate and turn, on a dime. Bureaucracy and specifications would just drag them down. Many felt that Sun had to mine some special middle ground between entrepreneurial aggressiveness and operational efficiency. An old-timer at Sun refers to it as trying to find *the secret sauce*. McNealy believed that, if such teams could be formed out of the existing organization, Sun could manage its way out of the current crisis.

In 1991, McNealy initiated a bold reorganization, and split the corporation into several mini-operating companies called *Planets*, each handling a separate product line. A planet would work on developing their own horizontal product roadmap, business, competition, customers and external relationships. The push to become more customer-centric began with the three largest planets:

- SunSoft would develop and license the Solaris operation system to any interested vendor, port the O/S to any interested hardware platform and get revenue based upon a pure *software licensing* model. Even if a third party competed with Sun, SunSoft would be allowed to do business with them. The model for SunSoft was Microsoft.
- SPARC Technology Business (STB) would license the SPARC processor to other original equipment manufacturers (OEM) who, also, may create products that competed with Sun's computer systems. The model for STB was Intel.
- Sun Microsystems Computer Company (SMCC), the largest of the planets, was responsible for the continuing development of SPARC/Solaris computer systems. SMCC brought in the bulk of the revenues (nearly 90%). The model for SMCC was traditional OEMs, similar to what Sun had been like in the early days.

The notion of planets worked under the principle that dealing with the demands of outside customers would promote a higher degree focused, fast-pace innovation bounded by real customer needs.

Conclusion (1985-1992)

Strategy

This represents the major transition point for Sun strategically. The recognition that open systems was a noble goal did not blind the company. Instead of relying on off-the-shelf and commodity technology, major investment in new technology and innovation continued.

Sun appears to have been one of the first companies to grasp that software ultimately drives the customer buying experience. Up until then, companies sold hardware then added software. The pendulum shifted. Now a customer first chooses the application they wished to run, then picks the hardware that runs it either the most efficiently or with the least amount of pain.

Technology

Technology development raced ahead. Sun significantly broadened its product line, producing products using three separate microprocessors. This created some controversy and confusion, when features among the different product lines were incompatible.

In major areas, Sun was able to drive new approaches to workstation features. The "pizza box" enclosure established a baseline for how compact a workstation could be. The development of SPARC and SBUS enabled Sun to make a generational leap in new architecture and performance capabilities. The new MBUS architecture introduced multi-processing to the desktop computer for the first time.

By the end of this period, over 75% of the hardware technology in Sun's workstations was custom-designed and optimized for systems performance. Processor speeds had leaped ahead to over 100Mhz. The complexity of designs, the overhead of advanced development and market pressures increased.

Organization

Organizationally, the company almost collapsed under intense pressure and growth. Bechtolsheim had virtually resigned and several important individuals left. The flat infrastructure pushed a lot of power into McNealy, but left everyone else confused. Political infighting over SPARC created turmoil. Overwhelming the analysts of the period questioned the competency of the leadership. The senior management group was not able to cope with the size of the company. The reorganization into planets is a textbook Greiner response to such a crisis.

Growth through expansion and decentralization (1993-1998)

Background (1993-1998)

PC comes of age

By 1993, the personal computer, with the introduction of Intel's 80486 microprocessor and the Microsoft Windows operating system, was capable of running many, compelling user applications at a reasonable price. A new breed of hardware company, the systems integrator, rose in prominence. Compaq, Dell and Gateway managed to design and manufacture increasingly cheaper and faster PCs. With the maturing of spreadsheets and word processors, many businesses incorporated PCs into their normal business practices.

Workstations were successfully capturing the technical computing market. Mainstream mainframe and minicomputer companies suffered substantial loses and many went out of business. With the introduction of Intel's Pentium, in 1995, PCs began to have enough power to run the sophisticated technical applications traditionally run on workstations. The economies of scale in the PC business made them substantially cheaper than workstations.

The World Wide Web appears

In 1986, Sun proclaimed, "The Network Is the Computer". This concept framed Sun's bundling of a network connection in each system as a differentiater. In the Sun paradigm, workstation *clients* on a network would access files and applications via a *server.*

In the mid-1990s, the development of programming languages and protocols that enabled efficient graphics and media transmission over the Internet formed the foundation for the

World Wide Web. Due the development of browsers, cheap PCs and increasing speed of network access connections, use of the WWW and the Internet went from a few 100,000 users in 1991 to 10's of millions by 1997.

The Internet connection represented a prototypical, *client/server,* compute environment. The user's PC and browser acted as a client, requesting web pages and other information from a server on the network. This drove an explosion in demand for an emerging type of computer system, the server, to manage shared resources over a network. Sun's networked computers were ideal for this emerging market.

32-bits is not enough

The growing size of applications began to stress another parameter of computer architecture, the addressable memory space. 32-bit microprocessors use a 32-bit address to manage data. Datasets for large applications exceeded the amount of space that could be addressed in 32-bits. All major microprocessor architectures were working on extensions to enable them to go to 64-bit.

Strategy (1993-1998)

One architecture - All the wood behind one arrow

With the success of the SPARCStation-1 and SPARCStation-10, Sun made a strategic decision to end-of-life the Motorola and Intel lines. Henceforth, all products developed within Sun would consolidate behind a single platform, SPARC. The lessons learned from the 386i, where a derivative version of SunOS confused the market, created a second strategic choice, a single operating system that could run on any platform without modification. This grand initiative was packaged under the corporate vision: All the wood behind one arrow.

In contrast, one of Sun's major competitors, Digital was shipping workstations with four different processors and three different operating systems.

Servers

Sun's 1994 server business consisted solely of products developed by a small server organization and deconfigured workstations, each representing approximately $100M in revenue (out of $4B in 1994). The maturing Unix operating system provided a level of robustness and stability that customer valued. Yet, Sun's competitive lead in this emerging market was tenuous and it responded by a focused market assessment. Out of this analysis, a three-tiered approach was proposed to compete in the commercial computer space:

- Create optimized low- and mid-ranged servers for small business and workgroup markets.
- Penetrate the growing network/telecommunication/Internet backbone emphasizing robustness and Solaris (the new name for Sun's Unix operating system).
- Drive performance up, into the traditional mainframe, supercomputer market by promoting the scalability of SPARC/Solaris

Technology (1993-1998)

UltraSPARC, Ultra-2

The development of UltraSPARC, the 64-bit implementation of SPARC, put Sun back into a competitive position with high performance, improved multi-processing and major innovation in the internal architecture of the chip. The first products out the door with the processor became instant hits in the market. The 2-processor Ultra-2 established several industry leading performance records.

The introduction of UltraSPARC reinvigorated the Sun product line and helped it regain the performance lead in RISC processing. Several models and variations of the processor were released, including the UltraSPARC-II that increased performance to over 400Mhz. The introduction of a unique system bus, the UltraSPARC Port Architecture (UPA) enabled the system performance to remain balanced as processors increased in speed.

Table 18 Ultra-2 Features and Product Architecture

Feature	Description
Microprocessor	Two 160Mhz UltraSPARC, 64-bit, later models going up to 450Mhz
Operating system	Solaris 2.5 through 2.7
I/O bus	SBUS, later models to PCI
Enclosure	Large "Pizza box" size desktop enclosure
Performance	200 MIPS going up to 600 MIPS
Other features	UPA System BUS, high performance graphics, multiprocessing
Models	U-1, U-2, U-5, U-10
Complexity	90%

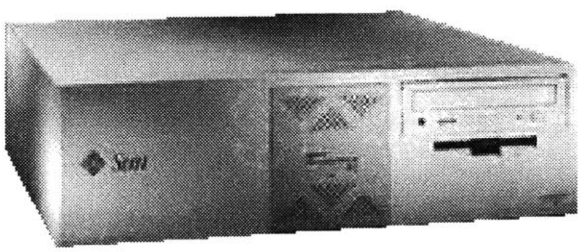


Figure 9 Ultra-2 "large pizza box"

UltraEnterprise 450 (E450)

In 1996, Sun renamed the East Coast Division into the Workgroup Server Business Unit (WGS-BU). Workgroup took the UltraSPARC and UPA architectures into a low-end server product family. In 1997, WGS-BU launched its first product, the UltraEnterprise 450 (E450).

Table 19 E450 Features and Product Architecture

Feature	Description
Microprocessor	Four 250Mhz UltraSPARC, 64-bit, later models greater than 400Mhz
Operating system	Solaris 2.5 through 2.7
I/O bus	PCI bus, 66Mhz
Enclosure	Large, deskside tower
Performance	200 MIPS going up to 1000 MIPS
Other features	3 UPA System Busses, 20 disk drives
Complexity	92%

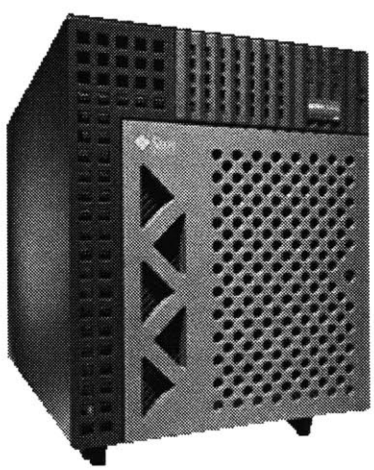


Figure 10 UE450 System Deskside

The E450 established a new benchmark in price-performance, with four UltraSPARC processors and became a dominant product its markets. The E450 was the first system to change the I/O bus from SBUS to PCI, an evolving industry standard, hence continued Sun's philosophy of openness. The E450, with 20 hard disks of storage was used as a small server in remote and small offices.

The design of the E450 included nearly 20 chips, custom designed by Sun. The UPA infrastructure required 10 chips designed uniquely for the E450. In 1998, the E450 generated nearly $1 billion in revenue. By 1999, Sun had established itself as the market segment leader in small servers. The E450 became the dominant design in its market segment. This single product and its family, within 24 months, became responsible for nearly 15% of the company revenues.

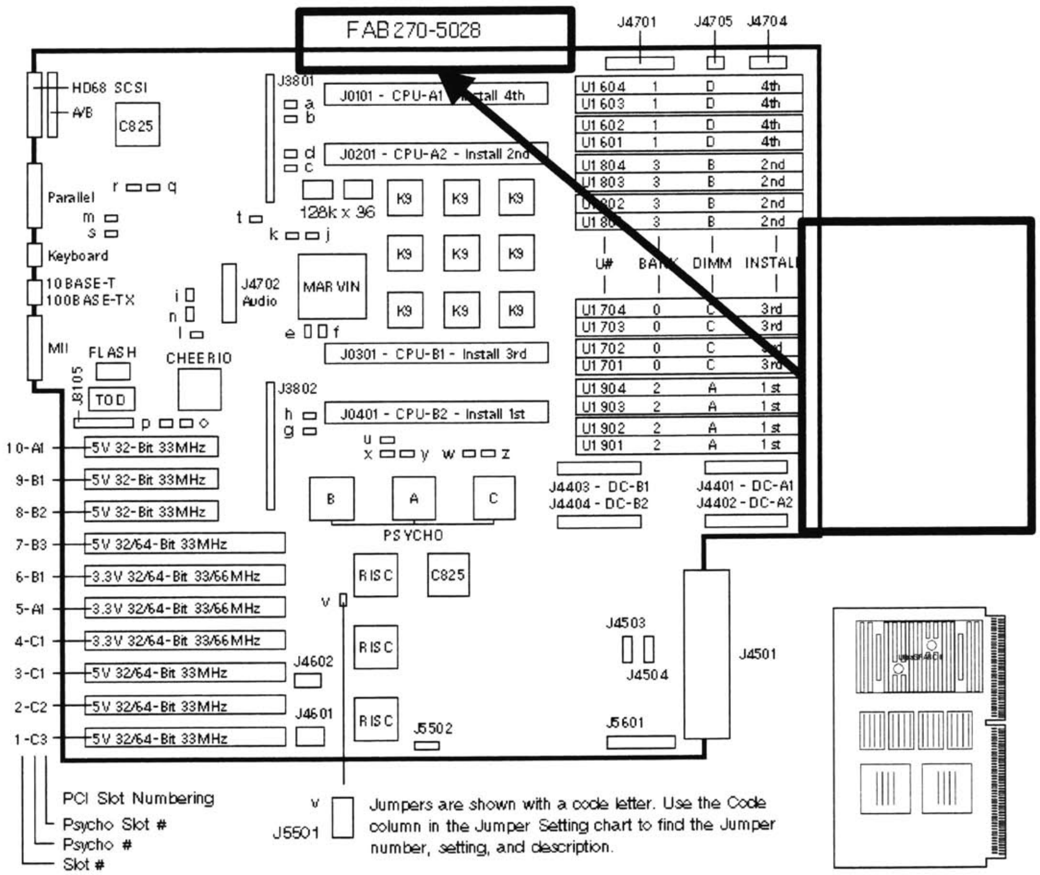


Figure 11 E450 System board and UltraSPARC CPU module

UE10000

In May 1996, SGI sold its San Diego-based, Cray Research's Business Division group to Sun. Sun renamed the division the DataCenter and High Performance Group (DHPG). DHPG took an existing Cray supercomputer design and re-released it as the UltraEnterprise 10000.

Table 20 UE10000 features

Feature	Description
Microprocessors	Up to 64 UltraSPARC processors, 250Mhz later models greater than 400Mhz
Operating System	Solaris 2.6, 2.7
I/O Bus	SBUS, then PCI, various configurations could support up to 80+ different I/O devices
Performance	10,000 MIPS (note this is not a real benchmark, just cumulative performance of processors, better metrics exist, this is just for comparison)
Enclosure	Large rack-centric design
Other features	Many, many features; Service processor, dynamic reconfiguration in case of error, replication of numerous subsystems for fault tolerance, exotic cooling, 20 hard disk drives for storage, clustering, etc.
Complexity	98%

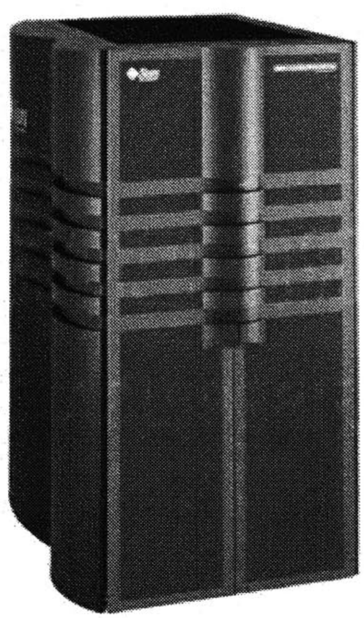


Figure 12 UE10000 Cabinet (vertical height, approximately 66 inches)

The UE10000 introduced radically new technology to the Sun product line. The ability to run 64 UltraSparc processors with a single operating system, the ability of the system to stay up while being repaired, and reliability features ensuring the system would remain available when subsystems failed were new benchmarks in technical capabilities. Nearly all of the technology within the UE10000 was custom designed. There were nine different printed circuit boards, many new chips, radical new industrial design and substantial improvements in operating system scalability. The UE10000 captured markets from traditional mainframe applications, previously dominated by IBM. It was named Datamation's "1999 Product of the Year", single-handedly grabbed nearly 20% of the high-end server market share within six months of launch and added nearly $1.5 billion in incremental revenue to Sun's bottom line.

Organization (1993-1998)

Growth through delegation

The individual planets created their own sales, marketing and distribution channels. The number of planets varied from six to eleven into the late 1990s. Each planet had its own profit-and-loss.

The push to get Solaris widely adopted, as the Unix of choice was a primary goal of the reorganization. By making the operating system *independent* of the systems group, the hope was that other companies would adopt it as the operating system of choice. Solaris was ported to several other hardware architectures, including Intel and Motorola. Similarly, the independent SPARC business unit would license chips. Several companies licensed SPARC, notably the Cray group that was subsequently acquired. The period of the planets helped to carve out a unique identity for both SPARC and Solaris.

UltraSPARC propelled Sun back into the role of price-performance leader at a critical time. This enabled the company to sustain its workstation business and augment it with the push into servers.

Server organization

The most remarkable accomplishment during this period was Sun's attack on the server market. The company's "Eat Lunch or Be Lunch" philosophy enabled it to clearly identify the exposure of PCs on the workstation market. Several competitors migrated their workstation lines to be similar to PCs, eating up valuable engineering resources to develop products only marginally different from each other. Sun's bold reorganization and acquisition strategy turned the company from a workstation centric to server centric business in less than three years.

Three important developments helped set the stage for the rapid implementation of Sun's server strategy. Each was possible by earlier attempts at licensing SPARC.

- The Cray supercomputer design business, an early customer of STB, had developed a high-end UltraSPARC based, multiprocessing server. Owned by Silicon Graphics, who wanted no part of SPARC, Sun was able to acquire Cray for a very attractive price. This group was in San Diego, California.
- Thinking Machines Incorporated (TMI), a Cambridge, MA based supercomputing firm, filed for Chapter 11. TMI's massively parallel computer architecture had used SPARC. Sun worked a deal to hire, intact the 40-person hardware design team of TMI.
- Integrated Micro Products (IMP), an UK-based, provider of fault-tolerant computers, licensed SPARC and Solaris for products aimed at the telecommunications market. Sun acquired IMP.

This strategy reaped huge, upside benefits when the wave of UltraSPARC servers hit the market. By 1997, with the new and innovative products, Sun took substantial market share away from traditional server suppliers, IBM and Hewlett-Packard. The UE450 and UE10000 create brand new segments.

Sun's grew to 23,000 employees and yearly revenues of $10 billion. By mid-1998, 50% of the company's revenue was coming from servers.

The success of UltraSPARC and the introduction of the Java programming language (not covered in this paper, but equally interesting!) dramatically transformed Sun. From a small company designing a single, highly optimized product line (technical workstations), to a multi-tiered, multi-segmented provider of hardware and software to the backbone of the Internet and world-wide-web, Sun faced several emerging markets simultaneously. The planets were ill structured to serve all of them well.

Crisis of decentralization

McNealy failed to provide guidelines on how the planets were supposed to negotiate contracts amongst one other[83]. He had expected that the rigid rules of engagement would work out the relationships. STB required non-disclosure agreements from SMCC and SunSoft before releasing specifications of the SuperSPARC architecture. This was intended to prevent Sun from gaining an unfair advantage over potential, third-party users of SPARC. Similarly, SunSoft concentrated on expanding the market for Solaris by porting the operating system to several other platforms. Yet, SMCC could only develop SPARC and Solaris based computers. Hence, as a captive customer to the other planets, SMCC suffered neglect as STB and SunSoft searched for new business outside. By 1994, it was clear that other major users of SPARC and Solaris had failed to materialize. No one was willing to try to compete with Sun, and SMCC accounted for over 90% of the customer base for both STB and SunSoft. Several senior engineers resigned in frustration over the lack of support from the other planets. Andreas Bechtolsheim, the visionary founder of Sun, resigned in 1996 to form a new startup.

The cross-planetary confusion affecting UltraSPARC generation products was handled via a heavyweight joint steering committee called the "Inter-Planetary Review team" (IPR). The IPR held weekly meetings among principle players in each of the planets contributing to the UltraSPARC product line. Design tradeoffs, organizational conflicts and joint development efforts were dealt with decisively and quickly by the IPR.

---

[83] Southwick, Karen, *High Noon*

Cooperation between SMCC and STB improved significantly, but the management overhead was considerable.

Response: Emergence of business units

STB and SunSoft were restructured to work collaboratively and constructively in the development of the UltraSPARC generation of machines. The UPA bus was jointly designed by SMCC and STB via the IPR and a close partnership emerged. Had this not occurred, Sun would probably not have released UltraSPARC in time to stave off competitive performance pressures. All had recognized that the current organization was not going to continue to be competitive.

In 1997, Sun reorganized again, into business units (BU) owning horizontal segments of the computer systems market, high-end servers, mid-ranged servers, small servers and desktop machines. This time, the company did an exhaustive analysis of the true, end-customer market segments and attempted to hit each one of them head-on.

The organization managing systems development was now called the Computer Systems Division (CSD). "All the wood behind one arrow" continued to be the watchword. All Sun computers must use the SPARC processor and run Sun's Unix operating system, Solaris. Scalability and compatibility up and down the product line was mandated. Incentives now included stock options and project bonuses that were substantially driven by the financial performance of the BU.

Between 1994 and 1996, Sun went on a major growth spurt, growing from 13,000 employees to over 18,000, and achieving $8 billion in revenue.

Conclusion (1993-1998)

Strategy

Sun dodged the onslaught of personal computers by moving both up and below the PC. By moving up into servers, it managed to move beyond the capabilities of any PC-centric architecture. By evangelizing the cheap, inexpensive thin-client, network computer, Sun attacked the PC from below. This strategy took time to crystallize but, by 1998, it was possible to buy a thin-client computer for less than $500. This paradigm shift, coinciding with the growth of web computing via the World Wide Web, created a huge demand for Sun's high-end servers.

Technology

Sun widened the product line to include computers ranging from small network appliances (JavaStation) at under $1000, to 128-processor mainframes costing a few million dollars. Specialized network and storage systems began to enter the product line.

During this period, the technical complexity of Sun's products grew exponentially. From a single processor SS-1, to a 64-processor UE1000, from 50Mhz to over 400Mhz, from a small product line to a broad product line; in every dimension Sun's technology was stretching. Along other axes, the amount of custom designed technology grew to be over 90% of the content in the product..

Organization

The first attempt at decentralization led to a broad, open system, almost market approach to organization. Sun thought that other computer companies would be interested in becoming customers of SPARC and Solaris, but that market never materialized. If SPARC had taken off as a viable open market processor, this might have been a brilliant move, but potential partners were wary. Hence, the consequence was alienation between the planets and a general slow down in cooperation. SMCC was responsible for over 95% of the worldwide sales of SPARC systems, yet was treated poorly as a customer. Had it not been for the heavy management oversight of the IPR, Sun may not have successfully transitioned to 64-bit.

This strict open organization was counter to the company vision of single architecture and created a very schizophrenic behavior in the employees. Customers of computer systems concluded that the planets confused more than helped their buying decisions.

The increase in complexity in the product line swamped Sun's internal manufacturing capabilities and a substantial amount of printed circuit board and mechanical assembly was outsourced.

The reapportioning of the organization into business units and the acquisition of some important assets realigned the mission of Sun to sell computer systems, not building blocks. This reaction occurred just in time to prevent wholesale capitulation by the workforce. The alignment of SPARC/Solaris enabled a broad product line to transcend many markets, price points and performance arenas.

This period is interesting because several attempts were made at delegating responsibility and decision-making.

Summary

The broadening of the Sun's product line occurred very fast. Sixty-five percent of Sun's 1999 revenue came from product lines that had not existed five years ago. BU autonomy enabled the development of finely tune implementations for narrow, profitable segments of the market.

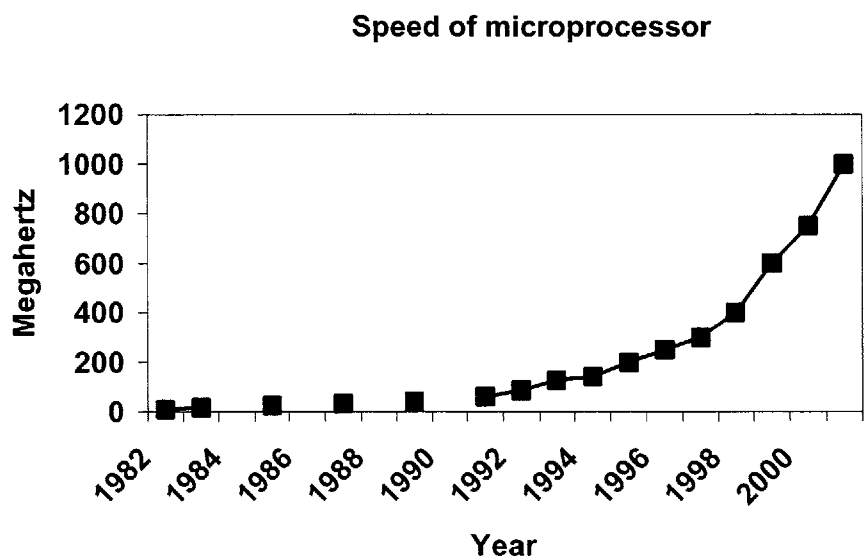
The customer base has broadened from the small technical computing market to include financial, commercial banking, service providers and Internet backbone companies. Thin-clients are emerging as cost effective solutions for education, point-of-sale and remote sights to hook into the Internet.

Technology

Sun's technology evolved in two different axes, performance and complexity.

Performance

Microprocessor performance will have increased from 0.5 to over 1000 Mhz in less than 20 years. The performance of systems has increased at an even greater pace due to the introduction of multiprocessing and higher speed system busses. Sun's ability to update its processor roadmap in step with Moore's law, is a major competitive advantage, but also a major investment in time and resources.

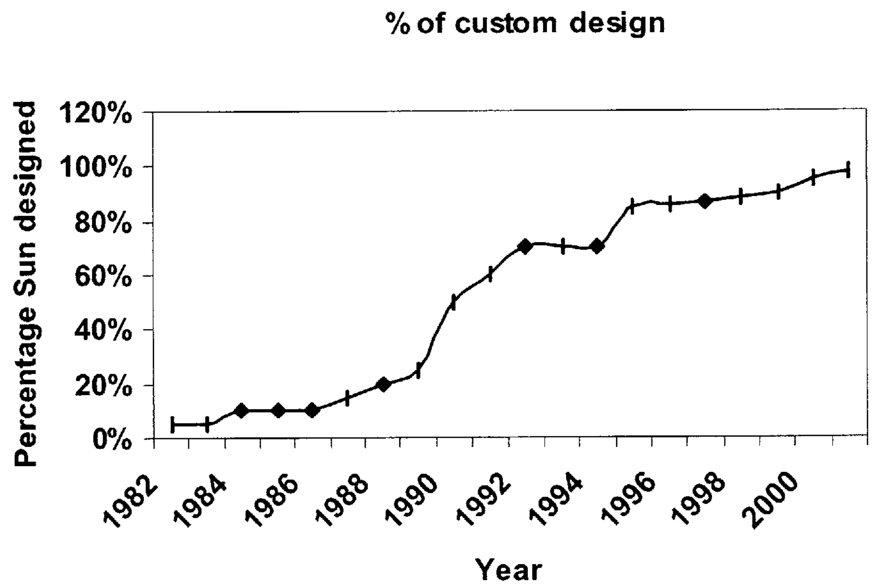


Complexity

To consider this, we take into account the amount of custom design, the number of discrete components and the speed of electrical and functional elements of the system. Mapping an estimate of complexity on a scale from 1 to 100% (with 5% being approximately the Sun-1 and 100% being the approximate complexity of the high-end UE10000) gives us a comparison across generations[84]

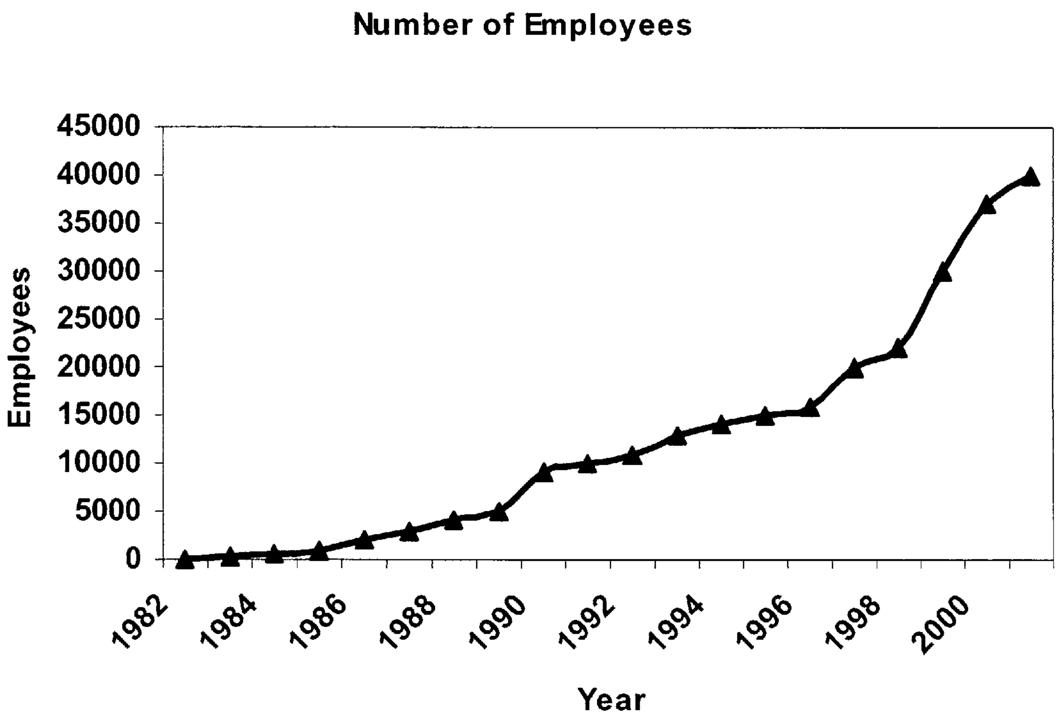
---

[84] These estimates were derived with the help of architects and engineers familiar with the product line.



Organizational size

The number of employees at Sun grew to over 35,000 in 1999. Geographically Sun made major commitments to engineering sites in Colorado, Massachusetts, Florida, Oregon and the United Kingdom. Sun's California presence outside of Silicon Valley extends to San Diego and Los Angeles. Over 50% of Sun's employees have been with the company two years or less.



The most rapid rate of growth has occurred within the past 3 years (1998-2000).

Financial growth

The attributes of growth evident at Sun are remarkably consistent. As microprocessor performance increased, the amount of custom designed complexity increased and the number of employees increased, consummate with the substantial growth rate that the company incurred. Sun has managed to maintain very consistent year-over-year improvements in revenue and profitability. This is striking evidence that, even with rapidly improving performance and increasing complexity, none of the crises faced by the company have significantly slowed growth.

Organization Overview

System

Sun's organizational system clearly changed between each of these periods. During the early part of the company, a *natural* system emerged, especially under the evangelistic verve of open systems. Especially evident with the SPARC team, despite significant controversy, the attitude of doing the right thing prevailed. If we consider the attributes of the natural system most obvious, they would include:

- Embodiment of a belief system creates the imperative common goal – open systems
- Vision comes from the top
- Integration is handled at peer levels
- Individuals is empowered and free to define their own processes
- Systems are adaptable and flexible

With the establishment of planets, Sun made an abrupt shift from the natural to the *open* system. The legal boundaries created between the independent operating groups forced negotiation, contractual diligence and the need to bargain win-win scenarios. This seems a highly unusual turn for a company to take, perhaps done prematurely. Nevertheless, the independent businesses created by licensing SPARC and Solaris (especially the Cray and Thinking Machines licensees), increased the utility of both technologies beyond what Sun's workstation business would have driven. Characteristics of Sun as an open system:

- Perfect market efficiencies force pragmatic decision-making
- Work is divided into autonomous sub-tasks (STB, SunSoft, SMCC)
- Contractual obligations drive requirements
- Integration is explicitly apparent in the design of the system
- Communication and coordination are handled by process

The reorganization into business units continued the mode of decentralization, but in a different domain.

Life-cycle

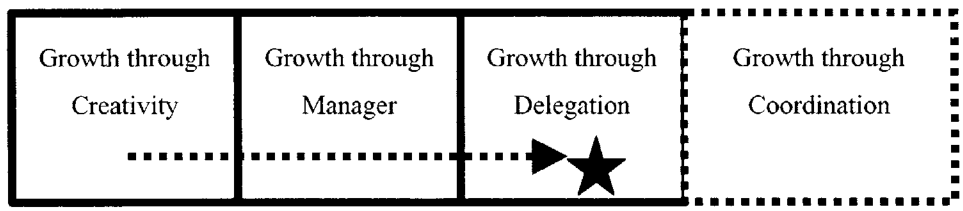


Figure 13 Sun's position in the organizational life cycle

Sun has clearly moved through the first two phases of the organizational life cycle. The experience of the entrepreneur, manager and decentralization maps easily onto the organizational structure. The evidence of crisis is easily identified. Yet, Sun has shown an adaptability that seems to pre-empt the major consequences of crisis before they become a threat to the sustainability of the firm.

Evident of decline

Whetten's model shows that Sun continuously leans towards stagnation. Sun looks internally for solutions to problems, which suggest that it is a Model versus Pioneering organization according to Niv. Remarkably, the symptoms of decline are quickly resolved. As the visages of stagnation appear, Sun reorganizes.

Sun's past follows what organizational theory predicts but the company has an unusually good, organizational-sense of when to change.

Individual

Sun insists that the individual be responsible for managing their own career and maintaining their employability.

In his study, Jeffrey Pfeffer comments on Sun's stated policy of career self-reliance: "Career Self-Reliance is a lifelong commitment to the proactive management of one's career and a continual focus on increasing learning opportunities. The rapidity of technological developments combined with the dynamism of the marketplace means it is essential for employees to become career resilient"[85].

Making employees responsible for managing their own career growth complements the open system philosophy. Yet, the rhetoric from the top clearly sends the strong message of common vision, which is an attribute associated with the natural system. Hence, Sun appears to be some type of a natural-open hybrid.

Conclusion

As we look at these three periods, the growth model gives us a convenient set of tools to analyze the evolution steps that a company goes through. The use of system and complexity metaphors enables us to look at the progression of Sun's product lines in a logical manner.

Sun has been resilient to crisis and aggressive in attacking new and evolving markets. The similarities with organizational theory appear more descriptive than predictive. Not what we would ideally use to predict what Sun would have done. The industry changing events of the past few years have disrupted the market in such a substantial manner that any organizational predictions have to be tempered. For example, it is unlikely any prediction circa 1990 would have foreseen the extraordinary impact of the Internet on equipment suppliers like Sun.

The ability to weather pending crisis bears some final words. Several phenomena appear to make a company like Sun unique:

---

[85] Pfeffer, Jeffrey, *The Human Equation*, 1998

- *Have lunch or be lunch.* Institutional-paranoia means "knowing when to run". Sun's adoption of *open systems* left it vulnerable to competition. Unlike proprietary business models, where companies would milk products that, in a perfect market, would be noncompetitive[86], Sun could not depend upon its installed base to sustain it. Hence, Sun depended upon continuous development of superb, compelling technology to achieve market success. If a product is unsuccessful, Sun quickly cancels it. If a product is threatened by a competitor offering, Sun attempts to pre-empt the competitor or compete on price. This pressure prevents the company from becoming complacent or technologically stagnant.
- *All the wood behind one arrow.* Clarity of Vision and consistency of message drive a common purpose. The single major contribution to Sun's success appears to be the ability of the CEO, Scott McNealy to be crisp, clear and precise in setting the overall corporate direction on open systems. The alignment of everyone in the company to a simple, easy to interpret, company vision relieves many organizational deficiencies. McNealy continuously reinforces principles, making the mission of everyone in the company very unambiguous.
- *Open software.* Lately, a model for software development called open source has developed[87], where software is treated as virtually free. This has created market awareness that open software interfaces are indeed preferred. This plays right into Sun's core strategy. "Sun scares software competitors. The company practically gives away system software, which scares companies like Microsoft and Adobe that prefer to sell it. Sun scares entrenched hardware competitors by actually encouraging cloning of its hardware architecture. Relying on a balls-to-the-wall attitude Sun will stay in the high-margin leading edge of the product wave simply by bringing newer, more powerful SPARC systems to market sooner than any of its competitors can"[88].

---

[86] Christensen, Clayton M., *The Innovator's Dilemma*, 1997

[87] Raymond, Eric. S., *The Cathedral and the Bazaar: Musings on Linux and Open Source*, 1999

[88] Cringely, Robert X., *Accidental Empires*, 1996

- *Technology vision.* Bill Joy is a leading prognosticator of leading edge technology. His understanding of open systems, RISC, the emergence of the Internet, the value of platform independent software, Java and its implications in the market is unparalleled. Joy's ability to mate technology concepts with practical architecture helps drive the technical agenda for the company. Through this influence, Sun has maintained a reputation for inventing and pushing technology.
- *Luck.* Sometimes it pays to be lucky. At important junctures, Sun was vulnerable to a competitor taking advantage of its lack of performance and features. Yet, even when Sun was last in performance during the waning days of SuperSPARC, no major competitor managed to knock them off. Several managers from those periods of crisis marvel that the company survived.
- *Leadership.* Scott McNealy, the CEO, has continued to personally grow and mature in step with the demands and needs of the company. His ability to articulate the company agenda, fluid, inspirational demeanor, and unwavering discipline anchor the company. He has surrounded himself with topnotch lieutenants and managers, all rigorous in step with the Sun vision.

Overview of current company initiatives

The paper concludes with a brief analysis of two ongoing initiatives within the company, the adoption of a phase-gate product release process, called the Product Life Cycle (PLC) and another dealing with systems architecture, the System Hardware Architecture Council (SHAC). Because of confidentiality issues, the author presents this at a conversational, strategic level. The intent and purpose of PLC and SHAC remain intact.

Background (2000)

Technology Trends

Number of new components

In the SuperSPARC generation of products, the entire product line used only a few unique CPU modules. By the time the UltraSPARC-II was introduced, in 1998, over 15 unique CPU modules were in production. Accompanying this has been an explosive proliferation of new chips, components, memory, modules, power supplies and enclosures. The number of unique components used by Sun has grown substantially in the past three years.

This trend causes substantial problems in qualification and testing, supply chain management, material handling, spare parts depots inventory tracking, installation and service procedures. Training requirements for field service personnel are exceeding the capacity of Sun's suppliers, manufacturing and support organizations. Different products, suppliers and styles of doing business drive inconsistent requirements into Sun's operation group.

Shift in customer needs

The computer industry has matured. In the past ten years, computers have become an indispensable tool for individuals, businesses, industries, and the government. They are now firmly entrenched in many of the mission-critical practices that users depend on. When a computer fails in a visible application, it can make national news[89]. Quality, performance, reliability and security have become more important than price-performance in the buying preferences.

This shift in customer preferences shows them increasingly intolerant of latent, nagging quality problems. For Sun, where technology development has focused on price-performance and getting products to market quickly, the renewed emphasis on quality presents a major, new challenge.

UltraSPARC-III

The UltraSPARC-III (US-III) microprocessor is due to launch in the year 2000. A multi-business unit effort has been ongoing for over four years to design this new processor and the accompanying, next-generation computer systems. UltraSPARC-III promises a substantial improvement in price-performance and may position Sun as the performance leader for the first time in several years. The component building blocks, in nearly every space, are at or near the leading edge of technological capabilities.

Major efforts are underway to collaborate on US-III generation product development. Over 1500 engineers, in six separate business units are working to make this product line successful. This represents nearly three times the number of people that worked on the previous generation of products.

---

[89] A December, 1999 failure of a computer system at Ebay, a major on-line auction site, put Ebay's website offline for several hours. This caused an estimated loss of millions of dollars of transactions. A February, 2000 failure of computers at Yahoo and other major websites, due to a malicious computer hacker attack, affected thousands of businesses and millions of users.

Organizational trends

Organizational System

Sun appears to be a hybrid of the *natural* and *open* organizational system:

- Corporate policies, management direction, and leading questions in employee quality surveys attempt to monitor the pulse of employee commitment. They show that employees value Sun's corporate personality and distinctive market presence.
- Memos to middle level managers emphasize improving employee satisfaction. A career center proactively helps employees assess capabilities, goals and deficiencies so that career development is facilitated.
- Common goals, vision and guiding principles are regularly reinforced through numerous on-line means. Sun portrays Microsoft[90], humorously, as an evil empire against which Sun has to be the defender of justice.
- Countless articles, market analyst and technology evangelists confirm that Sun is perceived as being one of the top technology leaders in the Internet-age, along with Cisco, EMC and AOL. This makes the company very appealing to employees.

Life Cycle

Sun's is currently in the life-cycle phase *Growth through Delegation*. Greiner predicts that the benefits of decentralization drives more timely responses to opportunity, but can lead to duplication of effort, turf wars and non-optimal uses of resources. The two approaches to decentralization at Sun were the creation of the planets, independent

---

[90] Sun has two lawsuits pending against Microsoft

operating companies, followed four years later by a shift to market-focused business units:

- The reorganization into planets, primarily segmenting the company into divisions concentrating on component building blocks, helped Sun establish unique product identities for the SPARC microprocessor and Solaris operating system.
- The reorganization into Business Units aided the development of a widening and diversified product line, strategic alliances with major software and service providers, penetration into new markets and an increased ability to deliver innovative solutions in many dimensions, simultaneously.

Employees

There are many attempts to tap this commitment and surface intrinsic employee good will in improving the company. At any time, there are dozens of initiatives underway intended to motivate employees to take on tactical or strategic issues outside of their job responsibilities. Participation in these activities seems to confirm that employees are motivated to assist positive change.

Incentives have expanded to include profit sharing, bonuses and stock options. In the year 2000, over 80% of the engineers in the company will become eligible for additional bonus and reward programs.

Two-thirds of the employees at Sun have been with the company less than 3 years. The lack of formal practice and process has created a major hurdle for new employees. In a survey of recent hires, a universal complaint was that it is very difficult to understand how Sun works. Well-intentioned efforts to improve assimilation and orientation are hampered due to lack of management bandwidth. A distressing number of new employees leave within 24 months of joining Sun.

Outsourcing

Finally, the company is retrenching and partitioning key operating groups into those that provide a compelling, value-add, core competence and those that are performing functions that could reasonably be outsourced. Many of Sun's manufacturing functions are handled by external contract agencies. This direction is gradually extending to certain design and administrative areas.

The implications of outsourcing are twofold. First, there is substantial, hidden cost in managing an outsourced relationship. Secondly, outsourcing makes many of the jobs within Sun obsolete or redundant. This affects employee morale, especially in those functions directly involved with the change.

Leadership

Recently, Scott McNealy, the CEO, has been moving away from managing the day-to-day operations of the company. Senior management attention is shifting further from the technology realm to pushing new markets. As noted earlier, many believe that McNealy is personally responsible for maintaining the style, culture and attitude of the company. Can the company continue to mature as McNealy begins to step away?

Chronic symptoms of stress due to growth

Culled from dozens of interviews, project reviews, and post mortem results, Sun has these visible signs of stress:

- Inconsistent quality, born out by widely varying performance of similar products[91].
- Product development slowing.
- Lag in microprocessor performance and features being added in a timely manner
- Too many products causing an overload on shared resources, particularly software, operations and supply chain, sales, service and support organizations.
- Feature inconsistency amongst similar products resulting in duplication of effort and lack of commonality in many subsystems.
- Inconsistent lifetime goals (system busses specified at one frequency are scaled to run at a higher frequency, well beyond the initial design spec, for example).
- Lack of investment in infrastructure, administration and coordination processes.
- Latent problems in products don't show up until they appear in the field, at which time they are harder to fix.
- Lack of a consistent knowledge management system to keep track of decision-making, technology justification, problems or lessons learned.

In response to a crisis of decentralization, we would predict that the company would be initiating corporate rules, procedures and dictates to promote collaboration.

[91] Based on factory run rates and customer field data.

Response to crisis of decentralization

In early 1999 Sun's office of the CTO conducted a study of the UltraSPARC-III projects under development. This study determined that, even with earnest overview and control, each business unit continued to drive unique requirements for their own product lines. This contributes to a lack of commonality in base designs. Duplication of effort, unclear chains of communication and local decision making, inconsistent application of metrics for quality and costs and time-to-market schedule pressures, have led to the UltraSPARC-III product line being late to market. Design methodologies, quality goals and test plans, interpretation of corporate guidelines, estimates of performance and costs, and specifications widely vary.

A retrospective look at this situation concluded that a root cause for many of these inefficiencies was inadequate attention to systematic implications of the original UltraSPARC-III architecture. For example, the system bus specified for the US-III requires each system to develop a unique technology in order to meet very tight electrical requirements. Lack of a rigorous specification for the system bus led to local interpretation and minor, but annoying divergence from a common standard. With all products using the same microprocessor and same operating system, this lack of consistency amongst the product development groups was surprising.

Because of this study, Sun management has begun two major initiatives, intended to monitor current practice and drive a corporate dialogue in how to manage technology and product development.

- The mandate that all product teams conform to the guidelines of a formal Product Life Cycle (PLC) process, a phase-gate release process.
- The creation of a Computer System Division-wide System Hardware Architecture Council (SHAC)

The Product Life Cycle (PLC)

The Product Life Cycle (PLC) initiative has produced a substantial, well documented and monitored list of required steps that every product team is expected to follow when managing a development effort. The details of the PLC are confidential, but generally conform to well-documented efforts at the Xerox Corporation and other proponents of quality management[92]. By the end of the year 2000, all middle level managers and program administrators are expected to have attended a two-day training session on the use of PLC.

Senior management has endorsed the PLC process and, in recent program reviews of the UltraSPARC-III generation of products, has refused to allow major programs to pass gated milestones without the proper backing information. This is driving a major shift in organizational behavior. In at least once instance, a major project was put on hold pending completion of items on the list where, in the past, these dependencies would have been waived.

There are signs in some business units that the adoption of PLC has forced activities, especially in documentation and specification writing that previously were deferred or ignored.

Push away from natural to rational behavior

PLC seeks to create a common framework, but states that it is intended to be *flexible*. It applies administrative oversight to ensure people are doing things in the proper way. There are explicit consequences for failing to follow the rules. The PLC rules are clearly traits of a mechanistic, centralized control structure evolving.

This is causing stress in the current incentive systems. At least two major bonuses on projects are heavily weighted to time-based deliverables. The application of PLC to

---

[92] Eppinger, Steven D., and Karl T. Ulrich, *Product Design and Development*, 1995

projects well underway has slowed several and delayed the payout of these bonuses by several months. In some circles, this has caused a major change in the ways goals are interpreted.

But, this also breaks with the pre-existing company culture of individual empowerment and many long-tenured employees feel that this has reduced some of the magic. Some managers believe that, through the transition to PLC, groups will experience significant employee stress, dissatisfaction and attrition[93].

PLC as a potential contribution to the next crisis

Greiner observes that, within solutions to a current crisis, are the seeds of symptoms that could contribute to a future crisis. Could PLC, even if successful, inadvertently change Sun in the wrong way? People that have now been following PLC for several months have observed these characteristics:

- Inconsistent application of PLC creates wiggle room. This creates an impression that some groups are being held to a different standard and causes resentment
- PLC notes that a phase-gate process is a method for "slowing down to speed up". Yet, it doesn't accurately address what needs to happen in early stages to achieve that or how to manage the back end of the process to take advantage of better up-front planning. Evidence to date is that activities in later phases of the PLC process are also slowing. If products are routinely late-to-market, without substantial evidence of better quality, performance or customer satisfaction, PLC may be blamed.
- Lack of knowledge and information flow and infrastructure forces time-intensive face to face meetings. PLC phase reviews, in some business units, have taken up a

[93] Survey of employees demonstrated a universal company bias towards operational goals above all else (over 98%). Some groups have been experience a nearly 17% attrition rate, well above a company target of less than 5% for key positions. Exit surveys indicate unrelenting pressure as a major contributor to dissatisfaction.

substantial amount of engineering, management and administrative time. One product spent over three days, with a large team, to go over one phase of the PLC. Multiplied by several phases, this adds weeks of overhead to a program.

- Continued lack of goal alignment. The operational incentives cause frustration in the rank-and-file members of project teams: "Are we supposed to follow PLC or ship product?" On one hand, management says follow the PLC. On the other hand, they ask for shorter schedules. This causes different interpretation of the goals, even within project teams.
- Product, market and competitive arenas are a moving target. PLC forces a rigor in upfront product requirements that presumes extremely accurate information and knowledge of the future market. To change a product, in mid-stream, requires a substantial amount of additional justification. Some engineers note that major programs were able to adapt to changing market conditions because of a team's authority to make decisions. If they now need to sanction this through PLC, will this valuable flexibility be lost?
- PLC review bandwidth. The number of projects at Sun is growing. Funneling review processes through a centralized management system force a small group of overseers to keep track of a large number of projects. Major projects get attention, but the dozens of small projects are left on their own.

The System Hardware Architecture Council (SHAC)

Recently, the office of the CTO wrote a position paper proposing an *organizational approach* to architectural definition for the next generation. They christened this "the creation of *breakthrough design*". From the presentations made by CTO representatives:

- Breakthrough design enables reduced time to volume, improved product quality, reduced product cost.
- Breakthrough design is achieved through concurrent design techniques and widespread use of common hardware components.

- Breakthrough design values common design tools, metrics, and bringing all parts of the value chain into the base architecture discussion.
- Breakthrough design focuses on product definition and architecture at the beginning., developing rigorous requirements for complete and detailed specifications.
- Breakthrough design accommodates the need to slow at the beginning of a project to speed up at the end.
- Breakthrough design oversight ensures that all of the right information up front from operations, service and customers is solicited and gives them sign-off authority on any product development projects.
- Through the CTO office, breakthrough design will be managed via technology roadmaps and interface specifications.
- Breakthrough design recommends using unique designs only where differentiation counts.

To facilitate and enforce these principles, the CTO established the System Hardware Architecture Council (SHAC), mandating participation by all managing directors from the business units. SHAC will meet on a bi-quarterly basis to review, sanction, approve funding and negotiate ownership of technology advancement within the company. Underneath SHAC, a group of targeted Strategic Working Groups (SWGs), manned by management and architects will provide the expertise, resources and bandwidth to drive initiatives. SWGs will publish technology roadmaps, interface specifications and work with product teams to ensure good fit of the technology with the product.

Product teams are expected to identify areas of differentiation and commonality based on customer needs and engage with the technology working groups. They must be able to defend a decision to vary from the recommendations of a working group. SHAC will be depending on the ability of peer-level directors wearing a corporate hat, even when potentially putting their own organizations at risk.

SHAC Working groups

The primary tools of SHAC will be the working groups. The partition of efforts into working groups came about after several agonizing attempts to group the architecture of the system in several ways. If we recall Koopman's decomposition strategy which states that a system can be looked at from a goals, behavioral and structure perspective, we can clearly see where SHAC has put together working groups aligned to all three axes. (Note, these are proxies. The actual make up of working groups is confidential).

Goal

Goal groups work on developing big rules and guidelines to create commonality in metrics, vocabulary, measurement techniques and specification. The two primary goal groups are:

- Performance. Consolidation of predictive modeling techniques, software requirements, benchmarking goals and competitive analysis fall into this working group. They will drive phase gate requirements for project groups to justify performance goals and methods for improving performance.
- Quality. Coordination and specification of different levels of reliability, availability, serviceability, testability and manufacturability will be proposed by this group so that there is consistency.

Behavioral

Behavioral groups work on developing common methods, processes and procedures. Among the behavioral groups is:

- *Design Methodology.* Standard design practices, knowledge management, tools and infrastructure administration will be adopted by this working group. This is intended to enable better use of best practices throughout the company.

Structural

Structural groups deal with details of system architecture, building blocks and specific technologies to ensure that all users of technology have a say and influence in the eventual end-architecture. The primary structural groups are:

- System Architecture. System busses, I/O busses, common features sets and system partitioning are specified and reviewed by this group.
- Mechanical. Enclosures, environmental, power supplies, and other non-electrical attributes of the products are discussed in this group.
- VLSI. Technology trends in large integrated-circuit technology are monitored by this group along with recommendations on best-fit solutions to architectural building blocks.

Participation in working groups

The company continues to be market and customer segment based. SHAC working groups are currently made up of volunteers. This could lead to members being torn between loyalty to their business unit and SHAC. As product development pressure increases, will participants drop out? In past initiatives, engineers eventually retreat back into their product development groups, leaving working groups in the control people who happen to have available time. This could bias working groups in unanticipated ways.

Culture

Managers and engineers who came up through the ranks feel they have a birthright to continue doing things their way. This institutionalized attitude is pervasive throughout the organization and is even used as an inducement to new employees. As a bow to this engineering culture, for example, SHAC will not hold formal architectural or specification reviews. (Note, when asked about this, the representative of the CTO office shrugged his shoulders and said "organizational reluctance"!). While accommodating the current personality of the company, this appears inconsistent with the goal of trying to improve discipline and change behavior.

Lack of incentives

SHAC currently depends upon the good will of participants. A major concern, yet to be addressed, is whether SHAC will have the authority to change how incentives are determined for participants.

Funding for activities in each one of the business units is allocated according to project plans and estimated return-on-investment. SHAC does not own a funding alternative that compensates a business unit for participating in technology development outside of a funded project, hence business unit participation in working groups varies.

SHAC does not address individual incentives hence salaries, bonuses and options continue to be heavily dominated by revenue and operational goals. Questions raised include:

- What personal motivation will drive an engineer to commit to a working group when it potentially means missing a project bonus?
- Will white papers, patents, or some quantifiable measure of "reduced complexity" or robustness result in rewards?

Changing incentives could be essential to getting engineers to agree to work on a working group.

Mental Model

Mental models dominate Sun's technology philosophy. In an interview, one executive referred to technology disruptions caused by Sun as "due to mini-epiphanies by small groups of highly motivated individuals. The company myths are filled with antidotes of renegade engineers 'bucking the system' or 'on a mission'. Against all odds, they followed a vision, proved it was valid and convinced management to follow."[94] They noted NFS, SPARC, UniSun, UE1000, IPR, Java and other projects that likely would not have survived the scrutiny of PLC or SHAC.

Danger of Red Tape

PLC and SHAC are introducing a degree of review and oversight that has never before been rigorously practiced at Sun. While not universal, some participants in these efforts find them arbitrary, unclear and oppressive. Interviewees also noted a Sun cultural norm of "shooting the messenger". Hence, the extra level of management scrutiny has added hesitation and conservatism to decision-making, making some managers and engineers wary about sticking their necks out. It is perceived as being safer to say "I'm not ready" instead of risking a wrong decision.

It is clear that some parts of the front end of the product development cycle are slowing to accommodate PLC and SHAC. That these delays result significantly better products remains to be proven.

Many PLC processes require a substantial amount of written test plans, results, justification, requirements and specifications. While a noble goal, recall that Sun has generations of engineers who have never been held accountable for doing this type of documentation. They lack basic writing skills, find it difficult to organization, and publish meaningful documents. Without clear and explicit guidelines for what these documents include or how they will be reviewed, the company is going to be awash with a great deal of inconsistent, poorly written and possibly, useless paperwork.

Finally, it is unclear who will be accountable for guidelines or mandates issued via SHAC working groups. Will groups be punished for not conforming? Will working groups be held responsible if it is discovered they have made an error in judgment?

---

[94] Quote from interview

There is a danger where proliferating strategic initiatives get dumped on the small number of people that are actually doing product development, effectively drowning in review and oversight[95].

Final thoughts

Alternative Views

This paper concludes with a final insight. We have presented PLC and SHAC as initiatives that are being endorsed and enforced by senior management. Both efforts are predicated on a fundamental philosophy that:

- Commonality is good.
- The overhead of collaboration is balanced by better and efficient use of resources.
- Conversations between peers in different organizations promote better use of best practices.
- Other factions within the company believe this approach is fundamentally flawed. They maintain that Sun is competing in several distinct and different technology and market spaces and that the pressure to make things common is forcing too many compromises. Remarkably, this perspective could be a useful lightning rod for keeping SHAC and PLC accountable. Symptoms of a pending next crisis, as positioned by SHAC detractors include:
- Product, market and competitive arenas are a moving target

---

[95] In one project, still in the concept, there have been nearly a dozen reviews of features. Preparation has required substantial time from the team. Each review ends with several new action items for the team, not all deemed reasonable or useful.

- SHAC concentrates on improving existing ways of doing business. There are mismatches between competencies and needs for future product development. SHAC could institutionalize the old way of doing things bringing about stagnation.
- Too much leverage could lead to lack of product distinctiveness.
- "One size fits all could become one size fits none!" – senior Sun architect
- Unexpected technical delays impact entire company not just a single product line
- Problem-solving delays amongst groups causes resentment
- No matter how many things are written down, there will remain unresolved product and policy issues (for example, cost, performance, and features, time-to-market, quality). The decisions related to these needs to be in the hands of people closest to the problem.

A healthy sign at Sun is that the people espousing this contrary point of view are heard. This influence is already driving towards the type of response necessary to weather a crisis of red tape.

Closing

The technological capability of a firm like Sun Microsystems requires the ability to assess a technology opportunity and either exploit it or avoid it. This influence on organizational systems is responsible for a company culture which continuously reevaluates the goals, behavior and structure of the products it produces. Sun has been able to rapidly adapt and succeed in the changing technology arena, driving sustained and substantial growth through innovation and appropriately targeted products. The cultural willingness to constantly review and modify product strategies affects the style, approach and form of the organizational structure the company puts in place. This enables the company to deal with pending crisis quickly.

While high-technology firms, like Sun, follow a predictable life-cycle pattern, the author concludes that the speed at which the company has been able to change minimizes the impact of those crisis. Discussions related to initiatives, such as SHAC, begin in times where the company is doing well. This attribute is consistent with the Whetten's *generating* response to decline, where the firm makes a virtue out its ability to learn from its own mistakes.

Nevertheless, as Sun continues to grow, it will eventually slow down and/or become vulnerable to a firm-ending crisis. It will be the ability of Sun to deal with that crisis that will determine whether the company becomes a long-term titan of the global economy or joins the many that have failed the test.

Conclusion and review

Sun has managed to use several approaches in undertaking technology strategy.

- In the early days, Sun adopted standards and leveraged them to take market share from a proprietary competitor.
- When the need for a leap in performance capability was needed, Sun created an external, entrepreneurial organization, UniSun, to enable the speedy development of the SPARCStation 1.
- The creation of the planets was a first attempt at shifting the organization from being functionally aligned to being customer focused. A breakdown in cooperation between the different planets resulted in the late, poor performing SuperSPARC. Yet, the creation of organizations to promote and create brand awareness for SPARC and Solaris ultimate proved to be an important factor in creating differentiation.
- The utilization of a steering committee to correct interplanetary disruption resulted in the major rollout of Sun's UltraSPARC 64-bit machines.
- Acquisition of important complementary products, especially Cray and IMP, enabled Sun to quickly widen the product lines and capture new segments of the market with a minimum expenditure of internal resources
- Organization into business units according to end-users of computer systems enabled highly optimized products to hit narrow, but growing customer markets, especially in companies building the Internet. Two product families that hadn't existed two years earlier became the market leaders in these new segments
- Expansion of the product line has stressed the value chain, putting disproportional accountability into operations. This is trying to be corrected.
- The company continues to reflect on its weaknesses and the SHAC initiative is intended to create the dialogue that can help the company mature to the next level in the organizational life cycle.

- Even while SHAC becomes institutionalized, healthy dialog within the company will make sure that it stays honest and relevant.
- Alternative viewpoints in the company will force SHAC to be honest and demonstrate proof of improved products or delivery of products.

From our organizational analysis, we conclude that Sun does indeed suffer from obvious crises as predicted by the growth model. Hence, the pressures on the company are consistent with those of firms in other times and other industries.

But Sun is also unique. Senior management's clarity in setting and maintaining an agenda, coupled with the motivation of employees to question and hold the company accountable to a high standard, enables Sun to quickly respond to crisis.

Bibliography

Abernathy, William, and Kim B. Clark, "Innovation: Mapping the Winds of Creative Destruction", *Research Policy*, 1985

Astley, W. Graham, "The Two Ecologies: Population and Community Perspectives on Organizational Evolution", *Admin Science,* 1985

Blau, Peter M, *A Formal Theory of Differentiation in Organizations,* 1965

Blau, Peter M., and W. Richard Scott, *Formal Organizations*, 1962

Boswell, J., *The Rise and Decline of Small Firms*, 1973, as cited by Kimberly

Burns and Stalker, *The Management of Innovation*, 1961

Carlton, Jim, *Apple: The Inside Story of Intrigue, Egomania, and Business Blunders*, 1998

Carroll, Paul, *Big Blues: Unmaking of IBM*, 1994

Chandler, Jr., Alfred D., *Strategy and Structure, Chapters in the History of the Industrial Enterprise*, 1962

Christensen, Clayton M., *The Innovator's Dilemma*, 1997

Churchill, N. and Lewis, V., 'The Five Stages of Small Business Growth', *Harvard Business Review*, 1983

Crawley, Edward, *Course Notes from Systems Architecture, Course 16.880*, 1998

Cringely, Robert X., *Accidental Empires,* 1996

Cusumano, Michael A. and Richard W. Selby, *Microsoft Secrets*, 1995

Deal, Jack, Deal Consulting Newsletter, 2000

Dell, Michael, Direct from Dell: Strategies That Revolutionized an Industry, 1999

Doerr, John, featured article, *Fortune*, October 13, 1997

Drake, William & Associates, report on "The True Costs of Losing Knowledge Workers", 1999

Eppinger, Steven D., and Karl T. Ulrich, *Product Design and Development*, 1995

Etzioni, Amitai, *A Comparative Analysis of Complex Organizations*, 1975

Farkas, Charles M. and Philippe De Backer, *Maximum Leadership*, 1996

Foster, R, *Innovation, the Attacker's Advantage*, 1986

Garr, Doug, *IBM Redux: Lou Gerstner and the Business Turnaround of the Decade*, 1999

Giddens, A., *Central Problems in Social Theory*, 1979

Greiner, Larry E., "Evolution and Revolution as Organizations Grow", *Harvard Business Review*, August, 1972

Gross, Edward, "Some Functional Consequences of Primary Controls in Formal Work Organizations", *American Sociological Review*, 1953

Grove, Andrew, *Only the Paranoid Survive*, 1996

Hall, Mark and John Barry, *Sunburst, The Ascent of Sun Microsystems*, 1990

Hammer, Michael, and Steven A. Stanton, *The Reengineering Revolution*, 1995

Hannan, Michael and Freeman, John, *The Population Ecology of Organizations*

Iansiti, Marco, *Technology Integration*, 1999

IEEE *Guide to the POSIX Open System Environment, 1003.0*, 1995

Johnston, Stuart J., "Microsoft's MSN Challenge: Getting Beyond the Blind Spots", *Information Week*, July 28, 1997

Katz, Daniel, Robert L. Kahn and J. Stacy Adams, *The Study of Organizations*, 1980

Katz, Ralph, *The Human Side of Managing Technological Innovation*, 1997

Kartz and Gartner, "Properties of emerging organizations", *Academy of Management Review*, 1988

Kidder, Tracy, *The Soul of a New Machine*, 1981

Kimberly, John H. and Robert H. Miles editors, *The Organizational Life Cycle*, 1980

Kirch, John, "Microsoft Windows NT Server 4.0 versus UNIX", http://www.unix-vs-nt.org/kirch/#stability, August 7, 1999

Kochan, Thomas A., "Rebuilding the Social Contract at Work: Lessons from Leading Cases", *Task Force Working Paper #WP09* for the Task Force on Reconstructing America's Labor Market

Koopman, Philip, "A Taxonomy of Decomposition Strategies Based on Structures, Behaviors, and Goals*", Proceedings of Design Theory & Methodology Conference*, September 1995

Kunstler, Daniel, *J.P. Morgan Securities, Discussion with Scott McNealy*, May 6, 1977

Levinson, John C., *Goldman Sachs Report on Computer System Market*, 1986

Lucero, Margaret A., and Marion White, "Integrating Employee Benefits and Competitive Strategy", *The Journal of Business Strategies*, 1996

Mai, Robert P., *Learning Partnerships*, 1996

Mano, M. Morris, *Computer System Architecture*, 1982

March, James and Simon, Herbert, *Organizations*, 1958

McNealy, Scott, as quoted in Sun Microsystems, Annual Report, 1999

Meyer, Christopher*, Fast Cycle Time, How to Align Purpose Strategy and Structure for Speed*, 1999

Millis, Marc, "Breakthrough Technologies", *NASA Archives*, 1997

Niv, Amittai, *Organizational Disintegration: Roots, Processes, and Types*, 1980

Oakey, R., R.Rothwell and S.Cooper, *The Management of Innovation in High Technology Small Firms*, 1988

Oster, Sharon M., *Modern Competitive Analysis*, 1994

Pearson, Jamie P., *Digital at Work: Snapshots of the 1st 35 Years*, 1990

Pfeffer, Jeffrey, *The Human Equation: Building Profits by Putting People First*, 1998

Raymond, Eric S., *The Cathedral and the Bazaar: Musings on Linux and Open Source*, 1999

Rechtin, Eberhardt and Mark W. Maier, *The Art of Systems Architecting*, 1997

Rosegrant, Susan and David Lampe, *Route 128, Lessons from Boston's High-Tech Community*, 1992

Sahal, D., *Information Exchange and Technological Innovation: In The Transfer and Utilization of Technical Knowledge*, 1982.

Salus, Peter, *A Quarter Century of UNIX*, 1994

Scott, W. Richard, *Organizations: Rational, Natural and Open Systems*, 1992

Sethi, Viram, David Meinert, Ruch C. King, "The Multidimensional Nature of Organizational Commitment Among Information Systems Personnel", *Proceedings of the Association For Information Systems*, 1996

Southwick, Karen, High Noon, *The Inside Story of Scott McNealy and the Rise of Sun Microsystems*, 1999

SPARC International, *The SPARC Architecture Manual, Version 8*, 1992

SPARC International, *The SPARC Architecture Manual, Version 9*, 1995

Stanworth, M.J.K. and Curran, J., 'Growth and the Small Firm - An Alternative Perspective', *Journal of Management Studies*, 1976

Summit Strategies, "Sun's Role in Redefining the PC/Workstation Boundary", *Market Report*, 1989

Tushman, Michael L. and Philip Anderson, "Technological Discontinuities and Organizational Environments", *Administrative Science Quarterly*, 1986

Veblen, Thorstein, *The Theory of Business Enterprise*, 1904

Von Glinow, Mary Ann and Susan Albers Mohrman, *Managing Complexity in High Technology Organizations*, 1990

Whetten, David J, Sources, *Responses and Effects of Organizational Decline*, 1979

Wheelwright, Steven C. and Kim B. Clark, *Revolutionizing Product Development*, 1992