

Management of Industrial Research

Exploring the Unknown Technical Future

William R. (Bert) Sutherland

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For information regarding the Sun Labs Perspectives Series, contact Jeanie Treichel, Editor-in-Chief <jeanie.treichel@sun.com>. All technical reports are available online on our website, <http://research.sun.com/techrep/>.

Editor's Notes

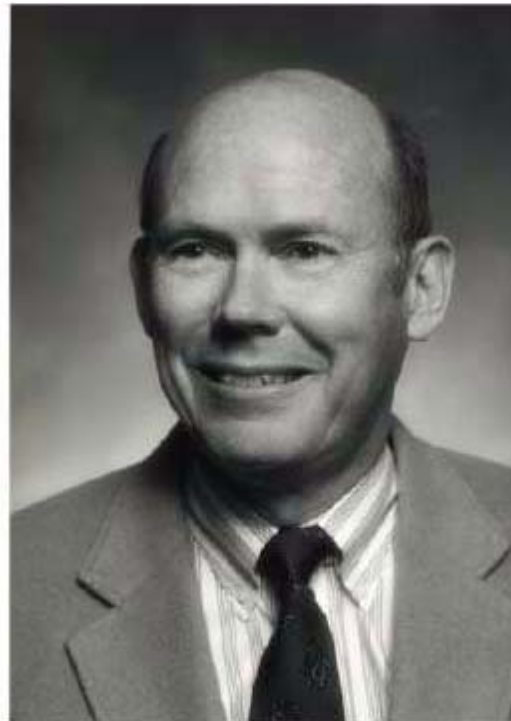
About the series—The Perspectives series is a collection of essays written by individuals from Sun Microsystems Laboratories. These essays express ideas and opinions held by the authors on subjects of general rather than technical interest. Sun Microsystems Laboratories publishes these essays as a courtesy to the authors to share their views with interested friends and colleagues. The opinions and views expressed herein are solely those of the authors, and do not in any way represent those of Sun Microsystems Laboratories, nor Sun Microsystems, Inc.

About the author—Dr. Bert Sutherland describes in detail his activities since his thesis was completed in the 1960s under Claude Shannon. The Editor of this series was honored to have worked with him at the Palo Alto Research Center (PARC) during the latter half of the 70's, then with Sutherland, Sproull, and Associates throughout the 80's -- until the consulting firm was purchased in 1990 by Sun Microsystems, Inc. where Bert helped establish Sun Labs and served as Director until 1998.

Bert managed his charges with a light rein. He sought out champions, gave them ample budget and headcount, opened every avenue to ensure their success, and let them run with their ideas. His support was unwavering and almost imperceptible so, with achievements in hand, champions were made to feel that they had succeeded all by themselves.

Dr. Sutherland is presently Director Emeritus, Sun Microsystems Laboratories

—Ed.



Bert Sutherland
Director, Sun Labs (1993-1998)

Foreword by Jim Mitchell

*Sun Fellow
VP, HPCS Research Program*

I first met Dr. William (Bert) Sutherland when he joined the Xerox Palo Alto Research Center in 1975 as Director of its System Sciences Laboratory. I was immediately impressed by his quiet and thoughtful manner, but came to value even more his wisdom, the depth of his thought, and the principles he held and espoused. He has been a practicing scientist and engineer; he has directed research (and therefore researchers) over an amazing period of growth and change in the computer industry and in the computer science and technological development that underlies it. Under his leadership his labs have produced some amazing and impactful inventions: things like modeless WYSIWIG editing, Java™, and IC design made accessible to everyone, to quote a few examples. It is that wealth of experience coupled with his high regard for good science and engineering that makes this paper such a worthwhile and great read.

Bert has written an excellent manual for research laboratory directors. If you need to know how to think about the decision making for starting (and stopping) projects, how to get new inventions to be used in products, how to lead responsibly and manage both downward and upward, or how to build and develop a first class research organization, read what he says and take it to heart.

It is a mark of the esteem in which Dr. Sutherland is held that virtually all his successors at Sun Microsystems Laboratories have continued to bother him for consultation long after his tenure in that position. It is wonderful that he has taken the time to distill his experience and wisdom in this excellent paper.

Jim Mitchell
Menlo Park, California
July 2008

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Exploring the Unknown Technical Future

William R. (Bert) Sutherland
Former VP, Sun Microsystems, Inc.
Director Emeritus, Sun Microsystems Laboratories

July 2008

Preface

It is now a bit over seven years since I retired from Sun Microsystems in 2000 and nearly a decade since I actively served as the Director of Sun Labs. Much of this document was written in the years of 2000-2002 shortly after I retired, and I am very aware of how much has changed since my time of active participation. Some of my comments that follow may have enduring relevance, some will have been overcome by events and the march of progress. I leave it to the reader to discern whatever of relevance can be gleaned from these words.

My Background

I have been a manager of industrial research organizations for most of my career thoroughly enjoying the many creative people with whom I have been privileged to work. In my early days of retirement, I am moved to capture some lessons I have learned and opinions I have developed about how industrial laboratories can effectively serve their sponsoring organizations and the information technology profession.

I have been fortunate to share career interests with my brother, Ivan Sutherland; we have worked together productively for the last 20 years. I treasure his counsel and critique on many matters. Ivan and I were introduced to computing about 1950 when we worked for Edmund C. Berkeley, one of the founders of the Association for Computing Machinery. As high school students we worked with a demonstration relay computer, Simple Simon, that Ed had constructed with a word length of two bits and paper tape programming. We added a table lookup

divide instruction. Ed Berkeley introduced us to Claude Shannon then at Bell Labs who later supervised both our PhD theses at MIT in the 1960s. After graduating in electrical engineering from Rensselaer Polytechnic Institute in 1957, I served in the U.S. Navy for 5 years as an anti-submarine carrier pilot. As my squadron's avionics officer I learned how difficult it is to operate and maintain complex electronic equipment in mission critical situations—each of my squadron's 20 carrier planes had 1250 vacuum tubes in forty black boxes. I am still appalled at the thought of being responsible for 25,000 vacuum tubes. Many carrier landings produced electronic repair events. The deep respect for operational technical skill and expertise I gained has been a continuing value of mine.

Next came earning a PhD at MIT graduating in 1965. I then joined MIT's Lincoln Laboratory to work on early interactive graphical design systems for integrated-circuit design, followed by a move to Bolt, Beranek, and Newman where my management career began. I took over the Computer Science Division there just as BBN embarked on developing the ARPANET (Advanced Research Projects Agency Network) that has subsequently evolved into the Internet. My division developed the TENEX operating system for the Digital Equipment Corporation's PDP-10 computer that became an early net host at many ARPANET research sites. In 1975 I moved to the Xerox Palo Alto Research Center (PARC) to manage the Systems Science Laboratory including Alan Kay and the Smalltalk group that inspired the Macintosh after Steve Jobs' visit to PARC. I also promoted Lynn Conway who along with Ivan's Caltech colleague, Carver Mead, developed the Mead-Conway approach to VLSI integrated circuit design. In 1982 I joined Ivan and Bob Sproull in a small consulting firm, Sutherland, Sproull, and Associates, until all four of us joined Sun Microsystems to help start the newly formed Sun Labs in 1990 where I served as Lab Director from 1993 to 1998.

During the 1980s and 90s I also had the opportunity to learn about business practices from participation with a venture fund, Advanced Technology Ventures, and by serving for 17 years on the Board of Directors of John Wiley & Sons, a NYSE-listed public publishing company that in 2007 celebrated its 200 year anniversary.

Functions of a Lab

An industrial research laboratory serves many purposes for its sponsor. Following are some of my opinions about the value that a lab can create for its sponsoring company.

Technology development

When asked about the purpose or value of an industrial research lab, most people will answer something about technology for new products, and that is indeed a primary reason for its existence. The advantages of owning your own proprietary intellectual property and technology know-how are great. A lab provides a special place where innovation can be nurtured in ways that are very difficult under the pressures of product development deadlines.

Behavior change

Presumably a company sponsors a research lab because the company needs new products and new ideas to compete successfully in a changing future. I have always found it very useful to think of a lab's effectiveness in terms of achieving change inside the company. Consider the following negatives. Suppose you had a lab and suppose no one in the company outside the lab did anything differently because of this lab. Suppose that the lab then vanished. No one in the company would even notice or care. Such a lab is a nearly useless expense for the company. My approach to researchers has been, "I'm a compulsive optimist—let's presume your new project idea will be a technical success. So who in the company might then change their behavior to capitalize on your wonderful result? Who will really care about what you have achieved? What difference might your technical success make? To whom?" Noticeable change in other parts of the company is one way to determine impact of a research lab.

Idea import

However, any company can afford only a small part of the world's search for new knowledge, and so a lab should also provide a means for importing useful ideas developed elsewhere. Often the relative freedom from company fire-fighting in a lab creates opportunity for external associations and awareness of what others are doing. Preventing technical isolation and resulting surprises from the outside

technical world is part of a lab's job. At the founding of Sun Labs in 1990, Bill Joy remarked, "Innovation happens all over the globe, mostly not at Sun." I have described this lab role as an "intellectual trading post" for the company. A requirement for success in this information trading role is that the lab be forthcoming with its own creative results in addition to being an acceptor of new ideas and knowledge from others. In trading, you have to give in order to receive. There is an intellectual bill to pay as part of sharing ideas and knowledge. A lab can increase its sponsoring company's "intellectual absorptive capacity" from interactions with and knowledge from the outside world.

University relations

A corporate research lab is a natural place to foster ties with academia since lab and university both share a common interest in creativity and fresh ideas. The nature of lab relations with higher education establishments varies widely from joint research projects, consulting or sabbatical relationships with key technical professors, direct sponsorship of promising students on the campus and as interns at the company, and general enhancement of the company's overall recruiting image. Considerable care will be needed to agree on intellectual property rights for any collaborative work.

Recruiting magnet

A research lab can play a significant role in recruiting technical talent. It can attract technical experts that may not yet be ready or willing to join a product development group. The cachet of a good lab and the chance to work with renowned colleagues are important attractors for technical talent.

Developing technical leaders

The relative freedom from product crisis pressure provides an opportunity to nurture and develop future generations of technical leadership for the company. I will say more about this aspect later after covering some of the special circumstances of a laboratory.

Impartial wisdom

The technical staff of the research lab can be a politically neutral source of technology expertise for addressing company problems. Senior lab members can

be called upon as referees and advisors to assist in the resolution of technical issues that puzzle company management or that are embedded in company cultural battles. Sometimes an impartial review to ascertain technical facts is essential to progress.

Proof of company foresight

Customers and investors often seek assurance that a company is investing in a long-term future vision. The existence of a research lab is tangible evidence of real corporate commitment to its future. The continued will to support a laboratory in the face of competing requirements for resources is proof that the company's senior management has serious commitment to understanding and promoting its future.

Managerial courage booster

Introducing new technology into products often appears risky and strains the courage of product managers who must bet their reputations and careers on some new technological concept in their next products. Demonstrations of feasibility and practicality of new technology bolster managers facing risky investment decisions in new technology. More on the issue of risk management later.

Avoiding technical tarpits

In a similar vein, if the lab can clearly demonstrate what technology is not yet ready for prime time, its sponsor can avoid difficulty, expense and even embarrassment. Several years ago, the digital transmission technology of Asynchronous Transfer Mode (ATM) was the rage and widely touted for rapid adoption to the desktop. A Sun Labs project tried to use ATM technology for our own building's internal network and found we could not make it work well enough. This seeming failure helped change an incipient Sun campus network plan from ATM to IP technology and avoid an expensive mistake.

Fundamental Management Precepts

In managing my labs, I have followed some basic conceptual rules for deciding what new projects to support, which people to hire, and how to keep the creative juices flowing in my people.

Lab as a change agent

First and foremost, the lab should help the company change itself in creative ways, for without achieving relevant changes for its sponsor a lab is an expensive luxury. A lab can address only a finite few of its sponsor's many needs for technology and creativity. Therefore, pressing forward with whatever creative results can be achieved is more important than an overly careful analysis of what might be done if only the environment were different. A lab manager must balance thoughtful planning and recruiting with pragmatic forward progress from the currently available talent base. I'm tempted to say, "A bird in the hand is worth two in the bush," translated as "a viable promising project ready to go is more concrete than a wishful need for knowledge or innovation lacking a champion."

Implied teaching role

As a developer or importer of new behavior-changing ideas for a company, a research lab is inevitably in the teaching business. Teaching and research have had a long and productive association in the academic world, and it is equally true in the contemporary industrial world. Part of my recruiting description for Sun Labs has been that I want new staff to come to the lab where their job will be to develop interesting curricula to teach the fruits of their creativity to the company. Of course, they must create something new and valuable through their research activities as the topical basis for such curricula, but their success is not solely determined by their innate creativity. The best idea in the world contained only in a small group of lab heads is worth little to the company. The job of the lab is to infect the company with new knowledge—often in spite of people's resistance to change and learning.

Creativity is people-based

The spark of creativity burns fleetingly in people in strange and unpredictable ways. Creativity cannot be forced, it can only be encouraged. Setting an atmosphere and environment that encourages the staff to think broadly, and to reach for new thoughts is a principal task of lab management. From Alice in Wonderland: "Think 400 impossible thoughts before breakfast." Creativity is bestowed on people in different proportions. While everyone has some, the most creative are light years ahead of the norm. Finding them and encouraging the

unexpected surprises they produce is one of the most rewarding and enjoyable parts of lab management.

Different risk profile

Research is inherently uncertain. I first heard a favorite of mine attributed to Wernher von Braun: "Research is what I am doing when I don't know what I am doing." My paraphrase goes; "If we knew **exactly** what we were doing, it wouldn't be research." This often draws strange reactions from senior managers who like crisp control. Research projects that, at inception, are certain to succeed or certain to fail add little new knowledge. Only when we are uncertain about an outcome do we learn from the experience of a project. Salesmen make cold calls on customers because they hope for a surprising success even though expecting frequent rejection. A research lab is an institution to make "cold calls on technology" in the hopes of achieving invention and creativity. A lab can also be described as an institution exhibiting "funded institutional curiosity" about technological matters.

I do not mean to imply here that risks should be treated other than carefully—but they should be acknowledged and perhaps even cherished. Part of a researcher's fun comes from overcoming problems in new creative ways. I personally remember coming home late at night when I was still a junior researcher with an enormous rush from whatever clever breakthrough I had accomplished that evening. The inner feeling of accomplishment and excitement is an important retention tool in these days of talent shortages.

Sponsor DESERVES a good return

The managers of a research lab are entrusted by their company with significant resources and allowed the freedom to follow and exploit the creative sparks they find in their research staff. This trust engenders a special responsibility to deliver real value to the company. I always viewed my lab budget of many millions of dollars as the largest block of reasonably flexible technical resource at Sun—a resource I could occasionally shift rapidly to support the company's technical needs. Since the lab budget at Sun is corporate money, I sometimes supported important technical endeavors in the company outside of the laboratory operation.

I am very proud of the results Sun Labs has delivered for Sun under my stewardship over the decade of the 1990s.

Lab Work as Technology Options

I have found it useful to think of a research lab as developing "technology options" for its company. When the uncertainties of the project are sufficiently reduced and understood, the company can then decide to exercise the option developed by the lab or to let the option lapse unexercised. Many times the decision hinges not on the research and resulting technology but on other business factors beyond the control of the lab's researchers and management.

Greater risk implies larger failure potential

With a charter of exploring the possibilities of an unknown technical future, managing the risks inherent in research projects consumes much management attention. A lab needs an ethos of willingness to try risky endeavors with the accompanying possibility of apparent failure. Research successes are easy to celebrate. It is more difficult to snatch value and staff morale from projects where the risk was indeed too great for the approach used or the resources applied. But an analysis of the reasons for failure of a project can often lead to valuable knowledge, but perhaps not of the expected type.

Some transferred projects will flourish, some will wither

A lab project moved into the company is like a fledgling bird being weaned from its supportive nest. It must cope with the unfamiliar realities of a new harsher environment of pressured deadlines, marketing requirements, manufacturing realities, customer service needs, quality assurance testing, and all the other factors that create product success. As always, leadership is a key ingredient in success but not a guarantee of it. A project that moves with its own dedicated champion determined to see the technology in practical use can withstand blows from the product development environment it enters.

Management training

Preparing lab project managers for larger future technical leadership and management roles is an important task for lab management. My strategy has been

strong delegation of project responsibilities to the Principal Investigators carefully supported by the lab's finance and legal staff. Shepherding a new idea to fruition along with a research team to explore it involves both creativity and practicality. Lab projects have technical risk as a key ingredient and new fledgling research managers add their own component of managerial risk that make a lab a good place to learn about budgeting, depreciation, and many of the other engineering and management practicalities that a corporate career will require. Senior lab managers have an important role as mentors of the skills their sponsoring company may need in its future. The support staff of a lab also has an important role in teaching and assisting the researchers with the niceties of finance, patents, intellectual property issues, etc.

Revenue - Expense = Profit

Conventional thinking about industrial research has largely focused on technology for new products—aiming at eventually increasing revenue. A new product idea coming out of research requires much additional investment for development, manufacturing, marketing, and sales before achieving a net profit for the company. However, reducing expense through new technology or tools is also a productive way of improving profit, often achieving fiscal results much more rapidly. A dollar spent in the research lab for new product may be returned to the company only after many years and much additional investment expense produce something that customers will buy in volume. The dollar spent in the research lab for some internal expense-reducing technology can be returned to the bottom line in the first year that the improvement is adopted in the company. The lab portfolio of activities must balance these two aspects of technology utilization.

Starting Projects

Sources for new ideas

The research lab should have a wide net for finding and filtering new project ideas. People in the company are a good source so the lab should have contact with and listen carefully to company colleagues. Ideas from within the company often have good relevance even when lacking in technical feasibility. Sometimes an idea champion from the company can move into the lab to prove and develop the proposed project concept. Customers are also a source of inspiration for lab

projects. As you will see later, for several reasons I am an advocate of lab contact with customers of the company. Sometimes new lab recruits will come with a pet idea to pursue. Other new projects seem to materialize somehow from thin air when the time for the idea is ripe. Whatever the source, lab management must pay attention to new ideas and assess their suitability for lab investment.

Three requirements

I have developed three conditions for starting a new project; I have generally disappointed myself when I violated these three concepts.

First, I must have available an interesting new idea with plausible relevance to the sponsor's interests. The articulation of the idea must contain more than the definition of an interesting problem domain; it must also delineate a novel approach to the solution of the problem. Very often I have seen (and rejected) project proposals that basically declare, *Topic X is an important problem for the company, and solving it will be very valuable. Therefore I plan to fool around in this area and see what I can turn up.* That may be adequate for a solo short-term experiment by a demonstrated successful innovator, but is not satisfactory for starting a real resource-consuming project.

The new idea to be pursued must have novelty, some risk, and the possibility of failure. Often the proposals I have received lack the element of surprise if successful. A retired two star USAF general once described to me desirable missile flight test conditions as having only a 50% probability of success. This maximizes the information to be gained from the test. Research labs must seek stretch goals beyond their comfort and predictability zones. A surprising result is usually a good outcome of pioneering research.

Second, I need an inspired champion to whom I can comfortably entrust the leadership of the project. The role of a champion is critical to successful research. A lab manager can only delegate resources to creative "principal investigators" (PIs) who have the passion and burning itch to explore some new topic. The PI in my world has two principal tasks; (a) leading the project activity, and (b) developing all the explanation needed to see the project concepts and ideas

migrate into many minds beyond those of the project staff. I have often told my lab members that "explanation is our most important product." The ability of an emergent Principal Investigator to develop the early explanation necessary to support his or her nascent project is a very useful harbinger of success. Remember my earlier comments about curriculum development as a description of lab results! The concepts behind a new potential project must also be "taught" to colleagues and lab management. The project proposal can be thought of as the first draft of the final curriculum that goes with transfer of a successful project.

Third, I must see the way to enough resources for critical mass of project activity to make progress in a reasonable time frame. There is a great tendency to spread the limited resource of a lab too thinly yielding poor results. A principal task of lab management is to say NO! often in order to focus on a few things done well. A well operated lab will be resource limited not idea limited. There should be a plethora of interesting new ideas worth exploring, far beyond the affordable funding a company can allocate for its research lab. So lab management should resist the temptation to explore all the interesting opportunities available and accomplish well only the affordable few. This implies saying NO to worthy ideas. Being selective is an important way that lab management contributes value to the company.

Portfolio mix

New projects chosen for support should fit the portfolio profile chosen for the laboratory's mix of topics and time horizons. As an instigator of change, the laboratory must itself change its activities on an aggressive basis. Common sense and managing risk appropriately dictate that the lab activities should be divided into more shorter term projects than long term efforts. The relatively few projects that will take several years to mature can be complimented by multiple projects that while extending beyond the product development horizon still can mature and be harvested in 2-3 years. I reiterate the importance of the Principal Investigator. The portfolio mix is a direct reflection of the cadre of the PIs in the lab. No leader, no project. I often replied to Scott McNealy's suggestions of new project problems, "Right on, good problem. Now WE have a recruiting need to find a qualified project champion!"

To recruit a star

In those few circumstances when a proven world class star can be hired, start a new project devoted to that person's particular interests. The management trick is then to guide the new activity into a direction that will provide plausible relevance for the company. Another way to convey this concept is to say that a potential Principal Investigator who can lead a new innovative research project is a real prize well worth great effort to capture.

A specific example may be useful. Sun builds computers and clearly the design and simulation tools we use are important. I had the opportunity to recruit Dr. Tom McWilliams, an experienced hand in CAD and computer design activities. I told Tom, "Spend the first year looking at how Sun does design, recruit a team, and start a project that you think useful." He did superbly, and his project was shared with and supported by Sun's processor division for awhile until changing circumstances led Tom to leave the company.

Stopping Projects

One of the hardest tasks of lab management is to prune the project portfolio of activities that have passed their prime. A successful project builds its own momentum and always has a bit more polish that can usefully be applied to enhance its success. The best way to end a lab project is to move it out into the company as a nucleus for change there.

Gently but firmly

Redirecting the efforts of a research team enamored with their so-far-successful project without demoralizing them is tricky. It requires discussion of the reasons for such unwelcome change and the assurance that this change is a result of changing priorities and sponsor values rather than failure of the team to do good work. In the Sun Labs examples during my tenure, when I ended projects without transfer to the company, a few team members left for greener pastures elsewhere while the majority managed to shift gears in the lab and use their talents in new ways to deliver great value to the company. Lab management needs the confidence and trust of the lab staff in order to redirect staff onto new endeavors without damaging morale and creativity. Successful and respected lab managers

are often remembered for their sensitivity and patience in nudging staff off of old work onto new projects.

Overtaken by events

Sometimes good project activities are rendered moot by external events in the dynamic external world of evolving technology. At one point, before the Java™ tsunami of internet acceptance and enthusiasm swept over us all at Sun, Sun Labs was exploring a variety of programming language issues with several projects, each working with a different programming language. When the dominance of Java in Sun's psyche became clear, some of these projects ended, some changed to focus on Java instead of their original language, and some of the staff moved on to invent new Java capabilities that their prior language skills suggested. Change in response to external events is inevitable.

Just too long or staff enamored with their rut

Some projects appear that they will continue forever unless blasted into new activities. A particularly focused PI can coherently articulate a chain of related follow-on activities without end. Projects should last only a few years and then end either by transfer or by management dictum. People do get stale working on the same thing forever and may need forceful encouragement to shift gears and renew themselves through a change of venue in their research activities.

Technology Transfer

Moving new technology out of the lab into productive application in the company is one of lab management's principal challenges. Lab technical results can go into revenue generating product or into improved internal processes that reduce time-to-market, enhance customer service, or reduce expense. Either way, the lab must act as a change agent and convince some other group of company people to change their behavior into something new, perhaps risky, and generally uncomfortable. Corporate change is very difficult.

A contact sport

Jim Mitchell, a former Director of Sun Labs, has often said that technology transfer is a contact sport. I learned that he adopted this term from Gordon Bell,

Digital Equipment Corporation's chief architect and subsequently a Research Fellow at Microsoft Research. By that Jim indicates that moving new ideas from their incubation and validation in the laboratory into routine practice in the company operating units is arduous, often bumpy with setbacks, requires continuous pushing, and can be mentally exhausting. There are days when a rugby scrum looks easy in comparison. One characteristic of a good lab project champion is the willingness and even dedication to the effort required to accomplish a successful transfer. Luckily, many lab folks are attracted by the opportunity to make a difference in the world's computing scene, an opportunity that is available through Sun's competitive position in the computing industry. All they have to do is have a good new idea, refine and demonstrate it, and then sell the company on using it. Unfortunately this simple three-step sequence involves ever increasing difficulty the closer one gets to the end step.

Pay to leave

When the time comes to transfer technology from the lab to a line operating organization, remember that the most effective method is moving a group of lab people over as the technical nucleus of the operating group. I will comment later that fiscal stability is critical for managing a vibrant, productive, innovation-generating lab. One way to combine these two principles is for the lab to retain its normal funding level and continue to pay for the transferred people as they transition to their new operating group. This transition can take several quarters funded on a declining basis. After all, it will take the lab some time to recruit replacements for groups that leave, and the company's money can usefully be spent in greasing the difficult transition process. Given that large corporations are not usually very flexible with fiscal changes outside their formal annual planning process, a potential recipient organization of a lab transfer in mid-year often lacks the funds to accept the project.

Success is best when unheralded

Human nature being what it is, lab results often move most easily when moved subtly and unnoticed. The transfer should be called "technology" or a "prototype," not a product. The lab must carefully avoid claiming it did all the work because much further development that the lab cannot do goes into a viable product. If the

transfer is successful, there will be plenty of credit to go around. I have always encouraged lab people to assist the company informally without demanding much recognition. These informal ties are the strong cement that bonds the working level technical folks for the company's benefit. It then becomes a lab management responsibility to provide recognition, thanks, and suitable rewards to its people. In addition lab management must be alert to notice informal contributions and weave them into the lab benefit story that keeps upper management satisfied with the value delivered for the company investment into lab operation.

Unexpected subtleties

Transferring a lab group or activity successfully into the company requires among other things considerable diplomacy. The transfer needs to be perceived as a win-win for all involved. Avoid at all costs the attitude of "The smart WE are coming to the rescue of the dumb THEY." Lab management must foster in the lab staff an appreciation and respect for all the company. I have always made a point of thanking the revenue generating parts of the company for supporting me and my lab; we help spend the money they make. Productive cooperation is the desired universal attitude.

Measuring Results

An obvious question about a research lab is, "What is the sponsor company getting in return for its easily measurable investment of resource budget in the lab?" Senior management needs to feel comfortable with the level of investment, and other employees need to understand why the sponsor company is allocating resources to a group dedicated solely to research, a group whose projects might not be understood or perceived as not being relevant to the company. Therefore, another lab management task is to make a very wide constituency feel comfortable with the value and benefit being delivered to the company by the research lab. "Perception is not everything, it is the only thing!"

Patents and publishing

The most easily quantifiable measures of research output have traditionally been patents and published papers and books. Independent external bodies judge the

quality of the work at the U.S. Patent office and the peer-review editorial panels of prestige journals. Good marks on these criteria help with the lab's reputation in its external communities. However, I believe that these measures miss the mark in assessing the value of a lab to its industrial sponsor as an agent of change and innovation for the company. As I have indicated, the real value of a research lab for its corporation is complex and subtle.

People moves

Counting the flow of staff through the lab is a simple way of recording important technology transfer opportunities. When lab people move with their lab-developed innovation or knowledge into other parts of the company, they accomplish some initial kind of know-how transfer, but real change in the recipient organization is yet to come.

Sometimes a lab project has been seemingly accepted as technology transfer but then canceled shortly afterward by the receiving organization as an opportunistic way of gaining additional resources for the receiver's ongoing work. After seeing some of my lab projects suffer this fate, I stressed the "pay to leave" funding model described above, retaining the transferred project on the lab's payroll until the innovation has visibly been accepted in the receiving organization. You first transfer operational control but retain the fiscal control. Later the negotiated financial changes can take effect. In addition, a large corporate accounting system may not always be able easily to accommodate split control of operating activities and fiscal reporting.

Counting people transfers measures another dynamic of a research laboratory. A research lab is a comfortable safe environment that researchers hate to leave particularly when doing work they love. As a consequence, industrial research labs seem to ossify in place as the staff grows inevitably older. New people are the innovative lifeblood of a lab bringing new attitudes, new methods, new viewpoints to foment progress. A strong exit rate implies the opportunity for fresh talent that should be seized at every opportunity. When I was managing the System Science Laboratory at Xerox PARC more than 30 years ago, I had an instructive meeting with the Xerox corporate human resources vice president. He

told me that I should ALWAYS make every effort to get staff to leave my laboratory—of course in a productive way. He said, "If your best scientist wants to go to a university, encourage him and support him. Then use the recruiting opportunity you get wisely."

Company opinions

For several years at Sun Labs I structured the senior lab manager's incentive bonus plan to include a rating by 40-50 selected constituent Directors and Vice Presidents in the company for their perception of the lab's value delivered. I chose this scheme as a way to measure and couple lab incentives to the perceptions of the lab generated out in the company. The engineering technical management participated, but so did executives from sales, business, manufacturing, personnel, finance, and other seemingly remote parts of the company. I set the unspecific measure of value to be the voter's pick of a number between zero (lab is useless) and seven (lab is great for the company). Each year the lab received a wide range of ratings; some zeros, a few sevens, and an average generally between 4-6. Better ratings naturally came from parts of the company that lab staff worked with proactively.

I think that the most valuable part of this scheme was the message conveyed to the lab staff about the importance of relationships with people in the company. I can't say that the promise of bonus money was a primary motivator for the lab staff who by and large appear to be working for the joy of creativity and innovation as long as their financial situation is acceptable. Rather, this bonus scheme was yet another way to combat the insularity that creeps up on focused research staff.

Other measures

Research labs traditionally have Technical Advisory Boards (TAB) with several implicit purposes. The company engages several high power external technologists to provide oversight and quality assurance to corporate management and to provide counsel to the lab director. Shortly after Sun Labs started, a TAB was put in place and met regularly for the first eight years. While it functioned, the Sun Labs TAB met twice a year and provided a written report to Scott

McNealy with its evaluation, conclusions, and recommendations. The TAB in a sense provided Scott with an additional outside appraisal of my performance as Lab Director. If one gets strong people on an advisory board, the result is often a reflection of the personal agendas of the individual members. I found the advisors most useful in the early formative years of the lab and less helpful after a routine and traditions were established.

Limitations on measurement

I have a personal dilemma on the topic of measuring a research lab's output. There is great wisdom in the adage, "If you can't measure it, you can't manage it." So quantitative measures are useful. On the other hand, the adage "Be careful what you ask for, you just may get it." imposes at least implicit constraints and pressures on setting goals for what a lab should produce. I have often seen foolish actions at year end to complete an arbitrary goal metric that has been rendered irrelevant by changes in the environment since the goal was set.

My own style for lab management is somewhere between these extremes. Fundamentally, a research lab is an expression of faith by the company and its senior management that such investment in an unknown future is good for the company. When that faith erodes, it is time for a new lab director.

Personal comments

When SunLabs was founded in 1990 Scott McNealy, Sun's CEO, was properly suspicious of how his new lab would work, particularly since a number of us had served at Xerox PARC of "Fumbling the Future" fame. He said, "I know about research labs—they are black holes for money! So stay small until you prove your worth. 100 technical staff is a suitable limit." This limit proved extraordinarily useful in the next few years in managing the lab. The size limit meant that in order to start something new, we had to stop something old. Given the problems I described above with stopping projects, the 100 limit turned out to be a useful fulcrum for encouraging researchers interests in doing something new and accepting the end of ongoing work. Scott added an additional push with the statement, "I know really how to control your size. You can have Building 29 on the Mountain View campus. DON'T ask for more space any time soon." Staying

relatively small also meant that in its early years while working to develop results of value, Sun Labs was not a huge expense for others to snipe at.

Level of Resources

How much should a company spend on its research lab? My brother Ivan comments that this is like the question of how much should a business spend on a "Yellow Pages" advertisement. His answer is "About the same as the competition, but only what you can afford."

Affordability with stability

I draw the analogy between research lab annual resources and a retirement development program for an individual. Both are aimed at enhancing the future viability of the plan's sponsor some years hence. Conventional wisdom says that a person should make steady retirement investments for their future each year even in tough years. Obviously this principle will be modulated by practical affordability each year, but it is a valuable guiding concept. A corporation should treat a research lab and its creativity in the same way. The creative people in a research lab do not respond well to being jerked up and down. You get to lay off world-class researchers only once. The word gets around and they stay away.

A corollary for lab management is to be cautious and careful about expansion beyond reasonable expectations of stable affordability. Lab management is charged with developing a view of the sponsor's future and managing lab resources accordingly. Part of that is to assess the sponsor's ability and willingness to afford its research enterprise in the out years. Early in Sun Labs existence, I declined a proposal to establish a European lab branch largely on my own intuition that the move was unwise on stable affordability grounds. Revenue gyrations in the immediately subsequent months proved that a wise decision for that particular time period in Sun's growth. Subsequently after my time, Sun has opened and later closed a European research lab.

Size flexible but critical mass needed

I often said to Sun's senior management that I could and would run Sun Labs at whatever size they desired to afford above a critical mass threshold. Below

critical mass, they would be better to shut down the lab. However, lab size must change slowly with great care to maintain stable staff morale. Consequently the portfolio of activities must be managed and pruned with a long term view of the lab future prospects. Growing more slowly than overall R&D growth for the company helps keep the peace with development organizations. Sun grew revenue successfully for all my tenure there, so my theories about lab stability in tough times remain untested in my personal experience.

Managing Upwards

A corporate research lab has a unique set of characteristics that make its management different from other business units. Senior management is not always aware of these differences, and so another task of lab managers is to bridge several gaps in management gestalt: 1) The time horizon of a research lab's work is of necessity longer than that of a business unit; 2) The risk profile of lab projects includes a necessary likelihood of failure that is an anathema to normal activities in the company; 3) A lab portfolio of activities must remain relevant to its sponsor's perceived and recognized needs while simultaneously exploring issues the sponsor may not yet even recognize as important; 4) What a lab is able to do is constrained by the skills of the available staff who must be motivated to deliver real value to the sponsor. Truly creative technical people are a rare breed not always attuned to business practicalities. So a lab is not always able to respond immediately to some technology needs when finally perceived by senior management.

Setting expectations

Supporting a research lab is a demonstration of faith by senior management—faith that the lab will enhance the company's future prospects, faith that the lab management and staff will figure out what to do to elucidate an uncertain technical future, and faith that the company will be able to utilize whatever understandings the lab produces. Lab management must recognize, appreciate, and act to bolster that faith and prove that it is not misplaced. Perhaps the best way to do this is to have a succession of pleasant surprises for management coming from the lab.

Fiscal attitudes

One management aspect I have found particularly important is for the lab actually to be and more importantly to be perceived as a fiscally responsible organization. The funds invested in a lab are a direct hit to the sponsor's profit line, and lab management must treat the resources allocated to a lab with the utmost respect. I have been perceived as a bit strange in my willingness to return my unspent budget to the bottom line in quarters where company profit was a better use of my allotted resources than unnecessary lab spending. In one particularly tough summer quarter in the early 90s, Sun's reported profit was 16 cents per share of which my lab underspending contributed 1 cent per share.

Let me also acknowledge the support received from management above me during my tenure as lab Director. Sun has been a splendid supporter of Sun Labs. I never felt a great compulsion to spend everything I had in a lab budget just to preserve the next one. I feel grateful for the luxury of just being fiscally conservative and trusted with the responsibility of investing the portion of gross margin allotted to Sun Labs in the best way I could.

Leading the Troops

It is a serious mistake to think of managing creative researchers. The seniors in a lab can only lead them. I like the old adage, "Management is the art of doing things right, leadership is the art of getting the right things done." I always felt that my job as lab Director was to ensure that all the necessary details got done that no one else would do while also encouraging and cheerleading the creative staff who have the brilliant new ideas. I got to guide, critique, and broker connections for the staff. Most of my own creative technical ideas turn out to be not as brilliant to the staff as they are to me. Ivan's former business partner Dave Evans periodically reminded me that "There are only two ways to get things done: by yourself or wrong." Leading researchers take much patience and tolerance of their strongly held and articulated opinions. I tried hard to err on the side of giving the projects strong autonomous control while minimizing my control and interference. Of course, when a firm hand is needed, management must step up smartly.

Listen well

Lab management should be in a permanent state of "hearing aid on, full sensitivity." Always! People enjoy meetings in direct proportion to how much they get to talk. For successful lab meetings, the research staff should do most of the talking about the new technology and its application.

Lab cohesiveness and esprit

During my time, Sun Labs considered its former members out in the company as a treasured resource for continued information exchange. Former lab members were invited to the parties and the summer picnics and encouraged to stay in touch. Working relationships are always easier with former colleagues.

Shortly after Sun Labs started, a staff member, Bob Ellis, instituted the Friday afternoon internal reception now known as "the Bash." This nearly two-decades old institution was an important weekly event for the Mountain View laboratory where research and support staff meet over refreshments. It is an exchange mechanism that even today binds the lab socially at the Menlo Park campus.

Financial Management

Delegation to project leaders

An important part of my style of research management is delegating the management of project expense directly to the project leaders. This is just good business practice but is not always the routine. Their own budget control gives the Principal Investigators the ability to respond creatively to new needs and opportunities by trading off various kinds of expense within their resource allocation. In addition, I believe that the management training implicit in handling a budget is an important part of developing the company's future technical leadership.

During my time at Xerox PARC, the research staff was carefully shielded from responsibility for depreciation charges, and the protection lead some years later to some nasty budget crunches for PARC when the depreciation obligations of past profligate capital purchases caught up with tough budget times.

Capital budget

I personally prefer to manage by planning depreciation affordability rather than an annual capital budget for the equipment aspect of my research lab projects. The capital budget highlights the requirements for cash outlay each year and is important for truly managing cash flow. However, my experience with the larger technology corporations I have served is that cash flow considerations are not an important part of daily management and are not addressed at lower management levels down in the organization. Thus the capital budget is not a particularly useful tool for instilling fiscal discipline in project managers. Instead it often appears just as a bureaucratic hurdle to be overcome.

I chose at Sun Labs to put capital equipment acquisition for my projects in much more personal terms for project managers with the following argument: "I do not buy equipment for the lab, YOU and your project lease it through depreciation charges from the "corporate bank" just as you might acquire your next family car with time payments over three years to the finance company. So what equipment your project buys now will constrain what you can afford to do for the next three years. Think carefully! Uncontrolled and unplanned depreciation can and will bite you badly in the future."

One year I used a particularly large capital budget request to emphasize the subsequent consequences of the depreciation implications. By scaling back the capital I approved, the depreciation avoided was converted into the next year's salary raise money and was very visible on each project's budget plan.

Contingency

Without planned contingency resources, the flexibility of a research lab is greatly curtailed because any new endeavor will detract from the mid-stream of some other worthy cause. Prioritization of activities is a critical part of planning, but unplanned disruptive reprioritization can be avoided by planning earlier to have some flexible contingency. Omitting contingency funds is a default prioritization that future flexibility to deal with any valuable surprising unknown opportunity ranks low in comparison with all known present activities. In some sense this often implicit prioritization to omit contingency is a denial of a lab's forward-looking mission.

Legal Issues

Conforming to a sponsoring corporation's legal policies is yet another responsibility for lab management. I have chosen in some cases to set more stringent requirements than my company required. Perhaps this is a case of the lab looking farther ahead to avoid potential problems. Many of my choices about how to handle legal issues for Sun Labs derived from my Xerox PARC experience as a lab manager there.

Protection of Intellectual Property

Much of a lab's output of ideas and know-how falls under the category of intellectual property (IP). The IP developed must become known to and used by others in the company or in company approved ways, while dissemination outside the company needs to be carefully thought through. It is all too easy to declare everything from the lab as top-secret IP to be held tightly. Unfortunately, such an attitude stifles the back-and-forth information exchanges inside and outside the company that stimulate creativity.

I chose to run Sun Labs as a very open organization that only in rare circumstances held critical information tightly for any considerable time. The penalties impeding innovation are too great to tolerate. Of course, the requirements for protecting information until patent applications are filed cannot be ignored, but after all the whole purpose of a patent as patent language indicates is "to teach the novel art" under the limited time protection afforded. As a lab becomes prolific, the legal load associated with timely patent application increases.

Moving quickly to understand and then derive advantage from an innovation is the really important value to be sought.

Lab visitors

Many of the reasons a corporation supports a research lab imply the presence of many visitors to the lab. What are the risks inherent in permitting lab visitors? What sort of intellectual property agreements should be established with visitors?

For long-term lab visitors like sabbatical professors who will become an integral part of the lab for some extended period, an employee-like arrangement for IP is appropriate. For short-term day visitors with limited exposure, I have seen two distinct approaches:

Some companies, Sun included during my time, see their principal visitor risk as leakage of proprietary lab information OUT of the lab in some unauthorized manner, and so via the visitor badge agreement that the visitor is asked to sign, the visitor promises to hold in confidence any proprietary lab information that may be disclosed to the visitor.

Other companies, Xerox PARC included during my time there, see their principal risk as the leakage of outside proprietary information INTO the lab with the potential future prospect of litigation for improper acquisition of some outsider's secrets. These organizations ask visitors signing in to agree NOT to disclose any of THEIR proprietary information INTO the lab during the visit.

Since the lab staff should seriously bear the responsibility for controlling the disclosure of lab information in all circumstances, I much prefer the policy of agree-to-avoid-import over the export control style agreements. In fact, on numerous occasions visitors to Sun Labs have stated that their own company rules did not permit them to sign Sun's badge agreement to hold information they might receive in confidence. To avoid a serious impasse in the Lobby about canceling the visit on the spot, I have upon occasion exercised my managerial discretion and waived the requested visitor badge signature and relied on lab internal control over the information to be exposed during a visit. Sun had a restrictive policy about its employees signing non-disclosure agreements to hold in confidence information they might receive from others. I sometimes wondered if Sun employees were technically allowed to sign in and visit a lab with a badge agreement identical to ours.

Since my time, much of this has changed due to increased emphasis on the USA national export control regulations that mandate specified ways of controlling the dissemination of technical information through visits. I think that the principal

aspect of appropriate information protection will always lie with individuals behaving in a sensible manner.

Legal clearances

Xerox taught me, and I have chosen to believe ever since, that a lab not only needs to protect its IP in fact, but also it should establish the practical evidence of "due diligence" in this protection. Consequently, upon becoming Sun Labs Director, I instituted a clearance process for review by management and the lab's legal staff of material that the lab staff proposed to publish. This clearance process was intended to create a record demonstrating that published material from the lab had been reviewed by management and by legal staff as being clean and appropriate for public release. I sought observable lab practices that showed we did indeed think that our IP is valuable and we employ appropriate review in a defined release process.

I can report that this "bureaucratic and ridiculous process" was not universally appreciated by the lab research staff. I was not particularly Draconian about punishing violators, but instead chose to promote and enforce the clearance review by denying any reference in the Lab's annual report to uncleared material. No credit or mention of publications that were slipped through the cracks without clearance! I just turned a deaf ear to the resulting howls of outrage.

Is my attitude about a clearance process important or effective? I do not really know since I have never personally been through the turmoil of litigation. Managing a research lab has many imponderable and undecidable choices about its uncertain future.

Developing the Staff

The technical capabilities of the research staff are what make the lab valuable to its sponsor. Improving the technical abilities of the lab staff is a glaringly obvious task for lab managers. However, I believe that a research lab can do more for a sponsor than just technology. It can provide development opportunities for future technical managers when lab projects transfer from protected research into practical product development.

Delegated budgets

I believe that managing his/her own budget is a necessary part of leading a research project. I generally apportioned out my own annual budget to support the planned activities at the levels I chose. Beyond that, the project leaders determined the details of their project's spending. All this as practice and preparation for when a successful project moved into a development stage. I have already remarked on how poorly in general the concept and restrictions of depreciation impact are understood by technologists.

Temporary assignments in the company

A company provides many opportunities for the research staff to broaden their horizons and knowledge of business. In many cases, some prodding by the management may be required to get staff to look out beyond their narrow research project horizons.

Guest internal auditors: I have always liked the role that a constructive internal audit department can play in a company. At Sun, the internal auditors would occasionally have "guest auditors" join an audit team when some special skill or background was required for an audit project. I once assigned two of my staff to such a role for a few weeks. I chose two rather than just one assignee so that they would have someone to talk over whatever was unfamiliar. As I recall, the audit was of an internal IT system. My technologists learned about both the audit practices and the IT system under review. I consider this a success because the two individuals involved reported that they had learned a surprising amount from the experience. And the head of internal audit told me my assignees were in fact helpful.

Shadowing: I talked one of Sun's senior sales executives into allowing one of my project leaders to accompany him on a trip to Europe and sit in on his staff meetings there. My person did learn a lot and the relationship established with the executive paid off later. When this lab project was ready to move into product development, and because he knew my leader, the executive was very supportive of the move into his organization. There are many ways to build confidence in the business abilities of the lab staff.

Staying in Touch with Outside

The staff of a research laboratory can get very wound up in their work to such an extent that they easily loose touch with the commercial context that an industrial laboratory supports. While dedication and focus are desirable for research work, a practical awareness of the sponsor's business context is valuable for creating a balanced view of laboratory activities and priorities. One management responsibility is to keep an appropriate balance between internal focus and external awareness in the staff. I used several methods to provide some degree of external focus for my staff both inside the company and in the larger external business environment.

Customer visits

Keeping close to customers is generally a good business practice even for a research lab. I encouraged the Sun Labs staff to visit with Sun's customers when they took trips to conferences and meetings. Sun's sales force is a company strength and has been very supportive if not eager to take lab staff for presentations to their customer organizations. One of my managers was charged with setting up such visits, and for several years visits were counted as part of the lab bonus goal set. Sun's sales people found it convenient to arrange customer visits by lab researchers if only to make opportunities for their own additional exposure to their customers. Each trip required a trip report circulated on email to the entire lab both to share what the visitor learned and to encourage other staff to schedule customer visits.

Some staff found the trips interesting and instructive, some thought them a distracting chore. I turned a deaf ear to the complaints believing that the experience was good for the company and for each staff member personally in developing their presentation and explanation skills, reinforcing my strong belief that "explanation is one of a lab's key products." I have another rationale for customer visits as a lab practice. One general function of a research lab is to help create products in the future that have increased value to customers. The lab staff needs some way of understanding what is now and could later be valuable to customers—a first hand personal opinion of the customer's value system. Interacting with customers on their turf is one way of gaining a better understanding.

Visitors and interns

While sending the lab staff out of the laboratory is useful, it is also possible to import some additional perspective balance through visitors and interns. I have always been a great supporter of a student intern program both at Sun and at PARC. At PARC, my lab almost doubled during the summer with interns while the Sun program was scaled smaller but more continuously. Sun Labs even had "winter summer-interns" that came about Thanksgiving and left at Valentines Day from Australian universities. In Silicon Valley and in the Massachusetts Route 128 area, even high school kids can make useful interns. Interns are inexpensive and can inject enormous energy and enthusiasm into a laboratory. Their principal cost is in supervision effort by the lab staff—a requirement easy to let slip by unless watched carefully by managers.

I always tried to have one or two sabbatical professors in residence at Sun Labs.

Visitors from within the company are yet another form of perspective enlargement. Sun Labs had a very productive four-month visit from a System Sales Engineer based in the Pittsburgh, Pa. sales office. His knowledge of customer needs and practices was quite a revelation to some of the staff.

Concluding Comments for the Constituents

Lab staff

Rejoice in your own personal creativity; but be most proud of your explanation and teaching! A true measure of your creative intellectual success is in how many other minds can effectively use your new ideas. A great idea trapped in your own little head is not very useful to the world at large or to your company sponsor for that matter! You will be successful in direct proportion to how many other minds can use your new ideas!

Colleagues are a critical part of the lab environment. Help them grow and develop, support their endeavors, and ask for their help when you are stuck. To have good colleagues, you must BE a good colleague! Collegiality is a two way street!

Curiosity leads to new thoughts. Exercise your curiosity continually; ask "why"

over and over as you observe your world. While I appreciated the devotion and focus of my lab staff to their own projects, I often wished they were in general more curious about the other lab projects and the company business.

It is important to develop respect for and understanding of the business and customers that support a lab. The company exists in a competitive world and each lab staff member has a significant role in its long-term viability. A lab should develop new knowledge that provides new value to the customer base, and to accomplish this you will need to understand the value system and needs of paying customers.

Lab management

Fiscal responsibility is a critical characteristic of good lab management particularly because a research lab consumes what otherwise might be company profits. Lab support is an expression of faith in an enhanced future by company senior management, and that faith must be respected and nurtured through wise effective stewardship of the resources provided. Lead, don't manage creative technologists. Whatever they are doing, they need to do it their own way with influence rather than overt direction from management. Management's job is to clear the way for your researchers both to explore their innovative ideas and to do so in a manner based on fiscally sound practices.

Contingency funds are evidence of flexibility to pursue new promising ideas on short notice. It is hard to explore new ideas when in a fiscal straight jacket of full resource commitment. Although it sounds contradictory—Plan for the unplanned!

Develop leadership opportunities to mature your troops. An environment of new ideas plus increasingly mature and capable people leads to new opportunities for the sponsor. A research lab is an ideal place to develop and refine leadership skills. In my opinion, encouraging leadership from subordinates is a primary responsibility of lab management.

Epilogue

The thoughts expressed in this paper are a personal exposition of my accumulated opinions and the most important lessons I have learned in a 40+ year career as a computer researcher and research lab manager. During this time I have been very fortunate to have been associated with some outstanding colleagues and some wonderful leaders and mentors whose best practices I have tried to follow. I was also the beneficiary of happening to be at interesting places at particularly interesting technical times—not something that can be decisively planned for a career. MIT Lincoln Laboratory had created the facilities for very early computer graphics developments and I trailed my younger brother Ivan there. Lincoln also through its work on the SAGE automated air defense computer systems had early interests in integrated circuit electronics. Bolt, Beranek, and Newman, Inc (BBN) happened to be the company where the Internet-precursor ARPANET was developed. The Xerox Palo Alto Research Center (PARC) was the source for the Ethernet, laser printing, modern bit-mapped graphic personal computers and the type of WYSIWYG software we all take for granted now. Sun Microsystems provided many of the early Internet servers and software middleware as the Internet grew rapidly in the 1990s. I have had a marvelous opportunity to watch and participate in many of these developments with an insider perspective.

I am also greatly indebted to the U.S. Government for an NROTC scholarship to RPI for my undergraduate BEE degree, for an NSF Fellowship and US Air Force support at Lincoln Laboratory for my MIT PhD, for the training I received to be a US Naval Aviator carrier pilot, and for research support for my projects during MIT and BBN years. I learned so much of value as a junior Naval officer—leadership, being individually responsible for outcomes as a natural course of action, and a real appreciation for the awesome difficulty of operating complex equipment reliably around the clock.

In conclusion, let me hope that this exposition of my research management experiences may be useful to someone, somewhere, sometime. I have enjoyed creating these memoirs and remembering for myself the good times I have had with the interesting colleagues with whom I have worked.