CREATIVITY AND INNOVATION IN A LARGE SYSTEM ENVIRONMENT: ︵A Personal Account︵

Amos Edward Joel, Jr.

Introduction

Receiving the prestigious Kyoto Prize is an occasion for great introspection. One wonders what have I contributed to the betterment of mankind to deserve this award? Why should I be so honored? There must be some mistake.

I have thought a lot about this. I have spent most of my life, since adolescence, becoming very knowledgeable about a subject little known to or of little interest to members of the general public. Yet they use it many times a day. In industrialized countries, where they are highly dependent upon telecommunications, it is an attribute they are acutely dependent upon but unknowingly aware of: switching.

Switching is my specialty. It has been that way since I was 10 years old. Switching is what makes telecommunications ubiquitous—as a result we may selectively call one another. A more familiar word is we can “dial” one another. Switching is needed whether we use the telephone, facsimile, telex, computers or any other means of telecommunication. We will need it for picture-phone (video) communication. Wherever there is selection there is switching. Even the remote control on your television set involves switching.

There are other functions, such as implementation of “connections” to establish paths representing the selections and “contention” for privacy. Insuring against intrusion into a connection is one of the most difficult design elements in switching. It has engaged the best minds since the earliest days. In fact, when shrewd salesmen attempted to sell early switches without provision for contention they were not at all successful.

Switching is accomplished by many cooperating elements giving rise to the term “switching systems.”

Nature of the Systems

There are many definitions of “systems.” One of the best comes from “An assemblage of structures in biology composed of similar elements and combined for the same general functions.” Never has this been more evident than with the present electronic switching systems composed largely of integrated circuit chips. Some systems, as with the human anatomy, evolve over very long periods of time. The systems about which I lecture today are different. They are composed of man-made technologies. As a result they may have evolved over a generation or two. As a result, I have had the good fortune of witnessing a great many changes, evolutionary changes, in my lifetime.

Eras of Technology

The tremendous changes in the elements of switching systems are not unlike those that have occurred in other industries—human labor replaced by machines and then machines replaced by information processing. These changes have been made possible by the progress of the technology.

There have been three major but similar technological eras in switching—and I have been privileged to have lived through a period that spans all three. I have observed the evolution from one to another. These eras are manual, electromechanical, and electronic switching.

With manual switching, human elements provide the intelligence and motor power to make the connections. Perhaps the greatest step taken in the evolution of switching was eliminating the need for operators.

Manual switching was replaced by electromechanical elements and the caller was provided with a dial to inform the switch what was required of it to establish the desired connection. The new field was then called “automatic telephony.” Deployment of this technology had just caught on about the time I was born and was in its infancy when I began studying switching. It took more than five decades for the manual switching of most calls to be replaced by automated systems.

The technology which has engaged my attention for the past 40 years has been the replacement of electromechanical devices by electronic elements. The transition from electromechanical to electronic switching is well along in most areas of the world, but may not be completed in some areas until well into the 21st century.

A Knowledge of History is Crucial

Truly dedicated artisans should be historians of their area of interest, career, or professional study. I have enjoyed not only studying and philosophizing about the history of switching but in a major sense feeling that I am a part of it. No place is this more important than in engineering. One should know what came before so that one can benefit from past experiences, good and bad. “Reinventing the wheel” in the context of a new technology may be useful.

The importance that I associate with the recording of history is one legacy I believe I am leaving to future students of switching. I have written articles and contributed extensively to a series of books on the history of switching in the United States, and I am jointly authoring a book for publication next year on the worldwide history of electronic switching.

Early in my quest for information about switching systems someone suggested that I examine issued patents in the field. This occurred when I was about 13 years old. By the time I completed high school, I had read and classified for my own use the information contained in several thousand United States patents on automatic switching systems.

Although by this technique I had acquired a great deal of knowledge about automatic switching systems, there was a lot that I did not really know and could not learn from the study of patents alone. Were the systems described in the patents ever built and placed into service? What were their costs? How were the systems engineered, that is, how were they applied to many different situations? I knew then that what I needed and wanted was to study engineering in college, electrical engineering. Where was the best place to study switching technology and engineering in the United States? At that time there was no place in America where one could study these subjects. (Even today there is a definite deficiency in the teaching of this aspect of telecommunication technology.)

At that time (1936) one hardly considered looking outside of the United States for an engineering education. There were several reasons: the cost, the transportation, and the curriculum. We knew little about an engineering education abroad. Later, I learned that the principles of switching, as they were then applied in specific countries, were being taught abroad. But even to this date it has not been possible to encourage faculty in the United States to offer courses even though authors, including myself, have written widely on such subjects.

The Massachusetts Institute of Technology (M.I.T.) had, and I believe still has, the reputation of being the finest engineering school in the United States. While they offered no courses in switching they had a very fine course in communication theory. Fortunately my grades in high school were high enough for me to be accepted at M.I.T.

More importantly, the spirit of creativity seemed to permeate the studies at M.I.T., reinforcing my own inclinations in this direction. Furthermore there was a freedom to write theses and prepare seminars on subjects of one's own choosing. Naturally mine were related to switching.

Entering M.I.T. was highly competitive. But more importantly, the tuition costs were very high and the country was in the midst of a depression. To aid in supporting my education I naturally turned to my subject area: I went to work in the dormitory's office where my principal task was to run the busy telephone switchboard. Here I learned things about telephone switching from the practical point of view. The money earned operating the switchboard helped with expenses, including the purchase of more copies of patents.

The difficulty of learning about switching in the United States was due, in large part, to the monopoly of AT&T. Not only did AT&T operate most of the United States telephone network but also manufactured and sold most of the equipment to its subsidiary telephone operating companies. They trained their own employees, generally on the job.

Perhaps the most important reason for this lack of formal education in switching was the lack of formal methods for describing switching techniques. Seeking more formal methods became an important pursuit of mine throughout my career. More of this later.

Up until the time of my employment there, training in switching even at Bell Telephone Laboratories, the world's greatest telecommunications research and development institution, was descriptive. This means that texts and courses were available for those interested in learning about specific systems and how they operated.

There was no attempt to extract from the vast sources of information about different systems the classification of knowledge and, deriving from that, the essence of system principles. Throughout my career I have tried with relatively little success to change this situation. As knowledge continues to accumulate in a subject, and this certainly has been the case over the past 50 years in switching, the greater is the need for digesting this knowledge so that it may be assimilated more readily by future generations.

What can you do besides switching?

Seeking employment in switching as my undergraduate years were coming to a conclusion was not as easy as I expected. Knowledge alone was not enough. A routine employment application to Bell Laboratories was turned down. They were not hiring. I applied for employment at other lesser companies designing and manufacturing switching equipment for the independent telephone companies and at railroad signaling companies.

Fortunately, the father of a classmate was an executive at Bell Laboratories. When he was told about me and my deep interest in and knowledge of switching, I was invited for an interview and eventually received a job offer. I accepted and thus began a happy and productive lifetime career of 43 years.

Technology changes at a rapid pace. Throughout a career spanning almost 50 years it is necessary to keep one's knowledge up to date and to retrain periodically. A good basic engineering education as a foundation is essential for this continuing education.

From the beginning of my employment at Bell Laboratories in 1940 I continually requested assignments where I would have an opportunity to demonstrate my ability to design switching systems. However, it was not then company policy to place new engineers in such responsible jobs. (How times have changed!) Therefore I was not given a switching system design assignment and perhaps in retrospect this was not a setback but an opportunity.

In 1941 I was asked to join a group engaged in the design of secret communication systems. Hidden in these systems were cryptographic key generators that required the application of complex logic circuits similar to those used in the control portion of switching systems. I became a cryptanalyst. In the course of this work I received several patents demonstrating my creativity in a different area.

When some of this work was completed many of my associates returned to the design of switching systems. I was invited to join the group and started to design a very important part of a new electromechanical switching system, known as the No. 5 Crossbar System. For various related reasons, this assignment was aborted. Here I was so close to what I had always wanted most to do and yet now it was taken away.

Instead I was assigned to design electrical computers. While this made full use of my circuit design creativity, it did not at the time appear to be leading toward my goals. This experience with computers later turned out to be most useful, actually, essential, to the furtherance of my career.

Working on cryptanalysis and computers had also given me an opportunity to associate with more professional people. Creativity does not always appear in theories or in the implementation of inventions. As indicated earlier, since my college days I had been dismayed by the lack of training opportunities in the principles of switching.

Having considered this deficiency for some time I proposed to Bell Laboratories management that a formal course in switching be developed to be given to new and offered to older employees in this area. I outlined the contents of a course that approached the subject from a philosophical rather than descriptive level.

My proposal was made at a time when Bell Laboratories was looking for ways to familiarize many new engineering recruits with the switching area that was recognized as being vital to future progress in telecommunications. It was adopted and along with several other engineers I was assigned to develop the course, writing the text, and teaching the first classes.

This approach to teaching switching was so successful that it was later expanded to other telecommunication technology subjects. While the course was my idea, I did not benefit directly from its success. Here was a career crossroad. Do I stay and repeat and refine what I started or move on to new ground?

I chose the latter and returned to designing special purpose computers for telephone billing applications. I was getting closer to my ambition of designing switching systems. Here I was designing complex circuits of the type and quality used in switching systems. From this I learned about some newer technologies, but more important I was challenged to design the most complex logic circuits. The result was a very large machine, the patent for which was at the time the largest issued in the United

States both in terms of the number of sheets of drawing and specifications and in the number of claims.

Inventors vs. Professionals

Since Bell first made his telephone and before with the telegraph, the inventor alone or with one or two partners, was the principal player on the field of telecommunications. Those inventions that became accepted products were eventually taken over by companies that continued to improve and expand their sales. However, the inventor continued to dominate sources of new ideas. The inventor was king. The designs emanating from their companies were largely the products of persons made from the same mold as their earlier brethren, the lone inventors. Relatively few of these switching designers were college graduates.

It is interesting that this condition did not exist with engineers working with telephone transmission. Here the more scientific attitude approach existed. As a result, many of the advances in transmission were founded upon more formal techniques. The reason for this is “measurability.” With the background of very cogent mathematical theories, the quantity and quality of telephone connections became measurable very early in the commercialization of telephony.

The differences between the more scientific approach and professionalism in telephone transmission and the lack of it in switching piqued my attention. Transmission was truly looked upon as a profession in engineering and the other, switching, as an art presided over by skilled artisans or inventors.

An area closely allied with switching that has yielded to theoretical methods is known as “teletraffic.” Teletraffic deals with the quantity of switching equipment and facilities needed to provide a desired quality of service relative to the simultaneous demand for switched connections.

To a lesser extent, computer technology and techniques have also had an influence on the formalization of switching. In the control of switching systems, a special branch of computer technology is generally applied. It is a question as to which came first. Ask a computer technologist, and he will say that they first studied and formalized these techniques. Ask a knowledgeable switching expert, and he will say that they first encountered and laid down principles for these techniques. One problem is that, even today, there is little cross-fertilization between these fields, where I believe more progress could be made if they could only get together and speak the same technical language.

Broadly speaking, switching still lacks “measurability.” However, switching can now be called a profession. Most of those entering this field have a college education, many with advanced degrees. I believe through meetings sponsored by professional societies and the growth of computer technology, switching has gradually been looked upon more favorably.

Early in my career, being young and idealistic, I had hoped that switching would soon advance to the same stature and become more formal. Unfortunately it still hasn't happened. But there has been much progress.

One of the problems is that we may not have achieved the optimal mix between inventors and professionals. By this I do not wish to imply that professionals are not creative, but that their scientific approach is more evolutionary than the way the old-time inventors would have approached a problem by jumping off the beaten path.

Creativity and Keeping Abreast of the State of the Art

At an early age my curiosity became so great that I read almost all of the literature that was available on the subject of switching. When these sources were quickly exhausted I turned to reading copies of patents on this subject. This opened my eyes and brain to a whole new world of invention. It stimulated me. It was then that I discovered this driving energy to create, to move forward from the state of the art with which I had become well acquainted.

Since then, I have always felt driven by a desire to create. I seldom give up on a technical problem. When I cannot solve a problem, I bury it in the back of my mind. Here it waits hoping that someday a specific event or unintended analogous creative opportunity, sometimes called a creative stroke, will unlock the way to a solution.

I developed a habit of reading all that I could about switching. While the literature grew, I grew with it and kept track of it. Today we use computer data bases to assist in this process. My advice to those in a particular field is to be sure they continually become aware of and follow the literature in their field so that they become entirely familiar with the “state of the art.”

Avoid the "Hype"

As part of this process one should develop a feeling for which authors and institutions provide the most useful and reliable contributions. Today competition among the manufacturers is so intense that it has stimulated the making of many spurious claims or "hype" associated with quasi technical information about switching systems.

This is contrary to what I encountered during my career as electronic switching was developing. Then there was much cooperation in the industry and progress in many areas was based upon mutual trust and the interchange of inventions.

Competition becomes more intense when new technologies result in new products coming to market. We had a similar period in our industry when automatic systems replaced manual systems. Some believed this was a revolution while others were more in favor of evolution where semiautomatic systems were introduced and operators would dial your calls for you. I predict these days will return in a future generation when voice recognition will replace a dial or calling device.

How have Switching Systems Changed?

The changes I have seen have not only been in the technology of switching but in the many functions switching systems are required to perform. No longer do we have in the industry what those of us who look back like to call "POTS": plain old telephone service, whatever that was!

What was "POTS" when I started is different from the present. Today we expect things like push button dialing as part of the basic service.

Today, to meet various service needs, there are many types of telephone calls, each of which is processed differently one from another. Furthermore, the functions required differ from market to market, making it necessary for a manufacturer to have several switching system products or be able to adapt the same system to many different sets of requirements.

One switching system cannot serve the world. There are one or more serving each geographical area. They are interconnected and work cooperatively to enable one to reach around the corner or across the world. The switching entities and their interconnections are known as “networks,” a term which in our field has several defintions.

Telecommunication networks with switching hubs or nodes have become large and complex—but they were not always that way. The vital necessity of telecommunications in modern commerce has spawned many new and useful services, the provision for which can only be implemented in switching systems or adjuncts thereto.

The complexity of the switching systems and the networks of which they were a part grew. As networks grew, the complexity of the service offerings grew. Once nationwide and worldwide dialing began, the networks became giant specialized computers.

We have all been captivated with computers and how they have contributed to human progress. They have taken over much of the drudgery of routine tasks and facilitated the storage of vast quantities of information.

Today, switching systems form the most sophisticated and complex network of computers. Each switch has thousands of terminals, which must process thousands of simultaneous calls, and must continue to function even when a component fails.

How the Individual Contributes?

I have already indicated that it took 7 years of employment before I was finally given an assignment designing switching systems. A few of these years were due to wartime assignments. However, it was good that I had this exposure to other fields and they certainly had a positive influence upon the remainder of my career.

Being at the right place at the right time is a cliche but there is much truth in it. Imagine being at Bell Laboratories in 1947 when the invention of the transistor was announced. What a challenge to the inventors in many different areas! Many of us said this was the technology needed to move switching into a new orbit. While there were experiments with electronic switches for years it was economically unsound to replace a simple relay or switch contact element with a vacuum or gas filled tube. Also the tubes used much more power than the semiconductor transistors.

Not only was I fortunate to be at Bell Laboratories then, but perhaps because my previous successes were well known to top management and because I had this burning desire to design switching systems, I was assigned to a small group given the task to explore the application of the new electronics to switching.

What a break! Perhaps if this had not happened I would not be before you here today! It took four years of exploratory work before we were finally convinced that we could and should build an electronic switching system.

There was intense internal competition within the company, between those still working to improve and extend electromechanical switching and those of us who were off into the new world of electronic switching. Furtheremore, I was most fortunate, since most of those assigned to electronic switching were more knowledgeable in electronics than switching. Because of my knowledge in the switching field I was placed in charge of the system planning where I could use to the fullest extent my knowledge in switching, computers, and electronics.

Electronic Switching Turns Out to be Something More

A whole new era and, to some extent, an unexpected era was opened when electronic technology was applied to switching. It was my good fortune to be there as it was happening. It is not unusual for one not to recognize a change in direction of an industry while it is occurring. That is why I say electronic switching turned out to something quite different than expected.

I will not repeat here all of the details of the history of my association with electronic switching. These have been well documented. But I must mention the most important event associated with these very early days of electronic switching. In 1955 an innovation was made applying the computer technique of programming to the realtime requirements of a switching system. This technique was given the title “stored program control” or “SPC.”

At that moment the adoption of this technique was important to the solution of a specific design problem for the electronic switching project. It required a technological breakthrough that accompanied the SPC concept.

In retrospect it turned out that SPC eclipsed the application of electronics to switching system design. It added to switching the whole new dimension of software. It created a revolution in switching. No longer were systems confined to processing simple telephone calls and making simple telephone connections. The great sophistication that is now beginning to permeate the world of telecommunication can be directly attributed to this aspect of switching system design. The inventors of this concept are William Reister and Al Budlong. Except for their place in history books their contribution is not recognized by the many in the industry throughout the world today who apply and benefit from this concept, even at Bell Laboratories.

Individual Contributors Harder to Identify

In the past you could name the inventors of various switching systems. The industry knew them. Their compatriots knew them. They were not written about nor did they receive awards. Certainly no one in switching received an award in those days.

When a new switching system was introduced, perhaps one omnibus paper would be presented before a professional society, not by the inventors, but by the top management people of the company. Fortunately, this is no longer the case today.

While changes have come slowly it is safe to say that professionalism has finally come to switching. Receiving the Kyoto Prize certainly epitomizes the truth of this statement. In the past 15 years the contributions of a number of switching engineers and leaders have been recognized by various organizations.

Now most published papers are by the individual contributors. Also the papers are more comprehensive. The managers now make their published imprint upon a new system by authoring a preface to a volume of papers by the specialists.

Years ago, at the time switching systems were just becoming automated, the individual inventors understood, and in a few cases, designed entire systems. They could tell you about the design choices for each element of the system. The skills of the individual inventors could encompass the technologies of entire systems.

They were so skilled they could explain how each and every part of a system worked. The growth in complexity has changed the creative process of these complex systems. No longer can the lone inventor, as I was in my youth, design a complete switching system.

We have moved from the generalist to the specialist. We have specialists in the many system elements of hardware and software; chip design, microprocessors, memories, physical design, tools, operating systems, call processing, diagnostics, etc., and the list goes on. Hundreds, even thousands of skilled engineers are needed to develop a single system.

Recognition of individual contributions changed at about the time electronic switching started. Companies began investing larger amounts in the development of new switching systems. Today, the estimate is one billion dollars.

Electronic switching systems use high technology in common with many other industries, particularly computers. There is greater integration and, to some extent, interdependence among the system elements. Software for a system is divided into many small portions that are assembled into the program for a complete system. Therefore, it is now difficult to identify significant individual contributions to a system.

Today there is no one who knows the details or even the rationale for most of the design choices for a particular system. One disappointment of a lifetime of searching is the lack of analytical tools to prove the advantage of one system organization over another for a fixed set of requirements.

How does a specific type of call progress through the cooperating hardware and software of a modern switching system? To find out one must refer to the detailed information to which many have contributed. Whether a specialist or a generalist, one cannot be expected to know everything. My experience has been to know the best sources of information and to utilize them without hesitation.

Today one of the most important aspects in the development of modern complex systems is in project management. Highly qualified and motivated professionals with experience in this field can make the difference between success and failure of even the most creative and innovative system design.

After being associated with the exciting birth of electronic switching I moved on, applying electronic switching to systems where the judgement of operators is still needed to aid in the processing calls. Also, I developed the first automatic call intercept system. This system is used to inform callers that the telephone number that they reached has been changed.

Now a crucial point was reached in my career. Did I wish to continue as a manager of such extensive switching developments with hundred of professionals working for me or did I want to direct my talents toward my interests in the technical aspects of switching? I looked upon this decision as one of choosing between specialization and generalization. I chose the latter. Why?

What it Takes to Create?

I decided my devotion to switching was greater than my desire to deal with budgets, manpower reports, and schedules. Ever since I entered engineering, I was aware that, unlike those in other professions, engineers on the average are paid less, unless they pursue the higher management roles. My desire to create was stronger than my desire for managerial advancement. Many of us choose this profession because our way of benefiting mankind is to create material things. Engineers reduce concepts to practice.

My choice was to continue in engineering. It was the best decision I ever made. It was a time when the technology and the field of telecommunications was changing rapidly. Of particular importance was a characteristic that is inimitable to switching. The complex logic circuits that originally captured my imagination were inherently “digital.” Now integrated circuit digital technology was attracting considerable attention, being applied not only to computers but to telecommunications transmission.

The buzz word was “integration” —not only in the semiconductor technology but also between switching and transmission and in new digital services. Japan is one of the leaders in introducing integrated services digital networks.

All paths one takes through a lifetime career are not straight. Being a generalist and having much background in our corporate stance in switching over several generations, I was chosen on several occasions to assist lawyers in preparing material to defend AT&T. Unfortunately, this took much time, and as some managers have said to me, “Think how many more inventions you might have made had you not been diverted to apply your knowledge to this important corporate legal work.”

In recent years I have been teaching these concepts and I still feel the drive to invent. In addition to the digital technology, optical technology is another newcomer to our field. Here again there are many new opportunities to integrate optical fiber transmission with switching. There are so many exciting new opportunities for the young creative person. Although I wish I was starting over, I am glad that, even in retirement, I have been able to continue with my lifetime vocation and avocation.

It has given me a chance to travel and meet people, particularly those in the same profession. I look forward to the workshop tomorrow where I will meet many

Japanese friends and those with whose work I am familiar through their writings.

I am frequently asked, "If your inventions have been so numerous and beneficial to mankind and to your employer, why are you not very wealthy?" Of course it is not just a cliche, when I say that I am very happy, content, and well compensated knowing that I have contributed something to mankind. As I said earlier, one must not forget the many highly creative professionals who "put meat on the bones" of the basic switching systems ideas that I have conceived.

Creativity cannot be taught. The stresses of deadlines may, for some, stimulate creativity. Creativity cannot be delegated as easily as some managers would like. There is something innate in one's creative ability. One can, however, provide an environment for creativity. Modern well-equipped laboratories such as the one where I spent 43 years of my life have done this exceedingly well. However, we know that some inventors have done their good work in poor surroundings and with inadequate facilities. But what more might have been accomplished if they had the best? Edison is a good example of this.

Ever since a telephone installer came to my home in 1928 to add a dial to the telephone I had this drive to study and design switching systems. It started as a hobby, but the more information, or lack of it I had, the greater was my drive to learn more about the subject. My avocation became a vocation when I was hired by Bell Laboratories. Here I was paid to invent.

Little did I know that my inventing would lead to this considerable recognition in Kyoto. I appreciate the opportunity that winning this prize has afforded me to convey to you today some of my thoughts on creativity in a systems environment.

I wish to thank Dr. Inamori for establishing these awards, for the broad concepts they encompass, and for what the Kyoto Prize medal stands. There are very few opportunities where engineers and technologists are recognized for their accomplishments. The award will be most useful in permitting me to attend professional meetings the world over without worrying about sponsorship.

I would like to close this lecture by again addressing the younger generation. Keep abreast of technology. Know the field well enough to anticipate future directions and needs, even though these are likely to be a moving target. (I have a record of an invention made in 1948 that did not become economically feasible until 1977.) Be sure you are working at something you enjoy, and to which you can contribute, and with peers you respect.