*Commemorative Lecture: The 2005 Kyoto Prize in Advanced Technology*

# A Moveable Feast

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It is indeed a great honor to become a Kyoto Prize Laureate and join such an elite group of current and previous recipients. All of us have silent aspirations as we pursue our professional careers, but to me, the Kyoto Prize was beyond my wildest dreams and aspirations. I wish to thank Dr. Inamori, once again, for his vision in making such a magnificent and inspirational contribution to the world of arts and sciences.

The author and Nobel Laureate, Ernest Hemingway, once wrote that to be in Paris in the 1920s was like a "moveable feast". In a different time and a different place, I experienced the same excitement and, indeed, a moveable feast as I pursued my professional career.

**In the Beginning – Building a Foundation**

I was born in Philadelphia, Pennsylvania in a section of the city that consisted of small, connected houses occupied by families like mine consisting of fathers who worked in the factories and mothers who raised the children at home. Few of the families had fathers or mothers who went to college. My family was not an exception to this family profile. My father, at various times, worked in the factories and when manufacturing moved to the Southern part of the country or closed completely, he worked as a janitor. My mother was a housewife except for the years my father was in World War II when she worked in a small store in our neighborhood. They are now both deceased but I know that they are still proudly looking down on my career and are with us today.

I was an only child but not a lonely child. I had no brothers or sisters but there were many children of my age that lived on our street.
I was intensely interested in competitive sports – basketball and baseball in particular. We started to learn and play in the streets, because in those days, our neighborhood was relatively free of automobiles because there were few families that could afford one. As I grew, we began to play in the schoolyard. As my skills increased, it became more structured and competitive and we moved up to playing in real ball parks and gymnasiums in real leagues. Of course, all of us just knew that we would be professional athletes some day.

I played competitively until I was 33 yrs. old when I was hit in the head by a fastball (no batting helmets in those days) and lost my memory. It was a frightening experience but fortunately my memory returned over a period of days. My wife had been telling me that I was getting too old to play against men who were much younger than me. This incident convinced me that she was right, and I never played competitively at that level again. I was involved in liquid crystal display research at the time and decided it was much safer.

My mother was a devout, Bible reading Christian. She came from a large family of 3 sisters and 5 brothers and, as the oldest, she served as a surrogate mother to her brothers and sisters after her mother died. She was forced to leave school in the 8th grade to help support the family. She never graduated from high school, but she had a strong understanding of the importance of an education. She was a frugal woman and a good cook except for the fried beef liver that I was forced to eat about once a week because it was supposed to be "good for me". I was told that there were hungry children around the world who would be so happy to eat it (or so I was told)! Mom would use my father as our model for healthy eating. "Look at your father", she would say. "He eats everything on his plate", and, indeed, he did. It took me more than a little time to deduce that the reason that he ate everything was that mom never served anything that he didn't like.
Our house was old but it was kept clean and neat by her constant efforts. My father always said that we could eat off our floors because Mom kept them so clean. We believed it, because in a German household, my father had said it was so. Needless to say, such an experiment was never performed.

School work and earning good grades were very important to them. Dad would help me with arithmetic and Mom would teach me spelling and composition. This was done in a manner that was like a competitive game and focused on stretching me beyond what was being taught to me in the public schools of Philadelphia. Mom and Dad were able to do this until I entered high school and the subject matter was beyond their limited education.

My father grew up in an immigrant German family of three sisters and a brother. He, too, left school in the eighth grade and never graduated from high school. Like my mother, he had a strong appreciation for the importance of higher education. He was often laid off from his jobs in the local factories but he always quickly found another one so that we never suffered. He took me to ballgames, airports, and local train stations to see these places in action. During the summers, we would attend church and then go immediately to a Philadelphia Phillies major league baseball game carrying a lunch that my mother had prepared for us the night before. After a year or two of this, my mother decided to go to the games with us and became a dedicated baseball fan. Like other families who lived in our neighborhood, we did not own a car. We had to change trolleys three times to get to the ballpark and we waited in long lines for the least expensive tickets because that was all we could afford. I guess today, people would say that we were poor but we never thought about things that way.

Besides the usual events of childhood, playing with friends in the street, and going to school, the most unforgettable events during my childhood were the years during World War II when my father served in the armed forces. He was in just about every major invasion in the Pacific beginning in mid-1944. I learned geography from the maps of the Pacific theater that hung on my bedroom wall. My mother lived in constant fear that my father would not return from the war. Every piece of news resulted in finding the battles on the maps in my room and praying that my father was still alive.

I have a very special memory of my father during those years. I was a little boy who always looked forward to the model electric train display that my dad would assemble for me at Christmas time. However, this Christmas was going to be different. My dad was away in the war in the Pacific Theater. Just thinking

about the fact that there would be no model trains with which to play until the war was over and dad came home was a major disappointment to this little boy. But imagine how thrilled I was when my uncle told me that my dad had sent him a letter telling him that the gift he most wanted to give was that model train display that he worked to give me each year. My uncle decided that he would build the model train display as a war time gift to my dad so that dad could give it to me. This occurred almost 60 years ago but I'll never forget that very special gift from my dad in the midst of war and the love for me that it exemplified. My father eventually came home after fighting in battles that are now part of the history books of that period. Many other fathers, both Japanese and American, never came home but they will live forever in our hearts and memories.

**Choices and Guidance along the Way**

While growing up, it seemed that I had a different job in mind at each grade level. These included a naval officer, a pilot, a train engineer, a professional baseball player, an FBI agent, a high school physical education teacher and coach, etc., etc. These career visions were usually driven by the latest movies I had seen. I became interested in engineering as a senior in high school. I had won a full tuition scholarship to several universities but my family could not afford the cost of room and board. The University of Pennsylvania was in Philadelphia and I could live at home and commute to school so I accepted their scholarship offer. I was still interested in majoring in physical education and coaching but since the University of Pennsylvania did not have a physical education major, I had to select another major. Guided by my father, my teachers and my interest in math and science, engineering was selected because there were good job prospects that offered challenging work, job security and a good salary. These were quite important given the environment in which I lived and the experiences of my "blue collar" family. Electrical engineering was my choice when I learned that electrical engineering did not require courses in engineering drafting since I did not excel in this area in high school.
Actually, selecting engineering as a field of study was a low risk decision.
I have seen engineering studies form the basis for careers in pure science,
medicine, education, banking and finance. Successful engineers are
usually knowledgeable in several fields. In my view, engineering, more than other fields, depends on the harmonization of diverse fields of knowledge such as physics, chemistry, mathematics, computer science, management, economics and yes, common sense. Engineering requires an analytical mind and is an output oriented profession. In my opinion, one is not truly practicing engineering if one doesn't have at least one application in mind. It may not be the only or ultimate application but, nevertheless, one must keep at least one application in mind. To be successful, the engineering profession requires a systems perspective to address the questions of how one's work fits into a complete system. How can it be made to fit and what is the real value of the work to the user? Yes, engineering may have been the lowest risk choice but it has proven to be the right choice for me.

I was strongly influenced by Armin Saeger, my high school German language and algebra teacher. He taught me beginning in the 9$^{th}$ grade. He was a stern but brilliant man with broad interests in history, languages, the arts and mathematics. It was he who guided me into areas beyond the comprehension of my parents. It was he who thought that I had a strong, analytical mind that should be applied to the sciences

and engineering and not physical education and coaching. I recently learned that this truly intellectual high school teacher had played a similar role with my deceased mother's cousin approximately 25 years before my high school years. This, to me, was a remarkable coincidence.

Later, during my doctorate studies at Princeton University, it was Professor George Warfield, my thesis advisor and mentor, who, among other things, shaped my view of research and development with his elegant, first principles approach to problems. When I reflect on my graduate education at Princeton, there are several things that standout.

1. The importance of developing a fundamental, first principles understanding of technical issues, assumptions, processes and procedures.
2. Second, the intellectual breadth of the graduate student body and the interdisciplinary interactions that were fostered and enabled by living on the Princeton campus in the residential Graduate College environment.

But there was something else that happened while I was at Princeton. I married a girl that I met at our neighborhood church in Philadelphia. She sang in the church choir and played the piano and I couldn't keep my eyes off of her as I sat in the church pew. I must admit, however, that at times, my attention to the worship service suffered. Our daughter, Beth, has given us three grandchildren who are all good students and fine athletes. Nevertheless, like their grandfather at their age, they seemingly have no interest in becoming engineers. In our 44 years together, I have learned many things from my wife.But perhaps the most important of these is that love is something that must be given away in order to keep it.

When I reflect on my days in high school, there were several books that influenced me. The first, however, was a book that I read when I was beginning high school. The book was All Quiet on the Western Front. This was a book about young German university students who became soldiers in World War I. I learned that soldiers on both sides loved their families and were homesick. Reading this book in the wake of World War II gave me a deeper view of our former adversaries as human beings just like us. As I mentioned previously, my father participated in just about every major battle in the Pacific after mid-1944. He respected the Japanese soldier but I was a captive of the views of the American media until I read All Quiet on the Western Front.

The Bible has also had a shaping influence on my philosophy of life, particularly Ecclesiastes 9:11. This was my mother's favorite passage as well. It reads that -
The race is not to the swift or the battle to the strong, nor does food come to the wise or wealth to the brilliant or favor to the learned; but time and luck happen to them all.
My mother would add that the harder I worked, the luckier I would become.
This has been a key aspect of my professional career and my life. I know that there are many scientists and engineers who are far more intelligent than me, but I refused to be out-worked.

An event that further shaped me spiritually occurred when I was serving my church as a young man. I was trying to help an elderly couple who had no children and no other family who were trying to enter a

retirement home. They had been told that this was not possible because the wife was incontinent and could barely walk. To be accepted, she had to walk through the door of the facility. The evening before the final decision, she was crying because she knew that her condition and the inevitable decision was going to deny them entry. Her elderly husband tenderly took her in his arms and said to her, "Don't worry sweetheart, things will be alright." The next morning she was able to walk into that retirement home with little evidence of her previous condition and they both were accepted for entry. This still can bring a tear to my eye whenever I recall its impact on me. Faith can, indeed, move mountains.

**Careers along the Way**

It seems as if I have had a new career for each decade of my professional life. After graduating from the University of Pennsylvania, Moore School of Electrical Engineering, I began my research career at RCA's David Sarnoff Laboratories in Princeton, New Jersey. My first projects were in solid state traveling wave parametric amplifiers, solid state millimeter wave generation and tunnel diode down converters for television applications.

In the 1960s, my primary research focus was electro-optic effects in nematic liquid crystals and their application in reflective liquid crystal displays (LCDs). This is the principle work for which I have been honored.

In the 1970s, my professional interests were the application of advanced technology in systems applicable to national security. As director of the Advanced Research Projects Agency, our focus, among other things, was on technology to make aircraft "invisible" to radar and technology to make the oceans "transparent" in the search for submerged objects and undersea vehicles.

In the 1980s, I was Senior Vice President and Chief Technical Officer of Texas Instruments directing, among other things, efforts in the design and processing of CMOS integrated circuits, infrared imaging technology, and display systems such as the digital light projection system based on arrays of micro mirrors. This approach to projection displays is currently a leadership product in this domain.

In the early 1990s, I decided that I wanted to be the president of my own company. I assumed this role in 1991 at Bellcore, a company that developed and deployed the software systems that operated the local telecommunications networks in the United States. Bellcore (now named Telcordia), became a billion dollar company that I sold in late 1997. I became Chairman Emeritus after the sale and began my current career as a corporate director, Chairman of the General Motors Science & Technology Advisory Board, and a member of various other technical advisory boards including the Board of Overseers of my alma mater, the School of Engineering and Applied Science at the University of Pennsylvania.

The principle work for which I have been honored is the pioneering work we did in the 1960s in discovering several new electro optic effects in nematic liquid crystals and applying this work to the first liquid crystal displays. My interest in liquid crystals began as a result of my interest in the physics of electro-optic in solids that could be used to modulate the light from a laser. Lasers had begun to emerge

from reseach laboratories and the ability to modulate laser light for commununications applications was still a major challenge. I had finished my dissertation on the electrical properties of organic semiconductors and was convinced that they would not make useful transistors. Nevertheless, I was intrigued that no one had done extensive research on their electro-optic properties. The fact that, unlike inorganic materials, one could modify the composition of organic materials more readily made them of special interest to me. I rapidly learned that this approach to new solid state electro-optic light modulators was not as productive as I had thought and I turned my attention to another class of organic materials – liquid crystals.

This work began in the early 1960s but was not released to the public until a 1968 press conference that drew worldwide attention to the potential of LCDs. We discovered five new electo-optic effects in liquid crystals and demonstrated prototypes of several LCD devices including alphanumeric displays, an electronic clock and an electronically controlled liquid crystal optical shutter or window. People were fascinated by the seemingly contradictory name, liquid crystal, a material that had some of the properties of a liquid, e.g., it poured like a liquid and filled its container as a liquid does, but also had some of the properties of a crystal, e.g., over a temperature range determined by its molecular structure and composition, its molecules exhibited alignment somewhat similar to that of a crystal. The application of a voltage to a "sandwich" consisting of two pieces of glass with transparent conducting electrodes containing a nematic liquid crystal material exhibited some unique properties that made possible low power, electronically controlled, reflective displays addressable by integrated circuits. While we understood the potential of liquid crystals in displays from the very beginning, the emergence of the flat panel liquid crystal television had to wait almost 20 years before integrated circuit technology achieved the required level of complexity to perform the matrix addressing function that was to replace the electron beam addressing in television picture tubes of that era.

One of the most memorable comments on our work came from Dr. Vladimir Zworykin, an Honorary Vice President of RCA, and the pioneer of black and white television.

After viewing our first liquid crystal displays, he asked how we came to discover so many new, important electro-optic effects. I replied that we "stumbled" on them. His unforgettable reply was, "Stumbled, perhaps, but to stumble you must be moving". Indeed, we were moving.

I left RCA Laboratories approximately two years after our first public announcement to serve, what I thought would be, a one year term as a White House Fellow in Washington, D.C. I had become disillusioned by the slow progress in commercialization of our discoveries at RCA and I needed a change. I had lost my passion and excitement for liquid crystal display work and it is my view that when your passion and excitement for work in a technical field leaves you, you should leave the field with it.

One year as a White House Fellow turned into a six year stay in the federal government in several high level technical leadership positions.

In retrospect, perhaps our team, suitably augmented, should have been given the responsibility for developing the business opportunity as well as advancing the technology. We were the ones who saw opportunities instead of problems; the ones who had no vested interest in the status quo. History seems to indicate that technical breakthroughs are the result of a small group of capable people fending off a larger group of capable people with a vested interest in their current views.

If one subscribes to this theory, it is perhaps not so surprising that the Polaroid process was not nurtured by the largest photographic supply company in the world; that most of the vacuum tube companies were not successful in the transistor business and office copiers were not pioneered by the giants of the office equipment industry.

If our team had been expanded and given the responsibility to develop the business opportunity and advance the technology, perhaps I would have had only two "careers" rather than five.

**The Final Chapter?**

My family tells me that I have failed at retirement. Science and technology are my hobby and who can "retire" from their hobby? In addition to my positions on the boards of directors of several companies, I serve on the Board of Overseers of the School of Engineering and Applied Science at the University of Pennsylvania, the Defense Science Board and I chair the Science and Technology Advisory Board of General Motors. At General Motors, we are currently working on a science and technology investment strategy that will introduce new technologies more rapidly and efficiently into their future vehicles. As Chairman Emeritus of Telcordia Technologies, my former company, I have interests in several technical projects but I have a special interest in helping people manage expectations for integrated, all-packet, broadband networks by separating the myths about the subject from the realities.

In my so-called spare time, I try to keep abreast of the technical literature in computers, networks, software, information systems and VLSI. I still have a strong interest in exercise and physical fitness and enjoy reading history.
In addition, I still enjoy watching my favorite professional sports teams on television and yes, I think that Matsui and Suzuki are great major league baseball players.

Creative work has always been a major part of my professional life. I have always viewed my professional creative challenges as a game, a competition, an extension of the sports of my younger days. To be good at this "game", there are many subtleties that give rise to different approaches that match different types of people. I personally feel strongly about the following necessities:

1. Understand the fundamental physical aspects that underlie a problem. This is particularly important as mathematical modeling and simulation become more important. One must understand what the numbers mean to understand and read the "weak signals" that may suggest new approaches and directions.

2. Thoroughly understand what you are trying to do.

3. Understand how the problem is being approached today and the limitations of these approaches.

4. Understand what is really new in your approach and why you think it might succeed.

5. Understand the impact of success and why the solution is important.

6. Approach each challenge with a passion for understanding, insight and success.

This has been my "catechism." There are other approaches to creative activity in the sciences and engineering that may be a better framework for others. I obviously did not enter my scientific and engineering career in one of the more traditional or conventional ways, hence, it should not be a surprise that my personal "catechism of creativity" would not be conventional or traditional.

Niels Bohr, a Noble laureate in physics once said, the predictions are always difficult especially about the future. I would add to that by noting that is great deal easier to predict the future than it is to change the past. In my life, I have no interest in changing the past. Because, as Charles Kettering once said, I am interested in the future, because I intend to spend the rest of my life there.

In closing, I would like to dedicate this lecture to my family and to the memory of my parents.

Based on the road that I have traveled, I believe you understand why I have chosen to do so.