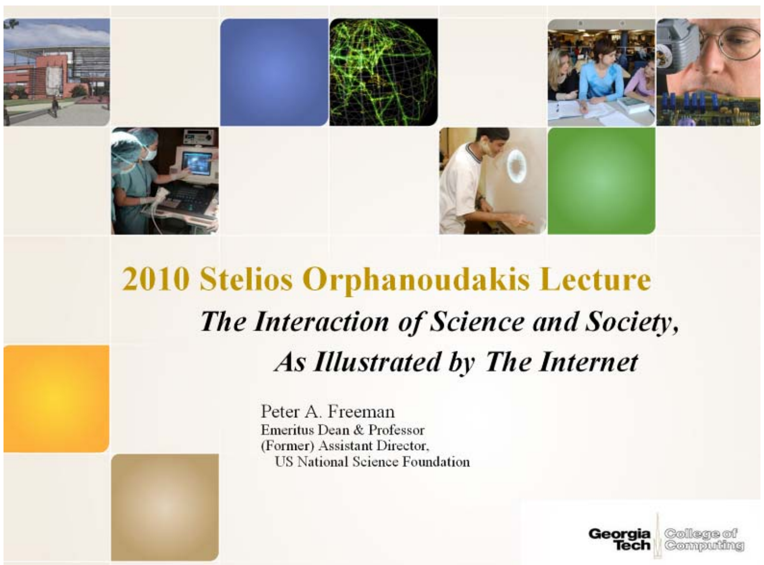
The Interaction of Science and Society,
As Illustrated by The Internet

Stelios Orphanoudakis Lecture

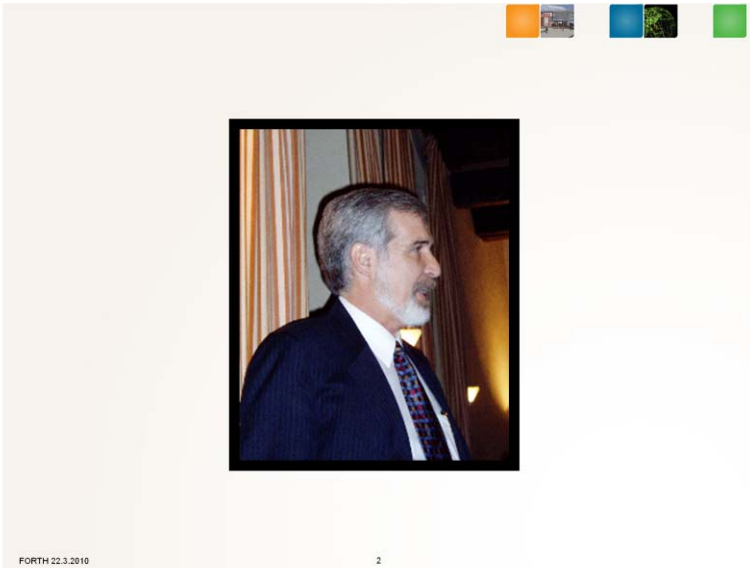
Prof. Peter A. Freeman
March 22, 2010



INTRODUCTION

Good afternoon!

It is a distinct honor and pleasure to deliver the 2nd Stelios Orphanoudakis Lecture. I had the pleasure of meeting and working briefly with Professor Orphanoudakis in 2003/2004 when I was at the U.S. National Science Foundation and he was Director of FORTH and Chairman of its Board of Directors, as well as President of ERCIM, the European Research Consortium for Informatics and Mathematics. My wife and I were seated with him at a banquet at which he was inaugurated as the President of ERCIM and I took this picture of him.



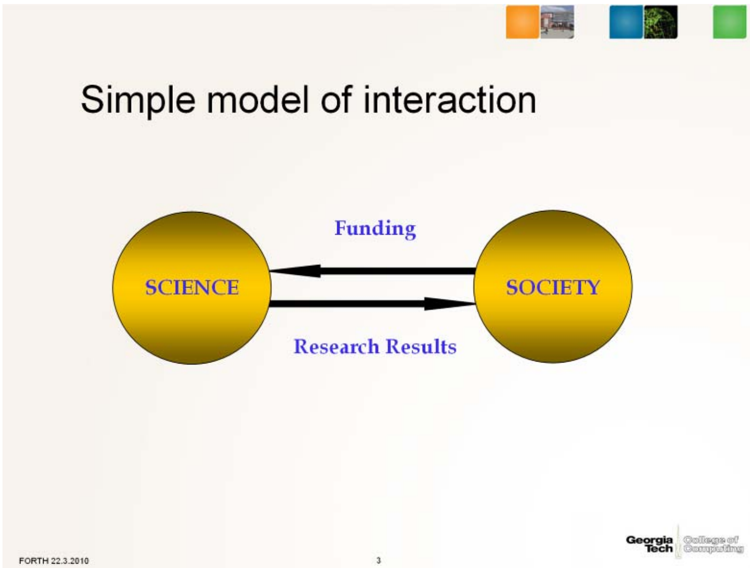
His death was a tragic loss not only for FORTH and for his loving family, but also to Greece, to computer science and to science broadly. He represented the best of our colleagues – an outstanding researcher who chose to work on problems of importance to society while also willingly accepting leadership positions that helped others in their endeavors. Nothing represents more clearly this dedication to helping others than his return to his birthplace – Crete. He was engaged in an outstanding research career at one of the world's great universities – Yale – when he chose to come home. As his lovely wife, Ava, has shared with me, he said that he "had to go home to help his people." He did that and the results will long be remembered. It is humbling to be asked to help honor such a great man.

My lecture this evening is one that Professor Orphanoudakis could have given and I'm sure he did in some form many times. My basic message is that science and society are more tightly intertwined than most scientists – or members of the public – realize, and that we scientists need to act on this fact – as does the public. To illustrate what may seem like a rather dry subject, I want to tell you a story – the story of how the Internet came to be, where it may be headed, and what we can learn from this story that may be of value in our own work.

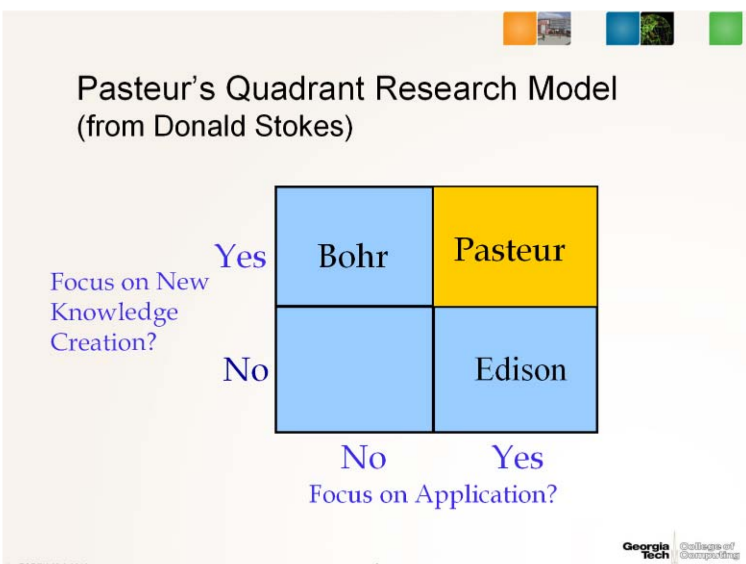
SETTING THE STAGE

Before talking about the Internet, let me set the stage for my later remarks on the interaction between science and society.

We all understand that science today depends heavily on society for resources to pay our salaries, buy our equipment, and pay for experiments. Similarly, most people in society understand that a large part of modern life in all spheres is dependent on science. Beyond this simple mutual-need relationship, however, most do not see a much deeper relationship.



There are a number of studies of the interaction between science and society, although they are largely unknown to working scientists. One that is current, quite readable, and very pertinent is the late Donald Stokes' *Pasteur's Quadrant*. In it, he develops a simple characterization of different types of scientific research that is portrayed in this simple diagram:



Stokes uses the great Danish theoretical physicist, Niels Bohr, as the exemplar of science for science's sake – research that is driven internally by questions that arise from research. Astronomy, most of theoretical physics, much of mathematics, even parts of theoretical computer science fall into this quadrant.

At the other extreme, Stokes uses the famous American inventor Thomas Edison as the exemplar. We all know of his inventive prowess – the light bulb, movies, the phonograph, and hundreds more – he held 1093 patents. Edison had no use for scientific theory or training and his research was driven solely by the desire to make things that solved practical problems.

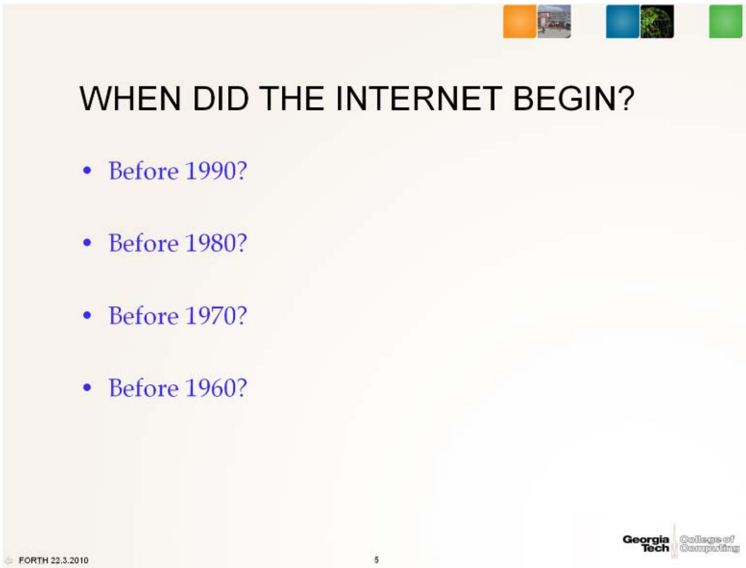
In between is what Stokes calls "Pasteur's Quadrant," where the research may be driven by a practical need, but may also result in a more fundamental discovery – or vice versa. Pasteur, the great French chemist was hired by a local beer brewery to solve a problem they were having with fermentation. In the process of working on this practical problem as a consultant (Pasteur was a professor) he demonstrated that fermentation is caused by the growth of microorganisms, and that the emergent growth of bacterium in nutrient broths is not due to spontaneous generation, but rather to biogenesis. This, and the work of several of his contemporaries, led ultimately to the founding of the field of medical microbiology.

A large amount of scientific research today falls into Pasteur's Quadrant – indirectly, if not directly. Indeed, I suspect much of the work here at FORTH is of this type.

No matter your field, you have probably been taught that there is a difference between science – a quest to discover and understand basic truths – and technology – the application of scientific knowledge and methods to create something of value to society, usually utilizing engineering principles. For many of us our scientific work today falls largely into Pasteur's Quadrant.

A corollary of this observation is that it is often hard to differentiate between science and technology in many situations. This is certainly true for computer science. Indeed, Stokes' model is an oversimplification, with work undertaken in one quadrant often migrating to another. For simplicity, I will simply talk about "science" today, although a good bit of the Internet story is about technology and engineering in the usual sense.

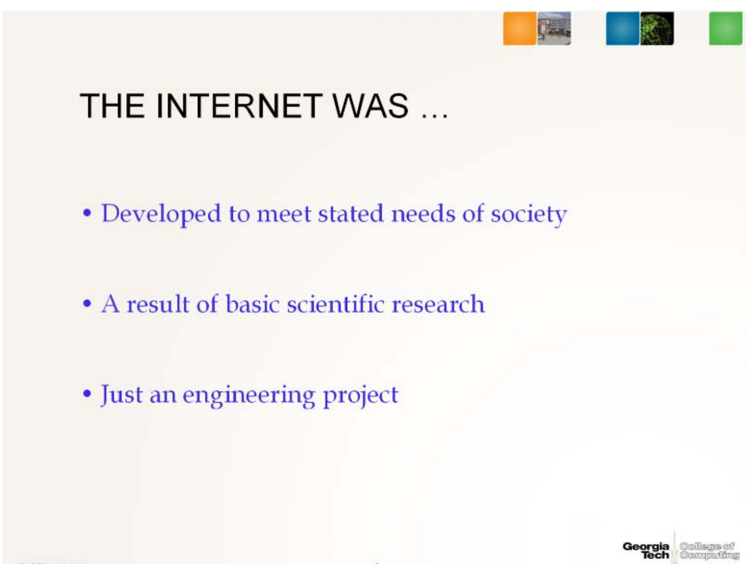
Before we begin the story of how the Internet came to be and where it may be headed, let me ask you a few questions – just answer by a show of hands – grades will not be given!



How many of you think the Internet as we know it today was created in response to an expressed need of society?

How many think it came out of some basic scientific research?

How many think that it is just a technological development – i.e. that it has not added to our basic understanding of the world (natural and artificial)?

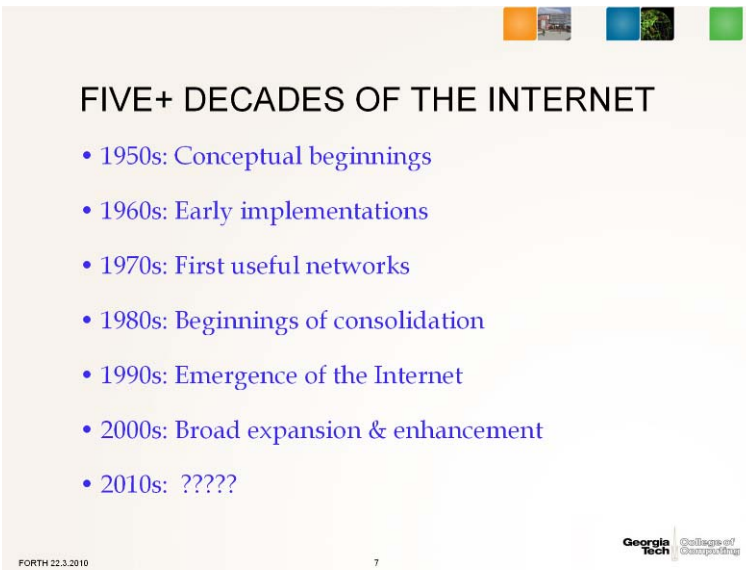


How many think that its beginnings were before 1990? Before 1980? Before 1970? Before 1960?

As with any complex subject, there are many "right" answers!

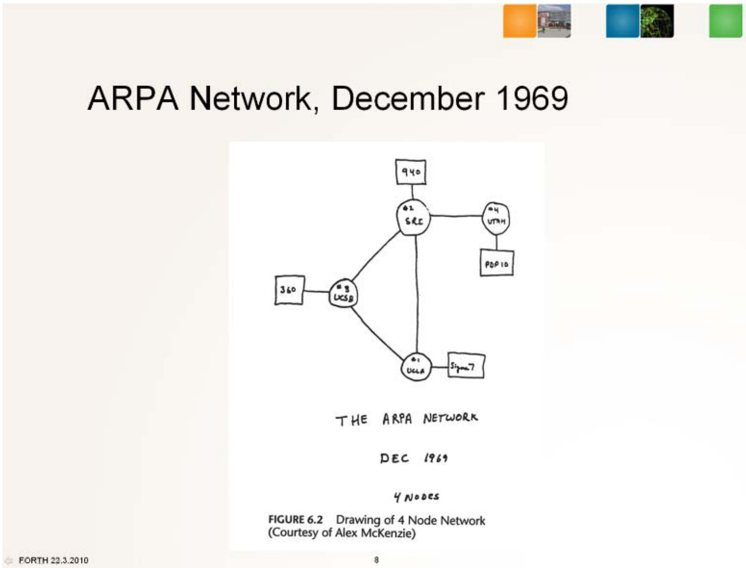
HOW THE INTERNET CAME TO BE

Books have been written on the origins of the Internet and, of course, the story is not over.



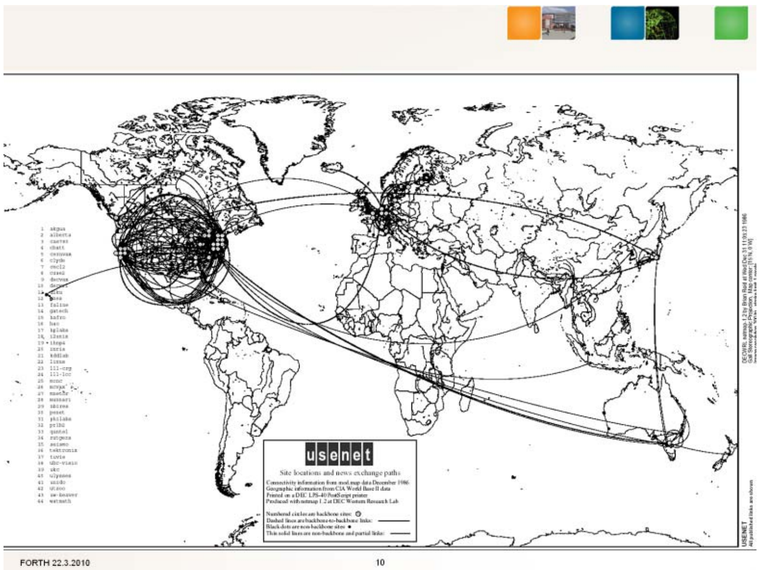
Starting in the late 1950s there were several threads of work that laid the foundations for the Internet. The concepts of decentralized networks that utilized store and forward techniques and operating systems that could deal with multiple tasks simultaneously (or so it seemed to humans) had been developed and were starting to be used in real systems. Interactions with computers at a distance and their use for communication, not just computation, were being developed. And, the concept of packet switching of information was being developed.

By the late 1960s, a number of early computer networks were being designed and built. Perhaps the best known was the ARPANET in the U.S. which brought together many of these strands and ultimately formed the first instance of what we know today as the Internet. Most of the development during this time was essentially driven by the desire of those involved to build a network that would have various properties – not so much to solve particular problems that anyone outside their small community might have – essentially an internally driven engineering project.

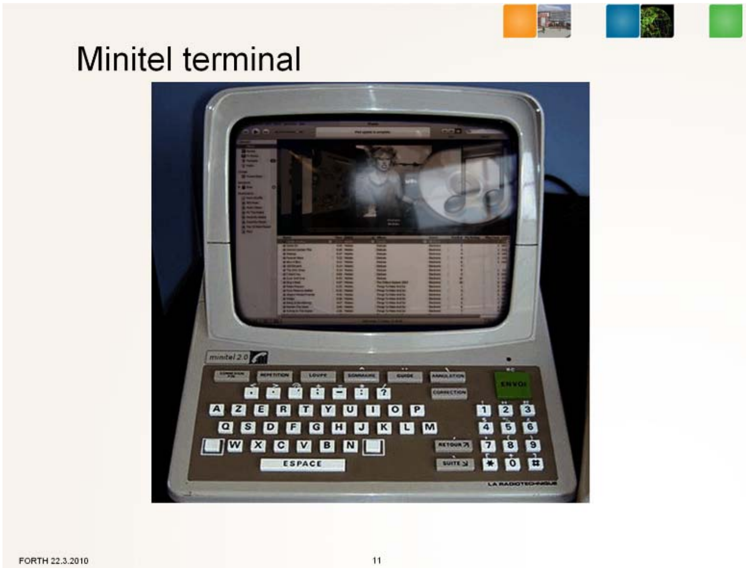


Indeed, throughout the 70s and much of the 80s, development of the ARPANET and a variety of other networks including CSNET, NSFNET, BITNET, and various corporate networks in the U.S; similar efforts in Europe such as EARN and EUnet; as well as efforts in Japan and Korea were being developed. IBM's SNA began in 1974 and was well developed and widely used by academic and industrial researchers by 1980. These developments served to introduce a substantial number of people outside the research communities to networking.

The primary usage of networks by researchers was for email, the transfer of files of data, and remote access to computers. Theoretically, all of the usage on the ARPANET was for non-commercial purposes, although in some cases the email and file transfers may well have been for non-research purposes. Because the users were almost entirely in the research sector (including some industrial labs) and because government policy makers and the commercial sector had essentially no understanding of or interest in what was going on, there was little interference or real controls.



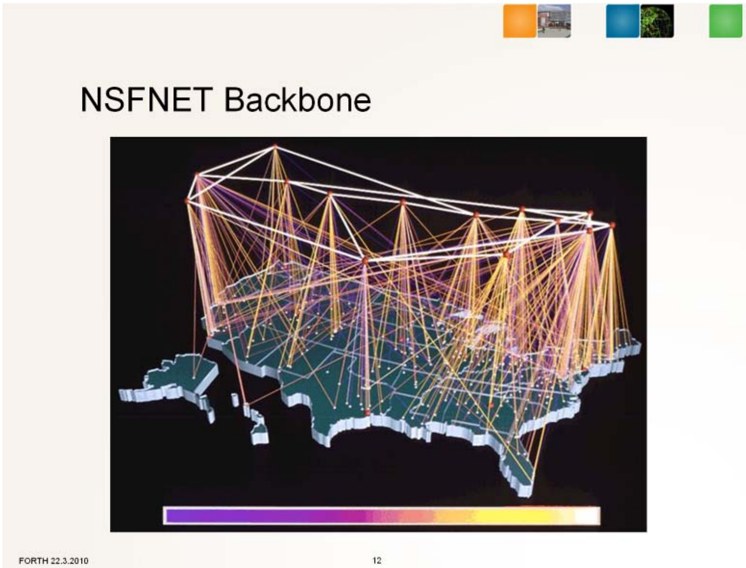
One of the developments in the civilian, non-research, sector was the use of networks for various informational and entertainment purposes. Notable among these were the various USENET groups (bulletin boards and discussion groups), Compuserve (1969), the Minitel system in France (1982), AOL (1983), The WELL (1985), and other commercial services that provided information and limited communication among subscribers, online games, and other forms of entertainment. This built the base for later commercialization and signaled to a few astute managers at ARPA and NSF (and elsewhere) that things were going to change.



Another factor was that there were no standard formats for addresses or messages. Until the mid-80s, to send messages or data from one network to another was via application-layer gateways using often-complex address mapping. Again, as an engineering imperative driven mostly by the needs of those building the networks – not the users of them – efforts were started to standardize and interconnect the various networks. With funding from the NSF (who mandated the use of the TCP/IP protocol suite), regional networks were established in the US and became part of the NSFNET. During the same period, there was vigorous sale and export by the US of high-performance workstations based on UNIX – with TCP/IP built-in.

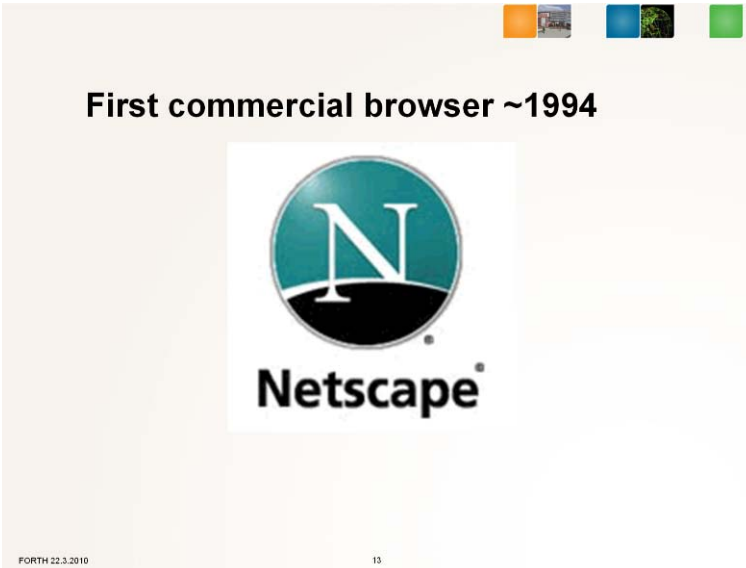
Also in the mid-80s, ARPA decided to eventually close down ARPANET. Their task had been to develop and show the feasibility of advanced networks and operational versions based on ARPANET (primarily MILNET) were being built. This timing coincided with the rapid expansion of NSFNET. By the late 1980s, most of the networks serving the research and education community in the then developed world were interconnected, and using TCP/IP. NSF recognized the exponential growth and consolidation that was underway and wisely made the decision to assume leadership and privatize NSFNET.

The Internet emerged from the interconnection of these research and education networks with the growing number of privately operated networks that were springing up to meet commercial demand. This was completed by 1995.

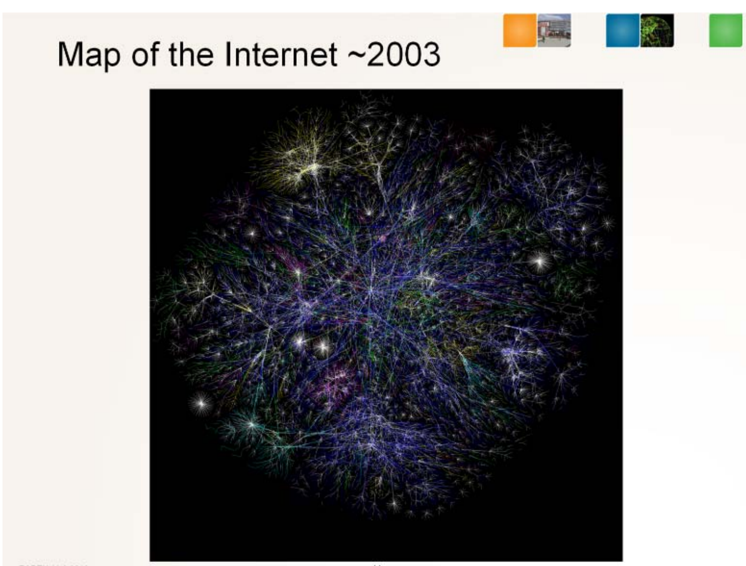


At the same time significant developments were taking place at the application level. Until the early 90s, there was no "killer application" that drove network usage, other than email, remote access (especially to supercomputers) and file transfer. Developments were all largely engineering driven.

In 1990, the first version of the World Wide Web was put into use at CERN to provide physicists and other researchers with a better interface to information stored on computers that were connected to a network. This led to the development of the first successful graphical browser, Mosaic, for viewing documents. By the mid-90s the Web had started to spread, Mosaic had been transformed into a commercial version – Netscape – and the "dot com" boom was on.



The past fifteen years has been an explosion of innovation and creativity built on the basic services of the Internet and the middleware of the Web and other platforms. This innovation has been in everything from process control of basic public infrastructure (like water systems) to science (online access to telescopes and digital catalogs of the sky) to government services (renewal of driver's licenses) to politics (the election of President Obama) to religion (online prayer sites) to war (terrorist recruiting sites) – and more. It was overdone by some in the rush to make money from online businesses in the late 90s, leading to the "dot-com bubble," which then burst at Internet speed. But the underlying enablement of innovation has gone on almost unabated.



There are two other sub-stories of the past fifteen years that are relevant to understanding where the Internet may be headed. One is the explosion of wireless devices worldwide from less than 100 million in 1995 to over 4 billion today, many of which are Internet-enabled.

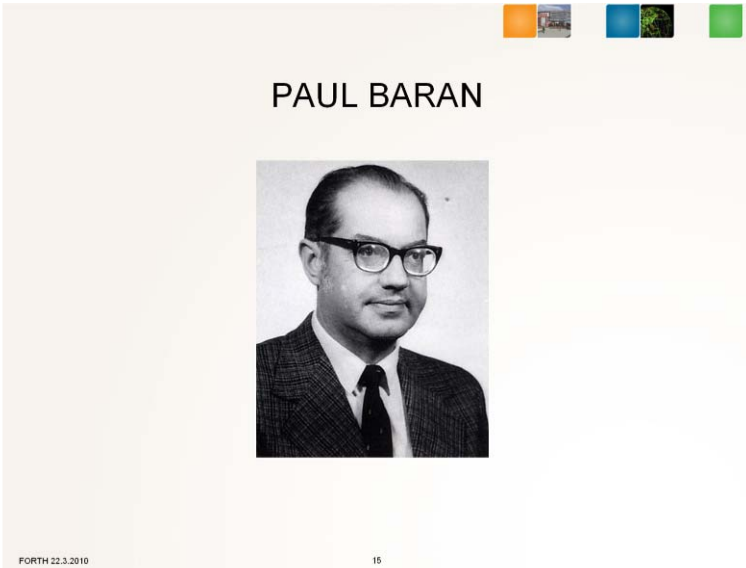
The other sub-story is that very little has changed since the mid-90s in the basic concepts on which the Internet is built. At the same time, the demands for more bandwidth, connectivity to new devices, protection from malware (viruses, Trojan horses, etc.), robustness, and guaranteed services have grown to the point that today almost everyone agrees something must be done.

Let me pause the story at this point and note that I have barely scratched the surface of this interesting story. There are many sources of more detail and I have listed several in the written version of this lecture which will be available on my website.

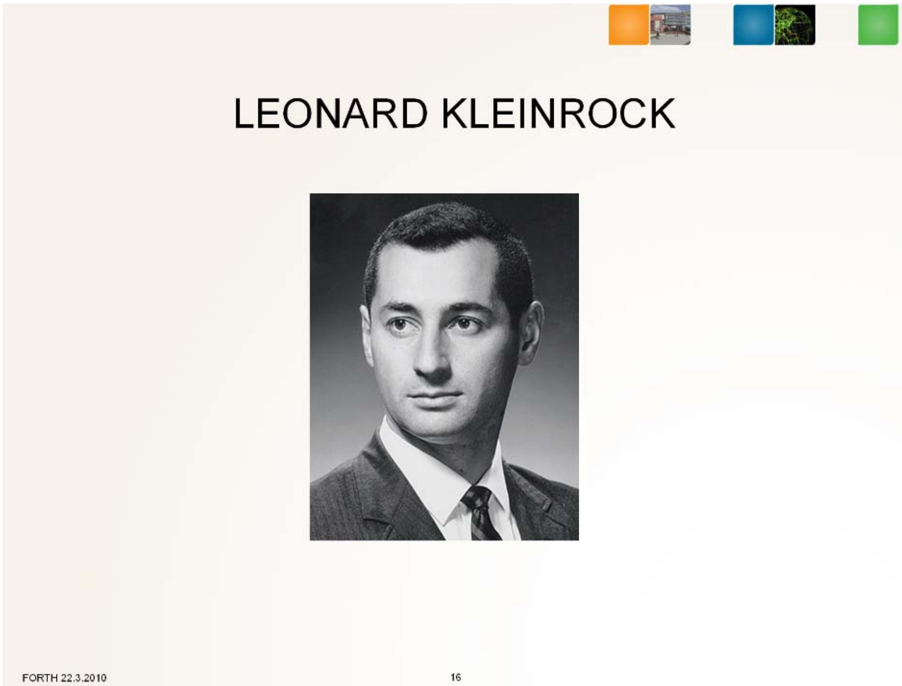
Before completing the story, however, I want to look at one of the seminal developments in more detail to illustrate some of the fine-grain interactions between society and those that were busy creating today's Internet. I will then return to the present to complete the story with some speculation about the future of the Internet.

WHAT REALLY HAPPENED?

Let's go back to the late 50s and early 60s and look at what happened in the development of packet switching. There were three, initially independent efforts that contributed significantly and eventually were brought together in the ARPANET. All relate to packet switching and all were driven by different objectives.



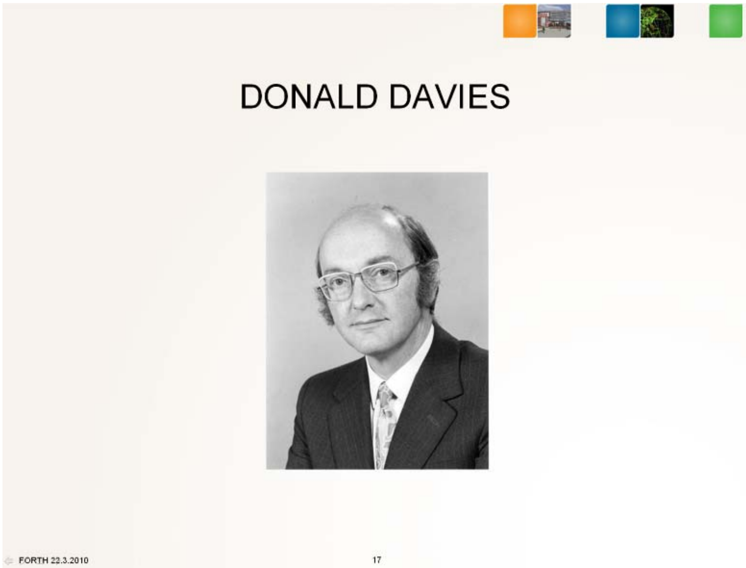
Paul Baran, a young systems engineer went to work in 1959 for the RAND Corporation in Santa Monica, California (a quasi-private research think tank supported by the US Air Force). He was assigned the task of designing a "survivable" communications system that could maintain connections in spite of damage by a nuclear attack. In addition to his engineering training, he had experience with computers and emergency radio communications systems and this background – clearly coupled with an innovative mind. He looked at the existing telephone network in the U.S. at that time and realized that it probably would not survive a nuclear attack because it was so centralized. He utilized the idea of a decentralized set of nodes that would do store-and-forward communication of messages that had been broken into packets. He first published the idea of packet switching in September 1962, and after doing some computer simulations that confirmed the value of his design, he went on to write an 11-volume set of technical reports that laid out the details and was published in 1964.



At about the same time (1959) a graduate student at MIT, Leonard Kleinrock, working under the information theorist Claude Shannon was looking for a thesis topic. Len recently described to me how he chose this topic:

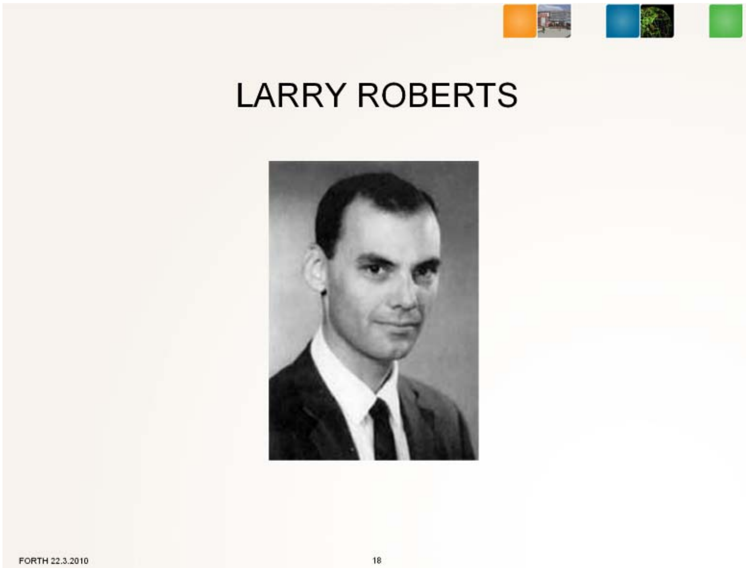
> *In 1959 I began to work with the legendary Claude Shannon at MIT on my PhD research. However, Shannon had solved most of the important problems and what were left were problems that were extremely hard and most likely of relatively little significance. I was surrounded by computers and realized that it would soon be necessary for them to communicate with each other. The existing technology of telephony was woefully inadequate for communication among such bursty data sources, and so I decided to devote my PhD research to solving this problem. Moreover, I had an approach to meeting this challenge and recognized that my research would have impact.*

He first published his ideas in April 1962 and in his thesis he developed the idea of packets and worked out much of the queuing theory necessary to build practical networks based on these ideas. In 1964, after joining UCLA as a faculty member, he published the first book on packet switching, *Communication Nets*.



The third person that is credited with contributing greatly to the stock of ideas relating to packet switching is the late Donald Davies of Great Britain. Davies was a very early computer scientist and engineer who had worked with the infamous Klaus Fuchs during World War II. He then joined the National Physical Laboratory (NPL) in 1947 and worked with Alan Turing on one of the earliest computer projects, the ACE. After Turing left NPL, Davies took over the project and delivered the Pilot ACE in 1950. A commercial spin-off, the DEUCE, became one of the best-selling machines of the 50s.

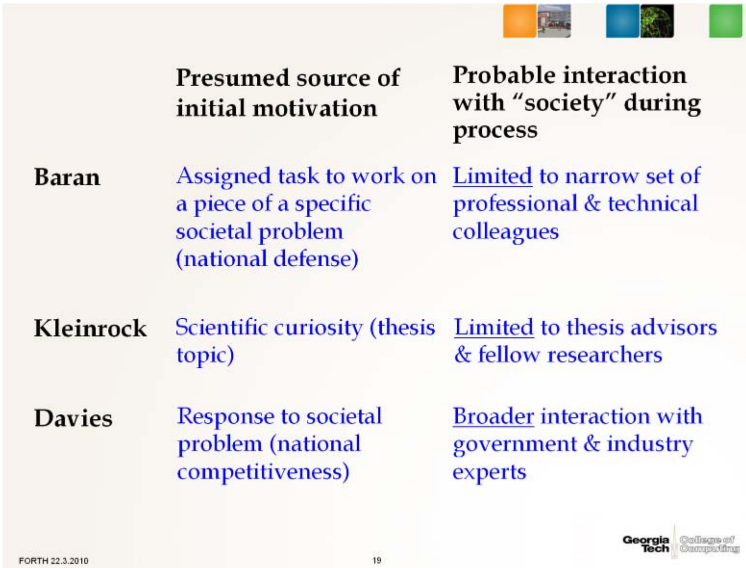
Davies worked on various government initiatives intended to make the British computer industry more competitive and then rejoined NPL in 1966 to lead their computer research department. He developed packet switching ideas very similar to Baran's and Kleinrock's, becoming aware of the others' work reportedly in 1967 when attending a conference in Tennessee. At that conference, he met Larry Roberts who had just been charged with creating ARPANET and was not fully aware of the work of Davies or Baran.



Davies was responsible for building and operating a network at NPL that incorporated many of these ideas. It ultimately served users there until 1986. He had plans for a national network in Britain, but the conservative stance of the British PTT made that impossible.

Now, let's go back and analyze the interactions between science and society in the development of packet switching.

As Baran did his work he was basically trying to solve a problem posed by society and assigned to him by his management – how to provide survivable communications. Once he started working on the problem, however, it appears he had very little contact with those outside the technical community. He thoroughly developed his ideas and set out to see them implemented, only to run into the intransigence of outside organizations.



Baran started his work in response to an expressed need of society (for a survivable communications system), not because of his scientific interest in the problem (although he certainly seems to have had that as well). Once started on the project, however, it appears that he was largely driven by scientific (engineering) imperative to carry the project through. In fact, after publishing his complete design, the U.S. Defense Department was prepared to build such a network (i.e. his job for society would have been completed) but he stopped the project because he felt that those assigned to build it did not have the requisite understanding of digital technology (i.e. he was driven by scientific ideals, not customer satisfaction).

It is clear that Kleinrock was led to his early work by one of the most basic scientific quests – search for a good thesis topic! – not by some expressed need of society. I think we could characterize him as one driven by the science and the engineering challenge.

Kleinrock came to work on network communications essentially out of intellectual curiosity coupled with his desire to change the way industry was building computer communications. His early work was then largely driven by the demands of the science – how to organize, predict, and model the communication flows. Indeed, he went straight from graduate school to being a professor developing the queuing theory necessary for building practical networks. It should be noted, however, that he later was one of the key people involved in experimentation and development of the ARPANET and has had a combined theoretical and practical career, including helping to create several seminal high-tech companies, in the best tradition of computer science.

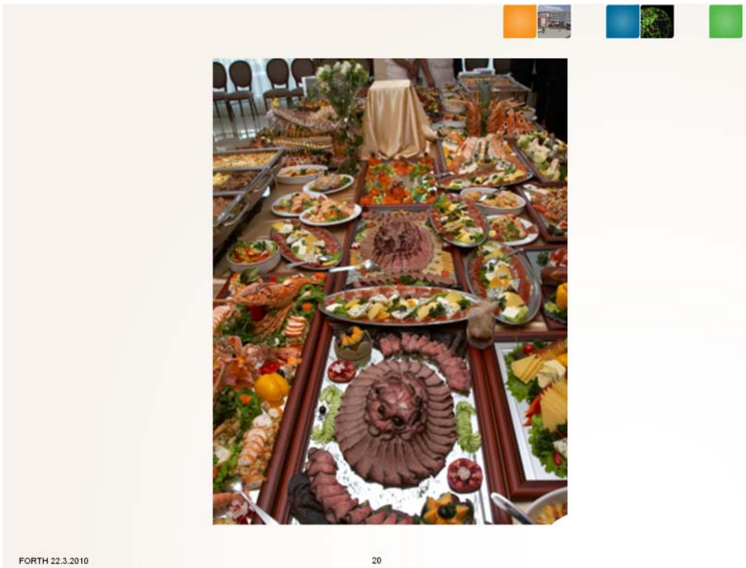
The third player, Donald Davies, had a career that alternated between government and industry. His move into networking came about very explicitly as a response to urgent efforts of a new government in Britain to boost the British computer industry. As with Baran, his start came from trying to meet an expressed need of society. Yet, while Baran was responding to the needs of the military (which in turn responded to the need of protecting society as a whole), Davies was responding almost entirely to the needs of industry as expressed by the government of the day.

If we look at the interaction between the work of these three players and society, it was clearly much more complex and subtle than society providing funding for scientists and engineers to work on problems. Similarly, the problems they worked on were not simple statements from society such as we sometimes hear today – "Find a cure for cancer," "Develop a way to reduce carbon emissions," or "Build a computer capable of modeling the entire atmosphere." Baran was responding to a derivative of an elemental need of society ("Protect us from enemies"), Kleinrock was driven by intellectual curiosity mixed with observation of what society was creating (computers working on scientific problems), and Davies was responding to his government's urgent and broad call for ideas that would make the British computer industry more competitive.

The complexity of the interactions continued during their work as well. Baran was working in a think-tank devoted to the problems of the military and it is reasonable to assume that, just as at here at FORTH, he was influenced to some extent as he worked by discussions with colleagues and knowledge of what they were working on. At the culmination of his scientific work, he then very directly interacted with those outside a research environment – the operational arms of the Defense Department.

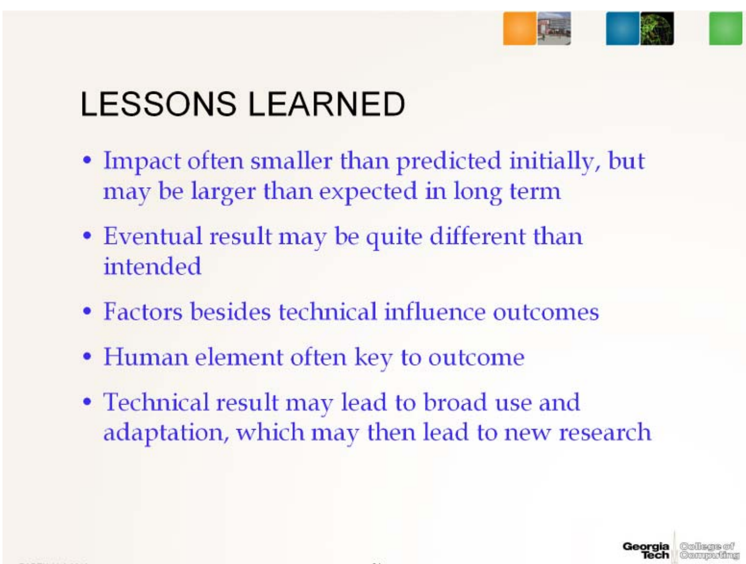
Kleinrock took a more direct, science-driven approach, but once he developed much of the needed theory, became directly involved in the engineering development. Nonetheless, at that point in time the work was largely an engineering project with its own dynamics independent of external society. Davies, on the other hand, was rather directly involved with society (in the form of government) not only from the start but pretty directly as he developed and tried to expand an early network.
There are many more fascinating stories of how the current Internet came to be, but my time is almost up. My host, Constantine Stephanidis, said I needed to limit my talk to one hour. I tried to bargain for two hours time,

but holding the lecture at six in the evening – just before food is served – has prevented that!



So, let me bring this to a close with some remarks on the future of the Internet and what we can do to improve the interactions between science and society.

WHAT CAN WE LEARN FROM THIS STORY?



This very brief history of the birth and growth of the Internet is a good reminder of the truth that the impact of our work on the world outside of science is rarely foreseen. It is often said “The impact of a discovery or development in the short term is almost always less than imagined, but often in the long term is much greater than ever imagined;" development of packet switching is a good illustration of this.

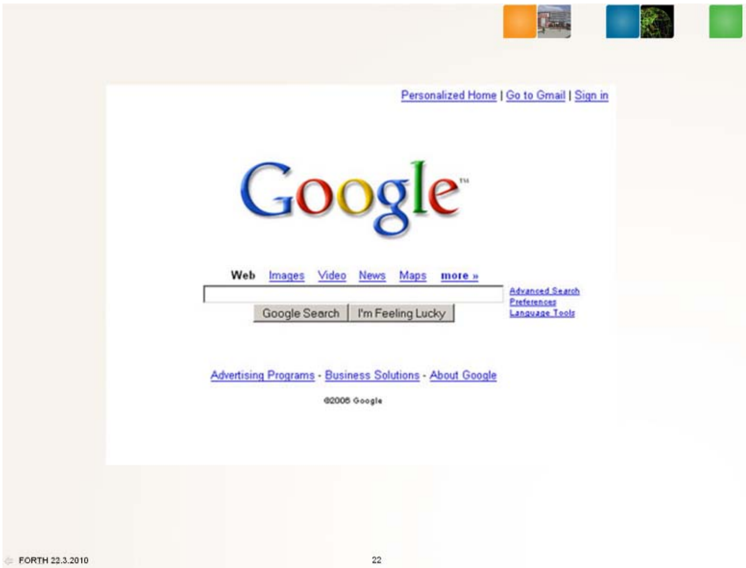
A slightly more subtle lesson is that whatever the original purpose or intention of our research and development, what results is often different. Alexander Graham Bell didn't intend to revolutionize communication when he developed the telephone. Henry Ford did not intend to transform society when he invented the mass-produced car. As they developed packet switching, Paul Baran, Len Kleinrock, and Donald Davies intended to transform specific functionalities and/or industries, not almost all of the institutions and business practices of the modern world.

This story is an excellent illustration of the complex interaction of science, people, organizations, and society broadly. Indeed, we would not have what we know today as the Internet or anything like it if it had not been for many non-technical forces and actions. It is not an exaggeration to assert that the non-technical forces may have been at least equal to the technical work in bringing about the Internet. Lest you think this is something unique about the Internet, just consider the development of genetically modified foods and the difference in their acceptance in different societies, or the application of nano-technology.

Almost all of what is shaping the future of the Internet is at the platform and application levels of the networking hierarchy. At the same time, the legal, commercial, and political forces that attend anything that touches the lives of so many people – and that involves so much money and power – are clearly shaping the future of the Internet much more than the underlying technology.

If you are interested in the forces that are trying to shape the Internet's future – for good and, perhaps, bad – I give several references that discuss some of what is happening.

One of the lessons of the Internet is that we must consider people and their behavior. It should be obvious that to have wide applicability technology must be easy to use. But it must also address fundamental needs and behavior of a large number of people. The Internet had no perceptible impact beyond a narrow slice of the scientific community until easily usable email, the World Wide Web, and browsers came along. These were not fundamental scientific or even technological developments, but they touched the basic need of everyone to communicate with a wide range of other people (in the case of email) and the desire for useful and readily available information (in the case of THE WEB and browsers).



While the Web and browsers popularized the Internet, it has been the advent of Google and social networking systems such as Facebook that are really causing it to have very wide impact. This has made frequent users of much of the population in advanced countries, which in turn is making it much easier for companies, governments and organizations of all kinds to implement many kinds of new services and features built primarily on only the Web and browser technology (at least so far). We are now starting to see the merging of various kinds of digital media (including TV) on the Internet as well as in the digital appliances so many of us have. The future that this heralds is just starting to unfold and the demands that it will make on the Internet are unknown – except that they will be many.

In a number of ways the development of the operational Internet has led to new or revived areas of fundamental research. The expansion of traffic on the Internet by orders of magnitude has pushed existing techniques to the limit in many instances, sparking renewed interest in the basic models and theory of communication. The creation of an operational network successfully connecting billions of people has spurred research interest in other types of networks that connect people. The ability of search engines like Google to make almost instantly accessible ever vaster amounts of information has triggered new basic research into the organization and accessing of information, the theory that underlies successful search techniques, distributed systems, and more.

At the same time, the lack of truly new underlying mechanisms in the Internet for the past 15-20 years, coupled with increasing demands on it not only in volume but in types of demands (e.g. increased security, guarantees of service quality, connection to mobile devices, intermittent connectivity to some devices, etc.), has convinced a number of us that it is time to create significant new technology and the underlying scientific understanding for the future of the Internet. Multiple efforts in the US, Europe, and Japan, as well as other countries are aimed at this goal. I have provided a reference to the US effort with which I am quite familiar.

So, what is the future of the Internet? And, more properly, what is the future of networking more generally, not just the email and Web-dominated Internet of today? I hope I'm wise enough to not try to predict that!

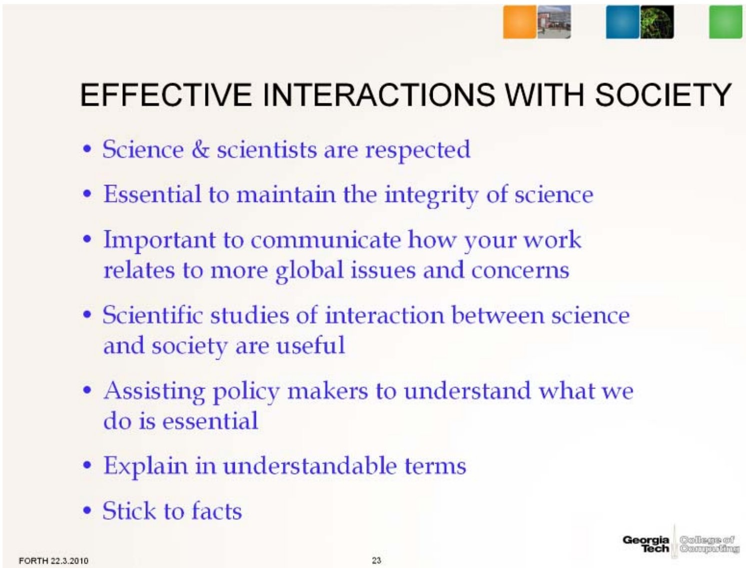
At the same time, I think we can say a few things about some general characteristics of the future of networking. For one thing, the positive value of networking in all spheres of modern life has been dramatically demonstrated – along with the negative aspects that it also supports. So, it is fair to say that we will see a continuing expansion of networking. A second safe observation is that what we experience in the future that is based on networking will be largely driven by the needs and interests of broad segments of society. It will be enabled by scientific/technological developments, but we technologists will not be the ones that drive it – at least not when we are just following our scientific interests. Lastly, I am convinced, as I have been for almost fifty years, that we have barely begun to see and understand what computer technology – most definitely including networking – can do for all of us individually and for society as a whole.

That brings me to my final remarks today.

SCIENCE AND SOCIETY – WHAT CAN WE DO?

Although trained largely to develop understanding – the core objective of the scientist – I have a large amount of the engineer in me – I always want to move beyond understanding to do something. Indeed, one of the attractions of computer science for many of us is precisely that it combines understanding and action in new, intriguing, and constructive ways.

I hope you will join me in my desire for action by thinking – and acting – seriously about what can be done to improve the interactions between science and society to the benefit of both. In most societies today, the interactions between science and society can be improved. While the details may differ from country to country and from field to field, there are global dimensions that almost always hold true.



We have a good foundation on which to build because in almost every society, scientists are highly respected and seen as seeking objective truth. I note in passing that those that are doing engineering work or applied science, while respected, may be seen as working first for their employer, not necessarily ideal truth. Respect is based on integrity and a dedication to facts, not opinions. As a result, whatever else we may do or not do, we must always strive to maintain the integrity and objective nature of science in our own work. Further, we must speak out when we see others failing to uphold those ideals.

A second, obvious point is that at some level and in some way, we all need to focus on global problems affecting our societies. That does not mean that we must all work on applied research, but at the same time as members of society and beneficiaries of the resources given us by society we need to have a compelling story that connects at least some of what we do to larger issues of importance. It is not difficult to make such connections in most cases, but they need to be made an explicit part of the context in which we work.

Every scientist should have as part of their basic education the study of the impact of science on individuals, organizations, and society. Included in this should be a study of the ways in which individuals, organizations, and society control and influence the course of science. Consider how Baran used his knowledge of the organizations that had been assigned to implement his ideas in deciding to stop the project so that the concept would not be killed because of poor implementation. Similarly, think about how many of the excesses of the dot-com boom of the late 90s could have been avoided if developers had had a better understanding of the behavior of non-technical people.

Few of us have had such formal education, but it is not too late to learn and to consider how your work may affect others outside of science – and how they may impact your work. Pay attention to what is happening in society. Notice what people are doing or asking for. Try to understand the impact of past technological developments. Understanding the context in which you are working can give your work more meaning and help you understand why sometimes your work is not understood or appreciated or funded in the ways that you think it should be. This is an activity that never ends and should be as much a part of your routine study as reading the latest journal articles. In short, we must continually engage society.

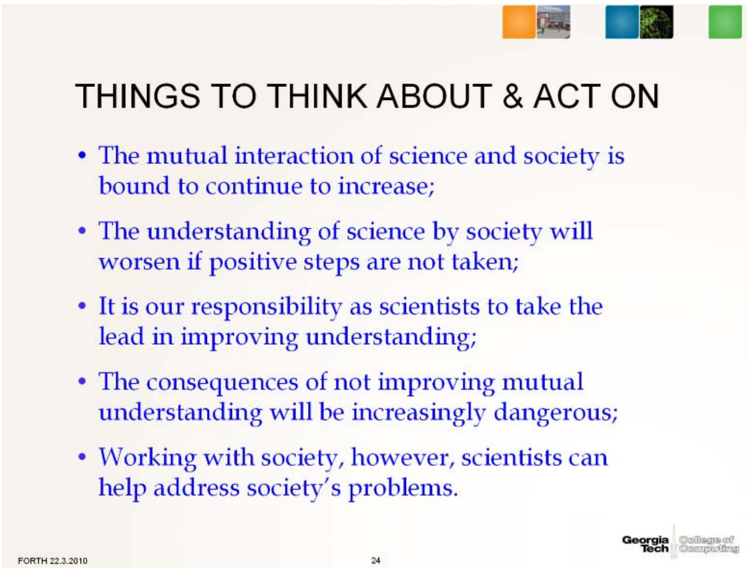
The responsibility for better interaction does not belong only to those of us in the scientific world. Policy makers that deal with science and its results (and that is almost all of them in a modern society) need to understand what science can and cannot do. They also need to understand how their policy decisions may impact important research efforts, even when that is not the intent.

What we in the scientific world can do is to help educate the public by explaining our work in terms understandable to the non-expert, and by working with policy makers at all levels to help insure that they craft informed policies. As a professor, I’ve always found that having to explain complex concepts in understandable terms improved my own, deeper understanding. Try it if you haven’t!

The media (newspapers, TV, online blogs) have a great impact on all areas of public policy and expenditure. In the case of science and technology, they may have more impact than you think. When there is reporting in the media on technical matters, it is often incorrect and/or made into something sensational – think of the portrayal of genetic engineering as leading to monsters sometime in the future. This is where you can be of direct help. When you have – or can get – the opportunity to write for the media or to assist those that do, take the opportunity – just remember that you must be careful to communicate with the layman and to make sure that your words are not misinterpreted or misreported.

We also don't need to wait to be asked to provide assistance to policy makers. My experience is that, in general, those responsible for making policies in all kinds of organizations welcome concerned, objective help. In doing so, however, it is very important to separate your efforts to influence them to make the policy decisions you favor from your efforts to help them understand the science and the potential impacts. The best approach is to be a good technical person. Stick to the facts and support what you say in a scientific way. Try very hard to refrain from doing anything to try to influence them that is not based on objective, solid data. When you do have to venture into areas in which there are competing theories or not enough is known to make statements that are solidly supported and accepted, make this clear and provide the opposing theories and approaches.

CONCLUSION



In closing, I want to leave you with some points that I would ask you to think about and act on:

The mutual interaction of science and society will continue to increase. Only a cataclysm can turn back the clock to a time when a large part of our existence was not dependent on science. Even the fundamentalists, who insist that we must go that way, utilize technology to the fullest in making their case and in extreme cases of trying to destroy society.

The understanding of science by society will worsen if positive steps are not taken. It is already the case that most people, at best, have only a rudimentary understanding of how advanced technologies work or of the scientific fundamentals on which they are based. Even most scientists will readily admit that their understanding of whole areas of science is very sketchy and incomplete.

It is our responsibility as scientists to take the lead in improving understanding. We have the ability to explain what we do and the principles underlying our field to those that do not yet understand – that is what we do every time we teach. While many details may be left out, abstractions and generalizations can be extremely useful in helping non-specialists understand the main points of a subject. Indeed, this lecture is just such an example because I have left out many details and yet I suspect you now have a better understanding of a complex topic.

The consequences of not improving mutual understanding will be increasingly dangerous. There is no better example than the current battle between climate scientists and those that choose for whatever reason to believe that global warming is just a hoax. The unfortunate and misguided efforts of a few scientists that came to light in the recent disclosure of some email exchanges has called into question the integrity of all scientific inquiry in this area. The scientists involved did not understand that transparency and the highest integrity are essential. In a contentious area such as global warming, the lack of understanding that has now been deepened could have disastrous effect on the entire world if it is allowed to spread and prevent needed research and remedial actions.

Working with society, however, scientists can help address society's problems. This is an article of faith with almost all scientists and is one of the primary drivers for many of us.

My theme today was one that Stelios Orphanoudakis lived – to help science and society interact in mutually constructive ways. His work here at FORTH is a living testimony to his vision. I feel certain that he would join me in urging you to do the same.

Thank you!

FOR MORE INFORMATION

NOTE: This is an adhoc list of references to get you started. Coupled with a few Google searches, they will quickly get you into current thinking, discussion, and work.

Pasteur's Quadrant, by Donald E. Stokes, Brookings Institution Press, 1997.

Where Wizards Stay Up Late: The Origins of the Internet*, by Katie Hafner and Matthew Lyon, Simon & Schuster, 1998.*

Inventing the Internet, by Janet Abbate, MIT Press, 2000.

The Future of the Internet--And How to Stop It, by Jonathan Zittrain**,** Yale University Press, 2008.

The Future of Ideas by Lawrence Lessig, Vintage Books, 2002.

Free Culture: How Big Media Uses Technology and the Law to Lock Down Culture and Control Creativity, by Lawrence Lessig. The Penguin Press, 2004.

Website of the Internet Society: http://www.isoc.org/internet/history/

Website of the GENI Project (U.S. NSF effort aimed at providing a more fundamental basis for network design): http://www.geni.net/