THE INTERNET AND ISI: FOUR DECADES OF INNOVATION

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It's an honor to be here today to mark the 40th anniversary of the University of Southern California's Information Sciences Institute. Thank you to Herb Schorr for inviting me to speak with you today and participate in the day's events. When he steps down he will leave some very large shoes to fill.

When I received Herb's invitation, I seized upon it as an opportunity to come before you to express the sincere gratitude that my colleagues and I feel for the work and support of ISI. When I think of ICANN and its development, and all we have accomplished, I never forget that we stand upon the shoulders of giants, many of whom contributed to my remarks today. In fact, I owe a special debt of gratitude to Bob Kahn, who has been a mentor to me. I am honored that he took the time to walk through a number of details in the history I have been asked to relate.

The organizers asked me to speak about the history of ISI and ICANN. They also invited me to talk a bit about the future of the Internet. In my role as President and CEO of ICANN, I have many speaking engagements that are forward looking. They are opportunities to talk about ICANN's work and how it will usher in the next phase in the history of the global, unified Internet that many of you have helped to create. Today, in speaking also about the past, I have an

opportunity to reflect upon ISI's foundational work, and – as I mentioned – to convey a message of awe and gratitude at what you have accomplished.

With that in mind, I hope you will bear with me if much of the tale is already known to you, if I have taken some editorial license, or if you detect an inaccuracy. I know I am addressing a very knowledgeable and precise crowd!
And now for the history….

The Late 1960s

George Bekey has done an excellent job of describing how ISI was born. Now, I would like to jump back a few years before ISI was founded, to 1968, when computer networking was an idea and not a proven concept.

That year, the Advanced Research Projects Agency (ARPA), wanted to see if a network of different computers could be created. They sent out a Request for Quotation to build a network of four Interface Message Processors (IMPs) that would allow this to be done through telephone lines. These packet switches were the predecessor to what we would later call gateways or routers.

A team at Bolt Beranek and Newman, or BBN, Technologies, won the proposal. A background piece on their website today says that at the time, many of the large computer and telecommunications companies didn't even want to bid. They didn't think it could be done. But BBN proved it could be done in less than a year. They built and delivered the first IMPs to four universities, and by 1971 the network had expanded to 13 sites.

From such humble beginnings, the revolution of mass connection began.

ISI's own Bob Braden, while at that "other" Los Angeles university, had the technical responsibility of attaching UCLA's IBM 360/91 supercomputer to the ARPANET in 1970.

At an international conference in Washington DC in October 1972, researchers proved that networking between once incompatible computers was possible via ARPANET, one of the world's first packet switching networks.

It was only the beginning of a network population boom that stretched beyond the United States and into France, Norway, Sweden, the United Kingdom, and other countries.

So it was that ISI was created just as the computer networking focus shifted to solving the problem of how to make these different computer networks talk to one another.

Bob Kahn of DARPA worked with Vint Cerf of Stanford University to figure out how to unify these packet switching networks that used telephone lines, radio, satellite or cable to connect with one another. They even recruited a couple of Vint's high school buddies – Steve Crocker and Jon Postel.

They worked out a solution, and Kahn and Cerf first presenting their ideas and later publishing them via the Institute of Electrical and Electronics Engineers (IEEE). They called it "internetworking."

Today, we call the resulting global information system the Internet.

Importance of USC ISI

There's an old saying about success having many fathers. The history of the Internet is still being written, but in most versions, you hear the same names. Vint Cerf. Danny Cohen. Steve Crocker. Bob Kahn. Leonard Kleinrock. Jon Postel. Larry Roberts. If I tried to list them all, we would be here for hours.

The Internet Society's new Internet Hall of Fame takes a stab at it – with 33 inductees named earlier this week. ISI researchers such as Danny Cohen, Steve Crocker, Jon Postel and Paul Mockapetris figure prominently.

Cerf and Kahn's solution for "internetworking" brought order to the chaos of disparate networks. But someone had to maintain that order, by recording and preserving the protocols, the identifiers, the networks, the addresses and the names of every outpost in the networked world.

That person was ISI's Jon Postel. As a graduate student he was one of the first to join a research project to build the ARPANET. Afterwards, he spent 21 years of his too-short career at the Institute.

When Postel joined ISI, he brought with him responsibility for two lists he had begun keeping while at UCLA. One was a list of ARPANET host names and addresses. The other was an index of Request for Comment papers written by ARPANET researchers.

Let's talk about the list of host names and addresses first. In the early days, the ARPANET and other networks were like small towns. Everyone knew everyone else. The informal structure of the networks reflected that familiarity. According to Internet lore, various individuals on the ARPANET kept their own lists of addresses on scraps of notebook paper...or maybe even a pocket notebook. Kahn kept his list on a three-by-five green index card.

If you wanted to find someone on the network, you looked up their address in your list and typed in the number.

As these networks expanded, paper lists were replaced by text files, but even these had the potential to become an operational nightmare. Host tables were still working even though the number of Internet hosts had soared from dozens to

thousands. But the files needed updating daily, and everyone on each network was uploading it each night. The potential for error was high. For those involved, it wasn't difficult to envision a future where a simple text file was no longer the right tool for the job.

Birth of DNS

In 1982, Postel asked a member of his ISI research team, Paul Mockapetris, to devise a new way of assigning and keeping track of Internet addresses across the different networks.

The solution was truly brilliant. Building from the general dot ARPA notation system introduced in the 1970s, the new system was based on numerical designations, but it also allowed a user to reach a computer by a human-friendly name as well. It was hierarchical and distributed. It classified top-level domains into seven different categories, like the United States government at dot gov or universities at dot edu. Local network administrators were responsible for numbering and naming individual computers in the domain.

Of the seven new top-level domains created, dot com was the least important at that time. This was because the Internet was off-limits to private companies until the early 1990s. Today, dot com is by far the largest with more than 100 million registered domains.

This combination of decentralized architecture with minimal centralized control is a clear handprint of Postel's involvement with Mockapetris and one reason why the Internet has scaled so well. They built the original DNS to support 50 million plus entries. Today it has been expanded and internationalized, and we estimate it holds more than 225 million across all top-level domains today. New gTLDs could add millions more, but the system will remain stable and secure, thanks to the design created by Postel and Mockapetris for DARPA while here at ISI.

Requests for Comment

I mentioned that Postel brought over two lists from UCLA. The second list was of series of papers called Requests for Comment.

Thanks to this list, an archaeologist interested in excavating the history of the ARPANET does not have to dig too far. They just have to find the old paper files and black leather-bound log books kept at ISI.

Through 2009, the Networking Division of ISI was the home of the RFC Editor function, with Bob Braden and Joyce K. Reynolds at the editor's helm after Postel's passing.

The first RFC, written by ICANN's current board chairman Steve Crocker in 1969, was a humble first volley aimed at starting a dialogue about applications and protocols for the ARPANET. Over decades, these documents became the mainstay for sharing technical designs in the Internet community and the archetype for other communities as well. Today, there are more than 6500 RFCs, searchable online in multiple formats.

The Internet's Many Milestones

The Internet was built as an open architecture. Anyone could – and still can – contribute to its operation. Membership in the organizations that define its standards and protocols is open.

Because of its open nature, there are many birthdays and many milestones you can point to within its evolution. Many people consider ARPANET's January 1983 transition to the Internet protocol suite, or TCP/IP, the actual birthday of the Internet as we now know it. But even that transition wasn't exactly one day – it actually took about six months to complete. The fact is that the Internet has had many important, game-changing beginnings.

We've talked about how the Internet evolved from a DARPA concept into a real operational network able to link different networks and computers. And that brings us into the early 1980s.

Computer networking had started out as a pure research project, primarily driven by DARPA with the goal of learning if and how it could be done. By the 1980s, researchers knew it could be done and they knew how. The Internet opened for broader use at university, U.S. military and U.S. government sites. Now, the focus was on what should come next.

In 1980, a little more than 150 host computers were connecting some 20,000 researchers, scientists, the military and government.

The personal computer was introduced in 1981, and it had found its way into offices, schools and homes so much so that *Time Magazine* had dubbed it "Machine of the Year" in 1982. The computer was the first non-human to get the honor.

More computers meant more people on the Internet. And by 1989, there were 200,000 host computers. More and more commercial networks emerged. The Internet had earned its place as a truly viable communications technology.

As the 80s turned into the 90s, researchers at CERN in Geneva, Switzerland, were working on the concept of the World Wide Web. Tim Berners-Lee and his colleagues transformed the Internet from a mechanism for delivering files to a "web" of information that Internet users could retrieve and view.

In 1992, a group of students and researchers at the University of Illinois developed a browser that they called Mosaic. (It later became Netscape.) Mosaic offered a user-friendly way to search the Web: it allowed users to navigate using scrollbars and clickable links (point and click) to see words and pictures together

on the same page. And it awakened commercial interest in the Internet far beyond the researchers at Xerox Parc, IBM, CERN and Cisco Systems who had played important roles in its early development.

That same year, Congress passed the Information Infrastructure and Technology Act of 1992, which opened the Internet for commercial purposes. What followed was a huge infusion of commercial investment, as companies of all kinds hurried to set up websites of their own, and e-commerce entrepreneurs began to use the Internet to sell goods directly to customers. The number of machines tapping into the Internet exploded. Where once the growth rate had doubled each year, now it was closer to doubling each quarter.

Internet Assigned Numbers Authority

Assigning Internet names and IP addresses was no longer a small activity. The Internet Assigned Numbers Authority, or IANA, was established informally as a reference to various technical functions for the ARPANET. Jon Postel and Joyce K. Reynolds performed the function at UCLA and later at ISI.

To deal with the influx of computers onto the net, IANA became a more formal entity, with Jon Postel as its director.

A formalized IANA gave the Internet stability and robustness by assigning and managing, in an orderly fashion, the unique numbers and names of the domain name system.

IANA allocated blocks of numerical addresses to regional registries throughout the world, which in turn assigned them to Internet service providers and users. IANA also managed a registry of values for several technical parameters – including protocol numbers, port numbers and other units – that had to be unique for the Internet to operate.

By this time, the IANA function was nearly synonymous with Postel. In 1997, *The Economist* magazine proclaimed, “If the Net does have a god, he is probably Jon Postel.”

From his third floor corner office in what is now ICANN’s Los Angeles location, Postel ruled by delegation, encouraging parties to work disputes out among themselves. He found volunteers at universities to manage country-code top-level domains. Bob Kahn tells a story about a call he received from Postel about a problem with the country-code operator in Jordan. It seemed the King of Jordan wanted to know why Postel had assigned management of their country-code top-level domain to a certain individual in one of their universities. Kahn’s advice was to tell the Office of the King of Jordan to work directly with the individual and let them know the outcome. The result? The Office of the King ultimately selected the man Postel had assigned. Problem solved.

But the hot seat Postel and ISI had been sitting on was about to get hotter.

Business users, non-commercial users like academics, non-profits and civil society, governments and individuals, many from outside the United States, were voicing concerns about how this important facet of the global information network was governed. Lawsuits were being filed or threatened over disputed domain names.

It was time for academia and research to disengage from the operation of the commercial Internet.

Discussion and debate roared around the world. Internet and intellectual property groups formed an International Ad Hoc Committee to create and implement policies and procedures for generic top-level domains.

The Clinton Administration's Electronic Commerce Initiative in 1997 laid out the United States' goal to make online trade safe and stable, and its commitment to work with other nations while the technology was still in its infancy. Part of this framework included direction for the Secretary of Commerce to privatize the domain name system in a manner that would increase competition and facilitate international participation in its management.

The U.S. Government released two discussion papers – the Green Paper and the White Paper – outlining ideas for the technical management of Internet names and addresses.

ICANN, The Internet Corporation for Assigned Names and Numbers, was born out of that White Paper, published in June 1998.

The ICANN Era

1998. The dot-com boom is on and the World Wide Web is exploding with content. Website directories turned into search engines and then morphed again into portals like Yahoo! which combined news, email and instant messaging. The first Google Index was published that year and contained 26 million Web documents.

Academics had outgrown the Internet. University researchers, including ones from ISI, collaborated on a new backbone network. Called Internet2. It was built to meet the bandwidth needs of supercomputers and support high-performance applications like medical imaging and particle physics. It also provided a "sandbox" for innovation separate from the commercial Internet.

Commerce had revolutionized use of the Internet in the 90s. Year over year trade on the Internet doubled or tripled. But in many ways, electronic commerce was like the Wild West of the global economy. And market valuations of many dot com companies reflected it.

One of ICANN's first actions was to concentrate on increasing competition in the registration of domain names, which had up until this point been controlled by DARPA and the U.S. Department of Defense (via SRI primarily) and then by others when the National Science Foundation assumed responsibility.

In 1999, ICANN accredited 34 registrars, and over time, this brought the price of registering a domain name down from about $35 to about $7.

ICANN also facilitated greater online competition and innovation through the introduction of several new top-level domains, such as dot aero and dot biz.

Remember the story about the King of Jordan asking how a certain person was appointed to run the country's TLD? Now, with the formation of ICANN, his government – and all other governments – had a seat at the Internet governance table through ICANN's Governmental Advisory Committee.

The Wild West era of the domain name industry was over. The netizens were self-regulating. And they'd brought a sheriff to town – ICANN.

Getting Social With the World

If the 1990s was the decade in which commerce discovered the Internet, then the 2000s were when individuals discovered its potential for social interaction. Napster taught the world about P2P file sharing; music swapping was rampant. The iPod allowed us to take our music collection anywhere. Blogging applications made everyone a content publisher; podcasting made them broadcasters. Wikipedia, Myspace, Facebook, Yelp and YouTube launched their web sites. Thousands and thousands of online gamers competed against one another in the online World of Warcraft.

It was the era of individuals on the Internet. And the whole world was going online. By 2010, there would be five times as many Internet users as there were in 2000.

And it wasn't just that it was getting larger. Internet users were also becoming more spread out geographically. More global.

After years of debate, ICANN introduced a new body designed to be the voice of the individual Internet user, called the At-Large Community. This important change to the ICANN community acknowledged the growth and increasing role played by the individual in the Internet's adoption.

With more individuals and more commerce on the Internet, cyber security moved to the forefront. In 2003, ISI collaborated with UC Berkeley to create the DETER cyber security facility. It later became the world's shared research facility for security technology development. But more on that later.

IPv6

There's an important issue in the history of the Internet that I have not yet addressed yet. And to give you context for that, I need to take you back to the 70s and early 80s. Jon Postel was heading from SRI to ISI, and TCP/IP was now a success. Postel contributed to and documented the standard Internet Protocol – Internet Protocol version four, or IPv4 in RFC 791. IPv4 was a descendant of the original IP version that Cerf and Kahn worked on with some added functionality, and it has been the dominant protocol ever since.

IPv4 and its predecessors used a 32-bit address structure that allowed for roughly four billion IP addresses. To Cerf and Kahn, it seemed like plenty. According to Kahn, they thought there would be perhaps a dozen networks around the world, and a limit of 16 million machines.

Remember, when they started working on this, the ethernet and the personal computer had not yet been introduced. But as the years went on and connectivity grew, the Internet community recognized that depletion was likely if no other serious architectural changes were made. They began working on the next version of Internet Protocol, IPv6.

Fast forward three decades. Not only have we gained three billion people on this planet, but the Internet's rapid expansion has claimed those four billion addresses once thought to be plenty.

And most individual Internet users need an IP address for each device with network connectivity. Mobile devices—smartphones and tablets—will account for four out of five broadband connections by 2016. And that's a driver for transitioning to IPv6.

IPv6 vastly increases the number of available unique Internet addresses. Where IPv4 provided four billion addresses, IPv6 provides a ridiculously large number. It is roughly 340 trillion trillion trillion—or far more than one trillion addresses for every person on the planet.

Over the past several years, the global Internet technical community has been working toward broad deployment of IPv6. For years to come we will likely see Internet networks running both protocols side by side. IPv4, like the domain name system created at ISI, has served the Internet community well and fostered decades of amazing growth.

Future of the Internet

The organizers of today's seminar asked me to spend the bulk of my time with you on the history of the Internet, and ISI's important and continuing role in its evolution. But they also asked me to touch briefly upon what I see as the future of the Internet.

This is one of my favorite topics.

I've talked a little about the vast globalization of the Internet, but I have a few more statistics to share with you about how international it has become.

Developing nations are witnessing the most rapid growth of information and communication technologies. That growth is bringing the potential for innovation, increased productivity, education and greater competitiveness. It is connecting more people to one another.

It is estimated that more than five billion additional people will connect to the Internet in the next 20 years. Most of the newcomers will not speak English.

As these new Internet users come online, they will expect technology to adapt to *them*, rather than the other way around. Half of the Internet users today – a billion of them – are in Asia. Approximately 500 million, or 25 percent, are in China. That is why Internationalized Domain Names, names written in non-Latin scripts, are so important.

For the past several years, ICANN has focused on the New gTLD Program. Soon, we'll be formally announcing the applied-for names. It is an exciting time, a historic time, in the evolution of the Internet.

The New gTLD Program opens up the domain name space for further innovation, competition and choice. This is what ICANN was created to do.

Recognizing the important role the developing world will play in the future of the Internet, the ICANN community has created a special support program for those from developing countries who wish to apply for a new gTLD. We want to make

sure this opportunity for growth and innovation is open to all, not just to those with the financial resources at hand.

Of course, ICANN is not without its critics. The Internet's tremendous growth has meant growing pains of global proportions. Built on the legacy of Jon Postel, ICANN has taken Internet governance beyond academia and into the global realm. Our strategy for dealing with critics is simple: bring them into the fold, and encourage their participation in the diverse and fractious multistakeholder debate that shapes the Internet's future.

Another key strategy during my tenure as CEO has been for ICANN to continue to evolve into a world-class institution dedicated to enhancing Internet security and increasing international engagement and participation. In recent months, we have demonstrated this commitment through the appointment of four highly respected regional Vice Presidents dedicated to facilitate ICANN's engagement with the regions of the world.

Cybersecurity and Collaboration

One of the issues that worries me the most about the future of the Internet is cyber security. I think there are many of you at ISI who feel the same way.

One highly visible example of ISI's critical cybersecurity research is the DETER project conducted with U.S. Homeland Security and other research centers.

This is important work. As the world grows ever more connected, it is an unfortunate fact that so does our risk of massive disruptions to the systems that run financial systems, electrical grids or water treatment plants. Just like nuclear technology shaped geopolitics in the last century, the Internet is changing the global security equilibrium today. Nuclear weapons could escalate any global conflict to Mutual Assured Destruction, or MAD, with the metaphorical "press of a button."

Today, we have a different kind of MAD – Mutual Assured Disruption. Now, cyber mercenaries and nation-states can threaten national electrical grids or other key infrastructure.

There are two laws of cyber security. One: anything connected to the Internet can be hacked. And two: everything is being connected to the Internet.

Think about the origins of the Internet that we talked about earlier. Here is an open architecture network, built by a small academic community where everyone was on a first name basis. Mutual trust and human authentication is woven into its very fabric. As Vint Cerf says, the Internet was designed for openness, not security.

Today, with two billion people connected, we have to make investments to enhance the security of the Internet itself. ISI is making that possible today, by advancing the science of cyber security and building the tools for further experimentation and research.

ICANN has also made investments aimed at enhancing the security of the Internet. One of these investments is deploying DNSSEC universally.

DNSSEC is the technology helps assure you, the user, that you are really receiving information via the Internet from the website you requested, and not from an impostor or hijacker who has corrupted the page for malicious intent. It deters what we call “man-in-the-middle” attacks.

In July 2010, we added cryptography and signed the root of the Internet with DNSSEC. And today, most major top-level domains like dot com, dot net and dot UK have signed their zones as well. We are asking organizations everywhere to

sign their domain names and to ask their Internet service providers to turn on DNSSEC validation.

Strengthening Internet security at ICANN is important, so important that we enhanced our team with the addition of cryptography legend Whit Diffie as a Vice President for Information Security, and legendary hacker Jeff Moss as our Chief Security Officer.

To me, another key response to cybersecurity threats is to continue to collaborate on Internet developments through a decentralized, multistakeholder approach. We've seen through examples like Napster, Craigslist and Wikipedia that decentralized efforts can take on rigid, hierarchical, and established systems with devastating consequences. The best defense posture, time and again, is to incorporate key principles of decentralization into our own efforts just as hackers and attackers do.

We also need more people to get involved in Internet governance. If you are not already directly involved in a multistakeholder Internet body, please join one. I certainly invite you to join the ICANN community. We have dozens of different stakeholder groups, constituencies, review teams and working groups.

Even after four decades, the Internet is still a work in progress. We would benefit from your continued participation.

Conclusion

I've covered a lot of ground here today. It reminds me of those package tours to Europe where you can see seven countries in seven days. You cover so much ground that you have trouble discerning the differences between Spain and France. There's an old joke about a tourist couple on one of these tours squinting at an ancient monument. The man asks his wife, "Now what is that?" His wife

looks at her guidebook and says, “Well, if it’s Tuesday, then this must be France.”

I hope that by covering forty years of history in 30 minutes or so, I haven’t left you as puzzled as that couple. One of the challenges of talking about recent history is determining what to include and what to leave out. And regrettably there was much in the history of the Internet I had to leave out to keep to my allotted time.

What I hope I left you with is an accurate impression of the important role that ISI played in the development and evolution of the Internet. From the domain name system to the operation of one of the first root servers to the top-level domain concept to the historical and practical Request for Comment series, ISI belongs with the giants of the Internet’s conception, design and implementation. And ICANN is proud to be counted as one of ISI’s many lasting legacies. I am sure that ISI’s future contributions to Internet and information sciences will be as valuable as its past ones have been.

Thank you.

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