A Concise History of the Internet–II*

V. Rajaraman

In this part, I describe how CSNET started in 1981 with funding from the National Science Foundation (NSF) of the US government and the formation of the Merit network and BITNET. Following this, I discuss the formation of the NSFnet in 1986 connecting the supercomputer centres set up by the NSF in the US and its expansion by connecting it to the ARPANET, CSNET, Merit, and regional networks. I then trace the steady improvement of the speed of the NSF net and its gradual privatization and the emergence of the worldwide Internet. I then describe the evolution of the Domain Name System and the consequences of the rapid expansion of the Internet. The article concludes with issues of governance of the Internet which has now become an essential infrastructure of our World.

V. Rajaraman is at the Indian Institute of Science, Bengaluru. Several generations of scientists and engineers in India have learnt computer science using his lucidly written textbooks on programming and computer fundamentals. His current research interests are parallel computing and history of computing.

Introduction

Starting as a network of four computers in 1969, ARPANET became a network of over 100 computers in 1979. ARPANET became more of a communication network among scientists allowing them to exchange email, transfer files, and share news through newsgroups rather than one that shared computing resources. Many universities could not join the ARPANET as the cost of IMPs was high and DoD could not fund them. Researchers in computer science departments in many universities felt disadvantaged as they could not interact with their colleagues in other universities like those connected by ARPAnet could. Lawrence Landweber of the University of Wisconsin at Madison took the initiative and called a meeting in May 1979 of computer science

Keywords
CSNET, merit network, BITNET, NSFnet, domain name system, ICANN, ERNET, internet governance.

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professors of eleven universities in the USA, a representative of the National Science Foundation (NSF) of the US government, and a representative of ARPANET to explore how services similar to those provided to ARPANET researchers could be given to a larger community of computer scientists. At this meeting, it was decided to request NSF to fund the formation of a computer science network and connect it to the ARPANET. This was the beginning of the NSF getting involved in networking that ultimately led to NSFNET which replaced ARPANET as the backbone of the worldwide Internet.

CSNET

In November 1979 Landweber, Peter Denning of Purdue University, David Farber of the University of Delaware, and Anthony Hearn of the University of Utah on behalf of a consortium of 11 universities spread throughout the USA submitted a proposal to the NSF to fund the creation of a computer science network. Initially, NSF was sceptical. It felt that it would be a parallel ARPANET. Besides this, the management policy was unclear as many universities were involved. In addition, it was an infrastructure project that would reduce funding for basic research, which was the main mission of the NSF. The consortium rewrote the proposal with the help of Vinton Cerf of ARPA to implement TCP/IP in their computers (that ARPA agreed to give) and connect CSNET to ARPANET using a digital packet communication network provided by Telenet (a private provider). In addition, it agreed to provide CSNET services to the universities connected to ARPANET and create a Phonenet with dial-up telephones for email and file transfer to smaller centres with a low budget and work out entry and usage charges of all members. The revised proposal was submitted to NSF in November 1980. NSF accepted the proposal in January 1981 and agreed to give a grant of US$5 million with the condition that NSF will appoint a manager for the first two years to coordinate this multi-institutional project and that CSNET will be self-supporting in 5 years. Work was divided among the cooperating Universities with major respon-

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Figure 1. Lawrence Landweber (Photo courtesy Wikipedia).

sibilities taken by the University of Wisconsin, Purdue University, and the University of Delaware. Telenet, a packet switched network provider was contracted to connect the centres and provide a gateway to the ARPANET [1]. By early 1982 the network had 24 sites and by 1984 the number of sites increased to 84. As promised to NSF, connection and usage charges for members of CSNET were determined, and by 1986 CSNET became self-supporting with 165 universities and some industries as members. The universities were not only in the USA but also in many countries in Europe and Asia.

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Merit Computer Network

In 1966 the three major state universities in the state of Michigan in the USA (the University of Michigan (U-M), Ann Arbor, Michigan State University (MSU), East Lansing, and Wayne State University (WSU), Detroit met to discuss how they could cooperate to share their computer resources to enhance education and research in their state [2]. With support from the then governor of Michigan state George Romney, a non-profit corporation named Michigan Education and Research Information Triad (MERIT) was formed in 1966. The state of Michigan agreed to give a start-up funding of US$ 400,000 provided MERIT could get a matching grant from another source. MERIT sent a proposal to NSF requesting it to support their networking initiative. NSF reviewed the proposal and granted $400,000. With a total grant of $800,000, MERIT started operations in August 1969 with U-M

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agreeing to house and fund the initial staff of MERIT.

U-M computer centre staff also wrote the Michigan Terminal System (MTS), a time-sharing operating system for IBM 360/67 that was extensively used by numerous universities.

Between 1966 and 1970 a project titled CONversational COMPuters (CONCOMP) was carried out with ARPA funding by U-M computer centre staff. In this project U-M staff interfaced a Digital Equipment Corporation's (DEC) PDP-8 minicomputer with the IBM 360/67 mainframe computer in the university computer centre and wrote software to allow multiple terminals connected to PDP-8 to time-share IBM 360/67. U-M computer centre staff also wrote the Michigan Terminal System (MTS), a time-sharing operating system for IBM 360/67 that was extensively used by numerous universities. MERIT gained from this experience of U-M staff.

The first project undertaken by MERIT in 1969 was to connect the mainframes at U-M, WSU, and MSU using Communication Computers (CC), similar to IMPs of ARPANET, and a packet switched network. Applied Dynamics, a Michigan-based company, was given a contract for around $300,000 to build the CCs and interface them with the mainframes at the three universities. DEC PDP-11s were chosen as the CCs. Applied Dynamics staff, MERIT staff, and the computer centre staff at the universities worked closely and implemented a network connecting IBM 360/67s at U-M and WSU by December 1971. MSU had a CDC 6500 and it was networked in October 1972. The network of these three universities started services including email, file transfer, remote login, and remote batch processing by early 1973, four years after ARPANET. In 1976 the network was connected to Telenet allowing dial-in by clients anywhere in the US and abroad to the computers in the network and use their services. In 1978 Western Michigan University (WMU), which had a DEC PDP-10 computer, wanted to join the network. A new communication computer, a cheaper version of PDP-11 was interfaced with it and with a DEC VAX computer running Unix OS in the Electrical Engineering department of U-M to create a five-computer network. MERIT was renamed Merit networks as it was no longer a Triad. In 1983 TCP/IP software was implemented as the communication software of the Merit network and it was ready to be connected

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Figure 2. **(left)** Ira Fuchs (Photo courtesy Wikipedia) **(right)** Greyden Freeman (Photo courtesy yale62.org).

to the ARPANET. In 1985 another state university in Michigan, Oakland University, and in 1987 Eastern Michigan University, Central Michigan University, and Michigan Technological University joined the Merit network and the network became a regional network using TCP/IP. Merit continues to operate by providing various computer communication services.

BITNET

Faculty and students in universities connected to ARPANET, CSNET, and Merit started using email and file transfer routinely whereas those not in any network felt they were disadvantaged. Ira Fuchs, director of the computer centre at the City University of New York (CUNY), and Greyden Freeman of the computer centre at Yale University got together to find a way of providing similar facilities, particularly to the liberal arts professors, in their universities [3].

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Both CUNY and Yale had mainframe IBM computers that had software called Remote Spooling Communication System (RSCS) and a Network Job Entry (NJE) protocol that allowed IBM computers to communicate with one another using a leased telephone line. In May 1981 they connected their computers and exchanged emails and files without having to develop any new software. They called this network BITNET (Because It's Time NETwork). Soon, many universities in the northeast of the US, primarily with IBM mainframes joined BITNET. The entry cost was low as the only requirement was to lease telephone lines and get one more member to connect to them. Each member of BITNET stored emails and files it received from its closest neighbour and forwarded them to the next computer in the chain towards the destination address. By 1983, 20 universities were on BITNET and the membership increased to around 400 by 1984. With an increase in membership, BITNET Information Centre (BITNIC) was started with funding from IBM to administer and answer user queries. When IBM funding ended in 1987, BITNET members contributed to continuing BITNIC. Non-IBM computers, many of them DEC VAX machines joined BITNET with an appropriate communication protocol. Eric Thomas, a student of Ecole Supérieure d'Electricité in Paris, developed software named LISTSERV for BITNET in 1986. This software maintained and managed emailing lists without human intervention. It also automated the administration of discussion groups, mass mailings, and maintained a searchable index of previous discussions.

By 1990, BITNET had around 500 US universities and 1400 universities in 49 countries worldwide as members. TCP/IP protocol was being standardized around this time. BITNET was merged with CSNET in 1989 and the new network was called Corporation for Research and Educational Network (CREN). CREN continued to function until 1991 when it was merged with NSF net.

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ARPANET Evolution

In the summer of 1975, the ARPANET which was funded by the DoD as a research project was terminated. ARPANET was handed over to the Defense Communications Agency of the US government. Starting in 1979, the ARPANET gradually shifted from the Network Control Program to TCP/IP. In 1983 ARPANET was split into two parts; a civilian ARPANET and a defence network MILNET. The civilian net had 45 hosts mostly universities and government research laboratories. On 1 January 1983 (called the "flag day") ARPANET discontinued using NCP permanently and shifted to the TCP/IP protocol. DoD made TCP/IP the stan-

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dard communication protocol and encouraged all computer vendors to implement TCP/IP in their operating systems. Bill Joy, a graduate student at the University of California, Berkeley, incorporated TCP/IP into the Unix operating system. By 1983 TCP/IP had become the standard to interconnect diverse computer networks. Meanwhile, NSF started expanding its network as we will see in what follows and ARPANET nodes were connected to it. ARPANET was officially closed in 1990.

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The Evolution of NSFNET

NSF which was reluctant to fund infrastructure projects until the late 1970s, changed its policy after the success of CSNET. NSF found that networking led to increased basic research output due to better communication and collaboration among computer scientists in universities. Merit network that was funded partially by NSF also became a successful regional network. Both these projects started with seed funding from NSF became self-supporting. This experience led NSF to fund a much bigger country-wide network that eventually became the backbone of the Internet.

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National Supercomputing Facilities

Researchers in the US were upset that they did not have access to supercomputers made in the US, whereas their European colleagues had easy access to them. In 1982, NSF, DoD, NASA, and the Department of Energy of the US government set up a panel of 15 members that included representatives of academia and government research laboratories under the chairmanship of Professor Peter Lax of the New York University to advise the government on providing access to supercomputers to researchers in science and engineering in the USA. The panel submitted a report [4] in December 1982 and recommended that all researchers in science and engineering should have easy access to supercomputers through high bandwidth connections. The panel also recommended the allocation of more funds for research in computational mathematics, algorithms, and software necessary for the

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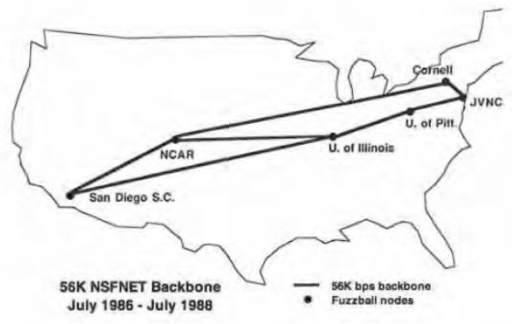

Figure 3. NSFNET with 6 nodes (Figure courtesy NSF).

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effective and efficient use of supercomputers. Based on these recommendations NSF allocated a budget of US$ 200 million in 1984 to set up supercomputer centres and invited proposals from universities. This resulted in the establishment of five supercomputer centres beginning in 1985. They were the Cornell Theory Centre at Cornell University, the John Von Neumann Centre at Princeton University, the National Centre for Supercomputer Applications (NCSA) at the University of Illinois at Urbana-Champaign, the San Diego Supercomputer Centre at the University of California, San Diego, and the Pittsburgh Supercomputing Centre as a joint project of Carnegie Mellon University, the University of Pittsburgh, and Westinghouse. Immediately NSF appointed Dennis Jenkins to establish NSFNET to connect these supercomputer centres and the National Centre for Atmospheric Research (NCAR) at Boulder, Colorado funded by NSF. A 56 Kbps leased line connected these six centres using TCP/IP protocol as the standard in 1986 with technical consultation provided by NCSA, the University of Delaware, and Merit networks. DEC LSI-11/73 minicomputers, with TCP/IP software called Fuzzball (written by David Mills of the University of Delaware), were used as routers. BBN technologies managed NSF Network Services Centre and assisted end-users of NSFNET. The NSFNET backbone is shown in *Figure* 3.

Starting in 1985 and until 1987, NSF assisted in the creation of several Regional Computer Networks connecting universities in various geographical areas in the USA. These included BARRNET in the San Francisco Bay Area, MIDnet in the US Midwest states, Northwest Net, NYSER net in New York State, Sequinet in Texas, WESTnet in Rocky Mountain states, SURAnet in the southeast US, and Merit Net of Michigan. These regional networks were connected to NSFNET's 56 Kbps backbone. By 1985, PCs and workstations with TCP/IP software were available at a reasonable cost and they were connected to campus-wide Local Area Networks (LAN) using the Ethernet protocol. These campus networks were connected to the Regional Networks near them. Most researchers in the universities were using PCs and workstations for their work and could access supercomputers of their choice connected to NSFNET via LAN and the regional network. This three-level network configuration (See *Figure* 4) allowed easy communication and collaboration among researchers in almost all the universities in the USA. By the end of 1986, more than 10000 computers were connected to NSFNET leading to increased traffic on the network. The backbone speed of 54 Kbps was too low to accommodate this traffic leading to network congestion and user frustration due to the long waiting time to get a response from the computers. Consequently, NSF decided in early 1987 to increase the speed of the backbone to 1.54 Mbps, a huge increase. Experience in installing such a high-speed network called the T1 network was scarce. Six organizations responded to the request for proposals to build the network. The best was from a consortium led by Merit Networks with IBM, and MCI (a communication company) as partners. Merit provided research input and acted as the operations manager and user support. IBM provided the routers and software. MCI provided the communication system. The consortium's bid to NSF was $14 million which was $10 million less than the next lowest bid. This low bid was due to a grant of $5 million to Merit by Michigan state to get this prestigious project and provide employment in Michigan. MCI also reduced their cost by $6 million and IBM by $10 million. The motivation of IBM was to be able to participate with universities and learn in-depth the use of TCP/IP protocol in inter-networking. For MCI it was a pioneering project as such a high-speed network was not existing and there were promising future opportunities. The consortium did a commendable job and

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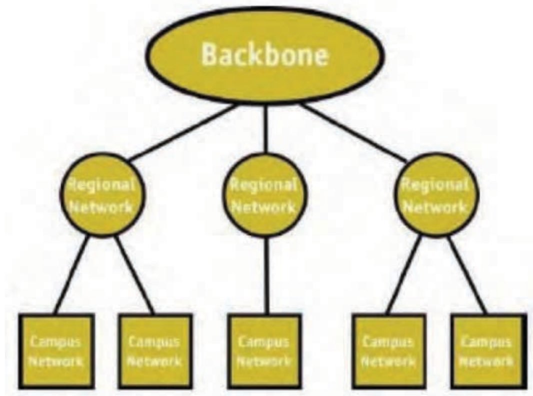

Figure 4. NSFNET backbone connected to Regional Nets and to member university networks (Figure courtesy NSF).

As the T1 backbone speed was high NSF decided to permit universities in several overseas countries (connected to their respective countries' education and research networks) to connect to NSFNET. This allowed international collaboration of researchers in the USA and the NSFNET was transformed into a global Internet.

the new T1 backbone was ready by July 1988 [5]. When the T1 backbone was ready for operation, the regional networks had increased to 13 connecting 170 campuses in the US and were carrying 152 million packets per month. Usage was increasing at the rate of 10% each month. As the T1 backbone speed was high NSF decided to permit universities in several overseas countries (connected to their respective countries' education and research networks) to connect to NSFNET. This allowed international collaboration of researchers in the USA and the NSFNET was transformed into a global Internet.

Privatization of the NSFNET

The Merit consortium decided in June 1990 to build a 45 Mbps T3 network to replace the T1 backbone.

In parallel with the growth of NSFNET, several private Internet Service Providers (ISP) started email and other Internet services. The proliferation of PCs increased the demand for their services. NSF enunciated an elaborate Acceptable Use Policy (AUP) of NSFNET and communicated it to all the users of NSFNET. As NSFNET was publicly funded, no private or commercial use was permitted. This policy of NSF prevented industries from sending even emails to entities connected to NSFNET. Many grey areas emerged. Some regional networks allowed commercial use without using the NSFNET backbone. The ISPs improved their backbones and cooperated to share traffic with appropriate settlement policies among them. By 1990, the T1 backbone of NSFNET had been successfully operated and most universities were connected to it. ARPA decided to close its network in 1990. It was also clear that the T1 network would be congested soon as traffic was doubling every seven months. Foreseeing this, the Merit consortium decided in June 1990 to build a 45 Mbps T3 network to replace the T1 backbone. As this transition was expensive and the consortium saw future commercial traffic on this network it decided to form a new not-for-profit company Advanced Network and Services (ANS) with the same partners. IBM and MCI pledged to invest several million dollars in ANS. Merit informed NSF that it would subcontract all services to ANS and will take overall responsibility for operating the network. NSF accepted this arrangement in September 1990 as it felt that it may not be able to invest as much as the consortium would. It allowed ANS to charge for commercial use of the net and the money collected was to be reinvested in improving the network infrastructure. This was the beginning of the transition of the NSF network towards a private network. Meanwhile, the number of regional networks increased to 16. In May 1991, ANS decided to start a for-profit subsidiary named ANS CO + RE (Commercial + Research and Education) to provide a purely commercial service using the T3 backbone. This decision took other ISPs by surprise as they felt it was unfair competition. Universities were also unhappy as they felt that their cost of using NSFNET would increase. An enquiry ordered by the US government cleared NSF of any blame as its long-range goal was to privatize the Internet [6]. A compromise was reached and it was decided to allow ISPs to use the T3 backbone. The transition to semi-commercial operation diluted the AUP of NSF and commercial use of NSFNET started.

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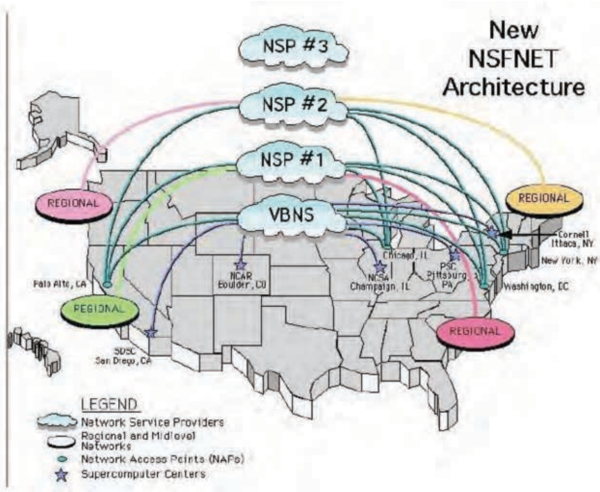
Meanwhile, in 1991 the US Congress passed the High-Performance Computing Act steered by congressman, and later Vice-President, Al Gore. This act envisaged building a National Research and Education Network (NREN) that would connect all libraries and high schools, besides colleges. NSFNET was reframed as "interim NREN" and asked to upgrade its backbone and regional networks to allow new members to connect to it. As NREN was

Figure 5. NSF Network in April 1995 (Figure courtesy NSF).



NSF decided in May 1993 not to have a new NSF-funded backbone. Instead, NSF asked the Regional and local networks to buy backbone services from commercial ISPs. NSF decided to fund the building of four routers called Network Access Points (NAP) to connect the ISPs to exchange traffic among them and a separate very high-speed Backbone Network Service (vBNS with a speed of 155Mbps) primarily to connect the supercomputer centres.

to be funded by the US government, NSF was in a dilemma as it was gradually privatizing the Internet. A debate started about whether to upgrade the backbone net to a higher speed of 45 Mbps to accommodate the impending extra traffic.

After extensive consultation and public debate, NSF decided in May 1993 not to have a new NSF-funded backbone. Instead, NSF asked the Regional and local networks to buy backbone services from commercial ISPs. NSF decided to fund the building of four routers called Network Access Points (NAP) to connect the ISPs to exchange traffic among them and a separate very high-speed Backbone Network Service (vBNS with a speed of 155Mbps) primarily to connect the supercomputer centres.

NSF awarded contracts in early 1994 (based on competitive bidding) to four companies for NAPs, to MCI to build vBNS, and to Merit and the University of Southern California's Information Systems Institute to manage routing in the entire network. The new network (*Figure* 5) started working in early 1995 and the T3 backbone was closed in April 1995 signalling the closure of NSFNET and the beginning of the Internet. The budget that was allocated for NREN was diverted to developing applications of the Internet for education.

Domain Name System

The number of ISPs grew with the privatization of the Internet in the USA. The bigger operators did have an advantage but there was no monopoly. The US government decided not to appoint a regulatory body to oversee the Internet. The policy of NSF to allow other countries in the world to join the Internet led to its rapid worldwide growth. The invention of the World Wide Web in 1989 and search engines in 1990 led to a huge increase in the use of the Internet, which became an essential infrastructure in the World. Numerous problems arose with the rapid growth of computers connected to the Internet. A major problem was assigning addresses to computers connected to the Internet to ease communication. Domain Name System was invented to solve this problem which I discuss in this section.

The US government decided not to appoint a regulatory body to oversee the Internet. The policy of NSF to allow other countries in the world to join the Internet led to its rapid worldwide growth. The invention of the World Wide Web in 1989 and search engines in 1990 led to a huge increase in the use of the Internet, which became an essential infrastructure in the World.

In the early days of ARPANET, each computer connected to it was given a numerical address and a name that was easy to remember. For example, the host at the Stanford Research Institute was called SRI. When the TCP/IP protocol was standardized IP addresses were assigned to the computers. A mapping of host names of computers connected to the ARPANET and their IP addresses was kept in a file named HOSTS.TXT at the Network Information Centre (NIC) of the SRI. Elizabeth Fainler of SRI updated this file regularly based on information sent by members (i.e., host computers connected to ARPANET) and all the members copied it for their use. This informal manual process was cumbersome and error-prone. As the number of hosts in ARPANET increased, the file HOSTS.TXT became large, unmanageable, and frequently out of date. The problem worsened when CSNET joined ARPANET. Jonathan Postel at the Information Sciences Institute of the University of Southern California (ISI-USC) managed RFC and IP addresses on behalf of ARPANET. He decided to automate the process of registering host names and their addresses and requested his group members to propose solutions. His group members proposed five solutions. He asked Paul Mockapetris, who was a doctoral student in his group, to select one of these. Mockapetris, instead, sug-

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Figure 6. **(left)** Jon Postel (Photo courtesy of postel.org) **(right)** Paul Mockapetris (Photo courtesy of isi.edu).

gested another solution which he called the Domain Name System (DNS). His idea was to map the IP address of a host that was a string of digits in a dotted-decimal format, for example, 192.168.0.105 to an orderly meaningful string of characters using a directory service. Mockapetris, Postel, and Craig Partridge of BBN refined the initial version of DNS in November 1983. In October 1984, Postel and Joyce Reynolds of USC proposed the idea of thirteen generic Top-Level Domain Names (gTLD). Some of them are .com for commercial, .edu for education, .org for non-profit, .gov for government, .mil for military, etc. A typical domain name is cs.wisc.edu (Computer Science Department of the University of Wisconsin, Madison, WI, USA). When the Internet became international one more component was added as the right-most part of a domain name to indicate the name of the country where the host computer is located. This part of the domain name is, for example, .in for India, .ca for Canada, and .uk for the United Kingdom. For example, the domain name of the Indian Institute of Science, Bengaluru is: iisc.ac.in

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Assigning Domain Names

The task of assigning domain names, maintaining RFCs, and a help desk for user queries was the responsibility of Postel (ISI-USC) who used the services of SRI NIC until 1991. In 1991, DoD contracted these services to Government Systems Inc. as the system was growing. The situation changed when the US government gave NSF the responsibility for managing the Internet based on an act passed by the US Congress in 1991 (commonly known as the Gore Act, as Senator and later Vice President of the USA,

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Al Gore steered it). In 1993, NSF decided to outsource these tasks (for five years) to three organizations based on competitive bids. The task of registering domain names was given to a company named Network Solutions Inc. (NSI), maintaining directory and databases to AT&T, and providing general information and a help desk to General Atomics. The performance of General Atomics was found poor based on a review and consequently, the tasks it performed were given to AT&T. NSI registered domain names in the generic Top-Level Domains (gTLD) and maintained a directory of IP addresses of these names. Domain names were given on a first-come, first-served basis. Domain name registration was free.

The commercial importance of domain names was realized with the emergence of the World Wide Web (WWW). The demand for domain names rapidly increased with many commercial organizations wanting to register their names.

Meanwhile, an organization named Réseaux IP Européens Network Coordination Centre (RIPE NCC) was established in 1992 in Europe to manage IP addresses and domain names in European countries. In 1993 Asia Pacific Network Information Centre (APNIC) was established in Japan to assign IP addresses and domain names to its region.

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The controversy over the registration of domain names led to the formation of an International Ad Hoc Committee (IAHC) in September 1996 to find a solution. This committee had besides NSF and NSI, World Intellectual Property Organization (WIPO), International Telecommunication Union (ITU), and the US Federal Networking Council as members.

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Consequently, in September 1998, IANA and NSI collaborated and released articles of incorporation and bye-laws for a new not-for-profit company named the Internet Corporation for Assigned Names and Numbers (ICANN). NTIA approved the establishment of ICANN with the power to supervise its activities. ICANN was incorporated in California on 30 September 1998 in the premises of IANA. Jon Postel actively participated in the establishment of ICANN and was slated to become its founding Chief Technology Officer (CTO). Unfortunately, he suddenly died on 16 October 1998.

Internet Corporation for Assigned Names and Numbers (ICANN)

Following the establishment of ICANN, NSI lost its monopoly. The registry and registrar functions were separated. Five new registrars were appointed and NSI was asked to allow these registrars to access the registry. Even then NSI was considered a valuable company as it had around 8 million customers. Verisign, a security company, acquired it for US$ 19.3 billion [8] in 2000! Slowly more registrars were added. Today there are around 1000 registrars. The cost of registering domain names is a few dollars and sometimes free if a customer buys other services from the registrar.

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One of the early decisions of ICANN was the separation of the management of IP addresses and Domain Names. Apart from the American Registry of Internet Numbers (ARIN), RIPE NCC for Europe, Central and West Asia, and APNIC of Asia Pacific, two more registries– one for Africa (AFRINIC), and the other for Latin America and the Caribbean islands (LATCNIC) were added and given a set of IP addresses and limited freedom to assign domain names. The status of ICANN has been shaky right from its inception. It was incorporated as a not-for-profit corporation with a broad-based "multiple stakeholder" board of directors devising policies. NTIA of the US government supervised ICANN's activities. A tussle between ICANN and international organizations such as ITU to gain control of DNS ensued. In successive meetings of the World Summit on Information Society and the Internet Governance Forum, held between 2006 and 2011, the functioning of ICANN was discussed. Based on suggestions in these meetings ICANN permitted the use of non-Roman scripts such as Arabic, Chinese, Hindi, and Tamil, among others, in domain names. Many more Top Level Domain (TLD) names such as .ai, .consultant , .xxx (for adult content) were added – some not very wise – for example, .sucks (American slang for highly unpleasant or disagreeable). There are around 1500 TLDs in 2021. ICANN charges huge fees (US$ 185,000) for TLDs. In 2014, NTIA formally relinquished control of ICANN. ICANN is now a self-sustaining not-for-profit corporation incorporated in California answerable to international stakeholders.

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Box 1. Internet in India

Research on computer networking started in India in 1986 when the erstwhile Department of Electronics (DoE) of the Government of India with the assistance of the United Nations Development Programme (UNDP) funded a project called Education and Research in Computer Networking (ERNET) at the National Centre for Software Technology (NCST), Bombay, Indian Institute of Science, Bangalore, Indian Institutes of Technology Bombay, Delhi, Kanpur, Kharagpur, and Madras. Each institute initiated research in computer networking and designed local area networks in their respective institutions. Another objective was to network these eight institutes and the DoE to exchange emails. The ERNET teams connected NCST's mainframe computer (VAX 8600) with computers at IIT, Bombay and Delhi in 1987 using dial-up telephone connections. By 1988 all the other centres (except IIT/Kanpur which had a poor telephone system) were connected to NCST by dial-up telephone. NCST established a telephone connection (X.25) to the Centrum Wiskunde & Informatica (CWI) in Amsterdam in 1987. CWI had a router that connected it to the Internet. This enabled the ERNET members to send and receive emails from colleagues worldwide. ERNET was in turn connected to some other education/research institutes in India that now had access to email. The ERNET members were inter-connected by 9.6 Kbps leased telephone lines during 1991–92. In 1988, NCST was connected by a 4800 bps dial-up line to an Internet host in Virginia, USA. This was upgraded to a 9600 bps analog leased line in 1989 and to a 64 Kbps leased line in 1992 funded by the DoE. This was the beginning of a reasonable Internet experience for ERNET members [9]. In 1988, NCST started registering domain names with the top-level domain of .in on behalf of the ERNET.

On 15 August 1995, Videsh Sanchar Nigam Ltd. (a government monopoly for overseas telecommunication services) started providing Internet service commercially. It was a 9.6 Kbps connection and was quite expensive. Soon there was clamour for faster and cheaper Internet service from the growing Indian software industry. In 1998 private ISPs started providing Internet services using dial-up modems and soon many Internet Cafes were established in the metros. It took till 2004 for the Government of India to develop a cogent policy for broadband (> 256 Kbps) services. By 2020 Internet came of age in India with more than 700 million Internet users with an average broadband download speed of around 50 Mbps.

Internet Governance [10]

You may be wondering who controls the Internet and decides the policies on its use. It is a vast subject on which books have been written. It is also contentious with the continuing international debates and disagreements. Under the aegis of the United Nations, two World Summits on the Information Society (WSIS) were held in Geneva in 2003 and Tunis in 2005. One of the outcomes was a definition of Internet Governance that states "Internet Governance is the development and applications by governments, the private sector, and civil society, in their respective roles, of shared principles, norms, rules, decision-making procedure, and programmes that shape the evolution and use of the Internet".

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I will explain the current status of Internet Governance briefly in what follows. The internet is made up of four layers. They are:

- The physical layer. It is the communication system consisting of cables, wireless, etc., within a country and those connecting the countries of the world. The communication systems of a country are governed by the laws/policies of that country's government. The communication system interconnecting countries of the world have evolved over centuries and the interconnection protocols and charges are agreed upon among the countries and overseen by the International Telecommunication Union (ITU).

- The logical layer. It ensures orderly communication between computers connected to the Internet. Assigning IP addresses to computers, communication protocol (the universally accepted TCP/IP protocol) to interconnect computers, and the Domain Name System are part of this layer. The governance of this layer is the most contentious. In 1986 an Internet Engineering Task Force (IETF) was formed by the Internet pioneers with the financial support of the US government to develop and maintain Internet protocol standards. Currently, IETF is the international Internet standards body that develops Internet protocols and proposes standards for orderly networking. It holds regular meetings and documents the standards. Internet Research Task Force (IRTF), another international group, promotes research on protocols, applications, and architecture. The Internet Architecture Board (IAB) oversees the IETF and the IRTF. It also appoints the editor of RFCs. In 1992, an international professional society with open membership named Internet Society was formed. IETF, IRTF, and IAB became part of the Internet Society in 1993. All technical decisions are arrived at by consensus among the members. At present ICANN allocates IP addresses to the five Regional Internet Registries (RIR), sets policies on domain names, and allocates top-level domain names. At the Tunis Summit of WSIS in 2005, it was decided to establish the Internet Governance Fo-

At the Tunis Summit of WSIS in 2005, it was decided to establish the Internet Governance Forum (IGF), a multi-stakeholder open international forum, to debate governance issues of the Internet. It was also recommended that ICANN be transformed into a multi-stakeholder global body with the authority to manage DNS.

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- The applications layer. It consists of major applications such as browsers, email, World Wide Web (WWW), search engines, and social media. Browsers, email, and search engines are provided by several vendors and there are no standards. World Wide Web Consortium (W3C) was founded at MIT in 1994 with Tim Berners-Lee, the inventor of the World Wide Web, as its chairman. W3C consists of around 400 members and maintains fulltime staff. It develops standards for the Web and is an open forum for discussions on the Web.

- The contents layer. It consists of data stored on the internet. Governance of contents is contentious and as of now, there is no specific international law in this area. Even though many feel that contents should be "open", most countries have laws regulating it. Governments block websites that they consider undesirable. Currently, laws exist for the protection of intellectual property rights and trademarks. There are no easy solutions for problems such as spying and cyber attacks by individuals, organized criminal groups, and governments.

Box 2. What is Net Neutrality?

Internet access has become an essential requirement in today's world. Internet Service Providers (ISP) wield a lot of power and responsibility in providing access to information on the Web. Some ISPs started filtering selectively some information and slowing down access to certain types of data such as video. This led to the need to regulate ISPs by governments requiring them to ensure "Net Neutrality". Net neutrality requires ISPs to treat all communications using the Internet without discrimination. In other words, the charges for contents, applications, types of data (text, audio, video), and the source/destination address should be uniform. In India, the Government's policy requires ISPs to maintain net neutrality.

Box 3. Internet Timeline

1967: ARPANET project approved for funding.

1969: Four-node Packet Switched Network starts working.

1971: ARPANET connected to University College, London by satellite. The first email message sent on ARPANET.

1972: International Computer Communication Conference. Fifty-node ARPANET using packet switching demonstrated.

1973: PRNET and SATNET ready.

1974: Transmission Control Protocol v1 was invented.

1975: Ethernet LAN built at Xerox PARC. ARPANET was declared operational.

1977: PRNET, SATNET, and ARPANET connected using TCP/IP protocol.

1980: Transmission Control Protocol/ Internet Protocol v4 stable version ready.

1981: CSNET and BITNET start functioning. CSNET connects with ARPANET using TCP/IP. ARPANET project funding stopped. No new ARPANET nodes.

1983: TCP/IP made the standard protocol and old protocols discontinued. Domain Name System (DNS) invented.

1986: NSFNET starts with six nodes and 54 Kbps links. Internet Engineering Task Force formed.

1988: NSFNET connects 170 universities using a 1.54 Mbps (T1) backbone.

1989: CSNET and BITNET merge to form Corporation for Research and Educational Networking (CREN)

1990: NSFNET upgrades to a 45 Mbps backbone and adds more universities and national laboratories. Starts gradual privatization.

1991: World Wide Web software released. CREN merged with NSFNET.

1992: Internet Society formed.

1993: DNS outsourced to a private company by NSF. IETF, IRTF, and IAB become part of the Internet Society.

1995: NSFNET closed and transforms into the Internet.

1998: ICANN incorporated.

2005: WSIS Tunis meeting. Decides to form IGF and internationalize ICANN.

Conclusions

I have traced in this brief history how an experiment to connect computers in four institutions in the USA to share their resources in 1969 evolved to become an essential "information infrastructure" of the world today. ARPA (now called DARPA (Defense Advanced Research Projects Agency)) of the US DoD initially

Box 4. Summary of Early Networks

Network name	Sponsor	Operational	Objective	Ceased
ARPANET	DARPA	1969	Resource sharing	1990
Merit Network	NSF & Michigan State	1973	Sharing resources of Michigan State Universities	Merit Continues
CSNET	NSF	1981	Connecting CS Dept. of universities and ARPANET	1991
BITNET	IBM	1981	Email and files between universities	Merged with CSNET 1989
NSFNET	NSF	1986	Share Supercomputers email, and files	1995

The managers in ARPA who were disbursing the funds were themselves researchers who picked the right recipients and worked with them providing valuable knowledge and experience.

funded interconnecting computers in universities and research-oriented companies all over the USA. The managers in ARPA who were disbursing the funds were themselves researchers who picked the right recipients and worked with them providing valuable knowledge and experience. Notable ARPA research managers were Larry Roberts, Robert Kahn, and later Vinton Cerf. When the project met its goals, the research results were used by universities and many start-up companies for further development and commercialization. A major goal of the networking project when it started was sharing the resources of computers connected to the network. However, it turned out that email and sharing information stored in computers in the network became the most popular applications. The "open" culture promoted by early leaders of the network research groups (eschewing patents and publishing RFCs) led to the fast development of the Internet. NSF, which was reluctant to fund infrastructure projects, changed its policy when it found that information interchange among researchers promoted by networking increased their productivity. NSF network which was built primarily for researchers was gradually privatized to allow everyone to use the infrastructure leading to the fast growth of the Internet. NSF's open policy of allowing international scientific collaboration led to the spread of the Internet from being a US network to one that became international. The invention of the World Wide Web, an important application of the Internet, rapidly increased the utility of the Internet. The Internet soon became an essential international infrastructure. With this development, the governance of the Internet has become a major concern of all countries in the world. Currently, the Internet Society oversees the technical issues of the Internet including standardization. The Internet Governance Forum of the United Nations debate issues related to its orderly growth. However, many contentious issues such as the assignment of domain names and net neutrality are not fully resolved.

NSF's open policy of allowing international scientific collaboration led to the spread of the Internet from being a US network to one that became international.

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Suggested Reading

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Address for Correspondence
Prof. V. Rajaraman
Supercomputer Education & Research Centre
Indian Institute of Science
Bengaluru 560 012, India.
Email: rajaram@iisc.ac.in