



Leonard Kleinrock

Internet Pioneer

Dr. Morten Bay
USC Annenberg School of
Communication

The emergence of the Internet has profoundly affected our existence and the world we live in. Rooted in the efforts of a small group of people who had a vision and performed the intense labor necessary to realize it, the Internet has grown into a technological movement born of the collaborations of its contributors. One of those essential early figures in the Internet's history is Leonard Kleinrock. Morten Bay describes Kleinrock's remarkable life and career as a co-creator of one of the greatest inventions in human history.

The emergence of the Internet has profoundly affected our existence and the world we live in. Despite its dark corners and inequities, the Internet has mostly been a benefit to humanity, allowing information to instantly travel further than any technology before it, creating new economic opportunities, and bringing people together into a truly global community. Its advent has justly been compared to that of Gutenberg's printing press, which also made knowledge cheaper, faster, and easier to distribute, while creating new markets and increasing the awareness and education of people who had previously had limited access to such resources.

The Gutenberg press ushered in the Renaissance, a transitional moment in history which shaped the world for hundreds of years. Yet those who led that charge were probably unaware that their actions would resonate through the centuries. Our current perception of the Internet's impact is probably a similar underestimation. Perhaps fifty years from now, when the Internet has seen its first century, the

resemblance between its effects and those of the Gutenberg press may be clearer to us. From that future vantage point, we should be able to truly recognize how the Internet accelerated decisions in business and politics and how it transformed exchange, distribution, and the sharing of goods and resources.

This year, for the first time in human history, a pandemic did *not* stop the world in its tracks. Although the consequences of COVID-19 have been devastating, business, education, healthcare, government, and simple socialization, albeit without physical proximity, continued. *Life* continued. And it was in large part because of the Internet.

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The modern Internet is a technological behemoth born of the collaborations of thousands, if not millions, of contributors and active participants. But like the Renaissance, it began with a small group of people who thought just a wee bit ahead and devoted themselves to the intense labor of realizing their vision. Leonard Kleinrock is one of those people.

Dr. Leonard Kleinrock was born in New York City on June 13, 1934. As a child, he visited the 1939 World's Fair and was enthralled by the many visions of future technology on display. A year later, the young Kleinrock built the first

of his many electronics projects, a crystal radio constructed from abandoned equipment and scraps of older radios. Already, it was clear that his future would involve technology. Kleinrock graduated from the Bronx High School of Science in 1951. While working during the day, he spent his evenings among former college dropouts, G.I. Bill veterans, and driven but underprivileged youngsters like himself. He was pursuing an electrical engineering degree at the City College of New York. Having been graduated from CCNY in 1957, Kleinrock received a full scholarship to the Massachusetts Institute of Technology (MIT) where he earned a master's degree in 1959 and a Ph.D. in 1963, both in electrical engineering. His doctoral committee included Dr. Claude Shannon, famous for his groundbreaking work on information theory and mathematical theories of communication.

Kleinrock contributed to the development of technologies that now underpin most networked data transmissions, including the Internet.

While at MIT, Kleinrock worked with a group of doctoral classmates which included fellow computing and Internet pioneers Lawrence Roberts and Ivan Sutherland. All three used the large TX-2 computer at MIT's Lincoln Laboratories and, in this common work environment, forged a lifelong bond of friendship. Kleinrock developed a mathematical theory of packetized data in networks for his doctoral dissertation. He expanded upon queuing theory to explore ways to model, analyze, and optimize these data networks. Most vitally, he realized

that routing data through fixed network paths, the default method used in the telephone system of the time, was inefficient, since data were transmitted in bursts. Instead, he proposed a routing concept in which network resources could be shared and allocated on demand. While exploring ways to route messages more efficiently and reliably, Kleinrock struck upon the idea of splitting them up into smaller blocks of data that could be routed independently through any available network connection and reassembled upon arrival. He evaluated the performance gains of packetization, providing a mathematical foundation for the technology which now underlies nearly all networked data transmissions and supports the Internet as we know it. Kleinrock's dissertation and its related publications elaborated upon his theory and proved that his system would be more efficient and reliable than most routing methods then available. In 1964, Kleinrock published this and other concepts in communication network theory from his dissertation in *Communication Nets – Stochastic Message Flow and Delay* from McGraw-Hill.

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By that time, Kleinrock had joined the faculty at the University of California Los Angeles' Department of Computer Science. In 1967, the Defense Advanced Research Project Agency, or DARPA (then ARPA), tasked Lawrence Roberts with planning and managing the construction of ARPANET, the

world's first network of heterogeneous computers. Roberts brought Kleinrock on board, the two of them having worked together since the MIT days. Kleinrock was instrumental in bringing packet switching to the network, one of the decisions that made ARPANET a stunning success. The network quickly spawned a plethora of copycat networks which would eventually come together into the Internet we now know. Kleinrock personally oversaw ARPANET's first connection on October 29, 1969, when a Sigma 7 computer at UCLA logged on to a PDP-1 computer at the Stanford Research Institute. In subsequent years, Kleinrock led the team which meticulously analyzed and measured the nascent network's efficiency and function. Throughout the 1970s, their work produced a host of groundbreaking research publications and important advances in computer science. Several graduate students who passed through Kleinrock's ARPANET lab at UCLA became Internet pioneers in their own right. Among them are Vint Cerf, co-author of the TCP/IP protocols, Steve Crocker, who invented the Request for Comments series, and Jon Postel, who pioneered the global allocation of IP addresses.

In 2018, Kleinrock revisited and extended a 1979 paper, introducing the concept that power is the key metric when optimizing flow in packet networks. The paper presented a better approach to TCP/IP congestion control and persuaded Google to adopt the power metric when it redesigned the YouTube network. Kleinrock also introduced the innovative concept of nomadic computing in a 1995 paper. He has received countless awards and accolades, including the National Medal of Science (2008), The National Academy of Engineering's Charles Stark Draper Prize (2001), The Marconi Prize

(1986) and the Swedish Ericsson Award (1982).

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In 1988, Leonard Kleinrock chaired the National Research Council committee upon whose report then-Senator Al Gore based his 1991 High Performance Computing Act. The bill dramatically improved computer network infrastructure across the U.S. and paved the way for the Internet's current ubiquity. While continuing his professorship at UCLA, Kleinrock has founded several successful companies. One of the first was Linkabit, founded with Dr. Andrew Viterbi, then a colleague at UCLA, and Irwin Jacobs. Viterbi and Jacobs went on to found Qualcomm. Kleinrock also founded Nomadix, Inc., which produces network gateway equipment. He currently leads TTI/Vanguard, another of his companies, which provides a membership-based

forum for high-level executives in the technology industry. Kleinrock is now a distinguished professor emeritus at UCLA which, in 2020, awarded him the UCLA Medal for his service to the university, an institution to which he has devoted himself for more than five decades. ■



Dr. Morten Bay is a research fellow at the Center for the Digital Future at USC's Annenberg School of Communication, where he also teaches. He has written three books, many research papers and countless news articles about Internet ethics, socioeconomic effects of technology, social media politics, and Internet history.