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Virtual cut-through: A new computer communication switching technique

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Editorial

Professor Leonard Kleinrock – Tribute Volume

Professor Leonard Kleinrock will celebrate his 80th birthday this year which presents an excellent opportunity to prepare a special tribute – a special edition of Computer Networks. The articles in this issue were contributed by his former students, friends, and colleagues in recognition of his contributions to queueing theory, packet switching, computer communication networks and the development of the Internet and related network technologies.

The editors for this issue contacted some of his former Ph.D. students and asked if they would be willing to contribute an article related to their research with Professor Kleinrock and to reflect on how that work has impacted the development of communication networks and related fields. In their contributions, many commented on how his teaching style, approach to research mentorship and the overall cordial relationship that he encouraged among his Ph.D. students have had an enormous impact on their professional lives and careers. Those that had the opportunity to work closely with Len at UCLA all commented on how they cherished their years in Boelter Hall (home of the computer science department at UCLA). ***These sentimens are well captured by the following personal recollection by one of us:***

> In June 1994 I had the privilege of participating in Professor Leonard Kleinrock's 60th birthday celebration, as his former student. His former students and participants had been previously asked to write short paragraphs which were collected and presented to Len.
> I recalled that in 1972, when I was studying for my Masters at the University of Waterloo, Canada, I met Professor Kleinrock when he gave a seminar about the, then, new technology called Packet Switching and the ARPAnet. It was a fascinating talk (typical of his classes). I literally fell in love and taken away by his enthusiasm, charisma and clear explanation of the complicated subject. I then applied at UCLA to pursue my Ph.D. studies and was fortunate to have him as my advisor. His teaching and friendship changed me and have a drastic impact in my life. I can attest that the event of seeing him for the first time be an "inflection" point in the curve of events in my life; and that is what I wrote in my reflection for Len in 1994. I thought I was the only one with this experience. During the celebration, I had a chance to read about his other students' reflections. I realized that ALL had the same experience, they met Len, fell in love, and that changed their lives; all of them, with no exception!
> I, like his other students, was fortunate and greatly benefited in having him as an advisor and a friend. I am privileged to be a member of a family that keeps growing and benefiting others. Paraphrasing what Yechiam Yemini (my academic brother) wrote, "Thank you Len for all these wonderful gifts that keep on giving."
>
> [– Parviz Kermani]

An excellent overview of Len's early life and career can be found in the oral history collected by the IEEE [1] in 2004. He completed his Ph.D. at MIT in 1963 with a dissertation, published as a book in 1964 [2], that developed a modeling framework for understanding the stochastic behavior of packet-switched networks. The first operational network using packet-switched technology was the ARPAnet in 1969 – a project under the direction of Professor Kleinrock at UCLA [3]. This emergent technology caught on and expanded steadily to become a nationwide facility for research use. Some early work on the performance of the ARPAnet can be found in [4]. The network continued to grow and eventually morphed into the Internet that we know today [5,6]. It is no exaggeration to say that the developments leading from the ARPAnet have had an impact on society comparable to, if not greater than, the Industrial Revolution.

Len's contributions are hard to quantify because of their breadth – he was one of the key founders of the use of stochastic models for the study of packet switched networks and related communication systems. His two books on queueing theory [7,8] were the standards for use in University courses in network performance modeling throughout the 1970s and 1980s and are still in use today. Over his career, he has published over 250 papers in conferences and journals [9] and supervised 48 Ph.D. students [10]; many of whom have gone on to academic careers themselves, with their own progeny of academic descendants.

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In addition to studying the performance of packet networks, his early work established other important results in queueing theory – e.g., optimal bribing for queue position [11], conservation results for priority queueing systems [12], analysis of time-shared systems [13] (with Edward Coffman – his first Ph.D. student).

In order to try and determine which areas of his group's research have generated the most impact and attention by other researchers, we looked at Google Scholar and selected publications for mention that have high citation counts. One of the highest citation counts we found was for work with Fouad Tobagi, on the analysis of Carrier Sense Multiple Access (CSMA) techniques [14,15]. These studies followed on from the studies of Aloha systems by another of Len's students, Simon Lam [16]. This work laid the foundation for protocol design leading to the explosion in wireless networks starting in the 1990s and continuing through today. (Unfortunately, neither Simon nor Fouad were able to contribute an article for this issue – they expressed great regret in being unable to do so.) Related work, extending the analysis to multi-hop radio networks was first studied by Kleinrock and Silvester in [17,18] and expanded to a more comprehensive analysis by Takagi and Kleinrock in [19]. Another highly-cited paper is on "Virtual Cut-Through" by Kermani and Kleinrock [20]. The technology studied in this paper was interesting when studied in the 1970s but did not have an easy way of broad implementation – however, there has been a resurgence of interest with the current focus on Software Defined Networks (SDN). Due to the current interest we are including the original article in this special issue. Fratta, Gerla, and Kleinrock's work on "Flow Deviation" [21], also highly cited, has had a great impact on the study of computer network optimization. The authors agreed to update their paper and include discussion of the application of the techniques to related optimization problems in a paper in this issue [22]. Kamoun and Kleinrock's work on hierarchical routing proposed techniques for managing large networks [23] – their approach can be considered a basis for the routing strategies in use in today's massive scale global Internet. (Farouk Kamoun also regrets that he was unable to contribute an article to this issue). Finally, we mention Len's paper on nomadic computing [24], where he was one of the first to recognize the significance of network access "anywhere, anytime" long before the commercial development of the ubiquitous "smartphone".

The papers mentioned here are the most highly cited according to Google Scholar, which was one of our criteria for including them in our discussion. Most of them were from the early days of packet networking and they have led to new areas of investigation for later researchers to pursue and had a significant impact of the development of networking technologies. We do not mean to ignore more recent work by Len's research group; but space in this issue was limited and, perhaps we can look forward to Len's 90th or 100th birthday celebrations to fully recognize their contributions. Several of the papers that we received for this special issue were authored by more recent members of Len's research group, building on some of his pioneering work to attack more currently relevant problems.

A brief description of the papers in this issue follows:

The first paper [20] is a reprint of the Kermani and Kleinrock's classic paper on "Virtual Cut Through" which has attracted significant additional interest with the advent of high speed flow switching and software-defined networks (SDN). This is followed by an update on "The Flow Deviation Algorithm" [22] by Fratta, Gerla, and Kleinrock (the authors of the original FD paper). They first review the initial development of the algorithm and its application in the design of the ARPAnet as it was expanding and then consider more recent work that has applied similar algorithms to other network optimization problems. In [25], Tychogiorgos and Leung, discuss optimization techniques for utility optimization in communication networks. In [26], Yemini looks at the application of one of Kleinrock's favorite results based on "Power" to study decentralized resource sharing. In [27], Afek, Bremler-Barr, and Schiff, propose recursive techniques for the design of hardware priority queues, such as are needed in high-performance switches and routers. In [28], Ben-Porat, Bremler-Barr, and Levy, consider the problems of efficient design when malicious behavior is taken as a given. They argue that traditional models and optimization techniques ignore malicious behavior which allows the adversary to use simple strategies to attack the network. In [29], Marsan, and Meo, utilize queueing models to study the energy consumption of a campus WLAN. In [30], Ding, Crowcroft, Tarkoma, and Flinck, consider how to use one of the current "hot topics" in networking - software defined networking (SDN) - to improve security in wireless mobile networks – another current "hot topic". In [31], Takagi considers the application of queuing models that were developed to study networks and computer system performance, to study patient flow and optimization in a hospital. Finally in [32], Kurose, looks at the next paradigm shift in networking: first there was telephony and circuit switching, then there was data transmission and packet switching, and now the focus is on content access where the content may migrate through the network to better satisfy demand.

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John Silvester is a Professor of Electrical Engineering at the University of Southern California and is currently serving as Vice-President (President-elect) of the Academic Senate. He was Vice-Provost of Academic Computing from 1994 to 1997 and Vice-Provost of Scholarly Technology from 1997 to 2006. His academic interests are in high speed, optical, and wireless networking. He has supervised more than 25 Ph.D. students and published over 150 technical papers. He is also actively involved in planning, management and implementation of advanced networking for the research and education community at the state, national, and international level. He was a member of the Board of Directors of CENIC (Consortium for Educational Networks in California), was Vice-Chair from its founding in 1997 to 1999 and Chair from 1999 to 2006; and has served on the Network Planning Committee of Internet2.

Parviz Kermani received a B.S. in Engineering, Master of Mathematics (M.M.) and a Ph.D. in Computer Science in 1969, 1973 and 1977, from University of Tehran, Iran, University of Waterloo, Canada and UCLA, U.S.A., respectively. From 1973 to 1978 he participated in the ARPA network project, led by Professor Leonard Kleinrock, at the University of California at Los Angeles (UCLA) and did research in the design, protocol, and evaluation of computer communication networks. Together with Professor Kleinrock they invented the Cut-Through Switching technique which is in use in most high speed switches and routers. He joined IBM at Watson Research Center in 1978 and retired from IBM in 2009. At IBM he did research in the area of computer communication networks and related areas which resulted in number of IBM products and over 15 patents and many of awards. Since 1987 he has been active in the academic circle and has taught courses in computer networking and security at Polytechnic University (now part of NYU). He was a senior research fellow at UMass Amherst in 2009–2010 and a lecturer at that university in the following years. He is now Professor of Information Technology at Guttman Community College of CUNY (City University of New York).