The "Nobel Prize in Engineering" Awarded for the Design of a Feedback Control System

The "Nobel Prize in Engineering" was awarded for the design of a feedback control system.

The Queen Elizabeth (QE) Prize for Engineering was created by the United Kingdom as a global prize for "recognizing and celebrating outstanding advances in engineering that have changed the world." The media commonly refers to this prize as the "Nobel Prize in Engineering," since the prize is open to anyone in the world and is intended to be an engineering counterpart to the well-known Nobel Prize for chemistry, physics, and physiology/medicine. In 2013 the first recipients of the QE Prize for Engineering were five people primarily credited with the development of the Internet and the World Wide Web: Louis Pouzin, Robert "Bob" Elliot Kahn, Vinton "Vint" G. Cerf, Tim Berners-Lee, and Marc Andreesen. More specifically, the first three recipients were recognized for their "seminal contributions to the protocols (or standards) that together make up the fundamental architecture of the Internet," and the latter two recipients were recognized for creating the World Wide Web and the Web browser, respectively.

This main focus of this column is the contributions of Bob Kahn, who designed the rules that govern the way information is passed between computers, that is, the main control engineering task. While working in Cambridge, Massachusetts, in the early 1970s, he developed the initial ideas for what became Transmission Control Protocol (TCP), which controls the flow of information in today's Internet [1], [2]. He structured the overall system to have specialized "control" computers, known as *gateways* (and later as *routers*), whose only purpose is to forward information packets to other computers. An important performance criterion is that the system is *decentralized*, that is, information can be transferred from one computer to another without requiring any centralized controller to manage the transfer. Another important performance criterion is that the system is *fault tolerant*, that is, no portion of the network can prevent information from being transferred in other parts of the network. A third performance criterion is that the system is *robust to time-delay uncertainties*, that is, insensitive to delays in the transfer of information between two computers. In control terminology, Kahn designed a *robust fault-tolerant decentralized control system* for managing information transfer between a large-scale network of heterogeneous computers that communicate with each other. In the early 1970s, Vint Cerf worked with Bob Kahn to complete the early version of TCP [3].

The TCP system designed by Kahn and Cerf employed feedback to ensure the reliable transfer of information between computers. A sequence number is associated with each piece of information to ensure it is placed in the correct order at the destination and to detect any missing pieces of information. The destination computer sends an acknowledgment packet, which is a simple form of feedback, to indicate it has successfully received information from the source computer. Lost information is retransmitted if the acknowledgment packet is not received. Each piece of information is accompanied by a small datum known as a *checksum* that is checked by the destination computer to verify that each piece of information is error free.

Kahn's papers on TCP and related topics were published in a wide variety of venues including *IEEE Transactions on Communications, Proceedings of the IEEE, IEEE Communications Magazine, IEEE Spectrum, Communications of the ACM, Computer Communication Review,* and *Scientific American* [1]–[8]. Although there is no doubt that Kahn employed feedback control principles in the development of TCP, his papers were not published in any control journal. Many possible reasons could be proposed for why this important control work did not appear in a control journal. Most likely he did not submit his work to any such venue. On the other hand, if he had submitted manuscripts on the design of the decentralized feedback control system underlying TCP to any leading control journal at that time, they probably would have been rejected for publication.

Digital Object Identifier 10.1109/MCS.2013.2269738
Date of publication: 16 September 2013

A new journal has been created in the control of network systems.

TCP is an example of control of a networked system, which has been recognized as a relevant and important research area by the control community in recent years. Kahn's receipt of the QE Prize in Engineering in 2013 with other Internet/Web pioneers is timely, as the IEEE Control Systems Society has created the new journal *IEEE Transactions on Control of Network Systems* (*TCNS*) with Editor-in-Chief Ioannis (Yannis) Paschalidis and Deputy Editor-in-Chief Magnus Egerstedt to publish papers in this topical area. Hopefully, the next major advance in the design of feedback control systems for communication networks will be published in *TCNS*.

REFERENCES

[1] R. E. Kahn and W. R. Crowther, "Flow control in a resource-sharing computer network," *IEEE Trans. Commun.*, vol. 20, no. 3, pp. 539–546, 1972.

[2] R. E. Kahn, "Resource-sharing computer communications networks," *Proc. IEEE*, vol. 60, no. 11, pp. 1397–1407, 1972.

[3] V. G. Cerf and R. E. Kahn, "Protocol for packet network intercommunication," *IEEE Trans. Commun.*, vol. 22, no. 5, pp. 637–648, 1974.

[4] R. E. Kahn, "Networks for advanced computing," *Sci. Amer.*, vol. 257, no. 4, pp. 136–143, Oct. 1987.

[5] B. M. Leiner, V. G. Cerf, D. D. Clark, R. E. Kahn, L. Kleinrock, D. C. Lynch, J. Postel, L. G. Roberts, and S. Wolff, "The past and future history of the Internet," *Commun. ACM*, vol. 40, no. 2, pp. 102–108, Feb. 1997.

[6] S. Weinstein and R. E. Kahn, "Interview with Internet pioneer Bob Kahn," *IEEE Commun. Mag.*, vol. 35, no. 7, pp. 9–10, July 1997.

[7] V. G. Cerf and R. E. Kahn, "A protocol for packet network intercommunication," *Comput. Commun. Rev.*, vol. 35, no. 2, pp. 71–82, Apr. 2005.

[8] B. M. Leiner, V. G. Cerf, D. D. Clark, R. E. Kahn, L. Kleinrock, D. C. Lynch, J. Postel, L. G. Roberts, and S. Wolff, "A brief history of the Internet," *Comput. Commun. Rev.*, vol. 39, no. 5, pp. 22–31, Oct. 2009.

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What To Expect From Engineers

A purely mathematical approach to the study of automatic control is certainly the most desirable course from a standpoint of accuracy and brevity. Unfortunately, however, the mathematics of control involves such a bewildering assortment of exponential and trigonometric functions that the average engineer cannot afford the time necessary to plow through them to a solution of his current problem.

—J.G. Ziegler and N.B. Nichols, "Optimum settings for automatic controllers," *Transactions of the ASME*, vol. 64, pp. 759–768, November 1942.

On the Relationship Between Control Theory and Applications

In no small measure, the great technological progress in automatic control and communication systems during the past two decades has depended on advances and refinements in the mathematical study of such systems. Conversely, the growth of technology brought forth many new problems (such as those related to using digital computers in control, etc.) to challenge the ingenuity and competence of research workers concerned with theoretical questions.

—Rudolph E. Kalman, "On the general theory of control systems," in *Proceedings of the First International Congress on Automatic Control*, USSR, vol. 1, pp. 481–492, 1960.