Teuvo Kohonen

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Academician of Science Teuvo Kalevi Kohonen died on December 13th, 2021, at the Jorvi Hospital in Espoo due to post-operative complications. He was 87 years old, born in Lauritsala on July 11th, 1934. He served as a professor of technical physics (electronics) at the Helsinki University of Technology from 1965 onwards, and from 1993 until his retirement in 1999, he acted as a permanent Academy Professor. In 2000, he was appointed Academician of Science by the President of Finland.

Kohonen was one of the world's best-known researchers in machine learning, neurocomputing and "intelligent" computer systems. Kohonen entered this new field of research when it was taking its fumbling first steps in the 1960s with the advent of the first digital computers. He lived through all the ups and downs of this sometimes controversial new research field right up to his last days. Today, you can read about artificial intelligence and neural networks in the daily press, as the methods have finally matured from theoretical considerations to general use and commercial applications, for example, in social media or medical diagnostics. This was not always the case, however, and the few pioneers in the field both home and abroad had to fight their way through scientific resistance and fickle funding.

Kohonen's background was in elementary particle physics. He graduated as Master of Science from the Helsinki University of Technology in 1957 and received his PhD in 1962. For his doctoral thesis, *Contributions to the study of lifetimes of positrons in solids*, he delved into electronics and digital technology. His supervisor was Professor Pekka Jauho, who later became an Academician of Science. In 1960s, Kohonen started teaching and researching computer engineering at the Helsinki University of Technology, first as an associate professor in 1963–65 and then as a professor of technical physics. He was a pioneer in computer technology in Finland, and the first computer fully designed in Finland, Reflac (Reflex Arithmetic Computer), was built under his leadership as a part of a wider research programme to investigate the problems and possibilities of direct computer control of industrial processes. The Reflac comprised a total of about 1,200 transistors and is now on display in the computer technology section of the Museum of Technology in Helsinki.

Kohonen took an early interest in a profound scientific problem, the learning capacity of machines. He began to reflect on this topic while working as a visiting professor at the University of Washington in Seattle in 1968–69 and learned there of US research on artificial intelligence. As a well-versed computer scientist, Kohonen was well aware of how simple a computing device a computer really is. After all, he had built one himself. Could some kind of programming give it properties that would resemble intelligence? Kohonen realised that something completely new would be needed if the computer and its software were to approach the learning and reasoning abilities of humans and animals. Thus began his career as one of the world's leading researchers in neurocomputing and artificial intelligence.

Kohonen's career in neurocomputing started with his theory of associative memory. In developing it, he had to explore a completely new subject: brain function. At that time, it was unknown whether some special neurons in human and animal brains would store memory traces of a specific part of the outside world, for example, a person's grandmother ("grandmother cells"), or whether the memory traces were distributed in a parallel neural network. Kohonen was excited about the latter possibility and developed for it a mathematical theory that could also be tested in computer simulations. He published this theory in his first monograph, *Associative Memory. A System-Theoretical Approach* (1977).

In the 1970s, neurocomputing or neuromodelling was still a very small and specific multidisciplinary field. Although actual neuroscientists were impressed by the general principles of theoretical neural network models, most of them rejected them as too crude simplifications and were unable to delve into the moderately sophisticated mathematics involved. For computer scientists, on the other hand, neural network models were often too simple, failing to solve some of the most basic problems in computer science. The field grew slowly until scientific breakthroughs in the 1980s attracted the interest of a wider range of researchers and funders.

One of these breakthroughs was Teuvo Kohonen's new invention, a neural network and computing algorithm called "Self-Organizing Map" (SOM). It is a key tool for organising and visualising large data sets. Although inspired by sensory maps of animal brains, SOM's most significant impact has been as a practical data processing technique. SOM has two important features: First, it can process almost any large data set, and second, its machine-learning method (known as Kohonen algorithm) requires very little pre-processing of data and is thus almost automatic. All that is required is a lot of computing power. The SOM method has been applied in thousands of scientific and applied studies worldwide. Kohonen's articles and his book *Self-Organizing Maps* (1995) have tens of thousands of citations in Google Scholar. Applications use a variety of data sets, such as statistical data, images, speech, video, text, biological signals as well as measurements related to chemistry and physics, traffic, telecommunication, industrial processes, financial and medical data. The aim is to understand the dependencies and laws inherent in data when visualising, predicting, clustering and profiling them.

Kohonen and his research group focused on several applications of the SOM method. Although Kohonen conducted theoretical algorithm research, his strict principle was

that the performance of methods must be tested on real data obtained from the real world. Both SOM and neurocomputing in general require large data sets for training and tuning the algorithms. In the 1980s, when the Internet, social media and big data phenomena were not like we know them today, Kohonen focused on speech recognition because it's reasonably easy to collect large amounts of digitised speech data. The second application centered on textual data, which were also widely available. Several of Kohonen's students at the time, including Professors Mikko Kurimo, Krista Lagus and the late Timo Honkela, became leading researchers in language technology in Finland. When the Academy of Finland's Centre of Excellence Programme was launched in 1994, Kohonen was appointed to head one of the first five-year centers of excellence called the Neural Networks Research Centre. Retirement in 1999 forced Kohonen to step down, but the centre continued to operate under the Helsinki University of Technology for more than 15 years under a different name headed by Professor Erkki Oja and, after his retirement, by Professor Samuel Kaski.

Kohonen's international leading role in neurocomputing is reflected in numerous awards, perhaps most notably the 1991 Neural Networks Pioneer Award from the IEEE, the world's largest engineering organisation. Kohonen was the first researcher in the world to receive this award. Other notable awards include the 1992 INNS Lifetime Achievement Award, the 1996 IAPR King-Sun Fu Prize, the 1998 SEFI Leonardo da Vinci Medal, the 2000 IEEE 3rd Millennium Medal and the 2008 IEEE Frank Rosenblatt Award. In Finland, Kohonen was awarded by the Finnish Cultural Foundation in 1994, by the Finnish Academy of Technology in 1997 and by the Finnish Foundation for Technology Promotion in 1999, among others. He held many positions of trust, including becoming the first president of the European Neural Network Society in 1991 and being the chairman of the first major neural network conferences in the late 1980s. Kohonen was invited to the Finnish Academy of Science and Letters in 1974.

Kohonen was a distinctively individualistic researcher. He worked in his chamber, reflected on the details of his algorithms and, as a skilled programmer, conducted a lot of small-scale experiments. He needed a team around him mainly for large-scale experiments with large data sets and for the final refinement of methods – such as speech recognition algorithms – towards ever better performance. As the leader of the research group, Kohonen was demanding to the point of being impatient, but most of all he was demanding of himself and sometimes anguished when new ideas did not emerge. Kohonen strongly believed that large research units do not necessarily lead to creativity. In his view, at least in basic research, ideas are generated in small units that should be given quite a lot of freedom to operate. Truly innovative researchers cannot know in advance what they are going to discover or invent. They have to be given time to concentrate. They also need to be able to take off in a promising new direction at the right moment, which can be difficult with a too fixed project plan.

Kohonen stressed that to become a world-class researcher, one must be the first to present a particular idea or result, and perhaps that is why he was reluctant to discuss his budding ideas. He was also reluctant to join collaborative projects pro-

posed by other researchers, preferring to focus on his individual line of research.

In his social relationships, Kohonen was selective and formal, but among friends he was a fun and versatile conversationalist, whose resourcefulness in dealing with everyday challenges was unparalleled. He was skilled at repairing old electrical and mechanical equipment, including building a shoulder-mounted periscope box for treating his own macular hole. To the delight of his grandchildren, he built a human-sized mirror illusion on Christmas. Kohonen was even a haiku writer. One of his favourite hobbies was playing a saw, which he had learned as a young boy. After receiving a real musical saw as a gift from his research group, he started practicing enthusiastically, eventually even performing at the banquet of an international conference in his field. His signature number was Camille Saint-Saëns' "Swan", whose dream-like melody and rhythm he found particularly suited for the instrument. In keeping with his character, Kohonen assembled a bag of tricks for his performances, ranging from a one-handed leather glove to moustache wax and special trousers for playing the saw.

Music was close to his heart and in his last years, Kohonen played a number of old popular songs on an electric organ with his son accompanying him on a guitar, which he recorded to be shared with his inner circle. The last recording was a 1940s jazz hit "How High the Moon" from Father's Day in 2021. Kohonen kept a meticulous record of his practice sessions with an old, time-tested technique – an abacus.

The significance of Academician of Science Teuvo Kohonen for Finnish information technology is hard to overestimate. In today's Finland, artificial intelligence based on neural networks is an increasingly used technology in medical analytics, industry and economy, to name a few. Finland's strong presence in the field is largely due to the pioneering work of Teuvo Kohonen, who attracted many followers and influenced the focus of research and education of information technology in Finnish higher education.

Obituary by Erkki Oja and Riitta Hari