EROL GELENBE: A CAREER IN MULTI-DISCIPLINARY PROBABILITY MODELS

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We focus on Erol Gelenbe's scientific and technical contributions to probability models in the computer and information sciences, but limit our survey to the last fifteen years. We start with a brief overview of his work as a single author, as well as his work in collaboration with over 200 co-authors. We discuss some of his recent and innovative work regarding a new probability model that represents Intermittent Energy Sources for Computing and Communications, introducing *Energy Packet Networks* which are a probabilistic representation of the flow, storage and consumption of electrical energy at the microscopic level (in electronic chips), and at the macroscopic level (e.g. in buildings or data centers) and for its routing and dynamic usage by consuming units (such as computer elements, chips or machines). We next discuss his work on designing computer and communication systems that parsimoniously use energy in order to achieve a satisfactory level of quality of service (QoS). Trade-offs between system QoS and energy consumption are also considered. Then we turn to Prof. Gelenbe's pioneering work on Autonomic Communications and the design and implementation of CPN, the Cognitive Packet Network, and we also briefly review his spiking random neural network that was used in CPN. This is followed by a brief review of work that he conducted since 1999 on human evacuation from dangerous or catastrophic environments, and the design of technology driven Emergency Management Systems. His research since the late 2000s on Gene Regulatory Networks is then covered together with its application to the detecting possible disease from microarray data. Finally, we briefly discuss some novel analytical models that he developed in this period with publications appearing in journals of physics and applied mathematics.

1. INTRODUCTION

It is hard to describe the scientific content of a still ongoing career that started in the early 1970s in higher education and research, especially for a productive research whose curiosity and interests have ranged so widely, delving into Computer Science, Applied Probability, Operational Research, Electrical Engineering and even Theoretical Biology. Thus, this overview will be a broad summary, remaining at a "high level", without entering into details that are beyond our expertise.

As this paper is being written, according to the DBLP database, Erol has had some 210 co-authors and collaborators. His work has over the years appeared in English, but

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also in French, Italian, Korean, Japanese and Russian. Yet according to Google Scholar, he is the *sole author* of ten out of his twenty most cited publications. This shows that while he has been constantly collaborative, he is also a "traditional" researcher, who spends substantial time in individual scholarly work. Several of his papers from 2014 and 2015 represent his work as a sole author. Despite this focus on individual work involving mathematical modelling and analysis, Erol's papers had received by the end of 2015 some 14,100 citations and a Google Scholar H-*index* = 66 Also, 40% of these citations are less than 5 years old. Similarly, his Web of Science Citation H-Index is relatively high at 36. With over 71 graduated Ph.D. students, he is among the *Top* 50 worldwide and of all times Ph.D. supervisors in the Mathematical Sciences as indicated by the American Mathematical Society's *Mathematical Genealogy Project* (see their web site at http://genealogy.math.ndsu.nodak.edu/extrema.php).

This mix of numbers describes an unusual researcher who is always involved in several large collaborative projects, currently involving funding from the UK Engineering and Physical Sciences Research Council and the European Commission. He typically supervises five to ten ongoing Ph.D. students and post-docs. Yet, he continues to write papers on his own. Indeed, since the early 1990s after he moved to the United States, and then to the UK, he has been the successful recipient of numerous grants from DoD, NSF and Industry in the USA, and likewise in the UK at Imperial College from EPSRC, the EU FP6 and FP7 programs, and other government agencies.

In terms of contributions to industry, early on he built the team that designed QNAP, a performance modelling software package (one of the first three in the world with BEST/1 of BGS Systems Inc. and RESQ of IBM) which contributed to the creation of SIMULOG, INRIA's first start-up. The FLEXSIM Object-Oriented Flexible Manufacturing Simulator that he designed with Ali Labed [91] is the prototype from which the successful commercial FLEXSIM tools were built. The patented SYCOMORE packet switch [29] was the world's first digital Voice-Packet network. Currently, his self-aware network design CPN [51,62,63] has attracted much funded contract research, and generated interest with a major telecommunications manufacturer. Industry links can also be seen through other patents such as [77,188].

However before we delve into the different areas in which Erol has made major contributions, let us introduce this special issue. The we will discuss Erol's work as a research supervisor and mentor. Finally we will discuss his more recent work over the last decade, and provide some links to his past contributions.

1.1. Analytical Models

Erol's earliest seminal work is about the verification of finite-state machines [168], a topic of great importance in computer science because of its usage in program verification and hardware testing. He has also contributed to modular realizations for deterministic finite-state machines [146].

However most of his subsequent work has been driven by the invention and use, of appropriate probability models [40,50,134,151] inspired by practical problems. An interesting relatively recent development of his work has been his incursion into the literature on Statistical Physics [6,64], and also with theoretical papers on the analytical solution for chemical master equations [59], and the related issue of stochastic modeling in gene regulatory networks [57].

Another multi-disciplinary link he has been able to make, ties the behavior of adversarial biological populations (such as germs and cells) to viruses in software or in computer networks [56]. His recent work has also linked particle motion in non-homogeneous media [6,64],
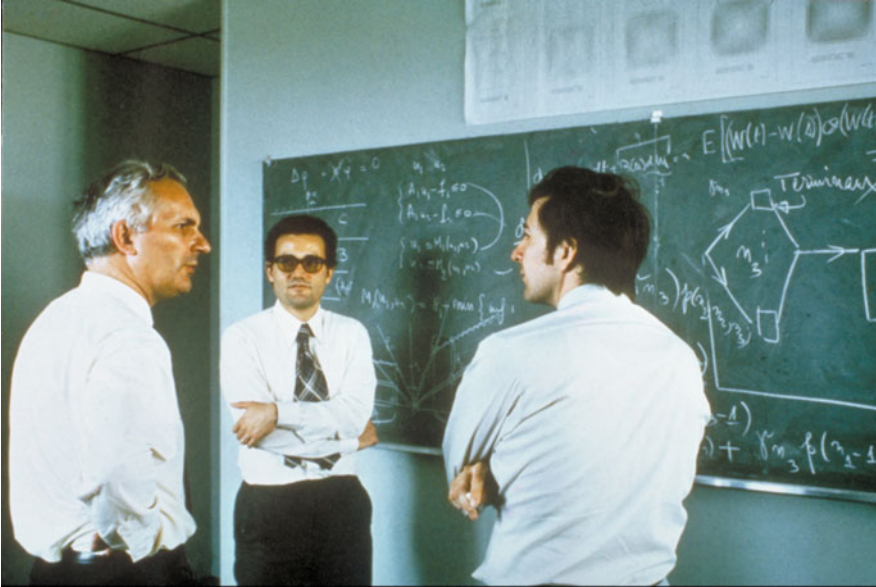
FIGURE **1.** Erol Gelenbe (right) describing the method of diffusion approximations for networks of queues to his mentors Professor Jacques-Louis Lions (left) and Professor Alain Bensoussan (right), using the analogy between a discretised partial differential equation and the queueing network model of a computer system (shown on the blackboard). This picture was taken sometime in the years 1973–1975, at the LABORIA laboratory of the *Institut National de Recherche en Informatique et Automatique* in Rocquencourt, France, and relates directly to one of Erol's seminal research papers [41].

where he has studied both the time it takes for a set of particles to attain a target, and the energy that is consumed in the process, which is related to the random motion of packets in a very large multi-hop sensor network [54].

Finally in my list of unusual analytic results, let me mention his work where he considers an (economic) market composed of N English auctions [61] where potential buyers enter the market according to a random process, they select one of the auctions where they bid for a product with a probability that depends on the current bid that has been attained by that product; the probability that a buyer bids for a project will depend on the level of the bid. Buyers leave the market if they are successful in purchasing the product, or they may leave because they have been unsuccessful, or they may go to some other auction if they are unsuccessful. This analysis leads to a closed form expression for the equilibrium prices of all the products in the market Figure 1.

2. A PH.D. ADVISOR AND MENTOR

We had mentioned earlier that Erol Gelenbe's is listed one of the "Top 50" all times and worldwide doctoral supervisors in the Mathematics Genealogy Project of the American Mathematical Society [10] by graduating some seventy Ph.D. students, This type of work requires the imagination to suggest viable Ph.D. topics, and the effort to provide supervision and helping with writing papers and theses. His proactive work has included finding the positions, the funding or scholarships to support the Ph.D. students during their Ph.D.,

FIGURE 2. Erol Gelenbe (left) seen giving his acceptance speach to an assembly in the Senate Chambers of the Parilament Building in Budapest, Hungary, after receiving the *In Memoriam Dennis Gabor Award* in 2013 from the Hungarian Academy of Sciences. The attendees include young students, members of the Hungarian National Academy, Government Ministers, members of the Hungarian Parliament and foreign diplomats.

and then often helping secure a position they could go to, or helping them toward their first academic or research position. His efforts have persisted across all the academic posts that he has occupied, in Belgium, France, the USA and the UK, and this considerable effort "beyond the call of duty" has been remarkably successful. He has also had a larger proportion of women Ph.D. students, such as one of the authors of this paper, and female post-docs, than most of academics in engineering and computer science Figure 2.

While in France, Erol co-founded the Graduate Program in Computer Science "DEA d'Informatique" at Université Paris-Sud, and then the program "DEA de Systèmes Informatiques" at Université Reneé Descartes and Université Pierre et Marie Curie, as well as the CNRS Research Lab "Equipe de Recherche Associee El Khowarizmi (ERA 452)", and collaborated with INRIA, Centre National de Recherches de Telecommunications (CNET), and industry. In the USA, both at Duke and at the University of Central Florida, he actively supported the expansion of the graduate and Ph.D. programs.

In return for the diligence he has put into mentoring and Ph.D. supervision, many of his former students have been very successful. To site just a few names:

- Jacques Labetoulle [110] received a Doctor of Science degree under Erol in 1978, and is now an emeritus professor at the Institut Eurécom in Sophia-Antipolis. His Ph.D. student Zhen Liu graduated from the Université Paris-Sud Orsay, was for a while the Directorof the NOKIA Laboratory in Beijing, and is currently at the Microsoft Beijing Laboratory. Philippe Nain, from the same early years, chaired INRIA's prestigious "Evaluation Commitee". Yutao Feng [33] received his Ph.D. with Erol at Duke University working on video compression using the Random Neural Network; he serves as an Adviser of Innovation Camp, he is a Vice President of

Ambarella Inc., and has been General Manager of Ambarella Inc., China, since 2007. Guy Pujolle [144] and Eric Horlait, also graduating with Ph.D.s from Université Paris-Sud with Erol, are Professors at Université Paris VI, and the latter is Industry Director at INRIA. Jean-Michel Fourneau [81,82], now at Université Versailles-Saint-Quentin, and Tülin Atmaca a Professor at Institut National des Télécommunications (INT) in Paris-Evry, received their Ph.D.s, respectively at Université Paris-Sud with Erol, as did François Baccelli [14], André Duda, Alain Chesnais [22], Jean-Pierre Le Narzul, Brigitte Plateau [24], Catherine Rosenberg [145], Rina Suros de Leon [39], and Andreas Stafylopatis [124,156] who later headed the Electrical and Computer Engineering Department at Greece's most prestigious academic institution, the National Technical University of Athens. Noufissa Mikou, also from the same years, is a Professor at the Université de Bourgogne, while Guy Bernard and Gérard Hébuterne, both his Ph.D. students from Paris-Sud, are now Emeritus Professors at Institut National des Télécommunications, Ferhan Pekergin is an Associate Professor at Université Paris-Nord, where Jean Vicard [8], another of Erol's students, is an emeritus faculty member.

- From his years at Université Paris-Descartes, we can cite his Ph.D. students Ali Labed [109] (now in Canada) and Hatim Guennouni (now in the USA) [91], Georges Hébrail [93] now a professor at ENST-Téécom in Paris, Myriam Mokhtari (now at the ENSI-Caen), Sophie Chabridon (now at INT-Evry) [21], Marisela Hernandez [94] (now at the Université d'Amiens), Christine Hubert (with the Chamber of Commerce of Caen), Alexandre Aussem (now at Université Lyon I), Volkan Atalay (now at METU) [13], Joseé Aguilar [9] (now at the University of Mérida, Venezuela), Nihal Pekergin, Ferhan Pekergin, Pierre Cubaud (now at CNAM Paris), Philippe Mussi (now at INRIA), and Vassilada Koubi [104] is teaching at the Alexander Technological Educational Institute of Thessaloniki (ATEITH).

- Rakesh Kushwaha [107], who received his Ph.D. with Erol at the New Jersey Institute of Technology, is the founder and CTO of mFormation, a company that operates in the US and the UK. Vijay Srinivasan [154], his Ph.D. student at Duke University, is now the CEO of Willow TV in San Francisco. Anoop Ghanwani [88] is Distinguished Engineer at Dell in Sacramento, California, and Xiaowen Mang [131] is a Member of Technical Staff at AT&T, both receiving their Ph.D. at Duke under Erol..

- Three of his Ph.D. students are members of their respective National Academies: François Baccelli [14] (French National Academy of Sciences), Catherine Rosenberg [145] (Canadian Academy of Engineering), and Jacques Lenfant [111,195] (National Academy of Technologies of France).

- Several of his former Ph.D. students currently have high-level duties in university administration. Volkan Atalay is the Provost of Erol's *Alma Mater* the Middle East Technical University in Ankara, a university that is currently ranked, right after Beijing and Tsinghua Universities, as the 3rd top BRIC institution worldwide. Brigitte Plateau [23] is the President (with title of "general administrator") of the Grenoble National Polytechnic Institute in France. Taşkin Koçak [2,101] his Ph.D. student at Duke University, is Dean of Engineering at Bahçeşehir University in Istanbul. Previously Jacques Lenfant, who was his first Ph.D. student in France, had served as President of the University of Rennes in France.

- From Erol's earliest days at the University of Liège in Belgium, his assistant Tri-An Banh [11] went on to become a professor at that university, and then a successful businessman. Alain Kurinckx [105] started working with Erol in Liège and then

received his Ph.D. with Erol at Université Paris-Sud, before joining Thomson-CSF (now Thales) where he rose to become a high-level technical executive.

- His Ph.D. students from the University of Central Florida include Ricardo Lent [120]. Zhiguang Xu [122] at Valdosta State University in Georgia, , Pu Su now at Microsoft [86], Qi Zhu [167] at the University of Houston, Khaled Hussain [95] at the University of Assiout, and Hossam Abdelbaki [4].

- Several of his recent Ph.D. students from Imperial have started academic careers at the University of Greenwich, George Loukas [127] and Avgoustinos Flippop-poulitis [34], University of Middlesex in London with Georgia Sakellari [198,199], in the USA and Ricardo Lent, Peixiang Liu [126] now in Florida, the University of Cyprus (Stelios Timotheou), while Haseong Kim is a Research Scientist at the Korea Research Institute of Bioscience and Biotechnology (KRIBB).

- Other recent Ph.D. graduates from Imperial College are researchers at Liquid Capital (Yu Wang), Imperial College (Omer H. Abdelrahman and Gökçe Görbil), and Verizon (Christina Morfopoulo), while Antoine Desmet is with Joy Global (Rutherford, NSW, Australia), Mike Gellman is with KCG Holdings, Inc. in Singapore, Varol Kaptan is a Vice-President at Goldman Sachs, and Kumaara Velan is a risk specialist with Zurich.

- Two of his recent post-docs in London are faculty members at Kings College London (Toktam Mahmoodi) and the University of Uppsala in Sweden (Edith Ngai).

Erol has helped many others to get started in research and then into careers in computer science, such as David Finkel [80], Guy Fayolle [32], Alexandre Brandwajn [143], Marc Badel [16], Dominique Potier [15,112,196], Danièle Gardy [83,84], and Rudolf Iasnogorodski [98] among others.

3. INTERMITTENT ENERGY SOURCES FOR COMPUTING AND COMMUNICATIONS

The wide variety of Erol's work over the last fifteen years is unknown to most of his peers who tend to know him through some specific research area. Thus our brief review will stress the variety of his work in key areas that have emerged over the last decade, such as energy efficiency of ICT [17] and autonomic communications [31] where (in both these cases) Erol has authored some very influential papers.

Erol's first work published in 2015 analyzes the link between the random nature of harvested energy, and the random nature of the data collection activities of a wireless sensor [73], leading to an original analysis of "synchronization" between the two resources that in this case enable wireless communications: the data packets and the energy packets, first studied in a paper published in 2014 [70]. However in some earlier work he had introduced of a novel way to view energy as a "packet-based" resource that can be modelled in discrete units which he called Energy Packets [66,67].

3.1. Energy Packet Networks

While Ohm's Law in the complex variable domaine is a good way to analyze the steady flow of electricity in RLC networks, there are areas where it is not the best model:

- At a nano-scopic level, say at the level of the flow of individual electrons, both the stochastic nature of the sources and the physical non-homogeneities which govern

the medium (e.g. metal) imply that different models may be needed; thus Erol recently proposed a stochastic flow model that addresses the conveyance of energy and information by individual particles [71,72].

- At a more macroscopic level, when one deals with intermittent sources of energy so that energy must be stored in batteries or other storage units (such as compressed air cylinders) that can include conversion losses to and from the electrical storage, and energy usage itself is intermittent, models descended from G-Networks [43,45, 46,49,82,109] become useful [5,68,69].

- This approach has raised interesting questions about how such large networks may be analyzed in the presence of flow of energy and flow of work [70,76] and some recent interesting results regarding "product form solutions" for such multi-hop networks have also been obtained [133].

4. ENERGY IN ICT AND ITS OPTIMIZATION

However, Erol's concern for energy consumption for communications actually started a decade earlier [52,114] in the context of Wireless Ad-Hoc Networks, when he contributed a technique to extend overall life of a multi-hop network by using paths that have the most energy in reserve, that is, the most full batteries. This work was pursued in papers related to network routing and admission control based on energy considerations [128,130,135,136, 152,153,162,201] and this resulted in a practical design for an energy aware routing protocol.

His research group's involvement with energy consumption in information technology was also developed through their participation in EU Fit4Green Project which resulted in a widely cited paper [17] regarding the energy optimization of Cloud Computing servers and of software systems [193]

4.1. Trade-Offs between System Quality of Service (QoS) and Energy Consumption

Although energy consumption by ICT is an important issue, it must be viewed as a compromise between the two aspects, where a reduction in energy consumption in the manner a specific system is being operated, for instance as a function of workload or of workload distribution, is "paid for" by a loss in performance or an increase in the response times experienced by users. This issue has been studied in several of Erol's recent papers [115,116,118,193].

Similar problems arise in wireless communications, but of course at far lower levels of energy consumption. Here the purpose is to minimize the amount of energy consumed per correctly received packet or bit. Indeed, in the wireless case, increasing the transmission power is often possible. This will overcome noise, but it has the opposite (negative) effect if *all* cooperating transcievers raise their power level, resulting in greater wireless signal *interference* and hence larger error probabilities for all parties. This in turn will *lengthen* the time needed to correctly receive a data unit, and hence will also increase the net energy consumed per correctly received bit or packet [92,117,142,191].

5. AUTONOMIC COMMUNICATIONS AND CPN

Erol has been long intrigued with the adaptive control of computer systems and networks since the 1970s [15,16,106,108,143,195], where the challenge is to deal both with the very large size of the systems encountered in computer science, the imperfection of the dynamic models that describe them, and the very large size of these dynamic models.

His most recent foray into this area, starting with early papers [87,113,141,166] that describe the Cognitive Packet Network (CPN) routing algorithm both for wired and wireless networks that uses reinforcement learning to provide network QoS in an automatic manner, is a pioneering initiative in the field of Autonomic Communications [53]. He is also co-authored a paper that made this field popular a few years later [31].

CPN related was a clear break with Erol's traditional research which has relied essentially on mathematical modeling and simulation [40–42,137,155].

Related work [150,192] suggests that decisions that have a "natural" appearance could also be incorporated in a similar manner, simulation systems where complex agent interactions occur, and agents take decisions based on their collective best interest. Similar questions have also been discussed with other methods in the context of search algorithms in dangerous environments [75].

The basic idea of CPN, amply tested in many experiments [119–122,125] is to use probe or "smart" Cognitive Packets (CPs) to search for paths and to measure QoS, while the network is in operation. The search for paths is run via Reinforcement Learning using a Random Neural Network, based on the QoS objective of goal pursued by the end user. The CPs furnish information to the end user about the QoS offered by different paths, and in particular those actually being used by the end user, but in CPN it is the end user, which may be a representative decision maker for a QoS Class, that actually decides to switch to a new path or select a given path [62,114,123]. An extension to CPN that uses genetic algorithms to construct hitherto untested paths based on predicted QoS was also proposed [187].

More recent work has considered CPN for specific applications. For instance in [100] the issue of dealing with web access applications where the uplink may require short response times for Web requests, while the download may require high bandwidth and low packet loss for video downloads, is considered, and a specific system that supports these needs is designed, implemented and tested. Similarly, other recent work deals with the QoS needs of Voice, and a VoCPN system is designed and evaluated [202] on an experimental test-bed.

One of the interesting developments of CPN relates to novel energy aware routing algorithms [128,129] that link to Erol's concern with energy savings. Other useful application concerns admission control [147] and denial of service defense [85,127]. Other work that is unrelated to CPN but that proposes adaptive techniques for the management of wireless sensor networks in order to achieve better QoS are discussed in [138–140,189], while adaptivity for the management of secondary memory systems is discussed in [205].

5.1. The Random Neural Network

The Random Neural Network was reported in Erol's earlier work and its theoretical foundations were developed in [44,47,48,78,79,97,132]. Some of its other applications can be found in [1,3,4,9,12,25,26,89,101–103,157,174] and several papers reviewing this subject can be found in the papers of the special issue in [49].

6. NETWORK SECURITY

Erol's work on network security came through some work on the impact of Distributed Denial of Service (DDoS) Attacks on network QoS, and a proposal to use CPN as a way to detect DDoS, counter-attack by tracing the attacking traffic upstream and use CPN's ACK packets as a tool to give "drop orders" to upstream routers that are conveying the attacking traffic [127,190]. This approach was also evaluated on a large network test-bed as a means to detect worm attacks and react to them by sending the users' traffic on routes that avoid the

infected nodes [197,200]. His work on security continued with more algorithmic issues [204], but recently moved to the analysis of signalling storms in mobile networks [7,169,170] and is currently one of the main centers of his attention.

7. EMERGENCY MANAGEMENT SYSTEMS

Like many people around the world who have a personal experience of large scale disasters, Erol was deeply struck by what he saw in Turkey in 1999, right after the major earthquake that took place near Istanbul, in the areas around Izmit and Yalova.

Although he himself was not present during the earthquake, he went the sites just *after* the earthquakes with family members in order to to try to find two family members who were missing and who has in fact perished during the event. Finding, identifying, and transporting the bodies was a traumatic experience.

One thing that impressed him was the very rudimentary nature of technology that was being used to seek, locate and try to evacuate the victims. The destruction of roads, bridges, electrical power lines and telecommunication networks, meant that only rudimentary construction technologies could be used by the numerous family members and professional rescuers who flocked to the area in the days that followed the earthquake.

Since that time, Erol has devoted a part of his research effort to better understanding the ongoing research of emergency management technologies [163,165], and developing a deeper understanding of the appropriate models and algorithms which are specific to this domain of research [27,28,90,164]. Unfortunately, many aspects of emergency management have a significant overlap with tactical planning of military operations [99,160,161] whose purpose is to destroy the capabilities of an adversary but also to save the lives of friendly forces and evacuate the injured of both sides.

In particular, his team investigated different simulation approaches [35,96,99] that could be used to represent the extremely dynamic and fast changing "transient" events in an emergency, and then developed a novel agent based simulator named the Distributed Building Evacuation Simulator (DBES) [30] for evacuation planning and simulation. A constant concern of this work has been to develop decetralized techniques that do not require large and expensive infrastructures [37], and his team has organized a series of annual workshops related to the Pervasive Communications conferences of the ACM [**?**,148,149].

His team studied fast decision algorithms based on learning a wide range of problem instances and their optimal rescuer and rescue vehicle allocations [38,158,159], and selecting in real-time the allocation that best matches the current observed emergency situation. They also studied low-cost, light-weight and disruption tolerant techniques that can offer robust communications in emergency environments [173], and many of these methods actually span both the military and the civilian domain [36,171,172,186,203].

More recent work has been devoted to autonomic routing techniques based on ideas derived from CPN or from directional techniques so that the management of evacuees can be carried out without the intervention of any centralized decision making agent [18–20,74,185]

8. GENE REGULATORY NETWORKS

Erol's interest in Gene Regulatory Networks [58], a very important topic in health sciences, started fortuitously during a visit in the mid 2000's to the well known French gene splicing center, the Genopole in Evry, near Paris. He had been invited there by a friend, Gabriel Mergui who was then the Genopole's industrialization and marketing director and who

knew about Er's interests in the interface between biology and computer science [65], to give a seminar (on his work in general) and to meet other colleagues.

At the Genopole, he met Professor Gilles Bernot who had known Erol when Gilles was an Assistant at the Laboratoire de Recherche en Informatique, co-founded by Erol at the Université de Paris Sud in Orsay, south of Paris, towards 1978-79. As we say in Turkish "nereden nereye" – as an expression of surprise at a fortuitous chains of events … "from where to where". At the Genopole, Gilles (whose background is in Formal Methods in Computer Science) was heading a group the specialized on the formal specification and simulation of Gene Regulatory Networks … and he handed to Erol some of the early papers on graph models of gene regulatory networks (GRNs).

On his return to London, Erol plowed into the subject and came up with the basic model that was published in the previously cited paper [58] and various conferences such as [55]. This initial paper took some time to attract interest from biologists, but it did attract interest in two directions.

It gave rise to an interesting development regarding the use of Erol's GRN model to detect anomalies in genetic data that can help detect or point to predisposition to certain diseases [176–178,180,182,184]. Typically, this line of work involved using Erol's GRN model to represent a set of gene interactions, including some measure of the time scale of these interactions through appropriate time constants, and then estimating the parameters from measured micro-array from known "normal" (i.e. non-disease) data [179,181], for instance using a learning algorithm similar to some earlier work [47,97]. Once this phase of model identification is complete, the model can be used for comparison with other micro-array data, to determine whether this other data shows an anomaly or a propensity for some disease such as cancer [175,183]. Another line of collaboration also emerged with biologists [194] regarding difficult problems of protein interaction networks. Interestingly enough, Erol also investigated how some of the underlying chemistry could be modelled [60].

About the Author

Mehmet Ufuk Cağlayan Is Professor of Computer Engineering at Boğaziçi University, Turkey's most selective institution in Istanbul. He received his Ph.D. in EE and CS from Northwestern University, Evanston, Illinois in 1981, a MS in CS from the Middle East Technical University, Ankara, Turkey in 1975, and likewise his BS in EE from the Middle East Technical University in 1973. His research interests include Computer and Network Security, Computer Communications, Computer Networks and Internet, Wireless and Mobile Networks, Distributed Systems, Operating Systems, Software Engineering, Software Design and Software Project Management. From 1979 to 1981 he served as an Instructor in the Department of Electrical Engineering and Computer Science, Northwestern University, Evanston, Illinois, and from 1978 to 1979 he was an Instructor in the Department of Mathematics at DePaul University in Chicago. From 1981 to 1987 he was an Assistant Professor in the Department of Computer Science and Engineering at King Fahd University of Petroleum and Minerals, in Dhahran, Saudi Arabia. He joined his current university in 1987 as an Assistant Professor. On leave of absence in 1989 to 1991, he was a Computer Scientist at BASF AG, Ludwigshafen, Germany. Author of some 200 publications, he is a full Professor sine 1999, and since January 2007 he is the Coordinator of the nationally funded TAM Project which aims at increasing the number of Ph.D. graduates in Computer Engineering at his university and in Turkey. From October 2000 to July 2004 he was the Chairperson of the Department of Computer Engineering of Boğaziçi University, He has graduated several Ph.D.s who are faculty in Turkey's leading universities, such as Professors Albert Levi and Sema Oktuğ, as well as many Master's students.

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