Proceedings of the IEEE Through 100 Years: 1990–1999

I. INTRODUCTION AND OVERVIEW

The collapse of the Soviet Union in 1991 marked the end of the Cold War and saw an easing of tensions across the globe (Fig. 1). With many countries shifting to democratic governments and capitalist economies, the IEEE experienced a trend toward internationalization. Over the course of the decade, 30 new sections formed in Regions 8–10, including many former Eastern Bloc countries like Bulgaria, Czechoslovakia, and Romania. Membership rose to 352 000 by 1999, and 35.2% of these members resided outside the United States, up from 22.5% in 1989. Region 10 saw the highest growth rate with 14 new sections, including Bangladesh, Kansai, and Taegu.

Fig. 1. *The Fall of the Berlin Wall, 1989. The photo shows a part of a public photo documentation wall at Former Check Point Charlie, Berlin, Germany. (Wikipedia; http://en.wikipedia.org/wiki/File:Thefalloftheberlinwall1989.JPG.)*

The IEEE also expanded in other ways throughout the 1990s. In 1990, the Board of Directors approved a more succinct Code of Ethics. Press sales exceeded $1 million for the first time in 1991, and in 1993, the IEEE received 501(c)(3) status, allowing for United States members' dues to become tax deductible as charitable contributions. The IEEE had previously had 501(c)(6) status since 1973. Publication and production of the journals migrated more toward a completely digital process; April of 1991 (Fig. 2) was the first issue of the PROCEEDINGS OF THE IEEE that used electronic versions of received manuscripts. Standards became available through a set of four CD-ROMs in 1990, and a windows-based version of a CD-ROM collection of IEEE journals became available in 1996. The IEEE launched Ask*IEEE, a document delivery service, and began to put journals on the Web in 1998 with the IEEE Electronic Library.

The PROCEEDINGS also expanded its scope during the 1990s. In addition to technical literature, the journal published tutorial reviews and papers on history, management, and ethics. Out of these topics, history was the most frequently published. The first

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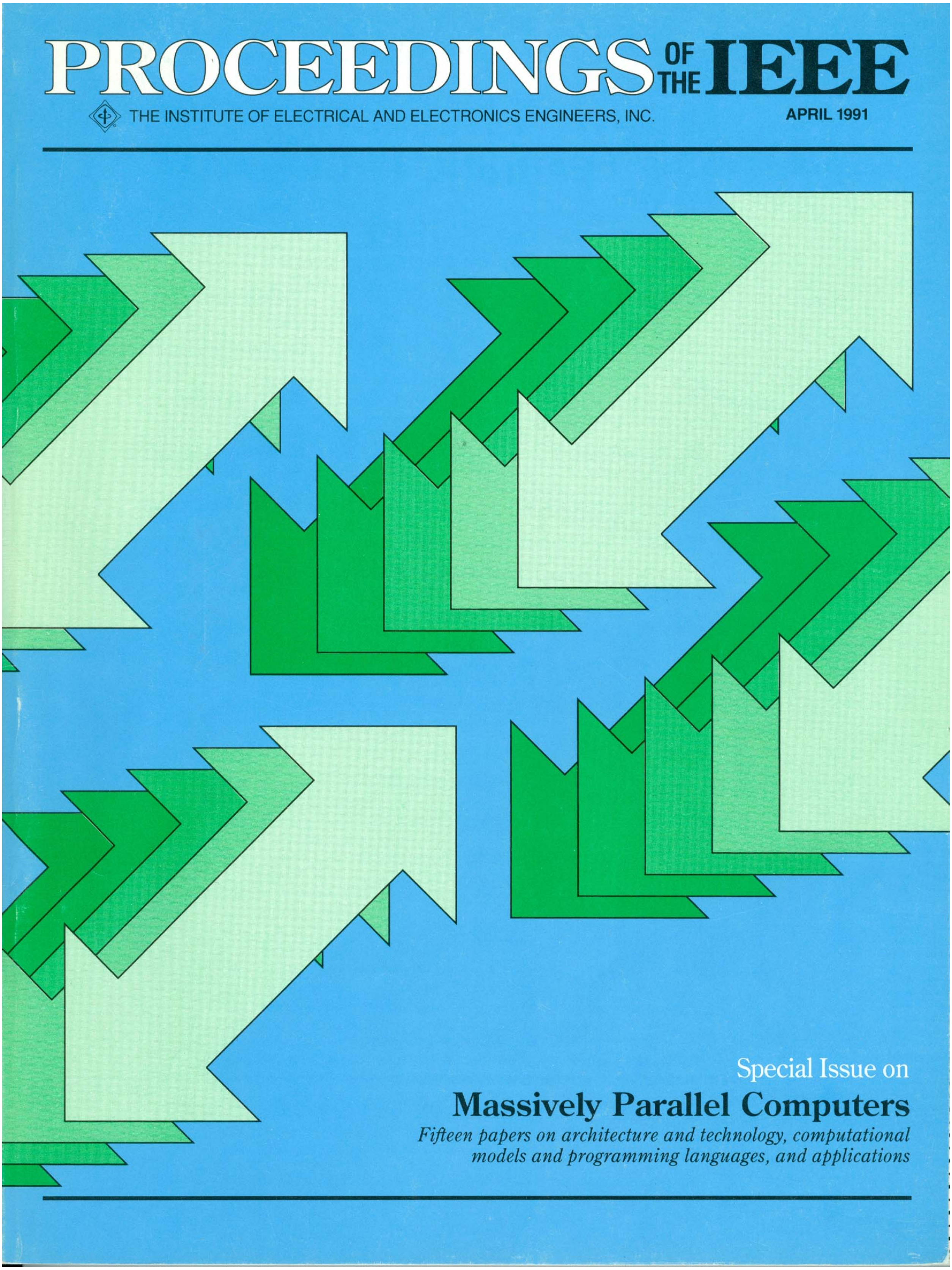

Fig. 2. *Cover of the* Proceedings of the IEEE *April 1999 issue.*

issue of the decade included J. E. Brittain's retrospective history of the evolution of electrical and electronics engineering reflected in the PROCEEDINGS OF THE IRE from 1938 to 1962 [1]. This was followed in the March 1990 issue by a history of engineering technologies as seen in the PROCEEDINGS OF THE IEEE from 1963 to 1987 [2]. A number of noninstitutional history articles were also published in the PROCEEDINGS, including Marconi (Fig. 3) and his inventions [3], the microcomputer [4], the personal computer [5], German radio [6], electrical engineering education [7], and an entire special January 1998 history issue on the 50th anniversary of the transistor.

With the expansion of the PROCEEDINGS's scope, the journal published on a vast breadth of materials, and all the important advances in power engineering, optical communication, satellite communication, signal processing, and biomedical technology cannot be covered in one paper. Computing, neural networks, nanotechnology, and digital multimedia all received significant attention in the pages of the PROCEEDINGS throughout the decade and have lasting ramifications for the future.

II. COMPUTING

Over the course of the 1990s, the use of personal computers became widespread and a part of many people's lives. Over 152 million personal computers throughout the world were in use in 1993, which would grow to 337 million by 1998. Usage of the Internet also became widespread during the 1990s. After the launch of the World Wide Web in 1992, information online became rapidly and easily accessible by the general public. The Internet had only ten million users in 1993, which expanded to 184 million five years later [8].

Reflective of these, and other trends, computing was the subject of the most special issues in the 1990s. Out of 90 special issues and special sections, 18 were dedicated to computing advances, and many other special issues throughout the decade deal with topics directly or indirectly related to computing applications and concepts.

As the number of computer users increased, so did the complexity of the machines themselves. Very large-scale integration (VLSI) continued to be an important topic as processing power increased. The special issue in February of 1990 on the future of computer-aided VLSI design discussed several recent advances in VLSI layout. In the "Scanning the Issue" introduction, the editor noted that the most dramatic of changes in the field since the last special issue on the subject in October of 1981 was a shift from viewing the computer as a passive partner (a tool that aids in the layout) to an active partner (a tool that automates the layout) [9]. Other topics in multichip module technology and VLSI reliability were addressed in the December 1992 and May 1993 special issues, respectively.

Parallel computing was the most frequently addressed topic in computing throughout the decade, with five special issues dedicated to the topic. The first, appearing in April 1991, was dedicated to massively parallel computers. Parallel computers fall under a number of different classes, including pipeline computers, systolic arrays, neural networks, multiprocessors, vector processors, and processor arrays. Massively parallel computers also incorporate elements of single-instruction, multiple-data (SIMD) streams, complexity control, programming languages, and interconnection.

One of the earliest concepts related to parallel computing was self-replicated cellular automata, which John Von Neumann (Fig. 4) theorized about in the 1950s. Stephen Unger published a paper in 1958 regarding the design of a parallel computer for the purpose of image processing, and two machines, the Solomon and Illiac III, appeared by 1963. Though both machines were ultimately unsuccessful, they paved the way for the UCPRI, a working array dedicated to simple analysis of bubble chamber tracks, which appeared in 1967 [10].

Research in the 1990s in parallel computing focused largely on processor structure, memory organization, interconnection networks, architecture and technology, fault tolerance, and programming languages. Topics related to languages and compilers for parallel machines were examined in the special section in the February 1993 issue, where papers were given

Fig. 3. *Guglielmo Marconi (IEEE History Center).*

Fig. 4. *John Von Neumann.*

on automated techniques [11], ParaScope parallel programming environments [12], approaches to distributed memory [13], and language features supporting multithreaded parallel programming [14].

By 1993, parallel processing was the standard for high performance computing, which necessitated a paradigm shift in the way that performance was evaluated. No set of fundamental laws describing overall performance exists for parallel computing, and methods for evaluating parallel computer performance are discussed in the August 1993 Special Issue on Computer Performance Evaluation [15]. Such problems like precedence constraints, load imbalance, and resource contention [16] were examined as were metrics like throughput, response time, reliability, and cost [17].

The July 1996 (Fig. 5) special issue returned to Unger's concept of using parallel computing for image processing. With the shift in design to new standards based on the reduced instruction set computing (RISC) microprocessors, papers discussed the evolution of image processing computer architectures, technology, and engineering of image processing computers, and applications of image processing [18].

Concepts borrowed from parallel computing can be applied to distributed shared memory systems, the subject of the March 1999 special issue. Distributed shared memory systems combine the concepts of shared memory and message passing multicomputers. Both high-end hardware-oriented DSM systems and low-end software-oriented distributed shared memory (DSM) systems were discussed [19].

Several applications of computing received their own special issues. The trend toward miniaturization was covered in the August 1998 Special Issue on Integrated Sensors, Microactuators and Microsystems, and the April 1995 Special Issue on Lower Power Electronics. Devices such as laptops, mobile devices, and personal assistants designed for use in the field, often with integrated sensors or other microdevices, were reliant on a battery source that required different power needs than a desktop computer designed to be constantly plugged in to a stable power source. These devices would gain popularity both in the civil and commercial sectors by the end of the decade and into the new millennium.

III. NEURAL NETWORKS, ADAPTIVE PATTERN RECOGNITION, AND COMPUTATIONAL INTELLIGENCE

While medicine and understanding of the human body had made a great deal of progress, the human brain continued to be one of the least understood organs of our body. Operating through its neurons, the brain functions as an extremely complex computer that is not only able to process data and perform accurate pattern recognition at incredibly high speeds, but also it is capable of adapting to changes. Neural computing is modeled after biological neural computing in order to gain a greater understanding of the brain's behavior and artificial intelligence. Neural networks were defined in the 1990s as any computing architecture that consists of massively parallel interconnection of simple neural processors [20]. During the 1990s, the PROCEEDINGS dedicated eight special issues to this topic.

The first of a two-part Special Issue on Neural Networks in September 1990 focused on the theoretical and mathematical background of neural networks. A historical overview on neural networks by Bernard Widrow opens the issue, and focuses on the literature and mathematical foundation of neural networks. 1990 was the 30th anniversary of the perceptron rule and the least mean square (LMS) algorithm, which were two early rules for training adaptive elements. Both were published in 1960, and initiated several other foundational developments, such as Steinbuch's learning matrix; Widrow's madaline rule I (MRI); and Stark, Okajima, and Whipple's mode-seeking technique. Developments in the 1970s included Fukushima's cognitron and neocognitron models, and Grossberg's adaptive resonance theory (ART), comprising a number of hypotheses regarding the underlying principles of biological neural systems. The 1980s saw pioneering work on feature maps by Kohonen and Hopfield's application of the early work of Hebb to form Hopfield models, a class of recurrent networks. By 1990, the field had become vast, and Widrow recognized that it could not all be encompassed within one paper [21].

Widrow noted that the main problems neural computing attempts to solve are those that are generally ill defined and those that require an enormous amount of processing. At the time, digital computers were excellent for performing tasks like solving differential equations with rapid speed, but fell short in performing tasks such as image or video recognition. The human brain is able to perceive depth, remember the faces and voices of people, and recognize the sights and sounds of objects within a fraction of a second. We are also able to watch television, listen to music, and read books while recalling relevant concepts and information, and even able to cognitively analyze the

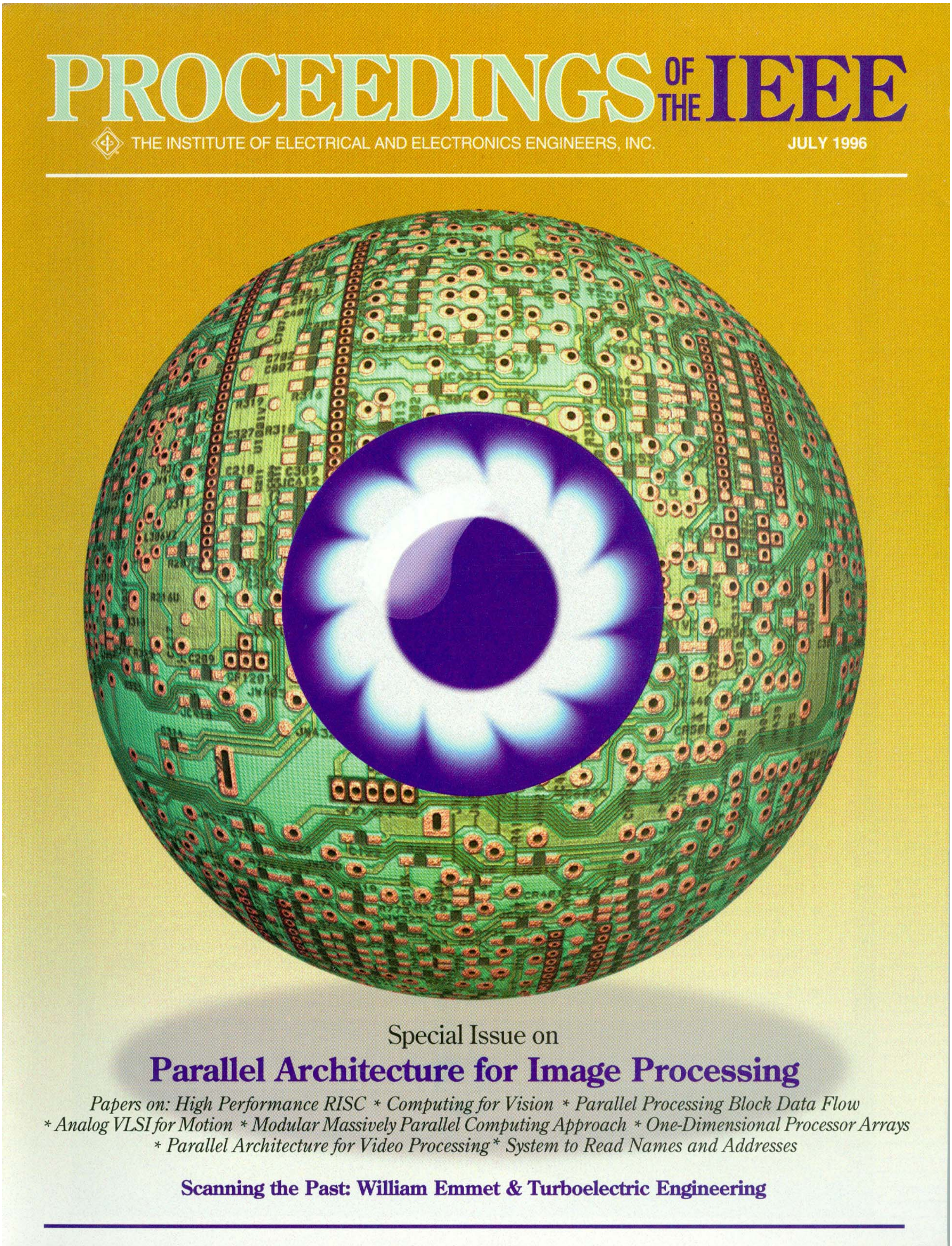

Fig. 5. *Cover of the* Proceedings of the IEEE *July 1996 issue.*

medium as we are absorbing it. Real-time image and video processing requires an enormous amount of computational processing power, for which the computers of 1990 were largely insufficient. Neural computing aimed to solve these problems as well as gain a greater understanding of how the human brain functions.

Shun-Ichi Amari's paper "Mathematical foundations of neurocomputing" described the mathematical theory of parallel processing, and detailed approaches of statistical analysis of one-layer neural networks which differed from popular methods like the backpropagation method, Hopfield networks, and the Boltzmann machine [22]. In a second theoretical paper, Kohonen described a self-organized map, an architecture suggested for potential neural networks, and provided a review of the associated algorithms [23], while Poggio and Girosi described the mathematics of neural networks for approximation and learning [24]. Neural modeling was described in three additional papers.

The second issue followed with a group of papers that explored the practical nine papers that detailed mathematical analysis of neural networks, including introducing time into the backpropagation algorithm [25], a cerebellan model arithmetic computer as an alternative to backpropagation [26], ground states and convergence properties of Hopfield networks [27], and analysis of multilayer perceptions [28], [29]. In addition to theoretical and analytical mathematics, VLSI implementation [30] and optical implementation are explored [31], as well as practical applications such as signal categorization [32], integrating visual and aural cues [33], and high-speed arithmetic computation on the chip [34].

The October 1996 (Fig. 6) issue was the next special issue related directly to neural networks. It focused on artificial neural network applications. The issue was not focused on pattern or target recognition as by that time there was a great deal of literature elsewhere dealing with these subjects [35]. Instead, five papers dealt with image-based applications of neural networks, including three on medical imaging applications [36]–[38]. Schmajuk discussed the potential psychology of intelligent robots through the study of the behavior of living organisms to attempt to build better robots [39]. Computational intelligence was discussed further in the September 1999 issue, which focused on topics in fuzzy systems, neural networks, evolutionary computation, and hybrid computational intelligence systems, the latter of which combined elements from the previous three [40].

Biometrics, the identification of persons based on unique character traits, such as fingerprints, was one of the potential applications of neural networks, and was discussed extensively in the September 1997 special issue. Traditionally, biometric techniques have been used by law enforcement and for access control [41].

Pattern and image recognition play a large factor into biometrics, and applications of neural networks. Zhang discussed this in his paper, which details facial recognition by way of neural networks as well as eigenface and elastic matching methods [42]. Other identification traits such as fingerprinting [44] and speaker recognition [43] were discussed as was iris recognition in the Fink award-winning paper "Iris recognition: An emerging biometric technology" [45].

Privacy concerns were one issue related to biometric identification. If an entity were to store a biometric feature template for each U.S. citizen, it would occupy less than one terabyte of hard drive space, an amount which, while larger than the average consumer could purchase in 1997, is easily and cheaply available today. Woodward's "Biometrics: Privacy's foe or privacy's friend" paper discussed biometric technologies and how they could potentially affect privacy, and encouraged engineers to think about the ethical concerns involved [46].

IV. NANOTECHNOLOGY

Like neural networks, nanotechnology is another relatively recent field of study that holds a great deal of future potential. The discovery of 2-D quantization by Fang and Howard, the Hall effect, and Esaki and Tsu's semiconductor superlattice, allowed for work on 1-D systems, or quantum wires [47]. Research on 1-D physics in semiconductors began with silicon metal–oxide–semiconductor field-effect transistors (MOSFETs) in the late 1970s. Over time, the semiconductors decreased in size, and reached a point where the electron transport phenomenon required quantum mechanics to explain. Nanoscale semiconductor devices which use a scale of less than 100 nm posed a number of challenges fundamentally different from microscale components. Nanoelectronics were difficult to construct and were fabricated by finely focused electron beams, a very slow and costly manufacturing process that was not practically feasible for the commercial market in the 1990s [48].

The PROCEEDINGS dedicated two special issues to nanotechnology in the 1990s, the first in August 1991, dedicated to nanoelectronics. Haroon Ahmed's paper "Nanostructure fabrication" detailed many of the methods used in creating nanoscale artifacts, the most important of which is high-resolution, high-voltage, electron beam lithography. Ahmed described a system that used a 100-kV probe to fabricate −15-nm-wide lines in resist over a 250-pm square field. He noted that at the time of publication arbitrary patterns with sizes less than 10 nm could not be fabricated in organic resists, and that special techniques had to be developed to accomplish this task [49]. Three papers discussed the use of resonant tunneling to substitute for the switching of a conventional transistor. They offered this alternative because of the degradation of performance, including output

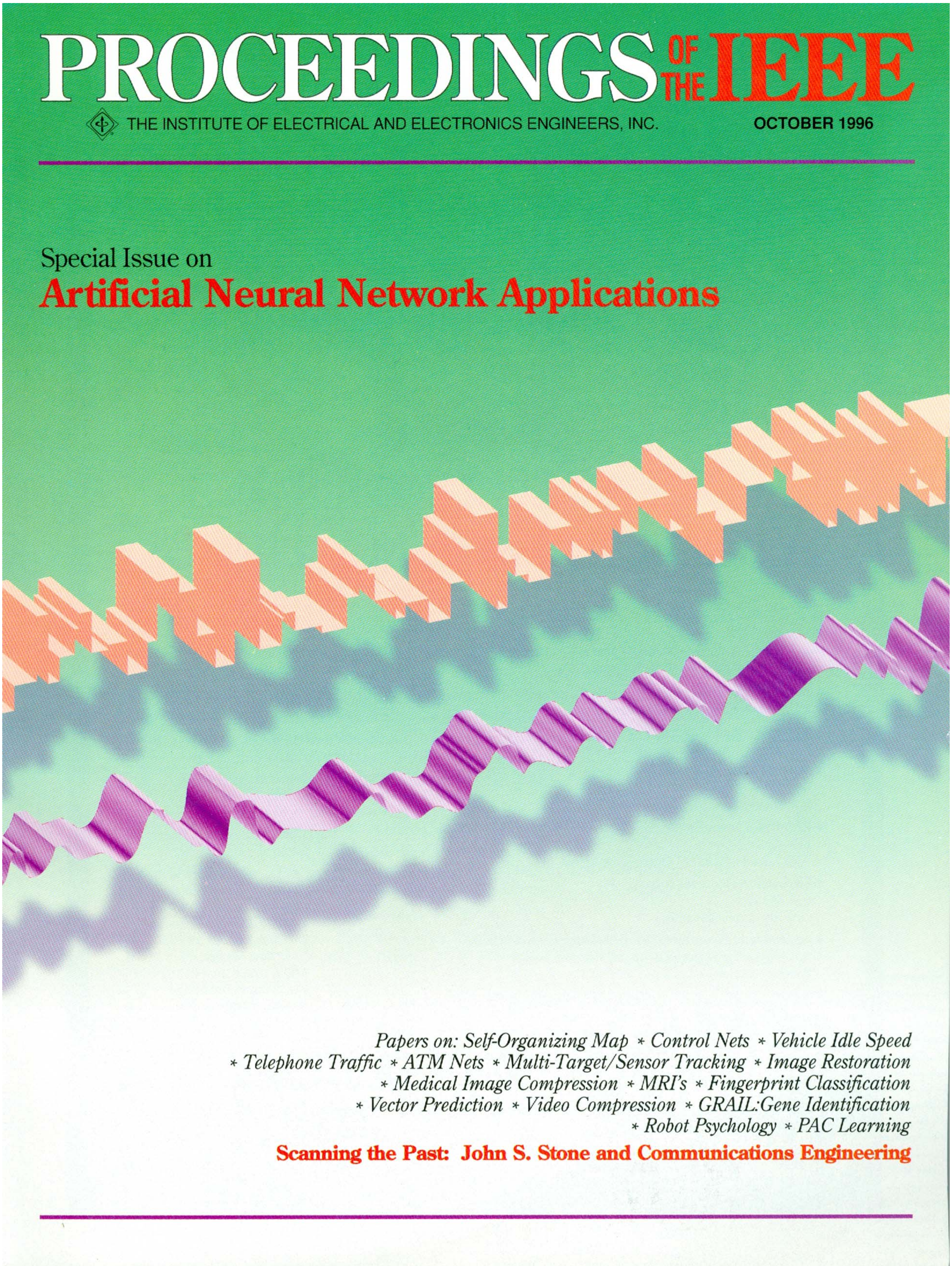

Fig. 6. *Cover of the* Proceedings of the IEEE *October 1996 issue.*

performance, when constructing devices on a nanoscale.

While in 1991 there was no immediate prospect of large-scale integration of nanoelectronics, the field had expanded significantly by the time that the April 1997 Special Issue on Nanometer Scale Science and Technology was published. Research was sparked by the invention of proximal probes such as scanning tunneling and atomic force microscopes, and the field saw great expansion. Dominated by researches tied to the microelectronics industry, the "Scanning the Issue" author speculated that it might be possible to scale down transistors to 30 nm according to Moore's law, but economically the technology of the time was not feasible outside the laboratory [50].

Despite the progress made using scanning tunneling and atomic force microscopes, the scaling of microelectronics to a nanoscale, specifically the silicon MOSFET, posed problems. Difficulties in the fabrication of nanoscale devices included threshold voltage variations due to doping fluctuations [51] and patterning product-level chips in a reasonable amount of time with current electron beam lithography methods [52]. Methods of nanofabrication such as nanolithography through ultrahigh-vacuum scanning tunneling microscopes [53] and atomic force microscopes [54] for developing a single electron transistor [55] are discussed. However, Moore's law would hold true according to the 30-nm "Scanning the Issue" prediction, as in 2008, IBM along with copartners Advanced Micro Devices, Freescale, STMicroelectronics, Toshiba, and the College of Nanoscale Science and Engineering announced a working 22-nm static random-access memory (SRAM) cell [56].

V. DIGITAL MULTIMEDIA

By the mid-1990s, analog television broadcasting had been in active service for approximately 50 years with very few fundamental changes in its standards or broadcasting technologies. By 1995, there were just under one billion television sets in use worldwide; the broadcasting industry was worth over $60 billion in the United States alone [57].

With the continual increase in computer processing power, practical image and video processing for high-quality digital broadcast became feasible. Digital television fundamentally differs from analog television in that it requires a great deal more bandwidth to transmit uncompressed video; to maintain or increase the number of broadcast channels, signal compression is necessary. Compression algorithms that ensure quality, robustness, rapid access, and symmetry are extremely complex and require a great deal of processing power, which is not required for analog television. A shift to digital television therefore required a massive shift in the infrastructure from the existing analog system for recording and broadcasting programs.

The field was still in its infancy when the PROCEEDINGS dedicated its first special issue on digital multimedia and television in April 1985. This issue, titled Visual Communication Systems, discussed digital representation of pictures, codecs, television receivers, and high-definition television [58]. Ten years later, the February 1995 Special Issue on Advances in Image and Video Compression detailed the great progress the field had made. In the "Scanning the Issue," Ya-Qin Zhang provides a comprehensive bibliography of technical literature relating to digital multimedia and television: 13 of these papers appeared in the PROCEEDINGS in the 1990s [59]. Shortly following this issue appeared a two-part special issue in June and July, consisting solely of invited papers on digital television. By 1995, digital video had begun to emerge from laboratories and enter the commercial world. Advances in computing led to compression algorithms which allowed for the transmission of good quality video at an adequate sample rate, VLSI technology made the implementation affordable, and standards pertaining to digital video emerged rapidly [60].

Compression methods and algorithms for digital video such as ITU-T H.26 [61], MPEG [62], [63], model-based video coding [64], [65], and the U.S. HDTV standard were published, as were specific applications of digital video including digital subscriber lines [66], cameras [67], recorders [68], lossless/lossy image compression for medical uses [69], and a paper on interactivity which described an on-demand system for viewing content [70]. Implementation aspects such as

Fig. 7. *KDKA (IEEE History Center).*

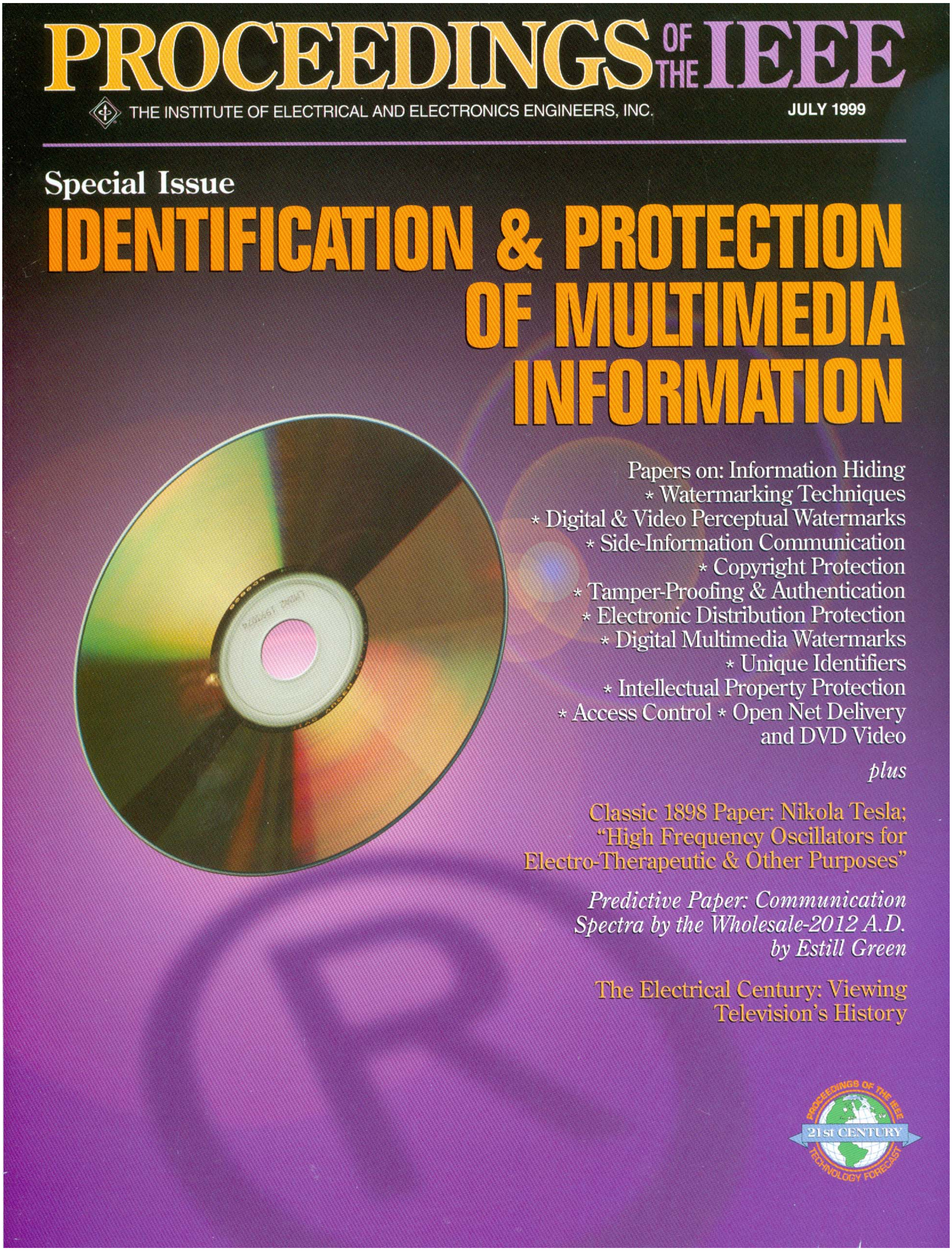

Fig. 8. *Cover of the* Proceedings of the IEEE *July 1999 issue.*

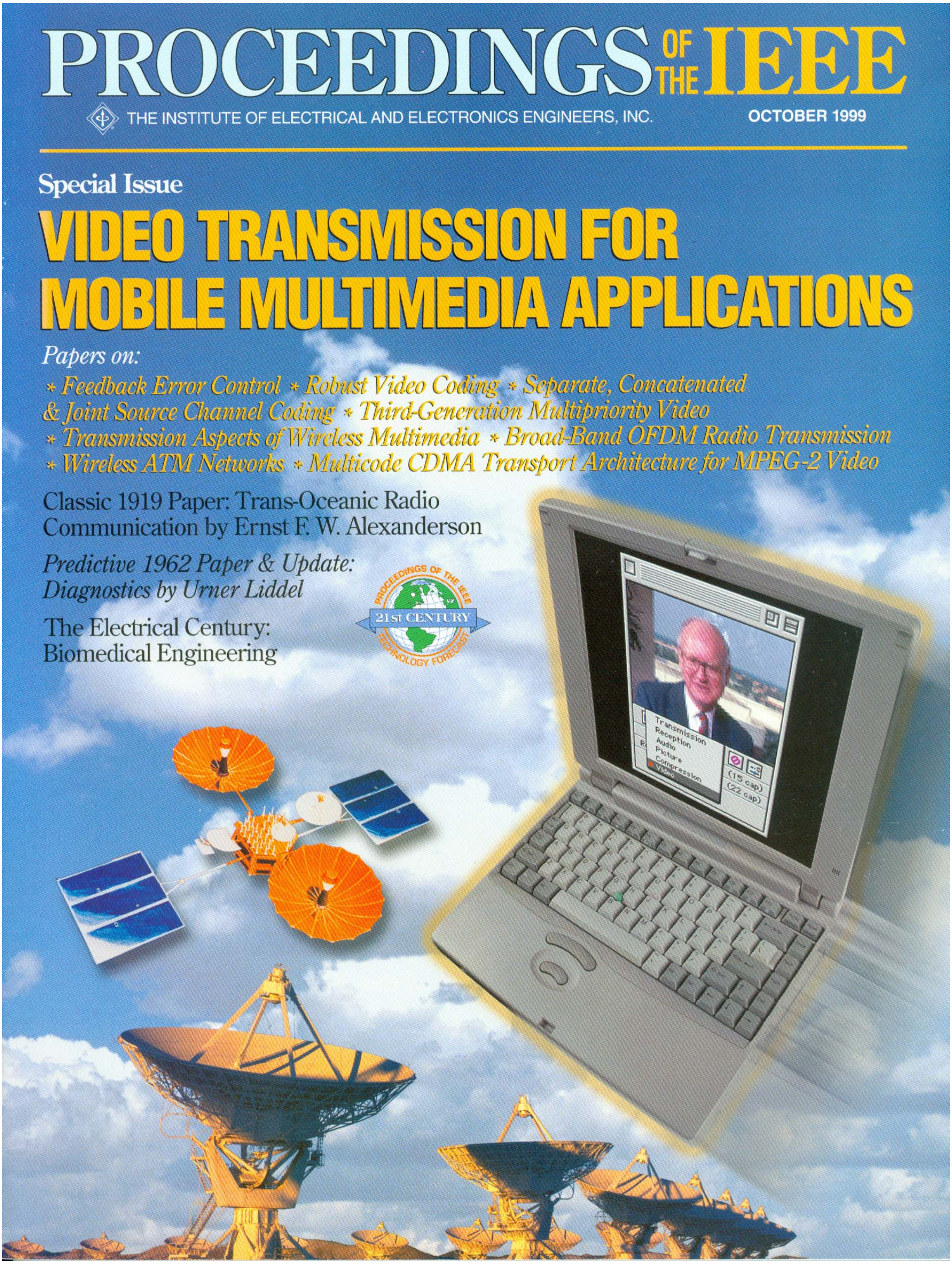

Fig. 9. *Cover of the* Proceedings of the IEEE *October 1999 issue.*

VLSI for video [71] JPEG [72], and chip production [73] were also discussed.

Related to digital television, but with a greater scope encompassing broadcasting of video over the Internet, multimedia signal processing was the subject of the two-part special issue in May and June 1998. Multimedia is the combined processing of multiple media streams, such as digital audio, video, and captioning, each stream having different algorithms for compression and different broadcast standards [74].

Providing historical context on the history of multimedia broadcasting, two classic papers dealing with breakthroughs in analog broadcasting were reprinted, "KDKA: The radio telephone broadcasting station of the Westinghouse Electric and Manufacturing Company at East Pittsburgh, Pennsylvania" (Fig. 7) by D. G. Little [75], and "Description of an experimental television system and the kinescope" by V. Zworykin [76].

In an overview of the technologies involved, Cox, Haskell, Lecun, Shahraray, and Rabiner discussed compression and coding, synthesis and recognition, organization, storage and retrieval, access, searching, and browsing of multimedia signals [77]. Many video standards and compression algorithms are also applicable to digital television; Chiariglione discussed the MPEG 1 and 2 standards [78], and MPEG-4 was discussed by Katsaggelos [79]. In addition to video, topics related to audio were published, including creation, transmission, and rendering [80], as well as the technological limitations of immersive audio systems [81]. Combining the two, audiovisual integration was discussed by Chen [82] and Nakatsu [83].

Topics in architecture for multimedia processing such as low power, high performance, multimedia signal processing in real-time environments [84], and potential applications of neural networks are discussed by Kung. He argued that neural networks are an essential technology for efficient representations for audio/visual information, detection, and classification techniques, fusion of multimodal signals, and multimodal conversion and synchronization [85].

Intellectual property issues were the subject of the July 1999 Special Issue on Identification and Protection of Multimedia. Interestingly (Fig. 8); this issue coincided with the June 1999 launch of Napster, the peer-to-peer filesharing Internet service that ushered in a new age of software and multimedia piracy. Much of the issue is devoted to the watermarking of digital objects. Seven papers explore this area, with the ultimate goal of having perfectly invisible, nonremovable, secret watermarks on images [77].

Two papers dealt with the identification of multimedia objects, and the final three dealt with the security infrastructure for contents. The Schneck paper discussed methods to combat piracy such as watermark-based persistent control, cryptographic containers, and copy protection schemes for cable boxes [86], while Bloom reviewed several copy protection schemes for DVDs, including constant scramble systems (CSSs), analog protection systems (APSs), and copy generation management systems (CGMSs) [87]. Successful implementations for copy protection to prevent mass piracy are still a major challenge that the media industries face today.

The popularity of third-generation (3G) mobile devices rapidly expanded in the latter half of the 1990s, as did the available bandwidth for transmission of video. The October 1999 Special Issue on Video Transmission for Mobile Multimedia Applications (Fig. 9) reflected the growing trend of wireless computing, with papers published on subjects including MPEG-2 transport over code-division multiple access (CDMA) [88] and channel coding [89]. As the decade came to an end, consumer wireless devices became more powerful and widespread, and their applications and implications expand significantly into the new millennium. ■

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APPENDIX
SPECIAL ISSUES AND SECTIONS IN THE PROCEEDINGS DURING THE 1990S (ENTRIES ARE SPECIAL ISSUES EXCEPT WHERE SECTION IS NOTED)

1990

January	High Speed Communication Networks.
February	Computer-Aided Design.
April	Multidimensional Signal Processing.
June	Magnetics.
July	Satellite Communication.
September	Neural Networks I: Theory and Modeling.
October	Neural Networks II: Analysis, Techniques, and Applications.

1991

February	ISDN.
April	Massively Parallel Computers.
May	Large Bandgap Electronic Materials and Components.
June	Special Section on Spaceborne Radar.
July	Time and Frequency.
August	Nanoelectronics.
September	Special Section on Real-Time Programming.
October	Electromagnetics.

1992

January	Antennas.
March	Quantum Electronics.
April	Special Section on Network Architecture for Common Channels.
May	Knowledge-Based Systems in Electric Power Systems.
June	Special Section on Lasers in Medicine.
July	OCR.
September	Computational Geometry.
October	Special Section on Chemical Vapor Deposition.

November Terahertz Technology.
December Special Section on Multichip Modules.

1993

January Engineering Research Centers.
February Special Section on Languages and Compilers for Parallel Machines.
March Advanced Power Generation Techniques.
April Special Section on Changing Nature of High-Speed Storage.
May VLSI Reliability.
June Special Section on Propagation Effects on Satellite Communication Links.
July Special Section on Programming Technologies.
August Computer Performance Evaluation.
October Special Section on Fractals in Electrical Engineering.
November Optical Communication Network Trends.
December Special Section on Gallium Arsenide Heterojunction Bipolar Devices.

1994

January Real-Time Systems.
March Hartley Transform.
April Consumer Electronics.
May Radio Telescopes.
June Data Compression.
August Power Electronics and Motion Control.
September Wireless Networks for Mobile and Personal Computing.
November Optical Computing Systems.
December Remote Sensing of the Environment.

1995

February Advances in Image and Video Compression.
March Engineering Applications of Fuzzy Logic.
April Low Power Electronics.
June Digital TV I: Enabling Technologies.
July Digital TV II: Hardware and Applications.
August Distributed Interactive Simulation.
November Nonlinear Phenomena in Power Systems.
December Microprocessors.

1996

January Molecular Control.
February Laser Radar Applications.
March Electrical Therapy of Cardiac Arrhythmias.
April Wavelets.
May Optical Information Processing I: Technologies.
June Optical Information Processing II: Applications.
July Parallel Architecture for Image Processing.
September Time–Frequency Analysis.
October Artificial Neural Network Applications.
November Special Section on Signals and Symbols.

1997

January Data Fusion.
March Hardware/Software Codesign.
April Nanometer-Scale Science and Technology.
June Ka-Band Propagation Effects on Earth-Satellite Links.
September Automated Biometric Systems.
October Communications in the 21st Century.
November Optoelectronics Technology.
December The Global Information Infrastructure.

1998

January 50th Anniversary of the Transistor.
March Virtual and Augmented Reality in Medicine.
May Multimedia Signal Processing I
June Multimedia Signal Processing II.
July Mobile Radio Centennial.
August Integrated Sensors, Microactuators and Microsystems.
October Blind System Identification and Estimation.
November Intelligent signal Processing.

1999

January GPS.
February Asynchronous Circuits and Systems.
March Distributed Shared Memory Stems.
April Quantum Devices and Applications.
May New Visions for Vacuum Electronics.
July Identification and Protection of Multimedia Information.
September Computational Intelligence.
October Video Transmission for Multimedia Applications.
November Photorefractive Materials, Devices, and Applications I: Optical Effects and Memories.
December Photorefractive Materials, Devices, and Applications II: Applications.

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