Biometric Pioneers: *Anil K. Jain*

Interview conducted by Aparna Bharati, Assistant Professor of Biometrics and Data Pattern, Lehigh University, Bethlehem, PA

Anil K. Jain is a University Distinguished Professor at Michigan State University where he conducts research in pattern recognition, computer vision, and biometrics recognition. He received his B.Tech. degree from the Indian Institute of Technology, Kanpur in 1969 and M.S. and Ph.D. degrees from Ohio State University in 1970 and 1973, respectively. For advancing pattern recognition and biometrics, Jain was also named Doctor Honoris Causa by Universidad Autónoma de Madrid, the Hong Kong University of Science and Technology, and Hong Kong Baptist University, and was elected to the U.S. National Academy of Engineering, Indian National Academy of Engineering, the World Academy of Science, the National Academy of Inventors, and the Chinese Academy of Sciences. A member of both the United States Defense Science Board and the DoJ/NIST Forensics Science Standards Board, Jain is a Fellow of ACM, IEEE, AAAS, and SPIE, and has served as Editor-in-Chief of *IEEE Transactions on Pattern Analysis and Machine Intelligence*. His honors include Guggenheim, Humboldt and Fulbright fellowships, and the IAPR King-Sun Fu Prize. Jain has licensed 9 U.S. and Korean patents. His publications are available through Google Scholar at https://scholar.google.com/citations?user=g-_ZXGsAAAAJ&hl=en.

BHARATI: You are a renowned computer scientist, and an expert in pattern recognition and biometric authentication. Can you tell me how you first became interested in this field?

Jain: This question brings back a lot of fond memories. I finished my Bachelor's degree in electrical engineering at IIT Kanpur in April 1969 and did not really have any idea of what I wanted to do. So, I took the easy path and followed about 200 of my classmates (from a graduating class of 250) to the United States for graduate studies. When I landed at Ohio State to pursue my M.S. degree, I did not know any professors there and my financial support came from the University Computing Center, where I ran large-scale computer programs. At that time, programs were decks of punched cards run on an IBM 360 mainframe. This required mounting hundreds of magnetic tapes containing "massive" data (tens of megabytes!). At the same time, I joined the "Legged Locomotion" project, headed by Professor Robert McGhee because it sounded interesting.

McGhee's team had the goal of building a four-legged robot. My task was to study the control problem of finding stable states for the robot leg placements for locomotion. I had to

determine how the robot would move from one location to another without toppling over. I posed this as a binary integer programming problem, with each of the four legs either "on the ground" or "off the ground." The resulting solution found stable states that could be interpreted in terms of the natural gaits of horses. This became my M.S. thesis, and I also published a paper about it in *Mathematical Biosciences* in 1972. By then, I was hooked on the research and I enrolled in the Ph.D. program in 1970.

My first encounter with pattern recognition happened in the Spring quarter of 1970 when Professor Chandrasekaran offered a course on the topic in the Computer Science department. He had a draft of the first edition of the Duda and Hart book called *Pattern Classification and Scene Analysis,* which was published by Wiley three years later. There were no copying machines at the time, so we had to share just one copy of the book. That's how I learned Bayes decision making, feature extraction and selection, classification and clustering, and error-reject tradeoff, among other topics. The 10-week course was pretty fast paced! One of the topics covered in the course, "dimensionality and sample size tradeoff," was new at the time. I liked it and it became the topic of my Ph.D. thesis, which was published in the *IEEE Transactions on Information Theory* and *IEEE Transactions on Systems, Man, and Cybernetics*. The course in pattern recognition, along with courses in signal processing, image transforms, graph theory, coding theory, probability and statistics, and experimental design, set me up with a strong background to conduct research in pattern recognition and computer vision.

Recall that 50 years ago, there were no word processing systems or desktop computers, so we had to exercise extreme care in writing technical papers. You had only one chance to edit the original draft. If you could get one or two papers published in a year, you were doing well!

BHARATI: Your early work in the 1970s and 80s focused on using pattern recognition for character recognition. How did you see the potential for applying these techniques more broadly?

Jain: My focus has always been on doing basic, foundational research in pattern recognition and computer vision, while keeping an eye on "application domains." As an example, I applied Markov random field models to image texture synthesis and classification, and for interpreting SAR remotely sensed images. When I worked on data clustering, my goal was not to invent a new clustering algorithm, but to address "cluster validity." The topic of cluster validity includes questions like "is a clustering method suitable for understanding the structure of given data?" or "are the clusters identified by a clustering algorithm valid?." A clustering algorithm will always find clusters in data, whether they are real or artificial! A better understanding of clustering algorithms helped me to use the technique to segment medical images, as well as to identify surfaces in range (depth) images. Our work on character recognition was motivated by our projects on identifying text in arbitrary images and for interpreting hydrologic maps.

BHARATI: In the 1990s, you started doing pioneering research on using fingerprint, face, and iris recognition for biometric identification.

What inspired you to shift your focus to biometrics?

Jain: You are correct. Our research in fingerprint recognition and face recognition started around 1991 and continues till this date. We never really worked on iris recognition because, given the already high performance of Daugman's algorithm, we did not see much room for improvement. Face recognition, on the other hand, was in its infancy at the time and fingerprints were predominantly used in forensics and law enforcement. Our opportunity came in the form of an NSA research project where we were asked to utilize a Field Programmable Gate Array (FPGA) to speed up image processing algorithms. We zoomed in on two generic problems—image enhancement and point set correspondence—but in the context of fingerprint recognition. We designed a bank of Gabor filters with their scales tuned to ridge spacings, and orientations quantized to coincide with ridge orientations. Our 1998 Pattern Analysis and Machine Intelligence (PAMI) paper on Gabor-filter based fingerprint enhancements has been cited over 3,500 times. We had similar success with establishing minutiae point correspondences on a FPGA processor which executed 100X faster than on a CPU (Sun 3/50 processor). With this experience, we were considered fingerprint recognition experts and started receiving research support from IBM, Siemens, and Lumidigm, as well as a number of federal agencies.

We had a slower start in face recognition, primarily because of lack of access to face images. Recall there were no mobile phone cameras or social media back then. We were stuck in the mode that range images (depth images) of faces could lead to higher accuracy than conventional 2D gray scale face images. But, once we identified the right problems where we had little competition, we did well. These problems included composite (forensic sketch) to mugshot matching, face liveness detection, large scale search, face clustering, and a longitudinal study on face recognition.

BHARATI: You founded the biometrics research group at Michigan State University in 1991. What were some of the early challenges you faced in establishing this new field of research? And, what do you think are the challenges that early career academics and entrepreneurs face in 2023?

Jain: A major challenge in research is to identify a direction with a vision for both short-term and long-term outcomes, and then to recruit and train students to work with you. In my case, my students and I had to learn domain knowledge about fingerprints and then figure out how to leverage it to design robust and efficient algorithms that pushed the state-of the-art forward.

To make an impact, you need to go into a problem in depth rather than simply scratching the surface. I do not invest in a problem to just write a conference paper. I am in it for the long haul. If one is able to show good results, research funding follows, and capable students are ready to join your group.

BHARATI: In a fast evolving research field, what according to you is the key to keeping ourselves informed and relevant? What should we pay attention to and what is noise?

Jain: One must read lots of papers, go to high quality conferences and talk to as many people as possible. The two-class problem of "good stuff" vs. "noise" takes some training data and

that's where reading and listening helps. Maybe ChatGPT can filter the literature for us!

BHARATI: You have authored more than 500 research papers and several books on pattern recognition and biometrics. What do you consider your most important contributions to the field?

Jain: I am extremely proud of our research dealing with infant identification from fingerprints and palmprints, which has shown that it is indeed possible to recognize children as young as 6-12 months with acceptable accuracy. Almost all biometric systems are designed for and used on adults. Even the world's largest biometric system, Aadhaar, has set an enrollment age of 5 years. We need to find a way to uniquely identify the approximately 600 million children below the age of 5 living on our planet.

BHARATI: What real-world applications of biometrics authentication are you most excited about? How do you see biometrics shaping the future of security and privacy?

Jain: Over the years, I have worked on a number of applications that my university has licensed to major vendors, including NEC, Morpho (now Idemia), and Thales. These are the three global heavyweights in biometrics and it is extremely satisfying when they license a technology from an academic lab like ours. Some of the most fun, as well as impactful, applications have been systems for tattoo identification, altered fingerprint detection, composite (face sketch) to photo matching, and synthetic fingerprint generation for data augmentation.

I have been very fortunate to be associated with India's Aadhaar civil registration system since its inception in 2008. Aadhaar now has an enrollment database of close to 1.5 billion, one order of magnitude larger than the closest system, which is the FBI's NGI system.

BHARATI: What advice would you give to young researchers interested in pursuing work in pattern recognition and biometrics today?

Jain: To work in biometrics, it is necessary to have a solid background in mathematics, statistics, machine learning, signal processing, optimization, as well as design of algorithms and system level skills. You need to build strong capabilities to shift your focus from one problem domain to another during your career. Funding opportunities for research change over time and you will be expected to adapt. Just 10 years back, very few researchers were working on deep networks. You need to be prepared when the next paradigm shift happens.

BHARATI: You have an incredible record of mentoring graduate students who have become leaders in the field. What is your approach to mentoring and what do you look for in a student?

Jain: As expected, every student joins my group with different backgrounds, interests and expectations. So, everyone needs to be mentored in a slightly different manner. Some come sufficiently prepared to run with a problem, while others need more prodding and pushing. As long as I can find the right problem to match the student's interest and capabilities, things work out. It is a shared responsibility.

What I like to do is to assign a new student to work with a senior student or a postdoc the first year so they can get a paper published together. This gives the new team member an opportunity to apply his skills to a research problem and to learn how to write a technical paper. Some newcomers will take off on their own after the first year, while others will still need hand holding the second year. Eventually, I want every student to demonstrate they can work independently to earn their Ph.D. Most of my students write papers with just one or two co-authors so we know who contributed significantly.

BHARATI: Outside of your professional work, what are some of your personal interests and passions?

Jain: I love to travel and explore other cultures. I am fortunate to have traveled from Tromso, Norway, in the north, to Punta Arenas, Chile, in the south, and from Anchorage, Alaska, in the west, and to Bali in the east. This past summer I had a chance to travel to Galapagos, Quito, Guayaquil, Bangalore, Ilulissat, Reykjavik, Prague, Pisa and Alghero. Chance encounters at pattern recognition conferences have resulted in many life-long friendships leading to repeat visits and extended stays in Delft, Seoul, Lisbon, Oslo, Hong Kong, Istanbul and Jakarta. This time away from campus gives me time to reflect and catch up on reading. Students in my lab are also happy when they are left alone.

BHARATI: As you look back on your highly impactful career, what are you most proud of? And what's next for you?

Jain: I did not drift much from biometrics for more than 30 years, which is good. Over this time frame, I am most proud of the numerous Ph.D. students and postdocs who have made their own mark in biometrics. Every time a student was ready to graduate, I was not sure what the next student would work on. But, somehow, we managed to identify one problem after the other, each time with more vigor and impact. The Ph.D. students found elegant solutions to the problems, carried out carefully designed experiments, and published in the best possible venues. Their work is second to none.

I am now curtailing the size of my lab, but increasing my off-campus activities. These include a collaboration with my former student, Anoop Namboodiri at IIIT Hyderabad, on large-scale identification problems, assisting the World Bank with building a civil registration system in Madagascar, and serving as a trustee for the Mohamed bin Zaid University of Artificial Intelligence (MBZUAI) in Abu Dhab, United Arab Emirates. I will keep busy.