Exciting Moments of Research

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When I joined the PhD program at my own alma mater, the very first question bugged me was, what I was supposed to do to qualify as a researcher? The other obvious question was why the Government was paying me a scholarship or fellowship? Was it meant for demonstrating creativity on my intellectual exercises? Was it a kind of support from the society, as it extends to other forms of recreational arts and faculty? Did my country really expect me to solve a burning problem, which would bring the progress and prosperity of this nation? Frankly, I was confused and I should admit that till date, there is no qualitative change in the state of my confusion in this regard. However, I started on my own way looking at various issues on a research area of electrical sciences called image processing, without bothering much about their impact and applicability.

Search for something ……

In my early research days I had the least idea about what I was going to do and what excitement awaited me in future. Of course I was very much excited to dream that excitement. Nevertheless there were other motivations also to pursue the doctoral degree. I wanted to be in academics and realized; that freedom can be bought by having a PhD degree. So I wanted the degree as quickly as possible. I was fortunate in various ways. I had wonderful friends, who also joined PhD programs of my Institute around the same time. The ambience surrounding us was intellectually vibrant with a mood of great expectation and excitement for coming days. Above all, my supervisor (Prof. B.N. Chatterji), one of the nicest persons I know, gave me all the liberty of choosing my research problem and carrying out my study in my own way. Frankly, it was an adventure for all of us. We didn’t really know what the things to prove were, but we wanted to prove something. It was that search for ‘something’ initiated my research career.

In those days, it was not easy to get reading material, in particular the published work in journals and conferences related to your field of interest. Our main resource was our library. It was quite a thrilling experience to walk down the semi dark allays of the bound-journal section of the library and then started looking for a paper you intended to read. I can tell you, the joy of getting the desired one is no less than the discovery of an island after an uncertain voyage across the ocean. Sometimes, we used to mail our reprint request, specially printed on a post-card size hard paper, to a researcher in foreign lands. Before it got lost into oblivion, you would be surprised to get a delivery suddenly with compliments from your peer researchers. Those were my prize collection and still I am having them in a few bound volumes. Now-a-days, we have the comfort of getting almost any work by the mouse-click from the digital library of our Institute and also some of them are available free in the internet. Even requesting an article from its author by sending an email is a rare phenomenon. Though digital connectivity has opened up the much coveted store house of knowledge and information, it has robbed the excitement of uncertain walk through among the journals and magazines lying in the corridors of a library.

First research problem …

My first research problem started with designing an algorithm for thinning a 3-D object, which is represented by discretization of its spatial occupancy in a 3-D binary array. The problem was introduced to me by my friend Dr. P.P. Das (PPD). In his Master's thesis he implemented a known 2-D thinning algorithm. When I approached him for a possible research problem, he suggested me, "Why don't you extend the algorithm to 3-D?" The next day, I came up with a solution with full implementation and results. The thinning of a pattern may be carried out by iterative deletion of boundary points, till the pattern gets fragmented or eroded completely. It provides a skeletal representation of the object. In the 2-D algorithm, there are a few neighboring conditions to be checked for a point before its safe deletion. I simply extended these conditions to 3-D. Fortunately, the work got accepted without any trouble in an international journal, which happened to be my first published research paper in a journal. Interestingly, a few months later, we got a rebuttal from two researchers, who showed and proved with counter examples that our method has flaws. In some cases, 3-D patterns loose connectivity. The editor-in-chief of the journal was kind enough to forward their criticism to us for a review. Not only we accepted it, but also we came up with an improvised version of the algorithm which got published along with the criticism in the same issue of the journal. It made me happy twice - it increased my understanding of the problem and it also increased my paper count! The incident was a good lesson to me. It revealed that we should not be afraid of criticism, which actually helps in improving ourselves. Sometimes we felt terrible when we find our work got rejected by our peer reviewers and our instant reaction appears to be a lamentation on the injustice ushered from irrational reviews! It should be otherwise. We should be positive enough to look for exciting revelations out of those comments and criticisms, and engage ourselves to resolve issues, that rise subsequently. Research is exciting as long as you are in the process of improving and developing your work.

Cooked up problems …

In those days I read a little, but worked more on my own ideas. I must admit it is not an ideal research methodology. Probably the pasture was green enough to get my work published in some of the reputed international journals. I do not think in today's research work it is advisable. We should have sufficient background information and knowledge about the topic of our research. In the past, our window to the outside world was also smaller and we needed to dream on our "cooked up" problems more than studying the real world applications. I was working on recognition of 3-D objects without even having any access to a digital camera. In fact I was looking for 3-D real life images for testing my algorithms and techniques, which were mainly developed on synthetic data set of small 3-D binary arrays. I soon found that the kind of data I was looking for was partially available in the form of depth maps of visible surfaces, called range images of an object or scene. I did go through a few papers on range imaging and analysis of range images, and started sending my request to peer researchers for providing me sample range data. In one fine morning, I received a big packet from Prof. Kosuke Sato of the Osaka University, Japan, containing the much needed data set in a floppy. However, he also threw me a challenge for deciphering the data file, as there was not sufficient information (or I was not good enough to deal with them readily) in understanding the format of the data. So it took a few days to dig those numbers, to arrange them in a meaningful 2-D array, and finally to get the display of objects on your screen for ultimate confirmation of your prized possession. Looking back, I must say those were my moments of excitement. How little it may appear in today's context, it gave me the opportunity of testing and adapting my algorithms on real life images! It did save my PhD work from being castigated as mere hypothetical exercises!

A few early concepts I was quite enthused about, were the concepts of digital neighborhood plane (DNP) and neighborhood plane set (NPS), which I had introduced for capturing local structural information of a 3-D point. Initially I conceived about nine DNPs each containing at most eight neighboring points. Later, my friends Prabir (Dr. P.K. Biswas) and Vosky (Dr. S.S. Biswas) incorporated four more additional planes which may contain at most six neighbors. The NPS of a point is the set of DNPs on which the point has sufficient numbers of neighbors. Using this feature we designed algorithms for segmenting 3-D surfaces and for extracting wire-frame structures of 3-D objects.

Distance functions …

Around same time we were also fascinated about discovering new metrics or distance functions in arbitrary dimension. My friend PPD did excellent work in this area and I was encouraged to join the search for new classes of distance functions. So one morning I went to PPD and suggested a new class of distance function based on t-maximum operations. I was not sure enough whether the function is sufficiently novel. But PPD was quick to fire it up and spent a few days to come up with a set of theorems and proofs elucidating properties of this class of distance function, which we named t-cost distance function.

What fascinated me most are shapes of digital circles and spheres of those distance functions in 2-D and 3-D, respectively. In particular, we observed interesting variations in those shapes for octagonal distances, which are defined from paths generated by a sequence of different types of neighborhood definitions. PPD showed how vertices of these hyperspheres could be computed given the neighborhood sequence of an octagonal distance function. We further simplified this computation and used it for computing vertices of a digital circle and a sphere, in the form of a convex polygon in 2-D and convex polyhedron in 3-D, respectively. When Ashwath (Dr. Ashwath Kumar) joined as a PhD scholar under the joint supervision of me and Prof. Chatterji, I suggested him to develop different geometric computational techniques exploiting their shapes. Subsequently, he came up with efficient techniques for computing geometric transformation, normals at boundary points of 2-D object, and cross-sections of 3-D objects using medial axis transform (MAT) based on octagonal distance functions. He also showed how these transforms are useful in fast rendering of 3-D objects. We studied also the proximity of these distance functions to the corresponding Euclidean norms exploiting the geometry of their circles and spheres. Previous to our technique researchers adopted only the analytical methods for computing the bounds of the deviations from Euclidean norms and obtained the optimum distance functions minimizing these bounds. However, the mathematics involved in this process, may be quite rigorous and in many cases (e.g. for octagonal distance functions), we still do not have such analysis. As our approach was from a different perspective, it gave a new insight to some of these distance functions, which were empirically found to provide good approximations, but remained unexplained from their mathematical properties. Yet, the limitation of our technique lies with its extension to dimensions higher than 3-D. Things get really murky there and I invite budding researchers to take the challenge for finding good approximations of Euclidean norms in higher dimensions using the geometric approach.

A lull period with fractals …

There are also lull periods in your research career. Particularly, you may feel tired and exhausted with similar nature of research problems and ideas. So in one fine morning you may find that all the excitement of having fresh ideas suddenly vanishes into your routine work and assignments. This is the time; you should ponder yourselves for a new direction. For me it was the fractal modeling of objects and patterns, which drew my attention. I was engrossed with the beauty of those fractal patterns generated from simple mathematical expressions, and interested on modeling 2-D patterns using iterated function systems (IFS), a set of contractive affine transformations. During this period, one of my B.Tech project students did develop a tool for modeling such pattern by covering the target shapes with tiles of different geometrically transformed replica of the same and created artistic scenes of trees, rocks, huts, etc. However, what impressed me the most is the tall claim of getting a very high compression ratio of images using this model, though its algorithm was not published apparently for commercial reasons. Still today I am not sure about its existence. In any case, I was motivated to look into compression algorithms based on the IFS and took Jacquin's algorithm using partitioned iterated function system (PIFS) as a case study. We studied its convergence properties during decoding and came up with an efficient linear time decoding algorithm, much faster than the iterative process. In this modeling we showed that the image space is partitioned into chains of pixels forming a typical structure named circular plant, which originates from a cycle (called limit cycle). The convergence of the fractal code depends on the convergence of these limit cycles. Hence by tracing a chain backward, we could compute these limit cycles and subsequently could compute the converged values of the pixels in one shot. We also used this concept to design a novel video compression algorithm. In this algorithm with the help of the circular plants of a reference frame other collocated temporal frames are encoded. Unfortunately, the performances of these compression algorithms were so poor compared to the standards such as JPEG, MPEG, etc., that these findings had little impact in this area of research.

Living with ideas …

In the mean time, I was also attracted to color processing and started playing with colors by changing their saturation and hue following CIE chromaticity chart. In fact, the idea came to me in early nineties while supervising an M.Tech thesis. But it finally got shape when I was visiting the University of California, Santa Barabara (UCSB) in the summer of 2000. Living with an idea and finally exposing it are quite exciting. It happened to me in other cases also. You live with these ideas for years and finally become bold enough to bring it out with much more details and impact. This was also true for our analysis of fractal decoding algorithms, which took around three years to be considered seriously. Very recently, I reported a new class of distance function, named weighted t-cost distances, which was actually conceived around six to seven years back. When you are pondering on research ideas, you have all the excitement of a child, who is impatiently waiting for a grand event being unfolded before him. However, the most difficult stage is the sustenance of that idea and repeatedly revisiting it under various contexts. Finally you have to take a decision for its full exposition. At that stage you are like a director of a movie, who has the sketches of his scenes and shots. You need to choose your actors, their roles and final execution plan with thorough experimentation and theorem proving. In this process, do not expect that the outcome will be always in confirmation of your hypothesis and expectation. However, in most cases, you are sure to reach a state of new realization and confidence in your research goals.

Necessity of survival …

I started my discussion with a few questions on motivating factors of research. Those questions are bound to occur at various stages of your career in different forms. It ranges from questions related to progress and evolution of human civilization, to mere mundane needs of an individual for getting a degree or promotion. Frankly speaking, motivation of research is multi-faceted. Sometimes it is the product of creativity of your passion; sometimes it is the necessity for the survival of an individual in his / her professional world. I am fortunate to supervise a few students toward their doctoral degrees. Some of them are very bright and capable of carrying their research work almost on their own. They mostly sought my opinion and suggestions on certain matters and queries. Some of them needed my involvement only in the stages of problem formulation, but could carry out on their own thereafter. For an exceptional few, I had to plan for almost everything including writing the codes of implementation. But I am doubly thankful to them for driving and pushing my research agenda. My passion on color processing rose also out of this necessity. I entered into the wonderful world of problems on color constancy, retinex processing and color demosaicing. In the retinex processing, we proposed a network model of retinex computation, which is aimed at annulling illumination variation in a scene toward restoration of colors of pixels. The model was inspired by biological processing that goes in our visual pathway. Color demosaicing is an operation required for converting a color filter array (CFA), which has only one predetermined color component at every pixel in an interleaved fashion, into a color image with full resolution for every color component. There are various algorithms for this purpose. We proposed a Markov random field (MRF) based post-processing technique for improving the quality of demosaiced images obtained by using any one of those algorithms.

A chance meeting …

While I was working on this problem, I had the luck of meeting Sanjit-da (Prof. Sanjit K. Mitra of UCSB), who was visiting my Institute in the year 1999. I consider that was one of the important turn around in my research life. That time he was also working with similar problems. He invited me to visit his laboratory in the summer of 2000. I readily accepted. Not only in 2000, I visited his laboratory in subsequent years of 2001, 2003 and 2004. I would have done it every year, unless I got myself busy with the headship of the Computer and Informatics Center of our Institute. When you work and spend time with a person like Prof. Mitra, you have the fortune of getting exposure to different types of problems in the areas of signal and image processing. In particular he drew my attention to the problems of processing in the compressed domain. That is how; I started looking at issues related to development of algorithms for compressed images and videos.

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I thought that I would try to capture my exciting moments of research. But it ended up with sketches of some of my research problems and a brief history about their genesis. My moments of excitation are hidden under those research impulses. They are under those sudden twists and turns, when out of nothing suddenly you come to realize that there are a few things yet to be done. However little is their impact, you are the only person in this world who thought about it. I had the fortune of sharing these excitements with my teacher, with my students, and with my friends. That is what I enjoyed the most and am still enjoying.