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Undergraduate Students Compete in the IEEE Signal Processing Cup: Part 2

This is the second part to [1], which summarized the first two editions of the IEEE Signal Processing Cup. The perspectives of the competition organizers and the student finalists are given in this column.

SHAPING THE FIRST TOPIC

In May 2013, Dimitri van de Ville, the chair of the IEEE Bioimaging and Signal Processing Technical Committee (BISP TC) [2] forwarded an e-mail to the members of the committee calling for proposals for the IEEE Signal Processing Society's (SPS's) First Signal Processing Cup. The idea was to promote signal processing, particularly its applications to solve real-world problems, among undergraduate students.

I work at the Instruct Image Processing Center [3] in Madrid, Spain, a reference center for image processing in structural biology. The call for proposals was a perfect match between the need to achieve higher resolution in the three-dimensional (3-D) reconstructions of biological macromolecules and the possibility to explore the recently introduced ideas in the areas of superresolution, image restoration, and denoising. The possibility of having students all over the world trying to tackle this problem sounded attractive and challenging. So, with the support of the BISP TC, the Instruct Image Processing Center submitted a proposal for enhancing the resolution achieved by electron microscopes in the elucidation of the structure of single particles. Students could be as creative as they wished as long as the resolution limit imposed by the microscope could be pushed toward atomic resolution.

In August 2013, the proposal was approved by the SPS and, in November, we already had training and testing data sets available on the Internet. We also set up an online system [4] that allowed participants to self-evaluate their performances: they only had to upload their results to a web page and the system returned immediate feedback about the quality of their 3-D reconstructions. This system has been most valuable to empower the challengers and let them explore multiple directions while pursuing the most promising algorithms. The website activity, as well as the interaction of students with the organizers of the challenge, was quite high in the following months.

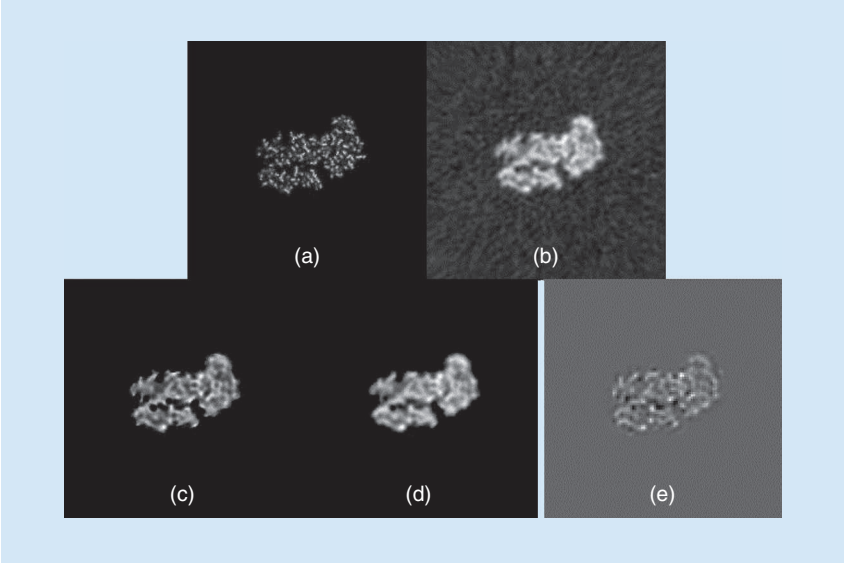
ALGORITHM FINALISTS

The objective of the challenge was to enhance the resolution of macromolecular structures reconstructed from images taken by an electron microscope (EM) (see Figure 1).

The best algorithm (Algorithm 1) consisted of three steps: 1) estimating the point spread function from the molecule background, 2) deconvolving with the Richardson–Lucy iterative algorithm, and 3) automatically detecting the location of the macromolecule and masking the output to produce a background-free volume.

The second-best algorithm (Algorithm 2) was an exemplar-based approach to enhance the degraded EM images. The key observation is that the protein data bank (PDB) data share a high degree of similarity within protein structures. The algorithm exploits PDB data as prior information to help recover the degraded input EM data.

The third-place algorithm (Algorithm 3) took advantage of the availability of multiple realizations of the same



[FIG1] (a) The central slice of one of the ground-truth volumes. (b) The corresponding slice in the challenging volume. (c)–(e) Slices produced by Algorithms 1, 2, and 3, respectively.

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molecule. Their superresolution approach is based on the idea that if one has multiple low-resolution images that are spatially shifted a bit, then a high-resolution image can be estimated by taking all of them into consideration.

THE WINNING TEAMS

In May 2014, during the final presentation of the shortlisted algorithms at the International Conference on Acoustics, Speech, and Signal Processing Conference in Florence, Italy, the jury members were impressed by the technical level of the presentations and the algorithms developed (see the algorithms summary in the "Algorithm Finalists" section). The presentations certainly covered a wide range of different image and signal processing techniques, showing the success of the challenge to promote creativity, learning in the area of signal processing, and engagement of undergraduate students to solve real-world problems. And not only that, students actually dived into the details of the application domain for which they were trying to provide innovative solutions. As the person who set up the problem, I was astounded when, five minutes before the final presentations in Florence, I heard a couple of students in different groups discussing how images were recorded and processed in electron microscopy (EM)—and I realized that most of the details they mentioned were technically correct. This was quite impressive for people who haven't been in a structural biology lab! In the final competition, teams EPOCH (Bangladesh University of Engineering and Technology), NtUeLsA (National Taiwan University), and Uchihas (Bangladesh University of Engineering and Technology) won first, second, and third place, respectively.

Enough of my babbling—I now give the floor to the three finalist teams of the Signal Processing Cup 2014 (see "Team EPOCH," "Team NtUeLsA," and "Team Uchihas").

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TEAM EPOCH—*FROM BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY*

We learned of the IEEE Signal Processing Cup 2014 from the IEEE Signal Processing Society's website. As we were highly interested in working on real-world problems in signal processing, we immediately decided to take part in the competition. However, the theme of the competition, "Image Restoration/Superresolution for Single Particle Analysis" was completely new to us. So we, four undergraduate students from the Department of Electrical and Electronic Engineering, contacted one of our faculty members, Dr. Mohammad Ariful Haque. We asked him to be our supervisor in the SP Cup. After reviewing the problem, he agreed to supervise our team.

We met three times a week to check our progress with Dr. Haque. At first, we did not know much about image processing, let alone single-particle analysis. Our supervisor suggested we read numerous review papers and explore the recent state of the art in image enhancement and restoration techniques. We started our journey with the book *Digital Image Processing* by Gonzalez and Woods. At the time of our review, we had realized that the main problem was to estimate the blur function in 3-D electronic microscopic volume. So, we concentrated our efforts on estimating the blur function from the noisy and low-resolution 3-D volumes. Without any prior information about the latent structure, estimating the blur function was really difficult. Our supervisor therefore suggested we exploit the noise cue that was generated from the amorphous ice (in which the macromolecules are embedded). After a long series of experiments, we could successfully estimate the blur function. We then applied the standard Lucy–Richardson (LR) deconvolution algorithm to restore the high-resolution volume. With the submission deadline quickly approaching, we started to work day and night to test, revise, and refine our algorithm. At this stage, we were able to improve the performance of our algorithm by applying constrained LR deconvolution as well as reducing the spatial noise outside of the main molecules using the breadth-first search technique.

Our joy knew no bounds when we won first place in the inaugural competition of the SP Cup. It was really interesting to work on a real-world signal processing problem. We are grateful to Mathworks: MATLAB made our work much easier and better. Without MATLAB, we would have had to divert much more effort to writing code rather than developing the algorithm. The technical group of the competition was really helpful. Last but not least, we feel very fortunate to work under a great supervisor. Thanks to our participation to the SP Cup, we could get a taste of real-world signal processing work, and it has been a lifetime experience for us.

—Anik Khan, Forsad Al Hossain, Tawab Ullash, and Abu Raihan, Undergrads

—Mohammad Ariful Haque, Supervisor

TEAM NtUeLsA—*FROM NATIONAL TAIWAN UNIVERSITY*

We heard about the IEEE Signal Processing Cup 2014 from Prof. Shao-Yi Chien. Thanks to his encouragement, a team of nine members—eight from the Department of Electrical Engineering and one from the Department of Computer Science and Information Engineering—was put together in a short time. Prof. Chien also asked his Ph.D. student, Wei-Chih Tu, whose field of research is image processing and computational photography, to help coach the team.

We were quite excited about the fact that the challenge was coming from a real-world problem, although we did not have any background in EM imaging. The first step was literature survey. Under the guidance of our supervisors, we reviewed the advances of image superresolution for natural images and adopted some of these ideas in our work. We categorized superresolution algorithms into signal processing methods and learning-based methods, and we finally decided to focus on the learning-based methods.

Indeed, we found out that the data in the Signal Processing Cup 2014 was not only about down-sampling and that more prior information could be considered in the learning-based methods to further improve performances. The second step involved algorithm development, implementation, and evaluation, with the latter part being facilitated by the online self-evaluation system provided by the Signal Processing Cup. In our final proposal, the 3-D input data is treated as a stack of low-resolution images, a mask is generated to highlight the region of interest for shortening processing time, and the concept of learning-based superresolution is adopted. The input image is split into patches, and their nearest neighbors are searched from the training set. With low-resolution data and their high-resolution counterparts in the training set, we directly take the high-resolution parts of the nearest neighbor as the high-resolution part of the target low-resolution input, and the overlapped pixels are averaged for smoothness. Eventually, we had to prepare the presentation. Although only one member was on the stage for the final competition, all team members spent a lot of time rehearsing for the presentation.

The Signal Processing Cup has been an unforgettable journey for us all. We were motivated by the real-world nature of the problem, which is quite a different experience from doing homework in textbooks. The online self-evaluation system providing immediate feedback was quite helpful for algorithm development. Moreover, we would like to thank Mathworks. With MATLAB, our ideas could be prototyped quickly for evaluation, and the quick feedback always stimulated our creativity. We learned a lot about how signal processing technology can solve real-world problems, and our problem-solving skills became more complete, including literature survey, algorithm development, and presentation. This wonderful experience motivated all of the team members to go for advanced studies, and we will definitely encourage other students to participate in the next Signal Processing Cup.

—Kai-Wen Liang, Yen-Chen Wu, Guan-Lin Chao, Kuan-Hao Huang, Shao-Hua Sun, Ming-Jen Yang, Po-Wen Hsiao, Ti-Fen Pan, and Yi-Ching Chiu, Undergrads

—Wei-Chih Tu, Graduate student

—Shao-Yi Chien, Supervisor

TEAM UCHIHAS—*FROM BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY*

We were all in our third year of undergraduate studies when we first heard about this competition. At that time, we only had a handful of baseline course experience on continuous signals and linear systems, digital signal processing, random signal processing, etc. However, we had no preliminary background on EM, which made the problem description quite technical and daunting for us but, even so, we still wanted to test ourselves. We eventually signed up as a team along with our supervisor, Dr. Md. Kamrul Hasan.

He encouraged and guided us through the whole adventure. At the very beginning, he used to ask for slide presentations on topics like single-particle analysis and superresolution…and we had just learned about these topics from simple Google and Wikipedia searches. In a couple of weeks' time, we had a basic understanding of SP and a more refined understanding of the problem statement. We then tried to think of plausible solutions that might work. Since the problem was essentially a 3-D image restoration problem, we looked at state-of-the-art algorithms for the two-dimensional case. We reviewed a lot of literature, and this was the point where our research truly began. We were literally overwhelmed with notions such as blur estimation, motion registration, regularization, dictionary-based-learning, etc. Nevertheless, with the help of our supervisor, we were able to cope and to make sense of the whole image processing landscape. We then sought ways to incorporate our ideas to the problem at hand. At this stage, we had to spend more time with MATLAB but, even here, we were facing a lot of technical difficulties. Thankfully, we had already gotten used to dealing with highly complex problems. We simply had to go ahead, and our progress slowly started to emerge. We also had to cope with academic pressure in parallel, and the competition vibe was really pressing. After months of trying various things such as Laplacian, total variation, etc., we went one step forward and tried to invent our own regularization term. Eventually, we settled on a wavelet-based sparsity constraint, which gave better results than our previous endeavors. By that time, the submission deadline had approached, so we started to wrap up our research in a paper format.

Even now, when we glance at the paper, we feel inspired as it bears testament to the adventurous research experience we had with the Signal Processing Cup 2014.

—Emroz Khan, Shiekh Zia Uddin, and Mukhlasur Rahman Tanvir, Undergrads

—Md. Kamrul Hasan, Supervisor

[SP]