"Mathematicians Have a Different Perspective" An Interview with Bernd Sturmfels

By Joe Gallian and Ivars Peterson

After receiving his PhD from the University of Washington in 1987, German-born Bernd Sturmfels held positions at Cornell University and New York University before landing at the University of California at Berkeley, where he currently teaches. Sturmfels has received numerous honors, including the MAA's Lester R. Ford Award for expository writing in 1999 and designation as a George Pólya Lecturer. Sturmfels served as the Hewlett-Packard Research Professor at MSRI Berkeley in 2003/04, and was a Clay Institute Senior Scholar in Summer 2004. A leading experimentalist among mathematicians, Sturmfels has authored eight books and about 140 articles, in the areas of combinatorics, algebraic geometry, symbolic computation and their applications. He currently works on algebraic methods in statistics and computational biology.

MAA FOCUS: Did you become interested in mathematics at a young age?

Bernd Sturmfels: I was a pretty good student in school, interested in almost all subjects. There was never anything special about mathematics, no competitions or Olympiads or any such in my high school. After graduating from high school, I was in the German army for 15 months to do my compulsory military service. It was during those lonely evenings in the barracks that I tried to figure out what I was really interested in. That turned out to be mathematics and the emerging field of computer science.

FOCUS: You came from Germany to attend graduate school at the University of Washington. What drew you there?

Sturmfels: My German advisor sent me to Seattle in 1985. I was interested in spending a year abroad, but I was thinking of France or England, something closer to home. My advisor strongly urged me to go to North America. His contacts were primarily at the University

of Washington and the University of Toronto, so I was told to go to one of these two schools. He was absolutely right: Victor Klee, a former MAA president, turned out to be a most wonderful thesis advisor for me.

I obtained a fellowship from the German government to study for one year in Seattle. Three months after arriving, I fell madly in love with this wonderful undergraduate English major from Korea, and I just had to stay awhile longer in Seattle. That's why I ended up getting my doctoral degree at the University of Washington. My now-wife and I stayed together all those years, and, after moving around for many years, we finally returned to the West Coast in 1995.

FOCUS: How does mathematics education at the college and graduate school level in the U.S. differ from that in Germany?

Sturmfels: The main difference is that in Germany, students declare their major before entering university. There are few breadth requirements, so once someone is a university student most of the classes taken are in mathematics. This makes for very focused studies; students tend to reach a higher level rather quickly. In the traditional German system, the first degree was called the "Diplom," and one obtained this degree after about five years. It used to be a rather rigorous program, comparable to a strong Masters program with a written thesis.

In the last 20 years, there have been many changes in the university systems in Europe, not just in Germany, and now most schools offer Bachelor and Masters Degrees more similar to the system in the States. Not everyone is happy about these changes, needless to say.

FOCUS: How do you describe your research area?

Sturmfels: I work in combinatorics and algebraic geometry, with a special emphasis on applications outside of pure mathematics. Recently, I have been especially interested in applications in statistics, optimization and computational biology. Computational biology offers fascinating opportunities to mathematicians, and can ultimately lead to new and unexpected developments within mathematics.

FOCUS: Which mathematicians have had a large influence on you?

Sturmfels: Victor Klee, my advisor in Seattle, ranks first. Others that have influenced me greatly include Louis Billera, Richard Stanley, I.M. Gel'fand and Bill Fulton.

FOCUS: You have been involved in "experimental mathematics." What, to you, is experimental? What are the experiments that you are doing?

Sturmfels: Well, computer experiments. I can experiment by hypothesis testing or it could be just plain old exploration, just to see what happens. "Gee I wonder what properties the following mathematical object has." Actually, that's often the first step. I think you can use computation as a tool to form hypotheses, or to test.

I don't trust humans a lot. You know, people think that a written proof is the gold standard. I think many mathematical papers and arguments contain errors and gaps and the only reason we don't find them is because they don't get read. On the whole, the building of mathematics is sound, but if a mathematical statement works out in a computer test, then I believe it a lot more. So I would say exploration, verification, and falsification. And then the last stage is once you have the conjecture or hypothesis then you can sort of go case by case and see: Is it true for $n=8$? And so on.

The design of experiments is very important. I think that's where I sort of see my strength. Just like a lab scientist, a lot of work needs to go into creating a well thought out model system and model organism, to design the experiment, to pick a range of test problems that are not too easy and not too hard, which will reveal the right phenomenon. That's the challenge that distinguishes a good experimentalist from one that's maybe not so good.

FOCUS: Is that influenced by changes in technology?

Sturmfels: Definitely! Certainly now you can do a lot more than when I started. But I would say that experiments in mathematics are not as technology-driven as in, say, molecular biology. Our technology is not progressing at the rapid rate it is in molecular biology, where it's crucial to have the latest equipment just to compete… It's a little less crucial in mathematics. You don't need the biggest computer!

FOCUS: What about on the software side?

Sturmfels: The software side… that's actually quite hard because developing and maintaining software is extremely difficult in an academic math environment. It's a little bit easier in the old German system where you have a professor who has many of these diploma students; that setting lends itself more easily to maintaining software. So the software in my field is quite difficult for an academic math person to develop and even more difficult to maintain. That's a real challenge. I admire anybody who does it and hope they get a lot of support.

FOCUS: Now that you're at Berkeley, a prestigious institution that attracts very good students, how do you find the students and their capabilities?

Sturmfels: I think the students are wonderful, but of course we have a large program in Berkeley. Compared to some of the smaller private schools we compete with, we have more of a spectrum, simply because our program is much larger and also because we try to be open. We have a tradition of letting in students that might not otherwise make the cut, so there's a spectrum. But I would say that the students I worked with are wonderful. I've learned a lot from, and with, them.

FOCUS: And it sounds like you work a lot with them.

Sturmfels: Yeah, it's the best part of the job.

FOCUS: I've known faculty who take the approach of identifying the graduate students they want and approaching them. Is that similar to your approach?

Sturmfels: Yeah I think that's probably similar. It's a little bit like dating. It helps to be proactive. But finding a good match is a two-way street. I think it helps the student along if this relationship is built early on, so I try to play as active a role as possible, both in recruiting when they come to Berkeley, and also in the first year, to identify who might be a good fit.

FOCUS: Has the kind of student you want changed over the years?

Sturmfels: That's a good question. Since I have become a bit more of an applied mathematician, I would also expect my students to be open to engage with people outside of math. Also, I want them to have good communication skills! I've learned over the years the value of communication skills. Of course you have to be good in math, but I think when I was younger I wasn't as keenly aware of how important social skills and communication skills are. One doesn't think about it in the math context, but that's something that I also pay attention to. So if there's a student I feel would have a very hard time communicating in either writing or verbally, then I'm more cautious.

FOCUS: Have you had any significant involvement with undergraduates in research?

Sturmfels: Some, but not as much as I would like to. Lior Pachter and I are teaching an upper division undergraduate course on mathematical biology at Berkeley, where the students work in teams on specific projects. This replaces the final exams, and some interesting research projects have sprung out of that. In fact, I just taught that course in the spring of 2007, and I think that three or four students have continued their research over the summer and beyond. However, I must say that supervising undergraduate research in mathematics is challenging, and essentially impossible for me, if and when it requires very regular one-on-one meetings. A laboratory setting, where undergrads learn from graduate students and post-docs, always works better for the problems of interest to me.

FOCUS: What about the sense of doing mathematics in a broader context, for example in biology and so on. Do students come in with that kind of interest or do they develop it?

Sturmfels: It works both ways. I had some students who were very pure and then found it interesting. There's a good example of a student I work with. He just finished his first year in graduate school. He was an undergraduate at Harvard, and he had a very strong undergraduate math background: a very pure, typical Harvard math undergraduate background. Then he went back to his hometown and worked in the biotech industry for a while. So he got a job and worked for a small private company that was involved in the Grape Genome project, so they got funding from the province of Trento in Northern Italy and they sequenced the pinot noir grape. That was a two and a half year project and in the course of that work he picked up a lot of statistics, genetics, and computational biology. Then he wanted to go back and get a math PhD, so he ended up working with me in Berkeley and it's a very good fit, because he has the biology background but he's now interested in pure algebraic geometry studies. He has the option to go both ways.

FOCUS: How did you become interested in mathematical biology?

Sturmfels: It all started with my junior colleague Lior Pachter. Lior is a computational biologist who ended up in Berkeley's mathematics department. Four years ago, we started talking about phylogenetics, and we soon discovered that the combinatorial structures he was using for problems such as gene prediction or sequence alignments are very similar to things I knew about. We started a joint seminar in the fall of 2003 and it has been a fascinating journey for me and my students ever since. Last year, we published a book called *Algebraic Statistics for Computational Biology*.

FOCUS: When there's a need for communication between mathematicians, and for example, biologists, what kinds of barriers are there? What makes it difficult?

Sturmfels: The language and the background are both very difficult and very different. First of all, people don't understand that mathematicians will speak about biology as a single discipline. But the concept of biology being one field makes no sense to biologists, because obviously there are a thousand different branches that are vastly different from each other. And conversely! At this stage most serious senior researchers in molecular biology in particular realize that they have massive data sets and that they need quantitative help, so often they will say "we are really interested in working with mathematicians," but they don't quite know what mathematics is. As mathematicians, we think that partial differential equations and combinatorics are very different subjects, and that statistics, computer science, theoretical physics, and mathematics are very *very* different subjects. To a typical biologist these are indistinguishable.

So I think we have a lot of educating to do and to explain that there are different areas of mathematics like there are different areas of biology, and they have different points of view. Partial differential equations can do this while combinatorics will do that. And so I think that is very important to explain just what it is you do and what techniques you use, and it's a long process, but an interesting one.

FOCUS: In terms of say, computational biology, what do you see as the important questions and the places where progress is possible?

Sturmfels: I think in evolutionary biology there are key questions. How does evolution really work for biological systems? What drives it? What's the notion of fitness landscapes? I think for the first time people have serious data, so there's statistical genetics. Evolutionary theory has existed for 80 or 100 years, going back to Fisher and Wright and other people in the early 20th century, but I think for the first time we really see a significant amount of data and I think there's some really interesting problems we can now address. Basically, how does evolution work?

FOCUS: Some recent genome comparisons were showing that there isn't that much difference in the genomes of related species, and that more and more important is the significance of what parts are turned on and off. That whole process is changing.

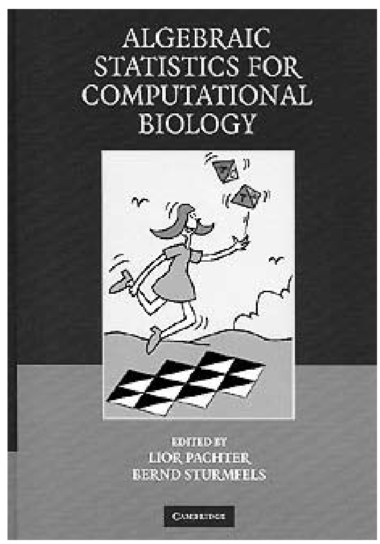
Sturmfels: Exactly, the networks and the regulatory mechanisms are what really differentiate cells, and differentiate organisms and species. I think the amazing variety we see in living systems cannot be explained by a static sequence which is relatively short. The human genome is less than 3 billion base pairs. If you see the complexity of us, that's not enough to explain it.

FOCUS: I think Dick Karp and others have spoken very strongly about the computer side of these things and how important those questions are. Are there similar things on the math side?

Sturmfels: I think so. I think mathematicians have a different perspective. Mathematicians can contribute a lot by clarifying the notions and helping to gain precise definitions of the objects and concepts involved, and that's kind of where I see my role. In the conversation, as a mathematician, I think I'm trained to give precision and rigor to the concepts and to the discussion, while computer scientists thinks more about the large scale model and the complexity of carrying out a certain computation. A mathematician would ask "what's meaningful?" or "what is it we're really computing?" A mathematician would say: "suppose we had a suffiently powerful computer, what would you do with the output?"

FOCUS: What kind of questions can biology suggest for mathematicians?

Sturmfels: I wrote an opinion piece on this for the Clay Institute called, *"Can biology lead to new theorems?"* and I highlighted four examples of such theorems. One that I was involved in was computational algebraic geometry and the study of certain families of algebraic varieties that come from phylogenetics. It turns out that statistical models for evolution can be described by algebraic varieties (in the sense of algebraic geometry). These are



generalizations of classically known varieties, but very interesting new objects. In the last couple of years, we've seen four or five really interesting papers. So I think biology and models for studying biological systems can suggest new and interesting mathematical objects that generalize known objects that have already been classically studied in math.

FOCUS: On a side issue, one of the things mathematicians feel compelled to become involved in are issues about math education, especially at pre-college levels. Do you have any interests or concerns in that way?

Sturmfels: Many concerns. My kid is in school right now so I can see it from that end, but I have not done much with that. I feel that it is more important to build a continuous spectrum of research. We now have K–12 and education research programs, and I feel it is all a little disconnected from the mathematics research community. I think there should be a layer in between; maybe the MAA could play a big role. Maybe also high school math teachers who are very interested in more advanced issues can help bridge the gap. For instance, there is the Park City Mathematics Institute, the summer program where they have a high school program and a college program, and that I think overall works pretty well. They have some joint activities that I think are pretty good. I personally don't see myself diving into the deep sea and the deep waters of K–12 education.

FOCUS: You were saying before that your impression is that too few MAA members participate in NSF and institute programs.

Sturmfels: And conversely, I think the NSF and the institutes could do a better job in reaching out to the MAA community. And in fact I just discussed this with Peter March and he agrees, so I hope that Peter and Joe Gallian will get together and have a chat about this.

FOCUS: Is it just more participation in the actual programs? That means taking time off to spend time for workshops and that kind of thing.

Sturmfels: Yeah, I don't necessarily have the ideal answer; I think that should be a discussion… which format works best? Workshops could work, but maybe other formats too? As a Pólya Lecturer, I've seen a lot of faculty at four-year colleges interested in doing research with undergraduates to stay connected to the research community, maybe to engage in interdisciplinary research with faculty at their college in say, biology for instance. The institutes, for instance MBI at Ohio State, could help find a way to facilitate this. Perhaps they can bring in people, give people a chance to speak about research results, to learn new things. I don't have the answer, but I'd like to raise it as a question. I feel that MAA members are amazing and that they are a slightly underrepresented group at these institutes.