applications are more like if you assemble ten percent of your information about the graph, then what can you say with high probability? I think there are many people doing beautiful theoretical research that's vaguely or not vaguely motivated by that approach.

I would like to take the classical questions I've worked on and translate them into this language. We used to prove that every vertex of this set is adjacent to *every* vertex of another set. Instead, we can think about if *many* vertices of one set are adjacent to many vertices of another. I would look for an analogue or translation like that.

Yesterday I was on the train, and I saw someone with a t-shirt with a graph on it. And I thought, how nice. It was a Princeton Computer Science t-shirt!

Credits

Figures 7 and 8 are courtesy of the Archives of the Mathematisches Forschungsinstitut Oberwolfach.

Figure 10 is courtesy of Emon Hassan/*The New York Times*/Redux.

Interview with Lisa Jeffrey[4]

Anthony Bonato

I met Lisa Jeffrey in Ottawa, where we worked together on the NSERC Evaluation Group for Mathematics & Statistics. Lisa comes off as modest and reticent, which reminds me of the quote by Stephen Hawking: "Quiet people have the loudest minds." We walked back to the hotel from dinner one evening and discussed her field of symplectic geometry, which was largely a mystery to me. She described the symplectic camel, and I knew then I had to learn more from her.

Lisa is a professor at the University of Toronto whose research focuses on symplectic geometry and mathematical physics. She is highly acclaimed, winning the Krieger-Nelson Prize and the Coxeter-James Prize from the Canadian Mathematical Society. She gave a prestigious Noether Lecture this year. Lisa is also a Fellow of the American Mathematical Society and a Fellow of the Royal Society of Canada.

This interview was conducted in December 2017.

AB: *Where were you born and what did your parents do?*

LJ: I was born in Fort Collins, Colorado. My (Scottish) father was doing his PhD in forest hydrology at Colorado State University. My (Canadian) mother also worked in forestry and forest pathology—she now is very much involved in the environmental movement.

Figure 11. Lisa Jeffrey.

My parents met in Calgary working for the Canadian government. She became research officer, which at that time wasn't something that very many women did. We moved to Canada six months after I was born.

AB: *What is your first mathematical memory? That is, a time in your youth where you had a vivid memory of something related to math.*

LJ: In grade 8 or 9, I did a project on the Goldbach conjecture (which states that every even integer greater than two can be expressed as the sum of two primes). I just stated that it was. I obviously didn't prove it!

Another mathematical memory came from the time we lived in northern Norway for a year and a half when I was nine and ten. My stepfather got a job there. I was in the Norwegian public school, and my mother arranged that I would take math classes at a grade level two years higher than my own. The teacher (Mr. Saeboe) was very helpful and encouraging. I was in grade 6 math, and there was an exam at the end of the year and, apparently, I got the highest score of anyone in the county. This is not a large-scale achievement (Norway is a small country—population four million—subdivided into twenty counties), but maybe this went to my head.

AB: *How did you decide to choose mathematics as a major in university?*

LJ: I was a physics major, and I switched to mathematics in graduate school. After having done a physics undergraduate degree, I was awarded a Marshall Scholarship for study in the UK. I did parts II and III of the Mathematical Tripos at

[4] *Chapter 8 of* Limitless Minds: Interviews with Mathematicians *by Anthony Bonato*, `https://bookstore.ams.org/mbk-118`.

DOI: https://dx.doi.org/10.1090/noti2444

Cambridge. That brought me up to the level where I could think about continuing with mathematics. If you are a physics major, then you take quite a lot of math anyway, but I wouldn't have been equipped to start a math PhD without my two years at Cambridge.

In my undergraduate years, I took real analysis, complex analysis, algebra, differential equations, and a course on Riemann surfaces; I took two courses on mathematical physics that were basically analysis (we followed a text by Ivar Stakgold which dealt with topics like the Fredholm alternative).

There were posters of historical mathematicians in the undergraduate physics and math library when I was an undergraduate. There were two female figures: Sofia Kovalevskaya and Emmy Noether. Both of them were role models for me.

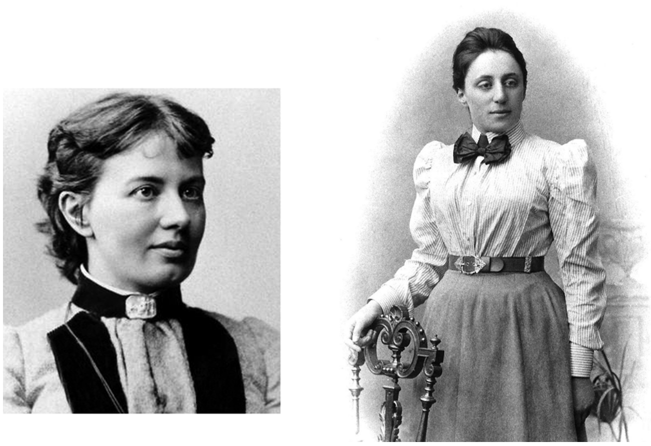

Figure 12. Sofia Kovalevskaya (1850–1891) and Emmy Noether (1882–1935).

AB: *How did you come to be Michael Atiyah's doctoral student? What was his style of supervision?*

LJ: We met weekly, and he always had an hour allocated for each student. There were always many ideas from him, and he provided a lot of starting points. By the way, Ruth Lawrence was two years ahead of me (also working with Atiyah), although she was six years younger than I was.

In my first year, Ed Witten had just written his paper on quantum field theory and the Jones polynomial. There was a seminar in Oxford that fall about this material. Ruth Lawrence edited the notes, and quite a lot of material in Atiyah's book *The Geometry and Physics of Knots* was based on that seminar. That was the point of departure for my thesis: I was working on Chern-Simons gauge theory.

AB: *What is symplectic geometry/topology?*

LJ: One of the standard examples people use to describe the field is the symplectic camel. Anyone in the Christian tradition will have heard the quote from the Bible: "It is

Figure 13. Sir Michael Atiyah.

easier for a camel to go through the eye of a needle than for a rich man to get into heaven." Now imagine you have a ball on one side of a plane and there is a small, circular hole in the plane. How would you get the ball through the hole and onto the other side?

If it were a question of volume, then you would squeeze out the ball and make it long and narrow. Then you would thread it through the hole. But to preserve the symplectic structure, that's not good enough. The radius of the ball would have to be smaller than the hole's radius. This example is discussed in the book *Introduction to Symplectic Topology* by McDuff and Salamon. Symplectic structure is the natural mathematical home for classical mechanics. It is the natural home for Newton's laws of motion, which can be rephrased as Hamilton's equations.

Noether's theorem (for any symmetry there is a conserved quantity—for example, symmetry under rotation corresponds to conservation of angular momentum) goes back to Emmy Noether and is a fundamental principle in symplectic geometry and Hamiltonian mechanics.

AB: *What are you working on now?*

LJ: The fundamental group of a space is the set of loops in the space, where you can deform the loops but not cut them. For example, the plane has a trivial fundamental group as you can always shrink any loop to a point. If you puncture the plane, then the fundamental group is no longer trivial, as a loop around the puncture cannot shrink to

Figure 14. In symplectic geometry, you cannot squeeze a ball through the eye of a needle unless the radius of the ball is small enough.

a point. Basically, the fundamental group is classified by the winding number, which counts the number of times the loop goes around the hole. So, the fundamental group of the punctured plane is the set of integers, counting the number of times and which direction you wind around the hole.

The space I've worked on is representations of the fundamental group into some other group such as the circle group. In the case of the punctured plane, this would be one copy of the circle group as you just have to say where the generator of the group goes (it goes to some point on the unit circle). I've worked on other more complicated examples that come up often. There was a groundbreaking paper of Atiyah and Bott in 1982 where they studied the space of representations of the fundamental group of a 2-manifold. A 2-manifold would be a torus or a 2-dimensional sphere, or anything you get by gluing these structures together (classified by the number of the holes, which is called the genus).

AB: *Does your research interact much directly with physics?*

LJ: I published a paper about five years ago that was from my PhD thesis that did have to do with physics. As a result of that, I spoke at a physics conference, Theory Canada 9, at Wilfrid Laurier University in Waterloo. Many of the talks there were straight physics. In hindsight, it would have been better if I had rephrased my talk in physics-language.

AB: *I've been thinking a lot lately about diversity in mathematics, and why women constitute only about twenty percent of mathematics departments in Canada. What are your thoughts on this? How can we change this culture?*

LJ: In our department, fifteen percent of our faculty are women, and the same percentage holds among our graduate students. I wish the numbers were higher. I don't understand the graduate percentage, as often our admissions committees are composed of women. It's not a matter of any discrimination, but we just have fewer women applicants. I don't think our field has as much gender disparity as in engineering or perhaps physics. How to change the culture? When I was in high school, there was a lot of attention paid to the question of why girls were dropping out of math class and what to do about it. Now there is much discussion of how the school system is failing boys. There are books on the "war against boys." So, somehow, the focus has changed.

Many people think that women are overrepresented in universities, but this is not true in STEM fields. Medical and law schools will typically have more women than men. People need to be reminded that there are still issues getting women to study STEM. The problems in the education system encountered by women have not disappeared.

Figure 15. Matilde Marcolli.

By the way, the University of Toronto and the Perimeter Institute just hired Matilde Marcolli from Caltech. This is fabulous news. Matilde is going to be a role model, splitting her time between both Toronto and the Perimeter Institute.

AB: *What is your advice to young people (especially young women) who are considering studying mathematics at university/grad school?*

LJ: The important thing is to understand that math leads in many directions, not just academic ones. People with mathematical training will be highly employable. One of my best students finished his PhD, got a postdoc, and within eighteen months he had a programming (non-academic) job at a physics research institute. He had no trouble at all getting a good job.

AB: *I always close looking forward. What would you say are some of the major directions for mathematics in the future?*

LJ: There are many questions related to the work of Nigel Hitchin on Higgs bundles (the same Higgs associated with the Higgs boson). That work has major ramifications in many different directions, including to representations of the fundamental group that I discussed earlier. That work is an outgrowth of the 1982 paper of Atiyah and Bott, but it takes things in a different direction.

Credits

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