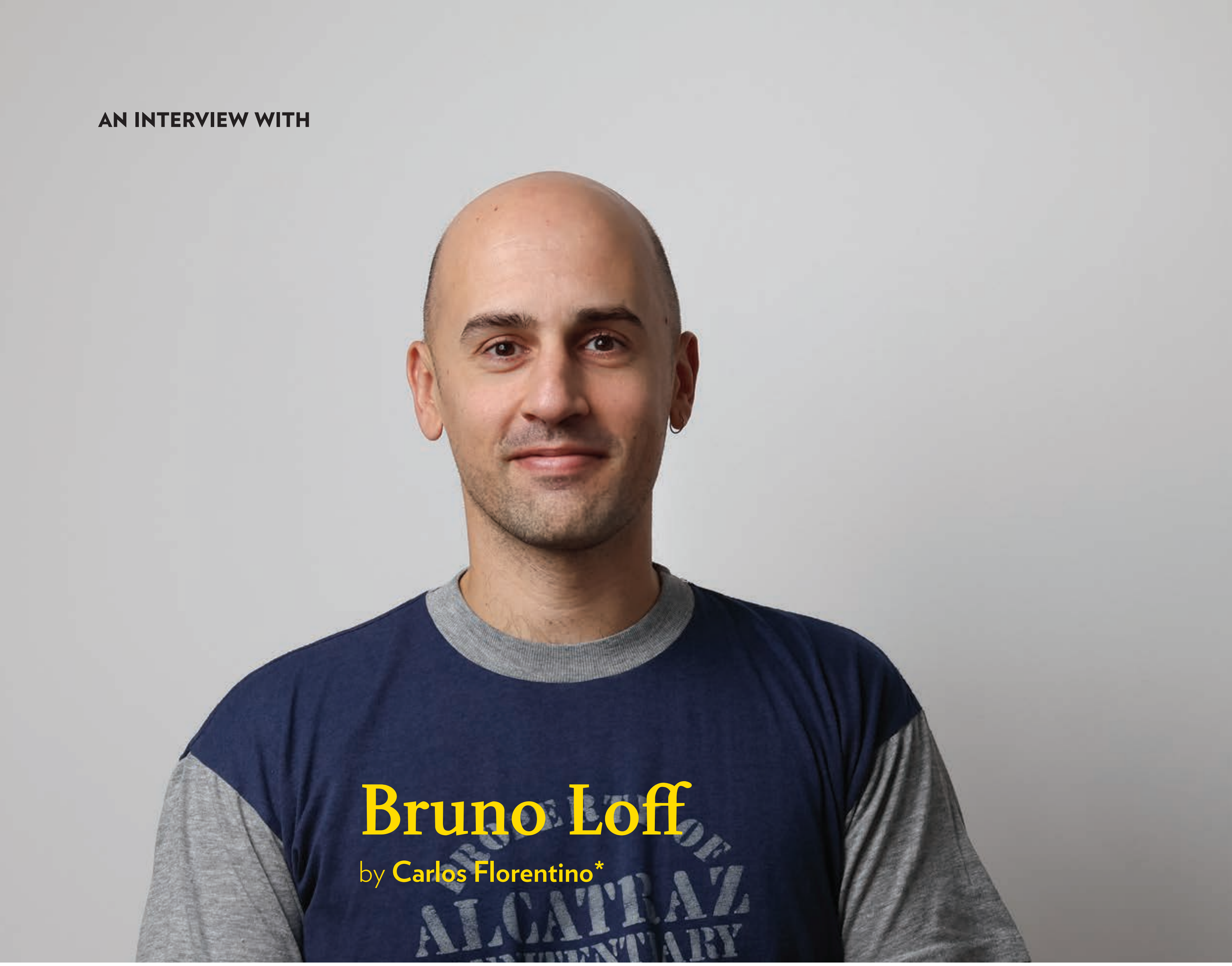
AN INTERVIEW WITH



Bruno Loff

by **Carlos Florentino***

Bruno Loff is a Mathematician and Computer Scientist working at the Faculty of Sciences at the University of Lisbon (FCUL). Last year, he was awarded with one of the only three European Research Council grants for research in Computer Science hosted by a Portuguese institution.

After completing the Undergraduate and Master degrees in Computer Science and Software Engineering at the Instituto Superior Técnico (IST), Bruno earned an FCT fellowship (the Portuguese State's Science Institution), and went on to do his PhD at the University of Amsterdam, under the supervision of Prof. Harry Buhrman, on the topic of computational complexity, finishing in 2014.

During the years 2015 to 2020, he held one postdoc position in Prague and another one in Porto. He then obtained a tenure track position at the University of Porto. Returning to Lisbon, in the context of his ERC grant, he is now developing an active group on computational complexity within the Research Center LASIGE, based at FCUL.

I first met Bruno, back in the year 2007, when he was finishing his Master studies at IST, and it is with great satisfaction that I see him reaching high international recognition. Moreover, it is a great pleasure to have him as our newest colleague at the Mathematics department of FCUL. This became the perfect opportunity for an informal interview. In these lines, we delve into the world of Bruno Loff, talk about his research journey, and collect his opinions on Mathematics and Computing.

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There is certainly no single path to a successful career in research, but everything has a beginning. Can you tell us how and when did you discover your interest in Mathematics and Computer Science?

Ever since I was 7 or 8 years old, I have had this fascination with computers . . . As a child and a teenager, I must have spent more hours in front of a computer than doing any other thing. Gaming, of course, but also coding, 3D modelling, audio editing, and so on. Even today, I'm still in awe of them. Time in front of a computer was replaced with time thinking about computers. Which is my job, nowadays. It just boggles my mind that reality includes these things.

So, during primary and secondary school, did you see Mathematics as a profession, as a challenge, or just as a fun thing? Did you ever think you would dedicate yourself to it?

Neither. The way I was taught Mathematics in high school is the reason I decided against pursuing Mathematics in university, and opted for computer science instead. In my days, and as far as I understand this is still largely the case today, high-school mathematics is taught as if it was some kind of game, where one learns how to do certain calculations.

I was always reasonably good at this game, but I also thought it was a waste of time, because of course: I can just program a computer to do the calculations for me. From this mistaken perspective, that Mathematics is just calculations, one saves a lot of time by learning Computer Science instead.

It was only in my third year of university that I finally understood what mathematical proofs are all about (of course, I had decent grades in all math courses, but understanding proofs is sadly not a requirement for non-math majors). Ironically, nowadays I have to spend a lot of time trying to catch up on all the Mathematics that I didn't learn in my Computer Science education.

I imagine your Master's degree in Computer Science and Software Engineering was very significant for your academic training. Some milestones certainly emerged along the way, as well as people who played an important, or even essential, role in terms of training, or as a source of inspiration. Which mathematicians or professors deserve such a mention and why?

One name before all others: José Félix Costa, my MSc advisor. (José Félix Costa is a professor in the Department of Mathematics at Técnico). It was from him that I first learned the theory of Computability, and then later Computational Complexity. His classes were marvelous: clear, compelling, exciting. I remember being aesthetically moved to tears by Rice's theorem. He somehow managed to teach the solution to Hilbert's 10th problem in a first course on Computability! (Hilbert's 10th problem asked for an algorithm to solve Diophantine equations, and a long line of work by Martin Davis, Hilary Putnam and Julia Robinson, culminating with a result of Yuri Matiyasevich, showed that such an algorithm does not exist). He is also a formidable role model as a researcher, hard working, with a vast knowledge of many fields, extremely ethical when it comes to collaboration and attribution, and driven by a love of the thing itself. Without him, I would be doing something else. He is also a really fun and wild person, and a humble guy, if you can believe it! We remain good friends to this day.

That explains why you chose him to supervise your Master's degree in Informatics. At this moment, were you already thinking about continuing for a PhD?

My mother tells this story . . . When I was 7 years old, my parents would hang out with this couple who had a daughter my age, Eva. Eva's mother once turned to me and asked the typical question: "So, Bruno, what do you want to do when you grow up?" Little 7-year-old Bruno looked up to her and said: "First I want to do a PhD in Mathematics, and then I want to do a PhD in Physics."

My mom says that she hesitated, and said: "Okay . . . so in the meantime would you like to go and play with Eva?" I have since gained some sense and have no plans to do a PhD in physics.

Was it obvious that you should obtain the doctorate abroad? Was it easy to choose the advisor (Harry Buhrman) and the thesis problem? How was your adaptation to another country, culture, way of teaching and studying?

I was excited to go abroad! New things! An adventure! I looked for people doing computational complexity in Europe, and Harry's name came up. I sent him a letter, said I would be coming with my own funding, and he took me in. I moved to Amsterdam on September 2008.

And within 4 months, I had entered a deep state of depression, including debilitating anxiety, panic attacks, mild paranoia and hallucination, and a complete lack of concentration, which made it very difficult to work. I also had brief periods when I was on top of the world, master of my game, had figured it all out, etc. A psychiatrist diagnosed me as bipolar, which presumably I had inherited from my mother, and which maybe, just maybe, was triggered by an LSD trip where I realized, in some deep, undeniable, immediate, visceral way, that every moment in time is dying all the time, and I myself am going to die some day.

The psychiatrist prescribed me antipsychotic medication. After reading about the side effects of the drug I had been prescribed, I decided against taking it, and started doing meditation instead. I did a vipassana retreat in August 2009, where it became clear that meditation really affects the condition I was in.

So by November 2009, I had all but decided to quit my PhD to become a Buddhist monk, when Harry gently suggested that I should take a temporary break instead, "do the meditation thing for a while", and see if I wanted to come back after that. So I asked for a temporary interruption of my grant, which FCT allowed. I did a solitary retreat in December 2009, and on the 30th I experienced a shift in my perception, and was never depressed again in the same way. With continued practice, eventually my emotions balanced out, and I have not experienced euphoria or depression since about 2014.

But sorry, I got a little sidetracked. I got a lot out of working at CWI (Center for Mathematics and Computer Science, in Amsterdam). They have a very strong scientific culture over there.

A doctoral thesis is the beginning of a research career. Right after finishing the thesis, were you prepared for this challenge? Do you think that, to gain experience, one or two postdoctoral positions are fundamental?

After my PhD, I had a lot of self-doubt and seriously considered giving up science. My PhD thesis is entitled *A Medley for Computational Complexity*. I.e., I had a bunch of disparate results and I stapled them together. It had always felt that every single result I discovered was a stroke of luck. I didn't really think I could turn such random events into a career. The word career suggests a straight line, of sorts, a natural uphill progression.

Again Harry offered me good advice: he said that giving up was completely fine, but he thought I was doing OK, and maybe I should give it a chance? So that was the second time a conversation with Harry pulled my career from the brink.

So I decided I should give it a fair shot, and if it flopped, then I had done the best I could. I contacted Michal Koucký, who had visited Amsterdam a couple of times, and proposed that we work on a particular problem (dynamic data structures for directed connectivity). I moved to Prague, and lived there for two years, with a lifestyle of a mathematical monk. I got up early, I went to my Tai Chi practice, and went to the office, where I would work until late. Next day, repeat. My bipolar disorder was gone at this point, so my concentration was back. I learned a huge amount. (But we never solved the above problem. It turns out to be a formidable problem.) I would never be able to do the research I do without those highly focused five years of postdoctoral research.

Oddly, each and every result I discover still feels like a stroke of luck. I'm just more used to it, I guess.

What do you consider to be your most relevant scientific contribution up to now, and why?

I think my favorite own paper, thus far, is *Computing with a full memory: catalytic space*. Quoting directly from the intro: "Imagine the following scenario. You want to perform a computation that requires more memory than you currently have available on your computer. One way of dealing with this problem is by installing a new hard drive. As it turns out you have a hard drive but it is full with data, pictures, movies, files, etc. You don't need to access that data at the moment but you also don't want to erase it. Can you use the hard drive for your computation, possibly altering its contents temporarily, guaranteeing that when the computation is completed, the hard drive is back in its original state with all the data intact? One natural approach is to compress the data on the hard disk as much as possible, use the freed-up space for your computation and finally uncompress the data, restoring it to its original setting. But suppose that the data is not compressible. In other words, your scheme has to always work no matter the contents of the hard drive. Can you still make good use of this additional space?"

Surprisingly, the answer is yes! It is possible to use full memory in a non-trivial way!

After the post-doctoral positions in Prague and Porto, you obtained an Assistant Professor position at the Faculty of Sciences of the University of Porto. How was the experience in Porto, in particular the need to balance teaching and research?

I was very lucky, because I got a CEEC grant (Concurso de Estímulo ao Emprego Científico). This grant disallowed the university of assigning me more than 6 hours of teaching duties per week. Even then, teaching made research significantly harder than it was during my postdoc years. It is very sad that there isn't really a research career in Portugal, and that so many researchers are working under precarious employment contracts. Some kind of solution really needs to be found.

In a world of research that tends to be very competitive, how did the idea of applying for an ERC grant come about? What aspects of the application were decisive for the positive evaluation?

Actually I did not plan and did not want to apply to an ERC grant. But Michal Koucký insisted that I should. Once I started working on it, I had a vision of what I wanted to do, and I wrote it down.

Well, I started writing a grant as usual, and then at some point I realized that this is a much bigger grant than FCT grants, so I threw away the few pages I had and started over. I also decided I would try to solve a difficult problem that people in my area care about, because why would anyone care otherwise? I also decided that people in the committee were probably really smart, so I would be brutally honest. I remember during the interview they asked me: "so, what applications do you think might come out of this project?" To which I promptly answered "probably none", and felt really dumb afterwards. But actually, I suspect that the committee knew as much, and they were testing whether I would reply honestly.

Curious fact: The project was awarded the ERC, which means the project was in the top 10% of the Computer Science projects submitted to the ERC that year. Well, between submitting to the ERC and getting the acceptance letter, I took the same project, trimmed it down to work with 1/5th of the budget, and submitted it to FCT. It was classified in the bottom 10% of the Computer Science projects submitted to FCT in that same year. This probably happened because that year, like, sadly, in most years, the FCT evaluation committee did not include people from Theoretical Computer Science (the ERC committee had several).

There also, I feel that something needs to change. Computer Scientists think of me as a Mathematician, and Mathematicians think of me as a Computer Scientist.

Amazing! . . . Ok, tell us a little about the objectives of your work plan for these five years. Do you think it is possible to achieve most or all the goals?

I will try, but the project is very ambitious. In Computational Compleixty, lower bounds are impossibility results showing that certain computational problems cannot be solved efficiently in a certain computational model. Some computational problems are harder than others, and some computational models are stronger than others. We know how to prove lower-bounds either for very hard problems no one cares about, or in very weak models no one cares about. The goal of the project is to prove lower- bounds in new ways. If we fail to do this, we would like to understand why we failed at it.

Since one of the goals is to advance on the resolution of the famous millennium problem: the "P versus NP" problem, we cannot resist asking: how close do you think we are to finding a solution? Will the answer be positive or negative, or will it be one of the undecidable questions, as in Gödel's incompleteness theorem?

This is a good question. Something which is not well understood outside Computational Complexity is that we know of a very good reason why lower bounds are hard to prove. For a long time it has been believed that there are functions which are easy to compute but hard to invert. So there exists an efficient algorithm for computing $f(x)$ when given x, but, simultaneously, there is no efficient algorithm to find x when given $f(x)$. Such one-way functions are known to exist in any sufficiently powerful computational model. For example, multiplication of natural numbers can be computed efficiently, but we do not know of any efficient (non-quantum) algorithm for factoring natural numbers.

Alexander Razborov and Stephen Rudich observed in the 90s that essentially every lower-bound proof technique that was known up to that point had a certain kind of structure. They called proofs with this kind of structure Natural Proofs. So all lower- bound proofs known at the time are natural, and this is still very much true today, with few, in my opinion not very relevant, exceptions. They then showed that natural proofs cannot be used to show lower-bounds against any computational model strong enough to compute one-way functions. It is a kind of independence result. We call it the natural proofs barrier.

So look at the difficult situation we were left with: we cannot prove lower-bounds by natural proofs on any model powerful enough to compute, say, multiplication. And yet every lower-bound proof we know is a natural proof. The big question is how to overcome this barrier.

Let's talk more about the research experience. How do you discover interesting and good problems to work on? And for solving them, are there methods or strategies that may be more effective?

A math problem is like a chronic disease, I don't go looking for them, they find me and won't let go, unless by chance I find the cure by solving the problem. I wish I knew of some effective general approach that works. I feel completely stuck 99% of the time. It's a very frustrating profession, at least for me.

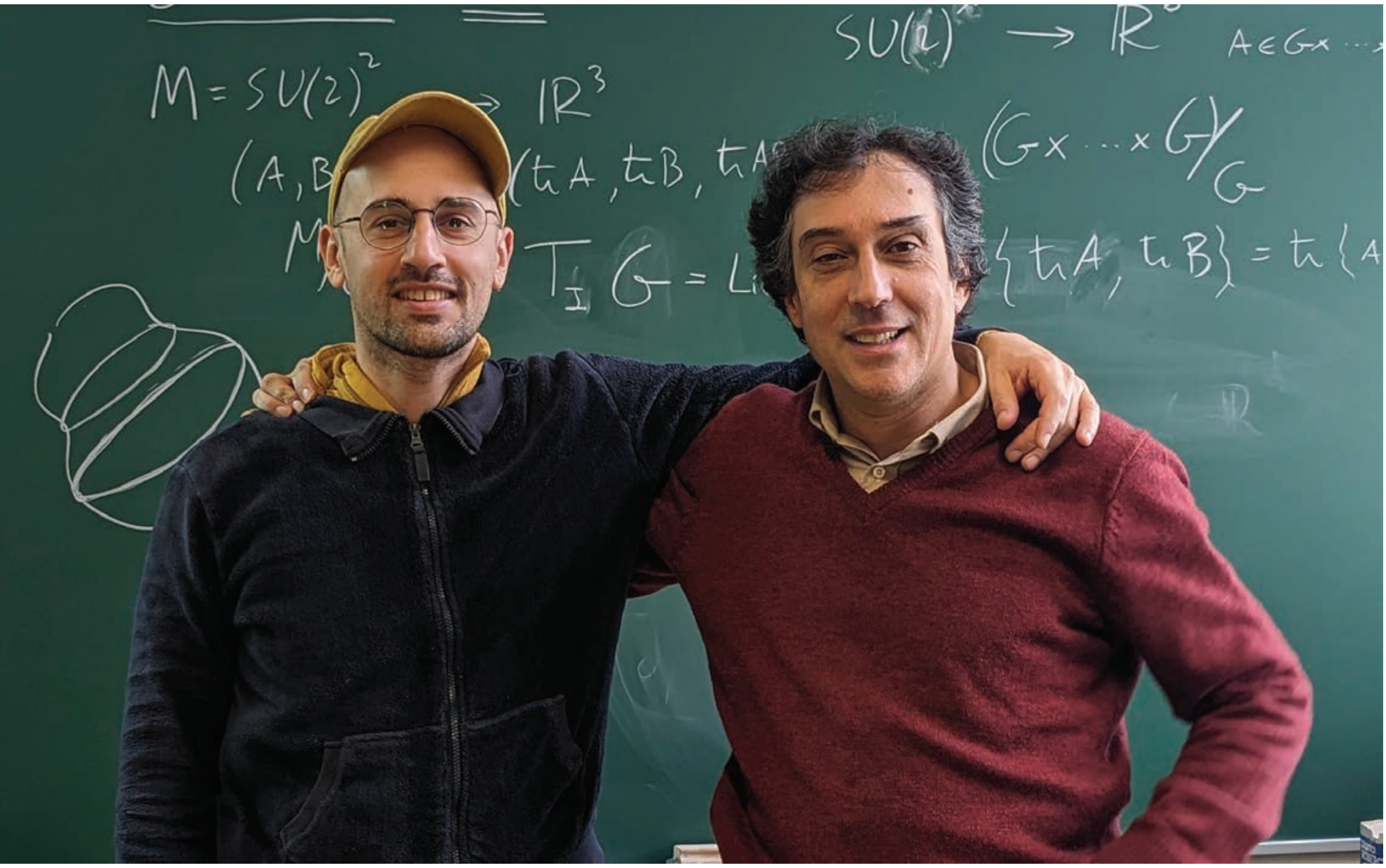
But I should add, of course, under the conjecture that P is not equal to NP, there does not exist any method or strategy that will be effective 100% of the time at solving math problems. Under a slightly stronger complexity-theoretic conjecture, e.g. that k-SAT or CLIQUE are hard on any sufficiently random efficiently samplable distribution, there does not exist any method or strategy that is effective even 1% of the time.

Of course, I'm totally stuck at proving these conjectures, hehe.

Even so, doing research is certainly satisfying and rewarding. What do you think is fascinating in the field of Mathematics?

Speaking for myself, I learned Mathematics because I wanted to understand computers. Understanding is the highest form of love, and I love computers. Computers were invented by Alan Turing, a mathematician, not a physicist, or an inventor, or anything more applied. And there is good reason why this was the case: the computer is the most mathematical of all human-made objects. So Mathematics drew me in. It took me some time to realize that: to understand computers is to understand lower-bounds. We understand algorithms quite well, i.e., we understand what computers can do very well. We are good at coming up with new algorithms. But we really don't understand computation, because we cannot prove lower-bounds, i.e., we cannot understand the things that computation cannot do. That understanding can only come from Mathematics.

Of course, Mathematics is beautiful and fascinating. And I have known of people who do Mathematics as a kind of leisurely stroll, just looking out over beautiful vistas, smelling each nice flower they come across. But I have a very goal-oriented approach to Mathematics, I want to get something out of it, and this adds a certain degree of stress. Maybe one day Mathematics will finally help me understand computation, and then I will be able to relax more into it.



Research collaborations are obviously important, both in terms of work and visibility. On the other hand, management of a grant adds responsibility towards the colleagues that work with us. What is the most important characteristic that a collaborator of yours needs to have? How important it is to have PhD students and develop a research group on your own main topics?

Skill is important, of course, but the most important characteristic of a collaborator of mine is, without a doubt, a love for what they do. You would think that this is easy to come by, but so many researchers have their egos wrapped up in their work, with their love of Mathematics soiled by a stronger desire to be a great Mathematician, or something along those lines. I am sad to say that I also have a big ego, but I do sincerely strive my best to keep an above-unit quotient of love-for-mathematics over ego (He said, in the magazine interview he accepted to participate in. It's work-in-progress).

How do you see the relationships, differences and similarities between research in Mathematics, Computer Science and Informatics?

There is one fundamental thing that good Mathematicians and good Computer Scientists have in common: an understanding of what it means to be precise. A mathematical statement is precise in very much the same way that an instruction in a computer program is precise. A good programmer can easily be taught what a proof is, and a good mathematician can easily be taught how to code.
I work in Theoretical Computer Science, which studies computers with the methodology of mathematics. So I don't really know how research happens in applied computer science. But I can say this: applied Computer Science is a discipline that entails very many non-mathematical skills. There is little mathematics going into requirements analysis, software architecture, interface design, testing, deployment, load balancing, etc. Not to mention management skills and people skills, all of which are necessary to produce a usable, reliable software product. Naturally, research in applied Computer Science includes all of these things, it's a whole other world.

What advice would you give to young mathematicians just starting their research careers? What specific skills or competences are essential for success in Mathematics research?

Wow, some advice for a young mathematician, let's see... You're probably pretty smart, try not to be a dick about it. Create and nurture a circle of mathematical friends. Work with researchers with all levels of skill. Get used to the feeling of being stuck, it will be with you for your entire mathematical life.

How do you balance your work as a mathematician with other aspects of your life? Are there hobbies or activities that are particularly enjoyable or essential to maintaining a healthy work/life balance?

I wish I knew. There is really no balance. Sometimes I'm so engrossed in a math problem that I get insomnia, spend hours awake at night thinking about it, and get out of bed exhausted the next day. I have forfeited entire holidays, quality time with loved ones, because I had some idea and couldn't let it go. Exercise helps a lot. I still meditate. But the job takes its toll. I have been noticing, lately, that I find it extra annoying when people use imprecise language in our day-to-day lives. It's such a silly thing to be annoyed about, but one's job shapes one's mind. And it is so isolating, to work in a field so abstract that you can't explain what you do to your friends, your partner, your family. It really is a labor of love, as nothing else would justify the sacrifice.

Mathematics is generally considered a difficult and hermetic subject. How could we make Mathematics more accessible and engaging to a wider audience, including students and the general public?

To be engaged with Mathematics, people have to experience the pleasure of understanding it. Maybe not for geniuses or whatever, but for the rest of us Mathematics is an acquired taste, and in that way it is not like hot chilies or sour pickles: it is particularly difficult to acquire because it takes a lot of time. There is no magical substitution for time spent together with people who already love mathematics, in a place that is suitable for it. A teacher, a friend, a desk, a classroom, a club. Yes, I would say, we need more math clubs.

Do you think Mathematics can play an important role in solving real-world problems, and contributing to facing global challenges?

No, of course not.

Seriously, though? The universe is made of the stuff. To forget mathematics is to forget a fundamental ingredient that everything is made with. I suppose a fish does not need to know what water is, if all he wants to do is be a fish, as God intended. But if the fish wants to have any semblance of control over his surroundings, he will need to understand water. There is no civilized world where Mathematics doesn't play a very important, fundamental role.

Having said that, none of the most important problems facing humanity today are mathematical problems. Just a few days ago ended COP28, which was held in one of the worlds largest fossil-fuel exporting nation, and, one might say unsurprisingly, resulted in a multinational agreement far less ambitious than what our climate scientist colleagues say is necessary to maintain global warming below 1,5 C°. I would happily give up my job as a mathematician if, in magical exchange, all humans everywhere would be 10% more reasonable.

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