

THE WONDER OF COMPLEXITY

"We could spend a lot of time talking about a complex system and, for example, it can quickly change its behaviour. This is essentially what interests me about complexity."

Telos: Why did you choose physics?

Giorgio Parisi: I was very interested in the exact sciences, mathematics and physics. Actually, as a kid, I was also drawn to astrophysics. I could also do calculations very quickly.

I started reading about the history of mathematics. I would go to the library and read everything in the encyclopaedias. However, they were never scientific texts, they were texts for a broad audience. My interest continued throughout secondary school, but I didn't imagine, I never even tried to imagine, what I might do in university. I thought I would decide at the last minute. My father was absolutely convinced that I had to study engineering. In my house, we essentially talked about building engineering. For him, studying engineering was the ultimate for a person who was good at maths.

After graduating from secondary school, I started really reflecting on what I wanted to do.

I didn't reflect on the fact that there was also electronic engineering, aeronautics and various other types. Plus, and I only realised this later, I had no information on what contemporary mathematicians studied, whereas I knew the topics of 20th-century physics, because this is what the books talked about. Especially Enrico Fermi! Contemporary physics struck my imagination much more than mathematics, because contemporary maths was an information black hole. Actually, mathematics is far more difficult to talk about than physics, because maths is more abstract. At least physics focusses on things, and there is a way to gloss over the concepts.

"I bring order to chaos." You won the Nobel Prize for your research on complex systems. What is a complex system?

In general, none of the words in natural language have one single meaning; they have many meanings, many different subtleties. For example, sometimes 'complex' is a synonym of 'incomprehensible', sometimes it is a synonym of 'complicated'. Some people might define the electrical circuit of a computer or television as complex. But actually, they aren't complex; they're complicated systems. 'Complex' is a different concept. Then others say: everything that isn't simple is complex. In mathematical physics itself, the word 'complex' has various meanings. One possible meaning of 'complex' is, for example, what we would call a 'complex problem', or rather, a problem without a solution that is easy to find.

Let's imagine you have to solve a puzzle where all the pieces are square and the same colour and size. You can solve this problem in an instant, a simple problem to solve. Instead, if what we have is a puzzle with pieces of all different shapes, it is harder to solve. Now, what we have is a higher degree of complexity. Let's start with a more pertinent example so we can better grasp the difference between simple and complex. Someone gives us a certain number of suitcases to arrange in the boot of a car. If the suitcases are regular cubes, they will obviously fit properly into the boot, and it is easy to find a solution. If, instead, the suitcases have different, irregular shapes, we may have to try different solutions, which are all quite different from one another, and some may be almost perfect.

So, you can find lots of solutions that are *almost* the best one, and it isn't easy to distinguish between these solutions. It's enough to think about the boot: you manage to get everything in except the poles, for example. Then, you suddenly change your mind and decide to turn the suitcases and arrange them horizontally rather than vertically. So, a totally different arrangement that allows you to fit all your suitcases inside. This is an example of a complex problem.

Here is another definition of a complex system. This is a system we could spend a lot of time talking about. If we have some water in a glass, we can: 1) confirm its presence, 2) quantify the liquid in the glass, 3) establish its temperature. If you are really nit-picky, you could also identify the atmospheric pressure of the water. However, at a certain point, you run out of characteristics for pure water. There just isn't much to say about it.

Or if we have a sequence of randomly written letters, like in Borges' experiment with monkeys that write randomly, and they tell us: give me some feedback on what is written here.

We might find, for example, that "E" is written far more often than "A" and that there are a lot of "Zs". But after a little while, we won't have much to add.

However, if they give us a passage from *Dei Sepolcri*, there is obviously a lot we can say. If they give us a dog and ask us to talk about this dog, describe what it does and so on, there are a lot of things we can say. The dog is playing, the dog is sleeping, the dog is doing this or that, the dog is fine, it has a bit of a temperature, it's a little old, it's got some arthritis in its paws... What we can say about a dog, which is a complex system, is totally different. Another important thing about system complexity is that a complex system can quickly change its behaviour. Take a sleeping dog: you clap your hands and the dog wakes up. This generally (implies that) it has the ability to react, so it can go from one type of behaviour to another type of behaviour. So, a complex system is a system with a large number of possible behaviours in its repertoire, that can go from one behaviour to another, whereas the glass of water can go from a liquid to a gas if you raise its temperature, or from a liquid to a

solid if you lower it, but it certainly doesn't have a large repertoire of possible actions.

Things change for all living systems, which are complex systems, because they can change, starting from the cells on up, starting from the situations. They can adapt to an environment; they can survive in a different environment. Our brain is one example: we think one thing, then we immediately think another thing, and then another. The number of things we can think about is vast and one thing can lead to another.

How important is it to teach science in school and how important is it to spread scientific knowledge? And why?

Teaching science is extremely important. Only if it is taught well can we recruit new young scientists. Science can only move forward if the new generations become interested in it, enrol in scientific faculties and decide to become scientists. But this interest in science only emerges if science is introduced. If they don't know what science is, it's impossible for young people to become interested in it. Then there are other, different considerations. In general, science is an endeavour that costs. Having an active scientific community takes a portion of the country's resources that is not insignificant. In some countries, 3% of GDP goes toward scientific research. In other countries like Italy, we are at a little over 1%. If scientists ask citizens to fund science, it is right for scientists to then explain to citizens what they have done with their money. Not only is this right, it is necessary; because if science remains in an ivory tower, we can't just assume that governments will decide to continue funding it. Another reason why it is extremely important to teach science is this: humanity is facing a series of crises. Crises from pollution, from exhausted resources, a climate crisis, we have a healthcare crisis, as we have seen in these last two years.

I am absolutely convinced that the least painful way for us to recover from these crises is to leverage science. Science needs constant progress.

The vaccines created for Covid are a typical example of what science has fortunately managed to do, because Covid arrived now. If Covid had hit us 20 years ago, we would not have had vaccines, and in any case not so quickly. But there is a certain wariness toward science, as shown by people's reluctance, if not refusal, to get vaccinated. I think that to ease this wariness, it is important for people to understand how science proceeds, how the scientific community validates results.

The point is this: scientific issues are becoming more and more important in political decisions. So, at this point, it becomes important for the people who make political decisions, ultimately the citizens that decide who they want as their representatives, to be capable of understanding, to the extent possible, the issues presented.

Politics and consensus. You studied how the group's direction is determined in flocks of birds in Rome. Can your theory be translated to politics, or to society?

You use the word *translation*. Translation is a term used in medicine. Translational medicine is the branch of medicine that tries to move scientific discoveries into clinical practice.

If this is what you mean, the word *translate* is just fine! The problem is that birds are very, very different from humans. When flocks have to make a decision, they have a very narrow range of possibilities: fly up, to the right, to the left, down, speed up, slow down, spread out or come together. From a political viewpoint, things are much more complicated. First, the range of things to choose from is much greater. Then there are a number of different types of choices.

The area where this type of idea we thought could be applied more to society was fashion. We tried but then it got too complicated and we weren't able to. It is true that, on the one hand, fashion is influenced by marketing and advertising. But we are also extremely influenced, or at least this is my impression, by what the people around us do, the people we see on the street, our friends. Perhaps this is what more closely resembles the behaviour of flocks of birds, because in this case, we look at what is happening to the people around us, and very often, but obviously not always, we tend to do what other people do. New things come up, and we follow them. One thing we have studied, for example, are names. We have all noticed that some names become trendy then go out of fashion. But how does this trend work? There are lots of different questions we can ask about names. For example, how long it takes for a name that was not being used to become extremely popular, how long that name stays popular and how long it takes before it goes out of fashion. But the first thing, like with the flocks of birds, is to have data. In the case of names, we looked at the US, where there is a list of how many names are used in each of the 50 states, year by year, and we started to study these lists of names. We realised that right now, it may sound ridiculous, but in the republican states, the names are all pretty similar to one another. And in the democratic states, whether in the East or the West, all the names are pretty similar to one another.

I don't think there is a *political* reason for calling someone Isabel or Jennifer. But what probably happens is that there is some kind of a connection between these people or they watch the same TV channels and so on.

This is a phenomenon, which is maybe kind of easy to study, and we have started studying it.

When it comes to politics, I'd say it's much more difficult.

Marco Sonsini

Editorial

A serious country must attract, cultivate and help scientists to grow, literally. This is what our interviewee this month, Giorgio Parisi, thinks. According to Parisi: *"Teaching science is extremely important. Only if it is taught well can we recruit new young scientists. Science can only move forward if the new generations become interested in it, enrol in scientific faculties and decide to become scientists."*

Yep, it's really him. The Nobel Prize winner for Physics, and he agreed to do this wonderful interview for PRIMOPIANOSCALA.

Just recently Parisi was also appointed chairman of the scientific committee that, by July of this year, will come up with the cultural project of the **Città della Scienza**, a science centre that will be built in Rome in the centrally located Flaminio neighbourhood.

This project has been in the works for a long time, to say the least, the newly elected Mayor of Rome, Gualtieri, has decided to take it up again and relaunch it. And we hope with better results than the administrations of the last 10 years.

Parisi will be just like “*a pea in a pod*” as he designs a project that, in the words of Mayor Gualtieri “*can speak to the city and visitors and attract a young audience, highlighting the greatness of scientific knowledge and its discoveries.*”

If anyone can render difficult concepts simple, it's Parisi. With several examples that are within even *my* grasp, he manages to explain what a complex system is and why he decided to study complexity. When he speaks, Parisi is funny, entertaining and interesting. He is NEVER boring, and actually you end up wishing he would go on talking forever.

Who would have ever imagined that your own dog conceals a complex system? You don't believe it? Read Parisi's answers to our second question. Then you'll swell with pride when you discover that managing to fit all your luggage into the car, especially on family vacations, makes you a complex problem solver.

Professor Parisi's kindness and *simplicity* are his distinguishing traits, with a dash of his unrivalled sense of humour. He talks about how science needs to win citizens' trust and tells us how “*it is important for people to understand how science proceeds, how the scientific community validates results*” so they are capable of choosing between one thing and another. Otherwise, like Manfredi **says** to Tognazzi in the 1960s Italian comedy *The Conspirators*, “*We just gotta trust each other.*” Giorgio Parisi says that he has worked on chaos and that there is nothing more fascinating to him than finding order within chaos.

This is what drew him to the dense flocks of starlings, swallows and other birds sometimes seen flying in an unpredictably shifting mass in the Rome sky, coming together and splitting apart, like a massive winged creature, a huge bird made of countless birds. A complex biological system, the meta-flock.

The chaos that organises itself into a new order, which is also instable and disorganised. Parisi realised that, in the flock, there is no leader commanding the others, rather it is the interaction between the various individuals that determines the direction of the group. This has always struck him because it shows that collective movements are nothing more than the sum of their single stories.

He firmly believes that scientists cannot remain closed inside an ivory tower but must be deserving of the funding citizens give them for their activities, through their taxes.

How? For example, by explaining as clearly as possible what they do. If a government decides to turn off the taps to science, the concrete impact on our lives would be felt almost immediately.

We shouldn't forget that we live in a technological society and that technology is based on science. “*If science gets drained, so does technology. Or it remains the prerogative of those few Countries that continue to invest in knowledge*” Parisi argues, and this outlook is more than a little unsettling.

The 2022 cover graphics for PRIMOPIANOSCALA**c**, with an almost dreamlike, pop feel, show the face of our interviewee with the distinguishing elements of their life and work arranged around their head like a sort of head-covering... mixed together in a *collage*. And like in a *collage*, the images are juxtaposed without elaboration.

For Parisi, what came to mind was the Nobel medal, his beloved Rome, dance and the Wizard Merlin. Why Merlin? Because the good professor, among his countless hobbies and passions, dabbles in writing fairy tales, and one of them is called “**La bimba, la strega ed il Mago Merlino**” (The Girl, The Witch and the Wizard Merlin). But where does he find the time for all this? Oh, I almost forgot, he's a Nobel Prize winner, not an *average Joe like us*.

Mariella Palazzolo



Giorgio Parisi is a tenured Professor of Theoretical Physics at the Sapienza University of Rome. In October 2021 he was awarded the Nobel Prize for physics “for the discovery of the interplay of disorder and fluctuations in physical systems from atomic to planetary scales.”

He is the sixth Italian to be awarded this prize. That same year he was also awarded the Wolf Prize. He is the first Italian scholar to be in the Clarivate Citation Laureates for “*ground-breaking discoveries in quantum-chromodynamics and the study of complex disordered systems.*”

After graduating in Physics in 1970, Prof. Parisi began his career as a researcher at the National Research Center (CNR), then at the National Institute of Nuclear Physics (INFN).

From 1973 to 1974 he worked at Columbia University, in 1976-1977 at the Institut des Hautes Études Scientifiques and in the subsequent two years at the École Normale Supérieure in Paris.

He returned to Italy and in 1981 became a tenured Professor of Theoretical Physics at the University of Rome “Tor Vergata”. In 1992 he was given the same position at the Sapienza University of Rome, where he also taught Quantum theories, Statistical physics and Probability.

Over the course of his career, he has received numerous awards and accolades, such as the 1987 Feltrinelli Prize for Physics, the 1992 Boltzmann Medal of the International Union of Pure and Applied Physics for his contributions to the theory of disordered systems, the 1999 Dirac Medal for theoretical physics, the 2003 Fermi Prize, the 2005 Nonino Prize, the 2006 Galileo Prize and the 2007 Microsoft Prize.

In 2010 and 2016 he won an advanced grant from the European Research Council. He is a member of the Italian National Academy of Science, the French Académie des Sciences, the National Academy of Sciences in the US, the European Academy and the American Philosophical Society.

From 2018 to 2021 he was the president of the Accademia Nazionale dei Lincei.

He has lots of hobbies, from reading “*all kinds of books*” to sports – skiing, swimming and snorkelling. However, in recent years he has become a fan of traditional circle dancing, mainly Greek dances. He also enjoys partner dances, such as the salsa and the bachata and, in recent years, the Forró “*a beautiful Brazilian dance with nice music and full of subtle rhythms.*”

He has written hundreds of articles, papers for scientific conferences and books, including *In un volo di storni. Le meraviglie*

dei sistemi complessi (*The Flight of Starlings: The wonder of complex systems*) and *La chiave, la luce e l'ubriaco. Come si muove la ricerca scientifica* (*The Key, the Light and the Drunk: How scientific research works*).

Giorgio was born and lives in Rome and is 74 years old. He is married to Daniella Ambrosino, has two children, Lorenza and Leonardo, and a three-year-old grandson named Martino, who dreams of being a *Tyrannosaurus rex*. And he's a really nice, funny guy!

Marco Sonsini

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