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CONNECTIVITY TIMES

No. 2, 2021 i-conn July - November '21

A hybrid network event

Brno goes ahead despite last minute hurdles—two perspectives
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And one in-person

Marseille sees almost all the Early Stage Researchers (ESRs) together at last *(page 4)*

Interview with Prof. Yamir Moreno

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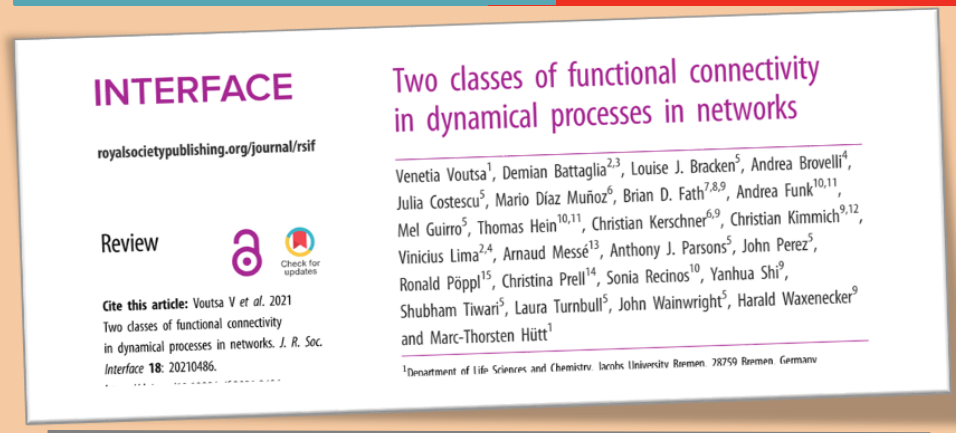

INTERFACE

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Review

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Two classes of functional connectivity in dynamical processes in networks

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A first publication

The highlight of this period is the first i-CONN publication about Structural and Function Connectivity relationships, with the first author being Venetia Voutsa. Congratulations especially to Venetia and her supervisor, Marc-Thorsten Hütt!

For an insider view of the experience of writing this collaborative publication from Venetia herself, *go to page 6.*

The article can be accessed at https://royalsocietypublishing.org/doi/10.1098/rsif.2021.0486

A Tale of Two Cities

It's a different world that we all have to navigate now. In many ways, it has been a gradual journey of tentatively returning to some of our old habits and behaviors, sometimes with the one step forward, two steps back approach of a patient undergoing rehabilitation. And the same has been the case for the i-CONN ESRs. The network training event in Brno signalled a return to in-person meetings and for many of the ESRs, a first face to face meeting. However, last minute tightening of covid precautions meant that for some, the trip to Brno would not be possible, and the difficult decision was made to push ahead and try to accommodate a hybrid format for the meeting…

(continued on page 2)

The Datathon

The Datathon (September 27 – 30, 2021) was the event attended in person by the most i-CONN members so far. Almost all ESRs spent a week at Centre International de Rencontres Mathématiques (CIRM), Aix-Marseille University, close to the beautiful Calanques National Park.

What is a Datathon? … *(continued on page 4)*

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement No 859937

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When in Brno

A tongue-in-cheek reflection on unknown places, known faces and in-between constellations

Marcel Mallow

We learned a great variety of things in Brno during our advanced course on socio-ecological systems and network analysis at Masaryk University; and not only about different conceptualisations and methods for assessing social-ecological complexity.

The first, rather general, take-away from this rare in-person event in the Czech Republic is about hidden gems. It has become evident to us that the city of Brno, even though not necessarily on the bucket list of most of us, is a city that has a lot to offer. As the Czech Republic's second biggest city it might have actually given us a more authentic insight into the local culture as it is not so much geared towards accommodating masses of tourists.

Just as Brno has quite a lot to offer, also Masaryk University, the second university of Czechoslovakia (by its founding date), and our host during the i-CONN workshop, is home to academic excellence and a thriving "Environmental Studies" department. Masaryk University was named after a former president, whom some consider one of the last truly European statesmen, Tomáš Masaryk.

However, apart from learning about Czech culture and cuisine, it was incredible to finally meet with a great part of the ESRs and some of our principal researchers; and without ever having met each other there was the feeling of knowing each other quite well. Just to give an example of this, when I walked into the lecture hall at Masaryk on the first day of the workshop, there was no "first-day-of-school" - awkwardness involved. It felt like a room full of old friends that you could share almost anything with; certainly ideas. Secret voices had even told me that I could just call my neighbour "Chris" instead of the slightly more complicated Greek / Cypriote version.

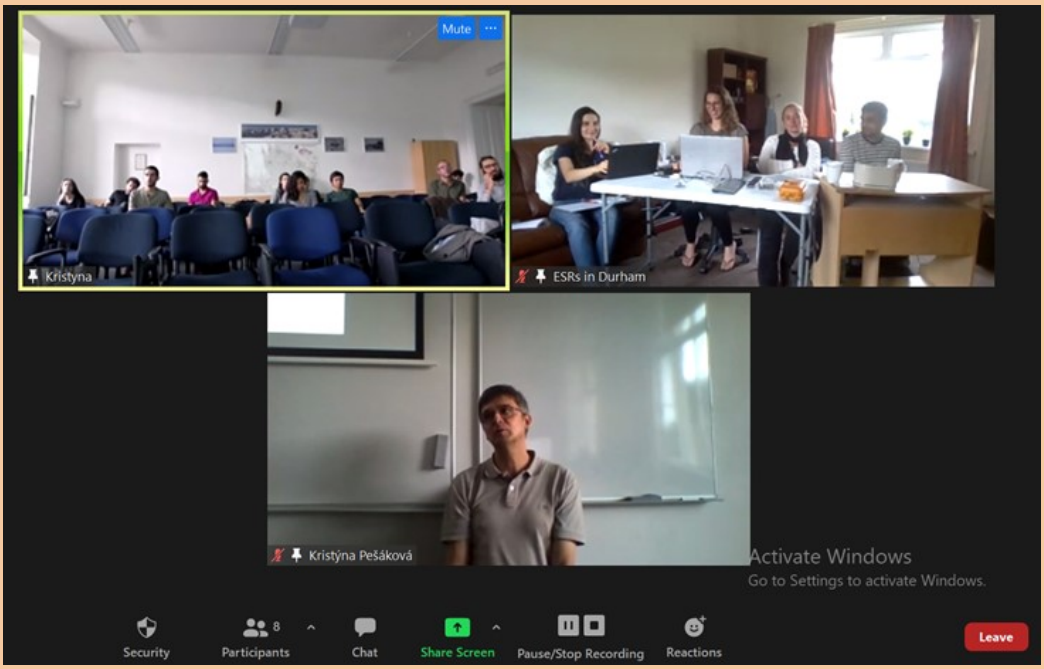
A further point to take away from our workshop is that real-life appearance remains a surprise package and that studies on zoom fatigue seem to have a valid point when they state that part of the reason for the fatiguing effect of our video-calls is that we are speaking to representations of our colleagues that are scaled-up in size, or at the beach in Honolulu or the Copacabana. It is a constant struggle for our brain to figure out what is true and what is false. We discovered in Brno, that if we now add the confusion of hybrid meetings with 3 cameras, 4 screens and different microphones our brains start to enter a special state of confusion called: constellation.

i-CONN constellations come in great disciplinary diversity, different shapes and sizes, but they are all connected. This exceptional connectivity was nurtured in Brno and great ideas and collaborations have emerged from our meeting. During our many rides in the elevators of the hotel in Brno, and thanks to the input of our theoretical physicists, we might have also come closer to a lay-person's explanation of time relativity: "Let's meet in 10 minutes in the lobby" triggered a wide range of behaviours in our group. A replication study might be carried out in Vienna.

i-CONN Advanced Course: Socio-ecological Systems & Network Analysis

Brno (Czech Republic), August 18-25 2021

- *Introduction to networks: an ecological perspective; Incorporating network analysis into research projects and comparison of approaches in ecology and economics*
  Brian Fath
- *Theoretical background: The PostNormal Science Approach; Societal Metabolism & Energy Studies; Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism*
  Silvio Funtowicz, Mario Giampietro, Helmut Haberl
- *Qualitative Approaches for Connectivity Science: Systemic Constellations*
  Nikolaus von Stillfried
- *Introducing ERGMs and SAOMs*
  Christina Prell, Petr Ocelik, Örjan Bodin
- *Additional methods and approaches from the social sciences*
  Christian Kerschner, Christian Kimmich



When life gives you virtual lemons

or: How I learned to live with the hybrid event

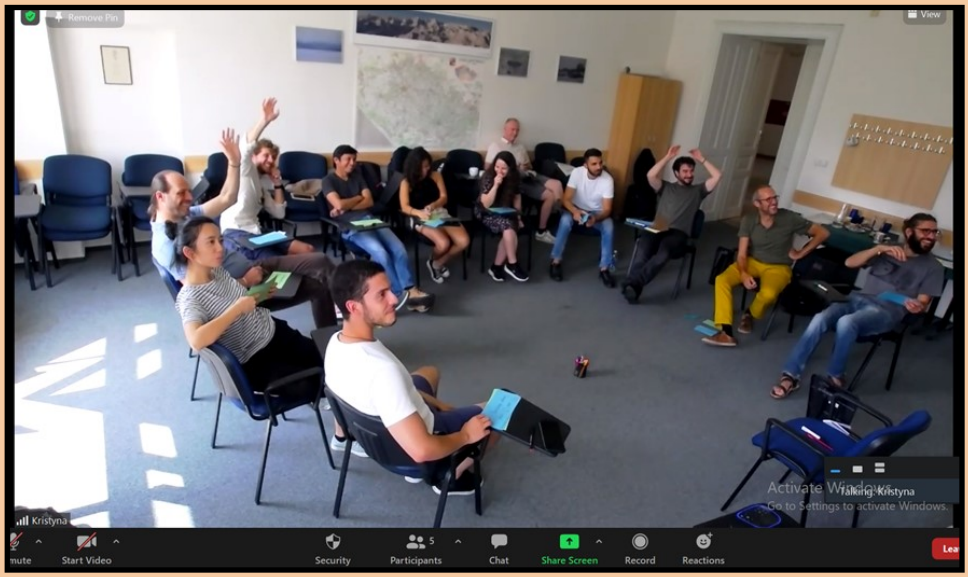
Julia Costescu

It seems to me that being left out is one of the quintessential sources of anxiety of the modern age. Call it FOMO or just plain envy, it must be a relic of our savannah-dwelling past, when seeing one's troupe of hunter gatherers trailing off in the distance was probably shortly followed by an unceremonious inclusion on the local sabretooth tiger's entrée list.

This is not unlike the range of emotions that those of us who found themselves on the Zoom participant list felt as events went underway in Brno. Here our peers would meet in person for the first time since the start of our i-CONN journey – but only for the most part, as the deceptively sci-fi term of "hybrid event" suggests. Unassuming things from our not-so-distant past took on a nostalgic aura: the relaxed coffee break chats, the bouts of contagious laughter to random jokes heard from across the room and of course, the ultimate crowd-pleaser, the hallway catering stand. But even more than these creature comforts, it was the sense of community and the irreplaceable energy of being in the room (not the breakout room, mind you!) that many of us behind the screen found ourselves longing for. Of course, no amount of positive spin can change the fact that not being there is a real shame and the efforts to put together the hybrid format took a toll on organizers and participants both present and remote. But we probably wouldn't be doing a PhD in the first place if we weren't the sort of people that like to take on a challenge. And as with many things in the pandemic, this new experiment was an opportunity to find creativity and resourcefulness in the less-than-ideal. In our case – that of the four students living in Durham – it took half a day of solitary Zoom-ing, in some cases mere meters apart, to realize that there is some lemonade that can be squeezed out of these lemons. Thus an invitation was issued, snacks and refreshments scraped together and the next morning a common workspace had materialized in the living room of the house where two of us live. Though we are the fortunate few lucky enough to have a sizeable contingent at our host-university, it was still great to be able to set up a way to have our own little side-chats and hallway snack sessions. And by sharing these challenges, we built a stronger camaraderie that we can maybe carry over in the case of future hybrid events.

From Brno as well, we found the patience and generosity to keep looking for ways to make the remote participants feel heard and included. Creative camera setups, upgraded microphones or even the odd wave to the camera made all the difference. To keep the connection with our Brno friends alive and kicking, behind the scenes, a friendly but merciless competition went on to determine who had the best catering – the Brno group or the Durham clan's assortment of home cooked meals, neighbourhood takeaways and frozen dinners. For my part, I had to admit defeat when I found out all the delicious-looking treats in Brno had been vegan as well. Chapeau, my friends, chapeau!

Now that the dust is settling on our once busy living room, even if we might have to learn to live with vocabulary like "socially distanced", "essential work" and "hybrid event" for a while longer, I can only hope to soon be in an overcrowded living room somewhere with our happy troupe of 15.



The Datathon

Exploring cross-disciplinary applications

Mel Guirro

The Datathon (September 27 – 30, 2021) was the event attended in person by the most i-CONN members so far. Almost all ESRs spent a week at Centre International de Rencontres Mathématiques (CIRM), Aix-Marseille University, close to the beautiful Calanques National Park.

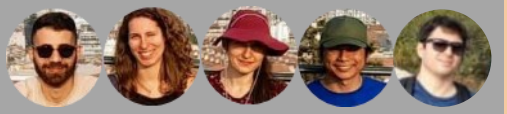
What is a Datathon? This event was hosted by Demian Battaglia. The idea of the Datathon was to encourage our ESRs to use an interdisciplinary approach to investigate contrasting complex systems. ESRs brought datasets to the table that described networks specific to their respective fields and formed groups that would apply their particular perspectives and tools to one or more of the datasets. There was no rule for what we could do with the data, so we could be creative! The goal was to promote creativity in network analysis by mixing different disciplines and expertise, with the potential of finding cross-disciplinary applications.

The Datathon began with the ESRs presenting their datasets. We had datasets on a variety of topics: rivers, ecogeomorphologic systems, scientific collaboration networks, global deforestation, public-private partnership contracts in Guatemala, neuroscience, etc. After what ended up being a spontaneous process of match-making, three groups emerged:

Group 1

The ESRs analysing social systems naturally tended to form a group because they could apply similar methods of network theory, specifically about critical nodes. In addition to social science datasets, another different topic analysing critical nodes was related to ecogeomorphic systems.

Group 2



The ESRs who study rivers chose to team up with the neuroscience experts, assuming that river and brain systems could share some similarities – both have relatively static physical structures in which something is transported over time: water/sediment or information, respectively.

Group 3

Lastly, the remaining participants formed the third, very multidisciplinary group about ecological and astrophysical systems. Also, the ESRs with network theory expertise were in this group. This group had the biggest challenge to find potential cross-disciplinary applications.

The Datathon was special because it forced us to work with people from different backgrounds. It was the first time that we were all actually collaborating in a multidisciplinary way. Each group had its own multidisciplinary collaborative approach:

The first group initially discussed the definition of node importance in each system and, later, each person worked with their own data by applying the same node importance methodology. They were able to help themselves by discussing how to apply the method, but each person worked on their own project individually.

In the second group, participants created a common model that could analyze network dynamics in both river and brain systems. ESRs from both backgrounds took a step back to have a general view of their own data until they found a model that could be used to both systems. They found the commonality between the disciplines.

The third group initially focused entirely on ecological systems. The ESRs with the network theory expertise tried to understand this system and think about what kind of analysis they could do. Afterwards, they focused on the astrophysical system. In the end, they explored numerical methods in both systems to find similarities between them.

It is interesting how three types of multidisciplinary work methodology emerged. We had three intense days working together and we learned a lot. Some projects are only in the early stages and they will continue progressing after the Datathon.

We really enjoyed the Datathon because it became clear that there is great potential for multidisciplinary work within i-CONN. We all agreed at the end that it would be great to have a second version of Datathon where groups are reshuffled and new disciplines are encouraged to work together. It's exciting to think about how many potential cross-disciplinary applications we can explore!

Apart from the actual scientific work, the food, the weather, the mountains and the beaches were amazing at the Aix-Marseille University and the Calanques National Park. We will definitely miss the Datathon.

The Brain Stream Buoys group

A research diary by Mel Guirro

"We spent two intense days creating the model, learning/explaining how it works to people from different backgrounds, creating options to simulate river and brain networks, and testing for some different network structures. We finally had a real collaborative and interdisciplinary work in the i-CONN. "

More: https://iconn.network/journal/datathon-the-brain-stream-buoys-group/

The Net-work Works

Venetia Voutsa

My first year as an ESR in the i-CONN network held a surprise for me: included in the description of the first deliverable of the Work Package 1 (WP1) was a deliverable requiring a publication that I, among other ESRs, was assigned to contribute to.

This first deliverable referred to theoretical knowledge about structural-functional relationships in networks, which is very much in line with my PhD project. Thus, under the guidelines of Prof. Hütt, who is my supervisor and leader of WP1, I took on the responsibility of its preparation.

Although the first months were devoted to acquiring technical skills and enriching my background in the theory of complex systems, knowing that an article must be submitted at a specific time pushed us in directing the work in such a way that the article deadline was met. Many meetings and discussions with my supervisor, successful and failed numerical experiments, childish mistakes and step-by-step progress led to the main idea that we considered being valuable enough to be communicated in a scientific article.

Having a clear idea of the theoretical framework of the article, it was time to embrace the opportunity that i-CONN offers us and ask for the contributions of people that work on application scenarios. This would not only support and enrich the content of the article but would also fulfil the actual goal of the deliverable and of i-CONN: encouraging collaborative work.

The response of the whole network was surprising! Every person in the network contacted us to discuss whether and how their ideas can fit with our main theoretical line.

Plenty of meetings and email exchanges providing feedback on each other's work during these months, as well as many iterations of the article, lead to a final article, ready to be submitted. The exchange with people from different scientific backgrounds brings out this exciting feeling of challenging your brain to understand their perspective and find the best way to communicate yours. It triggers new ideas and can offer a fresh point of view on one's work. I feel that this whole process was an excellent and beneficial experience for all of us and it was the start of real, scientific cooperation within the network.

The strict deadlines and the good organization, the expertise and the support of our supervisors, the encouragement I received from the other ESRs, the willingness of all people for such a collaboration were all reasons why this enormous team effort proceeded so smoothly and ended up being a success.

In conclusion, after nine months of work, stress and worries, I can say that the final result erased every difficulty that emerged during this period and the whole experience left only good memories of wonderful collaborations, grateful feelings and expectations for further scientific research.

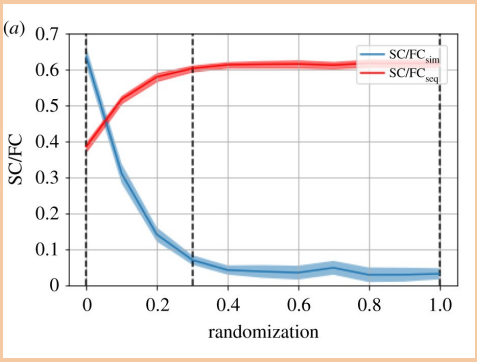


Fig. 2a from the published article, representing the correlation between structural and functional connectivity for simultaneous (SC/FC_{sim}) versus sequential (SC/FC_{seq}) activation in a modular network, for varying degrees of randomization of the network.

Mission Failed Successfully

(We'll get them next time…)

Michalis Papadopoulos

The i-CONN Project is organized in 7 Work Packages (WPs), each one focusing on different aspects of our Network (i.e. Training, Management, etc.). During the period of June-October 2021, the Network was working to prepare the first Deliverable of WP2, led by Vicky Papadopoulou-Lesta and the European University Cyprus team. As the ESR at the leading University, I worked alongside Vicky and the contributing teams in terms of content, reviewing and feedback.

WP2 focuses on developing a unified framework of methods that can be applied to different Disciplines. Ultimately, its goal is to create a common repository of connectivity methods, openly accessible and available to the members of our Network. In order for this to be manageable, the WP was pre-organized into specific objectives.

We had our first meeting on June 18th, to discuss ideas and approaches that would set the starting point of a back and forth exchange of knowledge and connectivity methods. Very quickly, the work was broken down into smaller groups, each one tackling a specific connectivity metric. Each contributor provided a solid theoretical framework for their methods, along with an application in their specific scientific domain.

After multiple rounds of reviewing, communicating feedback with the groups and trying to keep a coherent structure, a bulk of text/methods was converted into a self-consisted document. Among the different contributions, four major topics were identified: Emergence and Self-organization, Critical Node Detection, Connectivity Measures and Input-Output Analysis.

Finally, the report was published on the website of the Network (https://iconn.network/network-resources/deliverables/) on October 18th.

The work from here onwards will be to synthesize methods that share a common theoretical basis and describe similar aspects of connectivity. After deciding on the methods that will be useful from an interdisciplinary perspective, we will find their implementations in software packages or implement them ourselves when this is not possible.

On the Move

ESRs go on secondments

Mel Guirro

One of the greatest peculiarities of the I-CONN network is the potential for exchanging knowledge between people from different backgrounds and institutes. Early Stage Researchers (ESRs) are expected to have secondments (a temporary transfer of work institution). The proposal is that ESRs travel and work in other institutions. However, we were affected by the pandemic and many of these secondments were virtual.

I did a secondment in person at the University of Vienna last summer. It was the first time I left Durham (UK) since my PhD project started. I met other ESRs and supervisors in person.

My secondment stimulated me in different ways. First, the change of work environment renewed me and encouraged me to work more. I felt refreshed to work as if I had just started my project again. Second, the exchange of knowledge and informal conversations with other researchers brought me new ideas for my project. It was also good to see how other research groups work together. Finally, I had a field trip to a river catchment at the Thayatal National Park, at the border of Austria and the Czech Republic. It's always interesting to be in a new environment and a new river system. In summary, the secondment brought me a renewal of ideas, increasing my motivation and productivity in my work.

Secondments so far:

- ESR1 Shubham Tiwari : *AAISCS* and **BOKU**
- ESR2 Venetia Voutsa : **European University Cyprus**
- ESR3 Selim Haj Ali : *AAISCS* and *European University Cyprus*
- ESR4 Harald Waxenecker : *IIASA, Jacobs University*, **Groningen**
- ESR5 Vinicius Lima : ***AAISCS*** and ***European University Cyprus***
- ESR6 Mel Guirro: ***University of Vienna***
- ESR7 Michalis Papadopoulos : **AAISCS**
- ESR8 Sonia Recinos : *European University Cyprus*
- ESR9 Yanhua Shi : *IIASA*, *Modul, EA*
- ESR10 John Perez : *Durham University*
- ESR11 Christodoulos Karittevlis : **European University Cyprus,** *Jacobs*
- ESR12 Mario Díaz : *IIASA/UG, European University Cyprus,* **Jacobs**
- ESR13 Deborah Priß *: Groningen, IIASA*
- ESR14 Marcel Mallow : ***Masaryk University,*** *EA*
- ESR15 Julia Costescu : *EA*

*** in person** | *virtual* | ***partially virtual***

Network approaches to collaborative environmental governance

A research diary by Marcel Mallow

"During my first secondment at Masaryk University in Brno (CZ), the focus was on the identification and comparison of suitable network approaches for the case-based analysis of complex environmental governance situations. "
More: https://iconn.network/journal/collaborative-environmental-governance

Meanwhile

Mel Guirro

While we were busy researching our individual projects, developing the deliverables for Work Packages 1 and 2, and attending i-CONN events in Brno and Marseille, we had other minor i-CONN tasks and trainings.

Over three weekly sessions, we had a course on **'Networks, Teams, Interdisciplinary Collaboration and Research Impact'** by Hutchinson Training and Development. This course was very interactive and encouraged us to seek to develop networking and collaborating skills.

We've recently had an i-CONN seminar by Dr. Lorien Jasny about **'Can conversation change minds: applying mental models to the UC Davis Adaptive Rangeland Management study'.** It was very interesting to think about how network theory can be applied to understand human behaviour!

The i-CONN network gives the ESRs support to develop our future careers. Thus, we each had to revisit our **Training Needs Analysis** and **Career Development Plan** in conjunction - with our supervisors.

Finally, some ESRs organized themselves to have weekly informal meetings to share knowledge and learn together. We call this group ***'co-learning ESR to ESR'***. It's always a great way to know what the others are doing and to quickly learn some topics, such as coding, network tools, version control with Git, and others.

The Birth of a Network Scientist

An interview of Prof. Yamir Moreno by Shubham Tiwari and Mel Guirro

We spoke with Prof. Yamir Moreno, an esteemed member of our Advisory Board, about his perspectives on various aspects of Network Sciences. Yamir Moreno is a Professor of Physics at the Department of Theoretical Physics of the University of Zaragoza and is the elected President of the Network Science Society. He is a well-known network scientist who has made significant contributions to understanding the structure and dynamics of complex networked systems, with applications ranging from the dynamics of virus and rumor propagation to evolutionary game theory and the conceptualization of multilayered networks. During the interview, we discussed the start of his career, the current state of Network Sciences, and his advice for Early-Stage Researchers in this field.

When and how did you first develop an interest in complex systems?

That was at the start of my research journey. We were attempting to solve a problem involving how to improve the efficiency of combustion processes where there was a mixture of fuel and water, so there were some difficulties with oil combustion. Naturally, the fuel contains some water because we use water to extract it sometimes. To solve this problem, I remember that the process was that you inject the oil into a combustion chamber, followed by a second atomization. Let us refer to the first atomization as mechanical atomization. The second is simply because the boiling point of water is lower than the boiling point of oil, resulting in evaporation of water, which caused the second atomization. The question then became how to take advantage of this, as well as what droplet size distribution optimizes their combustion.

That was my first experience with a complex system. That was during my undergraduate studies, and it was there that I developed an interest in critical dynamics, which we solved using statistical physics tools. Following that, I developed an interest in the statistical physics of critical phenomena such as self-organized criticality. And then I started to think of other problems that could be solved using these methods. I realized in the late 1990s that when you start studying biological systems, social systems, and so on, the patterns of connections are not as regular or as organized as in a crystal or a solid structure. And then it was around the late 1990s to the early 2000s that we began to think about networks. We investigated what effects the topology has on the dynamics of the system, as well as how the dynamics shape the topology of the system.

What do you consider to be your most significant research accomplishments, given your diverse research background?

It's difficult to say because, you know, I'm proud of all my works because they all serve a purpose. For example, in disease transmission, we are now seeing the results of the community's enormous effort over the last 20 years. There are still many things that we need to learn. As in, how do we incorporate human behavior into our most sophisticated models? At the moment, we are running some data-intensive simulations to incorporate human behavior. However, from a theoretical standpoint, it is more difficult because we still do not know how to encode it in a differential equation. So, this is one thing that I have seen as an open challenge, and I believe we have made some contributions in that direction, so I'm happy with that.

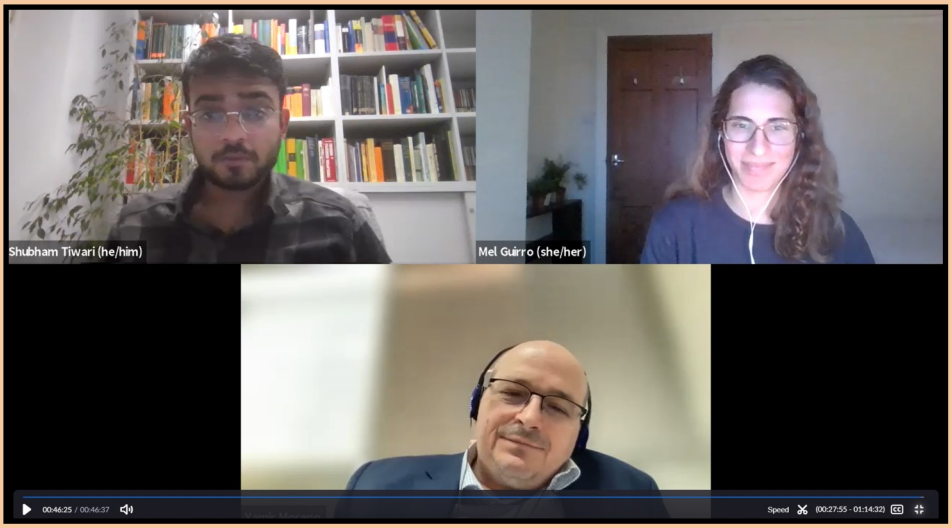
The work on multilayer networks was also significant, as my group and others developed a new way of thinking about interconnected systems. So, we began by assuming that everything, every interaction, was random, but then we began conceptualization and characterizing single layer networks. The next natural step was to consider how these networks interact with one another, and then we created a framework to study these coupled systems, which are in the form of multilayer networks. At first, it was all about developing the methodology and asking simple but important questions like whether I needed to consider the multilayer nature of my system. There are still some open problems that are easy to formulate but difficult to answer, as well as problems related to critical phenomena that occur on top of this.

Another area to which I am somewhat attached is our work on evolutionary game dynamics, which we began with a PhD student. We became interested in Darwinian evolution and game theory. We realized at some point that we were doing a little too much theory. When dealing with humans, it is important to ensure that your theory is heading in the right direction. And I am particularly happy that we decided to begin conducting experiments similar to those conducted by behavioral economists. And that was the most difficult step for us because we had to learn a lot about how these experiments are carried out, a lot about what you have to control, and so on. Most importantly, some of the experiments we conducted demonstrated that our theory was not accurate enough, because people did not behave as we expected them to. So that opened a whole new research area, at least for us. It was interesting to me because it reminded me of my research as a physicist, which is to observe the world, develop the theory, make predictions, and then return to the lab to test those predictions. And we were only doing half of that before. We were doing theory and making predictions, but we weren't learning from what was already there, so we weren't closing the loop by going back to the lab and testing the theories, which we did with great pleasure.

What is your opinion of the current state of network science (both theoretical and applied)?

One thing we have accomplished as a community - and by community, I mean network scientists, not physicists or mathematicians, but the entire network science community - is that it is now almost mandatory to think about networks in every field of science. This is something we've accomplished in the last 20 years. In that regard, I believe the current state of network science is, let's say, healthy. Of course, there are many theoretical challenges ahead of us. One of them is similar to what happened with the multilayer networks, and which is now happening with what we call higher order networks or higher order interaction. When considering single layer or multi-layer networks, the majority of these representations are based on pairwise interactions. In pairwise interaction, one node interacts with another, and there

is a link between the two, but there is more to it than that. There are some group interactions that are not encoded in those simple representations of pairwise interaction. We are now dealing with higher order interactions, which are essentially these so-called simplicial complexes, as well as hyper graphs. Again, mathematicians have been working on this for some time, but I believe that the next big revolution in this direction will require network scientists to begin incorporating data in these abstract representations. Following that, we must address some questions about the impact of the new structure on the dynamics. Should we consider the possibility of having other than pairwise interactions? Are there any hidden transitions that we haven't detected because we've only worked with low-dimensional systems and need to move on to higher-order systems? And so on.



I think there is also another niche for theoretical work that is inspired by physics. Some theorems, particularly in higher energy physics, are known as no-go theorems. No-go means that this is not physically possible. These phenomena are impossible to observe because they violate the laws of physics. There are such results, that can be considered "negative", that we also need to learn. We need to put boundaries to our current theory: when the theory can be applied, and when it cannot. So, a sort of no-go theory in the sense that you will never have an example of such a network or interaction dynamics because they are simply contradictory in real-world systems.

In terms of applications, there are a lot of things to do. There are many things to do in biology, in my opinion. There is a lot to do in the computational and social sciences. There is a lot to do, for example, in brain dynamics, and so on. All of these fields have used only a few network science results, some of them a little bit more, some of them a little bit less. However, I see some applications that are still awaiting theoretical developments, as well as others that can benefit from the application of theoretical development. For example, one thing that comes to mind is that we are familiar with dealing with undirected and unweighted networks. However, when working with biological systems, for example, there is directionality. There has been little work done in directional networks, both theoretically and practically. As you know, when you have directionality, the matrices are no longer symmetric. This means that eigenvalues are not real anymore. It is possible to get complex eigenvalues in the case of asymmetric networks, which greatly complicates matters. That could be one of the reasons we haven't gone far enough in that direction.

With regards to complex networks, there is a significant gap between theoretical network theory and its application in real world systems. For example, we can see that some disciplines are still using basic network concepts to understand the emergence of these systems; how do you see the future growth of the application of network science?

I believe there are some examples that have worked fairly well; for example, disease dynamics is one such success story in which you can use network-based concepts to reproduce the disease's trajectory to a certain extent. But yes, there are some differences between theory and applications, particularly in systems involving humans, because it is essentially unpredictable in many ways, and sometimes people try to simplify too much in terms of network approximation. However, I believe we are on the right track because science is step by step, and it is not as if these concepts can be incorporated into all areas overnight. Also, you should start with the simplest descriptions and then try to add complexity as you go, because if you start with the most complex model that you can design, you won't understand anything. There appear to be many variables that you cannot control, and at the end of the day, you will not be able to isolate what each of these elements contributes to the overall dynamics of the system. I believe we will learn how to do this, and we will get there at some point.

Do you believe it is relevant to teach network theory in schools? And, if so, to what extent?

It is really important, from the university level to the elementary school level. We live in an interconnected society, so I believe it is important for our society to develop network thinking. The Network Science Society has a group of scientists working on developing guides and books aimed specifically at primary school students. For example, they use characters from movies to draw connections between them. I think it is a great way to teach kids how to think in terms of networks, and we hope to spread the word about it more. This is something that I believe is becoming a must-have knowledge for everyone, from children to university students.

What advice would you give to Early-Stage Researchers/PhD students interested in network sciences?

One of the most important aspects of our field of research is interdisciplinarity. Even if you have a specific problem, you should interact with people from other areas, and I believe this will provide a very fresh perspective on what others are thinking about the same problem. If you interact with a biologist, sociologist, mathematician, or physicist, you will discover that you are sometimes discussing the same problem in a completely different language. You, as a PhD student, should learn to communicate your work to a diverse audience. I also advise my students to talk to people from different backgrounds so that they can learn to communicate with people from different backgrounds, because it is important for us as scientists to communicate our findings to as wide an audience as possible.

Another piece of advice I'd like to give is to focus on a specific research problem and do your best to solve it. It's always useful to have a broad background, but I believe that research is driven by curiosity, while learning is driven by

problem solving. You should try to concentrate on what you want to learn and why you want to learn it, so the first question you should ask yourself is what my research question is and what I need to answer it. Whether it is difficult or easy, once you have answered the question, the next step is to consider how to communicate it and what other avenues it will open.

I believe you are the future of science, and there are many things that are unrelated to technical education but to the ethics of being a scientist. For example, during this pandemic, I noticed a lot of people discussing topics on which they are not experts, which adds to the general public's confusion. You have to learn when to say "I don't know". You don't have to feel obligated to always answer whatever question is posed to you, because it is normal to say "I don't know, this is not my specialty".

Finally, an issue that a group of us is working towards: we need to go back to the old times, as it was when I first started doing research 30 years ago, when there was not as much pressure to "publish or perish". It was more about the problem you studied, and it was fine if it took some time. I try to teach my students that it is important to go through all the research stages, that you must focus on answering your question, and that you should not be concerned with reporting partial or preliminary results in the form of publications. After you have finished solving the problem, you can consider how you want to present it, which could be in the form of one, two, or three papers. By contrast, nowadays we see these "salami publications" - a series of papers that could have been merged into one self-consistent paper. When we sit on committees, we try to look at what people know how to do and how much they know rather than how much they have done. There is too much pressure on the younger generation these days to publish in order to apply for postdocs, but I personally do not look at volume. There are few exceptions of people who have done a high volume of good work, but normally having a high number of publications means they are of low quality or incomplete. So, you should not be concerned with numbers and instead concentrate on your research problem.

Could you recommend a book or any other material (for example, a documentary or a podcast) about science in general? And about complex system theory and network theory?

There is a lot of very good material out there. I don't want to pick just one in particular, but it depends on what you're looking for. If you are looking for a book to support your teaching on networks and complex systems, there are some very popular books, including Mark Newmann's introductory book, Ginestra Bianconi's book on multilayer networks and the book based on the lectures of Albert-László Barabási. Vito Latora also wrote a book that is very useful because it contains pseudo-code and some implementation examples. If you want to learn about non-linear dynamics, a classic book is the one by Steven Strogatz, which is pedagogical and very straightforward. Actually, he also ran a podcast for Quanta Magazine about science in general, which I would definitely recommend.

I would also recommend books for the general public because they help you to explain your work in simple terms. There are also entertaining books, like those dealing with misconceptions in science. One example is the book "Calling Bullshit: The Art of Skepticism in a Data-Driven World". These kinds of books are entertaining but also enlightening because they teach you what not to do and also how to explain science to the general public. While for technical topics, I would always suggest going back to the original papers, the most useful books for me in the last few years have been those that teach me how to better communicate what I do. And I think that could also be helpful for someone who is just starting out.

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