CACN25

A one-day workshop on

Computational Aspects of Complex Networks and Artificial Intelligence

Università di Roma Tor Vergata, Rome, December 3rd, 2025

Book of Abstracts

Scientific and organizing committee

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INVITED TALKS

Luca Becchetti

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"Approximate 2-hop neighborhoods on incremental graphs: An efficient lazy approach"

Abstract. We investigate lazy-update techniques to maintain accurate approximations of the 2-hop neighborhoods of dynamic graphs resulting from sequences of edge insertions.

We show that under random inputs, it is possible to achieve optimal trade-offs between accuracy and insertion cost. We further explore adversarial, worst-case scenarios, showing that while worst-case input sequences do exist, a necessary condition for them to occur is that the girth of the graph released up to any given time be at most 4. Empirical results are consistent with and typically better than our theoretical analysis anticipates. This further supports the robustness of our theoretical findings: forcing our algorithm into a worst-case behavior not only requires topologies characterized by a low girth, but also carefully crafted input sequences that are unlikely to occur in practice.

Michele Benzi

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"Sensitivity of centrality measures in networks: the role of localization and spectral gaps"

Abstract. The main goal of the talk is to present some results on the effect of edge modifications on centrality measures, especially eigenvector centrality, from the point of view of localization. The latter property is related to sparsity and the size of the spectral gap. For simplicity, the focus is on the undirected case. I will describe a recent approach to finding gaps in the spectra of symmetric matrices by means of randomized trace estimators.

Davide Bilò

Università dell'Aquila (davide.bilo@univaq.it)

"On the Design of Distance Sensitivity Oracles with Subquadratic Space"

Abstract. A Distance Sensitivity Oracle with sensitivity f (or f-DSO) is a data structure that, given any pair of vertices s and t of a graph G and a set F of at most f failing edges, efficiently reports the distance between s and t in G−F, up to a multiplicative approximation factor known as the stretch. The study of f-DSOs has attracted considerable attention due to their relevance in areas such as network routing, traffic engineering, and fault-tolerant distributed systems. Over the past three decades, a variety of f-DSOs have been proposed, exhibiting different trade-offs among space, stretch, and query time. This talk highlights recent advances in the design of f-DSOs that achieve subquadratic space complexity with respect to the number of vertices in the input graph.

Nicola Guglielmi

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“Changing the ranking in eigenvector centrality of a weighted graph by small perturbations” (joint work with Michele Benzi (SNS, Pisa).

Abstract. We study the robustness of eigenvector centrality for nodes of a (possibly weighted and directed) graph. Given the adjacency matrix A, the eigenvector centralities correspond to the entries of its Perron eigenvector. Robustness is assessed by determining the smallest perturbation of A that makes the largest m entries of the Perron eigenvector coalesce, thus producing ambiguity in the top ranking. To solve this matrix nearness problem, we propose a nested iterative algorithm combining a constrained gradient flow for the inner iteration with a one-dimensional optimization of the perturbation size in the outer iteration. The method yields the optimal (minimum-norm) perturbation causing coalescence and provides insight into the sensitivity of the graph. An explicit gradient formula and the analysis of the associated stationary points reveal an underlying low-rank structure. Numerical experiments show that our approach outperforms standard constrained optimization methods. The framework extends naturally to any nonnegative matrix, with applications in population dynamics, consensus models, and economics.

Fabio Massimo Zanzotto

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“Deep Neural Networks are really Complex? Building Transparent Neural Networks for Large Language Models”

Abstract. Deep Neural Networks - specifically, Transformer-based Large Language Models - demonstrate extraordinary capabilities and, thus, change the approach of the ML/NLP/NN communities when conducting research. Large chunks of research topics are neglected as Transformer-based LLMs seem to be the ultimate solution. However, it is already emerging that a large part of the capabilities of LLMs depends on their ability to memorize using very simple linear algebra operations. Moreover, the necessity for deep neural networks to memorize long-tailed data to obtain close to optimal generalization error has attracted a lot of discussion. In this talk, we aim to report our experience in the florid research area on LLMs, exploring how these models memorize and how they generalize from training data.

Riccardo Zecchina

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“Dynamical Learning in Deep Networks”

Abstract. Modern AI architectures—ranging from deep convolutional networks and diffusion models to large language models—are trained by gradient-based learning, a process that is computationally and energetically demanding, and fundamentally distinct from the local, adaptive mechanisms observed in biological learning.

This talk will first survey current advances in artificial and neural learning models, with a focus on emerging approaches that incorporate locality, dynamics, and biological plausibility into the learning process. I will then introduce a new theoretical framework grounded in asymmetric deep

recurrent networks, where learning is not imposed externally through gradient descent but emerges from the self-stabilization of densely connected clusters of fixed points—defining a Representation Manifold that supports robust and efficient computation.

ACCEPTED POSTERS

Alessandro Filippo

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"A novel betweenness-like centrality index for directed acyclic networks" (joint work with D. Bertaccini and L. Chiricosta)

Many real-world processes characterised by cascading interactions can be represented as source-to-sink paths in a Directed Acyclic Graph (or DAG for short). A crucial example can be found in protein interaction networks that model pathways related to diseases such as cancer, Alzheimer and Parkinson.

In this communication, based on the joint work [1] with D. Bertaccini (Università di Roma Tor Vergata), and L. Chiricosta (IRCCS Centro Neurolesi "Bonino-Pulejo", Messina), we present a new centrality measure for DAGs and how to compute it efficiently. This new index, which we call *source-to-sink communicability*, can be described as a "betweenness-like" centrality index that considers source-to-sink paths instead of shortest paths. Thanks to its effective bridge recognition and interpretability, source-to-sink communicability is particularly well-suited for analysing critical DAGs such as protein interaction networks, as it may help to identify nodes whose failure can severely compromise the underlying functions of the network.

[1] D. Bertaccini, L. Chiricosta, and A. Filippo. Source-to-sink communicability: a new centrality measure for directed acyclic networks. Numerical Algorithms, 2025. DOI:10.1007/s11075-025-02224-4

Fabio Giacomelli

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"Payment-failure times for random Lightning paths" (joint work with Taki E. M. Abedesselam, University of Rome Tor Vergata and University of Camerino; Francesco Pasquale, Michele Salvi, University of Rome Tor Vergata)

The poster will present the results in [AB25], where we study a random process over graphs inspired by the way payments are executed in the Lightning Network [PD16], the main layer-two solution on top of Bitcoin [NA08]. Participants in the Lightning Network are connected through bidirectional payment channels, forming a graph whose nodes represent users and whose edges correspond to channels with a public capacity.

Each channel's capacity is split into balances privately held by its endpoints and updated whenever a payment is routed through it. A payment fails if at least one of the edges on the chosen path has insufficient available balance to support the transaction. The process we studied is the following: Given an undirected graph G, where each edge e has a capacity $c(e)$ and an initial balance equally divided between the two endpoints, at every discrete round a source node u and a destination node v are chosen uniformly at random (u.a.r.) among all the nodes, then a shortest path $\mathcal{P}$ is chosen u.a.r. among all shortest paths between u and v, and a payment of unit value is executed from u to v over path $\mathcal{P}$. Our goal is to investigate how long it takes for a payment failure to occur, depending on the topology of the graph and on the channel capacities. We first prove almost tight upper and lower bounds on the time it takes for a payment failure to occur, as a function of the number of nodes and the edge capacities, when the underlying graph is complete. Then, we show how such a random process is related to the edge-betweenness centrality [GN02] measure and we prove upper and lower bounds for arbitrary graphs as a function of edge-betweenness and capacity. Finally, we validate our theoretical results by running extensive simulations over some classes of graphs, including snapshots of the real Lightning Network.

[NA08] S. Nakamoto. Bitcoin: A peer-to-peer electronic cash system, 2008.

[PD16] J. Poon, T. Dryja, The Bitcoin Lightning Network: Scalable Off-Chain Instant Payments, 2016. White paper.

[GN02] M. Girvan, M. E. J. Newman, Community structure in social and biological networks, PNAS 99(12), 7821–7826, 2002.

[AB25] T. E. M. Abedesselam, F. Giacomelli, F. Pasquale, M. Salvi, Payment-failure times for random Lightning paths, Proc. BRAINS 2025 (to appear).

Daniele Pasquini, Giacomo Pace, Simone Paris

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“A Space-Efficient Algorithm for Community Detection in Temporal Networks”

(joint work with Paola Vocca, Università degli Studi di Roma Tor Vergata)

The analysis of community evolution in social networks is crucial for understanding phenomena like polarization and the spread of misinformation within echo chambers. While temporal graphs provide a powerful framework for modelling these interactions, existing algorithms for community detection can be memory-prohibitive, especially for networks spanning long time periods.

This work introduces a space-efficient, incremental algorithm designed to detect and track community evolution in large-scale temporal networks. Inspired by the Leiden method, our approach processes the network one temporal snapshot at a time, overcoming the memory limitations of methods that analyze all snapshots simultaneously. The core of the algorithm involves an iterative process for each new time slice that uses a warm start, where the community partition from the previous slice serves as the initial configuration to promote temporal stability. A temporal bonus is applied to edge weights to reinforce persistent community structures, followed by local optimization and the alignment of community labels to maintain coherent identities across time. We validated our method by comparing its output partitions against those from the standard temporal Leiden algorithm. The results demonstrate that our space-efficient approach achieves highly comparable accuracy, as measured by standard metrics including Normalized Mutual Information (NMI), Adjusted Rand Index (ARI), and the Jaccard index. The primary advantage is a substantial reduction in memory consumption, which enables the analysis of community dynamics over an arbitrary number of temporal slices.

Alessandro Straziota

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“Detecting Large Quasi-clique on Dynamic Networks”

(jont work with Luciano Gualà, Simone Pellegrini, Luca Pepè Sciarria, Università di Roma Tor Vergata)

Motivated by the problem of community detection in large networks, the task of finding large *quasi-cliques* has attracted considerable attention across different research areas. From a computational complexity perspective, strong inapproximability results are known for this problem, yet several heuristics have been proposed to identify large quasi-cliques in real-world networks. Recently, [*Pang* et al, 2024] introduced a similarity-based approach that represents the current state of the art.

In this work, we extend that approach to *dynamic* networks, thereby addressing an open problem posed by [*Pang et al., 2024]*. We design an algorithm that maintains a large quasi-clique in a *fully dynamic* setting, where edges of the network can be both inserted and deleted. Moreover, we propose an ad hoc solution for the *incremental* case -- where only edge insertions are allowed -- achieving a substantial speed-up. We provide a formal analysis of our algorithms and validate them through an extensive set of experiments on real-world datasets.

Veronica Tora

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"Network Transport Models in Alzheimer's brain"

(joint work with M. Bertsch and E.Cozzolino, Università di Roma Tor Vergata, A. Raj and J. Torok, UCSF)

Mathematical and computational models have recently been developed to explore the dynamics of toxic proteins like Tau protein in Alzheimer's disease (AD). The main trend is to describe toxic proteins' spreading throughout the brain in AD by means of "graph diffusion models": given an initial distribution of regional pathology in the brain, the diffusion process is governed by the concentration gradients and connectivity weights between all region pairs and it is suitably modeled by means of the graph Laplacian matrix. Graph diffusion models have been shown to be robust in predicting important patterns of AD propagation as, for example, the pathology progression in human subjects [2], but they lack of adequate sophistication to fully capture the more complex mechanisms of toxic protein spreading. Indeed, in addition to pure diffusion, the propagation of Tau protein is governed by active transport along axonal microtubules resulting in distinct directional bias of Tau deposition.

Here, we present a novel modelling approach which combines an active transport mechanism of soluble tau in the white-matter tracts [4] with the dynamics of soluble and insoluble tau in the gray-matter regions and enables to simulate the dynamics of soluble and insoluble tau in terms of the diffusion- advection and aggregation- fragmentation processes at the network level. In addition, the resulting model, which we call Network Transport Model (NTM), is suitable to deal with the existence of two timescales in Alzheimer's disease, a fast one for most of the involved physical and chemical mechanisms and a much slower one for the evolution of the disease. Considering the physical and chemical mechanisms in the fast time scale as instantaneous in the slow time scale, one can rigorously define a quasi-static approximation of the NTM in the slow timescale. The numerical implementation of the quasi-static NTM has been developed by classical finite difference methods and the model dynamics as function of some key parameters has been explored. However, at numerical level, the implementation of the quasi-static NTM is a computationally intensive task even for a single set of parameters. In order to bypass the need for calculating time-consuming integrals, we are developing an hybrid implementation approach, where advanced machine-learning tools will be combined within the current NTM numerical algorithm. This will open up the possibility to model fitting to experimental data both in mice and humans being.

[1] M. Bertsch, E. Cozzolino, V. Tora, Well-posedness of a network transport model, Nonlinear Analysis, Volume 253, 2025, 113714, ISSN 0362-546X, https://doi.org/10.1016/j.na.2024.113714.

[2] A. Raj, V. Tora, X. Gao, H. Cho, J. Y. Choi, Y. H. Ryu, C. H. Lyoo, and B. Franchi. Combined Model of Aggregation and Network Diffusion Recapitulates Alzheimer's Regional Tau-Positron Emission Tomography. Brain Connectivity, 11(8):624–638, oct 2021.

[3] V. Tora, J. Torok, M. Bertsch, Ashish Raj, A network-level transport model of tau progression in the Alzheimer's brain, Mathematical Medicine and Biology: A Journal of the IMA, Volume 42, Issue 2, June 2025, Pages 212–238, https://doi.org/10.1093/imammb/dqaf003

[4] J. Torok, P D. Maia, P. Verma, C. Mezias, A. Raj Emergence of directional bias in tau deposition from axonal transport dynamics. PLoS Comput Biol 17(7): e1009258, 2021.

Mahsa Yousefi

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"Estimating Coefficient Functions in Inverse PDEs via PINNs"

(joint work with Stefania Bellavia, Università di Firenze and Elisa Riccietti, ENS Lyon)

In this study, we address the problem of estimating an unknown coefficient function in one-dimensional inverse partial differential equations (PDEs) using physics-informed neural networks (PINNs). Building upon the Data-Guided PINNs (DG-PINNs) framework [1], originally designed for inverse problems with constant parameters, we extend the methodology to cases where the coefficient varies spatially. The proposed approach first employs a data pretraining phase to stabilize the learning of the PDE solution from observations. Subsequently, in the physics-informed fine-tuning phase, both the solution and the inverse solution, i.e., spatially varying coefficient are learned simultaneously by minimizing a composite loss function that combines data and physical residuals. Through numerical experiments on a one-dimensional elliptic PDE, we demonstrate the performance and effectiveness of the proposed method.

[1] W. Zhou and Y.F. Xu., Data-Guided Physics-Informed Neural Networks for Solving Inverse Problems in Partial Differential Equations, arXiv preprint arXiv:2407.10836, 2024.

Francesco Zigliotto

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"Past-aware game-theoretic centrality in complex contagion dynamics"

We introduce past-aware game-theoretic centrality, a class of centrality measures that captures the collaborative contribution of nodes in a network, accounting for both uncertain and certain collaborators. A general framework for computing standard game-theoretic centrality is extended to the past-aware case. As an application, we develop a new heuristic for different versions of the influence maximization problems in complex contagion dynamics, which models processes requiring reinforcement from multiple neighbors to spread. A computationally efficient explicit formula for the corresponding past-aware centrality score is derived, leading to scalable algorithms for identifying the most influential nodes, which in most cases outperform the standard greedy approach in both efficiency and solution quality.