Research Project 2027

Predictive maintenance for networked systems

Theme: Optimization & Operation Research

Keywords: Predictive maintenance, resource allocation, network control, combinatorial optimization, linear arrangement, graph structure analysis, infrastructure networks, uncertainty.

Institution: Centre Borelli, ENS Paris-Saclay | MLMDA research group

Contact: Argyris Kalogeratos | <argyris.kalogeratos@ens-paris-saclay.fr>

Permanent researcher, co-ordinator of the theme *ML on Graphs*

Context and motivation

Real-world networked systems comprise several interconnected entities organized in a topological structure, e.g. distributed spatially, or in a graph related to operational interactions. Contact networks and large infrastructure systems, such as transportation and electricity networks, are examples of networked systems. *Predictive network maintenance* is a network decision and control problem involving detection, upkeep, and repairing tasks that are challenging due to the uncertainty about the state of each part of the system, and due also to the difficult and costful management of the maintenance resources. Managing resources refers to the decision making behind the *resource allocation* of the available maintenance resources, which implies -for instance- taking online decisions for dispatching experts and materials to problematic parts of the system. Failures in an infrastructure network may come from the natural wearing of the equipment or other unexpected events, while in a contact network, processes like epidemic outbreaks can cause the degradation of the network health. In both paradigms, the administrator needs to spot the most critical parts of his system and decide/plan effective interventions that optimize a given objective function.

Graph-based modeling has proved to be useful in dealing with such complex problems. Significant advancements can be achieved when operation research problems get related to well-studied graph-theoretic properties, since this can highlight clear objective functions to then optimize computationally.

Scientific objectives

This project puts forward the following non-exhaustive list of directions of work:

• Studying and developing efficient solvers for the graph linear arrangement problem, which can be a crucial tool for several operation research tasks, and resource allocation in particular.

• Formalizing a framework for studying the structure of a given network based on randomized greedy approximations of the graph linear arrangement (or partial arrangements), which can define different ways of traversing through (or walking) over a graph.
• Studying network rewiring procedures that could alter the network connectivity by respecting at the same time operational constraints of the system.
• Studying online selection algorithms, within the *secretary problem* setup, that can be combined with learning objectives over streams.
• Studying predictive maintenance applications, such as prediction of faults and resource allocation strategies, under the presence of uncertainty.

The project can be transversal to a number of fields in mathematics and theoretical computer science. After establishing the theoretical framework, the expected output is the production of a number of articles aiming to high-quality conferences and journals.

A fitting candidate should have an excellent background in applied mathematics, and also some experience with operation research problems. He/She should be eager to do research in a dynamic team where the expected contribution is both at the theoretical and the implementation level. The research will be in the frame of the Machine Learning on Graphs research theme of Centre Borelli. In addition, this research will be put in relation to certain initiatives between Centre Borelli and Industry of broad public interest, namely RTE and SNCF, and the AI Chair, which could both offer opportunities to apply the produced methodologies to real industrial applications.

Indicative references

[1] K. Scaman, A. Kalogeratos, and N. Vayatis. (2016). Suppressing epidemics in networks using priority-planning.

[2] K. Scaman, A. Kalogeratos, and N. Vayatis. (2015). A Greedy Approach for Dynamic Control of Diffusion Processes in Networks. IEEE International Conference on Tools with Artificial Intelligence.

[3] J. Dıaz, J. Petit, and M. Serna. (2002). A survey of graph layout problems.

[4] E. Rodriguez-Tello, J.-K. Hao, and J. Torres-Jimenez. (2008). An effective two-stage simulated annealing algorithm for the minimum linear arrangement problem.

[5] Z. Wu, S. Pan, F. Chen, G. Long, C. Zhang, and P.S. Yu, (2019). A Comprehensive survey on graph neural networks. IEEE Transactions on Neural Networks and Learning Systems.

[6] Z. Li, et al. (2018). Combinatorial optimization with graph convolutional networks and guided tree search. Neural Information Processing Systems.

[7] K. Zhao, Y. Rong, and J. Xu Yu. (2020). Graph Ordering: Towards the Optimal by Learning, arxiv prepring.

[8] H. Dai, E.B. Khalil, Y. Zhang, B. Dilkina, and L. Song. (2017). Learning combinatorial optimization algorithms over graphs. Neural Information Processing Systems.

[9] I. Safro. (2015) Multiresolution methods for large-scale learning. Tutorial in Neural Information Processing Systems.

[10] B. Perozzi, R. Al-Rfou, and S. Skiena. (2014). DeepWalk: Online learning of social representations. ACM International Conference on Knowledge and Data Discovery.

[11] A. Grover and J. Leskovec. (2016). node2vec: Scalable feature learning for networks. ACM International Conference on Knowledge and Data Discovery.

[12] A.Y. Ng, M.I. Jordan, and Y. Weiss. (2001). On spectral clustering: analysis and an algorithm. Neural Information Processing Systems.

[13] C.D. Hofer, F. Graf, B. Rieck, M. Niethammer, and R. Kwitt, (2019) Graph filtration learning. arxiv preprint.

[14] J. Petit. (2003) Combining spectral sequencing and parallel simulated annealing for the MinLA Problem. Parallel Processing Letters.

[15] I. Safro, D. Ron, and A. Brandt. (2008). Multilevel algorithms for linear ordering problems. ACM Journal of Experimental Algorithmics.

[16] J. Dıaz, J. Petit, and M. Serna. (2002). A survey of graph layout problems. ACM Computing Surveys.

[17] E. Rodriguez-Tello, J.-K. Hao, and J. Torres-Jimenez. (2008). An effective two-stage simulated annealing algorithm for the minimum linear arrangement problem. Computers & Operations Research.

[18] N. Tatti. (2019). Density-friendly graph decomposition. ACM Transactions on Knowledge Discovery from Data.

[19] A. Iravanizad, E.I.S Medina, M. Stoll. (2021) RaWaNet: Enriching Graph Neural Network Input via Random Walks on Graphs. arxiv prepring.