PhD Projects
Advanced Reasoning Research Group

1. Granular computing for explainable and interpretable knowledge modelling
2. Digital twin-based functional imagination
3. Principled Application of Evolutionary Algorithms
4. Anytime Analysis for Dynamic Optimisation Problems

Title

Granular computing for explainable and interpretable knowledge modelling

Supervisors

- Richard Jensen (rkj), Neil Mac Parthalain (ncm)

Abstract

The rise of important initiatives such as Explainable AI, has placed increased focus on the accountability and human understanding of data and knowledge modelling techniques. Such initiatives focus upon sub-symbolic techniques with the aim of attempting to create some form of mechanism or framework which can be applied that makes them interpretable in some way. Granular computing (GrC) is a recent paradigm that is concerned with the processing of complex but interpretable information entities called information granules and has been applied extensively to problems such as data pre-processing and analysis and real-world problems such as human decision support and health informatics. The information granules emerge from the processes of abstraction and knowledge modelling of information or data. From a general perspective, such information granules are collections of entities that are usually formed at an atomic or numeric level and are arranged together based upon a form of relatedness or topological adjacency. This means that such modelling techniques are already explainable and interpretable using the concepts a human would use and do not require an additional framework. This project focuses upon proposing new models of hybrid granular computing techniques and extending them to the areas of semi-supervised, and unsupervised learning, both of which are emerging areas in knowledge modelling domains due to the prevalence of unlabelled or partially labelled data. The project will include the development of novel formal approaches to facilitate the analysis as well as the development of new hybrid granular techniques using robust theoretical foundations. Collaboration with other disciplines and industrial partners will assist in supporting recent efforts to link the theoretical contributions and applications in this area.

Title
Digital twin-based functional imagination

Supervisor
- David Jones (dej35)

Abstract
The processes of simulation, modelling, and optimisation are virtual processes used in manufacturing systems to improve performance. These analyse input states of a system in a bid to maximise the output performance. While there are a range of tried and tested approaches to simulation, modelling, and optimisation, as a field of research there are continued efforts to make improvements – it is an on-going research challenge with direct industrial application. In parallel to these research efforts, the new paradigm of the digital twin has attracted growing interest from academia and industry [1]. Digital twins are high-fidelity virtual representations of the physical system and its environment, enabled through internet-of-things sensors that capture physical states and update the states of the virtual models such that the two remain synchronised. The paradigm of the digital twin is pitched to deliver the next generation of manufacturing systems, with simulation, modelling, and optimisation forming a cornerstone [1].

With the research and development of digital twins comes the opportunity to experiment with virtual processes that have yet to be applied to manufacturing systems. Virtual processes that, when coupled with the digital twin, may address limitations in current approaches [2]. This PhD project is aimed at the research and development of one such virtual process: functional imagination. Functional imagination is a method of simulation and modelling stemming from the scientific field of artificial cognitive systems: a field of research concerned with recreating the capabilities of the human mind. Marques et al. [3] states that systems capable of functional imagination must be able to 1) represent alternative sensory states; 2) predict future sensory states; 3) execute actions/behaviours to achieve goals; 4) evaluate actions/behaviours against goals; and 5) select actions/behaviours against goals. This project is aimed at developing and integrating the software architectures required to integrate functional imagination and the capabilities outlined by Marques et al., within the digital twin in order to evaluate the merits of such an approach against traditional methods.

[1] Jones, D., Snider, C., Nassehi, A., Yon, J., & Hicks, B. (2020). Characterising the Digital Twin: A systematic literature review. CIRP Journal of Manufacturing Science and Technology, 29, 36-52.
[2] Jones, D. (2021). Artificial cognitive systems: the next generation of the digital twin. An opinion. Digital Twin, 1(3), 3.
[3] Marques, H. G., & Holland, O. (2009). Architectures for functional imagination. Neurocomputing, 72(4-6), 743-759.

Title
Principled Application of Evolutionary Algorithms

Supervisors
- Christine Zarges (chz8), Thomas Jansen (thj10)

Abstract
Evolutionary algorithms are general and robust problem solvers that are inspired by the concept of natural evolution. Over the last decades, they have successfully been applied to a wide range of optimisation and learning tasks in real-world applications. Recently, some researchers [1,2] argue that evolutionary computation now has the potential to become more powerful than deep learning: While deep learning focuses on models of existing knowledge, evolutionary computation has the additional ability to discover new knowledge by creating novel and sometimes even surprising solutions through massive exploration of the search space.

While evolutionary computation methods are often easy to implement and apply, to achieve good performance, it is usually necessary to adjust them to the problem at hand. The main goal of this project is to exploit recent theoretical advances that shed light on the fundamental working principles of evolutionary algorithms [3] in real-world applications. It will build upon recent momentum and progress in both, theory and applications of evolutionary algorithms and related randomised search heuristics and further contribute to bridging the gap between these two branches of evolutionary computation research [4]. Starting point for the investigations will be modern benchmarking frameworks, e.g., [5,6], and competitions that tackle important societal and industrial challenges, see [7,8] for examples. Possible application areas can be discussed with the supervisors. They include but are not limited to routing, scheduling, and planning problems, bioinformatics, as well as benchmarking and combinatorial optimisation in general.

[1] Neural Networks Research Group at the University of Texas at Austin. Evolution is the new deep learning. http://nn.cs.utexas.edu/pages/evolutionary-ai/newdeeplearning/
[2] Risto Miikkulainen. https://venturebeat.com/2018/05/17/evolutionary-computation-will-drive-the-future-of-creative-ai/
[3] Benjamin Doerr, Frank Neumann (eds). Theory of Evolutionary Computation - Recent Developments in Discrete Optimization. Springer, 2020. http://doi.org/10.1007/978-3-030-29414-4
[4] COST ACTION CA15140: http://imappnio.dcs.aber.ac.uk
[5] IOH Profiler. https://iohprofiler.github.io
[6] Nevergrad. https://facebookresearch.github.io/nevergrad/
[7] ACM GECCO 2021 Competitions. https://gecco-2021.sigevo.org/Competitions
[8] IEEE CEC 2021 Competitions. https://cec2021.mini.pw.edu.pl/en/program/competitions

More information
https://www.findaphd.com/phds/project/principled-application-of-evolutionary-algorithms/?p138605

Title
Anytime Analysis for Dynamic Optimisation Problems

Supervisors
- Thomas Jansen (thj10), Christine Zarges (chz8)

Abstract
Many optimisation problems are too difficult to be solved efficiently by standard algorithms. Heuristic optimisation methods like evolutionary algorithms or simulated annealing are frequently applied in these situations. The theory of these heuristics still puts an emphasis on runtime analysis and is at odds with the way these heuristics are actually applied. This project addresses this gap by concentrating on anytime analysis targeting dynamic problems that change over time.

Building on existing anytime analysis results (sometimes also called fixed budget results [2]) as well as recent results from fixed target analysis [1], the project performs a systematic study of dynamic optimisation. The starting point are simple static unimodal and multimodal benchmarks [3] and simple different tools to construct dynamic optimisation problems from static ones. Starting from simple heuristics like random sampling and local search the tools and methods are developed to compare these baseline methods with more advanced methods, employing populations, crossover, and different approaches to deal with dynamic optimisation problems like hall of fame approaches or diploidy.

[1] M. Buzdalov, B. Doerr, C. Doerr, and D. Vinokurov (2020): Fixed-target runtime analysis. In Proceedings of the 2020 Genetic and Evolutionary Computation Conference (GECCO 2020), ACM Press, pages 1295-1303. https://doi.org/10.1145/3377930.3390184
[2] T. Jansen (2018): Analysing stochastic search heuristics operating on a fixed budget. In B. Doerr, F. Neumann (Eds.): Theory of Evolutionary Computation - Recent Advances. Springer, pages 249-270. https://doi.org/10.1007/978-3-030-29414-4_5
[3] T. Jansen and C. Zarges (2016): Example landscapes to support analysis of multimodal optimisation. In Proceedings of the 14th International Conference on Parallel Problem Solving From Nature (PPSN XIV). Springer, LNCS 9921, pages 792-802. https://doi.org/10.1007/978-3-319-45823-6_74

More information
https://www.findaphd.com/phds/project/anytime-analysis-for-dynamic-optimisation-problems/?p138617