ERCIM "ALAIN BENSOUSSAN" FELLOWSHIP PROGRAMME

Scientific Report

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Nationality	Italian
Name of the *Host Organisation*	Fraunhofer SCAI
First Name / family name of the *Scientific Coordinator*	Jochen Garcke
Period of the fellowship	01/11/2020 to 31/10/2022

I – SCIENTIFIC ACTIVITY DURING YOUR FELLOWSHIP

Summary of Initial Research Programme

The Fellow conducted his activities in the context of the project EVOLOPRO – Evolutionary Self-adaptation of Complex Production Process and Products, with the goal of using concepts from biology, evolutionary computation, and machine learning, to design flexible production processes, that is, to make production systems able to adapt to new conditions instead of having to design a new procedure every time the conditions change. Other institutes involved would be responsible for the production problems and simulations, and SCAI for the algorithmic aspect. The work developed consisted, first, of participating in the development of a framework for flexibility and the research for elements that enable flexibility in nature. Then, a first use case considered a benchmark control problem from the literature for demonstrating this framework, and a second use case involving an analytical model for an orthogonal cutting process was prepared fur further investigation. These three developments are summarized below.

Flexibility Framework and Elements of Flexibility

The flexibility framework developed during the project has two goals: 1) provide a unified language over different domains, such as transfer learning, dynamic optimization, and engineering, and 2) provide a structure way to study flexibility in task-performing systems. It is composed of a notion of *task*, that can be varied to form a *task context*, and a *task-performing system* that will learn how to solve the task. A *flexibility measure* is used to determine how well the given system adapts to solving new tasks given that it has learned how to solve previous tasks. A high-level overview of this notions is given in Figure 1.

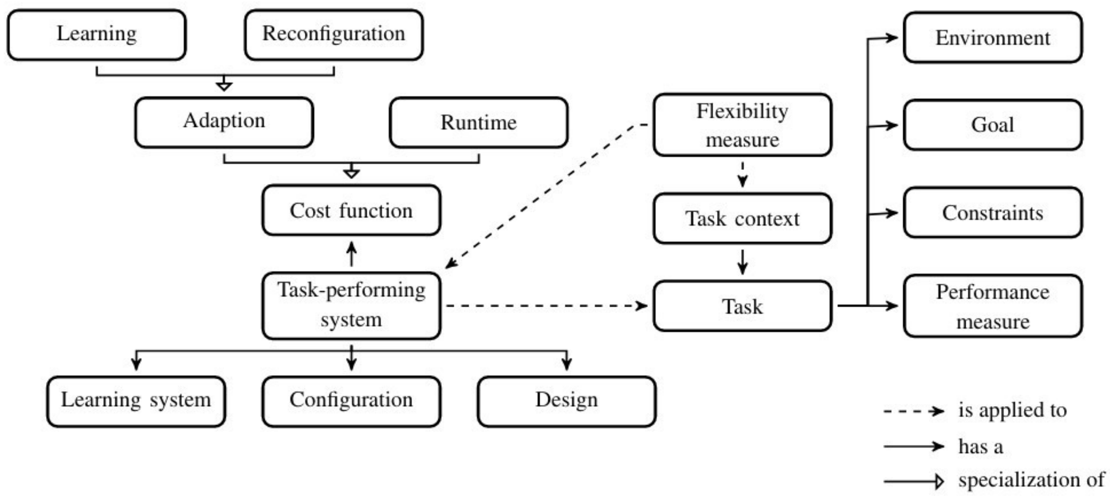

Figure 1: *High-level overview of flexibility framework (from [5]).*

Additionally, we have also conducted a systematic literature review to identify six recurring properties present in many levels of biological systems and that are responsible for their high flexibility. We call these the *elements of flexibility*: hierarchy, modularity, weak regulatory linkage, exploration, degeneracy, and weak links. We also investigated how some of these elements are already used in technical systems and how they could be further incorporated. A detailed description of the framework and the elements of flexibility is found in [5].

Use Case I – Pole Balancing

The pole balancing problem is a well known control theory and reinforcement learning benchmark where an agent has to learn to balance a cart with a pole attached to it without letting the cart or the poles move out of a pre-specified range. For demonstrating the framework on this problem, we took the standard problem with one pole and created a task-context by varying the pole length. We have then used a Genetic Algorithm (GA) to learn the weights of a controller for each task, stored the final population learned, and used it as the starting point for each other task, thus performing a systematic study of how well the GA adapts given pairs of tasks with different degrees of similarity. Additionally, we also considered GA variants that promote structural and behavioural diversity in the population of solutions, thus addressing the elements of exploration and degeneracy. Structural diversity refers to solutions that perform equally well but have different weights, while behavioural diversity refers to different behaviours explicitly.

We have concluded that adapting a solution can significantly reduce the learning cost, and promoting diverse populations also have the potential to reduce the adaptation cost, although behavioural diversity was not suited for this specific problem. Detailed results are found in [3].

Use Case II - FlexBench

After demonstrating the framework in a simple use-case, we prepared together with Frauhofer IWM a second use case based on an analytical model of an orthogonal cutting process. This task consists of removing a certain amount of material using a cutting head, and different tasks can be generated by varying the material parameters. The system consists of the cutting head and some process parameters (cutting speed, angle, width, depth) that should be learned by an optimizer. As the analytical model is quick compared to a more costly simulation, this should enable us to experiment with different methods and elements of flexibility, that should be afterwards validated on more complex models.

At the same time, we want to implement an API that defines the structure of a flexibility experiment and that allows for the easy integration of benchmarks of different domains by following a given interface. This second use-case will be further investigated in the next months.

II – PUBLICATION(S) DURING YOUR FELLOWSHIP

[1] Sotto, L. F. D. P., Kaufmann, P., Atkinson, T., Kalkreuth, R., Basgalupp, M. Graph representations in genetic programming. Genetic Programming and Evolvable Machines, 22, 607–636, 2021. https://doi.org/10.1007/s10710-021-09413-9

[2] Sotto, L. F. D. P., Rothlauf, F., de Melo, V. V., Basgalupp, M. P. An Analysis of the Influence of Non-effective Instructions in Linear Genetic Programming. Evolutionary Computation, 30, 51–74, 2022. https://doi.org/10.1162/evco_a_00296

[3] Sotto, L. F. D. P., Mayer, S., Garcke, J. The pole balancing problem from the viewpoint of system flexibility. Proceedings of the Genetic and Evolutionary Computation Conference (GECCO), Boston, 2022, 427–430. https://doi.org/10.1145/3520304.3529040

[4] Kalkreuth, R., Sotto, L., Vašíček, Z. Graph-based genetic programming. Proceedings of the Genetic and Evolutionary Computation Conference (GECCO), Boston, 2022. https://doi.org/10.1145/3520304.3533657

[5] Mayer, S., Sotto, L. F. D. P., Garcke, J. The elements of flexibility for task-performing systems. Arxive Preprint, 2022, Submitted to IEEE Access. https://doi.org/10.48550/arxiv.2206.00582

III – ATTENDED SEMINARS, WORKHOPS, CONFERENCES

Genetic and Evolutionary Computation Conference, 2022, Boston, USA.

IV – RESEARCH EXCHANGE PROGRAMME (REP)

Identification: Inria Nancy, Research Group Larsen, Nancy, France.
Local Scientific Coordinator: Dr. Jean-Baptiste Mouret.
Dates: 17th of October (Monday) to 21st of October (Friday)

The exchange with the research group in the host organization took place during an online meeting. In this meeting, the Fellow presented an overview of the project he has been working on during the Fellowship and the use cases considered, as discussed in Part I of this report. The research group from Dr. Jean-Baptiste at Inria has a leading role in the field of Quality-Diversity algorithms, which are one of the methods we are interested at for enhancing the flexibility of task-performing systems. We have discussed some works in the field and how we could integrate and experiment with that in our research. As this exchange was done at the end of the Fellowship period, it did not result in any concrete collaboration yet, but possibilities for that have been discussed and can be further pursued in the future.