Towards realistic task and capability descriptions in self-organizing production systems

Martin Neumayer
Institute for Software & Systems Engineering
University of Augsburg
Augsburg, Germany
neumayer@isse.de

***Abstract*—Modern production systems are facing rapidly changing requirements due to personalized products, smaller lot sizes, and shorter time to market. Bio-inspired processes, especially self-organization, provide inspiration on how to achieve the required flexibility. Self-organizing systems achieve flexibility by autonomously monitoring themselves and their environment and adapting to changes observed. Therefore, approaches promising self-organization have received great attention in the research community. Despite the promising characteristics of self-organizing production systems, uptake in industry is small. This paper presents unrealistic task and capability descriptions as an impediment for further adoption and identifies areas of contribution. Furthermore, we outline a research agenda and methodology to address the problem. Finally, the expected results are discussed.**

***Index Terms*—Self-organisation, Production systems, Autonomous systems**

I. Motivation

Mass production systems are designed to produce one product in high quantities which allows for low prices. Yet, mass production systems do not offer the flexibility to easily change the type of product manufactured. As customers begin to look for a greater variety of products, manufacturers offer standard products with several options. Combining different options results in a customized product. This process is termed mass customization [1].

The latest trend of personalized production imposes even higher requirements in terms of flexibility: Instead of choosing from a list of options, customers now play an active role in the creation of the product they want to purchase [1]. After an initial phase where the manufacturer chooses a product architecture, customers tailor the product to their needs in the personalized design phase [1]. The resulting product might be unique, nevertheless, customers still expect the price of a mass-produced good. Flexible automation is required to meet these goals.

Inspiration for the required flexibility can be found in nature: Social insects, e.g., can adapt to changes in their environment without central control, while maintaining huge populations [2]. Therefore, the idea of using bio-inspired algorithms in technical domains is widespread in research [3]. In the domain of manufacturing, especially approaches promising self-organization have received great attention. Serugendo describes self-organization as a process or mechanism, allowing systems to change their organization at runtime without external control [4]. With the ability to adapt their organization, self-organizing production systems offer flexibility in terms of the product manufactured.

Despite these promising characteristics of self-organizing production systems, uptake in industry has been slow [5], [6]. While other authors discuss the absence of clear definitions for autonomy and self-organization [5] or higher investment as barriers for widespread acceptance [6], this paper addresses unrealistic task and capability descriptions as an impediment for further adoption.

II. Background

Before explaining the problem of unrealistic task descriptions in greater detail, we introduce the basic terms used throughout this paper. Based on previous work [7], [8], we consider autonomous systems containing *products* and *agents* transporting, or processing those products. Agents transporting products are also referred to as *autonomous guided vehicles* (AGVs). Processing agents offer several *capabilities* to process a product. The blueprint on how to manufacture a product is termed *task*. We mainly study the effects of the task and capability description on the following two problems:

Task allocation The problem of task allocation [9] is concerned with the question of which agent will apply which capability to a product. We can also think of the problem as matching required capabilities for a task to offered capabilities of available processing agents.

Product routing The problem of dynamic product routing is concerned with connecting the processing agents for a given task through AGVs. Colloquially, we can imagine this as finding a valid way through production.

III. Contribution

We plan to contribute to the following areas:

a) Realistic task description: Several publications describe a task as an ordered sequence of capabilities that are executed one after another, altering one particular product [8], [10], [11]. A visualization of this so-called sequential task is presented in Fig. 1a: A workpiece has to be sawn, drilled, and then assembled. Yet, this model of a task can only describe a part of the processes found in practice.

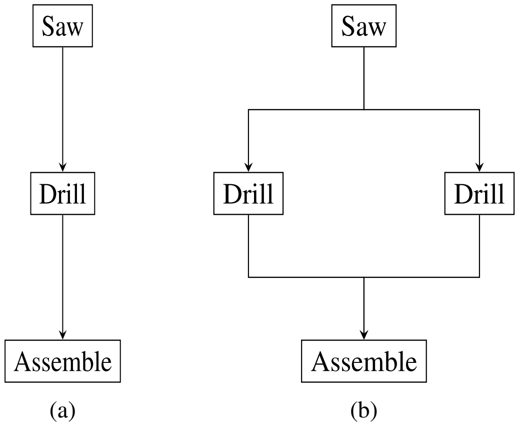

Fig. 1: Visualization of different task structures following Keddis et al. [13]: (a) Sequential task, (b) fork and synchronization task

In the furniture industry, for example, wooden panels are sawn into several workpieces, which are then machined individually [12]. Later the workpieces are assembled to make up the final product. Keddis et al. [13] reference these structures as fork and synchronization (Fig. 1b). Additionally, there are cases where capabilities can be replaced by other capabilities (selective tasks) or executed in arbitrary order [13]. Hence, one key aspect of the proposed project is to develop new methods to model tasks more realistically, supporting the structures mentioned.

b) Data structures for realistic capability description: Furthermore, a more detailed description of capabilities is required, e.g., stating that an agent can perform the capability 'drill' does not satisfy the need for practical application. More information describing the material, geometry, and process is required [13]. A description of the materials is needed to determine whether an agent is capable of performing the required capability: An agent might be able to drill a piece of wood, while it might not be able to drill a piece of metal. Specific grippers or fixtures can add constraints to the products an agent can handle. Therefore, a description of the product's geometry is needed to check whether an agent can handle a product. Lastly, process-related information is required. In our drilling example, the agent needs to know the position, depth, and diameter of the hole. Process-related information should also contain auxiliary materials, such as screws, if necessary. Depending on the process, process-related information can take different forms, thus flexible data structures are essential.

c) Generating task descriptions: Manually creating task descriptions could become a tedious and error-prone exercise, as the number of capabilities and the data needed to describe a capability increase. This poses a further challenge: Generating task descriptions from user input, such as 3D models. Literature provides some exciting approaches, e.g., Lau et al. split 3D models of furniture into parts and connectors using formal grammars [14]. However, this challenge will be covered in future work.

IV. Methodology

a) Implementation of task allocation and product routing: Implementing realistic task and capability descriptions is the first key part of this project. Afterward, we'll extend the existing Constraint Satisfaction Problem (CSP) for task allocation and product routing to fit the newly implemented descriptions. Thus, the implementation from previous research, written in Minizinc [15], will be extended. Realistic capability descriptions will add new constraints to the problem of task allocation, e.g., instead of searching for an agent with the capability 'drill', we are now searching for an agent able to drill a piece of wood with a given geometry and diameter.

b) Measuring the effects: Additional data and constraints will add complexity to the CSP. Besides, allowing replacing and arbitrary order of capabilities in the task description might render the problem of task allocation more difficult, as the search space enlarges. Therefore, we expect the problem of task allocation to turn out as more complex with realistic task and capability descriptions. Rising complexity might negatively influence runtime and even render the corresponding CSP unsolvable within a reasonable amount of time. Yet, these effects have to be measured and evaluated.

c) Comparing different approaches: Measuring the runtime allows a comparison between different approaches. Besides formulating the problems of task allocation and product routing as a CSP, other researchers devised a variety of methods to solve similar problems such as the Flexible Job Shop Scheduling Problem (FJSP) [16] or the Job Shop Scheduling Problem with Transportation resources (JSPT). Chaudhry and Khan point out that most researchers devised evolutionary algorithms, tabu search, or hybrid methods for solving the FJSP [16], yet advice for the selection of a particular method is lacking. Hence, we plan to conduct comparative studies that will help to decide which approach is best suited for a specified use case. The comparisons will cover the runtime and solution quality for every approach. Therefore, it can act as a guideline for practitioners confronted with a similar problem.

V. Conclusion

In this paper, we present unrealistic task and capability descriptions as a research problem for self-organizing production systems. As a resolution, we suggest implementing more realistic task descriptions, including structures such as selective tasks, forks, and synchronizations. Furthermore, capability descriptions must become more comprehensive and encompass material-, geometry-, and process-related information. The effects of elaborating task and capability descriptions on the problems of task allocation and product routing have to be studied. Comparing different approaches can guide practitioners when choosing an approach for a particular use case. Finally, further research has to be directed to generating task descriptions from user input automatically, as manually creating task descriptions becomes increasingly complex and error-prone.

REFERENCES

[1] Y. Koren, *The global manufacturing revolution: product-process-business integration and reconfigurable systems*. John Wiley & Sons, 2010.

[2] E. Bonabeau, G. Theraulaz, J.-L. Deneubourg, S. Aron, and S. Camazine, "Self-organization in social insects," *Trends in ecology & evolution*, vol. 12, no. 5, pp. 188–193, 1997.

[3] P. Leitão, J. Barbosa, and D. Trentesaux, "Bio-inspired multi-agent systems for reconfigurable manufacturing systems," *Engineering Applications of Artificial Intelligence*, vol. 25, no. 5, pp. 934–944, 2012.

[4] G. Di Marzo Serugendo, M.-P. Gleizes, and A. Karageorgos, "Self-organization in multi-agent systems," *Knowledge Engineering Review*, vol. 20, no. 2, pp. 165–189, 2005.

[5] P. Leitão, "Self-organization in manufacturing systems: Challenges and opportunities," in *2008 Second IEEE International Conference on Self-Adaptive and Self-Organizing Systems Workshops*. IEEE, 2008, pp. 174–179.

[6] D. Sanderson, J. C. Chaplin, L. De Silva, P. Holmes, and S. Ratchev, "Smart manufacturing and reconfigurable technologies: Towards an integrated environment for evolvable assembly systems," in *2016 IEEE 1st International Workshops on Foundations and Applications of Self* Systems (FAS*W)*, 2016, pp. 263–264.

[7] M. Güdemann, F. Ortmeier, and W. Reif, "Formal modeling and verification of systems with self-x properties," in *Autonomic and Trusted Computing*, L. T. Yang, H. Jin, J. Ma, and T. Ungerer, Eds. Berlin, Heidelberg: Springer Berlin Heidelberg, 2006, pp. 38–47.

[8] F. Nafz, H. Seebach, J.-P. Steghöfer, G. Anders, and W. Reif, *Constraining Self-organisation Through Corridors of Correct Behaviour: The Restore Invariant Approach*. Basel: Springer Basel, 2011, pp. 79–93.

[9] Y. Chevaleyre, U. Endriss, J. Lang, P. Dunne, M. Lemaitre, N. Maudet, J. Padget, S. Phelps, J. Rodriguez-Aguilar, and P. Sousa, "Issues in multiagent resource allocation," *Informatica*, vol. 30, pp. 3–31, 2006.

[10] D. Trentesaux, C. Pach, A. Bekrar, Y. Sallez, T. Berger, T. Bonte, P. Leitão, and J. Barbosa, "Benchmarking flexible job-shop scheduling and control systems," *Control Engineering Practice*, vol. 21, no. 9, pp. 1204–1225, 2013.

[11] N. Zbib, C. Pach, Y. Sallez, and D. Trentesaux, "Heterarchical production control in manufacturing systems using the potential fields concept," *Journal of Intelligent Manufacturing*, vol. 23, no. 5, pp. 1649–1670, 2012.

[12] K. Y. Tippayawong and T. Prapasirisulee, "Productivity enhancement in a wood furniture manufacturing factory by improving work procedures and plant layout," *Recent Advances in Manufacturing Engineering*, pp. 30–34, 2011.

[13] N. Keddis, G. Kainz, A. Zoitl, and A. Knoll, "Modeling production workflows in a mass customization era," in *2015 IEEE International Conference on Industrial Technology (ICIT)*. IEEE, 2015, pp. 1901–1906.

[14] M. Lau, A. Ohgawara, J. Mitani, and T. Igarashi, "Converting 3d furniture models to fabricatable parts and connectors," *ACM Trans. Graph.*, vol. 30, no. 4, Jul. 2011.

[15] N. Nethercote, P. J. Stuckey, R. Becket, S. Brand, G. J. Duck, and G. Tack, "Minizinc: Towards a standard cp modelling language," in *International Conference on Principles and Practice of Constraint Programming*. Springer, 2007, pp. 529–543.

[16] I. A. Chaudhry and A. A. Khan, "A research survey: review of flexible job shop scheduling techniques," *International Transactions in Operational Research*, vol. 23, no. 3, pp. 551–591, 2016.