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Using an Auction-based System in Cloud Manufacturing for Selecting Manufacturing-as-a-Service Providers

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Abstract. The shift towards mass customization in production and technological advancements lead to new manufacturing paradigms. Such paradigms facilitate the distribution of production to distributed companies, located all around the globe, essentially creating a cloud-based manufacturing platform. In such a system, manufactures may provide their production facilities as services to others – leading to the paradigm of Manufacturing-as-a-Service (MaaS). One major challenge in MaaS is the discovery of manufacturing resources and the distribution of orders to them. We propose an ontology based template matching method to find fitting manufacturing resources. Based on this selection we introduce a multi agent-based auction system for distributing orders and production planning. To illustrate its practical applicability we integrated the proposed approach in an existing cloud manufacturing platform.

Keywords: Manufacturing-as-a-Service · Cloud Manufacturing · Ontologies · Auction-based Production Planning.

1 Introduction

The manufacturing industry has been subject to major changes in recent years as technological advancements are becoming increasingly versatile. The digitization of manufacturing processes elevated these processes from mere physical hardware components to complex Cyber Physical Systems (CPSs) manufacturing systems including pervasive mining of process data as well as IT supported production planning and control approaches.

The digitization of manufacturing enables the distribution of orders to multiple manufacturing facilities or even multiple manufacturers. From this approach, which is in contrast to conventional manufacturing systems, *Cloud Manufacturing (CMfg)* systems emerged. In these systems, production of a single order by a customer may potentially involve distributed manufacturers for each step in the manufacturing process. This is due to the increasing customizability [1] of products, which makes on-site production considering all variations difficult and, hence, the outsourcing of some production steps to third-party manufacturers

inevitable. Essentially, one manufacturer uses services of other manufacturers for producing goods – this is known as *Manufacturing-as-a-Service (MaaS)*.

In MaaS manufacturers register their offered manufacturing services at a central cloud platform, allowing other manufacturers to select them based on specific attributes and characteristics such as price or quality. This selection process typically involves manual steps, which can be more prone to error with the increasing number of available manufacturers. Furthermore, distributing workload, i.e., scheduling and production planning, in CMfg is still not solved [2], and most approaches are neither flexible nor can they be automated. To take full advantage of CMfg and MaaS, establishing an automated selection of manufacturing services, taking changing attributes such as price quota into account, is desirable.

In this context, we propose a novel approach for production planning for CMfg and MaaS platforms using an ontology-based template matching algorithm. Our approach allows the automatic extraction of fitting manufacturing services from a knowledge base given a set of required and preferred attributes. For the actual selection of a specific service, we propose using an auction-based approach, which takes constraints, e.g. maximum price, defined by the service providers as well as the customers into consideration. To this end, the overall manufacturing process is split into single manufacturing steps, which are handled individually, allowing for a more flexible distributing system.

The remainder of this paper is organized as follows: First, we provide background information on technologies to make the paper self-contained and give an overview of relevant literature. Second, we describe our proposed solution and its implementation. Building on this section we demonstrate our findings in a feasibility prototype. Finally, we conclude with a discussion and sketch future work.

2 State of the Art

There exists research covering a vast variety of topics regarding distributed manufacturing environments, such as CMfg. In particular, the use of semantic technologies for specifying tasks and the use of multi-agent systems for distributing workload, as the number of resources strongly impacts the complexity [3], have been a research topic for quite some time. Typically, a CMfg platform provides manufacturer services to its users [4] and in this field MASs have been used for service discovery [5] and also as an effective technology for solving issues in scheduling and distributing workload [3].

Bratukhin and Sauter [6] propose two strategies for increasing flexibility in distributed manufacturing systems based on decision-making algorithms. In one of their strategies they propose the utilization of agents for increasing flexibility in manufacturing systems. Ameri and Kulvatunyou [7] combine a reference ontology for supply chains with agents for connecting manufacturing suppliers in order to establish a supply chain for an order. Both approaches, in contrast to our approach, do not consider alternatives and, in particular, constraints of

customers when distributing workload. Furthermore, we divide larger processes into single manufacturing steps, which are individually handled and assigned by auctions, for creating a more flexible distribution approach.

Vogel-Heuser et al. [8] present a distributed production system utilizing CPPS and agents as a possible solution for increased flexibility and adaptability. Agents can also compete with each other to achieve the best outcome for themselves [9]. For example in [10] the authors propose a MAS, which is capable of scheduling multi-project instances via auction-based communication. In this decentralized approach of decision-making, project agents try to allocate resources, which are represented by resource agents, by bidding on free time slots in an auction held by an exchange agent. We partly build upon this work and utilize these techniques for selecting a single provider using auctions. However, we also further investigate the utilization of auctions for providing alternatives and, thus, enabling customers to select the best fitting results for their needs.

Semantic technologies, such as ontologies, are commonly used in combination with CMfg [11,12,13], e.g., to realize scheduling systems [14], and are a means for formally specifying tasks and systems. Obitko and Marik [15] use ontologies with MASs for addressing issues in heterogeneous systems. Kulvatunyo et al. [16] propose a framework to support design and manufacturing tasks in CMfg as well as the distribution of them. In [17] an upper ontology for distributed manufacturing is proposed. Other ontologies for CMfg are, for example, the ManuService ontology [18], the ontology described by Talhi et al. [19], and the multi dimensional information model for manufacturing capabilities [20]. Similarly, Jang et al. [21] use semantic manufacturing capability profiles for discovering manufacturing services. We build upon this previous work and utilize the knowledge representation in ontologies provided by an existing CMfg platform [22] for systematically extracting matching services for given orders and combine them with a MAS for distributing and scheduling workload.

Typically, work with MAS utilize well-established frameworks. One well-known framework is JADE [23], which uses the Foundation for Intelligent Physical Agents (FIPA) [24] standard for communication between agents. A more recent framework is SARL [25], which utilizes a statically typed programming language to create multi-agent systems. We base our implementation on SARL and integrate it with an existing CMfg platform.

3 Manufacturing Resource Selection

In this section we first sketch the data model needed for representing manufacturing resources and products, then we show how fitting resources can be selected given a set of characteristics and demonstrate how auctions may be used to determine service providers. Finally, we present an integration with an existing CMfg platform for demonstrating the practical applicability.

3.1 Representing Resources and Template Matching

Formalizing manufacturing resources and products is essential for a feasible implementation of a MaaS platform. Typically, this is accomplished via a knowledge base that provides flexible data structures. Using *templates* for parts of this data model, in our case manufacturing steps, allows matching against the knowledge base for an automatic selection of fitting service providers.

Our approach builds upon the knowledge representation used in the CMfg platform described in [22]. This platform consists of an upper ontology as well as specifically tailored ontologies. While the upper ontology provides shared concepts, the tailored ontologies focus on specific views on the domain of manufacturing, e.g., configuration of orders, the processes involved in producing an order, or the representation of manufacturing resources. For example, for the manufacturing resources ontology it is sufficient to view the concept *Product* as a single entity, as specified in the upper ontology, while the process related ontology also includes information about the configuration provided by the customer. In this section we do not describe the full ontology but instead only some of the concepts pertinent to the work described in this paper. Figure 1 gives an overview of parts of the ontology concepts relevant to this work.

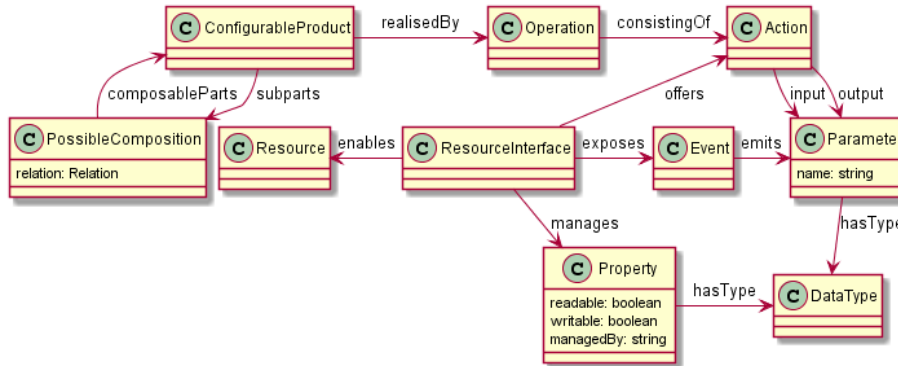


Fig. 1. Simplified classes from the ontology, used in the auction system

Before a product can be manufactured it has to be configured in two ways. First its sub-parts, e.g. what type of bearing should be included, and second, which *Operation* is used to manufacture a specific part, needs configuration. In this paper we specifically address the automation of the second configuration, i.e., assigning specific manufacturing operations, and subsequently service providers, to sub-parts of a product. Technically speaking, each product is represented by an *ConfigurableProduct* in the knowledge base and each *Operation* describes possible sequences of *Actions* for manufacturing the product. In this context, each *Action* describes a single capability of a manufacturing resource. It is defined by its *inputs* and *outputs*, which consist of a *name* and a *type*.

Since both, the manufacturing service providers as well as the products use the same data model concepts, we can automatically derive a *template* for selecting resources. The generation of the template is based on an actual operation connected to a product, i.e., we generalize from a concrete instance to a generic representation. This template decouples the *Operations* from a specific product and enables the automated selection of fitting resources. The previous link between an operation and a product is now represented by the template, which serves as a placeholder, and therefore, it may be necessary to enrich it with additional metadata. Essentially, we identify service providers that may substitute the *Actions* specified in the *Action-* and *OrderTemplates*. Figure 2 illustrates the process of selecting eligible *Actions*, where the second action is eliminated as its structure is not fitting.

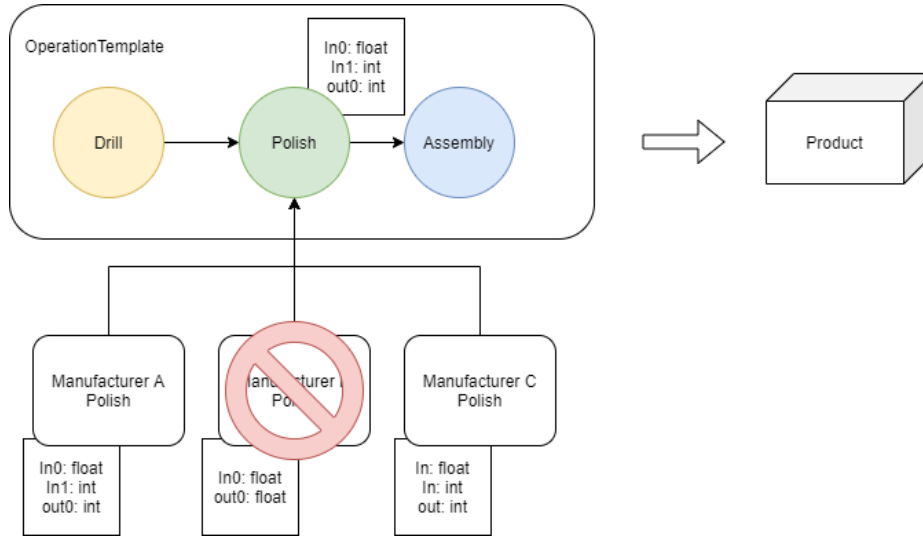


Fig. 2. Selecting fitting resources via template matching

We dynamically create these templates using SPARQL queries. Via this query we are able to filter all fitting structures from the knowledge base and, additionally, filter them by constraints, e.g., price. Each SPARQL query for an *Action-Template* is executed exactly once and returns a list of fitting manufacturing services. An abridged version of the query is shown in Listing 1.1.

Listing 1.1. General structure of a SPARQL-Query for *ActionTemplate* matching.

```

SELECT ?action WHERE {
  ?action rdf:type cidop:Action;
    cidop:input ?in0;
    ...
    cidop:input ?inN;
    cidop:output ?out0;
    ...
}

```

```

        cidop:output ?outN;
?in0 cidop:hasType cidop:integer;
      cidop:name "inputName0" .
      ...
?outN cidop:hasType cidop:string;
      cidop:name "outputNameN" .
}

```

3.2 Auction

To automate the resource selection process we propose using a multi-agent auction system, which includes constraints by customers, e.g., preferred price or due date, and manufacturers, e.g. lowest acceptable price. According to these constraints, the auction process identifies appropriate service providers for each individual *Action* of the product, i.e., an auction is held for each *ActionTemplate* in a given *OperationTemplate*.

From a technical perspective, the software agents of the auctioning process are implemented using the SARL framework. A central *AgentHandler*, which acts as a bridge between SARL and Java, starts the auction by forwarding customer preferences and bidder configurations of the manufacturer to the *SARLMainAgent*. The *SARLMainAgent* is responsible for spawning the *AuctionerAgents* that are needed for carrying out the auctioning process. Consequently, the *AuctionerAgents* spawn the *BidderAgents* each representing a provider for a viable *Action*, which then bid on the auction. Figure 3 illustrates the behavior of the auction system.

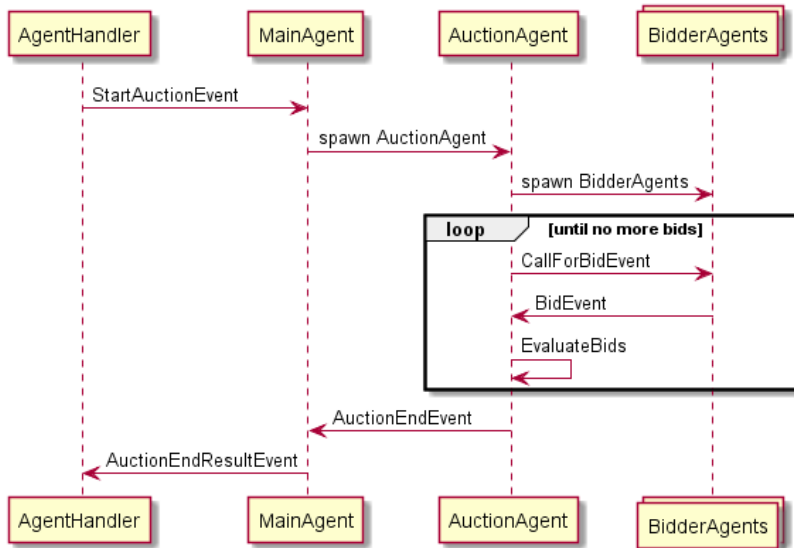


Fig. 3. Course of the auction process

SARL organizes agents in so-called *spaces*. *Spaces* determine which events an agent or any other object subscribed to the *space* may receive. The *MainAgent* exists in the *global space*, to which the *AgentHandler* is also subscribed to. *AuctioneerAgents*, spawned by the *MainAgent*, reside in the *inner context space* of the *MainAgent*. Subsequently, the *BidderAgents* spawned by the *AuctioneerAgents* reside in the *inner context space* of their respective *AuctioneerAgent*. By utilizing these *spaces*, the bid events sent out by the *BidderAgents* can only be received by the corresponding *AuctioneerAgent*, whereas the *AuctioneerAgents* direct their results to the *MainAgent* via an *AuctionEnd* event. Furthermore, *AuctioneerAgents* and their *BiddingAgents* are spawned in parallel to speed up the auctioning process.

In addition to customer preferences and the bidder configurations by the manufacturers, the auction process depends on the selected auction type, e.g. *English*, *Japanese*, or *Sealed*. After all auctions have been held for each *ActionTemplate* in an *OperationTemplate*, the results of these auctions, specific *Actions*, are aggregated to form a concrete *Operation*. Because a product may consist of multiple sub-products, and each sub-product may require an *Operation*, an aggregation on this level is necessary as well. The *ConfiguredProduct* is then finalized with the aggregated *Operations* and can be forwarded to the respective manufacturing scheduling services in the system. By performing auctions for all production steps of a product, the final order may consist of *Actions* of various manufacturers.

3.3 Integration

To apply the methods for template matching and for selecting the most applicable service provider for a production step, a reusable implementation is necessary. We have chosen to implement the auction and template matching functionalities as single (micro-)services with well-defined interfaces. This enables their reuse in different platforms and scenarios, such as CMfg. To show the practical applicability we integrated our presented services within the existing cloud platform described in [22], as it already utilizes OWL for its knowledge base and uses a (micro-)service infrastructure. Figure 4 gives an overview of its architecture.

Each service communicates via an event based communication system implemented in the cloud platform. As the auction and template matching functionalities are also implemented as services, the integration of them into the platform was trivial. We implemented our services using the Java programming languages and utilized SPARQL queries to perform the template matching against the knowledge base. The auctions themselves are implemented using SARL.

3.4 Discussion

While the system produces the optimal results according to the given parameters, e.g., asked price, work has to be done in order to balance the distribution of orders. For example, if the same manufacturing resource is constantly selected, some kind of penalty may be required for a fairer distribution of resources.

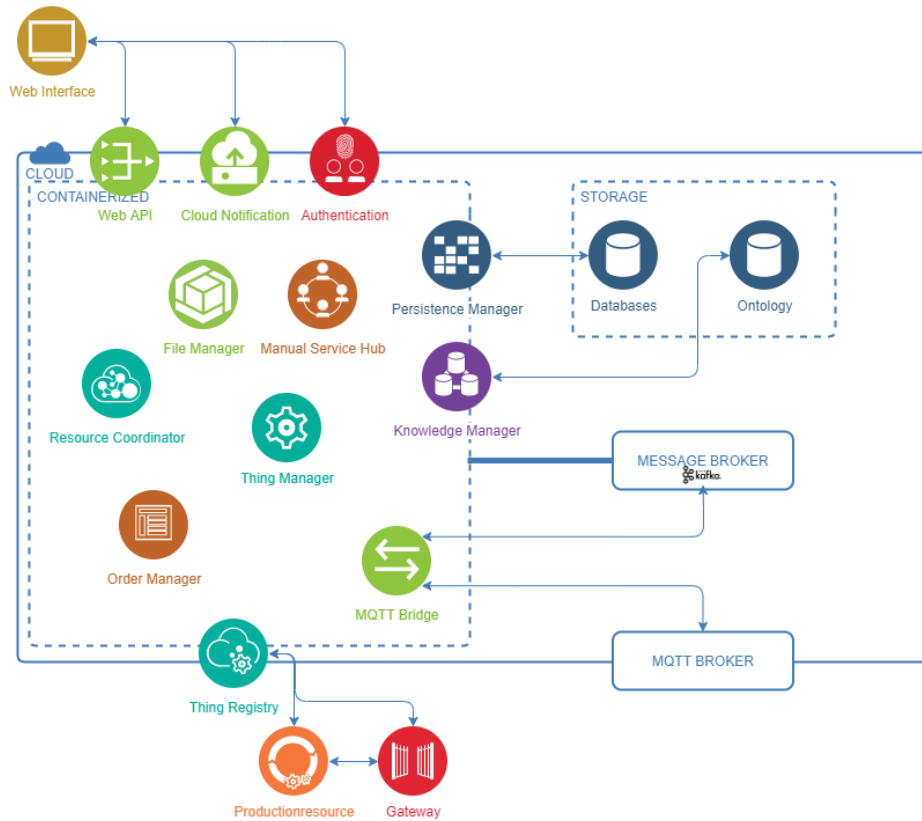


Fig. 4. Conceptual representation of the cloud platform

Consequently, manufacturers with fewer orders and slightly less preferable bids would have a chance to be involved in the production of a product.

The parameters for the auctions are currently fixed for each manufacturing resource. In future work we intend to request such quotas from each service on-demand, which enables the integration of time constraints based on the current workload of a service.

4 Conclusion

With the shift from *Mass Production* to *Mass Customization* the production of goods has to become more flexible. This can be achieved by distributing manufacturing not only to different production plants, but to different companies. A concept supporting the distribution of production is CMfg. In CMfg manufacturers can offer their production capabilities as services creating MaaS. For scheduling production orders in such an environment we use an auction-based

approach in combination with an automatic manufacturing service discovery via template matching in ontologies with SPARQL.

We created an auction system consisting of a standalone, coordinating service and multiple agents, where each agent represents a service provider participating in the auction. By doing so, we are able to balance customer needs and those of service providers and identify the optimal manufacturer. Furthermore, we can easily integrate additional requirements and support various types of auctions.

In conclusion, the combination of template matching and agent based auctions offers a dynamic and highly scalable approach to the problem of scheduling in a distributed manufacturing environment. Especially, for systems like CMfg this can be a viable solution, though, further work is required.

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