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A novel approach to define and solve the Container Terminals Problems

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***Abstract*—The logistic processes integrate various interdependent elements such as Vessel, Human resources, Vehicle etc. These elements inherently represent the actors, resources, and activities of a characterised process. A large variety of elements need to be managed to improve a logistics process. In this context, we propose the use of optimization methods.**

We develop a software framework that use the concepts of logistics and optimization to identify and specify the type of logistics problem and propose the optimal methods for their solution. The ontology definition may help to better understand the terminologies that may assist a logistic expert to specify his problem (using the logistics terms).

In this paper, we present a reasoning system, based on logistics ontology. The objective of this work has been to build the shared concepts of logistics and optimization to better specify the logistic processes. Which may further lead to identify the type of logistics problem and propose list of respective solution methods. Moreover, it may also propose the web-services (that implements the corresponding solution method) to execute the evaluated logistic data. In the current work, we consider the Container Terminal Problems for the pragmatic validation of our proposed approach.

***Keywords*—Container Terminal Problems, Logistic process improvement, Logistic ontology, Optimization, Reasoning System**

1. Introduction

The quality of evolving logistic processes tends to decline with increased complexity. The optimization method can help to better control the quality logistic processes [1].

In this regard, most of the research work in the literature is focused on ontology definition for the analysis of logistic processes, and the simulation and modeling perspectives [2]. Leukel specifies the logistics model as five process types such as plan, source, make, deliver, and return [3]. Kayikci defines an ontology to recognize similarity between many knowledge written in natural languages [4]. Hoxha discusses different functionalities involved in the logistics domain [5].

The current literature also defines some optimization ontology such as SoPT [6] and GOO [7]. The Simulation oPTimization (SoPT) includes many concepts from both traditional mathematical and the simulated optimization [6], otherwise, General Optimization Ontology (GOO) is focused on the global structure of optimization and defines the general concepts of optimization [7].

We focus on the Container Terminals Problems (CTP), it is observed that a large portion of the container terminal turnaround time is spent on discharging and loading containers for a ship, therefore the terminal management can present different types of optimization problems [8].

We propose a reasoning system to better assist the Logistic experts to identify and specify their transportation problems.

In this context, we define logistics and optimization ontologies. Later on, with the help of Description Logic and the concepts of Semantics Web, we further define the general concept of both logistics and optimization ontologies [9]. In the current paper, we extend the work presented in [1] to specify a particular logistic problem, the Container Transportation Problems (CTP), and find the appropriate methods for its solution using the reasoning system.

The rest of the paper is organized as follows: the section 2 discusses The Container Terminal Problem. The section 3 shows the architecture of reasoning system; it has two sub sections, where 3.1 specifies general concepts of logistic and also define the concepts of CTP and 3.2 shows the individuals of solution methods in optimization ontologies. The section 4 shows the implementation of our approach from the functional aspects. Finally, in the section 5, we present the results and the perspectives of the current work in order to conclude the content.

2. Container terminals problems

The container terminals may involve three crucial resources which are the yard, vessel berths and the vehicles. The main objective of port terminals is the efficient use of these resources while performing different operations. The yard is a temporary container warehouse where containers remain until transported to their next location by territorial transport (truck, train, or vessel). The containers are stacked on top of each other to use the yard space more efficiently [10].

However, the stacking crane can only directly access the containers at the top of the stack. In order to extract a container stored underneath, a reshuffling/shifting is essentially

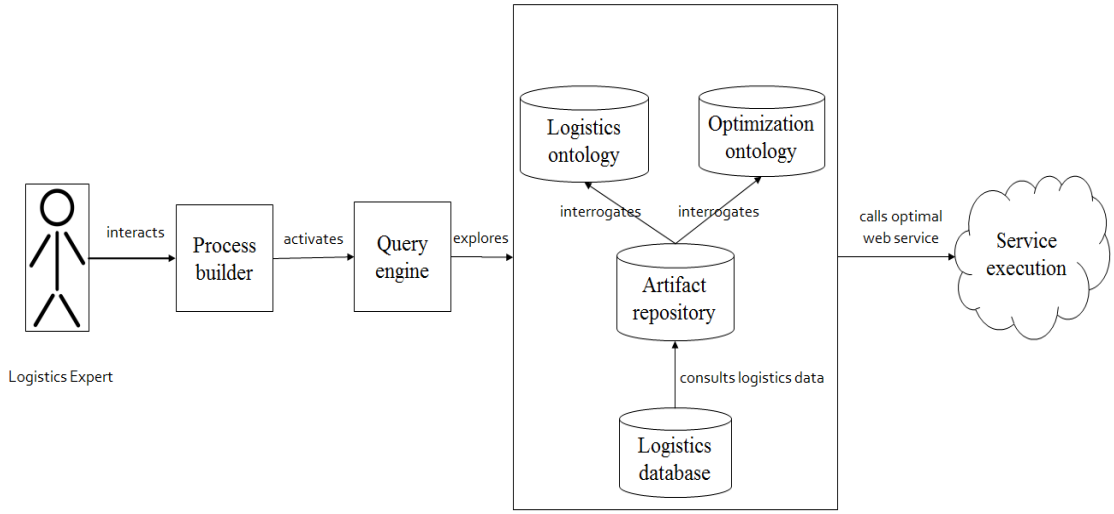

Figure 1. The global schema of reasoning system

required, which is generally considered as an unproductive move of containers.

In the current work, we focus on enhanced efficiency of the yard while considering the container stacking optimization problem for transshipment of inbound and outbound containers at a container terminal.

The objective of the problem is to minimize container retrieval time with minimum reshuffles. It may help to make the loading/unloading operations more efficient, and in turn minimize the dwell time of containers. The main inputs are the type, weight, discharge port/location, destined vessel/vehicle of the container, and the expected departure time.

There exists many optimization methods to solve the CTP and its variants. In the following, we discuss briefly some of the CTP variants and the methods to solve them:

The Container Reshuffling Problem (CRP) can be solved with the help of several methods such as proposed in [11] to use the genetic algorithms, also in [12] to use a heuristics method (considering the problem for export terminal), and in [13] to use the stochastic dynamic programming to find minimum reshuffling with departure time windows for import terminal. Alot of strategies are proposed for stacking policies considering the departure time as parameter to stock the container in yard [10].

The Berth and Quay Crane Allocation Problem (BQCAP) can be solved with the help of methods such as in [14], the authors propose the branch-and-price algorithm and in [15] using the dynamic deployment scenario.

The Appointment Time for External Trucks Problem(ATETP) can be solved using the methods such as in [16], the authors propose an integrated model that includes vehicle scheduling and container storage in Container Terminals, and in [17], the authors propose a stacking policy to solve the container stacking problem for departure container from terminal.

3. The architecture of reasoning system

We have been developing an ontology based reasoning system. The Fig. 1 shows its global architecture along with its major constituents which are process builder, query engine, the ontologies (Logistics and Optimization), artifact repository and their interaction with the Web services (intended to resolve the logistic problem).

A logistic expert can interact with the reasoning system through process builder. It instantiates the logistic processes with the definition of problem attributes. It allows, on one end, a logistic expert to interact with the system with the help of usable interfaces, and on the other end, to interact with query engine.

Therefore, we require to extract concepts from the ontologies and repository, also to compare the concepts specified by logistic expert with knowledge base. The query engine assists to extract knowledge from ontologies, it provides as well a mechanism to select an optimal web-service among the existing web-services available on Internet .

The Ontologies are specification of conceptualization. The Logistics Ontology presents the general concepts of logistics, and specific concepts and roles to identify logistics problems, and the Optimization Ontology presents general concepts of optimization domain, it also implicate the optimization problems and list the optimization methods.

The artefact's repository is used to store data needed to execute the reasoning such as the Resource Concepts and Resources Concept Paths, in respect to a particular Logistic Problem.

The web services component interacts with the communication software available on Internet to resolve a particular optimization problem.

3.1. Logistics ontologies for CTP

The essence of the logistics ontologies is to define the concepts of the logistics domain. It can be achieved by using semantic constructs like classes (or concepts) and the roles (relationships) that link these concepts. Finally the axioms can be derived using the defined classes and roles.

We define the top level of logistic ontology classes as: Process, Service, Resource, Performance, Activity, and Logistics Problem. These are later on extended into subsidiary classes as follows: Process has a sub-class which is the Logistic Process. Likewise, the Service has a sub-class which is Logistics Service and so on. Consequently, we define more than 70 concepts and 13 roles [1], [9].

In this paper, we focus on to extend logistic ontology to define the variants of CTP. Thus, we restrain our scope on the concepts, roles and axioms concerning this problem. We define some more concepts such as Container Transportation class which is a sub-class of Activity, Marine Container Transport is a sub-class of Logistics Process, and Container Terminal Problems (CTP) is a sub-class of Logistics Problems.

The Fig. 2 shows the roles that links the newly defined concepts such as *Get/Put Container in Vessel*,the *Get/Put Container in Yard*, and *useTruck* are sub-role of *useResource*. The *Get/Put Container in Vessel* connects *Container Transportation* and *Ship* classes. The *Get/Put Container in Yard* connects *Container Transportation* and*Warehouse*. Likewise, *useTruck* connects *Container Transportation* and *Vehicle* classes.

Similarly, *hasContainer* is sub-role of *has-a* role, it connects *Marine Container Transport* and *Container Transportation* classes and finally *hasObjectveFunction* connects *Marine Container Transport* and *Objective Function* classes.

We then define the axioms concerning each type of Container Terminal Problems, as following:

Axiom 1: The *Berth and Quay Crane Allocation Problem (BQCAP)* is a *Container Terminal Problem* produced by the *Marine Container Transport* process. The *Marine Container Transport* has some *Container Transportation* and an *Objective function* that is minimize loading time of the vessel (minLoadTime). Each *Container Transportation* uses a *Vehicle*. It has a *Warehouse* and an allocated *Ship*.

$$
\begin{aligned}
BQCAP \subseteq CTP \\
&\cap \exists producedby.(MarineContainerTransport \\
&\cap \exists hasContainer.(ContainerTransportation \\
&\cap \exists useTruck.Vehicle \\
&\cap \exists Get/PutContainerInYard.Warehouse \\
&\cap \exists Get/PutContainerInVessel.(Ship \\
&\cap isAllocationInBerth.true)) \\
&\cap \exists hasFuction.minLoadTime)
\end{aligned}
$$

Axiom 2: The *Container Re-shuffling Problem(CRP)* is a *Container Terminal Problem* produced by the *Marine Container Transport* process. The *Marine Container Transport* has some *Container Transportation* and an*Objective function* that is minimize the number of movements of container. Each *Container Transportation* uses a *Vehicle*, *Ship*, and *Warehouse* where the containers are arranged.

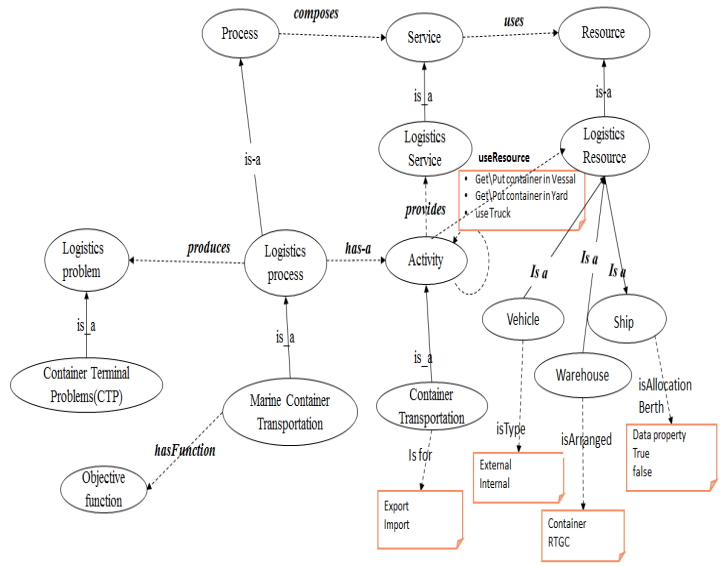

Figure 2. Top Level of logistics ontology For CTP

$$
\begin{aligned}
CRP \subseteq CTP \\
&\cap \exists producedby.(MarineContainerTransport \\
&\cap \exists hasContainer.(ContainerTransportation \\
&\cap \exists useTruck.Vehicle \\
&\cap \exists Get/PutContainerInYard.(Warehouse \\
&\cap isArranged.Container)) \\
&\cap \exists Get/PutContainerInVessel.Ship \\
&\cap \exists hasFuction.minReshufflingOfContainer)
\end{aligned}
$$

Axiom 3: The *Rubber Tyred Gantry Crane Problem(RTGCP)* is a *Container Terminal Problem* produced by the *Marine Container Transport* process. The *Marine Container Transport* has some *Container Transportation* and an *Objective function* that is to minimize the Vessel Wait Time and each *Container Transportation* uses a *Vehicle* ,*Ship*, and *Warehouse* where the Rubber Tyred Gantry Cranes (RTGC) are arranged.

$$
\begin{aligned}
RTGCP \subseteq CTP \\
&\cap \exists producedby.(MarineContainerTransport \\
&\cap \exists hasContainer.(ContainerTransportation \\
&\cap \exists useTruck.Vehicle \\
&\cap \exists Get/PutContainerInYard.(Warehouse \\
&\cap isArranged.RTGC)) \\
&\cap \exists Get/PutContainerInVessel.Ship \\
&\cap \exists hasFuction.minVesselWaitTime)
\end{aligned}
$$

Axiom 4: The *Scheduling and Routing Vehicle Problem(SRVP)* is a *Container Terminal Problem* produced by

the *Marine Container Transport* process. In this problem, the *Marine Container Transport* has some *Container Transportation* and an *Objective function* that is to minimize the wait time (QCandRTGC) for Quay Cranes (QC) and RTGCs. Each *Container Transportation* uses a *Ship* , *Warehouse*, and *Internal Vehicle*.

$$\begin{aligned} SRVP \subseteq\ & ContainerTerminalProblems(CTP) \\ & \cap \exists producedby.(MarineContainerTransport \\ & \cap \exists hasContainer.(ContainerTransportation \\ & \cap \exists useTruck.(Vehicle \cap isType.Internal)) \\ & \cap \exists Get/PutContainerInYard.Warehouse \\ & \cap \exists Get/PutContainerInVessel.Ship \\ & \cap \exists hasFuction.minWaitTime(QCandRTGC)) \end{aligned}$$

Axiom 5: The *Appointment Time for Extranal Trucks Problem(ATETP)* is a *Container Terminal Problems (CTP)* produced by the *Marine Container Transport* process. The *Marine Container Transport* has some *Container Transportation* and an *Objective function* that is to minimize the wait time for external trucks (minWaitExternalTrucks) and each *Container Transportation* uses a *Ship*, *Warehouse*, and *External Vehicle*.

$$\begin{aligned} ATETP \subseteq\ & CTP \\ & \cap \exists producedby.(MarineContainerTransport \\ & \cap \exists hasContainer.(ContainerTransportation \\ & \cap isFor.Import) \\ & \cap \exists useTruck.(Vehicle \cap isType.External)) \\ & \cap \exists Get/PutContainerInYard.Warehouse \\ & \cap \exists Get/PutContainerInVessel.Ship \\ & \cap \exists hasFuction.minWaitExternalTrucks \end{aligned}$$

3.2. Optimization ontology for CTP

The basic structure of optimization ontology specifies the general terminology of optimization. The top level includes the concepts like *Optimization Problem*, *Optimization Method*, *Logistics Optimization Problem*, and *Optimization Component*.

We define the relationships (or roles) among the concepts for example *isType* role between the *Logistics Optimization Problem* and *Optimization Problem*. The related complex concepts and axioms are defined in [1], [9]. One of the concerned axioms is as follows:

Axiom 6: A *Logistics Optimization Problem* is subset of *Optimization Problem*, it has many components and there exist an *Optimization Method* to solve it.

$$\begin{aligned} LogisticsOptimizationProblem \subseteq\ & OptimizationProblem \\ & \cap (\exists SolveBy.OptimaztionMethods) \\ & \cap \exists hasComponent.OptimizationComponent \end{aligned}$$

The Fig. 3 shows the core of Optimization Ontology. The Concepts (Classes), Relationship (Role) and Instances (Individuals) are prominent. It explains also some individual variant of CTP and their solution methods. There are two individual methods such as EX1 (Exact Method) and CRPGA1 (Genetic Algorithm) to solve the CRP problem.

4. Implementation

The reasoning system is implemented using Ontology Web Language (OWL), SPARQL, Java, and web services description language (WSDL).

The semantic web languages OWL is used to develop the ontology [18]. SPARQL queries to extract the knowledge [19]. Java and Jena API to interact between the logistics expert and ontologies, moreover, we use the WSDL to transfer data to web services.

The Reasoning System allows to incorporate a sequence of tasks for a logistics expert to better identify his problems. The SPARQL queries can be launched to find Logistics Resource Concepts (RCs) from logistics ontologies. The Fig. 4 shows a screenshot for a logistic expert to choose the relevant Logistics Resources (RCs), later on the reasoning system extracts Resources Concepts Paths (RCPs) depending on the chosen RCs. In this context, the system use the Depth-First-Search (DFS) because of the wider structure of inter-linked RCs. The Fig. 5 shows a scenario of the resulting RCPs, for the chosen RCs which are Vehicle, Warehouse, and Ship. Then the reasoning system automatically uses inter-linking Roles between RCs and the logistics problem to identify the RCPs.

Let us consider the example where it uses the Roles *useTruck*, *hasContainer*, and *Produces* to identify the CTP; The resulting RCP (RCP1) would be Vehicle ⇒Container Transportation ⇒ Marine Transportation and eventually the CTP.

Therefore the results of DFS for each RC are as follows :

- RCP1 and RCP2 for Vehicle
- RCP3 and RCP4 for Warehouse
- RCP5 for Ship

Hence, we can identify Similar Concept Path Groups(SCPGs) where each group can include one RCP for each Resource Concepts (RCs). For example SCPG1 contains RCP1, RCP3, and RCP5. It does not include RCP2 and RCP4. Conceptual Path Database (CPDB) can compare the SCPGs, eventually to find general type of logistics problem which in this case is CTP.

So, logistic expert must specify the attributes of the his problem. These attributes can identify the exact type of problem. For instance the general problem is CTP. Specifically it can have several variants (sub-types) such as BQCAP, CRP, RTGCP,SRVP, and ATETP. Each sub-type of the problem is different from the other, as explained in section 3.1. In the following we discuss some specific pragmatic differences:

- BQCAP has the value of the data property, allocation in berth, as true and the objective function is minimum load time for vessel

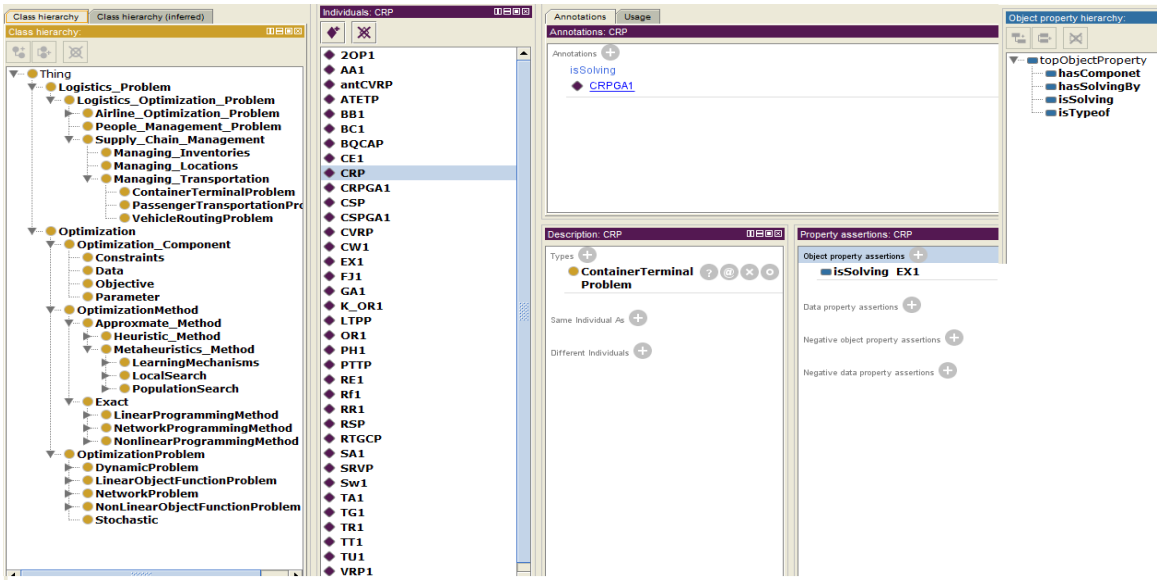

Figure 3. The Interface Shown the individuals of CTP in Optimization Ontology

Figure 4. The Interface identify the RCs in Reasoning System

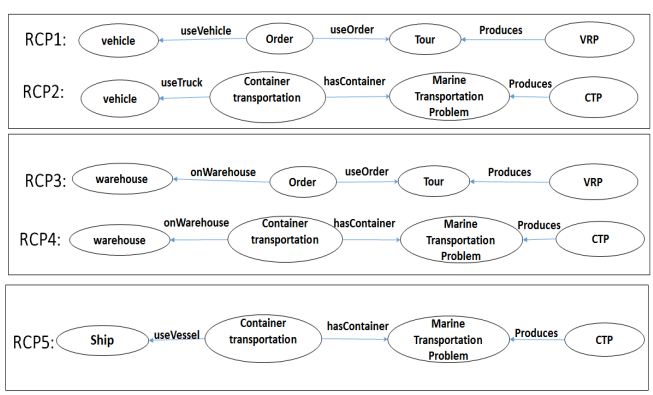

Figure 5. The Resource Concept Paths (RCPs)

- CRP has an attributes that the warehouse has arranged containers and the objective function is minimum reshuffling of container

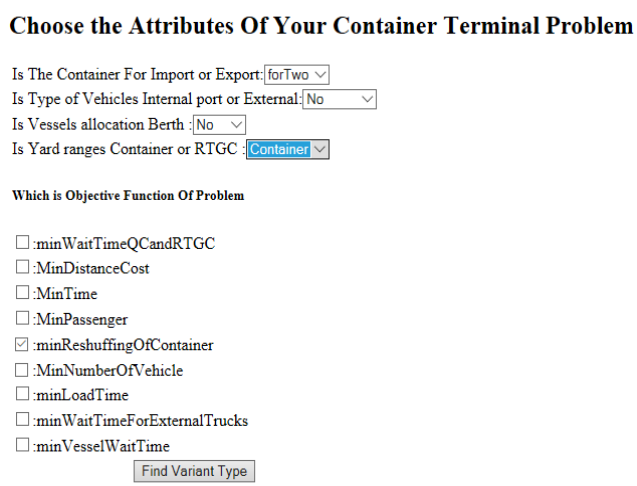

Figure 6. The Interface identify type of CTP

- RTGCP has an attribute that the warehouse has arranged RTGC and the objective function is minimum wait time for vessel.
- SRVP has an attribute that the type of vehicle is internal and the objective function is minimum wait time for QC and RTGCs.
- ATETP has an attribute that the type of vehicle is external and the objective function is minimum wait time for external trucks.

The Fig.6 shows the important attributes of CTP problems to identify the exact type of CTP. For instance, it characterise the CRP problem depending on the chosen attributes such as ”Warehouse” has arranged ”container” and the objective function is minimum reshuffling of container,

and *vice versa*.

In the next step the Reasoning System finds the corresponding concept of CRP problem to characterise the optimization problems in Optimization Ontology. Therefore the optimization ontology assists to find the list of methods that can be used to solve the CRP problem. These methods are linked with the web-services either available online or registered in the Web services Database (WSDB). Furthermore, we developed some web-services internal to the reasoning system for the purpose of validation.

5. Conclusion

In this paper, we present an approach and software system intended to assist logistics expert in formalizing their problems. Such a formalization consists primarily to identify the type of logistics problem, this is done by means of an ontology classifying the logistic problems. So, we develop a software suite capable to exploit precisely the logistics ontologies and find the well known problems matching with the initial problem data provided by the logistic expert.

We define an ontology formalizing the main optimization problems. We explore optimization methods used to solve them. We define, as well, the mapping between logistics problem in logistic ontologies and optimization problems in optimization ontology, hence, between optimization problems and methods linked as the web services to solve them.

The developed system describes a logistics problem, to precisely define the logistic problem, find the corresponding optimization problem and the solution method and subsequently the web services implementing these methods.

In the future, we intend to consider also the web service descriptions which may contain some information concerning the quality attributes of such services. It is thus possible to query the system in order to find the web services respecting some quality criteria.

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