Design and Usage of an Ontology for Supply Chain Monitoring

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Abstract

We present an agent-based supply chain monitoring system for tracking orders and their related suborders. We introduce an ontology to enable the necessary communication between the agents. Its design and implementation are discussed in detail.

1 Introduction

Fulfillment processes in a supply chain may show different kinds of irregularities and disruptions. Irregularities like delays in a production process are the result of variances in processing times and processing quality. The orders issued by different supply chain partners are often linked, e.g. an order for a car induces suborders for parts from suppliers (tires, seats, etc.). The tighter integrated the partner's supply chain processes are the greater will be the impact of disruptions on the fulfillment processes. Existing systems for order tracking typically generate standard messages for each order at certain intervals or milestones. As a result, large databases with information on orders are filled with data that are in most cases not related to the serious problems mentioned above. Only a small percentage of the orders encounters problems during fulfillment. Although information might be available, it is generally communicated too late, the content will often not match the needs of a decision maker to react to the problem and is lost in the large set of data.

Supply chain monitoring solutions for tracking orders need to be analyzed in the context of a domain. A typical logistics scenario consists of a variety of manufacturers, suppliers, and logistics service providers. Figure 1 illustrates

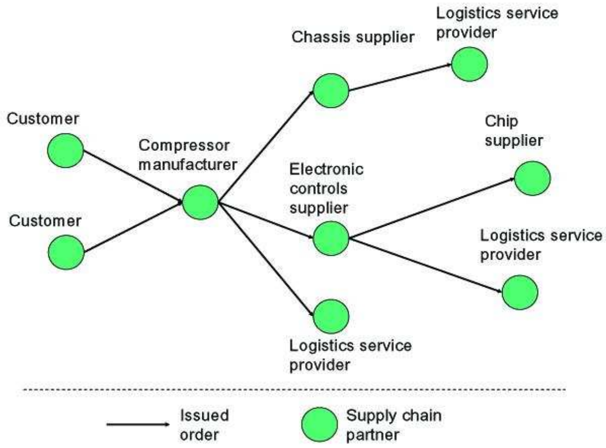

Figure 1: Supply Chain scenario.

a scenario of a compressor supply chain. The links between the organizations represent the issued orders and suborders resulting from customer orders.

We developed a decentralized agent-based concept for supply chain monitoring that differs from traditional isolated and centralized tracking systems that are widely implemented within logistics service provider networks [6] and similar approaches of production control [7]. The solution focuses on critical orders, allows for real-time tracking of orders across the supply-chain, and offers the opportunity to react in a timely manner to unforeseen events during order fulfillment. Our supply chain monitoring approach focuses on tracking of individual orders already issued. The aim is to gather information on orders and their related suborders with the help of software agents.

Two layers characterize such an agent architecture. The first layer is represented by a discourse agent which is concerned with communicating the tracking information across the supply chain by interacting with the different agent platforms of the supply chain participants. The second one, the application layer, has to gather and aggregate the tracking information from which actions can be derived. A detailed description of the functionality and interaction of these agents is presented in [10]. To enable the communication of information between the agents an ontology for supply chain monitoring is designed.

2 Ontology-Based Agent Communication

Agent-to-agent communication is the key to realize the potential of the agent paradigm and is a requirement for cooperation. Agents use an Agent Communication Language (ACL) to communicate information and knowledge about the domain. Systems which communicate and work together must share an ontology which can be implicit or explicit. Implicit ontologies are typically represented only by procedures whereas explicit ones are (ideally) given as declarative representation in a well-defined knowledge representation language. It introduces the concepts and relations needed to exchange messages about application relevant information. Once an ontology has been incorporated into the communication, it can be used to construct the message content, one of the key points for communication. The message content can have different granularity with respect to the ontologies level of abstraction. In communication with an agent, another agent can ask about both the general knowledge and the knowledge of a specific topic.

On the one hand, the ontology determines what is the possible content of a message and on the other hand is used to analyse the messages that should lead to appropriate tasks or actions. For this purpose a reasoning module is needed. The agent must verify the content with regard to misconceptions. The reasoning module is used to check if all concepts and relations exist in the ontology and if they are used properly. If the message contains a question about some individuals the agent has to verify their existence. In both cases, if an error is detected, the resulting answer would be negative and should be explained further in order to be cooperative. In this response the agent must revise the misconception. If the content is correct, the agent interprets the message and tries to find an answer. An answer can be a response containing the requested information or some course of actions to fulfil a postulated goal.

Different ontology description languages exist to formalize ontologies. The supply chain tracking ontology is modeled using the Ontology Inference Layer (OIL) [4]. OIL unifies three important aspects provided by different communities: it inherits the formal semantics and reasoning support from Description Logics, incorporates the essential modeling primitives of Frame-based systems, and uses existing Web Standards by providing XML and RDF based syntax [1]. The reasoning is done with Racer [2] a tableau based reasoning module.

3 The Supply Chain Monitoring Ontology

3.1 Methodological Approach

To design an ontology, it is important to define the functionality of the ontology and to characterize the users of the ontology [8]. The ontology represents an integrated supply chain model spanning all processes, organizational units, and objects involved in the scenario. The supply chain monitoring ontology defines all concepts necessary for the supply chain environment as well as basic concepts of tracking data. It is not the aim of this ontology to provide a formal representation of all the aspects of supply chain management. Its purpose is to model the characteristic features of tracking orders in a supply-chain. Therefore the modelled concepts are restricted to this domain. Based on this understanding, a rough first draw of the ontology can be derived that is iteratively refined step by step. There are several possibilities to derive this initial design. Holsapple and Joshi [3] identify five basic approaches to ontological design: inspiration, induction, deduction, synthesis, and collaboration. Combinations of these approaches are possible. For the design of the supply chain monitoring ontology a combination of the inductive and the synthetic approach is used. The inductive approach is characterized by observing, examining, and analysing (a) specific case(s) in the domain of interest and applying this specific case(s) to other cases in the same domain [3]. The intitial ontology is based on a scenario derived from data of a business partner. This basic scenario consisted of one customer, one vendor and one logistics service provider. In a top-down process the most general concepts of this specific scenario were defined and subsequently refined. In a second step, the ontology was enlarged to incorporate scenarios including several manufacturers, suppliers and logistics service providers. However, not all concepts in the ontology are new. Concepts from existing ontologies are adopted and synthesized into the supply chain monitoring ontology (synthetic approach). To model this ontology the Enterprise Ontology [9] is partially reused. It specifies a wide variety of concepts from the domain of enterprises. As the supply chain monitoring ontology belongs to the same domain, the Enterprise Ontology already provides some important general concepts that are also necessary for the supply chain scenario. The main benefit of using the Enterprise Ontology is to allow different multi-agent systems that may be concerned with varying aspects of supply chain management (e.g. procurement planning vs. order tracking) to communicate on a generic level as long as they commit themselves to the same top-level-ontology (e.g. the Enterprise Ontology). However, besides refinements of existing concepts, some important high-level concepts for the supply chain domain are missing and have been added, e.g. the concept of an order.

3.2 Concepts

The concepts of the supply chain monitoring ontology described are needed to reflect the scenario of a supply chain and to express the tracking data in a formalized mode. To represent the scenario the fulfilment process can be described as the interaction between three main concepts: *Actors*, *Activities/Processes* and *Orders*. Linked to the concept of an *Order* are the different tracking data types. An *Actor* issues an *Order* which is then received by another *Actor* in the supply chain. More *Actors* can be involved in the fulfilment process if further *Orders* have to be issued to be able to fulfil the first *Order*. This is the case if a customer orders a product from a manufacturer who then needs to order components from his suppliers for the assembly of this product. When issuing the *Order*, a sequence of *Activities/Processes* is triggered which has to be performed to fulfil the *Order*. These *Activities* are carried out by the respective *Actors*. As the fulfilment process is dynamic the concept of *Time* is relevant in the context of supply chain monitoring. The time axis is necessary for tracking the status of the fulfilment process as the *Activities* are carried out over a period of time.

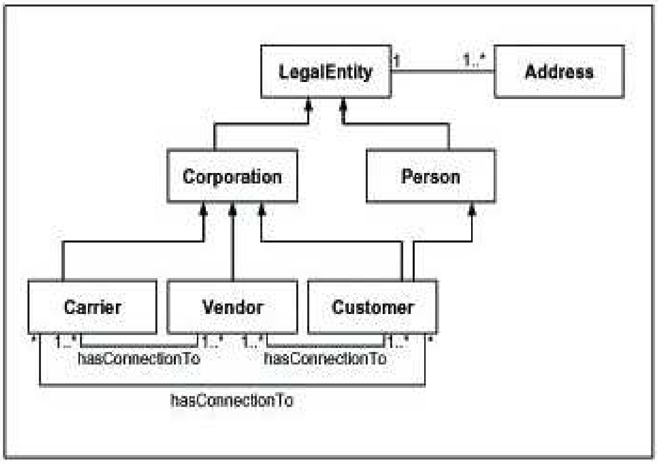

Figure 2: Legal Entity.

The central concept concerning *Actors* is *LegalEntity* (see fig. 2). A *LegalEntity* is recognized as having rights and responsibilities in the world by large and by legal jurisdiction in particular [9]. It includes *Person* and *Corporation*. *Vendor* and *Carrier* are both *Corporations*. The *Customer* can either be a *Person* or a *Corporation*.

The central concept *Activity* (see fig. 3) represents the generalization of all actions that need to be executed within the fulfillment process. On the one hand *Activity* is needed to describe a specific scenario while on the other hand the fulfillment of an *Activity* can indicate the achievement of a *Milestone* and is therefore also important for representing tracking data.

For the supply chain monitoring ontology eleven specific activities can be identified: *OrderReceipt*, *ConfirmationOfOrder*, *ProductionOrderOpening*, *ProductionPlanning*, *Manufacturing*, *QualityAssurance*, *Picking*, *Packaging*, *OutgoingGoods*, *Handling*, *Delivery*. The execution of an *Activity* leads to a specific *Effect*, which consists of a *StateOfAffairs* that must hold true at a point of time (which is specified by the *EffectWhenHold* concept). An *Activity* has a begin and an end date. The state of the *Activity* at a point of time is described by the *ActivityState*. The fulfillment process is a sequence of *Activities* that can usually only be performed one after another. Therefore most *Activities* have as a *Precondition* the execution of another *Activity*. An *Activity* is performed by an *Actor*.

The concept of an *Order* is another basic concept to model a supply chain

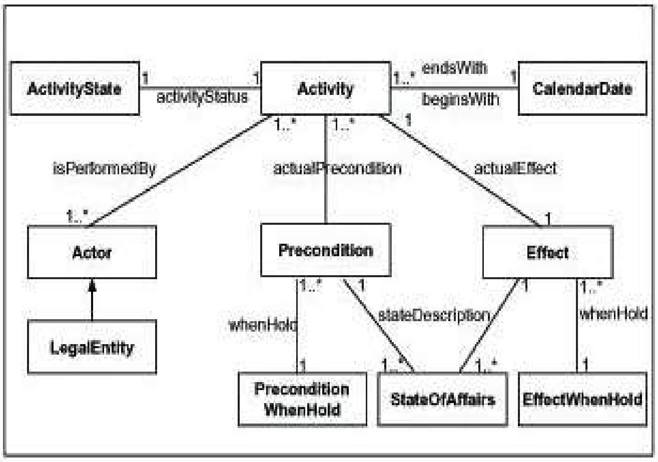

Figure 3: Activity concept.

scenario (see fig. 4). As it is a legally binding contract concerning a transaction between *LegalEntities* an *Order* defines the relationships between the partners in a supply chain. An *Order* consists of one or more *OrderItems*. There are various subconcepts of *Order* depending on whether the *Order* is incoming or outgoing and depending on the type of recipient: A final *Customer* issues an *OriginalOrder* addressed to a *Vendor*. This *OriginalOrder* corresponds to the *OrderIncoming* that the *Vendor* receives. Usually this *Vendor* will not produce all the parts needed for the fulfillment of this *OrderIncoming*. Therefore this *OrderIncoming* can trigger an *OrderOutgoing* for the components needed that is addressed to other *Vendors*. It can also trigger a *DeliveryOrderOutgoing* directed to a *Carrier* for the delivery to the final *Customer* or to a *Vendor* if a supplier (another *Vendor*) issues this subtype of *Order*. The *Carrier* receives this as a *DeliveryOrderIncoming*. An *Order* can be identified by its *OrderId*. An *Order* receives an *OrderId* from its issuer as well as from the recipient: An *OrderOutgoing* receives an *OrderOutgoingId*, an *OrderIncoming* an *OrderIncomingId*. For tracking purposes it is necessary to find the corresponding *OrderIncoming/OrderOutgoing* combination. Therefore the *OrderIncoming* also contains the *OrderOutgoingId* of its corresponding *OrderOutgoing*.

Besides the description of a supply chain scenario the *Order* is the point of reference for the tracking data. One important concept derived from the tracking data is the concept of a *Milestone*, that belongs to the status data in specific to the type of time data. A *Milestone* is the unit of the *Effect* of an executed *Activity* and the *CalendarDate* of its achievement. For each *Activity* a *Milestone* is defined. During the fulfillment process, the *Milestones* are realized when the respective *Activities* have been executed. Other types of status data that are incorporated in the ontology but not further explained here refer to

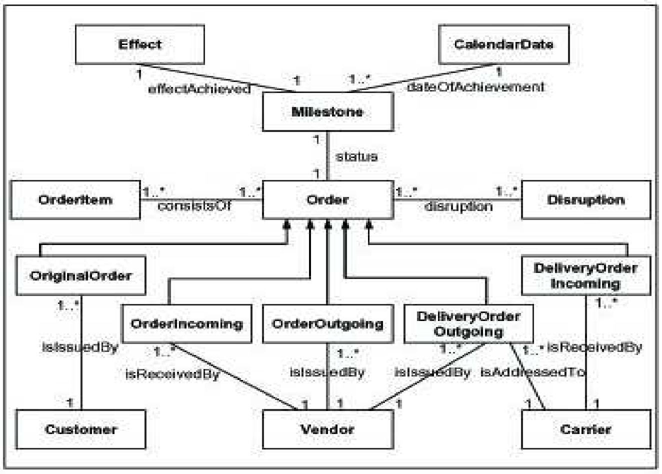

Figure 4: Order Concept.

the group of quality measures that can be derived from measures of time and of quantities of an order (e.g. the relation of delivered to ordered quantity). Apart from status data, so called decision data has been modeled in the ontology. During the fulfillment process of an *Order*, *Disruptions* may occur. These can be *OrderProcessingDisruptions* such as an *OrderLost*, *ProductionDisruptions* such as *MaterialNotAvailable* or a *MachineFailure*, or *DeliveryDisruptions* such as a *TrafficJam*.

The concept of *Time* plays an important role for tracking *Orders* along the supply chain. However, it is not specific to this environment. The Enterprise Ontology uses a *Time* concept imported from Allen's work [5]. This concept is also used for the supply chain monitoring ontology. *Activities* are performed over a *TimeRange* that is comprised of two *TimePoints*: a start and an end date, represented by *CalendarDates*.

4 Conclusion

Irregularities and disruptions in fulfillment processes have a major influence on supply chain performance. It is necessary to optimize the processes of gathering and communicating information related to such events. An agent-based concept presented for supply chain monitoring allows to speed up these processes and to focus on tracking critical orders. To enable the communication of tracking information between the software agents, an ontology has been developed that comprises relevant tracking information and important concepts of a supply chain scenario. The formalized model enables the efficient reuse of the ontology in different applications. As a result complex, dialogs with other supply chain partners agents emerge using the ontology as the necessary model to specify the content of the agent communication and to interpret the received message to determine appropriate actions. Currently, a first prototype of the supply chain monitoring framework is being implemented in cooperation with a business partner, and the ontology is used to implement an advanced prototype of the discourse agent with reasoning capabilities.

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