Chapter 1
An environment to build and track agent-based business collaborations *

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Abstract This chapter describes an environment to support the rapid assembly of agent-oriented business collaborations. Our environment allows: (i) to set up a collaboration environment as a virtual organization; (ii) to reach agreements within the collaboration environment to form short-term business collaborations; (iii) to enact business collaborations; and (iv) to track the performance of agents within business collaborations to build their trust and reputation within the collaboration environment.

1.1 Introduction

Globalisation and technological innovation are driving the creation of the extended enterprise – the dynamic network of interconnected organizations, from suppliers' suppliers to customers' customers, which work collaboratively to bring value to the marketplace. This is, today's companies are in need for support to swiftly cre-

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* Funded by Agreement Technologies (CONSOLIDER CSD2007-0022), EVE (MICIN TIN2009- 14702-C02-01 and 02), the Secretaría de Estado de Investigación, the EU FEDER funds, the Generalitat de Catalunya (grant 2009-SGR-1434) and the proyecto intramural CSIC 201050I008.

ate *business collaborations* that allow them to readily respond to changing market needs. Furthermore, they are also in need for tools that allow them to quickly react to collaboration exceptions so that their goals can still be achieved. To summarise, the capability of forming and sustaining collaboration has become central for companies.

Several works have focused on guaranteeing temporal constraints in dynamic environments allowing agent decommitment (usually with a penalty). On one hand, with MAGNET[7], Collins et al. propose a solution for business collaborations based on contracts. In their approach, agents reach agreements through a negotiation protocol. Moreover, all interactions between agent are supervised and coordinated by a central entity. Thus, the existence of this central entity discourages fraud and simplifies communication between agents. On the other hand, Norman et al., with CONOISE [14], propose an approach based on virtual organizations. In CONOISE, agents reach agreements through a series of combinatorial auctions over requested goods or services. Moreover, agents bidding to provide a service are allowed to create virtual organizations themselves. Thus, CONOISE allows to decompose a collaboration in subcollaborations thanks to this mechanism of creating virtual organizations within virtual organizations.

In this chapter we present a novel approach to enable business collaborations that is based on concepts introduced in chapter **??**. Unlike MAGNET and CONOISE, our work focuses in the creation of supply chains and the follow-up of the whole business collaboration from the early stages of its creation to the final steps of its realisation. In our environment agents can request and offer services thus creating virtual organizations that represent market places. From those market places we create supply chains that allow to produce the requested goods or services. After asserting a supply chain, the actual performance of the participants can be tracked in real time. Data gathered during the execution of the tasks is fed into the environment and can be used in future collaborations.

The rest of this chapter is structured as follows. In Sec. 1.2, we introduce mixed auctions as a mechanism to solve the problem of supply chain formation. Next, Sec. 1.3 introduces the readily available base technology upon which the platform is built. Finally, we present the architecture of the platform in Sec. 1.4, and give an overview of possible future improvements in Sec. 1.5.

1.2 Mixed Auctions for Supply Chain Formation

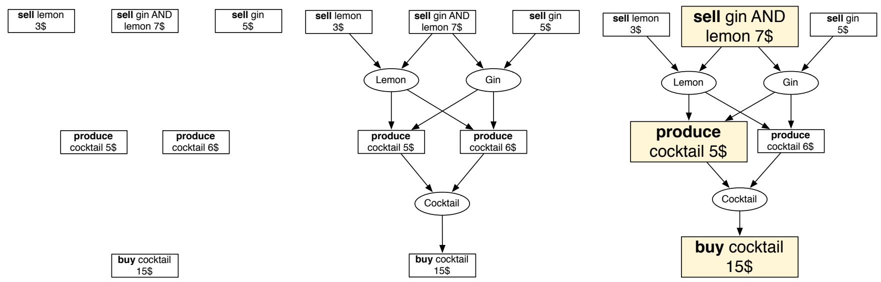
According to [19], “Supply Chain Formation (SCF) is the process of determining the participants in a supply chain, who will exchange what with whom, and the terms of the exchanges”. Combinatorial Auctions (CAs) [8] are a negotiation mechanism well suited to deal with complementarities among the goods at trade. Since production technologies often have to deal with strong complementarities, SCF automation appears as a very promising application area for CAs. However, whilst in CAs the complementarities can be simply represented as relationships among goods, in SCF the complementarities involve not only goods, but also *transformations* (production relationships) along several levels of the supply chain.

1.2.1 Mixed Multi-Unit Combinatorial Auctions

The first attempt to deal with the SCF problem by means of CAs was done by Walsh et al. in [19]. Later on, Mixed Multi-Unit Combinatorial Auctions (MMUCAs), a generalisation of the standard model of CAs, are introduced in [5]. Rather than negotiating over goods, in MMUCAs the auctioneer and the bidders can negotiate over *transformations*, each one characterised by a set of input goods and a set of output goods. A bidder offering a transformation is willing to produce its output goods after having received its input goods along with the payment specified in the bid.

While in standard CAs, a solution to the Winner Determination Problem (WDP) is a set of atomic bids to accept, in MMUCAs, the *order* in which the auctioneer "uses" the accepted transformations matters. Thus, a *solution* to the WDP is a *sequence of transformations*. For instance, suppose the market in Fig. 1.1a where a bidder offers to sell one kilogram of lemon for 3$, another bidder offers to sell one litter of gin for 5$, a third one offers to sell one kilogram of lemon and one litter of gin together for 7$; there are bids for making a cocktail given one kilogram of lemon and one litter of gin for 5$ and 6$ respectively; and there is a bidder willing to pay 15$ for the cocktail. Such a market and its dependencies can be expressed graphically as in Fig 1.1b, where goods are represented as ellipses and transformations over goods as boxes. Solving the WDP for this market equals to choosing the bids that maximise the auctioneer revenue (the bidder offering to buy the cocktail). Notice that a solution for this problem will be the sequence of highlighted transformations in Fig. 1.1c. According to this solution, task "sell gin AND lemon" must be executed before "produce cocktail" which, in turn, needs to be executed before "buy cocktail".

Unfortunately, the MMUCA WDP has been proved to be NP-complete [5]. Although reasonably fast solvers have been introduced [11], MMUCA still turns out to be impractical in high complexity scenarios. Furthermore, a bidder in MMUCA only knows the desired outcome of the supply chain and the current stock goods. Hence, it is difficult, specially for providers placed in the intermediate levels of the supply chain, to decide what to bid for. Therefore, in order for mixed auctions to be effectively applied to SCF, we must ensure computational tractability and reduce bidders' uncertainty.



(a) Market. (b) Supply chain problem. (c) Supply chain solution.

Fig. 1.1: Example of MMUCA.

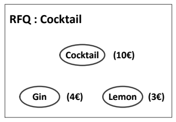
1.2.2 Sequential Mixed Auctions

Aiming to alleviate MMUCA's complexity and uncertainty problems , Sequential Mixed Auctions (SMAs) were introduced in [13], a novel auction model conceived to help bidders collaboratively discover supply chain structures.

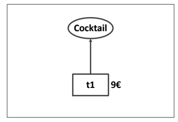
SMAs propose to solve a SCF problem by means of a sequence of auctions. The first auctioning round starts with the desired outcome of the supply chain as requested goods and the stock goods as available goods. During the first auction, bidders are only allowed to bid for transformations that either (i) produce goods in the set of requested goods or (ii) consume goods from the available goods. After selecting the best set of transformations, the auctioneer updates the set of requested and available goods after the execution of these transformations and then it will start a new auction. The process continues till no bids can be found that improve the supply chain.

Figure 1.2 illustrates the operation of an SMA. Say that a cocktail bar intends to form a supply chain using an SMA to produce a gin & lemon cocktail. Assume that the bar knows approximate market prices for a gin & lemon cocktail as well as for its ingredients. The auctioneer starts the first auction issuing a Request For Quotation (RFQ) for a gin & lemon cocktail (Fig. 1.2a). During the first auction, the auctioneer receives two bids: one offering to deliver a cocktail for 9€ (Fig. 1.2b); and another one to make a cocktail for 1€ when provided with lemon and gin (Fig. 1.2c). The auctioneer must now choose the winning bid out of the bids in Fig. 1.2d. Since the expected price of the second bid is $8(=1+4+3)$€ , the auctioneer chooses this bid.

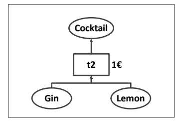
At this point, the structure of the supply chain is the one depicted in Fig. 1.2e. Nonetheless, the auctioneer must still find providers of gin and lemon. With this aim, the auctioneer starts a new auction by issuing an RFQ for gin and lemon (Fig. 1.2f). This time the auctioneer only receives the combinatorial bid in Fig. 1.2g, which offers both lemon and gin for 5€ . This bid is selected as the winning bid of the second auction. Figure 1.2h shows the resulting structure of the supply chain after



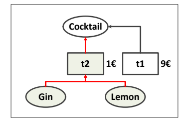
(a) First auction.



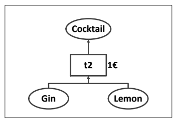
(b) Bid for good.



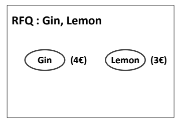
(c) Bid for transformation.



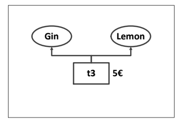
(d) All bids.



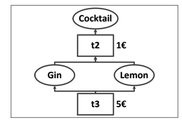
(e) Winning bid.



(f) Second auction.



(g) Combinatorial bid for goods.



(h) Resulting supply chain.

Fig. 1.2: Example of sequential mixed auction.

the second auction. Since there are no further goods to allocate, the auctioneer closes the SMA. The resulting supply chain produces a cocktail at the cost of 6€ .

Notice that each auction in the sequence involves only a small part of the supply chain, instead of the whole supply chain as MMUCAs do. Thus, auctions in an SMA are much less computationally demanding than a MMUCA. Moreover, the incremental nature of an SMA provides its participants with valuable information at the end of each auction round to guide their bidding.

1.3 Base Technology

Assembling Business Collaborations for Multi Agent Systems (ABC4MAS) platform [15] is built upon four readily available modules, each managing a different aspect of supply chain formation and maintenance processes. In this section we briefly present each of these building blocks, along with a general description of their functionalities.

1.3.1 MMUCATS

MMUCATS [10, 18] is a test suite for MMUCAs that allows researchers to test, compare, and improve their WDP algorithms for mixed auctions. MMUCATS provides several graphical facilities for the structural analysis of WDP instances. Thus, it allows to depict: (i) the supply chain structure along with the distribution of goods and transformations between tiers (Fig. 1.3); (ii) the bid graph structure capturing the relationships among bids, goods, stock goods, and goods required as a result of the supply chain operation; (iii) the transformation dependency graph showing the dependencies among transformations; and (iv) the strongly connected components of the transformation dependency graph.

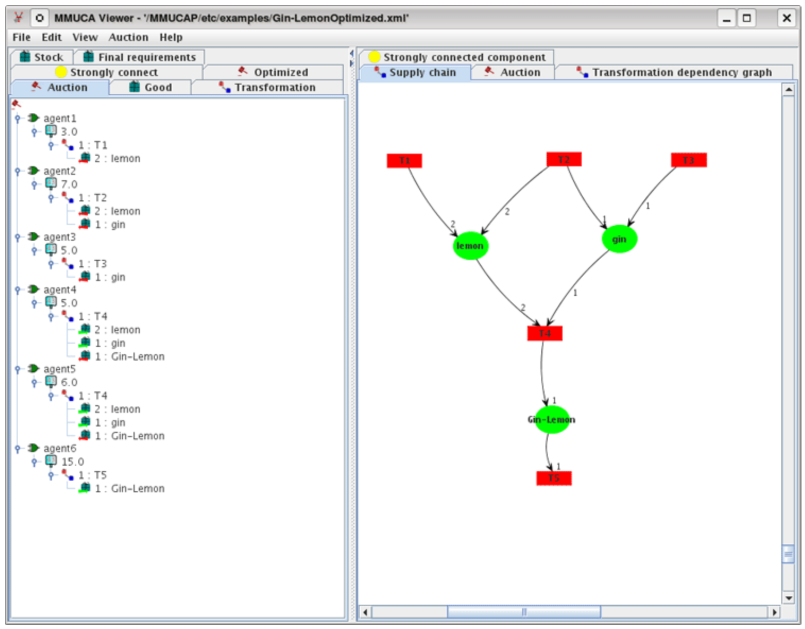


Fig. 1.3: Mixed multi-unit combinatorial auctions test suite.

MMUCATS interprets the solutions output by the solver to graphically display the optimal structure of the supply chain, the net benefit of the formation process, the time employed by the solver, and the number of decision variables employed.

1.3.2 Virtual Organizations

The THOMAS framework [3] allows any agent to create a virtual organization with the structure and norms needed (as described in chapter **??**), along with the demanding and offering services required. Virtual Organisations (VOs) are a set of individuals and institutions that need to coordinate resources and services across institutional boundaries [4]. In addition, system functionalities should be modelled as services in order to allow heterogeneous agents or other entities to interact in a standardised way. The integration of MAS and service technologies has been proposed as the basis for these new and complex systems [12].

The THOMAS framework is able to manage the organization structure, norms and life cycle, as well as controlling the visibility of the offered and demanded services and the fulfilment of the conditions to use them. All the functionalities of the framework are offered as *semantic web services* which are classified into two different entities: the Service Facilitator (SF) and the Organisation Management System (OMS).

On the one hand, the service facilitator is a mechanism and support by which organizations and agents can offer and discover services. The SF provides a place in which the autonomous entities can register service descriptions as directory entries, acting as a gateway to access the THOMAS platform. The SF can find services searching for a given service profile or searching by the goals that can be fulfilled when executing the service. This is done using the matchmaking and service composition mechanisms that are provided by the SF.

On the other hand, the organization management system is in charge of the organization life-cycle management, including specification and administration of both the structural components of the organization (roles, units and norms) and its execution components (participant agents and roles they play). Hence, the OMS keeps record on which are the organizational units of the system, the roles defined in each unit and their attributes, the entities participating inside each organizational units and the roles that they enact through time. Moreover, the OMS also stores which are the norms defined in the system. Thus, it includes services for creating new organizations, admitting new members within those organizations and member resigning.

1.3.3 Electronic Institutions

Electronic Institutions Development Environment (EIDE) [2] is a set of software tools that support all the stages of an Electronic Institution (EI) engineering. An electronic institution defines a set of rules that establish what agents are permitted and forbidden to do, and the consequences of agent's actions. Hence, an EI can be regarded as a coordination artifact that mediates agent interactions. Figure 1.4 depicts the role of the EIDE tools in an EI engineering cycle.

To support the engineering of EIs, ISLANDER allows designers to define a formal specification of the institutional rules according to its formalisation presented in [1]. ISLANDER combines both graphical and textual specifications of EI components. In addition, the tool also supports the static verification of specified EIs, which amounts to checking the structural correct- ness of specifications. The second tool, SIMDEI, allows to run EI simulations with different agent populations. Thus, SIMDEI enables EI designers to analyse simulation results and decide whether the institutional rules yield the expected behaviour or should be tweaked. An EI specification defines the possible behaviours agents may have, but it is a task of agent designers to incorporate agents with the decision making mechanisms that will determine the concrete agent behaviour. Nonetheless, EIDE includes the aBUILDER tool that automatically generates agent (code) skeletons based on the graphical specifications, hence easing the development of such agents.

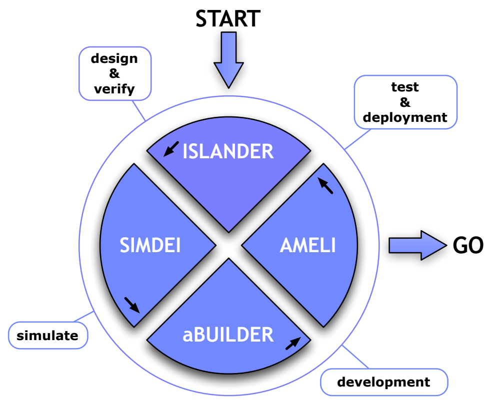


Fig. 1.4: Electronic Institutions Development cycle.

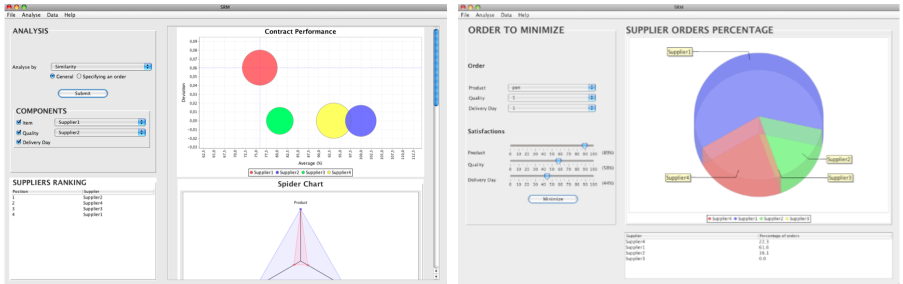
Last but not least, EIDE also includes AMELI, an execution environment for EIs. Unlike approaches that allow agents to openly interact with their peers via a communication layer, we advocate for the introduction of a social layer (AMELI) that mediates agent interactions at run time. On the one hand, AMELI provides participating agents with information about the current execution. On the other hand, it enforces whenever possible the institutional rules to the participating agents. At this aim, AMELI keeps track of the execution state, and uses it along with the institutional rules encoded in the specification to validate agents actions. Additionally, an EI execution can be monitored thanks to the monitoring tool that depicts graphically all the events occurring during an EI execution. Fairness, trust and accountability are the main motivations for the development of a monitoring tool that registers all interactions in a given enactment of an EI.

1.3.4 Supplier Relationship Management

Supplier Relationship Management (SRM) [9] is an application that gives support to a company in the task of deciding which supplier to choose when a new supply has to be ordered. It is based on a measure of trust and provides several tools that visualise that measure and support its use on decision making.

The used trust model, extensively described in [17], can deal with multiple requirements, including: (i) importance of each order's characteristic, (ii) how accurately the supplied goods match the specification and (iii) preferences. The model is based on a knowledge base populated with past experiences with the suppliers. Each experience is composed of an order commitment and the observation of the execution of this commitment.

This model is then used to provide the following four analysis tools. The trust tool allows to analyse the trust evolution over time in a supplier for a given commitment.



(a) Supplier analysis. (b) Minimal cost analysis.

Fig. 1.5: Supplier Relationship Management tool suite.

The supplier analysis, shown in Fig. 1.5a, a tool to analyse suppliers by similarity or satisfaction in the historic of interactions. The critical order tool that allows to rank suppliers based on their trust level for a desired order and the relative importance of each order characteristic. The minimal cost tool, shown in Fig. 1.5b, enables users to obtain a split of orders along suppliers such that the split guarantees certain user levels of satisfaction whilst minimising the overall cost.

1.3.5 Agreement Technologies Environment

The Agreement Technologies Environment (ATE) is an environment that provides the seamless interplay of agents and services. We choose OSGi as the technological framework to support the development of ATE as a service-based environment. This choice allows us to follow the *de facto* industry standard software, providing a way to create modules (bundles) facilitating the collaboration between different groups. We have implemented all previously mentioned technologies (MMUCA, THOMAS, EIDE and SRM) as OSGi bundles allowing them to interact as ATE modules.

By default OSGi framework provides us with a way to: (i) install, start or stop bundles, and (ii) register, deregister, search and access services enabled by bundles. However, OSGi does not provide all the services needed to have seamless interaction between agents. In order to overcome OSGi's limitations we build a series of services on top of it that constitute the core of the ATE (Fig. 1.6). We group these new services into:

Environment services. Manage the ATE environment ensuring that dependencies between modules are met and facilitate collaborations in a distributed environment.

User interface services. Provide a way for the user to interact with the environment and define an interface for the other modules to implement interaction with humans.

Organisation services. Provide tools to make alliances between the agents. These are the base for EIDE and THOMAS bundles.

Service tools. Allows to discover and call remote services in a distributed environment.

Agreement services. Provide tools for agents to reach, monitor and manage agreements. These are the base for trust, argumentation and ontology services.

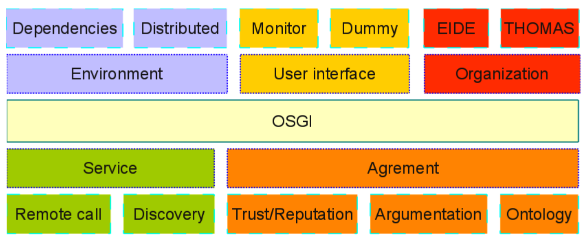


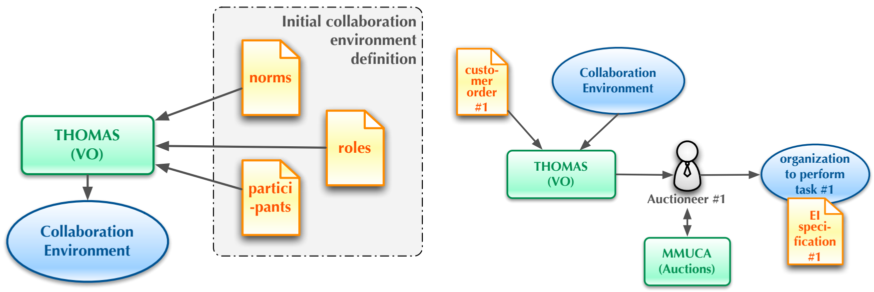
Fig. 1.6: ATE services and tools.

1.4 Architecture

In this section we provide an overview of the ABC4MAS platform architecture. This architecture allows us to implement a solution for collaboration environments introduced in Sec. 1.1 by using the currently existing technologies presented in Sec. 1.3. The remaining of this section defines the functional integration between the different components, as well as the objective of their interactions.

First of all, the ABC4MAS platform must allow for the definition of a supply network. A supply network includes all participants that may take part in the production of the requested goods, including both external and internal resources/companies. Additionally, the entity requesting the goods must be able to specify which roles can play each participant. These definitions will be fed into the THOMAS service, which will in turn create a virtual organization representing the whole supply network, as shown in Fig. 1.7a.

Thereafter, when a customer order is received, the system must define the supply chain to serve it. Hence, the auctioneer agent inside the global virtual organization receives the customer order specification and initiates the auction. Whenever the auctioneer needs to resolve the supply chain according to current supplier's bids, it calls the Mixed Auctions (MA) service. MA is readily available to resolve the



(a) Collaboration environment creation. (b) Collaboration formation.

Fig. 1.7: Main processes.

winner determination problem, as well as to represent it as an ISLANDER specification. Hence, the MA service replies to the auctioneer with a full-fledged ISLANDER specification. Once the auctioneer decides to end the auction process, it creates a new virtual organization whose participants and roles correspond to those in the resolved supply chain. To clarify, the whole process of determining the supply chain for a given customer order is depicted in Fig. 1.7b.

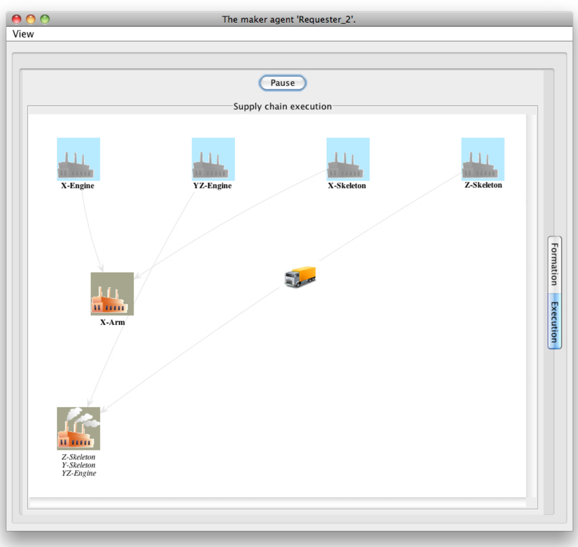


Fig. 1.8: AMELI execution environment.

Once the supply chain has been defined, it is time to start the production process. Thus, the auctioneer launches an electronic institution using the AMELI service.

AMELI then tracks each and every action as defined in the supply chain, allowing the auctioneer to monitor: (1) which entity is performing each task, (2) that all the agreements are being fulfilled, and (3) that no task is overdue. AMELI has been modified to report graphically the execution of each task with the data obtained in real time (Fig. 1.8). Additionally, AMELI generates reports about all the transactions being made in the form of events, that are stored in a central event database shared among all organizations within the platform. When AMELI detects that the production process has finished, both the EI and the machine-specific virtual organization are terminated.

During the production, the SRM service interacts with the central event database to feed its trust and reputation model. Hence, the different SRM tools can be used to evaluate supplier's performance.

Finally, Fig. 1.9 shows a diagram of the complete workflow, from the creation of the supply network to the production of multiple requested goods. Notice that, although the auctioneer agent shown in this diagram is specific to this market-based supply chain formation business case, the functional integration between services is usable in any other scenario.

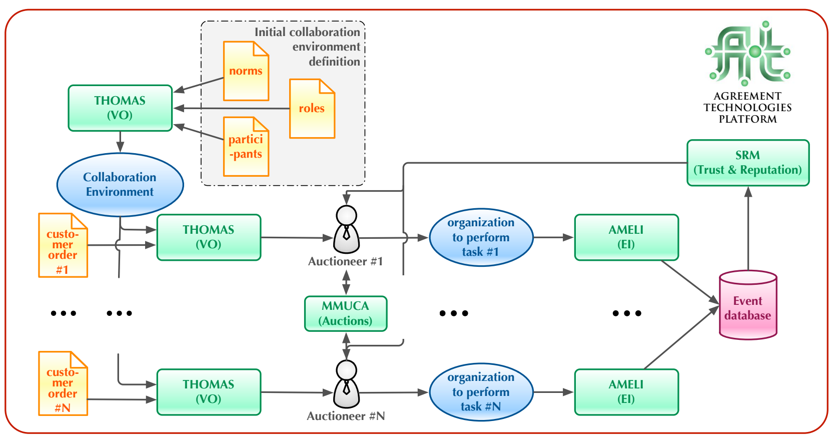


Fig. 1.9: ABC4MAS platform architecture.

1.5 Future Work

Firstly, a key aspect to be taken into account in future versions of the platform is robustness. Although the ABC4MAS platform tracks how well each agent performs the tasks it is committed to, that information has limited effect on future interactions. At present, the trust information collected during the execution of supply chains is only employed by the auctioneer to filter out low-performing agents. However, we plan to employ trust information as part of the auction mechanism along the lines of [16] and chapter **??**.

Secondly, at present the negotiation process takes into account a single attribute: price. In actual-world scenarios, it is common practice to negotiate over further attributes (e.g. delivery time, quality, or features of the tasks/goods at auction) [6]. Hence, we plan to extend mixed auctions to cope with multi-attribute negotiations.

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