Combining AOR Diagrams and Ross Business Rules' Diagrams for Enterprise Modeling

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Abstract

An enterprise model is a comprehensive description of the organizational structure, the information resources and the business processes that constitute an enterprise with the help of a conceptual modeling method. Existing methods, however, have difficulties to capture the physical and social dynamics which is inherent in organizations, and to integrate it with a static information model. *Agent-oriented* methods represent a promising approach to overcome these difficulties. In this paper, we investigate the combination of a recently proposed agent-oriented approach, called *Agent-Object-Relationship* (AOR) modeling [8], with the more established business rule modeling method of Ross [10] in modeling a car rental company.

1. Introduction

Agent-Orientation is emerging as a new paradigm in software and information systems engineering. It offers a range of high-level abstractions that facilitate the conceptual and technical integration of communication and control with conventional (object-oriented) information storage and retrieval. Agent-Orientation is highly significant for business information systems since business processes are driven by and directed towards agents, and hence have to comply with the physical and social dynamics of interacting individuals, groups and markets.

In order to capture more semantics of the dynamic aspects of information systems, such as the events and actions related to the ongoing business processes of an enterprise, it is necessary to make an ontological distinction between active and passive entities, that is, between *agents* and *objects*. In particular, the semantics of business transactions can only be captured if the specific business agents

associated with the involved events and actions are explicitly represented in the information system in addition to passive business objects.

Current information system technologies do not support the concept of an agent: no matter if the customers of an enterprise are represented in a relational or in an object- relational database table, they are not explicitly represented and treated as agents but rather as objects in the same way as items or bank accounts. E.g., UML [26], the current object-oriented modeling standard, does not support the concept of an agent as a first class citizen. In UML [26], agents are only considered as "actors" that are involved in "use cases" but remain external to the system model. Both the customers and the suppliers of a company would have to be modeled as UML objects in the same way as currencies and bank accounts. UML treats the dynamic aspects of an application system by providing a multitude of process modeling diagrams largely unrelated with each other and with the object class diagram of the system.

In this paper, we investigate the combined application of agent-oriented modeling and of business rule modeling by using the example of a *car rental company where customers make rental reservations via Internet, and pick up and drop off cars by using chip cards*. The geographical distribution of such an enterprise over a headquarter and a number of branches suggests to view and model it as a group of interacting agents represented by their respective information systems.

2. Notations Used For Enterprise Modeling

2.1 Agent-Object-Relationship Diagrams

Agent-Object-Relationship (AOR) diagrams were proposed in [8,9] as an agent-oriented extension of Entity-Relationship modeling. In AOR modeling, an entity is either an event, an action, a claim, a commitment, an agent, or an object. Only agents can communicate, perceive, act, make commitments, and satisfy claims. Objects do not communicate, cannot perceive anything, are unable to act, and do not have any commitments or claims. An organization is viewed as a complex *institutional agent* defining the rights and duties of its *internal* agents (or *subagents*) that act on behalf of it, and being involved in a number of interactions with them and with *external* agents. Communication is viewed as asynchronous point-to-point message passing. The expressions *'receiving a message'* and *'sending a message'* are taken as synonyms of *'perceiving a communication event'* and *'performing a communication act'*.

In addition to the two designated relationship types *specialization* and *composition* of ER/OO modeling, there are twelve designated relationships in which specifically agents, but not objects, participate. Six of them relate agents with events and commitments: an agent *perceives* environment events, *receives* and *sends* messages, *does* physical actions, *is-committed-towards* and *has-claims-against* other agents. The remaining six of these designated relationships associate subagents with particular rights and duties: a subagent may have the *right-to-do* an action, the *right-to-send* a

message, the *duty-to-respond* to a message, the *duty-to-react* to a physical event, the *duty-to-fulfill* a commitment, and the *duty-to-monitor* a claim.

Some of the AOR modeling concepts are *indexical*: taking the perspective of the agent to be modeled, actions of other agents are viewed as events, and commitments of other agents are viewed as claims against them. Likewise in the case of an organization: only the actions of the organization itself and of its subagents count as actions, while the actions of external agents count as events.

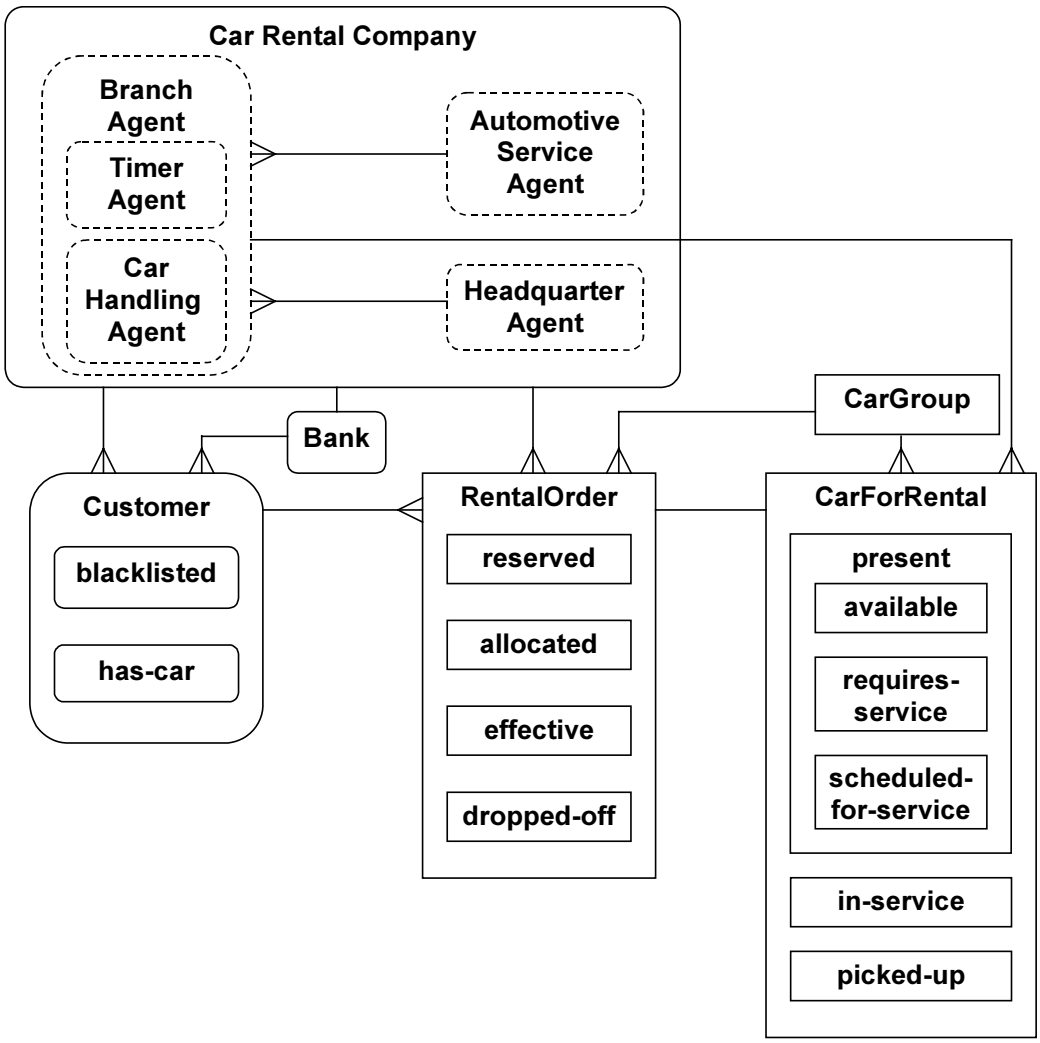


Figure 1. The AOR model of the car rental company from an objective observer's point of view

Recall that entity types are visually represented by rectangles while relationship types are represented by connection lines (possibly with crows feet endings in order to indicate multiplicity). In AOR diagrams, a *subclass* is visualized as a rectangle within its superclass. A *component class* is visualized as a rectangle with dotted lines drawn within the superior class it belongs to (recall that a component cannot exist independently of the whole; if the whole ceases to exist, all of its components also cease to exist).

An *agent class* is visualized as a rectangle with rounded corners. In order to distinguish an internal agent (subagent) class from an external agent class and from an agent subclass, it is visualized by such a rectangle with a dotted line (like *CarHandlingAgent* in Figure 1).

Both actions and events may be communicative or physical. Events have a concave (incoming) rectangle side, while actions have an convex (outgoing) rectangle side. Communication event rectangles and communication act rectangles have a grey background color.

In the perspective of an organization, commitments are commitments towards other agents, while commitments of other agents are viewed as claims against them. A commitment towards another agent (such as a commitment towards a customer to provide a car) is coupled with the associated action (such as a *provideCar* action). It is visualized as a rectangle with a dotted line on top of the associated action rectangle like shown in Figure 3. A claim against another agent (such as a claim against a customer to return a car) is coupled with the associated event (such as a *returnCar* event). It is visualized as a rectangle with a dotted line on top of the associated event rectangle like shown in Figure 6.

Since the *state* of an entity can be interpreted as a subclass of the entity (see e.g. [6]), we use the notation for subclasses also for representing states. For example, an entity of the class *RentalOrder* in Figure 1 can be in the state *reserved*, *allocated*, *effective*, or *dropped-off*. States can also have *substates*, like in Figure 1 the state *present* of *CarForRental* has the substates *available*, *requires-service*, and *scheduled-for-service*.

The AOR model of the car rental company from an objective observer's point of view is represented in Figure 1.

2.2 Ross Notation

AOR diagrams can be complemented by depicting *intensional predicates* (*derivation rules*) evaluated by the agents in the course of business processes. In Figure 2 the Ross Notation [10] is used for representing derivation rules. The Ross Notation enables to represent both *materialized* (i.e. instantiated) and *computed-on-the-fly* views of intensional predicates. According to the Ross Notation, each rule consists of an anchor, rule symbol, and correspondent. *Anchor* is a data type or another rule for whose instances a rule is specified. In the graphical representation of the Ross Notation, the anchor connection *exits* the anchor and *enters* the rule symbol. *Correspondent* is a data type, another rule, or action whose instances are subject to the test exercised by the rule. In the graphical representation of

the Ross Notation, the correspondent connection *exits* the rule symbol and *enters* the correspondent. Both the anchor connection and correspondent connection are dashed.

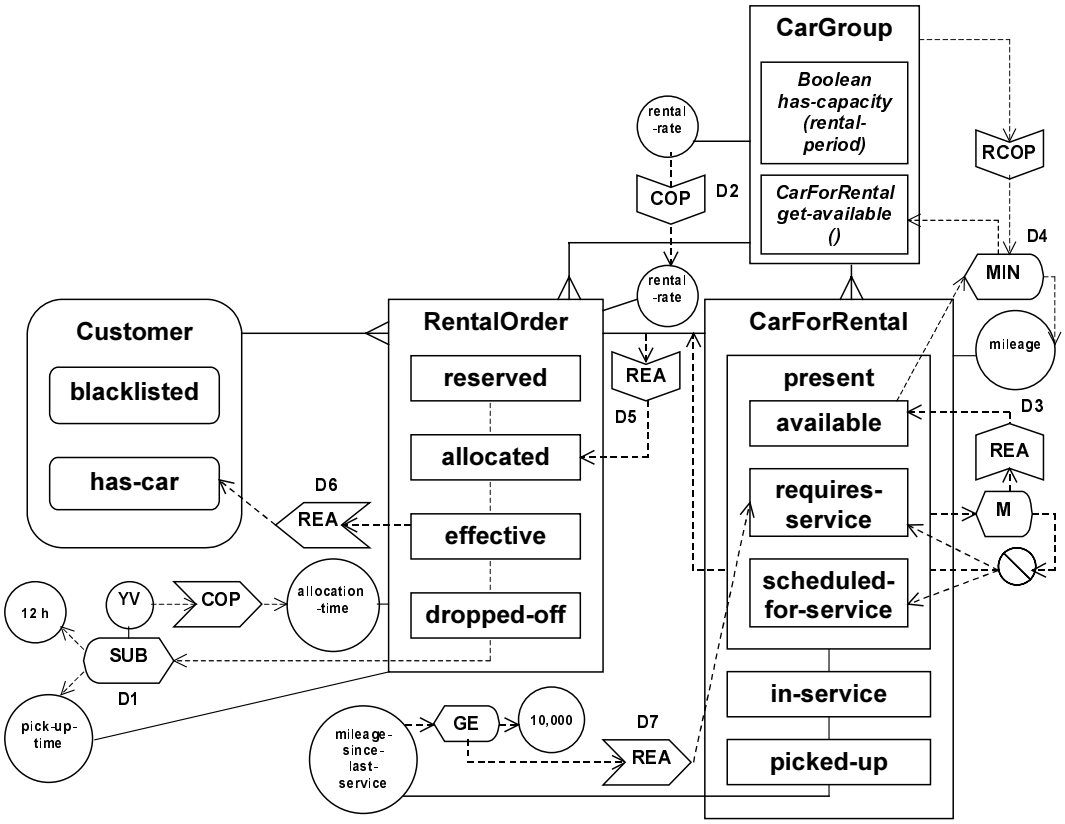


Figure 2. A part of the ontology of car rental

Every rule produces a value, called the *Yield Value* (abbreviated YV), at any point of time. Usually this value is hidden. It is used internally by the rule to achieve the appropriate truth value for the rule. Sometimes, rules require testing the Yield Value of a rule directly. To satisfy this need, the Yield Value of a rule may be externalized. When externalized, the Yield Value appears as an attribute type for the rule itself.

The symbols of the Ross Notation, used in our model of the car rental company, and their basic meanings are given in Table 1. They are used for representing the derivation rules in Figure 2.

The derivation rule D1 in Figure 2 subtracts 12 hours from the *pick-up-time* of a *RentalOrder* in the state *reserved*, and copies the yielded value to the attribute *allocation-time* of the *RentalOrder*.

The derivation rule D2 determines that the rental rate of a *RentalOrder*, expressed by its attribute *rental-rate*, is copied from the rental rate of the *CarGroup* that the car allocated for the *RentalOrder* belongs to.

The derivation rule D3 defines how to determine the set of cars that are available to rent. This rule determines that a given car *CarForRental* in the state *present* is available if and until it is not allocated for any *RentalOrder*, doesn't require service (i.e. does not belong to the subclass *requires-service* of *present*), and is not already scheduled for service (i.e. does not belong to the subclass *scheduled-for-service* of *present*).

The derivation rule D4 determines that the return value of the intensional predicate *get-available* of the object class *CarGroup* is equal to the instance of *CarForRental* in the substate *available* with the minimal value of the attribute *mileage*. The RCOP component rule reduces the scope of the overall rule to the *CarGroup* of the given *RentalOrder* (see also the explanation for RCOP in Table 1).

The derivation rule D5 determines that if an instance of *CarForRental* is assigned to an instance of *RentalOrder*, the state of the *RentalOrder* changes to *allocated*, and stays that for exactly as long as this relationship persists.

The rule D6 is a derivation rule prescribing that a customer belongs to the class *has-car* if and until any *RentalOrder* related to it is in the state *effective*.

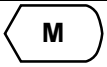
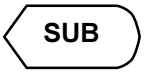
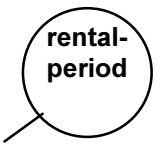
The derivation rule D7 says that if the mileage since the last service of a car physically present at the branch, represented by the value of the attribute *mileage-since-last-service* of *CarForRental* in the state *present*, is greater or equal than 10,000 km, the substate of the corresponding instance of *CarForRental* changes to *requires-service*, and stays that until the car is scheduled for service (because the substates *requires-service* and *scheduled-for-service* are mutually exclusive).

Since the Ross Notation does not allow for graphical modeling of intensional predicates whose values depend on the values of parameters, such intensional predicates should be represented textually rather than graphically. In our case study, the intensional predicate *has-capacity* of the object class *CarGroup* determines the existence of rental capacity in the given *CarGroup* during the requested rental period at the time of making a rental reservation. Therefore the truth value of this predicate is also dependent on the value of the parameter *rental-period.*

AOR diagrams together with derivations rules expressed by the Ross Notation and textually form a graphical representation of an ontology[1] of the problem domain. A partial representation of the ontology of car rental is depicted in Figure 2.

[1] A *problem-oriented ontology* is a description by truth values of the concepts and relationships of the problem domain that exist for an agent or more commonly for a community of agents [24].

Table 1. A selection of rule symbols and other graphical symbols according to the Ross Notation

Symbol	Basic meaning
	Given an instance of the anchor, do instances of all the correspondent types simultaneously exist for that instance?
	Is the value of the anchor greater or equal than the value of the correspondent?
	The Yield Value produced by the rule is the subtraction of the values of the correspondents
	Creates an instance of the correspondent
	Creates an instance of the correspondent, but does not materialize it (i.e. terminates such an instance when the instance of the anchor is deleted)
	Requires propagation (i.e. copying) of the value of an instance of the anchor to instance(s) of the correspondent.
	Same as COP, except that reverses the value of instance(s) of the correspondent upon deletion of the instance of the anchor, if ever. *If the correspondent is another rule, forces interpretation of this other rule exclusively across instances of the copier's anchor*
	Negation
	Attribute type

3. Representing Business Rules

3.1 The Nature and Classification of Business Rules

At the business level, a *business rule* is defined as a statement that defines or constrains some aspect of the business [11]. A business rule is based on a business policy. An example of a business policy in a car rental company is "only cars in legal, roadworthy condition can be rented to customers" [11]. A business rule is also subject to one of the following enforcement levels: *mandate* (must be followed), *requirement* (may be deviated from only with permission), and *guideline* (suggestion) [4]. Many

business rules are of a *declarative nature*: they describe certain states of affairs that are either required or prohibited while not prescribing the steps to be taken to achieve the transition from one state to another, or the steps to be taken to prohibit a transition [11].

Alternatively, a business rule may be defined as a law or custom that guides the behaviour or actions of the actors connected to the organization [12]. We view all *actors* connected to the business, which can be individuals, organizational units, software systems, or external units like customers or suppliers, as agents and assign *actions* to them. We view an agent's action in a broader sense as something that the agent *does*: a human may make a decision, an agent wrapping a database may execute certain retrieval primitives, a statistical computation agent may run certain mathematical procedures, and one agent may send a message to another agent [1]. Consequently, *business rules define and constrain agents' actions*. Actions consume and affect different *resources*, including information resources.

Examples of business rules from the problem domain of car rental are:

1. A car is available for rental when it is physically present, is not assigned to any rental, and is not scheduled for service.
2. When receiving from a customer the request to reserve a car of some specified car group, the branch checks with the headquarter to make sure that the customer is not blacklisted.
3. Transferring a car to the automotive service station requires that the car has been scheduled for service and commits the automotive service station to return the car after completing the service.

Rule 1 defines the conditions how to determine the set of cars that are available to rent. It can be naturally represented as a *derivation rule* that may be applied either top-down to compute answers on the fly, or bottom-up (like a "production rule") to compute a materialized view. Rule 2 defines how to proceed when some event (a reservation request) occurs. It corresponds to a *reaction rule*. Finally, rule 3 defines the conditions under which some action (transferring a car to the automotive service station) may be performed, and the effects of its actual performance. It corresponds to an *action rule*. Notice that reaction rules are triggered by the occurrence of specific events, and thus represent automated business process steps, while action rules are applied when an agent decides to perform an action of that type.

3.2 Mapping Business Rules to Operational Rules of Agents

Business rules, being of a declarative nature, can in principle also be declaratively represented as functions between different knowledge states of an agent and accordingly implemented by using e.g. the BDI agent architecture [18, 21]. The biggest benefit of such an approach lies in a small gap between the formal specifications and actual implementations of the rules. However, if we want to create an effective agent system, business rules should be *operationalized* in order to facilitate their implementation. According to the thesis [3], in practice very few, if any, declarative implementations for industrial use live up the criterion of effectiveness.

We have chosen to map business rules to action and reaction rules of the *vivid agent* architecture of [5] because of the relative straightforwardness of this kind of mapping and the effectiveness of the

vivid agent model needed for business applications in comparison with other candidate agent architectures like e.g. the BDI-architecture [18, 21] mentioned above. Following the work [7], we define an *agent* to be consisting of three components:

- a *virtual knowledge base*[2] *X*, consisting of the agent's *beliefs*;
- an *event queue EQ*, i.e. a buffer receiving messages from other agents or from perception subsystems running as concurrent processes;
- a set of *action rules AR* and *reaction rules RR* respectively determining the agent's *proactive* and *reactive* behaviour.

Action rules have the general form of *Action* ← *Condition* where *Condition* refers to the agent's information state represented in its VKB. According to the actions prescribed by action rules, action rules are divided into [5]:

- *epistemic action rules* of the form *Eff* ← *Cond* where *Eff* is an epistemic effect formula specifying a corresponding update of the agent's VKB;
- *physical action rules* of the form **do**(α), *Eff* ← *Cond* where **do**(α) calls the procedure α affecting some actuators available to the agent;
- *communicative action rules* of the form **sendMsg**[*m(c), i*], *Eff* ← *Cond* where **sendMsg**[*m(c), i*] is a procedure call to send the message *m(c)* to agent *i*.

Agents communicate in some high-level *agent-communication language* (ACL) that is based on *typed messages* such as "ASK", "TELL", "REQUEST", and "PROPOSE". In contrast to the application-specific messages in OO-programming, ACL message types are appplication-independent and therefore, in combination with an ontology, defining the semantic vocabulary of a problem domain, allow for true software interoperability [7].
Reaction rules encode the behaviour of an agent in response to perception events created by the agent's perception subsystems, and to communication events created by communication acts of other agents. Both perception and communication events are represented by incoming messages of an agent [7].

There are three types of reaction rules [7]:

- *epistemic reaction rules* of the form *Eff* ← **recvMsg**[*m(c), j*], *Cond* where the event condition **recvMsg**[*m(c), j*] is a test whether the event queue *EQ* of the agent contains the message *m(c)* sent by agent *j*;
- *physical reaction rules* of the form **do**(α), *Eff* ← **recvMsg**[*m(c), j*], *Cond*;
- *communicative reaction rules* of the form **sendMsg**[*m'(c'), i*], *Eff* ← **recvMsg**[*m(c), j*], *Cond*;

Additionally there are *derivation rules* of the form *Conclusion* ← *Premise* which define intensional predicates in the agent's virtual knowledge base [7]. They are described by the ontology of the problem domain (v. Figure 2).

[2] An agent's *virtual knowledge base* (VKB) is called "virtual" because it is not necessarily implemented as a classical knowledge base.

Table 1 shows how business rules of the Examples 1-3 from section 3.1 can be respectively mapped to the derivation, reaction, and action rule of the vivid agent model.

While reaction rules are triggered by events, thus representing automated business process steps performed by an enterprise information system (or, for instance, by an automated teller machine as a subagent), action rules represent process steps recorded in the enterprise information system but performed by human agents.

Table 2. Correspondences between business rules and their formal representations by means of derivation, reaction and action rules

Business Rule	Operational Rule
1	available(*x*) ← CarForRental.present (*x*) ∧ ¬∃*y* (RentalOrder(*y*) ∧ *y*.CarID = *x*) ∧ ¬CarForRental.requires-service (*x*) ∧ ¬CarForRental.scheduled-for-service (*x*)
2	**sendMsg** (ASK-IF (blacklisted (*customer*)), *HeadquarterAgent*) ← **recvMsg** (request (reserve (*car-group rental-period*)), *customer*)
3	**do** (sendCarToService (*x*, *AutomotiveServiceAgent*)), **claim** (returnCar (*x*), *AutomotiveServiceAgent*) ← **commit** (CarForRental.scheduled-for-service (*x*), *service-period*)

3.3 Modeling Action and Reaction Rules by AOR Diagrams

In AOR diagrams, a (re)action rule is visualized as a named circle with incoming and outgoing arrows. The incoming arrows start from the graphical symbols representing the triggering event of a rule and the epistemic conditions to be evaluated. The epistemic effects of a rule are visualized as update arrows from the circle representing the rule to the entities or their specific (sub)states affected. The communicative and physical effects of a rule are represented as arrows from the rule symbol to the symbols representing communicative and physical actions. For example, the triggering event of the rule R1 in Figure 3 is the reception of the reservation request message, the condition to be checked is *has-capacity (rental-period)*, and the communicative effect is sending the query message with the content *?blacklisted (customer)*. The mental effect caused by the rule R2 in Figure 3 is the creation of a *RentalOrder* in the state *reserved.*

3.4 Multi-Perspective Modeling of Business Processes

Business rules define and control business processes. A *business process* can be defined as a collection of activities that takes one or more kinds of input, and creates an output that is of value to the customer [13, 25]. A business process describes from start to finish the sequence of events required to produce the product or service [13]. Business processes typically involve several different autonomous units of an organization. Often business processes also cross organizational boundaries.

Business processes can be modeled from an objective observer's point of view like, for example, described in [13]. However, in this paper business processes are modeled from the perspectives of different agents (resp. actors) involved in them, that is, we take the design perspective. We model a business process by a set of related reaction and action rules representing single process steps. The business processes of the car rental company to be modeled are those of *rental reservation, allocating a car for a rental order*, *picking up a car*, *dropping off a car*, and *scheduling a car for automotive service*. Because of the lack of space, we have omitted from this paper the business processes of paying for a rental and transferring a car from one branch to another.

The reaction and action rules defining the above-mentioned business processes are described below along with the AOR diagrams modeling them. In the diagrams reaction rules are denoted by $\mathbf{R_n}$ and action rules by $\mathbf{A_n}$. The reaction and action rules described make use of the derivation rules of the ontology represented in Figure 2.

In the modeling of reaction rules, we have omitted the reaction rules describing the standard behavior for answering queries with the content like *?blacklisted (customer)* and *?has-car (customer)*.

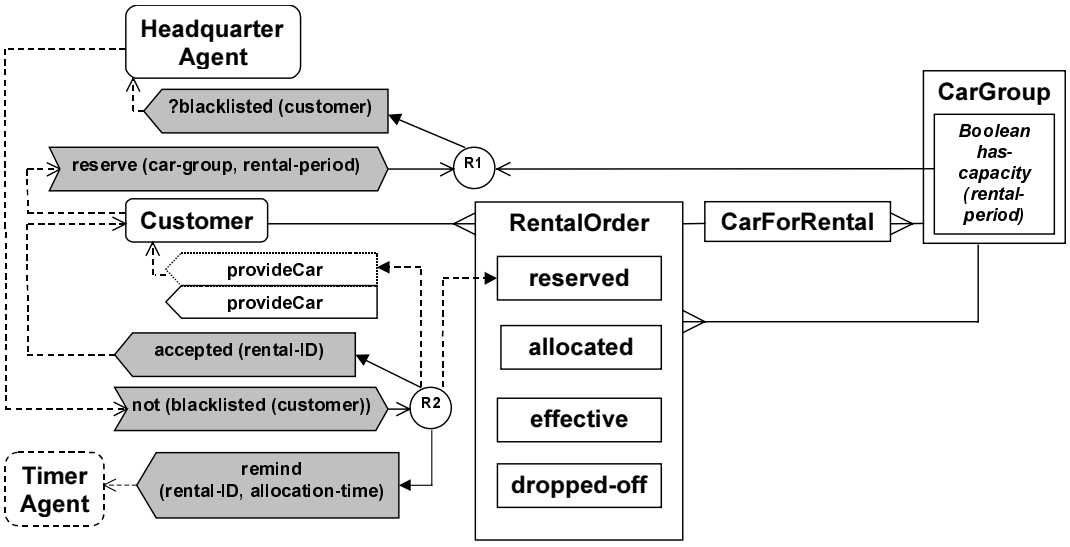


Figure 3. The AOR model of the business process of rental reservation from the perspective of a Branch Agent

In Figure 3 the business process of *rental reservation* is represented *from the perspective of a Branch Agent*. It contains the following reaction rules:

R1. Upon receiving from a *Customer* the request to reserve a car of some specified *CarGroup* for some specified rental period, if that *CarGroup* has enough rental capacity during the requested rental period (found by evaluating the intensional predicate *has-capacity (rental-period)* of

CarGroup), the *Branch Agent* sends a query to the *Headquarter Agent* to make sure that the *Customer* is not blacklisted (see also Operational Rule 2 in Table 2);

R2. Upon receiving from the *Headquarter Agent* a reply telling that the *Customer* is not blacklisted, the *Branch Agent* creates the corresponding rental reservation (i.e. an instance of *RentalOrder* in the state *reserved*), commits towards the *Customer* to provide a car, sends to its subagent *Timer Agent* a request to remind about the allocation time of a car for the given *RentalOrder*, computed and assigned to the attribute *allocation-time* of the *RentalOrder* by the derivation rule D1 (v. Figure 2), and sends an acknowledgement to the *Customer*.

Figure 4 models the *business process of car allocation for advance reservations from the perspective of a Branch Agent.* This business process is defined by just one reaction rule:

R3. When the *allocation-time* of a *RentalOrder* arrives, the *Branch Agent* receives from the *Timer Agent* a reminder to allocate a car for the given *RentalOrder*, and if there is an available car of the specified *CarGroup*, expressed as the return value of the intensional predicate *get-available ()* that, in turn, makes use of the derivation rules D3 and D4 as shown in Figure 2 (see also Operational Rule 1 in Table 2), this car is assigned to the *RentalOrder* by creating the corresponding relationship between the *RentalOrder* and *CarForRental*.

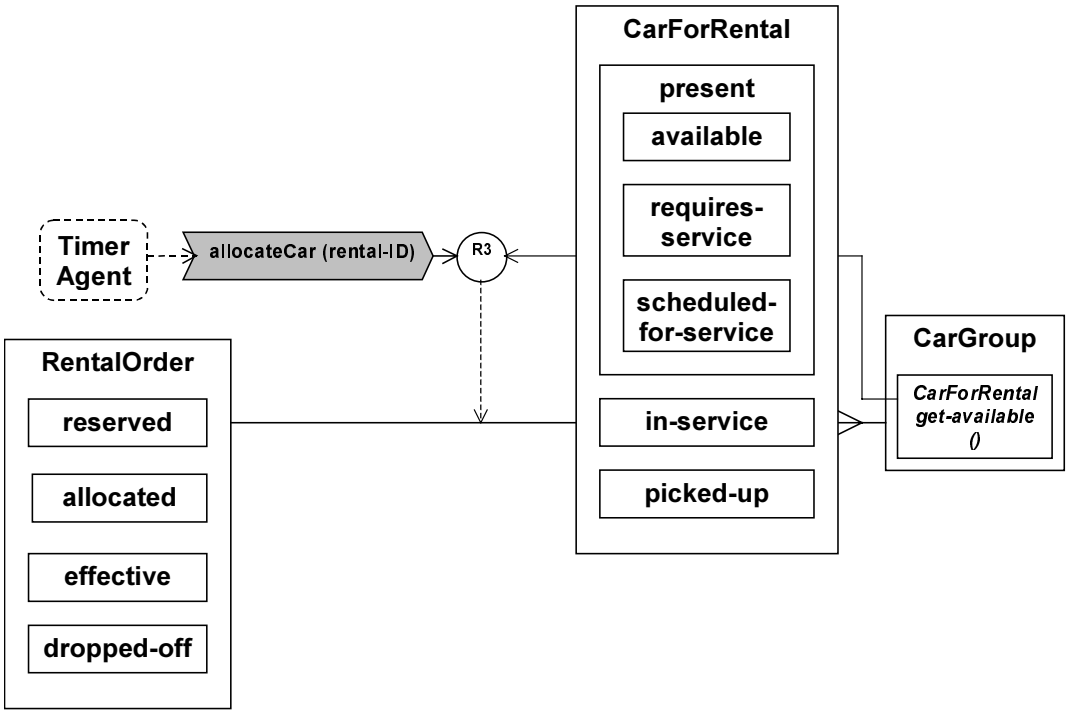


Figure 4. The AOR model of the business process of car allocation for advance reservations from the perspective of a Branch Agent

The business process of picking up a car from the perspective of a Branch Agent is represented in Figure 5. It consists of the following reaction rules:

R4. Upon receiving from a *Customer* a pick-up-request referring to some *RentalOrder*, the *Branch Agent* first makes sure that the *Customer* does not already have a car rented from any branch of the company by asking that from the *Headquarter Agent*;

R5. Upon receiving from the *Headquarter Agent* a reply confirming that the *Customer* does not have a car rented from any branch of the company, the *Branch Agent* provides the car (and the customer respectively picks up the car), changes the state of the corresponding instance of *CarForRental* to *picked-up*, and informs the *Headquarter Agent* about the new effective *RentalOrder* (i.e. a *RentalOrder* where the car has been picked up).

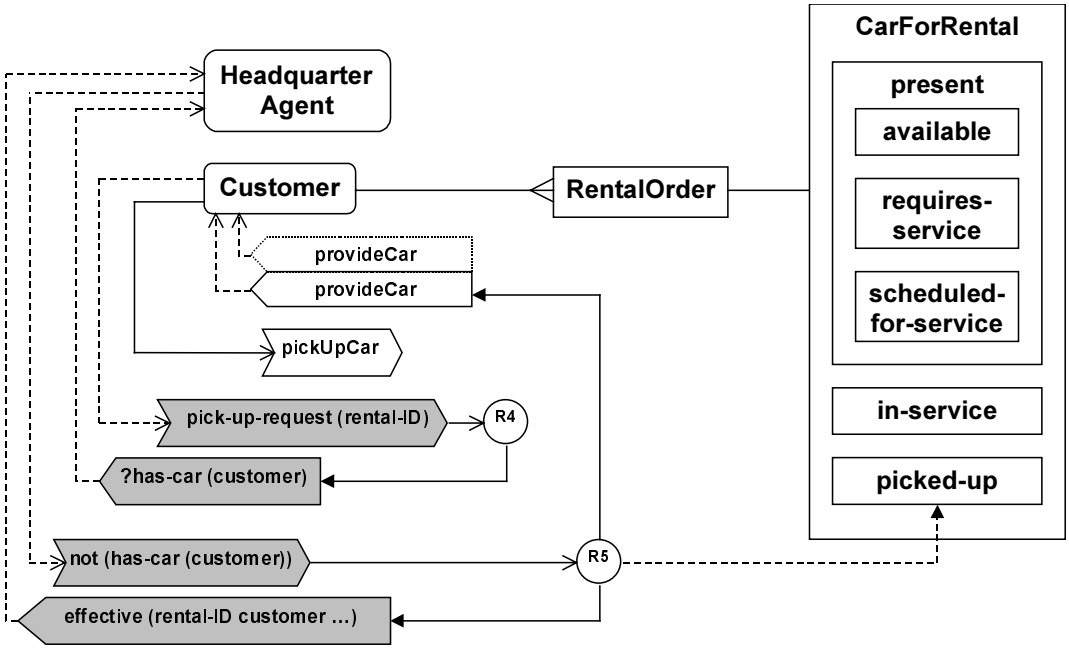


Figure 5. The AOR model of the business process of picking up a car from the perspective of a Branch Agent

Figure 6 depicts the business processes of *picking up a car* and *dropping off a car from the perspective of the Headquarter Agent*. The reaction rules represented in Figure 6 are:

R6. Upon receiving from a *Branch Agent* the message about the new effective *RentalOrder*, the *Headquarter Agent* inserts into its VKB the corresponding instance of *RentalOrder* in the state *effective* (as a result of which the derivation rule D6 changes the state of the *Customer* to *has-car*, see Figure 2), and inserts a claim against the *Customer* to return the car;

R7. Upon receiving from a *Branch Agent* a message telling that the car of the given *RentalOrder* has been dropped off, the *Headquarter Agent* changes the state of the corresponding instance of *RentalOrder* to *dropped-off*.

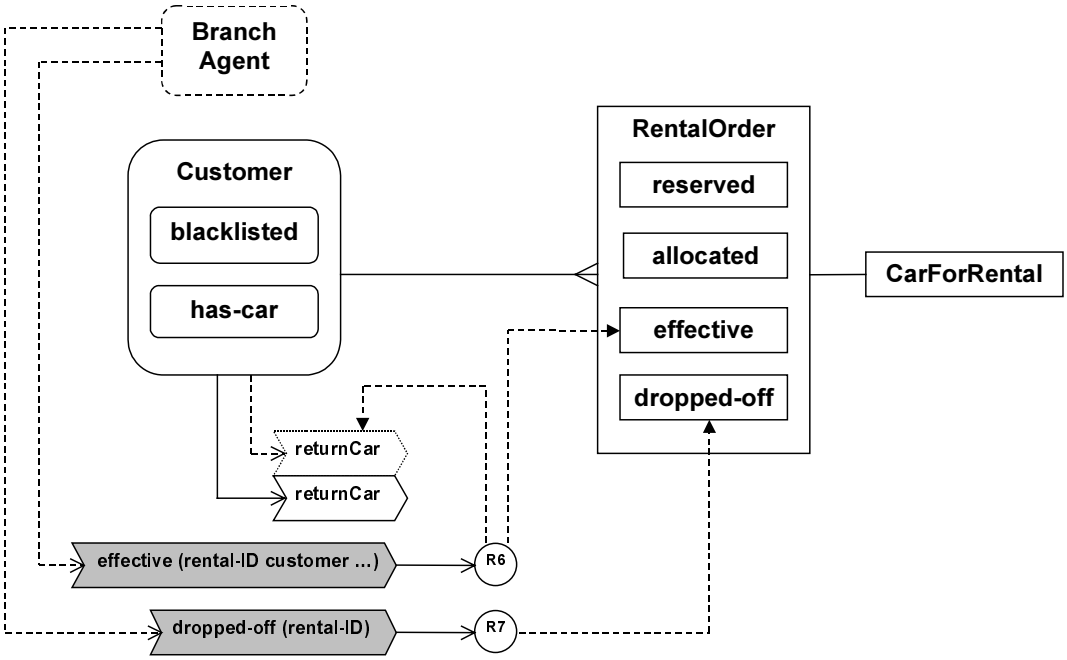


Figure 6. The AOR model of the business processes of picking up and dropping off a car from the perspective of the Headquarter Agent

And finally, the business processes of *dropping off a car* and *scheduling a car for automotive service from the perspective of a Branch Agent* are represented in Figure 7. The rules of these business processes are:

R8. When the *Customer* drops a car off at the branch, then:
- the *Branch Agent* informs the *Headquarter Agent* about the drop-off;
- an instance of *CarForRental* in the state *present* is created for that car, or if *pick-up-branch = drop-off-branch*, the state of the corresponding instance of *CarForRental* is changed from *picked-up* to *present*;

R9. When the *Customer* drops a car off at the branch, then if the car requires service (i.e. the corresponding instance of *CarForRental* is in the substate *requires-service,* determined by the derivation rule D7 depicted in Figure 2), the request to schedule the car for service is sent to the *Automotive Service Agent*;

R10. Upon receiving from the *Automotive Service Agent* the automotive service confirmation, the *Branch Agent* changes the state of the corresponding instance of *CarForRental* to *scheduled-for-service*, and inserts the commitment to send the car to service;

A1. In order to fulfill the *sendCarToService* commitment, the human subagent *Car Handling Agent* of the *Branch Agent* sends or takes the car himself to the *Automotive Service Agent* for service (see also Operational Rule 3 in Table 2) which results in the change of the state of *CarForRental* from *scheduled-for-service* to *in-service* and in the insertion of the claim against the *Automotive Service Agent* to return the car.

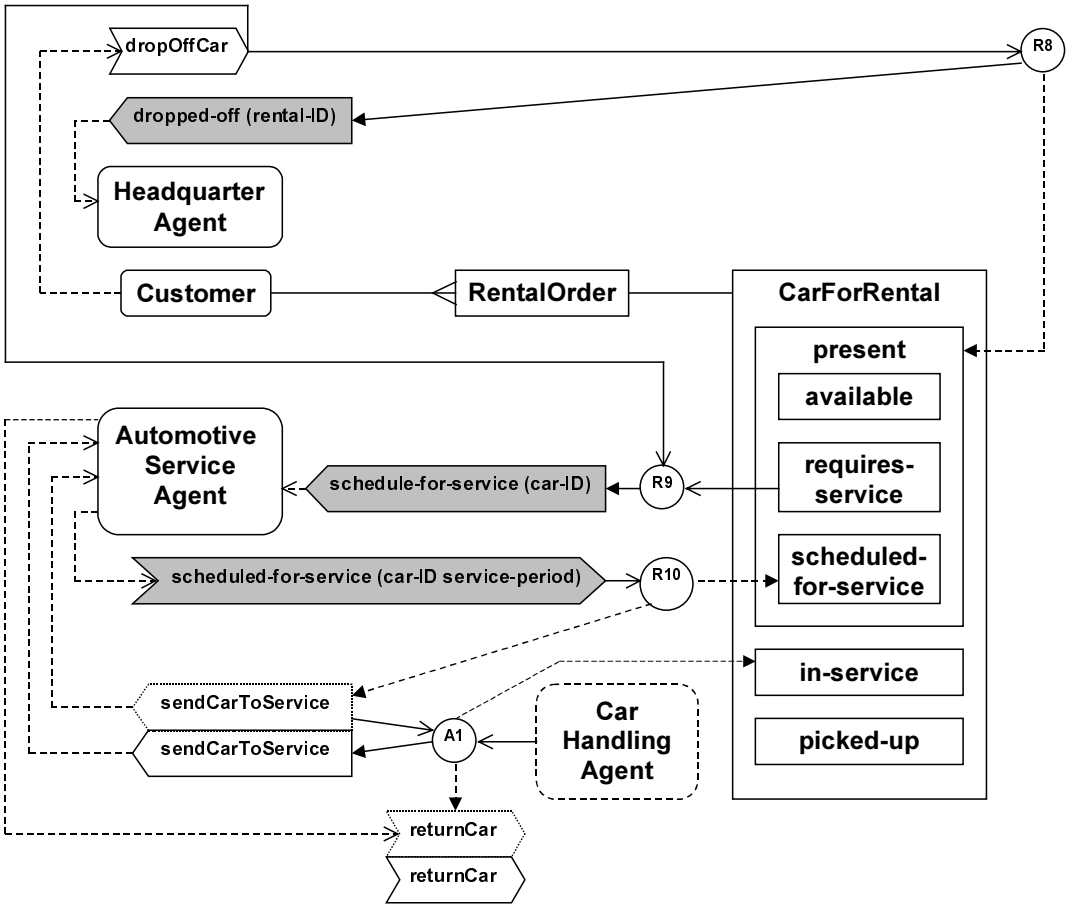


Figure 7. The AOR model of the business processes of dropping off a car and scheduling a car for automotive service from the perspective of a Branch Agent

4. Related Work

In the paper [22] a general methodology for agent-oriented analysis and design is presented. The proposed methodology deals with both the macro-level (societal) and the micro-level (agent) aspects of systems. In the analysis phase of the methodology, the *roles* in the system are identified and the patterns of interaction that occur in the system between various roles are recognized. The functionality of each role is defined by its liveness and safety responsibilities. *Liveness responsibilities* are those that say "something will be done", e.g. "whenever the coffee machine is empty, fill it up". *Safety responsibilities* relate to the absence of some undesirable condition arising, e.g. "the coffee stock should never be empty". In the design phase, the liveness and safety responsibilities are respectively

mapped to agents' *services* and *pre-* and *postconditions* on each service. Liveness and safety responsibilities thus bear a close resemblance to business rules. The difference from our work is that the methodology proposed in [22] is a software engineering approach, while our approach is aimed at creating business information systems. Another important difference is that while [22] has adopted an objective observer's point of view in modeling agent systems, the AOR modeling enables modeling from the perspectives of different agents involved.

In the work described in [15] agents are directly applied to managing business processes. The main difference from our work is that [15] focuses on the interaction and negotiation aspects of business processes, and does not explicitly treat conceptual models of the problem domain, and agents' beliefs and (re)actions.

The paper [19] also concentrates on the interaction aspects of agents in the domain of integrated supply chain management, and particularly on the agents' mutual obligations and interdictions.

Conceptual modeling of the problem domain is included in the paper [23] where concepts and relations between concepts are defined in hierarchies and rules that are used for automatic generation of prototype agent applications directly from their specifications. The latter is also one of our future intentions.

As was already mentioned in section 1, object-oriented approaches such as described in [13], [25], and [26], do not support the concept of an agent, and are therefore not relevant to be discussed here.

5. Conclusions and Future Work

Agent-oriented concepts allow the seamless integration of business rule modeling and information modeling. Our approach is based on the rather well-developed methodology of capturing information systems' requirements in the form of business rules (see e.g. [10, 11, 20]). Implementation of business rules has been traditionally connected to (active) databases [16]. We have widened the sphere of applying business rules by showing that they can also be interpreted and implemented as a combination of action and reaction rules, and of derivation rules associated with the ontology of the problem domain.

Additionally, we have empirically proved that the claim in [14] according to which dynamic integrity constraints cannot be represented through a visual formalism is not entirely true. In particular, the conditional parts of dynamic integrity constraints can be represented by using the Ross Notation, while the AOR modeling enables to represent their event and action parts. However, the Ross Notation does not allow for graphical modeling of intensional predicates whose values depend on the values of parameters. The AOR modeling proposal in its present stage leaves several issues unanswered. Although [9] provides a sketch how an AOR model can be transformed into an object-relational database schema, the logical and operational semantics of AOR models is not yet sufficiently established. In particular, the semantics of the deontic concepts of AOR modeling seems

to be a challenging research issue. Furthermore, the relationship of AOR diagrams to the process modeling concepts of UML needs to be investigated.

We think that agents are well-suited to be used in *cooperative information systems* [2] where both data and application logic are distributed like e.g. in our experimental information system of car rental. We hope our work to be a step from the currently predominant client/server systems [17] towards the peer-to-peer systems of the future.

Our present models represent just positive scenarios, and do not address the cases where something goes wrong, like e.g. when a customer does not appear to pick up a car as agreed, or when the automotive service station fails to return a car on time. We plan to introduce *models for exceptions* in our future work.

Our other future aims include further *formalization*, *verification*, and *validation* of our work. Another important aim is is to work out the environment that would enable *semiautomatic generation of object-oriented implementations of agent-oriented business information system*s from their high-level descriptions by graphical agent-oriented models. Such an environment should also enable interactive visualizing of graphical models. Since many business rules in real life are essentally of a "fuzzy" nature, we plan to introduce *fuzzy business rules for agents*. We also plan to introduce modeling-time *consistency checks* for the rules, commitments, and claims of an agent and deal with the *delegation of commitments* between agents.

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