

# Modelling and Administration of Contract-Based Systems

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**Abstract.** Mirroring the paper versions exchanged between businesses today, electronic contracts offer the possibility of dynamic, automatic creation and enforcement of restrictions and compulsions on agent behaviour that are designed to ensure business objectives are met. However, where there are many contracts within a particular application, it can be difficult to determine whether the system can reliably fulfill them all; computer-parsable electronic contracts may allow such verification to be automated. In this paper, we describe a conceptual framework and architecture specification in which normative business contracts can be electronically represented, verified, established, renewed, etc. In particular, we aim to allow systems containing multiple contracts to be checked for conflicts and violations of business objectives. We illustrate the framework and architecture with an aerospace example.

## 1 Introduction

It has often been argued that agents interacting in a common system, society or environment need to be suitably constrained in order to avoid and solve conflicts, make agreements, reduce complexity, and in general to achieve a desirable social order (e.g. [4, 5]). For many, this role is fulfilled by norms, which represent what *ought* to be done by a set of agents. Views of norms differ, and include fixed laws that must never be violated as well as more flexible social guides that merely seek to bias behaviour in different ways. Yet the obligations, prohibitions and permissions that may affect agent behaviour in a normative system can also be *documented* and communicated between agents in the form of *contracts*. Electronic contracts, mirroring the paper versions exchanged between businesses today, offer the possibility of dynamic, automatic creation and enforcement of such restrictions and compulsions on agent behaviour. However, where there are many contracts within a particular application, it can be difficult to determine whether the system can reliably fulfill them all; computer-parsable electronic contracts may allow such verification to be automated.

There are two pre-requisites to realistically applying an electronic contracting approach in real-world domains. First, to exploit electronic contracts, a well-defined conceptual framework for contract-based systems, to which the application entities can be mapped, is needed. Second, to support the management of contracts through all stages of the contract life-cycle, we need to specify the functionality required of a contract management architecture that would underly any such system, leading to ready-made implementations for particular deployments of that architecture.

The CONTRACT project<sup>3</sup> aims to do just this. Funded by the European Commission as part of its 6th Framework Program, the project seeks to develop frameworks, components and tools that “make it possible to model, build, verify and monitor distributed electronic business systems on the basis of dynamically generated, cross-organisational contracts which underpin formal descriptions of the expected behaviours of individual services and the system as a whole.” In this context, this paper documents the CONTRACT project’s work on both of the pre-requisites identified above. The aims and vision of the project are described in full elsewhere [17]. More specifically, the technical contributions described in this paper are: the specification of a model for describing contract-based systems; the specification of an architecture for managing such systems; and the mapping of an aerospace application to those models.

Our approach takes a distinct approach in several respects. First, its development is explicitly driven by a range of use cases provided by a diverse set of small and large businesses. One consequence of this diversity is that our approach must account for different practices and possibilities in each stage of the lifecycle of a contract-based system. It is therefore defined in terms of abstract *process types*, to be instantiated in different ways for different circumstances. We provide a non-exhaustive set of options for instantiating these process types, and technologies to support these processes. A more specific requirement addressed by our approach is in managing not just fulfilment or violation of contractual obligations, but also other states of the system with regard to those obligations, such as being in danger of violation, being expected to easily fulfil an obligation, and application-specific states.

In the next section, we provide an overview of the overall structure, introducing the conceptual framework and applying it to a running example. Then, in Section 3, we discuss how the contractual obligations imply *critical states* of the system that we may wish to detect and react to in order to effectively manage the system. In Section 4, we describe the architecture: the process types that are required to manage contract-based systems and components that can support such processes. We discuss related work in Section 5 and conclude with future work in Section 6.

## 2 CONTRACT Framework and Architecture

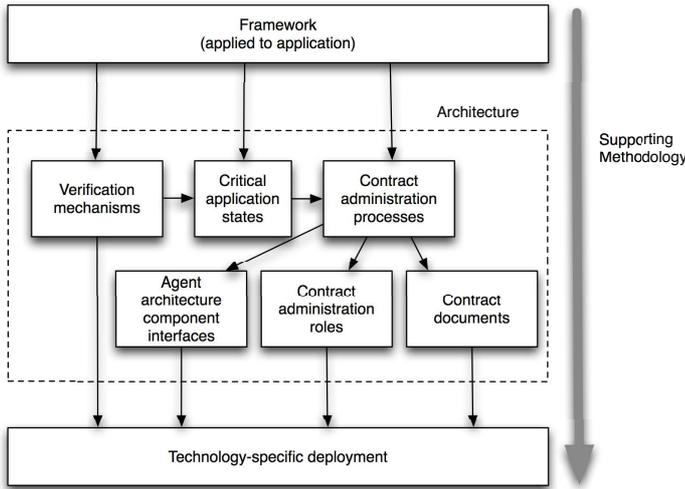
The models and procedures comprising the CONTRACT *framework* and *architecture* are shown in Figure 1. The primary component of this is the framework itself, depicted at the top of the figure, which is the conceptual structure used to describe a contract-based system, including the contracts and the agents to which they apply.

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**Figure 1.** The overall structure of the CONTRACT architecture and framework

From the framework specification of a given application, other important information is derived. First, understanding the contractual obligations of agents allows us to specify the *critical states* that an application may reach. A critical state of a contract-based system with regard to an obligation essentially indicates whether the obligation is fulfilled or fulfillable, e.g. achieved, failed, in danger, etc. This is discussed in detail in Section 3. A state-based description, along with the deontic and epistemic implications of the specified contracts, can then be used to verify a system either off-line or at run-time [11] (though we do not discuss this further here).

The framework specification is used to determine suitable processes for administration of the electronic contracts through their lifetimes, including establishment, updating, termination, renewal, and so on. Such processes may also include observation of the system, so that contractual obligations can be enforced or otherwise effectively managed, and these processes depend on the critical states identified above. Once suitable administration processes are identified, we can also specify the roles that agents play within them, the components that should be part of agents to allow them to manage their contracts, and the contract documents themselves. Such process types and roles are described in Section 4.

## 2.1 A Contract-Based System Framework

We first specify a conceptual framework by which contract-based systems can be described. This framework provides a clear indication of how particular applications can exploit contracts and how they must be supported in managing them. By being abstract and generic, such a framework may also be used to translate contract data from one concrete format to another.

*Contracts* document *obligations*, *permissions* and *prohibitions* (collectively *clauses*) on agents and are *agreed* by those agents. Simply, obligations are statements that agents should do something and prohibitions are statement that they should not. Since agents are *autonomous*, external control can only be specified through normative structures such as contracts. Thus, permissions are defined as exceptions to prohibitions: if something was not prohibited, it is not mean-

ingful for a permission to be granted.

The agents obliged, permitted and prohibited in a contract are *parties* to that contract, which specifies *contract roles*, played by agents within it. Each clause in a contract applies to roles, to which agents are *assigned*, and each agent can hold multiple contracts with the same or different parties. Finally, a *contract proposal* is one that has not yet been agreed. These concepts are summarised in Table 1.

Concept	Definition
Role	A named part that can be played by an agent in a system.
Obligation	A statement that an agent playing a given role should do something.
Prohibition	A statement that an agent playing a given role should not do something.
Permission	An exception to a prohibition for an agent playing a given role under given circumstances.
Clause	An obligation, prohibition or permission.
Assignment	A statement that an agent should play a given role.
Proposal	A document containing a set of clauses and assignments, where every role referred to which each clause applies has been assigned to an agent.
Contract	A proposal to which all assigned agents have agreed.

**Table 1.** The primary concepts in the CONTRACT framework

## 2.2 Aerospace Use Case

To test and illustrate the efficacy of our approach, we adopt an engineering application, based on the aerospace aftercare market, targeted by Lost Wax’s agent-based Aerogility platform [1], and used as a running example through the paper.

The application concerns the continued maintenance of aircraft engines over their lifetime. In this domain, an engine manufacturer is contractually obliged to ensure operators’ aircraft have working engines. For an engine to be working, it should not be overdue for regular servicing or left waiting to be fixed after a fault is discovered. An aircraft’s engine can be replaced when it lands at some location if there is a suitable spare engine present at that location. As well as replacing engines to ensure continued operation of the aircraft, an engine manufacturer will service the engines it has removed, so that the serviced engine can be added back into circulation (the “engine pool”) and used to replace other engines.

In addition to long-term contracts between engine manufacturers and operators, we consider short-term contracts regarding particular instances of servicing engines. These sit in the context of long-term contracts but, by being specified explicitly, allow the parties to use and commit to resources more flexibly. In a long-term contract between an aircraft operator and an engine manufacturer, the manufacturer agrees to service the operator’s aircraft to some overall specified standard over the duration of the contract. Such a contract is provided in Table 2, using the framework concepts. Here, the operator specifies a preferred time within which the manufacturer must service an aircraft, and the manufacturer is obliged to meet this in 90% of cases. If the manufacturer does not meet short-term contract requirements (see below), penalties are deducted from the long-term payment the operator is obliged to make. The operator is obliged to provide adequate engine data so that the manufacturer can fulfil their servicing obligations. Finally, the operator may have demands on the provenance of an engine: operator *A* may be happy to re-use engines previously used by operators *B* or *C* but not those used by *D*.

In this context, a short-term contract concerns the servicing of a particular aircraft at a particular time (see Table 3). It is again between two parties: the aircraft operator and the engine manufacturer.

<b>Roles</b>	Manufacturer, Operator
<b>Obligations</b>	<b>O1</b> Manufacturer agrees to servicing contracts requested by operator during aftercare contract period.
	<b>O2</b> Manufacturer services engines within the preferred time specified by the servicing contracts in at least 90% of cases.
	<b>O3</b> Operator pays for servicing of engines, minus any penalties.
	<b>O4</b> Operator must supply engine health data to the manufacturer in an adequate time to allow problems requiring unscheduled maintenance to be detected.
<b>Prohibitions</b>	<b>P1</b> Manufacturer is prohibited from supplying engine parts previously used by other operators not on an approved list (if one is given) or on a disapproved list (if one is given).
<b>Permissions</b>	<b>R1</b> Manufacturer is allowed to supply engine parts previously used by other operators on an approved list (if one is given).

**Table 2.** Long-term aftercare contract

In this case, the manufacturer has more specific obligations: that they must either service an aircraft in the preferred timescale or pay a penalty, and that they must service it within a maximum period. The limitations on provenance apply in the particular short-term servicing as they do in the long-term aftercare.

<b>Roles</b>	Manufacturer, Operator
<b>Obligations</b>	<b>O5</b> Manufacturer services aircraft in preferred time, or pays penalty (taken out of aftercare contract payment from operator).
	<b>O6</b> Manufacturer services engine in maximum time.
<b>Prohibitions</b>	<b>P2</b> Manufacturer is prohibited from supplying engine parts previously used by other operators not on an approved list (if one is given) or on a disapproved list (if one is given).
<b>Permissions</b>	<b>R2</b> Manufacturer is allowed to supply engine parts previously used by other operators on an approved list (if one is given).
	<b>R3</b> Operator is allowed to take a penalty from the manufacturer if an aircraft is left on the ground for longer than the preferred time agreed.

**Table 3.** Short-term servicing contract

Such formal documents of agreements are important, especially when there are multiple agreements and when these agreements can interact, because they can reveal critical points of potential or actual conflict. If it is possible to examine such contracts, and determine where these critical points lie, so that they may be monitored for violations, or even modified to avoid the potential for violation. In what follows, these aims inform the elaboration of our architecture. For example, a short-term conflict between two servicing contracts in the aerospace domain occurs when a manufacturer is obliged to service two operators' aircraft at the same time, but can only service one due to a lack of resources. Long-term conflicts are also present, as in a conflict between a servicing contract and an aftercare contract arising when a manufacturer must choose between servicing one operator's aircraft within the maximum time limit and servicing another operator's aircraft within the preferred time, where the manufacturer is in danger of not having serviced the latter operator's aircraft within the preferred time limit for 90% of cases.

### 3 Critical States of Contract-Based Systems

By identifying the *critical states* of the system with respect to given contractual obligations, indicating whether the obligation is fulfilled or fulfillable, it is then easier to determine which of these needs to be checked for and acted upon to ensure that the system performs well. A state-based description can also be used as a basis for verifying whether the system will always result in a desirable state.

### 3.1 Obligation States

Each obligation implies a set of states for the system with regard to that obligation. In part, these can be specified independently of the application. For example, we classify obligations into three types:

- An obligation to *achieve* some state  $G$ , e.g. to pay some amount to another agent.
- An obligation to *maintain* some state  $H$ , e.g. to keep an aircraft in working order.
- An obligation to *behave* in some way, where that behaviour is to fulfil obligation  $O(X)$  whenever event  $E(X)$  occurs, e.g. when aircraft  $X$  requires servicing, to service  $X$  in an acceptable time.

For an achievement obligation, there are three significant states: *Pre-achievement*, *Succeeded* and *Failed*. Each of these has particular properties with regard to the goal state  $G$ , as shown in Table 4 (top). In *Pre-achievement*, the goal state is achievable but not yet achieved; in *Succeeded*, the system is in the goal state; and in *Failed*, the goal state is no longer achievable. Similarly, a maintenance obligation implies three significant states, as shown in Table 5 (top). In the *Maintained* state, the system is in the goal state; in *Succeeded*, the system can no longer leave the goal state; in *Failed*, the system has left the goal state. Finally, the significant states of a behaviour obligation depend on the obligation,  $O$ , triggered in reaction to each event, but it has some states of its own as shown in the top of Table 6. In the *Pre-trigger* state, the triggering event has not yet occurred; in the *Reaction Active* state, an event has occurred but the obligation it has triggered into taking force has not yet reached a *Succeeded* or *Failed* state; in *Reaction Failed*, that reaction obligation has reached a *Failed* state, and so the behaviour obligation as a whole has failed; in *Reaction Succeeded* state, the particular reaction obligation has succeeded; and in *Succeeded*, no more applicable events can ever occur and so the behaviour obligation as a whole has succeeded. All obligations also imply a state, *Cancelled*, when the obligation no longer holds.

State	Properties
Pre-achievement	Not $G$ $G$ achievable Agent obliged to achieve $G$
Succeeded	$G$
Failed	$G$ unachievable Agent obliged to achieve $G$
Cancelled	No agent obliged to achieve $G$
Sub-State	Additional Properties
Initial	
Danger	$G$ in danger of becoming unachievable
Likely Success	$G'$ achieved, where $G'$ is a significant subset of $G$

**Table 4.** Basic states (top) and sample pre-achievement sub-states (bottom) of an achievement obligation

### 3.2 Significant Sub-States

In addition to the application-independent system states above, applications often refer to significant sub-states part-way between an obligation coming into force and its success or failure. Examples of these are shown in the bottom portion of Tables 4, 5 and 6. For example, an application may need to detect whether an obligation is in danger of violation and so allocate more resources to ensure that it is fulfilled instead, implying a *Danger* critical state of the system with regard to that obligation as shown in Table 4 (bottom). On the other hand, if an obligation is being fulfilled unexpectedly easily, an

State	Properties
Maintained	H Not H achievable Agent obliged to maintain H
Succeeded	Not H unachievable
Failed	Not H Agent obliged to maintain H
Cancelled	No agent obliged to maintain H
Sub-State	Additional Properties
Initial	
Danger	Not H in danger of becoming true

**Table 5.** Basic states (top) and sample maintained sub-states (bottom) of a maintenance obligation

application may take advantage of this by transferring resources being used in support of this obligation to other tasks, e.g. the *Likely Complete* critical state shown in Table 6.

State	Properties
Pre-trigger	No new E(X) has occurred Agent obliged to achieve G(X), maintain G(X) or behave in way B(X) on every E(X)
Reaction Active	E(a) occurred  As Pre-achievement, Maintenance or Pre-trigger state for G(a)/B(a) Agent obliged to achieve G(X), maintain G(X) or behave in way B(X) on every E(X)
Reaction Failed	E(a) occurred  As respective Failure state for reaction G(a) or B(a) Agent obliged to achieve G(X), maintain G(X) or behave in way B(X) on every E(X)
Reaction Succeeded	E(a) occurred  As respective Succeeded state for reaction G(a) or B(a) Agent obliged to achieve G(X), maintain G(X) or behave in way B(X) on every E(X)
Succeeded	E(X) can never occur again
Cancelled	No agent obliged to achieve G(X), maintain G(X) or behave in way B(X) on every E(X)
Sub-State	Additional Properties
Initial	
Imminent	E(X) is likely to occur imminently
Likely Complete	E(X) is unlikely to occur again

**Table 6.** Basic states (top) and sample pre-trigger sub-states (bottom) of a behaviour obligation

### 3.3 Example

As an example, in Table 7, we enumerate critical states for an achievement obligation, indexed **O2**, in the long-term aftercare contract of Table 2. It is an achievement obligation as it describes an eventual state of the system in which a state has been achieved, i.e. 90% of servicing cases were performed in the preferred time period. When the contract first comes into force, i.e. the system time is within the contract period, the state Pre-achievement: Initial holds. In this state, insufficient cases have been performed to determine whether success is likely. After 5% of cases are performed, the system will be in either Pre-achievement: Satisfactory or Pre-achievement: Danger states, and may vary between them over the contract period. Pre-achievement: Satisfactory holds where over 5% of cases are performed within the preferred time, while Pre-achievement: Danger holds where between 5% and 10% of cases exceeded that time. The value of taking account of these two states is that transfer of resources between fulfilment of different obligations can be triggered by changes of state. Eventually, the system will reach either Succeeded state, where the contract period is exceeded and over 90% of cases were performed on time, or Failure state, where over 10% have

exceeded the preferred time. The choice of the appropriate sub-states (Pre-achievement: Satisfactory and Pre-achievement: Danger in this case) is entirely application dependent: considering more states allows finer control as appropriate, but may also add overheads.

Pre-achievement: Initial	Less than (estimated) 5% of servicing cases performed and within contract period
Pre-achievement: Satisfactory	Over 5% of cases performed, less than 5% exceeded preferred time and within contract period
Pre-achievement: Danger	Between 5% and 10% of cases exceeded preferred time and within contract period
Succeeded	Less than 10% of cases exceeded preferred time and beyond contract period
Failed	More than 10% of cases exceeded preferred time

**Table 7.** States of aftercare contract obligation **O2**

## 4 Architecture of Contract-Based Systems

Aside from modelling contract-based systems using the CONTRACT framework, we also address the issue of administration: how to manage the processes involved in creating, maintaining, acting on and otherwise processing contracts and contract proposals. We identify four key process types in the contract life-cycle.

**Establishment** brings about the existence of the contract.

**Maintenance and Update** ensures a contract's integrity over time.

**Fulfilment** brings about the fulfilment of obligations while observing its prohibitions.

**Termination or Renewal** end the normative force of the contract, or renew it to apply for a longer period.

Each of these process types can be instantiated in different ways, depending on the application and its deployment. The choice dictates the roles agents must play to fulfil the administration duties implied. Below, we examine each process type in turn.

### 4.1 Establishment

There are many potential ways to establish a contract, varying in complexity. To give an illustration, we present two below.

**Full Proposal Establishment Process** Here, one party, the *proposer*, creates a full proposal, excluding some assignments of roles to agents, and signs it. It then uses a *registry* to discover agents that may fulfil the unassigned contract roles. For each unassigned role in turn, it offers the proposal to an agent, a *potential party* it is satisfied can assume that role. If the party is willing, it signs the proposal and returns it. When the last role is filled, a contract is established

**Template Discovery Establishment Process** Alternatively, a process may be used in which an agent discovers a contract *template* that may be instantiated in a way that fulfils its goals. This implies the use of a *template repository*, where templates can be stored. Such templates may have some assigned roles; that is, they may describe services for which a provider is willing to negotiate terms.

### 4.2 Maintenance and Update

The continued existence and integrity of a contract after establishment is important in reliable systems. As with establishment, there

are multiple ways in which this can be achieved, and the functionality that needs to be provided depends on the particular contract and application.

**Contract Store Maintenance Process** Here, contract parties use a *contract store* to maintain and control access to contracts. The store is obliged only to allow agents to change the contract when all parties send a signed agreement of the change to be made.

**All Party Signature Maintenance Process** In this process, integrity is preserved by the contract being signed by all parties in a way that prevents editing without detection; for example, digital signatures based on reliable certificates. The signed document includes the contract itself, and an indication of whether it is a revision of a previous version. Each party should check the signatures of the contract before accepting it as binding.

### 4.3 Fulfilment

For every contractual obligation and prohibition, there are certain processes that can be performed to help ensure they are fulfilled. As with the processes above, these imply particular administrative roles that must be played by agents. The administrative roles carry with them obligations, prohibitions and permissions, which may be documented in the same contract as the one that is the target of administration, or another contract. The processes below often refer to particular system states with regard to obligations: these are the states specified in Section 3.

**Observation of Fulfilment Process** An *observer* observes state changes to determine whether contractual obligations are being fulfilled. It can notify other agents when an obligation is being violated or in danger of violation<sup>4</sup>. An observer  $X$  is in an obligation pattern of the following form:

$X$  is obliged to observe for critical state  $S$  of contract clause  $C$ , and notify registered listeners when it occurs.

**Management of Fulfilment Process** A *manager* is an agent that acts when an obligation is not being fulfilled, is in danger of not being fulfilled or a prohibition is breached. It knows about the problem by (conceptually at least) registering to listen to the notifications from an observer. Manager is a role, and one agent may play the role of both manager and observer. The nature of the action taken by a manager may vary considerably. In highly automated and strict applications, an automatic penalty may be applied to a party. In other cases, a management agent may be a human who decides how to resolve the problem. Alternatively, a manager may merely provide analysis of problems over the long term, so that a report can be presented detailing which obligations were violated. A manager  $X$  is in an obligation pattern of the following form:

$X$  is obliged, whenever the system reaches a critical state  $S$  of contract clause  $C$ , to perform action  $A$ .

Note that we avoid the sometimes used term, *enforcer*, because enforcement implies action either in the case of failure or in the case of likely failure, and often sanctions or financial penalties. In the applications we are considering, likely success is also a good state to act upon, e.g. to reallocate resources used for the successful obligation,

<sup>4</sup> Note that we do not use another term sometimes appearing in the literature, *monitor*, because it is also often used to refer to quantitative infrastructure-level measurements of system metrics: in the case of many business applications, observation is of discrete high-level states.

and actions may take softer forms, e.g. notified humans renegotiate the contract, so the more generic term, manager, is used.

An example of an observer's obligation in the aerospace application is shown in Table 8 (top), and of a manager's obligation in Table 8 (bottom). The observer, Checker, is obliged to check that a Danger state has not been reached for the number of suitable engines available at a given location, and the manager, Enforcer, listens to observations on this state and rectifies the situation when it occurs.

<b>Roles</b>	Checker, Manufacturer, Operator
<b>Obligations</b>	Checker monitors the number of engines available to the manufacturer at a given location that are suitable for a given operator, and notifies registered agents if it falls below a minimum quantity.
<b>Roles</b>	Enforcer, Checker
<b>Obligations</b>	Enforcer, on hearing from checker that the number of suitable engines at a location has fallen below a minimum level, transports a suitable engine from another location.

**Table 8.** Engine supply checking contract (top) and Engine supply enforcement contract (bottom)

### 4.4 Termination and Renewal

Termination of a contract means that the obligations and other clauses contained within it no longer have any force. A contract may be terminated in several ways: (i) it may terminate *naturally* if the system reaches a state in which none of its clauses apply, e.g. a contract's period of life expires or all obligations have been met; (ii) it may terminate *by design* if the contract has an explicit statement that the contract is terminated when a particular event occurs (e.g. if one party fails to meet an obligation, the contract is terminated and all others are released from their obligations); or (iii) it may terminate *by agreement*, if parties agree that the contract should no longer hold, and update it accordingly (in line with the process chosen for the Maintenance and Update type above). Renewal of a contract means that a contract that would have imminently terminated naturally is updated so that termination is no longer imminent (again depending on the Maintenance and Update process type above).

### 4.5 Administrative Roles and Components

The processes above all require the fulfilment of particular administrative roles, e.g. contract store, registry, observer, manager. For some of these components, we can provide generic implementations. For example, a contract store, based solely on contract documents and having nothing to do with the application itself, is easy to implement generically. Others, such as managers, need to have application-specific instantiations, as dealing with a contractual obligation not being fulfilled varies greatly between applications. Specifying the components further is largely a technology-dependent issue out of scope of this paper.

## 5 Related Work

There has been much previous work on various aspects of contract-based system modelling, enactment and administration, and our approach is intended to build on and be compatible with other ideas presented elsewhere. For example, there are many approaches to negotiation which may be used in the establishment of contracts [12], and the administration of contracts can integrate with other useful behaviour, such as observation of fulfilment and violation of obligations

potentially feeding into a longer-term assessment of agents [7]. Work on multi-party contracts [18] adopt modelling techniques specifically designed to enable detection of parties responsible for contract violation, but do not use normative concepts to regulate agent behaviour, or model other contract administration processes.

In addition, the wider domains of normative systems and agreement in service-oriented architectures informs our work. Concepts such as norms specifying patterns of behaviour for agents, contract clauses as concrete representations of dynamic norms, management or enforcement of norms itself being a norm, are all already established in the literature [6, 7, 14, 8].

However, the approach in this paper is distinct in that it is concerned with the development of practical system deployments for business scenarios. In particular, business systems operate in the context of wider organisational and inter-organisational processes, so that *commitments*, providing assurance over the actions of others assumes great importance. While potentially less flexible over the short term, explicit contracts provide just such commitments and are therefore more appropriate for business systems than more flexible, less predictable *ad hoc* approaches [9, 16].

We also believe our system to be more widely applicable than some other approaches. By classifying processes into types with different instantiations, the architecture can be incorporated into a wider range of application domains and deployments than fixed protocols would allow. In addition, we describe how administrative functions, such as storing or updating a contract, can be achieved. This contrasts with specifications such as WS-Agreement and Web Services Service Level Agreement, where the specifications cover only part of the necessary administration [2, 15]. Abstract architectures for electronic contracting, and associated case studies, have been described elsewhere; most notably in the work of Grefen et al [10, 3]. However, accommodation of deontic specifications in order to regulate agent behaviour is not modelled in this work. Our approach aims for broad observation and management of obligations and prohibitions, so as to verify whether they are being achieved, prevent failure when in danger of violation and take advantage of success when obligations are being easily met. Some existing work does consider system states with regard to contract clauses [13], but none, to our knowledge, classifies obligations and the critical states they imply as we have done in this paper, a necessary pre-requisite to observing and managing obligation fulfilment in accordance with a particular application.

## 6 Conclusions and Future Work

In this paper, we have presented the CONTRACT conceptual framework and architecture, and shown how they apply to aircraft aftercare. By creating a technology-dependent implementation along these lines, an application can take advantage of the reliable coordination provided by electronic contracts. The CONTRACT project aims to allow multi-agent systems to be verified on the basis of their contracts, building on work by Lomuscio et al. on deontic interpreted systems [11]. While this verification is beyond the scope of this paper, it places a requirement on our framework that the properties of the target system are identified and isolatable, and a requirement on the architecture that such information can be captured in order to pass to a verification mechanism. Perhaps equally importantly, we also aim for an open source implementation built on Web Services technologies, requiring the architecture to be compatible with such an objective. Finally, taking a very practical standpoint, we intend to construct a methodology to guide development of applications that

use electronic contracts through the process from conceptual framework to deployment.

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## REFERENCES

- [1] Aerogility. <http://www.aerogility.com/>, 2007.
- [2] A. Andrieux, K. Czajkowski, A. Dan, K. Keahey, H. Ludwig, Jim Pruyne, J. Rofrano and S. Tuecke, and M. Xu, 'Web services agreement specification (ws-agreement)', Technical report, Global Grid Forum, (2004).
- [3] S. Angelov and P. Grefen, 'A case study on electronic contracting in on-line advertising - status and prospects', in ; *Network-Centric Collaboration and Supporting Frameworks - Proceedings 7th IFIP Working Conference on Virtual Enterprises*, pp. 419–428, (2006).
- [4] R. Conte and C. Castelfranchi, 'Norms as mental objects. From normative beliefs to normative goals', in *MAAMAW93*, pp. 186–196, (1993).
- [5] R. Conte, R. Falcone, and G. Sartor, 'Agents and norms: How to fill the gap?', *Artificial Intelligence and Law*, **7**, 1–15, (1999).
- [6] C. Dellarocas, 'Contractual agent societies: Negotiated shared context and social control in open multi-agent systems', in *Workshop on Norms and Institutions in Multi-Agent Systems, 4th International Conference on Multi-Agent Systems*, Barcelona, Spain, (June 2000).
- [7] F. Duran, V. Torres da Silva, and C. J. P. de Lucena, 'Using testimonies to enforce the behaviour of agents', in *AAMAS'07 Workshop on Coordination, Organization, Institutions and Norms in agent systems*, eds., Jaime Sichman and Sascha Ossowski, pp. 25–36, (2007).
- [8] Andrés García-Camino, 'Ignoring, forcing and expecting concurrent events in electronic institutions', in *Coordination, Organization, Institutions and Norms in agent systems (COIN@AAMAS'07). Co-held in Sixth International Joint Conference on Autonomous Agents and Multiagent Systems*, Honolulu, Hawai'i, USA, (May 2007).
- [9] M. Ghijsen, W. Jansweijer, and R. Wielinga, 'Towards a framework for agent coordination and reorganization, agentcore', in *AAMAS'07 Workshop on Coordination, Organization, Institutions and Norms in agent systems*, eds., J. Sichman and S. Ossowski, pp. 13–24, (2007).
- [10] P. Grefen and S. Angelov, 'On  $\tau$ ,  $\mu$ ,  $\pi$  and  $\epsilon$ -contracting', in *Proceedings CAiSE Workshop on Web Services, e-Business, and the Semantic Web*, pp. 68–77, (2002).
- [11] A. Lomuscio and M. Sergot, 'Deontic interpreted systems', *Studia Logica*, **75**, (2003).
- [12] H. Lopes Cardoso and E. Oliveira, 'Using and evaluating adaptive agents for electronic commerce negotiation', in *Proceedings of the International Joint Conference, 7th Ibero-American Conference on AI: Advances in Artificial Intelligence*, volume 1952 of *Lecture Notes In Computer Science*, pp. 96–105, (2000).
- [13] H. Lopes Cardoso and E. Oliveira, 'A contract model for electronic institutions', in *AAMAS'07 Workshop on Coordination, Organization, Institutions and Norms in agent systems*, eds., J. Sichman and S. Ossowski, pp. 73–84, (2007).
- [14] F. Lopez y Lopez, M. Luck, and M. d'Inverno, 'A normative framework for agent-based systems', *Computational and Mathematical Organization Theory*, **12**(2–3), 227–250, (2005).
- [15] H. Ludwig, A. Keller, A. Dan, R. P. King, and R. Franck, 'Web service level agreement (wsla), language specification', Technical report, IBM Corporation, (January 2003).
- [16] E. Muntaner-Perich, J. Lluís de la Rosa, and R. Esteva, 'Towards a formalisation of dynamic electronic institutions', in *AAMAS'07 Workshop on Coordination, Organization, Institutions and Norms in agent system*, eds., J. Sichman and S. Ossowski, pp. 61–72, (2007).
- [17] S. Willmott, M. Dehn, M. Luck, M. Pechoucek, A. Lomuscio, J. Vazquez, and J. Dale, 'Contract based approaches to robust, verifiable cross-organisational web services applications', Technical report, Universitat Politècnica de Catalunya, (2007).
- [18] Lai Xu, 'A multi-party contract model', *ACM SIGecom Exchanges*, **5**(1), 13–23, (2004).