Agreeing on Defeasible Commitments

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Abstract. Social commitments are developed for multi-agent systems according to the current practice in law regarding contract formation and breach. Deafeasible commitments are used to provide a useful link between multi-agent systems and legal doctrines. The proposed model makes the commitments more expressive relative to contract law, improving the model for the life cycle of the commitments. As a consequence, the broader semantics helps in modelling different types of contracts: gratuitous promises, unilateral contracts, bilateral contracts, and forward contracts. The semantics of higher-order commitments is useful in deciding whether to sign an agreement or not, due to a larger variety of protocols and contracts.

1 Introduction

Artificial agents and the contracts they make are ubiquitous, while at the same time, there is a lack of application of the current practice in law to multi-agent systems (MAS). From the point of view of law, there is a philosophical debate regarding when to attach person-hood to artificial agents. The actual context of web services representing business entities and agents interacting with services implies legal responsibilities for each agent. From the engineering point of view, agents have to be built and synchronized with the norms and values of society.

Social commitments were introduced as a way to capture the public aspects of communications [1] and research has been focused on the development of agent communication languages and flexible interaction protocols [2, 3]. As commitments appear to be sometimes too restrictive (direct obligations) and sometimes too flexible, allowing unconstrained modification of commitments, social commitments should be more flexible than usual obligations but also more constrained than permissions [1]. On this line, we apply principles of contract law as an objective measure to decide on the flexibility of the operations on commitments, beginning with a commitment-based representation of different types of agreements from contract law. The main advantage of applying current practice in law to model commitments within multi-agents systems is that the principles of contract law are verified and polished during years of economical and judicial practice.

Modeling agent communication implies several approaches: mental (BDI and modalities), social (which highlights the public and observable elements like social commitments that agents exchange when conversing), and argumentative (based on agent reasoning capabilities). When participating in an agreement, agents should use their mental states, share information and reason about new facts. We seek to synchronize the social commitments developed for MAS with the existing legal doctrines, which the law applies in case of contract formation. We define a framework by using the temporalised normative positions in defeasible logic [4] to introduce defeasible commitments for representing contract laws [5] in the model of the life cycle of commitments.

2 Temporalised normative positions

For defining defeasible commitments, we are using the temporalised normative positions [4]. A theory in *normative defeasible logic* (NDL) is a structure (F, R_K, R_I, R_A, R_O, $\succ$) where F is a finite set of facts, R_K R_I R_A R_O are respectively a finite set of persistent or transitive rules (strict, defeasible, and defeaters) for knowledge, intentions, actions, and obligations, and $\succ$ representing the superiority relation over the set of rules.

A rule in NDL is characterized by three orthogonal attributes: modality, persistence, strength. As for modality, R_K represents the agent's theory of the world, R_A encodes its actions, R_O the normative system or his obligations, while R_I and the superiority relation capture the agent's strategy or its policy. *A persistent rule* is a rule whose conclusion holds at all instants of time after the conclusion has been derived, unless a more powerful rule, according to the superiority relation, has derived the opposite conclusion. *A transient rule* establishes the conclusion only for a specific instance of time [4].

Strict rules are rules in the classical sense, that is whenever the premises are indisputable, then so is the conclusion, while *defeasible rules* are rules that can be defeated by contrary evidence. For "sending the goods means the goods were delivered", if we know that the goods were sent then they reach the destination, unless there is other, not inferior, rule suggesting the contrary. *Defeaters* are rules that cannot be used to draw any conclusions. Their only use is to prevent some conclusions, as in "if the customer is a regular one and he has a short delay for paying, we might not ask for penalties". This rule cannot be used to support a "not penalty" conclusion, but it can prevent the derivation of the penalty conclusion.

$\rightarrow^t_X$, $\Rightarrow^t_X$ and $\rightsquigarrow^t_X$ denote transitive rules (strict, defeasible, defeaters), while $\rightarrow^p_X$, $\Rightarrow^p_X$ and $\rightsquigarrow^p_X$ denote persistent rules (strict, defeasible, defeaters), where $X \in \{K, I, A, O\}$ represents the modality. A conclusion in NDL is a tagged literal where $+\Delta^\tau_X q{:}t$ means that q is definitely provable of modality X, at time t in NDL (figure 1); and $+\partial^\tau_X q{:}t$ means that q is defeasibly provable of modality X, at time t in NDL (figures 2, 3). Here $\tau \in \{t, p\}$, t stands for transient, while p for a persistent derivation. A strict rule $r \in R_s$ is $\Delta_X - applicable$ if $r \in R_{s,X} \forall a : t_k \in A(r) : a_k : t_k$ is $\Delta_X - provable$. A strict rule $r \in R_s$ is

$\Delta_X - discarded$ if $r \in R_{s,X} \exists a_k : t_k \in A(r) : a_k : t_k$ is $\Delta_X - rejected$, and similarly for ∂. The conditions for concluding whether a query is transient or

$+\Delta^t_X$: If $P(i+1) = +\Delta^t_X q : t$ then
$q : t \in F$, or
$\exists r \in R^t_{s,X}[q : t]$ r is $\Delta_X - applicable$

$+\Delta^p_X$: If $P(i+1) = +\Delta^p_X q : t$ then
$q : t \in F$, or
$\exists r \in R^p_{s,X}[q : t]$ r is $\Delta_X - applicable$ or
$\exists t' \in \Gamma : t' < t$ and $+\Delta^p_X q : t' \in P(1..i)$.

Fig. 1. Transient and persistent definite proof for modality X

persistent, definitely provable is shown inthe figure 1. For the transient case, at step $i+1$ one can assert that q is definitely transient provable if there is a strict transient rule $r \in R^t_s$ with the consequent q and all the antecedents of r have been asserted to be definitely (transient or persistent) provable, in previous steps. For the persistent case, the persistence condition allows us to reiterate literals definitely proved at previous times. For showing that q is not persistent definitely provable, in addition to the condition we have for the transient case, we have to assure that, for all instances of time before now the persistent property has not been proved. According to the above conditions, in order to prove that q is definitely provable at time t we have to show that q is either transient, or persistent definitely provable [4].

$+\partial^t_X$: If $P(i+1) = +\partial^t_X q : t$ then
(1) $+\Delta_X q : t \in P(1..i)$ or
(2)$-\Delta_X \sim q : t \in P(1..i)$ and
(2.1) $\exists r \in R_{sd,X}[q : t]$: r is ∂_X-applicable and
(2.2) $\forall s \in R[\sim q : t]$: s is ∂_X-discarded or
$\exists w \in R(q : t)$: w is ∂_X-applicable or $w \succ s$

Fig. 2. Transient defeasible proof for modality X

Defeasible derivations have an argumentation like structure [4]: firstly, we choose a supported rule having the conclusions q we want to prove, secondly we consider all the possible counterarguments against q, and finally we rebut all the above counterarguments showing that, either some of their premises do not hold, or the rule used for its derivation is weaker than the rule supporting the initial conclusion q. A goal q which is not definitely provable is defeasibly transient provable if we can find a strict or defeasible transient rule for which

$+\partial_X^p$: If $P(i+1) = +\partial_X^t q : t$ then
(1) $+\Delta_X^p q : t \in P(1..i)$ or
(2)$-\Delta_X \sim q : t \in P(1..i)$, and
(2.1) $\exists r \in R_{sd,X}^p[q : t]$: r is ∂_X-applicable, and
(2.2) $\forall s \in R[\sim q : t]$: either s is ∂_X-discarded or
$\exists w \in R(q : t)$: w is ∂_X-applicable or $w \succ s$; or
(3) $\exists t' \in \Gamma : t' < t$ and $+\partial_X^p q : t' \in P(1..i)$ and
(3.1) $\forall s \in R[\sim q : t"], t' < t" \leq t$, s is ∂_X-discarded, or
$\exists w \in R(q : t")$: w is ∂_X-applicable and $w \succ s$.

Fig. 3. Persistent defeasible proof for modality X

all its antecedents are defeasibly provable, $\sim q$ is not definitely provable and for each rule having $\sim q$ as a consequent we can find an antecedent which does not satisfy the defeasible provable condition (figure 2). For the persistence case, the aditional clause (3) from figure 3 verifies if the literal $q : t$ has been persistent defeasibly proved before, and this conclusion remained valid all this time (there was no time t“ when the contrary $\sim q$ was proved by firing the rule s, or the respective rule was no stronger than the one sustaining q).

3 Types of commitments

The classical definition of a conditional commitment states that a commitment is a promise from a debtor x to a creditor y to bring about a particular sentence p under a condition q. Starting from this definition we provide a generalized commitment abstract data type.

Definition 1. *A commitment is a relation*

$$C_m^n(x, y, q^n : [t_{issue}], [\star]p^m : [t_{maturity}]) : [t_{expiration}]$$

with optional literals within square brackets, representing the promise p made by debtor x to creditor y in exchange of which the action q is requested, where the time of maturity $t_{maturity}$ shows the time remaining until the promise p^m is satisfied by the debtor x if the request q^n holds until time t_{issue} and $\star \in \{+\Delta, -\Delta, +\partial, -\partial, ?\}$ is an optional tag used to express informing messages.

The parameters m and n help us to define meta commitments or higher-order commitments. Their role is to provide a rich semantics used to express a large variety of contractual clauses or negotiation patterns: m is a measure of the promises made by the debtor, while n is a measure of the requests made by the debtor (figure 4). We define two operators for the composition of commitments: $\circ_q$ which deals with requests and $\circ_p$ which deals with promises.

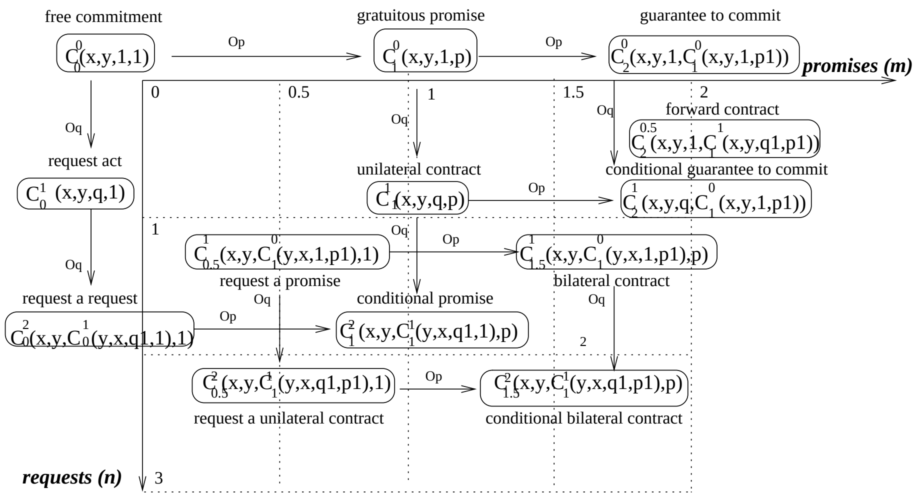

Fig. 4. Types and composition of the commitments

3.1 Contractual commitments

When $m \in [1, 2)$ we name the resulting commitments contractual commitments. Next, we discuss each type of contractual commitments from a legal point of view.

The example "I will give you the item g_1 in 5 days." is represented by $C_1^0(me, you, 1, g_1 : 5)$, defined by law as *gratuitous promise.*

Definition 2. *In a Gratuitous Promise (n=0, m=1) the debtor x promises the creditor y to bring about p until $t_{maturity}$ without requesting anything ($n = 0$).*

$$C_1^0(x, y, 1, p_1 : t_{maturity})$$

The example "I will give you the item g_1 in 5 days after you will pay the price" will be represented by $C_1^1(me, you, pay(you) : t_{pay}, g_1 : t_{pay} + 5)$, and "I will give you the item g_1 as long as the oil price is 135$" by $C_1^1(me, you, price = 135 : t_{price}, g_1 : t_{price} + 5)$. In the first example the condition is brought about by the creditor y, while in the second the condition is an environment fact and does not necessarily depend on y. The law defines such a commitment a *unilateral contract*, involving an exchange of the offerer's promise (p) for the oferee's act (q), with the completion of the act required to indicate acceptance.

Definition 3. *A Unilateral Contract (n=1, m=1) involves an exchange of the offerer's promise p for the oferee's act q, where the debtor x promises the creditor y to bring about p until $t_{maturity}$ if condition q holds at time t_{issue}.*

$$C_1^1(x, y, q : t_{issue}, p : t_{maturity})$$

Consider the examples "I will give you the item g_1 no later than 5 days, if you promise me in maximum 1 day that you will pay the price no later than 3 days" represented as $C^1_{1.5}(me, you, C^0_1(you, me, 1, pay : 3) : 1, g_1 : 5)$ and "I will give you the item g_1 no later than 5 days, if the bank promises me in maximum one day to pay the price no later than 3 days" as $C^1_{1.5}(me, you, C^0_1(bank, me, 1, pay : 3) : 1, g_1 : 5)$. According to contract law, a contract in which both sides make promises is called a *bilateral contract.*

Definition 4. *In a Bilateral Contract (n=1, m=1.5) both sides make promises, the debtor x promises the creditor y to bring about p if the creditor y promises x to bring about p_1.*

$$C^1_{1.5}(x, y, C^0_1(y, x, 1, p_1), p)$$

We note that a $C^1_{1.5}$ commitment is somehow weaker than a C^1_1 commitment. This fine grained mechanism opens the possibility of designing agents with different levels of attitude towards risk and it also refines the idea of leveled commitment contracts [6].

"I will give you the item g_1 no later than 5 days, if you promise me to pay the price no later than 3 days under the condition that oil price reaches 135\$; my offer expires in 10 days." is represented by $C^2_{1.5}(me, you, C^1_1(you, me, oilPrice = 135, pay : 3) : 10, g_1 : 5)$.

Definition 5. *In a Conditional Bilateral Contract (n=2, m=1.5) the debtor x promises the creditor y to bring about p if agent y promises x to bring about p_1 under condition q_1.*

$$C^2_{1.5}(x, y, C^1_1(y, x, q_1, p_1), p)$$

Here $n = 2$ means that agent x has two requests: it requests the promise C^1_1 which contains the second request q_1. On the other hand, $m = 1.5$ means that it promises p and also p_1 which, being an inner promise, in our model weighs only 0.5. The above semantics includes a form of negotiation because, at the creation of the inner commitment, both $C^2_{1.5}$ and C^1_1 commitments are open offers (see section 4). Therefore, the agents are not committed to them and they may be canceled anytime in this state, without considering it a breach.

3.2 Request commitments

When $m \in [0, 1)$ the debtor does not promise anything directly, called request commitments. For both $m = 0$ and $n = 0$ we have a *free commitment* $C^0_0(x, y, 1, 1)$, while $n \neq 0$ gives the following types of requests.

"Please pay me the price of the product g_1 in two days" is represented as a *request act* $C^1_0(me, you, price : 2, 1)$[1].

Definition 6. *In a Request Act (n=1, m=0) the debtor x requests the creditor y to bring about q until time t_{issue}.*

$$C^1_0(x, y, q : t_{issue}, 1)$$

[1] With $n = 1$ we denote $q^1 = q$ and $p^0 = 1$.

Observe that the debtor does not promise anything. The acceptance of the above request is made simply by causing the sentence q or performing the requested action. If the requested act is a negative sentence, it represents a *taboo* [7] or interdiction.

"Please promise me that you will pay for the item in 3 days" is represented as $C^1_{0.5}(me, you, C^0_1(you, me, 1, pay : 3), 1)$.

Definition 7. *A Request a Promise (n=1, m=0.5) is used by a debtor x to request the creditor y to promise until* $t_{expiration}$ *that it will bring about* p_1 *until* $t_{maturity}$

$$C^1_{0.5}(x, y, C^0_1(y, x, 1, p_1 : t_{maturity}) : t_{expiration}, 1)$$

obtainable from $C^1_0 \circ_q C^0_1$.

The acceptance of the request is done by creating the inner commitment $C^0_1(y, x, 1, p_1 : t_{maturity})$ until the deadline $t_{expiration}$. When the time-out elapses the request commitment reaches the failed state. If the creditor wants to explicitly reject the request, it will respond by creating the negative commitment $\neg C^0_1(y, x, 1, pay : 3) : 5$, having the same deadline with the request commitment[2]. The meaning of the above rejection is "I will not commit to you to bring about p_1 in 3 days; I will reconsider your request after 5 days".

"Ask me to give you the money" is shown as $C^2_0(me, you, C^1_0(you, me, money, 1), 1)$ and "Please request the bank to pay you" as $C^2_0(me, you, C^1_0(you, bank, pay, 1), 1)$.

Definition 8. *In a Request a Request (n=2, m=0) the debtor x requests the creditor y to request the sentence* q_1 *from another agent* z[3] *until time* t_e

$$C^2_0(x, y, C^0_1(y, z, q_1, 1) : t_{expiration}, 1)$$

obtainable from $C^0_1 \circ_q C^0_1$.

"Please buy me shares as soon as their price reaches 10$" is represented by $C^2_{0.5}(me, you, C^1_1(you, me, price = 10, buy), 1)$.

Definition 9. *In a Request a Unilateral Contract (n=2, m=0.5) the debtor x requests the creditor y to commit to bring about* p_1 *if the condition* q_1 *holds*

$$C^2_{0.5}(x, y, C^1_1(y, z, q_1, p_1) : t_{expiration}, 1)$$

obtainable from $C^0_1 \circ_q C^1_1$.

3.3 Guarantee commitments

In these commitments the debtor promises that a specific commitment will exist in a given window of time.

For "I guarantee you that the bank will commit in maximum 7 days to give you the credit" we use the formula $C^0_1(me, you, 1, C^0_1(bank, you, 1, credit) : 7)$.

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[2] Otherwise a form of negociation may arise.

[3] The agent z may be the debtor x.

Definition 10. *In a Guarantee to Commit (n=0, m=2) the debtor x guarantees the creditor y that a special commitment will exist until $t_{expiration}$*

$$C_2^0(x, y, 1, C_1^0(z, y, 1, p_1) : t_{expiration})$$

obtainable from $C_1^0 \circ_p C_1^0$.

If $z = y$ the creditor manifests its own intention to commit or it guarantees that it will make the respective gratuitous promise no longer than $t_{expiration}$. It can be seen as a precommitment or an intention to commit.

"If you have all the papers, I promise you that the bank will commit in maximum 7 days to give you the credit" is represented as $C_2^1(me, you, papers, C_1^0(bank, you, 1, credit) : 7))$.

Definition 11. *In a Conditional Guarantee to Commit (n=1, m=2) the debtor x guarantees the creditor y that a specific commitment will exist until $t_{expiration}$ if condition q holds*

$$C_2^1(x, y, q, C_1^0(z, y, 1, p_1) : t_{expiration})$$

obtainable from $C_1^1 \circ_p C_1^0$.

We represent "I commit you to sell my house to you next year at the price 20000$" by $C_2^{0.5}(me, you, 1, C_1^1(me, you, 20000, house) : 365))$.

Definition 12. *In a Forward Unilateral Contract (n=0.5, m=2) the debtor x guarantees the creditor y that a specific unilateral contract will exist until $t_{expiration}$.*

$$C_2^{0.5}(x, y, 1, C_1^1(z, y, q_1, p_1) : t_{expiration})$$

According to contract law, the particular case in which $z = x$ is a form of a *forward contract*, obtainable from $C_1^0 \circ_p C_1^1$. Applying the composition operators $\circ_q$ or $\circ_p$ we can also model *forward bilateral contracts* and *forward conditional bilateral contracts.*

3.4 Informing commitments

We see the informing act as a form of commitment in the sense that the agent who propagates some information guarantees its validity. In other words, it is committed to the creditor that the notified fact is true, based on the debtor's view of the world. Contract law names such type of statement *terms*. The truth of the term is guaranteed by the agent that made the statement. We use this type of commitment to allow information sharing between agents. The literature shows that information sharing is a key-point in the coordination of multi-agent systems.

The situation "My partner informs me that he has already sent the money, while the bank says that the payment has not been made yet" is coded with $C_1^0(partner, me, 1, +\partial_K^p pay)$ and $C_1^0(bank, me, 1, -\partial_K^p pay)$. The agent me will fire both defeasible rules $r_1 : C_1^0(partner, me, 1, +\partial_K^p pay) \Rightarrow pay$ and $r_2 : C_1^0(bank, me, 1, -\partial_K^p pay) \Rightarrow \neg pay$, but it will give more credit to the statement of the bank $r_2 > r_1$.

Definition 13. *In a Fact Notification the debtor x informs creditor y if a specific sentence p is $+\Delta^{\tau}_{X}p$, $-\Delta^{\tau}_{X}p$, $+\partial^{\tau}_{X}p$, or $-\partial^{\tau}_{X}p$ according to its defeasible theory D.*

$$C^0_1(x, y, 1, \star p)$$

"I inform you that agent z has an active commitment for delivering to me the item g_1 within 3 days" is represented by $C^0_2(me, you, 1, +\Delta^{p}_{O}C^0_1(z, me, 1, g_1 : 3))$, which may help "me" in the negotiation process with "you".

Definition 14. *In a Commitment Existence Notification the debtor x informs the creditor y about the existence of a specific commitment according to its defeasible theory D.*

$$C^0_2(x, y, 1, \star C^0_1(z, w, 1, p))$$

"If you promise me to keep it secret I will tell you if z is committed to me or not to deliver g_1" will be $C^2_2(me, you, C^0_1(you, me, 1, secret), \star C^0_1(z, me, 1, g_1))$, an example of a *confidentiality agreement*. This situation may arise during negotiations for a larger contract, when agents may need to divulge information about their operations to each other, also known as non-disclosure agreement.

Definition 15. *In a Conditional Notification the debtor x informs the creditor y about the existence of a specific commitment if condition q holds until t_i.*

$$C^0_2(x, y, q : t_i, ?C^0_1(z, w, 1, p))$$

Asking for represents a composition between a request commitment and an informing commitment, e.g., "Please tell me if the payment was made", represented as $C^1_2(me, bank, C^0_1(bank, me, 1, ?pay), 1)$.

Definition 16. *In an Asking For the debtor x asks the creditor y about the existence of a specific fact p.*

$$C^1_2(x, y, C^0_1(y, x, 1, ?p), 1)$$

4 Commitment life cycle

During its life cycle, a commitment may be in one of the following states: *open offer, active, released, breached, fulfilled, canceled, or failed* (figure 5), which are also useful to be considered from a legal perspective.

First consider a gratuitous promise $C^0_1(x, y, 1, p : t_{maturity}) : t_{expiration}$. Under the donative-promise principle, a simple, unrelied-upon gratuitous commitment is unenforceable since there is no consideration [8] or no element of exchange. Therefore, the breach of a C^0_1 commitment attracts only social sanctions or trust sanctions. The use of normative foundation of trust attached to a C^0_1 commitment serves to promote business relations. In case the creditor y has relied on the commitment, one can make use of the doctrine of *promissory estoppel*. This doctrine comes from the equity part of the law and it prevents one party from withdrawing a promise made to a creditor, if that creditor has relied on

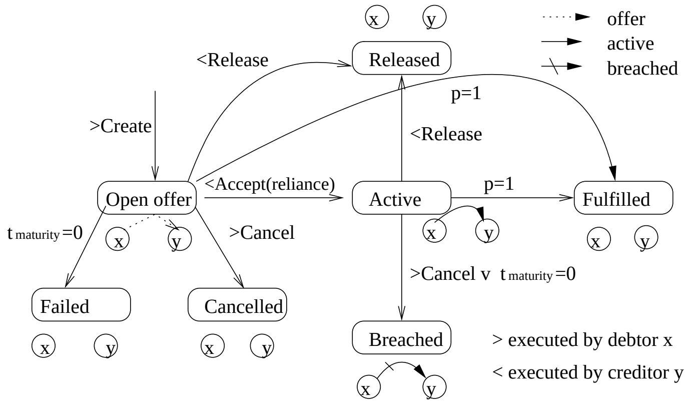

Fig. 5. The life cycle of a gratuitous commitment

that promise and acted upon it. The only remedy of contract law that can be applied in this case is *reliance damages* [8]. Also, the law stipulates that this reliance must be foreseeable. In the context of open agent systems we define a foreseeable fact as one which has been notified to the potential breacher. For instance, in a supply chain scenario, the creditor must notify the promiser that, based on the C_1^0 commitment, it has signed other contracts: "I inform you that, based on your gratuitous promise, I commit to deliver item g_1 to my client z within 3 days". This is represented by $C_2^0(me, you, 1, +\Delta_K^p C_1^0(me, z, 1, g_1 : 3))$. On the other hand, the estoppel is "a shield, not a sword". It cannot be used as the basis of an action of its own. Hence, we implement estoppel with defeaters.

$$
\begin{aligned}
&\rightarrow_I^t promise(p : t_m, y) : t_i \\
&\Rightarrow_I^p riskProne : t_i \\
&\rightarrow_K^p promissoryEstoppel : t_i \\
r_0 &: promise(p : t_m, y) : t_i, riskProne : t_i \Rightarrow_A^t create(x, c) : t_i \\
r_1 &: create(x, c) : t_i \rightarrow_K^p c : t_i \\
r_2 &: c : t_i, t_m = t_i \rightarrow_K^p \neg c : t_i \\
r_3 &: c : t_i, cancel(x, c) : t_i \Rightarrow_K^p \neg c : t_i \\
r_4 &: c : t_i, release(y, c) : t_i \rightarrow_O^p \neg c : t_i \\
r_5 &: breached : t_i \Rightarrow_O^p relianceDamages : t_{i+3}, \neg c : t_i \\
r_6 &: specificPerformance : t_i \rightsquigarrow_O^p \neg c : t_i \\
r_7 &: execute(p) : t_i \Rightarrow_K^p p : t_{i+2} \\
r_8 &: assign(y, z, c) : t_i, c : t_i \Rightarrow_O^p \neg c : t_i, C_1^0(x, z, 1, p : t_m) : t_i \\
r_9 &: delegate(x, z, c) : t_i, c : t_i \Rightarrow_O^p \neg c : t_i, C_1^0(z, y, 1, p : t_m) : t_i
\end{aligned}
$$

Fig. 6. Sample of rules for commitment operations

Possible operations on commitments: create, cancel, release, assign, and delegate (figure 6) are discussed next, considering their effect on a gratuitous commitment $c = C_1^0(x, y, 0, p : t_m)$. Similar rules are defined for other types of commitments, the main difference results from what acceptance means for each type of commitment. For instance, the acceptance of a gratuitous commitment means reliance and acted upon it, the aceptance of a unilateral contract means the execution of the required task, the acceptance of a bilateral contract means the creation of the required promise, etc.

Create. Consider that agent x has the intention to satisfy sentence p for agent y, until deadline t_m. Its policy is risk prone, meaning that it creates the gratuitous commitment c, while it has no guarantee that its partner will give something in exchange. Moreover, the interaction is made under the doctrine of promissory estoppel. The above intentions drive the agent to create the commitment c (rule r_0, which being transient, the *create* action is executed once). The creation of a commitment, an action typically undertaken by the debtor, is equivalent to an *open offer* in contract law. Therefore, it is derived only as persistence knowledge (rule r_1) and is not considered an obligation in this state[4].

Cancel. The debtor x may *cancel* a commitment with no penalties only if the commitment is an open offer (rule r_3). The *breached* state is reached when the time for accomplishing the promise elapses. This state activates the mechanism for computing reliance damages, which usually suppose the creation of another commitment or contrary-to-duty obligation[5]. In some situations, a commitment may be active even after it is breached, allowed by defining rule r_5 as defeasible. Therefore, a normative agent may block the derivation of that conclusion in order to force the execution of the specific commitment c (rule r_6)[6]. When the time-out of an open offer commitment expires, the state of the commitment becomes *failed* (rule r_2).

Release. If the acceptance has been made, this operation releases the debtor from its gratuitous commitment (rule r_4). The agent x executes p, but the effect is expected to be seen after two time steps (rule r_7). The defeasible rule r_7 leaves space to treat some exceptions.

Assign. The *assign* operation, transferring the rights held by the creditor y to another party, the assignee z, may be executed only by the creditor y and the state of the commitment is preserved (rule r_8). Common law favors the freedom of assignment, unless there is an express prohibition against it, requiring that it must occur in the present, to assign in the future having no legal effect.

Delegate. The *delegate* operation, transferring the duties held by the debtor x to another party z, is executed only by the debtor x and the state of the

[4] Equivalent to a proposed or attempted commitment.

[5] The sooner it notifies by executing the *cancel* operation, the lower the reliance damages.

[6] In common law [8] expectation damages and no specific performance are granted as the usual remedy in case of breach. Since contracts, more often, are essentially about profit, the granting of expectation damages provides an acceptable substitute to the innocent party. While the state of granting of a performance remedy would amount to doing unnecessary harm to the party who has committed the breach [6].

commitment is preserved (rule r_9). The creditor must be informed of the act of delegation. In case z breaches, the creditor y may elect to treat this failure as a breach of the original commitment and to sue the delegator x or to choose the role of a third party beneficiary.

In the case of the life cycle of a unilateral contract, the debtor x can revoke his commitment anytime before acceptance. When the condition q becomes true, the commitment becomes active. Until then, the debtor may cancel without considering this as a breach. Most courts now hold that creditor y must give notice of its acceptance after it has done the requested act. If it does not do that, the commitment that was formed by the act may be canceled without breach (of course, the debtor must return the money). Therefore, the acceptance of a C_1^1 commitment can be viewed as a compound operation: execution of the q and a fact notification $C_1^0(x, y, 1, +\partial_K^p q)$. Due to the late activation of the C_1^1 commitment the promiser x has maximal protection. What happens if the creditor executes a part of the q condition and notifies about this? The common law stipulates that an *option contract* was formed, which protects the creditor y from the debtor's ability to cancel the commitment (i.e. $partPerformance \rightarrow optionContract,\ optionContract \rightsquigarrow \neg C_1^1(x, y, q, p : t_{maturity})$). If acceptance is late ($t_{issue} < t_{acceptance} < t_{maturity}$), it becomes a counter-offer and it creates the power of acceptance for the initial debtor x.

5 Using higher-order commitments

5.1 English auction

We illustrate the usage of commitments in the *English auction* (figure 7). According to contract law, when an item is put up for auction, this is usually not an offer, but rather a solicitation of offers (bids) or an invitation to treat. The English auction protocol uses the pattern "request a unilateral contract"[7]. Therefore, the auctioneer a has to compose a request commitment with a unilateral contract (f_1 in figure 8, where "-" is used to express existential quantification)

$$r_{21} : deliver(g_1) : t_3 \rightarrow_K^p C_1^0(b, a, 1, +\partial_K^p g_1 : t_7)) : t_3$$
$$r_{22} : deliver(g_1) : t_3 \Rightarrow_K^p g_1 : t_7$$
$$r_{23} : g_1 : t_3 \rightarrow_O^p C_1^0(b, a, 1, +\partial_K^p g_1 : t_7)) : t_3$$
$$r_{24} : pay : t_9 \rightarrow_A^t release(a, b, C_1^0(b, a, 1, 12 : t_9)) : t_9$$

Fig. 7. Sample rules for English auction

[7] For the simplified Net bill protocol [9] which ignores the cryptography-related aspect and also the existence of a third party agent, unlike the complete version of the Net bill protocol [10] we would use the "request a conditional bilateral contract" $C_{1.5}^3(x, y, C_{1.5}^2(y, x, C_1^1(x, y, Deliver, EPO), receipt), 1)$.

$$
\begin{array}{ll}
f_1: & C^2_{0.5}(a, -, C^1_1(-, a, g_1 : t_7, bid > 10 : t_9) : 3, 1) : t_1 \\
f_2: & C^1_1(b, a, g_1 : t_7, 12 : t_9) : t_2 \\
f_3: & C^1_1(b', a, g_1 : t_7, 11 : t_9)) : t_2 \\
f_4: & C^{0.5}_2(a, b', 1, +\Delta^p_K \neg C^1_1(b', a, g_1 : t_7, 11 : t_9))) : t_3 \\
f_5: & C^{0.5}_2(a, b, 1, +\Delta^p_O C^1_1(b, a, g_1 : t_7, 12 : t_9))) : t_3 \\
f_6: & deliver(g_1) : t_3 \\
f_7: & C^0_1(a, b, 1, +\partial^p_K g_1 : t_7)) : t_3 \\
f_8: & C^0_1(b, a, 1, +\Delta^p_K g_1 : t_7)) : t_7 \\
f_9: & C^0_1(b, a, 1, +\partial^p_K 12 : t_9)) : t_7
\end{array}
$$

Fig. 8. A trace in English auction

for item g_1 with starting price 10$, and bids expected for 3 time steps. In case of accepting the bids, a has to deliver the item g_1 in 7 time steps, while b has to pay for it in 9 time steps.

Suppose that two bids are received (f_2 and f_3) at t_2, both open offers. Hence, at this stage, both b and b' may cancel their C^1_1 commitments without breach, and a also may cancel its $C^2_{0.5}$ commitment, because the inner commitment is not active yet (according to current practice in law). The above commitments reach the *active* state and they become obligations only if a accepts them. The bidders have made offers according to the auctioneer request regarding the deadline for sending bids and $t_{maturity}$. In other encounters they might react with different terms, which would be considered a counter-offer and a more complex form of negotiation would arise.

At t_3, when the deadline for receiving bids expires, a clears the auction, considering the bids that conform to the request and accepting the winning one (lower level aspects of coordination are not shown). It may explicitly reject one bid (f_4) and accept the other one (f_5). In a unilateral contract the completion of the requested act is necessary to indicate acceptance. Most courts now hold that creditor y must also give notice of its acceptance after it has done the requested act. Therefore, the acceptance of a C^1_1 commitment can be viewed as a compound operation: execution and a commitment notification. Due to the late activation of C^1_1 the promiser has maximal protection. At this time, the existence of the requested commitment C^1_1 is verified and $C^2_{0.5}$ is discharged, leaving C^1_1.

The defeasible derivation rule r_{22} allows to treat some exceptions[8]. When the partner informs that the item has arrived (f_8), the strict rule r_{24} fires, C^1_1 becomes *active*, and when the item arrives after 4 time steps b_1 releases it. With the payment made, the auctioneer would release the debtor b from its commitment (rule r_{24}), otherwise the mechanism for treating exceptions should be activated according to a's policy.

[8] For instance, due to an accident the item has not arrived.

5.2 Considering risk in the supply chain

Consider the contract between two agents *me* and *you*, with agent *me* having to deliver the item, while agent *you* having to pay for it. There is more than one possibility to represent this process, depending on the commitments signed between them, identified by five levels of risk attitudes (table 1). Now consider the situation when agent *me* is conditioned by its supplier *sup*. In order to deliver its output item, it has to obtain first its input item (table 2) with other possible attitudes towards risk.

Risk	**Commitments**	**Meaning**
risk prone	$C_1^0(me, you, 1, deliver) \wedge$ $C_0^2(me, you, C_1^0(you, me, 1, pay), 1)$	I commit to deliver the item and I request you to commit to pay for it
moderate risk prone	$C_1^0(me, you, 1, deliver) \wedge$ $C_0^1(me, you, pay, 1)$	I commit to deliver the item and I request you to pay for it
risk neutral	$C_{1.5}^1(me, you, C_1^0(you, me, 1, pay),$ $deliver)$	I commit to deliver the item if you commit me to pay for it
moderate risk averse	$C_1^1(me, you, pay, deliver)$	I commit to deliver the item after you pay for it
risk averse	$C_2^1(me, you, pay, C_1^0(me, you, 1, deliver))$	I will commit to deliver the item if you pay me

Table 1. Risk attitudes between two agents

Risk	**Commitments**	**Meaning**
risk averse	$C_{2.5}^1(me, you, C_1^0(sup, me, 1, deliver'),$ $C_1^0(me, you, 1, deliver)$	If my supplier commits to deliver my input item, I commit to deliver my output item
risk neutral	$C_{2.5}^{2.5}(me, you, C_{1.5}^1(sup, me,$ $C_1^0(me, sup, 1, pay'), deliver'),$ $C_1^0(me, you, 1, deliver))$	If my supplier commits to deliver my input item if I promise him to pay, I commit to deliver my output item
risk prone	$C_{1.5}^{2.5}(me, you, C_1^1(sup, me, pay, deliver),$ $C_1^0(me, you, 1, deliver)$	If my supplier commits to deliver my input item if I pay it, I commit to deliver my output item

Table 2. Risk attitudes considering a third party

Assuming agent *me* has a risk prone strategy ($\Rightarrow_I^p riskProne : t_i$), it will create commitments $C_1^0(me, you, 1, deliver)$ and $C_0^2(me, you, C_1^0(you, me, 1, pay), 1)$. The acceptance of $C_1^0(me, you, 1, deliver)$ appears when agent *you* relies on it and it also notifies agent *me* about this reliance[9]. Once the acceptance occured, the commitment reaches the active state ($\Rightarrow_O^p C_1^0(me, you, 1, deliver)$) and thus it becomes an obligation for agent *me*. On the other side, agent *you* has no obligation at all, knowing only that its partner has requested to promise to pay

[9] Such a notification may look like this: "I (agent *me*), based on a gratuitous promise, commit to deliver item g_1 to my client z within 3 days", represented by $C_2^0(you, me, 1, +\Delta_K^p C_1^0(you, z, 1, g_1 : 3))$.

for the item[10]. In case of a risk neutral strategy, the acceptance occurs at the creation of the inner commitment ($\rightarrow_A^t create(you, C_1^0(you, me, 1, pay))$). Thus, each agent has one obligation: $\rightarrow_O^p C_1^0(me, you, 1, deliver)$ for agent *me* and $\rightarrow_O^p C_1^0(you, me, 1, pay)$ for agent *you*. In case of a risk averse strategy the acceptance of the unilateral contract is done by the completion of the requested act, in this case the payment. Therefore, agent *me* has the obligation to deliver the item only after it had received the payment ($pay \rightarrow_O^p C_1^0(me, you, 1, deliver)$). In table 2 agent *me* has the obligation to deliver its output item only in case it has active contracts with its supplier regarding its input item. A similar risk averse strategy can be adopted on the other side of the flow within the supply chain. In this situation, the contracts with the suppliers become active only if demand exists for the items, a part of the market fluctuations being taken by the supplier instead of *me*.

6 Related work and conclusions

Ideas from legal reasoning have been applied to social commitments [1, 7], but without the use of the contract law, although the rich semantics of higher-order commitments [7] introduces concepts like: ought, pledge, taboo, convention, collective commitment, obligation, claim, privilege, power, and immunity.

The declarative contracts using RuleML [11] use a semantic part for contracts, while contracts have already been represented with defeasible logic and RuleML [12]. By introducing commitments, we offer a more flexible solution for contract monitoring and for agents reasoning on current actions.

Causal logic has been used [13] for protocol engineering, leading to a formal method for protocol design, and more realistic commitments can also be modelled in event calculus [14]. Our commitments are addressed in a more contractual style, with the deadlines attached to commitments offering a more realistic approach from a contractual point of view.

Commitments between a network of agents have also been analyzed [3], but without time constraints. Our higher-order commitments are closer to the leveled commitment contracts [6], with different attitudes towards risk.

Verdicchio and Collombetti [15] treat the semantics of communicative acts in terms of social commitments, instead of the classical approach, with a precommitment similar to our commitment having the *open offer* state derived from contract law. Our higher-order commitments have a similar semantics to the derivative communicative acts [15], but we also cover the completion of the requested act.

By introducing defeasible commitments in the execution of contracts, we obtain two main advantages. On the one hand, agents can reason with incomplete information, including confidential contractual clauses. On the other hand, this framework is suitable for exceptions and legal reasoning: (i) concerning resolution of a dispute, strategies are explainable; (ii) skeptical mechanism; (iii) allows

[10] In the case of a moderate risk prone strategy, agent *me* requests agent *you* to effectively pay for the item and not only to promise to pay.

preferences; (iv) linear complexity; (v) fine-grained mechanism to deal with exceptions in the same manner for expected or unexpected ones.

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