Constraints among Commitments: Regulative Specification of Interaction Protocols

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Abstract. Interaction protocols play a fundamental role in multi-agent systems. In this work, after analysing the trends that are emerging not only from research on multi-agent interaction protocols but also from neighbouring fields, like research on workflows and business processes, we propose a novel definition of commitment-based interaction protocols, that is characterized by the decoupling of the *constitutive* and the *regulative* specifications and that explicitly foresees a representation of the latter based on *constraints among commitments*. A clear distinction between the two representations has many advantages, that are explained in the paper, mainly residing in a greater openness of multi-agent systems, and an easier re-use of protocols and of action definitions. A language, named 2CL, for writing regulative specifications is also given.

1 Introduction

The term "interaction protocol" refers to a pattern of behavior that allows a set of agents to become a multi-agent system (MAS), by engaging expected cooperations. Particularly relevant are *commitment protocols* by Singh [29, 36, 35]. Commitments are literals that can hold in the social state of the system, representing the fact that a debtor commits to a creditor to bring about some condition. All agents using a commitment protocol share the semantics of a set of actions which affect the social state. The greatest advantages of commitment protocols, w.r.t. other approaches to interaction, are that they *do not over-constrain* the agents' behavior by imposing an ordering on the execution of the shared actions, and that by giving a shared meaning to the social actions, they allow working on actual knowledge rather than on beliefs about each others' mental state. Nonetheless, commitment protocols *do not yet suit well* those situations where the evolution of the social state is constrained by laws, preferences or habits, because they do not allow the specification of legal patterns of execution, although this kind of constraints makes sense in many practical situations, as noticed also in [31].

In this work, we face this issue by taking on Chopra and Singh's [11] distinction between the *constitutive* and *regulative* specifications of interaction, deriving from the seminal work of Searle [27]. Roughly speaking, constitutive rules give the semantics of actions. Regulative rules rule the flow of execution, by capturing some important characteristics of how things should be carried on in *specific contexts* of interaction [7]. An actual separation of the constitutive from the regulative specification would bring many advantages in the construction of MAS, mostly as direct effects of the obtained

modularity: *easier re-use* of actions in different contexts, *easier customization* on the protocol, *easier composition* of protocols. For instance, commitment protocols are sets of shared actions. When some behavioral patterns are desired, some authors, e.g. [34], force specific orderings by introducing additional preconditions/effects to actions: these actions cannot be used out of the context they were thought for. If, instead, an explicit regulative specification were given, actions should not be *over-specified*, in the spirit of the commitment approach to protocol definition. Actions would be simpler and easier to understand because the constitutive part would correspond to the definition of the action *per se* and not of the action in a context of reference.

As a consequence, MAS would gain greater *openness*, *interoperability*, and *modularity* of design. Interoperability would be better supported because it would be possible to verify it w.r.t. specific aspects (e.g. at the level of actions [11, 9, 12] or at the level of regulation rules [5]). Protocols would be more open in the sense that their modularity would allow designers to easily adapt them to different contexts. Agents could more easily enter a system due to the increased probability of re-using their actions. Agents could also check individually (against the protocol specification) if they have actions that, when executed maybe according to some pattern, *match* with the constitutive rules independently from the context given by the regulative specification.

In the light of the distinction between constitutive and regulative rules, this work analyzes alternative commitment protocol models (namely [11, 22, 18, 19, 35, 34, 26, 21, 3, 30], Section 2), showing that, despite the fact that it is possible to recognize various attempts to capture both specifications, these proposals still miss the degree of modularity postulated in [27, 7] and described above. We show that none allows the specification of both parts (1) *in a decoupled way*, (2) *by means of first-class languages*, (3) *which allow flexible representations* – either one of the two specifications is disregarded or it is too strict or the two representations are to some extent mixed. Section 3, then, proposes a model for commitment interaction protocols that separates the constitutive and the regulative parts and supplies first-class languages for representing both in a flexible way. In particular, for the constitutive specification we adopt [11, 9], while for the regulative specification we propose the use of *constraints among commitments* as well as a language, 2CL, that allows the specification of different kinds of such constraints. The language inherits from [26, 21] but it is very different from it in its basic principles. In fact, it builds on *commitments* and not on events (actions). Section 4 shows how it is easy to tailor an interaction protocol, expressed in 2CL, to different contexts of use, by modifying the regulative specifications only. For the sake of simplicity we chose the well-known Contract Net Protocol (CNP) [14]. In the Conclusions we finish the comparison with the models in Section 2 showing that our proposal includes the others as a special case or overcomes their limits.

2 Actions and Protocols: Constitutive and Regulative Specifications

Let us consider commitment-based protocols. Commitments are directed from a debtor to a creditor. The notation $C(x, y, r, p)$ denotes that agent x commits to an agent y to bring about condition p when the condition r holds. All commitments are conditional.

An unconditional commitment is merely a special case where r equals $true$. Whenever this is the case, we use the short notation $C(x, y, p)$. Agents share a social state that contains commitments and other literals that are relevant to their interaction. Every agent can affect the social state by executing actions, whose definition is given in terms of modifications to the social state (e.g. adding a new commitment, releasing another agent from some commitment, satisfying a commitment, etc. see [35]). Commitment protocols are interaction patterns given in terms of commitments. Usually a commitment protocol is made of a set of actions (messages), whose semantics is known to – and agreed upon by – all of the participants [35, 36, 9].

There are many definitions for actions in the literature. In *UML* and in the literature about workflows, actions are atomic executions. They are considered to take zero time, and cannot be interrupted, while activities represent more complex behaviors, that may run for a long time, and may be interrupted by events. Most of works on agents adopt, instead, a *precondition-effect* view of actions, independently from the time they take to complete or from possible interruptions. *Preconditions* can be of two kinds: preconditions to the action execution, and preconditions to some effect. The former are literals that must hold in the social state to make the action executable, the latter are additional conditions that, when holding, allow the production of the specific effect that they control. For instance, in order to pay by credit card it is necessary to own a credit card (precondition to the action). If a credit card owner uses it for paying, the payment will be done only if the card is valid (conditional effect). For example, in [11, 9] actions have no preconditions of any kind, in [10, 20] actions have both preconditions to the executability and conditional effects, while [34] uses only preconditions to the execution of actions. Given these basic notions, let us, now, focus on *regulative rules* and overview the most relevant works in the context of *commitment-based interaction protocols*, in order to compare and discuss the proposed models, which are graphically summarized in Fig. 1 and Fig. 2.

Chopra and Singh. ([11], Fig. 1(a)) Chopra and Singh introduce the distinction between constitutive and regulative specifications in the definition of commitment protocols. Each agent is publicly described by the *effects* of the messages it can send, which make the *constitutive specification* of the agent. Such specifications allow agents to agree on the meaning of their communications. Instead, the *regulative specification* rules the data flow among messages. For instance, the constitutive specification of the action *buy* could be the commitment to pay the merchant, while the regulative specification may require that goods are sent only after the payment has been done. In that work (personal communication) and in [10] the regulative specification is based *on the actions themselves*; in particular, the flow is controlled by the *preconditions to the (non-)executability of the actions*. So, in order to impose that sending goods should follow payment, the action *send-goods* should have as a precondition a literal that is made true as an effect of the action *pay*. This solution (which is adopted also in works like [19, 35, 36, 9, 34]) is characterized by a *strong localization* of the regulative specification. Both the constitutive and the regulative specifications are indistinguishable (being both based on actions, see Fig. 1(a)). *The problem is that by doing so the definition of an action becomes dependent on the protocol where it is used*. This limits the openness of the system and in particular complicates the re-use of software (the agents' actions). Actions,

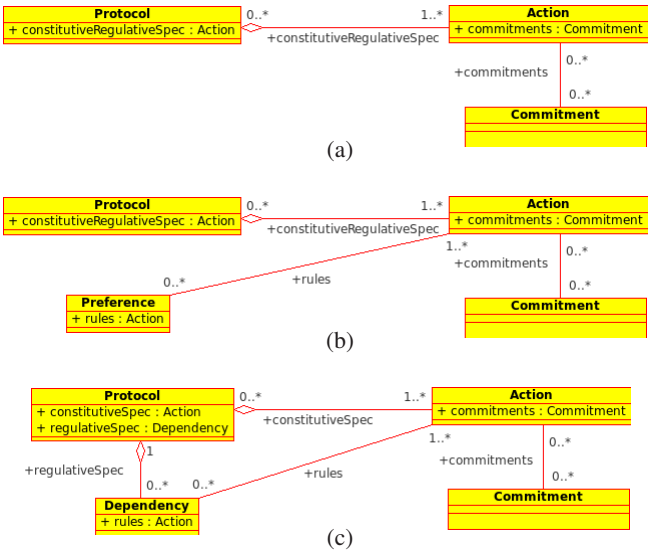

Fig. 1. (a) Chopra and Singh's implementation model: regulative specifications based on actions; (b) Mallya and Singh's model: adding preferences on actions; (c) Singh's dependencies among events.

in fact, are defined not only for what concerns their effects (constitutive specification) but also taking into account their context of use. When changing context (protocol), the regulative specification inside the actions is to be updated or new, specific actions are to be defined. Analogously, when adding a new action, it is necessary to enrich it with the correct regulative specification. In our view, a greater decoupling between the actions and the regulative specification would have the advantage of facilitating the re-use of actions because it would allow the avoidance of the over-specification that is necessary to impose an ordering among actions.

Preferences and dependencies. ([22], Fig. 1(b) and [30], Fig. 1(c), respectively) Mallya and Singh [22] propose to order the possible executions according to a set of preferences that take into account the policies of the various parties. No execution is strictly forbidden but a preference criterion is specified. Differently than above, here the constitutive specification is given in terms of commitments but the preference rules are given in terms of actions. Preferences do not precisely correspond to regulatives rules because they specify selection policies rather than constraining the execution flow. Nevertheless, giving them in terms of actions makes the specification less flexible and less easily adaptable or open. The same limits, Fig. 1(c), can be ascribed to the work to which [22] is inspired, i.e. [30], although in this work it is possible to recognize the introduction of a regulative specification, based on the *before* relation applied to events.

ConDec. ([26, 25, 8, 21], Fig. 2(a)) Pesic and van der Aalst propose an approach that is radically opposite to the one by Chopra and Singh [26]. In this approach, which totally lacks of a constitutive component (and does not build on commitments nor is set in

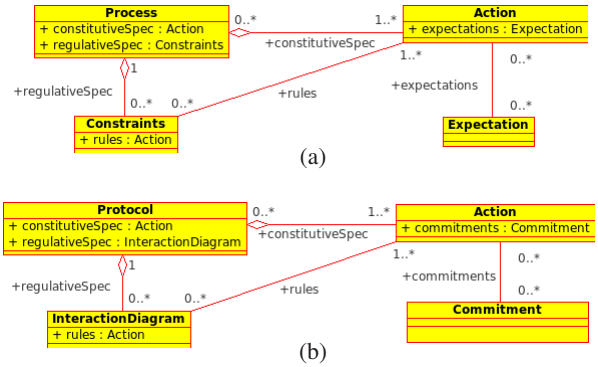

Fig. 2. (a) ConDec model: regulative specification given by means of constraints on actions, an extension supplies an expectation-based semantics for actions; (b) Fornara and Colombetti's model: regulative specification given by interaction diagrams defined on actions.

the agents framework), the declarative language ConDec is proposed for representing business processes which, though not exactly interaction protocols, specify the expected behavior of a set of interacting parties by constraining the execution of their tasks. The regulative rules are a first-class element of the protocol which are given by means of an ad hoc *declarative* language. They are not local to single actions as in Fig. 1(a), rather they are constraints that rule the flow of activity execution (activity in UML sense). In [25, 8, 21], the authors use this approach to specify interaction protocols and service choreographies. To this aim, they integrate ConDec with SCIFF thus giving a semantics to actions that is based on *expectations*.

Still, however, in these proposals there is a too tight connection between the regulative rules and actions because such rules define temporal constraints over actions (events), see Fig. 2(a). This, in our opinion, clashes with the openness of MAS. Let us explain our view with an example. Let us suppose that payment should occur before sending the goods, and that the protocol foresees the actions *pay-by-credit-card* and *send-goods*. Then, it will specify that *pay-by-credit-card* must occur before *send-goods*. Now, if a client arrives which can pay cash, it will not be in condition to take part to the interaction unless the regulative specification is changed by adding a rule that says that paying cash should occur before sending the goods. This should be done even though the action has the same semantics of *pay-by-credit-card* in terms of commitments. The need of modifying the regulative specification (even in the case when actions have the same semantics!), gives *an undesired rigidity to the protocol*. Problems arise also in the case an agent can execute a sequence of actions which *altogether* implement one of those foreseen by the protocol. The problem is that the regulative specification is given in terms of *actions*, so, when changing the actions names we need to change regulative specifications as well. It is also easy to make mistakes by forgetting to update the regulative part when a new action is changed or when its semantics is changed.

Fornara and Colombetti. ([15, 18, 17], Fig. 2(b)) Fornara and Colombetti define a commitment-based semantics for the speech acts of agent communication languages,

like FIPA, and then use *interaction diagrams* to define agent interaction protocols. In this proposal, the social actions are represented by the speech acts and the constitutive specification is given in terms of commitments. The choice of relying on interaction diagrams is, however, very strong because it forces the ordering of action executions, loosing, in our opinion the flexibility aimed at by the adoption of commitments.

Summary. The distinction between a regulative and a constitutive specification is surely interesting but the current proposals show some limits in the realization of this model, each with its pros and cons. Fornara and Colombetti's proposal is too rigid: the use of interaction diagrams conflicts with the desirable flexibility of commitments. In this respect, ConDec's use of constraints is better: the declarative approach that is proposed is aligned with the declarative nature of commitments. The problem is that constraints are defined in terms of performing actions rather than of bringing about conditions. Also Chopra and Singh propose an implementation where the regulative specification is given on top of actions: again, while commitments are given on conditions and not on the actions that should bring them about, constraints are posed on the action execution, with the result that modularity is not obtained. The same holds for [34, 19, 35, 36].

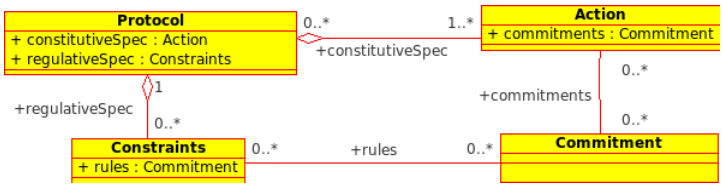

Fig. 3. Our proposal: decoupling between constitutive (actions) and regulative (constraints) specifications.

Our proposal aims at overcoming the listed limits. As in [22, 18] we propose the use of commitments to give constitutive specifications. As in [26, 25] we propose the use of a declarative language, 2CL, for capturing constraints that rule the execution flow. The difference is that in our proposal such constraints relate commitments and not actions (see Fig. 3). The consequent greater modularity brings along the mentioned advantages: an easier re-use of actions in different contexts, an easier re-use of protocols with different actors, greater openness, better support to interoperability checks, simpler customization of protocols. The next section illustrates our proposal for the representation of regulative specifications.

3 Commitment Protocols: A Decoupled Approach

In this work, we propose an approach to the definition of commitment-based interaction protocols which includes a *constitutive* specification, that defines the meaning of actions for all the agents in the system, and a *regulative* specification, which constrains the possible evolutions of the social state. Both are defined based on *commitments*.

Definition 1 (Interaction protocol). *An interaction protocol* P *is a tuple* $\langle Ro, F, A, C\rangle$*, where* Ro *is a set of roles, identifying the interacting parties,* F *is a set of literals (including commitments) that can occur in the social state,* A *is a set of actions, and* C *is a set of constraints.*

The set of social actions A, defined on F and on Ro, forms the *constitutive specification* of the protocol, while the set of constraints C, defined on F and on Ro too, forms the *regulative specification* of the protocol. The *constitutive specification* of an action, similarly to [9], defines its meaning in terms of how it affects the social state by adding or removing literals or by performing operations on the commitments (the usual create, release, delete, etc., see [28, 36]). The constitutive specification follows the grammar:

$A \rightarrow (Action$ **means** $Operation)^+$
$Action \rightarrow protocolAction([paramList])$
$Operation \rightarrow Op(commitment) \mid fact \mid Operation \wedge Operation$
$Op \rightarrow$ CREATE $\mid$ DELETE $\mid$ RELEASE $\mid$ DELEGATE $\mid$ ASSIGN

where *protocolAction* is the name of an interactive action of the protocol; *paramList* denotes the possible parameter list of the action; *Op* is one of the operations on commitments; *commitment* is a commitment of form $C(x, y, r, p)$, as specified in Section 2 (see also [9, page 49]), where x and y are roles in Ro and r and p are formulas in disjunctive normal form of propositional literals in F; and fact is a positive or negative proposition that does not concern commitments and which contributes to the social state (they are the conditions that are brought about – when necessary they are enriched by two parameters: the actor and the recipient). For instance, the action *cfp* of the contract net protocol (which is used as an example below) is given in this way: $cfp(i, p)$ **means** CREATE$(C(i, p, assigned_task(i, p)))$, i.e. its effect is to add to the social state the commitment $C(i, p, assigned\_task(i, p))$ by which the initiator (role i) commits to a participant (role p) to assign a task of interest. Not necessarily the task will be assigned to the p at issue; if many participants propose to solve a task, the choice depends on the criteria implemented by the specific initiator, which are not modeled by the protocol.

In order to represent the *regulative specification*, we propose a *constraint-based representation* following the grammar:

$C \rightarrow (Disj\ op\ Disj)^+$
$Disj \rightarrow Conj \vee Disj \mid Conj$
$Conj \rightarrow literal \wedge Conj \mid literal$

C, see Def. 1, is a set of constraints of the form $A\ op\ B$, where A and B are formulas of literals in disjunctive normal form and op is one of the operators in Table 1; *literal* can be either a commitment or a positive or negative proposition (where negation means that a certain literal does not hold in the social state). Such constraints rule the evolution of the social state by imposing specific patterns on how states can progress. For instance, $C(i, p, assigned\_task(i, p)) \multimap (refused\_task(p, i) \vee C(p, i, solved\_task(p, i)))$ expresses the fact that a participant cannot refuse a task nor it is allowed to commit to solve it before the initiator has taken a commitment, stating its intention to assign the task to that participant. Notice that the constraint *does not* specify *which* actions should bring these conditions about, in fact, constraints do not rule the occurrence of events. The

declarative nature of the specification adds flexibility w.r.t. an algorithmic specification, in fact, while the latter specifies *all* the allowed evolutions, declarative constraints allow *any* evolution that respects the relations involving the specified literals.

Relation	*Positive*	*LTL meaning*	*Negative*	*LTL meaning*
Correlation	$a \bullet\!\!- b$	$\Diamond a \supset \Diamond b$	$a \bullet\!\!\not- b$	$\Diamond a \supset \neg\Diamond b$
Co-existence	$a \bullet\!\!-\!\!\bullet b$	$a \bullet\!\!- b \wedge b \bullet\!\!- a$	$a \bullet\!\!\not-\!\!\bullet b$	$a \bullet\!\!\not- b \wedge b \bullet\!\!\not- a$
Response	$a \bullet\!\!-\!\!\triangleright b$	$\Box(a \supset \Diamond b)$	$a \bullet\!\!\not-\!\!\triangleright b$	$\Box(a \supset \neg\Diamond b)$
Before	$a \multimap\!\!\bullet b$	$\neg b \mathsf{U} a$	$a \not\multimap\!\!\bullet b$	$\neg a \mathsf{U} b$
Cause	$a \bullet\!\!-\!\!\triangleright\!\!\bullet b$	$a \bullet\!\!-\!\!\triangleright b \wedge a \multimap\!\!\bullet b$	$a \bullet\!\!\not-\!\!\triangleright\!\!\bullet b$	$a \bullet\!\!\not-\!\!\triangleright b \wedge a \not\multimap\!\!\bullet b$
Premise	$a \bowtie\!\!- b$	$\Box(\bigcirc b \supset a)$	$a \bowtie\!\!\not- b$	$\Box(\bigcirc b \supset \neg a)$

Table 1. 2CL operators and their semantics in LTL.

We named the language for representing the regulative specification 2CL (the acronym stands for "Constraints among Commitments Language") . The names of the operators and the graphical format, used in Section 4, are inspired by ConDec [26]. We remark again that the main difference is that constraints are defined over commitments and facts, while in ConDec they are defined on actions. This distinction motivates the differences both on the names of the operators (e.g. before instead of precedence) and on the LTL translation of them. For allowing the application of reasoning techniques (e.g. to check if an interaction is respecting the protocol, to build sequences of actions that respect the protocol, or to verify properties of the system) it is necessary to give the operators a semantics that can be reasoned about. To this aim, we use *linear temporal logic* (LTL, [13]), which includes temporal operators like next-time ($\bigcirc$), eventually ($\Diamond$), always ($\Box$), weak until (U). Let us describe the various operators. For simplicity the description are given on single literals rather than formulas.

Correlation: this operator captures the fact that in an execution where a occurs, also b occurs but there is no temporal relation between the two. Its negation means that if a occurs in some execution, b must not occur.

Co-existence: the mutual correlation between a and b. Its negation captures the mutual exclusion of a and b. Notice that in LTL the semantics of negated co-existence is equivalent to the semantics of negated correlation.

Response: this is a temporal relation, stating that if a occurs b must hold at least once afterwards (or in the same state). It does not matter if b already held before a. The negation states that if a holds, b cannot hold in the same state or after.

Before: this is a temporal relation, stating that b cannot hold until a becomes true. Afterwards, it is not necessary that b becomes true. The negation of $a \multimap\!\!\bullet\ b$ is equivalent to $b \multimap\!\!\bullet\ a$.

Cause: this operator states that if a occurs, after b must occur at least once and b cannot occur before a. The negation states that if a occurs, b cannot follow it and if b occurs, a is not allowed to occur before.

Premise: is a stronger temporal relation concerning *subsequent* states, stating that a must hold in all the states immediately preceding one state in which b holds. The

negation states that a must never hold in a state that immediately precedes one where b holds.

Notice that the negated operators semantics (column 5) not always corresponds to the negation of the semantics of the corresponding positive operator (column 3). This is due to the intention of capturing the intuitive meaning of negations. We show this need by means of a couple of examples. For what concerns correlation, the negation of the formula in column 3, which is $\Diamond a \wedge \neg\Diamond b$, is too strong because it says that a must hold sooner or later while b cannot hold. What we mean by negated coexistence, instead, is that *if a becomes true* then b must not occur in the execution. For completeness, the semantics of negated correlation is not equivalent to the semantics of $a \bullet\!\!- \neg b$.

For what concerns *premise*, by negating the semantics in column 3 we obtain $\Diamond(\bigcirc b \wedge \neg a)$ which says that b occurs in some state and a does not occur in the previous state. Instead, the intended meaning is that a does not have to hold in the states that precede those in which b holds (but b does not necessarily have to hold). Analogous considerations can be drawn for the other operators. The choice of sticking to the intuitive semantics of the operators is done to give the user only *seven* basic operators. Had we defined the negated operators semantics by negating the semantics of the positive operators, we would have defined *fourteen* different operators.

3.1 Constraints, conditional commitments and normative aspects

Is there any relationship between conditional commitments and constraints among commitments? Indeed, the two have different natures. A conditional commitment $C(x, y, r, p)$ does not capture a temporal relation: in fact, p can occur before r becomes true or even before the commitment is ever taken. When the conditional commitment holds, r immediately triggers $C(x, y, p)$ because this behavior is intrinsic to the commitment's life cycle (see also [34], where the complete transition diagram is reported). The expressions that we represent in 2CL, instead, define *properties* of the interaction, that are to be checked against the evolution of the social state.

For what concerns the violation of commitments and of constraints, according to Singh [28], commitments have a *normative* nature. Agents can freely decide if and when committing to do something but when they do, they are obliged to fulfill their commitments. Consider the conditional commitment: $C(p, i, assigned\_task(i, p), solved\_task(p,i)$ XOR $failed(p, i))$. Here the participant p commits to either do some work or declare a failure, if the initiator i assign it a task ($assigned\_task(i, p)$). The problem is that, since the participant is free to decide whether or not taking the commitment, the initiator has *no guarantee* that its decision to assign a task will be followed by an answer by the participant because there is no guarantee that the commitment will ever be taken. If, instead, we use one of our constraints, e.g. $assigned\_task(i, p) \bullet\!\!\rightarrow\!\!\bullet\ solved\_task(p, i)$ XOR $failed(p, i)$, imposing that after the decision of i to assign a task ($assigned\_task(i, p)$), the participant p must either solve it or declare a failure ($solved\_task(p, i)$ XOR $failed(p, i)$), the initiator has some *guarantees* about the behavior of the participant. The initiator knows this before starting the interaction, because the protocol is public, and can use this information to decide whether to use the protocol. Guarantees, however, are given only if constraints have a normative nature: the

violation of a constraint, as well as the violation of a commitment, pushes the agent out of the protocol. In case of constraints, being out of the protocol does not imply that the interaction will be unsuccessful but only that the participants lose the guarantee that all the parties involved will achieve an effective result. By sticking to the constraints, the agents waive part of their autonomy but they do this autonomously, because they consider it advantageous w.r.t. interacting without rules.

4 Tailoring Protocols to different needs

In this section, we show the use of the proposed model by, first, representing the well-known Contract Net Protocol (CNP for short) [14] and, then, by showing how easy it is to produce variants by playing with its regulative specification, separately from the constitutive specification of its actions. Briefly, CNP includes two roles, the initiator (i in the following) and a participant (p). The initiator calls for proposals. The participant may send a proposal or refuse to do it. When a proposal is received, the initiator may either reject or accept it. Notice that, for the sake of simplicity, we do not model the exchange of information concerning the proposal itself but only the interaction concerning the task assignment and solution. We report the CNP as represented according to our proposal, by giving its constitutive specification followed by its regulative specification.

Constitutive specification of CNP. The actions of CNP, as expressed according to the grammar in Section 3, are:

(a) $cfp(i,p)$ **means** CREATE$(C(i,p,assigned_task(i,p)))$
(b) $propose(p,i)$ **means** CREATE$(C(p,i,solved_task(p,i)))$
(c) $refuse(p,i)$ **means** $refused\_task(p,i) \wedge$ RELEASE$(C(i,p,assigned_task(i,p)))$
(d) $accept(i,p)$ **means** $assigned\_task(i,p)$
(e) $reject(i,p)$ **means** $rejected\_proposal(i,p) \wedge$ DELETE$(C(i,p,assigned_task(i,p))) \wedge$ RELEASE$(C(p,i,solved_task(p,i)))$
(f) $inform\_done(p,i)$ **means** $solved\_task(p,i)$
(g) $failure(p,i)$ **means** $failed(p,i) \wedge$ DELETE$(C(p,i,solved_task(p,i)))$

Since such definitions are quite straightforward, we get into the details of just a couple of them. The effect of action *cfp* is to create the commitment $C(i,p,assigned\_task(i,p))$. Intuitively, this commitment states the resolution of the initiator to assign a task to a participant because it needs someone to solve it. This does not mean that, at the end, the task will be assigned to *that* participant. Indeed, during the execution the participant may refuse to solve the task or the initiator may reject its proposal because, for example, it is not convenient. The action $refuse(p,i)$ (the participant refuses to solve a task), instead, has, as effect, the action RELEASE$(C(i,p,assigned_task(i,p)))$, by which the participant releases the initiator from the commitment of assigning a task to it, and the fact $refused\_task(p,i)$, whose meaning is clear.

Regulative specification of CNP. The regulative rules of CNP, as expressed according to the grammar in Section 3, are:

c1: $C(i, p, assigned\_task(i, p)) \bullet\!\!\rightarrow\!\!\bullet\ C(p, i, solved\_task(p, i))$ XOR $refused\_task(p, i)$
c2: $C(p, i, solved\_task(p, i)) \bullet\!\!\rightarrow\!\!\bullet\ rejected\_proposal(i, p)$ XOR $assigned\_task(i, p)$
c3: $assigned\_task(i, p) \bullet\!\!\rightarrow\!\!\bullet\ solved\_task(p, i)$ XOR $failed(p, i)$

Fig. 4 reports them as a graph, whose nodes (the rectangles) contain literals that should be in the social state at some point of the execution, while the arrows are operators from Table 1 (for the sake of readability we omitted parameters of literals in the figures). The

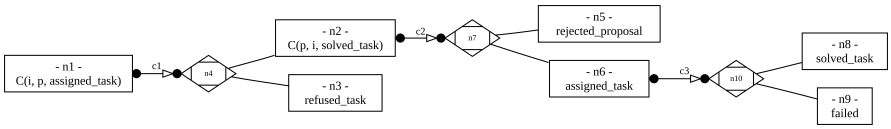

Fig. 4. Regulative specification of the Contract Net Protocol.

initiator declares its intention to assign a task (node $n1$, $C(i, p, assigned\_task(i, p))$). If this happens, afterwards the participant takes its decision and alternatively refuses or states its intention to solve the task. This is represented by the fact that the node $n1$ is connected to the nodes $n2$ ($C(p, i, solved\_task(p, i))$), and $n3$ ($refused\_task(p, i)$): $n2$ and $n3$ are alternative evolutions of the social state after $n1$. The connector $n4$ denotes the *exclusive or* of the two. It is a graphical simplification of the and-or formula implementing the "exclusive or". The arrow used (of kind $a \bullet\!\!\rightarrow\!\!\bullet\ b$) represents the fact that when the initiator must assign a task, the participant necessarily has to either refuse the task or take the commitment to solve it. It is not obliged to do it as the next step of its execution but sooner or later it must take one of the two ways. The specification foresees that the participant cannot take the initiative of proposing to solve a task (or of refusing to do something) if the initiator has not declared that there is a task to solve. This is the intuitive meaning of the circles at the two sides of the arrow $c1$.

Notice that we have not mentioned which actions should be executed to change the social state. Actually, we do not care. Any action, whose effect is compatible with the schema of evolution of the social state reported above is feasible. In the same way it is not necessary, in commitment protocols, to say which action to take to satisfy a commitment. Moreover, the transition from one state to one of its next (w.r.t. the description given by regulative specification) states may require the application of many actions (not necessarily one). The regulative specification does *not* give any *procedure* for achieving the social state change, that it captures. In fact, constraints on the evolution of the social state are independent from the actions that are used by the agents. Both, however, are specified on top of the literals in the social state.

If the interaction continues because the participant has proposed to solve the task, the initiator must either reject the proposal or accept it and assign the task to the participant, which, in this case, will try to solve the task and give back to the initiator an answer (the solution or the information that it has failed). The arrows in the graph between nodes $n2$ and the alternative between $n5$ and $n6$, on a side, and between $n6$ and the alternative between $n8$ and $n9$ are again of the kind $\bullet\!\!\rightarrow\!\!\bullet$ (causality operator).

4.1 Tailoring the Contract Net Protocol

Let us show the versatility of the proposed representation by showing how a designer can easily modify the specification of CNP, given above, so as to build new protocols which adapt to different conditions. All the variations are produced by working exclusively on the regulative specification without modifying the actions. Of course, it is possible to do the opposite or to modify both parts if needed.

Lazy and zealous participant. (Fig. 5(a), Fig. 5(b)) The first two simple variants are obtained by changing a single arrow with another operator from Table 1. With reference to Fig. 5(a), if we use a *before* relation ($\rightarrow\!\!\bullet$), the participant *would not be obliged* to answer (it is allowed to have a lazy behavior). In constraints the whole variant is:

c1: $C(i, p, assigned\_task(i, p)) \rightarrow\!\!\bullet\ C(p, i, solved\_task(p, i))$ XOR $refused\_task(p, i)$
c2: $C(p, i, solved\_task(p, i)) \bullet\!\!\rightarrow\!\!\bullet\ rejected\_proposal(i, p)$ XOR $assigned\_task(i, p)$
c3: $assigned\_task(i, p) \bullet\!\!\rightarrow\!\!\bullet\ solved\_task(p, i)$ XOR $failed(p, i)$

Instead, Fig. 5(b), if a *response* ($\bullet\!\!\rightarrow$) is used, the participant *can also take the initiative* to solve a task even though the initiator has not made any request (zealous participant):

c1: $C(i, p, assigned\_task(i, p)) \bullet\!\!\rightarrow\ C(p, i, solved\_task(p, i))$ XOR $refused\_task(p, i)$
c2: $C(p, i, solved\_task(p, i)) \bullet\!\!\rightarrow\!\!\bullet\ rejected\_proposal(i, p)$ XOR $assigned\_task(i, p)$
c3: $assigned\_task(i, p) \bullet\!\!\rightarrow\!\!\bullet\ solved\_task(p, i)$ XOR $failed(p, i)$

These two variants correspond to protocols that differ from CNP but that can easily be obtained by working at the level of constraints among commitments.

CNP with Anticipated Failure (Fig. 5(c)) The next context that we consider is a call for bids, where an initiator publishes an open call, e.g. in an official gazette, that does not require the subscribers to the gazette to answer. Fig. 5(c) shows the new protocol: the fact that the participant is not obliged to send a bid is captured by the constraint $c1$, which is a *before* ($\rightarrow\!\!\bullet$) instead of being a *cause* ($\bullet\!\!\rightarrow\!\!\bullet$, in Fig. 4). We have further modified the CNP by changing the constraint $c3$ in Fig. 4, in order to capture the fact that a participant can notify a failure in the task solution also in the case in which the task has not been assigned to it yet but, for some reason, it has found out that it has become impossible for it to proceed with the solution, in case the task is assigned to it. Instead, it is not allowed to communicate the solution until the task is assigned to it. The new protocol can be obtained by modifying the regulative specification as in Fig. 5(c). In rules:

c1: $C(i, p, assigned\_task(i, p)) \rightarrow\!\!\bullet\ C(p, i, solved\_task(p, i))$ XOR $refused\_task(p, i)$
c2: $C(p, i, solved\_task(p, i)) \bullet\!\!\rightarrow\!\!\bullet\ rejected\_proposal(i, p)$ XOR $assigned\_task(i, p)$
c3: $assigned\_task(i, p) \bullet\!\!\rightarrow\ solved\_task(p, i)$ XOR $failed(p, i)$
c4: $assigned\_task(i, p) \rightarrow\!\!\bullet\ solved\_task(p, i)$

The changes concern the constraints after node $n6$. In the new version, instead of having simply a *cause* constraint, we have a *response* ($\bullet\!\!\rightarrow$). Response is a softer constraint because it does not forbid to the alternatives specified by $n10$ to hold before $assigned\_task(i, p)$. For this reason, in order to enforce that the solution is communicated only after the assignment, another constraint is to be added ($c4$). In this way, failure can be notified at any moment.

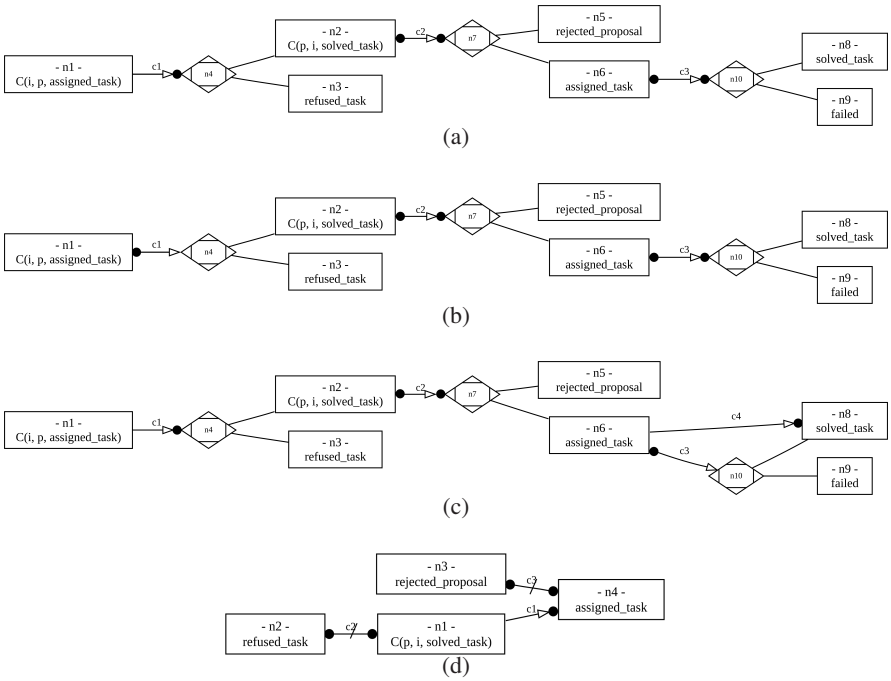

Fig. 5. (a) Lazy Participant; (b) Zealous Participant; (c) CNP with Anticipated Failure; (d) Soft CNP.

Soft CNP. (Fig. 5(d)) The last example is a very soft interaction protocol that, differently than the previous ones, expresses just a few regulative constraints, leaving a much greater freedom of behavior to the initiator and to the participant.

c1: $C(p, i, solved\_task(p, i)) \rightarrow\!\!\bullet\ assigned\_task(i, p)$
c2: $refused\_task(p, i) \bullet\!\!\not\rightarrow C(p, i, solved\_task(p, i))$
c3: $rejected\_proposal(i, p) \bullet\!\!\not\rightarrow assigned\_task(i, p)$

This example also shows the use of *negative* constraints. The only constraint that is imposed on the evolution of the social state is that a task cannot be assigned to a participant who has not yet committed to solve it. Moreover, there are two negative constraints (of kind $\bullet\!\!\not\rightarrow$) stating that proposal assignment and rejection are mutually exclusive ($c3$), and that the refusal of a task is mutually exclusive to the commitment to solve it ($c2$). So, for instance, a participant can express its intention to solve a task for which no call has been made, and it is also possible for it to give a solution before any assignment of the task has been made to it. On the other hand, the initiator can ignore the participant even though it has committed to solve the task by avoiding to answer to it. It can call for proposals even if it already has a commitment by the participant, and it can reject a participant even though it has not made any proposal. It is not even necessary that the initiator commits to assign the task.

5 Conclusion and future work

Constitutive and regulative specifications have been recognized as fundamental components of the interaction based on communication starting from Searle [27, 7], and including various authors in the Multi-Agent community, e.g. [11, 9, 6]. In this paper we have presented a model of commitment-based interaction protocols that includes an explicit representation of both constitutive and regulative specifications. From a graphical point of view, the language 2CL is inspired to [26, 4]. The semantics of the operators is based on linear temporal logic due to the fact that this logic is well-known and simple and opens the way to possible integrations with model checkers like SPIN or NuSMV. We mean, however, to study both alternatives to LTL (such as CTL*) and alternatives to model checking techniques (such as SAT solvers and ASP).

The proposal includes as special cases some of the representation models discussed in Section 2. Specifically, we can model the proposal by Chopra and Singh [11] as well as the models adopted in [19, 36, 34] which follow the same principles, by introducing for each action a literal that is univocally associated to it, as an effect of the action, and, then, to define constraints (typically of kind *premise*, $\rightarrowtail$) among these literals. The use of constraints of kind *premise* also allows the designer to specify *strict sequences* of action executions, as in [16, 18, 15]. Last but not the least, the proposal overcomes the limits of [26, 30, 25, 8, 21] because the regulative specification rules the evolution of the social state and not the execution of actions/events. However, if the designer wishes to constrain the execution of specific actions, he/she can do it, as explained.

An approach similar to commitment-based protocols is the one introduced in [3], where *expectation*-based protocols are presented. Expectations concern events expected to happen (or not to happen) and can be associated to time points. Protocols are specified by constraining the times at which events occur. As for the previous works, the limit of this approach is that it works directly on events (i.e. actions); by constraining actions the approach lacks the openness discussed in the Introduction and in the discussion about ConDec in Section 2. On the other hand, our proposal does not handle time explicitly so we cannot yet represent and handle timeouts and also compensation mechanisms. The aim of this paper is, indeed, to present the idea of an explicit, declarative, and decoupled representation of both the constitutive and the regulative specifications. We mean to tackle also issues concerning time, deadlines, faults and compensation, like in [32] (where commitments are implemented by means of expectations), in future work.

The adaptation of commitment-based protocols to different contexts of use has been tackled in [10]. The authors show how declarative approaches suit well this aim. Our proposal is set along this line. In fact, not only the constitutive rules are given in a declarative way but also the regulative specification is made of declarative constraints and it is possible to contextualize it by adding or removing constraints. The advantage w.r.t. [10] is the modularity of the two specifications discussed along the paper.

The work in [24] contains a comparison of various approaches to interaction protocols, including but not limited to commitment-based protocols. Specifically, also normative systems, algebraic-operational approaches (like $\mathcal{RASA}$ [23]), and Petri nets are considered. The comparison is done along many directions. The authors confirm our opinion that declarative approaches (like commitment-based ones) are very flexible. However, they claim that they are less readable (and sometimes more verbose) than

algorithmic approaches. To support this consideration they cite some of the major existing tools for the designer (like AgentUML), which are algorithmic. For verbosity, they cite the CNP representation in [3] which consists of seventeen rules. We underline that our regulative representation of CNP consists instead of *three* rules only. The constitutive specification is made of *seven* rules (because there are seven actions). For what concerns commitment protocols, the difficulty in reading declarative specifications is, in our opinion, due to the lack of separation between the constitutive and the regulative specifications that many approaches show. Moreover, as [33] notices, there is a lack of graphical intuitive representations oriented to designers. We have tried to overcome these problems by decoupling the regulative and the constitutive specifications and by giving a graphical representation. This representation has the advantage of giving the *perception of a flow* in the execution, remaining however at a *what* rather than at a *how* level (*no-flow in-flow*). This representation also supports the compositionality of the protocols. In fact, to put it simply, in order to produce a new protocol starting from existing ones, it is sufficient to draw together the sets of constraints of interest and produce a bigger graph without any effort. Protocols can, then, be designed bottom-up. This aspects will further be studied as future work.

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