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Agents on the Web

Commitments Among Agents

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We sent one of our agents off to buy a book for us last month, but the book never arrived. The publisher claimed they had sent it, but the shipping company they chose could not find a record of it. Unfortunately, the credit card debit succeeded!

There appear to be several points of failure in this transaction, which we typically describe in terms of “blame.” Software agents, however, require terminology that is more formal, which we can supply in the form of temporal commitments. Commitments are a powerful representation for modeling multiagent interactions. Previous approaches have considered the semantics of commitments and how to check compliance with them (see the sidebar on p. 93). However, these approaches do not capture some of the subtleties that arise in real-life applications such as e-commerce, in which contracts and institutions have implicit temporal references. In this column, we describe a rich representation for the temporal content of commitments that lets us capture realistic contracts and avoid ambiguities. Consequently, this approach lets us reason about whether, and at what point, a commitment is satisfied or breached, and whether it is or ever becomes unenforceable.

Properties for Business Applications
Business contracts commonly involve many clauses and have subtle time periods of reference. The following is an informal list of some properties that are relevant in practice, but not naturally handled by current commitment-based approaches.

• Time intervals. Contracts often involve time bounds, which simplify decisions about the satisfaction or breach of commitments. Their existence in contracts is a significant reason traditional representations (such as paper documents) rely on them. Practical commitments often must be satisfied either in a fixed, bounded interval or at a specified instant in the future.

• Maintenance. Current work on commitments has concentrated on conditions for their achievement, whereas real-life commitments are as likely to be about the maintenance of certain conditions. For example, a typical service-level agreement could involve committing to maintaining network connectivity during business hours.

• Temporal anaphora. A particular variety of time bounds arises in the notion of temporal anaphora, an implicit range of salient times within which a specified action occurred or will occur. A promise such as “I will send you the goods,” or a claim such as “I tried to call you five times,” involves such a time range. Although we are not concerned here with commonsense reasoning, our representational framework for commitments should be able to accommodate the results of such reasoning.

Real-World Challenges
To motivate our study of temporal aspects of commitments, we use situational examples that arise in...
practical applications of Web services. (We present solutions to these examples later.) Consider a travel agent who wishes to book an airline ticket to a certain destination, a rental car to use while there, and a hotel room at which to stay.

- **Example one.** The travel agent wants the passenger to fly on a particular day while still reserving the right to choose any flight on that day. If the airline offers such a deal, it becomes committed to maintaining a condition—a booked ticket—over an extended time period. We must be able to specify such maintenance conditions in commitments.

- **Example two.** The car rental company might offer a one-week free rental in January. This is a maintenance condition in another time period. We must be able to capture such temporal intricacies without bloating the domain language.

- **Example three.** Some commitments might violate constraints about time that commonsense reasoning would have detected. Such a situation can arise, for example, when a hotel offers an electronic discount coupon that expires today, but text on the coupon states that it can only be used during a future spring break.

- **Example four.** The car rental company might offer a warranty that cannot be used during the period in which the warranty is valid. The company might guarantee that its cars will not break down for at least two days, promising an immediate replacement if one does. However, if the company is closed on weekends, then a customer who rents a car on a Friday would not benefit from the warranty if the car broke down on Saturday.

Our method’s main contribution to reasoning about commitments is that it applies a richer temporal representation and shows how to detect when a commitment is satisfied or breached. Further, it keeps the temporal aspects independent of the domain-specific semantics of the condition that the commitment is about. Thus, we can reason about the temporal aspects in a domain-independent manner.

### A Temporal Commitment Framework

Commitments are obligations that one agent has to another. Formally, a commitment \(C(d, x, y, p)\) relates a debtor \(x\), a creditor \(y\), and a condition \(p\) in such a way that \(x\) becomes responsible to \(y\) for satisfying the condition \(p\); the commitment has a unique identifier \(d\). The commitment is satisfied when the condition \(p\) holds.

A framework’s essential elements for representing and reasoning about commitments are, first, a way to describe commitments and operations on commitments. Second, because of their temporal nature, there must be a way to describe moments and time intervals. Third, because commitments extend into the uncertain future, there must be a way to describe alternative outcomes.

#### Describing Commitments

For the first requirement, the following operations create, satisfy, and transform commitments:

- \(\text{create}(x, c)\) establishes the commitment \(c\) in the system. This can only be performed by \(c\)'s debtor \(x\).
- \(\text{cancel}(x, c)\) cancels the commitment \(c\). This can only be performed by \(c\)'s debtor \(x\). Generally, making another commitment compensates cancellation.
- \(\text{release}(y, c)\) releases \(c\)'s debtor \(x\) from commitment \(c\). This can only be performed by the creditor \(y\).
- \(\text{assign}(y, z, c)\) replaces \(y\) with \(z\) as \(c\)'s creditor.
- \(\text{delegate}(x, z, c)\) replaces \(x\) with \(z\) as \(c\)'s debtor.
- \(\text{discharge}(x, c)\) \(c\)'s debtor \(x\) fulfills the commitment.

The operators are applied to commitments during a time interval.

#### Describing Time Intervals

For the second requirement, we define two temporal quantifiers:

- \(\text{Existential, } [t_1, t_2]p\) means that \(p\) is true at one or more moments in the interval beginning at \(t_1\) and ending at \(t_2\).
- \(\text{Universal, } [t_1, t_2]p\) means that \(p\) is true at every moment in the interval beginning at \(t_1\) and ending at \(t_2\).

To reason about future possibilities, we need to consider the different things that might occur during future time intervals.

#### Describing Alternative Outcomes

A branching-time logic, such as CTL (shown in Figure 1), satisfies the third requirement. It defines the following operators that apply over a particular
scenario (defined as a path into the future from a moment in time):

- Until. A statement \( p U q \), read \( p \) until \( q \), is true at a moment \( m_1 \) on a scenario if and only if \( q \) is true at some moment \( m_2 \) in the future and \( p \) is true at all moments from \( m_1 \) until \( m_2 \).
- Eventually. A statement \( F p \), read eventually \( p \), means that \( p \) will be true at some point in the future of the given scenario.
- Always. A statement \( G p \), read always \( p \), means that \( p \) is true at every moment in the given scenario.

The operator \( Ap \) denotes that \( p \) holds in all scenarios that are valid at the present moment.

Finally, we need three predicates to indicate whether a commitment \( c \) has been satisfied, breached, or still holds, written \( \text{satisfied}(c) \), \( \text{breached}(c) \), and \( \text{holds}(c) \), respectively. Also, \( \text{active}(c) \) is an abbreviation for a commitment that has not been cancelled, delegated, assigned, released, or discharged.

Using the Framework
With these definitions, we can define the semantics of the language for commitments, which for a model \( M \) will have rule statements such as this one that defines the \( \text{satisfied}(c) \) predicate:

\[
M \models m \text{satisfied}(c) \iff (\exists m_1 : m_1 \leq m \text{ and } M \models m_3 \text{ discharge}(x, c) \text{ and } (\exists m_1 : m_1 < m_3 \text{ and } M \models m_3 \text{ create}(x, c) \text{ and } (\forall m_2 : m_1 < m_2 < m_3 \Rightarrow M \models m_2 \text{ active}(c))))
\]

This says that a commitment is satisfied if and only if it was created and later discharged by an agent \( x \), and if it was continuously active between the time it was created and the time it was discharged. We can also impose constraints on the model, such as

\[
M \models m \ (\text{cancel}(x, c) \Rightarrow AG \text{--holds}(c)),
\]

which states that a cancelled commitment no longer holds. Mallya and colleagues have described a complete semantics for this model elsewhere.\(^4\)

Resolving Temporal Commitments
A temporal commitment is resolvable if its satisfaction or breach can be determined at some moment. Under certain conditions, we can ascertain the irresolvability of a temporal commitment even before the specified time interval occurs.

Solutions to examples one and two are straightforward; we can represent the temporal structure of the events in the examples using nested time intervals. We move on to the more interesting examples here.

Solution to Example Three
To model example three, the hotel \( H \) makes a commitment to a guest \( g \). The commitment is \( C(d, H, g, [t_1, t_1 + 24\text{hrs}]) \), which states that the time it was created and the time it was discharged by an agent \( g \) is the warranty that the rental company on Friday closing of the rental company on Friday from a moment in time):

\[
M \models m \ (\text{great_car}) \iff (\exists m_1 : m_1 \leq m \text{ and } M \models m_3 \text{ rent}(c, R) \text{ and } (\exists m_1 : m_1 < m_3 \text{ and } M \models m_3 \text{ create}(c, R) \text{ and } (\forall m_2 : m_1 < m_2 < m_3 \Rightarrow M \models m_2 \text{ active}(c))))
\]

We see that there exists a moment in the set of all moments of the disjunctions at which every literal is either breached or is unresolvable because its time interval has passed. If the car breaks down a day after it was rented — that is, at \( t_2 = t_1 + 1\text{ day} \), then the only proposition that is not yet breached at that point is the guarantee by the renter to replace it. However, the latest upper bound of the instant at which we could have ascertained the truth of this proposition has passed.

Formally, \( \exists m_{\text{early}}, m_{\text{latest}} : m_{\text{early}} \leq m_{\text{latest}} : \forall i: (M \models m_{\text{early}} \text{ breach}(L_i)) \vee (T(m_{\text{latest}}) > T(L_i)). \)

In this example, \( T(m_{\text{early}}) = t_1, T(m_{\text{latest}}) = t_1 + 2\text{days}, i = 2, L_1 = [t_1, t_1 + 2\text{days}] \), great_car, \( L_2 = [t_1, t_1 + 2\text{days}] \text{replace_car}, \) and the \( T \) operator finds the latest instant at which the satisfaction of its proposition can be determined. The solution shows that the warranty is unfavorable to the customer.

Advantages of Deadlines
The concept of deadlines is necessary for practical use of commitments. Traditionally, deadlines have been hidden in the atomic propositions, but as we have shown, an explicit formulation of temporal commitments is highly desirable. It ensures uniform treatment of operational characteristics across domains. Our approach to developing such a system not only allows for the expression of statements that involve deadlines, but also decouples the temporal quantification from the proposition, allowing us to reason about the temporal aspect without regard to the propositions’ meaning.

Future Directions
Our work on the temporal aspects of commitments is far from complete. In the larger scheme of things, agents would use commitments while interacting within the bounds of some protocol. Commitments between participants would shape the protocol and it, in turn, would constrain the commitments made within it. We therefore focus on agent interaction protocols and the flexibility in execution that commitments afford to these protocols.
Our theory of deadlines is similar to that of Fornara and Colombetti, who introduce the concept of a commitment lifecycle, explaining how obligations on commitments create, modify, delete, and satisfy commitments. Their work is a good first step toward operationalizing commitments, but it does not focus on developing semantics for temporal commitments as we have done.

Our work lies in the middle ground between two orthogonal streams of research: the semantics of interaction protocols, and the implementation of business processes. We have embodied desirable properties of both streams in this theory.

Interaction Protocols

Dignum and colleagues describe a temporal deontic logic that helps specify obligations and constraints so that a planner can take deadlines into account while generating plans. However, their approach is based on the notion of obligations, and it does not give operational methods for obligations. Once a deadline has passed and a certain rule has been violated, the logic has nothing to say about the effects on the system. Nevertheless, their approach is semantically rich and detailed in the kinds of deadlines and constraints it allows agents to model. For example, the deadline “as soon as possible,” which cannot be modeled in our grammar, can be modeled using theirs. However, our system is closer to being implemented.

Business Processes

Grosof and colleagues’ courteous logic programs (CLPs) can be used to specify business rules and instructions for deciding which to use among a set of conflicting rules. However, they do not provide semantics for the grammar that a CLP uses. They represent rules by if-then clauses, and all concepts beyond the structure of these clauses are domain-specific, including temporal references. CLPs, however, are used in actual business systems.

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References


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