Reasoning about normative update

Natasha Alechina      Mehdi Dastani      Brian Logan

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Normative MAS

- Norms (obligations & prohibitions) have been proposed as a means of coordinating and regulating the behaviours of agents within a multi-agent system (MAS)

- Norms can be seen as standards of behaviour which specify that certain (sequences of) states or actions in a multi-agent environment should or should not occur or should incur some sanction

- A key problem in the design of normative MAS is whether a proposed set of norms will have the effect intended by the designer of the system
What is normative update?

• **Normative update** of a system with a set of norms is the result of applying the set of norms to the system.

• The question we are interested in is: how do norms change agents' behaviours?

• How to check the properties of the normative update?

• Some related work:
  • Ågotnes, van der Hoek, Wooldridge 2008 (logic of norm compliance)
  • Dastani, Grossi, Meyer 2011 (normative update with counts-as rules)
  • Knobbout and Dastani 2012 (acting under norm compliance)
Key contributions

- Previous work on verifying properties of normative updates has considered only a relatively simple view of norms, where some actions or states are designated as violations.

- We look at **conditional norms** and reason both about **regimented norms** (behaviours violating norms are impossible) and **non-regimented norms** (violations are possible, but incur a sanction).

- If an (undesirable) state is achievable by the agent(s), how many **sanctions** do they have to incur in order to achieve it?
Conditional norms

- Assume we have disjoint sets of **brute facts** propositional atoms $\Pi_b$ and **normative facts** propositional atoms $\Pi_s$; $\Pi_s$ contains a distinguished atom $san_{\bot}$

- Let $cond$, $\phi$, $d$ be boolean combinations of propositional variables from $\Pi_b$ and $san \in \Pi_s$

- A **conditional obligation** is represented by the tuple

  $$(cond, O(\phi), d, san)$$

- A **conditional prohibition** is represented by the tuple

  $$(cond, P(\phi), d, san)$$

- A **norm set** $N$ is a set of conditional obligations and conditional prohibitions
Meaning of conditional norms

- Conditional norms are evaluated on runs of a transition system.

- A conditional norm $n = (\text{cond}, Y(\phi), s, \text{san})$, where $Y$ is $O$ or $P$, is detached in a state satisfying its condition $\text{cond}$.

- A detached obligation $(\text{cond}, O(\phi), d, \text{san})$ is obeyed if no state satisfying $d$ is encountered before execution reaches a state satisfying $\phi$, and violated if a state satisfying $d$ is encountered before execution reaches a state satisfying $\phi$.

- A detached prohibition $(\text{cond}, P(\phi), d, \text{san})$ is obeyed if no state satisfying $\phi$ is encountered before execution reaches a state satisfying $d$, and violated if a state satisfying $\phi$ is encountered before execution reaches a state satisfying $d$.

- If a detached norm is violated in a state $s$, the sanction corresponding to the norm is applied in $s$. 
State violating a norm

- A state $\rho[i]$ violates a conditional obligation $(\text{cond}, O(\phi), d, \text{san})$ on run $\rho$ iff

$$\rho, i \models d \land \neg \phi \land (((\neg \phi \land \neg d) \text{Since} \ (\text{cond} \land \neg \phi \land \neg d)) \lor \text{cond})$$

i.e., obligations are violated if $\phi$ does not become true in or before the deadline state.

- $\rho[i]$ violates a conditional prohibition $(\text{cond}, P(\phi), d, \text{san})$ iff

$$\rho, i \models \phi \land \neg d \land (((\neg \phi \land \neg d) \text{Since} \ (\text{cond} \land \neg \phi \land \neg d)) \lor \text{cond})$$

i.e., prohibitions are violated in the first state where $\phi$ becomes true.
Regimentation sanctions and resource sanctions

- **Regimentation sanctions** ensure that certain behaviours never occur.

- If a norm labels a state with the distinguished sanction atom \( san_\bot \), then the run containing this state is removed from the set of runs of the system by the normative update.

- **Resource sanctions** treat sanctions essentially like fines or taxes.

- Penalize rather than eliminate certain execution paths by reducing the resources of the agent.
Normative update

• Let $M = (S, R, V)$ be a finite transition system with initial state $s_o$ and $N$ a finite set of conditional obligations and prohibitions

• A normative update of $M$ with $N$, $M^N = (S^N, R^N, V^N)$, is a tree unravelling $T(M)$ of $M$ where all norms from $N$ are enforced on all runs:
  
  • in each tree node $s'$, $V^N(s')$ contains sanction atoms for all norms violated in $s'$
  
  • paths which contain a state satisfying the distinguished sanction atom $san_{⊥}$ are removed from $M^N$
Example

Consider an obligation \((c, O(q), d, sanO)\) and a prohibition \((c', P(p), d', sanP)\)
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Language of $CTLS$

- We propose a new logic, $CTLS$, for reasoning about normative updates of single-agent systems

- $CTLS$ is $CTL$ with Sanction bounds

- Path quantifiers have the form $E^{\leq Z}$, where $Z$ is a multiset of sanction bounds (where multiplicity of a sanction $san$ is infinity, we represent this as $\infty \ast san$

- $E^{\leq Z}$ means ‘there exists a path of sanction cost at most $Z$ ’

\[
p \in \Pi_b \cup \Pi_s \mid \neg \phi \mid \phi \land \phi \mid E^{\leq Z} \phi \mid E^{\leq Z} \phi \text{ Until } \phi \mid E^{\leq Z} \phi \text{ Until } \phi
\]
Semantics of CTLS

The truth of CTLS formulas is defined relative to a tree model $T$ (intuitively, a normative update) and a state $s \in T$:

- $T, s \models E^{\leq Z} X \phi$ iff there exists a fullpath $\rho'$ with $\rho'[0] = s$, such that $T, \rho'[1] \models \phi$ and $\text{sanctions}(\rho') \leq Z$

- $T, s \models E^{\leq Z} \phi \text{ Until } \psi$ iff there exists a fullpath $\rho'$ with $\rho'[0] = s$, such that for some $n \geq 0$, $T, \rho'[n] \models \psi$ and for every $i$, $i < n$, $T, \rho'[i] \models \phi$ and $\text{sanctions}(\rho') \leq Z$

- $T, s \models E^{\leq Z} G \phi$ iff there exists a fullpath $\rho'$ with $\rho'[0] = s$, such that for every $i$, $T, \rho'[i] \models \phi$ and $\text{sanctions}(\rho') \leq Z$
Model-checking problem for normative update in $CTLS$

- The model-checking problem for a normative update in $CTLS$ takes as inputs
  - a finite transition system $M = (S, R, V)$,
  - a state $s_0 \in S$,
  - a finite set of conditional norms $N$, and
  - a formula $\phi$ of $CTLS$
- It returns true if $M^N, s_0 \models \phi$, and false otherwise
The model-checking problem for a normative update in CTLS is in PSPACE (proof uses guessing and checking a polynomially representable path)

It is PSPACE-hard by reduction of QSAT problem (proof idea adapted from Bulling and Jamroga’s (IJCAI 2011) proof of PSPACE-hardness of $CTL^+$)
We also consider normative update of a multi-agent system (concurrent game structure)

Properties of a normative update of a MAS can be expressed in \textit{ATLS} (\textit{ATL} with Sanction bounds)

\[ p \in \Pi_b \cup \Pi_s \mid \neg \phi \mid \phi \land \psi \mid \langle\langle C\rangle\rangle \leq^Z X \phi \mid \langle\langle C\rangle\rangle \leq^Z G \phi \mid \langle\langle C\rangle\rangle \leq^Z \phi U \psi \]

\( \langle\langle C\rangle\rangle \leq^Z \gamma \) means ‘the group of agents \( C \) has a strategy, all executions of which incur at most \( Z \) sanctions and satisfy the formula \( \gamma \), whatever the other agents in \( A \setminus C \) do’
ATLS semantics

- Inspired by Resource-Bounded ATL (Alechina, Logan, Nguyen & Rakib, IJCAI 2009), with sanction costs of strategies defined in terms of sanction costs of paths.

- Normative update defined as for single agent case (assume all norms apply to individual agents).

- $M^N, s \models \langle \langle C \rangle \rangle \leq^Z \gamma$ iff there exists a strategy $F_C$ of sanction cost at most $Z$ in $s$ such that for all $\rho \in out(s, F_C)$, $M^N, \rho \models \gamma$. 

Complexity for ATLS normative update checking

- The model-checking problem for a normative update in ATLS is in PSPACE
- It is PSPACE-hard from PSPACE-hardness of CTLs
Summary

- The model-checking problems for normative updates of both single and multi-agent systems is **PSPACE-complete**

- Future work: define normative update for group norms