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PRIORITIZED IMPERATIVES AND NORMATIVE CONFLICTS

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ABSTRACT

Imperatives occur ubiquitously in natural languages. They produce forces which change the addressee's cognitive state and regulate her actions accordingly. In real life we often receive conflicting orders, typically, issued by various authorities with different ranks. A new update semantics is proposed in this paper to formalize this idea. The general properties of this semantics, as well as its background ideas are discussed extensively. In addition, we compare our framework with other approaches of deontic logics in the context of normative conflicts.

Keywords: imperatives, update semantics, priorities, forces, normative conflicts

1. Introduction

Imperatives occur ubiquitously in social communications. To act successfully in a society, we have to understand their precise meaning, as imperatives often regulate actions. From the 1990s, several prominent new frameworks have been proposed. Following the slogan "you know the meaning of a sentence if you know the change it brings about in the cognitive state of anyone who wants to incorporate the information conveyed by it", update semantics (Veltman (1996)) was proposed to deal with information update. It provided a new and powerful view to interpret natural sentences. So far, attempts have been made in Veltman (2010), Mastop (2005) and Ju (2010) to apply the framework to imperatives. On the basis of deontic logics, Belnap et al. (2001) made a proposal to study actions that are typically expressed by STIT-sentences "see to it that . . . ", bringing actions with choices made by agents together. Other recent works in this line are Horty (2001), Broersen et al. (2006) and Herzig and Troquard (2006). Adopting dynamic epistemic logic (*DEL*) approach, Yamada (2006; 2008) introduced a new dynamic action of "commanding" to deontic logic, and interpreted imperatives in the framework of dynamic deontic logics.

In real life, we often receive conflicting orders issued by different *authorities*. Consider the following example:

Example 1.1. A general d, a captain e and a colonel f utter the following sentences, respectively, to a private.

(1) The general: Do A! Do B!
(2) The captain: Do B! Do C!
(3) The colonel: Don't do A! Don't do C!

It is clear that these are imperatives containing conflicts, w.r.t actions A and C. Intuitively, instead of getting stuck, the private will come up with the following plan after a deliberation: She should do A, do B, but not do C. What made her mind settled is the following fact: The authorities of d, e and f are ranked as follows: $e < f < d$. This makes her decide on which orders to obey, and which ones to disobey. However, the main focus of those previous works has been to understand the meaning of one *single* imperative. Not much attention has been paid to conflicting orders, which were simply taken to be absurd, thus resulting in very trivial facts in the existing frameworks. In this paper, we will propose a solution to such problems.

Our work is based on the following ideas. Imperatives have core propositional content.[1] Imperatives produce imperative forces, which tend to "push" the agent to make their propositional content true. In practice, all sentences are uttered by specific speakers. One same imperative may produce imperative forces differently to an addressee, if it is uttered by different speakers. To realize these ideas, we will borrow some thought from the logics of agency, especially the priority-based preference models (de Jongh and Liu (2009), related ideas occur in the literature on normative conflicts). On the other hand, we retain the tradition of update semantics and we think that the meaning of an imperative lies in how it changes an agent's cognitive state, more specifically, *imperative force state*, which is the state of imperative forces the agent bears.

The following sections are organized as follows. We will first introduce the basic definitions and techniques of update semantics for imperatives in Section 2. In Section 3, we present our new proposal and study its general properties. In Section 4, we show that introducing ranks of authorities into the update semantics

[1]We are well aware of the development (cf. von Wright (1963), Segerberg (1982), and Belnap et al. (2001)) which takes imperatives to be agency-involved actions. We think that is a promising approach, however, in this paper we will discuss imperatives in the tradition of update semantics.

for imperatives can solve the difficulties we had in Example 1.1. Besides, we also discuss some further issues concerning the semantics. In Section 5 we compare our framework with what was proposed in Hansen (2006) in the context of normative conflicts. Finally, we end our paper with some conclusions and possible directions for future work in Section 6.

2. Force Structures and Track Structures

An update system is a triple $\langle \mathcal{L}, \Sigma, [\cdot] \rangle$, where $\mathcal{L}$ is a language, Σ a set of information states, and $[\cdot]$ a function from $\mathcal{L}$ to $\Sigma \to \Sigma$, which assigns each sentence ϕ an operation $[\phi]$. For any ϕ, $[\phi]$ is called an update function, which is intended to interpret the meaning of ϕ. The meaning of a sentence lies in how it updates information states—the core idea of update semantics.

In his recent work (Veltman (2010)), Veltman has presented a new semantics for imperatives based on the update semantics, and argued that the meaning of imperatives is an update function on *plans*. Inspired by Veltman (2010), Ju (2010) interpreted the meaning of imperatives as an update function on *force structures*. In this section, we introduce an equivalent version of the semantics given in Ju (2010) in a different way, and then extend it in the next section and make it work for our problems.

Definition 2.1 (languages). Let Φ be a set of propositional variables, and $p \in \Phi$. The standard language of propositional logic $\mathcal{Y}$ is defined as follows:[2]

$$\phi ::= p \mid \neg\phi \mid \phi \wedge \phi \mid \phi \vee \phi$$

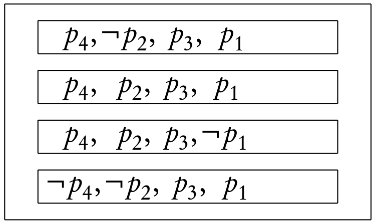
The language $\mathcal{L}$ of imperatives is defined as the set $\{!\phi \mid \phi \in \mathcal{Y}\}$.

Each finite set T of literals of $\mathcal{Y}$ is called a *track*. A track T is *consistent* if and only if it does not contain both p and $\neg p$ for any p. Information states are identified with track structures, as defined below.

Definition 2.2 (track structures). A finite set L of tracks is a track structure iff (1) Each $T \in L$ is consistent; (2) Any $T, T' \in L$ contain the same variables.

[2]We do not consider the connective $\to$ as a primitive symbol. The reason is that we will use the language $\mathcal{Y}$ to express propositional content of imperatives. In natural languages, imperatives do not take implications as propositional content.

Example 2.1. The following picture represents a track structure.

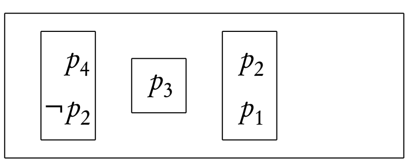


The reading of track structures is this: For any track structure L, the agent has to choose a track of L and make all literals in it true, but she may freely choose which one. If the agent makes all literals of some track of L true, we say that L is *performed*. There are two special track structures: $\{\emptyset\}$ and $\emptyset$. The former can always be trivially performed, which is called the *minimal* track structure. The latter can never be performed, which is called the *absurd* track structure.

In what follows we define a procedure which recursively outputs a track structure for any given imperative $!\phi$. To do that, we first introduce the notion of force structures.

Definition 2.3 (force structures)**.** Each finite set K of finite sets of literals of $\mathscr{Y}$ is called a force structure.

Example 2.2. The force structure $K_1 = \{\{p_4, \neg p_2\}, \{p_3\}, \{p_2, p_1\}\}$ can be illustrated in the following picture:



Definition 2.4 (tracks of force structures)**.** Let $K = \{X_1, \ldots, X_n\}$ be any force structure. For any X_i, let X_i' be the smallest set such that both p and $\neg p$ are in X_i' for any p occurring in X_i. $T = X_1'' \cup \cdots \cup X_n''$ is a track for K iff (1) $X_i'' \subseteq X_i'$ and $X_i'' \cap X_i \neq \emptyset$; (2) For any p occurring in X_i, one and only one of p and $\neg p$ is in X_i''.

Example 2.3. The picture in Example 2.1 represents the set of all consistent tracks of the force structure in Example 2.2.

Let K be any force structure, we define functions T^+ and T^- as follows:

Definition 2.5 (T^+ and T^-).

(a) $T^+(K,p) = \begin{cases} \{\{p\}\} & \text{if } K = \emptyset, \\ \{X \cup \{p\} \mid X \in K\} & \text{otherwise.} \end{cases}$

$T^-(K,p) = \begin{cases} \{\{\neg p\}\} & \text{if } K = \emptyset, \\ \{X \cup \{\neg p\} \mid X \in K\} & \text{otherwise.} \end{cases}$

(b) $T^+(K,\neg\phi) = T^-(K,\phi)$
$T^-(K,\neg\phi) = T^+(K,\phi)$

(c) $T^+(K,\phi \wedge \psi) = T^+(K,\phi) \cup T^+(K,\psi)$
$T^-(K,\phi \wedge \psi) = T^-(T^-(K,\phi),\psi)$

(d) $T^+(K,\phi \vee \psi) = T^+(T^+(K,\phi),\psi)$
$T^-(K,\phi \vee \psi) = T^-(K,\phi) \cup T^-(K,\psi)$

For any imperative $!\phi$, $T^+(\emptyset,\phi)$ is called the force structure of it. Clearly, imperatives correspond to force structures in a recursive way.

Example 2.4. $\{\{p_1,p_3\},\{p_1,p_4\},\{p_2,p_3\},\{p_2,p_4\}\}$ is the force structure of the imperative $!((p_1 \wedge p_2) \vee (p_3 \wedge p_4))$.

Let $U(\phi)$ be the set of all consistent track of $T^+(\emptyset,\phi)$.[3] $U(\phi)$ is the track structure of $!\phi$.

Definition 2.6 (compatibility of track structures). Track structures L_1 and L_2 are compatible iff (1) For any track $T_1 \in L_1$, there is a track $T_2 \in L_2$ such that $T_1 \cup T_2$ is consistent; (2) For any track $T_2 \in L_2$, there is a track $T_1 \in L_1$ such that $T_1 \cup T_2$ is consistent.

Compatibility is used to characterize conflicts among imperatives.

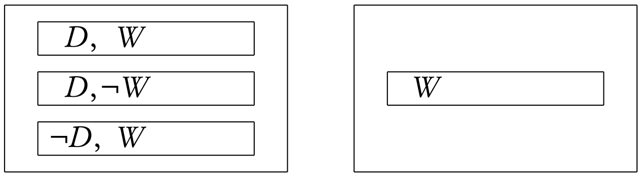
Example 2.5. Two speakers respectively utter these two imperatives to an agent:

(a) Close the door or the window!
(b) Close the window!

Intuitively, there is some conflict between these two commands, although they are consistent from the propositional logic point of view. The following two

[3]Readers may realize that $T^+(\emptyset,\phi)$ corresponds to a conjunctive normal form (CNF) of ϕ in propositional logic. That is true. However, please note that the new notions (e.g. compatibility, validity) to be defined on the basis of track structures have very different meaning in this context.

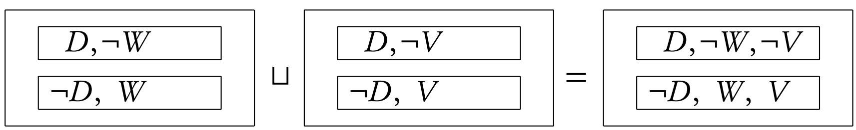
pictures represent the track structures of the two imperatives respectively:



It is easy to verify that the two track structures are not compatible.

Definition 2.7 (merge of track structures). [4] $L_1 \sqcup L_2 = \{T_1 \cup T_2 | T_1 \in L_1, T_2 \in L_2, \text{ and } T_1 \cup T_2 \text{ is consistent}\}$

Example 2.6. The merge of the track structures $\{\{D, \neg W\}, \{\neg D, W\}\}$ and $\{\{D, \neg V\}, \{\neg D, W\}\}$ is $\{\{D, \neg W, \neg V\}, \{\neg D, W, V\}\}$.



The semantics for imperatives is defined as follows:

Definition 2.8 (update of track structures with imperatives). [5]

$$L[!\phi] = \begin{cases} L \sqcup U(\phi) & \textit{if } L \textit{ and } U(\phi) \textit{ are compatible} \\ \emptyset & \textit{otherwise} \end{cases}$$

Basically, updating a track structure L with an imperative $!\phi$ is the merge of L and the track structure of $!\phi$. The exceptional cases are those that L and the track structure of $!\phi$ are not compatible. When this case takes place, the result of the update is the absurd track structure $\emptyset$. [6]

At this point, we would like to return to Example 1.1. We take the minimal force structure $\{\emptyset\}$ as the beginning point. After the general's and captain's commands, the track structure of the private becomes $\{\{A, B, C\}\}$. This means that the agent has to make A, B and C true. The track structure of the imperative "don't do A" is $\{\{\neg A\}\}$, which is not compatible with $\{\{A, B, C\}\}$. Therefore, after the colonel's first command, the track structure of the private becomes $\emptyset$. Intuitively,

[4]This terminology is from Veltman (2010).

[5]Veltman (2010) defines meaning of imperatives as an update function on *plans*. Intuitively, a *plan* is a set of free choices, and a track structure is also a set of free choices. In this sense, the update defined here is similar to Veltman (2010). Their main difference lies in what are viewed as free choices.

[6]The notion of validity by the invariance of track structures can solve Ross's paradox.

this means that the agent gets stuck, and she will be stuck forever. We see that the semantics given in Definition 2.8 does not work for Example 1.1. Similarly, regarding this example, no satisfying solution has been provided in Veltman (2010) either. This is the starting point of the current work. In our view, to handle such difficulties, we should take the ranks of the speakers into account. Our attempt will follow in the next section.

3. Update with Priorities

3.1. Introducing Authorities

A new update system is a tuple $\langle \mathscr{L}, \Sigma, [\cdot], A, \leq \rangle$, where A is a finite set of speakers, and $\leq$ is a preorder on A. For any $a, b \in A$, $a \leq b$ means that b has a rank at least high as what a has. Now we formulate the semantics based on the new update system, incorporating the authorities in the framework presented in the preceding.

Definition 3.1 (agent-oriented language)**.** The language $\mathscr{L}$ of imperatives is defined as the set $\{!_a\phi | \phi \in \mathscr{Y}, a \in A\}$, where $\mathscr{Y}$ is the language given in Definition 2.1.

One can see that all imperatives are relative to specific speakers now.

Let L be the set of literals of $\mathscr{Y}$. Let $\mathsf{L}' = \{l_a | l \in \mathsf{L}, a \in A\}$. Each finite set T of L' is called a track. We define three properties of tracks below.

Definition 3.2 (resolvability of tracks)**.** A track T is resolvable iff for any p_a and p_b, if both p_a and $\neg p_b$ are in T, then either $a < b$ or $b < a$.

Example 3.1. Suppose $a < b$, then the track $T_1 = \{p_a, q_c, r_d, \neg p_b\}$ is resolvable. In case $a \leq b$ and $b \leq a$, T_1 is not resolvable. In case $a \not\leq b$ and $b \not\leq a$, T_1 is not resolvable.

If $a < b$, the conflict of T_1 can be resolved by obeying commands from b while disobeying commands from a. However, if $a \leq b \wedge b \leq a$ or a and b are not comparable, T_1 is not resolvable, for the agent does not know whether she should make p true or not.

Definition 3.3 (succinctness of tracks)**.** A track T is succinct iff there are no p_a and p_b such that (1) $a < b$; (2) Either both p_a and p_b are in T or both $\neg p_a$ and $\neg p_b$ are in T.

Example 3.2. If $a < b$, the track $T_1 = \{p_a, q_c, r_d, p_b\}$ is not succinct. In case $a \leq b \wedge b \leq a$, T_1 is succinct. In case $a \not\leq b \wedge b \not\leq a$, T_1 is succinct.

Definition 3.4 (consistency of tracks)**.** A track T is consistent iff (1) T is succinct; (2) There are no p_a and p_b such that both p_a and $\neg p_b$ are in T.

The property of consistency is not just stronger than succinctness, but also stronger than resolvability: For any track T, if T is consistent, then it is resolvable, but this might not be the case the other way around.

Example 3.3. Suppose $a < b$. The track $T_1 = \{p_a, q_c, r_d, \neg p_b\}$ is resolvable and succinct, but not consistent.

Compared with the ordinary notion of consistency in logic, the notion of consistency defined here seems somewhat heavy, as it contains the notion of succinctness. We do this for technical reasons, which will be explained in Section 4. Intuitively, consistent tracks are "good" ones, while inconsistent tracks are not.

Definition 3.5 (track structures with authorities)**.** A finite set L of tracks is a track structure iff (1) Each $T \in L$ is resolvable; (2) For any $T, T' \in L$, T and T' contain the same variables.

Definition 2.2 defines track structures without authorities, where each track of a track structure is required to be consistent. This requirement gets relaxed for track structures with authorities, namely, each track of a track structure is resolvable. Finally, if all tracks of a track structure are consistent, we call it a consistent one.

Example 3.4. Suppose $a < d$. The following picture represents a track structure with authorities, where each literal is relative to some speaker.

$p_a, \neg q_b, r_c, p_d$
p_a, q_b, r_c, p_d
$p_a, q_b, r_c, \neg p_d$
$\neg p_a, \neg q_b, r_c, p_d$

If $a \leq d \wedge d \leq a$ or a and d are not comparable, this picture is not a track structure.

In the previous section, we describe a procedure by which an imperative $!\phi$ corresponds to a track structure, where authorities are not considered. Similarly, we can build up a correspondence between an imperative $!_a\phi$ and a track structures with authorities. Here we don't go through the details. We simply use $U(!_a\phi)$ to denote the track structure of $!_a\phi$.

3.2. Update Function and Some Properties

First, again, some technical notions. For any two tracks T and T', we call T a sub-track of T' if $T \subseteq T'$. If T is consistent, it is a consistent sub-track.

Definition 3.6 (maximally consistent sub-tracks)**.** A track T' is a maximally consistent sub-track of a track T iff T' is a consistent sub-track of T and for any sub-track T'' of T, if $T' \subset T''$, then T'' is not consistent.

Example 3.5. Suppose $b < a$. The track $\{p_a, q_c, r_d\}$ is a maximally consistent sub-track of the track $\{p_a, p_b, q_c, r_d, \neg p_e\}$. Note that the track $\{p_a, p_b, q_c, r_d\}$ is not a maximally consistent sub-track of $\{p_a, p_b, q_c, r_d, \neg p_e\}$, as $\{p_a, p_b, q_c, r_d\}$ is not succinct.

Proposition 3.1. *For any track T, all of its maximally consistent sub-tracks contain the same variables as what T has.*

Proof. Let T be any track. Let T_1 be any maximally consistent sub-track of T. Suppose that T and T_1 do not contain the same variables. Since $T_1 \subseteq T$, there is a variable, say p, such that T contains p but T_1 does not. Then there is a literal l_i containing p such that $l_i \in T$ but $l_i \notin T_1$. Since T_1 does not contain p, then $T_1 \cup \{l_i\} \supset T_1$ is consistent and a sub-track of T. Therefore, T_1 is not a maximally consistent sub-track of T, which is strange. Hence, T_1 and T contain the same variables. □

Definition 3.7 (preorder $\preceq$ on maximally consistent sub-tracks)**.** Let T be any track. Let T' and T'' be any maximally consistent sub-tracks of T. $T' \preceq T''$ iff for any $l'_a \in T'$, there is a $l''_b \in T''$ such that l''_b contains the same variable as what l'_a has, moreover, $a \leq b$.

It is easy to see that $\preceq$ is reflexive and transitive, so it's a preorder. $\preceq$ may not be antisymmetric. Here is a simple counter-example. Let $T = \{p_a, \neg p_a\}$, $T' = \{p_a\}$ and $T'' = \{\neg p_a\}$. Both T' and T'' are maximally consistent sub-tracks of T. $T' \preceq T''$ and $T'' \preceq T'$, but $T' \neq T''$. Hence, $\preceq$ might not be a partial order.

Definition 3.8 (strict partial order $\prec$ on maximally consistent sub-tracks)**.** Let T be any track. Let T' and T'' be any maximally consistent sub-tracks of T. $T' \prec T''$ iff $T' \preceq T''$ but $T'' \npreceq T'$.

Lemma 3.1. *Let T be any resolvable track with only one variable. Let X be the set of its maximally consistent sub-tracks. X has a greatest element under the relation $\prec$*[7]*.*

[7] Note that $\prec$ is a strict partial order. a is a greatest element of X under the relation $\prec$ if and only if for any $x \in X$, if $x \neq a$, then $x \prec a$. Here we use the notion "greatest element" in a slightly different sense from set theory where it is usually defined relative to a partial order. We thank Berislav Žarnić for pointing this out.

Proof. We consider two cases. First, we suppose that T is consistent. Then X is a singleton. Clearly, X has a greatest element. Next, we suppose that T is not consistent. Again, there are two possible cases: (1) There are no p_a and $\neg p_b$ such that both of them are in T; (2) there are such p_a and $\neg p_b$. In the first case, $T = \{p_{a_1}, \ldots, p_{a_m}\}$ or $T = \{\neg p_{b_1}, \ldots, p_{b_m}\}$.[8] we can verify that X is a singleton, no matter whether $T = \{p_{a_1}, \ldots, p_{a_m}\}$ or $\{\neg p_{b_1}, \ldots, p_{b_m}\}$. Therefore, X has a greatest element. We consider the second case. Let $T = \{p_{a_1}, \ldots, p_{a_m}$, $\neg p_{b_1}, \ldots, \neg p_{b_n}$ }, where $1 \leq m, n$. T has two maximally consistent sub-tracks: $T_1 = \{p_{a_{m_1}}, \ldots, p_{a_{m_k}}\}$, $T_2 = \{\neg p_{b_{n_1}}, \ldots, \neg p_{b_{n_l}}\}$, where $k \leq m$ and $l \leq n$. Hence, $X = \{T_1, T_2\}$. Suppose that X does not have a greatest element under $\prec$, then $T_1 \not\prec T_2$ and $T_2 \not\prec T_1$. We can get that for any b_j, there is an a_i such that $a_i \not\prec b_j$, because otherwise $T_1 \prec T_2$. Since T is resolvable, we have that for any b_j, there is an a_i such that $b_j < a_i$. Similarly, for any a_i, there is a b_j such that $a_i < b_j$. Now we can obtain an infinite decreasing chain, say $b_h < a_i < b_j < \ldots$. This is impossible. Therefore, X has a greatest element. □

Proposition 3.2. *Let T be any resolvable track. Let X be the set of its maximally consistent sub-tracks. X has a greatest element under the relation $\prec$.*

Proof. Suppose that T contains n different variables. Let $T = T_1 \cup \cdots \cup T_n$ such that for any T_i, all literals in it contain the same variables. In fact, $T' \in X$ if and only if $T' = T'_1 \cup \cdots \cup T'_n$, where each T'_i is a maximally consistent sub-track of T_i. By Lemma 3.1, each T_i has a greatest maximally consistent sub-track under $\prec$. Let $T'' = T''_1 \cup \cdots \cup T''_n$, where T''_i is the greatest maximally consistent sub-track of T_i. We see that $T'' \in X$. It can be easily verified that T'' is a greatest element of X under the relation $\prec$. □

Example 3.6. Suppose $a < d$. The track $\{\neg p_d, q_b, r_c\}$ is a greatest maximally consistent sub-track of $\{p_a, q_b, r_c, \neg p_d\}$ under the relation $\prec$.

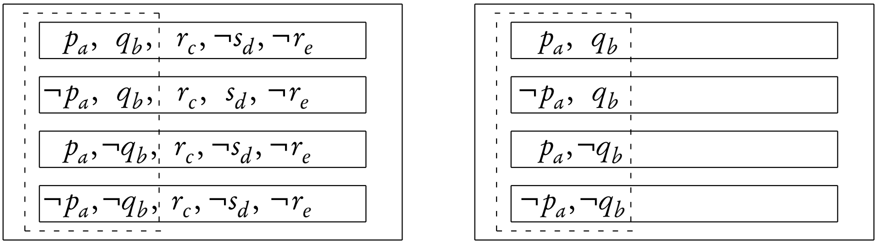
The conflict in the track $\{p_a, q_b, r_c, \neg p_d\}$ can be resolved according to the given authority rank $a < d$ and the conflict-free result is $\{\neg p_d, q_b, r_c\}$.

Definition 3.9 (sub-structures). Let L be any track structure. A track structure L' is a sub-structure of L iff (1) For any $T' \in L'$, there is a $T \in L$ such that $T' \subseteq T$; (2) For any $T \in L$, there is a $T' \in L'$ such that $T' \subseteq T$.

If L' is consistent, we say that L' is a consistent sub-structure of L.

[8]Note that $\{p_{a_1}, \ldots, p_{a_m}\}$ and $\{\neg p_{b_1}, \ldots, \neg p_{b_n}\}$ might not be consistent, because they might not be succinct.

Example 3.7. Suppose $c < e$.[9] L' is one of sub-structures of L[10].

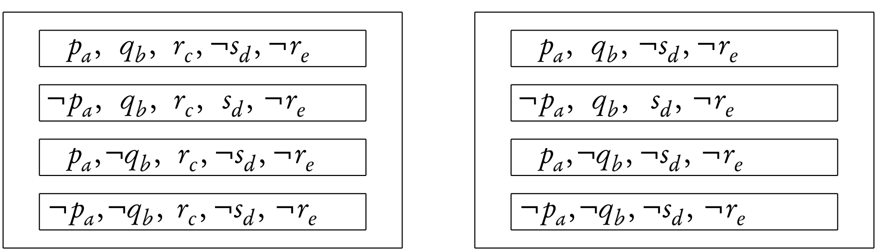


L $\qquad$ L'

Definition 3.10 (sufficient consistent sub-structures). Let $L = \{T_1, \ldots, T_n\}$ be any track structure. A track structure L' is a sufficient consistent sub-structure of L iff $L' = \{T'_1, \ldots, T'_n\}$, where each T'_i is the greatest maximally consistent sub-track of T_i under the relation $\prec$.

By Proposition 3.1, it can be verified that for any structure $L = \{T_1, \ldots, T_n\}$, the set $\{T'_1, \ldots, T'_n\}$, where each T'_i is the greatest maximally consistent sub-track of T_i, is always a consistent sub-structure of L. Therefore, any track structure has a sufficient consistent sub-structure. Furthermore, any track structure has only one sufficient consistent sub-structure.

Example 3.8. Suppose $c < e$. L' is the sufficient consistent sub-structure of L.



L $\qquad$ L'

Track structure L is not consistent. The sufficient consistent sub-structure of L is the result of making L consistent while respecting the authorities in L to the greatest extent.

Definition 3.11 (merge of track structures). $L_1 \sqcup L_2 = \{T_1 \cup T_2 | T_1 \in L_1, T_2 \in L_2, T_1 \cup T_2 \text{ is resolvable}\}$.

[9]By Definition 3.5, any track of a track structure is resolvable. In this example, if we do not suppose that $c < e$ or $e < c$, L might not be a track structure.

[10]The dash lines in this picture are intended to help us understand the notion of sub-structure.

Definition 3.12 (compatibility of track structures). Track structures L_1 and L_2 are compatible iff (1) For any $T_1 \in L_1$, there is a $T_2 \in L_2$ such that $T_1 \cup T_2$ is resolvable; (2) For any $T_2 \in L_2$, there is a $T_1 \in L_1$ such that $T_1 \cup T_2$ is resolvable.

We can verify that L_1 and L_2 are compatible if and only if both L_1 and L_2 are sub-structures of $L_1 \sqcup L_2$.

For any track structure L, we use $V(L)$ to denote the sufficient consistent sub-structure of L. The semantics for imperatives which takes authorities into account is defined as follows.

Definition 3.13 (update of track structures with authorities).

$$L\lceil !_a \phi \rceil = \begin{cases} V(L \sqcup U(!_a \phi)) & \textit{if } L \textit{ and } U(!_a\phi) \textit{ are compatible} \\ \emptyset & \textit{otherwise} \end{cases}$$

Meaning of imperatives is an update function on track structures. Let L be any track structure and $!_a\phi$ be any imperative. If L and the track structure L' corresponding to $!_a\phi$ are compatible, the result of updating L with $!_a\phi$ is the sufficient consistent sub-structure of the merge of L and L', otherwise the result is $\emptyset$, which is an absurd track structure.

Based on the semantics, the notion of validity for imperative inferences can be defined as what follows.

Definition 3.14 (validity of imperative inferences). $!_{a_1}\phi_1, \ldots, !_{a_n}\phi_n \models !_b\psi$ if and only if the track structure $\mathsf{O}\lceil !_b\psi \rceil$ is a sub-structure of $\mathsf{O}\lceil !_{a_1}\phi_1 \rceil \ldots \lceil !_{a_n}\phi_n \rceil$, where $\mathsf{O} = \{\emptyset\}$.

It can be proved that if $!_{a_1}\phi_1, \ldots, !_{a_n}\phi_n \models !_b\psi$, then $\mathsf{O}\lceil !_{a_1}\phi_1 \rceil \ldots \lceil !_{a_n}\phi_n \rceil \lceil !_b\psi \rceil = \mathsf{O}\lceil !_{a_1}\phi_1 \rceil \ldots \lceil !_{a_n}\phi_n \rceil$. We will come back to this notion in Section 5.

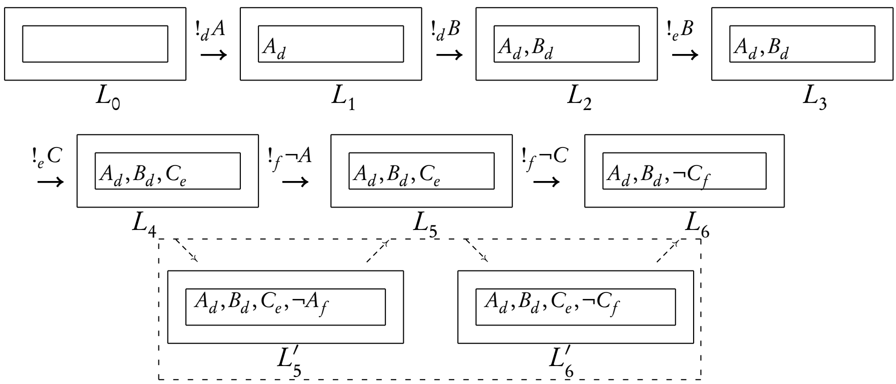
4. Illustration and Discussion

4.1. Illustration

We illustrate some properties of the semantics defined above. First, let us look at Example 1.1 again. Recall that a general d, a captain e and a colonel f utter the following sentences, respectively, to a private.

(1) The general: Do A! Do B!
(2) The captain: Do B! Do C!
(3) The colonel: Don't do A! Don't do C!

Suppose that the starting track structure of the private is $L_0 = \{\emptyset\}$, which means that the private does not bear any imperative force. According to our new semantics, these imperatives update the track structures of the private in the following way.



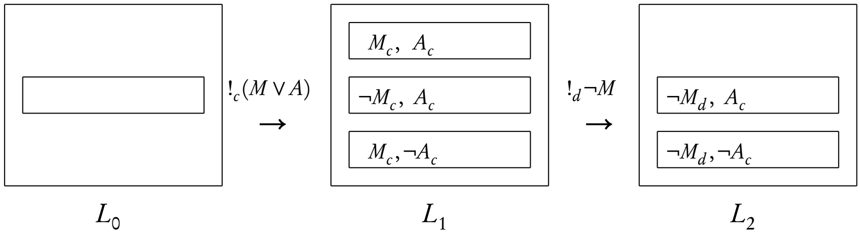
After the imperative $!_d A$, the track structure L_0 changes to L_1, and after $!_d B$, L_1 changes to L_2, and so on. L_6 is the final track structure, according to which the private should do A, B, but should not do C. This is what we expect. The track structures L'_5 and L'_6 in the dash rectangles are auxiliary for us to understand the update process, and they are not results of any update of this process. When $!_f \neg A$ is uttered, L_4 is updated to L'_5. Since L'_5 is not consistent, it changes to L_5 after a deliberation of the private. Actually, L_5 is equal to L_4. L_5 is the sufficient consistent sub-structure of L'_5 and respects the authority of the general. The similar case also happens to L'_6. This example shows how our semantics works in practice.

Next, let us consider an example from Veltman (2010) which involves free choices.

Example 4.1. John is ill and goes to see doctors c and d respectively.

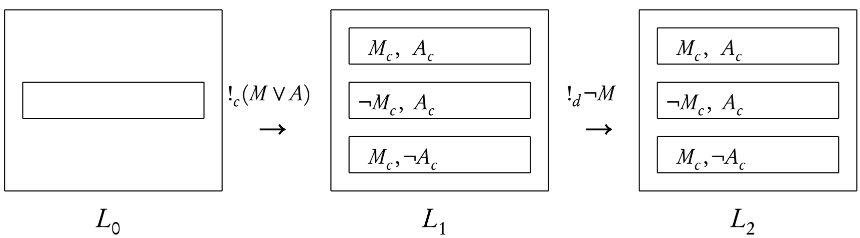
(1) The doctor c: Drink milk or apple juice!
(2) The doctor d: Don't drink milk!

Suppose that the original track structure of John is $L_0 = \{\emptyset\}$. First, we suppose that John trusts d more than c. The update process of John's track structures is illustrated by the following picture.



L_2 is the final result of this update process. According to L_2, John should not drink milk, and he may and may not drink apple juice. As d has a higher authority, this result is perfectly fine.

Now we suppose that c has a higher authority than d has. With this constraint, John's track structures are updated in the following:



L_2 is the final result of this update process. The imperative uttered by d does not essentially make much sense to John, because $L_1 = L_2$. According to L_2, John should drink milk or apple juice, and he may only drink milk, only drink apple juice and drink both. We see that drinking milk is allowed. This result seems not plausible. It seems practically reasonable to think that John should drink apple juice but not drink milk, as if he does so, both of the imperatives could be performed. In other words, only drinking apple juice seems to be safer than only drinking milk or drinking both. However, we think that even not to drink milk is more practically reasonable than to drink milk, John is still allowed to drink milk in this case. We show this point by an example.

Example 4.2. A general and a captain utter the following to a private respectively.

(1) The general: You may have a rest.
(2) The captain: Move!

These two sentences are conflicting. Suppose that the private chooses to have a rest, then normally, she will not be punished. This implies that the private is allowed to stop, even to move is safer for him. Hence, we think that the result mentioned above is plausible. Actually, the following claim seems reasonable: An agent a has a higher authority than what b has in giving commands if and only if a has a higher authority than what b has in giving permissions.

The semantics given in Definition 2.8 is a special case of the semantics given in Definition 3.13: When restricted to singleton of agents, the latter collapses to the former. In other words, the former can be taken to be an update mechanism for one agent case, but with agent omitted in notation. Note that the semantics defined in Definition 2.8 does not satisfy the property of commutativity.[11] Therefore, the semantics given in Definition 3.13 does not have that property either.

Previously, we have taken tracks which are succinct and do not contain any conflict as "good" tracks. The reason why we require succinctness is out of the following consideration: Without succinctness, some thing "bad" could happen, in which commutativity plays a role. Here is an example.

Example 4.3. Consider some agent a, her grandmother has a higher authority than his parents, and his father and mother have the same authority. Here are two sequences.

(1) Grandmother: Stop! Father: Don't stop! Mother: Stop!
(2) Grandmother: Stop! Mother: Stop! Father: Don't stop!

If we keep all other things unchanged and just drop the succinctness requirement, the second sequence makes the agent get stuck, while the first one does not. This is weird.

4.2. Discussion

In this subsection, we are going to address several further issues that are related to our new framework.

As mentioned in the section of introduction, we think that imperatives produce imperative forces, and uttering an imperative may change the addressee's state of imperative forces. In the semantics proposed above, we do not distinguish forces and states of forces conceptually. They are considered to be the same, and they are both represented as track structures.

About imperative force, there is one more thing we want to emphasize here. Whether an agent is bearing some imperative force is not objective, but is determined by the agent's mind. The word "imperative force" might be misleading, as it reminds us of physical forces. Instead of saying that an agent is bearing some imperative force, perhaps we better say that, the agent *thinks* that she is bearing some imperative force. Consider the following example.

[11] See Ju (2010) for examples.

Example 4.4. A general and a captain utter the following imperatives to a private.

(1) The general: Move!
(2) The captain: Stop!

After a deliberation, the private thinks that the imperative of the captain is not in force.

Concerning the authority order, here are some comments. First of all, an authority order is relative to some specific agents. Two speakers might be ranked differently from one agent to another. For example, two doctors might be in different authority relations for different patients. Also, an authority order is not fixed universally. It often depends on specific contexts. Speaker *a* might have a higher authority than speaker *b* for agent *c* in one context, but *b* might have a higher authority than *a* in another context. For instance, suppose that *a* is *c*'s father, and *b* is *c*'s mother. Suppose that *a* is a general, *b* is a colonel and *c* is a private in the same army. In the army, *a* has a higher authority than *b* for *c*, but *b* might have a higher authority than *a* in their family.

A core idea behind Veltman (2010) is that the borderline between semantics and pragmatics for imperatives is not always clear, which is different from indictives. We agree with this. Imperatives are usually used by speakers to generate obligations directly, while indicatives are used to report on something, including on obligations. We think that the scope of semantics for imperatives is broader than that for indicatives. We will explain this more in the following.

Firstly, we think that, for an addressee, one imperative may mean different things if it is uttered by different speakers. This means speakers also contribute to the meaning of imperatives. It can be better understood from the perspective of dynamic semantics. According to the meaning theory of dynamic semantics, the meaning of an indicative lies in how it changes an agent's information state. Following the same philosophy, the meaning of an imperative lies in how it changes an agent's imperative force state. Naturally, one same imperative may cause different changes to an agent's imperative force state, if it is uttered by different speakers with different authorities. Therefore, we think speakers should be put into the semantics of imperatives, not in pragmatics. One step further, in fact, speakers also contribute to the meaning of indicatives, one same indicative may change an agent's information state very differently, if it is uttered by different speakers. Consider the situation in which something uttered conflicts with the addressee's previous knowledge. It is an important issue for the addressee to decide whether and how to take the new information, too.

Next, we show the difference by comparing imperatives "close the door" with their corresponding obligation sentences "it is obligatory that you close the door".[12] As we said before, imperatives are used by speakers to generate obligations directly, while as indicatives, descriptive obligation sentences are mainly used to inform an agent that she is in some obligations, although in some cases they can also be used to generate obligations. This implies that speakers of imperatives are always the sources of the relevant obligations[13], but speakers of descriptive obligation sentences might not be. This results in the difference in meaning between imperatives and the corresponding obligation sentences. Consider the following example:

Example 4.5.

(1) Close the door or the window!
(2) It is obligatory that you close the door or the window.

Suppose that speaker A utters the second sentence to the agent. A might not be the source of the obligation. Such a case is possible: Someone else made the obligation, but the agent has not known it yet; A heard about it, but did not get it precisely; All A knows is that the agent should close the door or the window; A tells the agent about it by the second sentence. Therefore, we can not say that the second sentence implies the permission, say, the agent may close the window but keep the door open. Now suppose that speaker B utters the first sentence to the agent. B is the source of the obligation that the agent should close the door or the window. Therefore, B knows exactly what she wants to order the agent to do. If B just wants the agent, say, to close the door, she should not utter the imperative "close the door or the window". Therefore, by this imperative, what B wants the agent to do is to close the door or the window, but she does not care which. Therefore, the first sentence implies that the addressee is allowed not to close the door, and is also allowed not to close the window, although it is not allowed for him not to close any of them. This reminds us of Grice's maxim of quantity given in Grice (1975). Actually, this fits well with our way of thinking: For imperatives, we should put more into semantics.

This discussion paves the way for the next section.

5. Comparison with Normative Conflicts

Normative conflicts refers to situations in which an agent ought to make some propositions true, but it is impossible for him to do so. The impossibility may be logical or practical. Suppose that an agent ought to join the army, and at the same time ought not to join the army. In this case, it is logically impossible for

[12] A deep philosophical discussion about this connection was made in Žarnić (2003).

[13] Here we do not consider the sentences like "yesterday you father said to you: close the door, but you didn't hear it.

the agent to do both. Suppose that an agent ought to meet a friend at 12:00 and ought to take a train at 12:30, and suppose that if she meets his friend at 12:00, she will miss the train. In this case, it is practically impossible for the agent to do both. Logical impossibility does not involve any fact of the world, while practical impossibility does involve some.

Generally speaking, situations in which an agent bears conflicting imperative forces belong to normative conflicts, as imperatives generate obligations. Previously, we have introduced priorities on speakers in update semantics for imperatives, to model how an agent manages to solve normative conflicts. In the literature, Horty (2003) and Hansen (2006) dealt with moral conflicts in deontic logics by use of priorities on norms. Moral conflicts are special normative conflicts, and they only involve obligations for moral reasons. The ideas of Horty (2003) and Hansen (2006) are somehow similar. They both introduced priorities on norms and adopted the "disjunctive solution" for moral conflicts, which will be explained later. As what Hansen (2006) argued, the theory proposed in Horty (2003) was not adequate in some aspects. By using a technical method which was used in Brewka (1989; 1991) and Nebel (1991; 1992), the theory given in Hansen (2006) can avoid those problems. In this section, we compare our work with the theory of Hansen (2006).

Descriptive obligation sentences are what deontic logics use in language. In Section 4.2 we have presented some ideas on the connections between imperatives and descriptive obligation sentences. For each $\phi \in \mathscr{Y}$, let $O\phi$ be a descriptive obligation sentence and $P\phi$ be a permission sentence. Here is a claim concerning the connection between $!\phi$ and $O\phi$.

Claim 5.1 (translation of imperatives to norms). *Let the set* $\{\{l_1^1, \dots, l_1^n\}, \dots, \{l_m^1, \dots, l_m^n\}\}$ *be the track structure of* $!\phi$. $!\phi$ *has the same meaning with* $O\phi \wedge P(l_1^1 \wedge \cdots \wedge l_1^n) \wedge \cdots \wedge P(l_m^1 \wedge \cdots \wedge l_m^n)$.

For any imperative, any track of its track structure is a way to perform the imperative. This claim says, uttering an imperative $!\phi$ is equivalent to say that it is obligatory to make ϕ true and it is permitted to make ϕ true in any possible way. We give an example:

Example 5.1.

(1) Close the door or the window!
(2) It is obligatory that you close the door or the window, it is permitted that you close the door but do not close the window, it is permitted that you close the window but do not close the door and it is permitted that you close both.

According to Claim 5.1, these two sentences have the same meaning. However, the imperative “close the door or the window” and the descriptive obligation sentence “it is obligatory that you close the door or the window” have different meaning, because none of the permission sentences in this example is implied by the descriptive obligation sentence. Take another example:

Example 5.2.

(1) Close the door and the window!
(2) It is obligatory that you close the door and the window and it is permitted that you close the door and close the window.

Again, according to our claim, these two sentences have the same meaning. In fact, the imperative “close the door and the window” has the same meaning with the descriptive obligation sentence “It is obligatory that you close the door and the window”, as the latter implies the permission sentence. Generally, for any ϕ, if there are more than one way to make ϕ true, then $!\phi$ has a different meaning from $O\phi$, otherwise they have the same meaning.

Based on the bridge between imperatives and descriptive obligation sentences, we make it clear that in what sense our model can be compared with the proposal of Hansen (2006). In Section 3, we introduced a set of speakers and a preorder on that set and make imperatives relative to specific speakers. Then we defined the entailment relation $\models$ between a sequence $!_{a_1}\phi_1,\ldots,!_{a_n}\phi_n$, which may be inconsistent, and an imperative $!_b\psi$. We did not consider any fact of the world there, so the inconsistency is logical. Hansen (2006) introduced a strict partial order $<$ on obligations and defined the entailment relation $\vdash$ between a set $\{O\phi_1,\ldots,O\phi_n\}$ of obligations, which may be logically inconsistent or inconsistent according to some facts of the world, and an obligation $O\psi$. We use $<_A$ to denote an authority order on speakers. In what follows, we only compare $!_{a_1}\phi_1,\ldots,!_{a_n}\phi_n \models !_b\psi$ with $\{O\phi_1,\ldots,O\phi_n\} \vdash O\psi$ when the following conditions are satisfied:

(1) No facts of the world is involved;
(2) For any $i,j \leq n$, $a_i <_A a_j$ if and only if $O\phi_i < O\phi_j$;
(3) For any $k \leq n$, there is at most one way to make true ϕ_k.

There are two reasons to keep the third condition. When this condition is satisfied, then firstly, $!_{a_k}\phi_k$ has the same meaning as $O\phi_k$, and secondly, a sequence of imperatives have the same meaning with that of the corresponding set of imperatives, as the semantics for imperatives satisfies the principle of commutativity in this case.

Let $O\phi_1,\ldots,O\phi_n$ and $O\psi$ be any obligations. Let $<$ be a strict partial order on the set $\{O\phi_1,\ldots,O\phi_n\}$. Intuitively, $O\phi_i < O\phi_j$ means that $O\phi_j$ has a higher priority than $O\phi_i$ does.[14] We restate the definition of $\{O\phi_1,\ldots,O\phi_n\} \vdash O\psi$ in Hansen (2006). Here is a result, the proof of which can be found in Hansen (2006):

Theorem 5.1. *For any relational structure $\langle A,<\rangle$ where $<$ is a strict partial order on the set A, there is $\langle A,\prec\rangle$ such that (1) $\prec$ is a strict partial order on A; (2) $\prec$ is total, that is, for any $a,b \in A$, if $a \neq b$, then $a < b$ or $b < a$; (3) $\prec$ preserves $<$, that is, for any $a,b \in A$, if $a < b$, then $a \prec b$.*

Any $\prec$ satisfying the above condition is called a total extension of $<$. We look at $\langle\{O\phi_1,\ldots,O\phi_n\},<\rangle$. Since $\{O\phi_1,\ldots,O\phi_n\}$ is finite, there are finite total extensions of $<$. Let $\prec_1,\ldots,\prec_m$ be all total extensions of $<$. Let f be a function such that for any $\{O\phi_{n_1},\ldots,O\phi_{n_k}\} \subseteq \{O\phi_1,\ldots,O\phi_n\}$ $(n_i \leq n)$, $f(\{O\phi_{n_1},\ldots,O\phi_{n_k}\}) = \{\phi_{n_1},\ldots,\phi_{n_k}\}$. Let $\vdash_{PL}$ be the entailment relation of classical propositional logic. Now we fix a total extension $\prec_i$ of $<$, that is, a chain $O\phi_{n_n} \prec_i \ldots \prec_i O\phi_{n_1}$. $S^i_j \subseteq \{O\phi_1,\ldots,O\phi_n\}(0 \leq j \leq n)$ is defined recursively as follows

Definition 5.1.

$$(1)\quad S^i_0 = \emptyset$$

$$(2)\quad S^i_{j+1} = \begin{cases} S^i_j \cup \{O\phi_{n_{j+1}}\} & \textit{if } f(S^i_j)\cup f(\{O\phi_{n_{j+1}}\}) \nvdash_{PL} \bot \\ S^i_j & \textit{otherwise} \end{cases}$$

This definition describes a procedure, by which we can get S^i_n. Firstly, we have $S^i_0 = \emptyset$. Then we check whether $f(\emptyset)\cup f(\{O\phi_{n_1}\})$ is classically consistent. If it is, let $S^i_1 = \{O\phi_{n_1}\}$, and if it is not, let $S^i_1 = S^i_0$. After doing this for n times, we get S^i_n finally. It can be verified that for any $i \leq m$, S^i_n is a maximal consistent set of $\{O\phi_1,\ldots,O\phi_n\}$. Let $\Delta = \{S^1_n,\ldots,S^m_n\}$. Note that Δ might not consists of all maximal consistent sets of $\{O\phi_1,\ldots,O\phi_n\}$, and it only consists of those which respect some total extension of $<$. Δ is called *the preferred remainder set* of $\{O\phi_1,\ldots,O\phi_n\}$ with respect to $<$. The entailment relation is defined as follows.

Definition 5.2. $\{O\phi_1,\ldots,O\phi_n\} \vdash O\psi$ if and only if for any $S \in \Delta$, $f(S) \vdash_{PL} \psi$.

Let $\vdash_D$ be the entailment relation of standard deontic logic. It can be proved that, for any set $\{O\phi_1,\ldots,O\phi_n\}$, if $\{O\phi_1,\ldots,O\phi_n\}$ is consistent according to standard deontic logic, then $\{O\phi_1,\ldots,O\phi_n\} \vdash O\psi$ if and only if

[14]Hansen (2006) uses $<$ in a converse sense: $O\phi_i < O\phi_j$ means that $O\phi_i$ has higher priority than $O\phi_j$. But if we only consider finite sets of obligations, there is no essential difference.

$\{O\phi_1,\ldots,O\phi_n\} \vdash_D O\psi$. The entailment given in this definition is a simplified version of the one defined in Hansen (2006), where practical inconsistency is also considered.

This solution for moral conflicts is called the "disjunctive solution". The name comes from the following results: Suppose that for some A, the priorities of OA and $O(\neg A)$ are not comparable, i.e., $OA \not< O(\neg A)$ and $O(\neg A) \not< OA$, then it can be verified that $\{OA, O(\neg A)\} \vdash O(A \vee \neg A)$. This means, in the normative circumstance where making A true is not more obligatory than making $\neg A$ true and vice versa, what the agent really ought to do is to make $A \vee \neg A$ true. This method can avoid deontic explosion, that is, $\{OA, O(\neg A)\} \vdash OB$ for any OB, hence provides Hansen (2006) with an advantage which our theory lacks. Consider the following.

Example 5.3.

(1) It is obligatory that you do physical exercise and drink milk.
(2) It is obligatory that you do physical exercise but do not drink milk.

When the two obligations are not comparable in priorities, it is implied that the agent ought to do physical exercise and ought to drink milk or not to drink milk. That is to say, though it is hard for the agent to decide whether she ought to drink milk or not, it is clear that she still ought to do physical exercise. This result is fine. In our theory, for any sequence of imperatives, if there is an irresolvable conflict in that sequence, the agent would get stuck. However, an easy extension of the current framework is possible to cope with this problem, we leave it to the readers.

There is a problem with this theory. $\{O\phi_1,\ldots,O\phi_n\} \vdash O\psi$ means that ψ is really obligatory in the normative circumstance represented by $\{O\phi_1,\ldots,O\phi_n\}$, which may contain conflicts[15]. Suppose that there are some $O\phi_i$ and $O\phi_j$ in $\{O\phi_1,\ldots,O\phi_n\}$ such that $O\phi_i < O\phi_j$, $O\phi_i$ and $O\psi_j$ are in conflict but $\{O\phi_1,\ldots,O\phi_n\} - \{O\phi_i\}$ is consistent. It can be verified that $O\phi_i \notin S_n^k$ for any $S_n^k \in \Delta$. This means that $O\phi_i$ is completely conquered by $O\phi_j$. However, the conflict between $O\phi_i$ and $O\phi_j$ might be caused just by the conflict between some sub-formula of $O\phi_i$ and some sub-formula of $O\phi_j$, and dropping $O\phi_i$ completely might mean dropping too much. We look at an example:

[15] What is the intuitive meaning of $\{O\phi_1,\ldots,O\phi_n\} \vdash O\psi$ is an awkward question. To answer this question, Horty (2001) distinguishes two kinds of obligations: *prima facie* and *all things considered* ones. We think that this theory is problematic. Hansen (2006) technically avoids to answer this question. Here we give a vague but still understandable interpretation. In any case, this is an interesting question.

Example 5.4.

(1) It is obligatory that you do physical exercise and drink milk.
(2) It is obligatory that you do not drink milk.

We use $O(P \wedge M)$ and $O(\neg M)$ to denote the two sentences respectively. Suppose that both of the obligations are made to keep the agent's health but the second one has higher priority than the first one. In this case, the preferred remainder Δ of the normative circumstance $\{O(P \wedge M), O(\neg M)\}$ relative to the priority order is $\{\{O(\neg M)\}\}$. This implies that not drinking milk is really obligatory and doing physical exercise is not obligatory any more. This result does not seem reasonable. It seems plausible to think that the agent still ought to do physical exercise, besides that she ought not to drink milk. Our proposal can deal with this case better.

Example 5.5. Suppose that two doctors, *a* and *b*, utter the following imperatives to an agent respectively, and *b* has a higher authority than *a*.

(1) Doctor *a*: Do physical exercise and drink milk!
(2) Doctor *b*: Don't drink milk!

We use $!_a(P \wedge M)$ and $!_b(\neg M)$ to respectively express the two imperatives. It can be verified that $!_a(P \wedge M), !_b(\neg M) \models !_b(\neg M)$ and $!_a(P \wedge M), !_b(\neg M) \models !_a P$, which means that the agent should not drink milk, but she still should do physical exercise. This ends our comparison.

6. Conclusions and Future Work

In this paper we have proposed a model of imperative action and multi-agent commands that combines ideas from natural language semantics and logics of agency. We think that the resulting picture of "force" and "priorities" is more realistic, both in understanding imperative discourse and commands driven human action. We have illustrated how the current framework can be applied to interpret many examples in natural languages. Its background ideas, as well as some further technical issues have been discussed too. In addition, we have compared our framework with Hansen (2006) in the context of normative conflicts and showed that though some of our ideas coincide, the proposal presented in this paper can provide a more realistic and finer solution to normative conflicts.

Next on our agenda are several open questions. Firstly, our discussions have been mostly semantic-oriented, and we have not explored the idea that whether one could come up with a complete logic for it and how it looks like. Secondly, we have represented imperatives as propositions in a track structure in the current work. We think that alternatively, taking imperatives as a program that leads to transitions of states may be more attractive. We plan to adopt dynamic logics in our future investigations. Thirdly, conflicts come with different kinds or degrees, due to that imperatives are issued by different authorities. A closer study on the general features of conflicts is needed here, and we can extend the current framework to deal with more subtle issues there. Finally, given the current framework, it would be interesting to see its applications. Say, in social settings we can infer an agent's authority order by observing how she reacts to orders she has received. This is similar to what the notion of *revealed preference* tells us. We will leave those further studies to other occasions.

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