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Directing Actions

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Abstract. Informational entities, such as words, can be used not only to make statements about the world, but also to direct actions. This happens when they describe actions, and those actions are then performed by some agents on the basis of this description. This paper investigates the characteristics of the relation of directedness and compliance and distinguishes between attempted, successful and maximal direction. It discusses the case when directive entities are synonymous or specialize one another.

Keywords. Directive information entity, Information content entity, Action

1. Introduction

Informational entities, such as words, can be used to represent existing entities, such as material objects, properties, or processes. Some informational entities, however, can *direct* processes. This happens when they represent how to perform some actions and such actions are then performed on the basis of this description. Consider for example a recipe, a drug prescription or an industrial procedure: those informational entities do not primarily describe actions that have been performed, but explain how to perform actions.

Although some work in applied ontology have been published on *aboutness* [1], we are not aware of any that investigate in detail the notion of *directedness* (but see below 2.2). It is of fundamental importance in ontology, as it connects three realms: informational entities (specification of actions), cognitive entities (intentions) and processes (the actions themselves). This article will concentrate on the connection between the directive informational entities and the actions, skipping over the relevant cognitive entities. Thus, this article aims at providing some bases for representing directedness in applied ontologies.

We will first provide some more specific motivations for such a work, and present some work that have been done in related areas. We will then introduce several relations of directedness that capture different aspects of this notion, as well as the related (but different) notion of compliance. A following section will then present the notions of

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synonymy and specialization that can hold between directive entities. A summary and presentation of future work will conclude the paper.

2. Example and Background

2.1. A Simple Example

We will use throughout the article the following examples of simplified martini recipes:

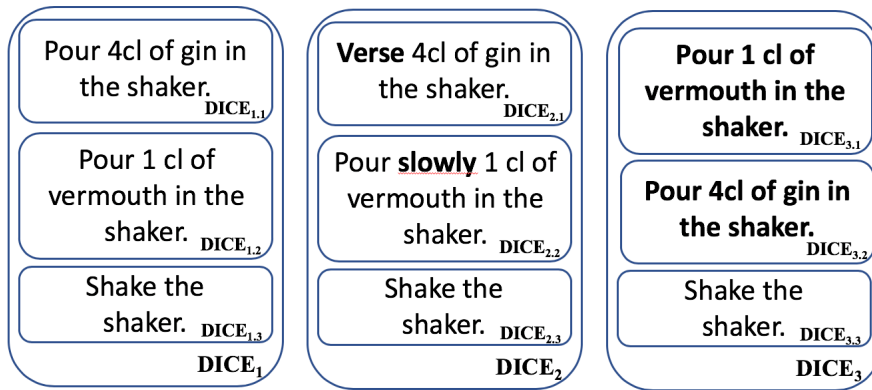


Figure 1. Three martini recipes **DICE**₁, **DICE**₂ and **DICE**₃

At some time t_1 , Mr. Bond makes a martini following the recipe **DICE**₁ from his favorite book. He pours 4 cl of gin in the shaker (action g_1); adds 1 cl of vermouth in the shaker (action v_1); and shakes the shaker (action s_1). We will call m_1 the mereological sum of g_1 , v_1 and s_1 , and we will say that **DICE**₁ *directed* m_1 , **DICE**_{1.1} directed g_1 , **DICE**_{1.2} directed v_1 and **DICE**_{1.3} directed s_1 .

Suppose now that in the second edition of the book, the author introduces two modifications, writing in **DICE**₂ ‘verse’ instead of ‘pour’, and adding ‘slowly’. We will say that **DICE**_{2.1} is *synonymous* with **DICE**_{1.1}: any action *compliant* with **DICE**_{2.1} (that is, of the type specified by **DICE**_{2.1}) is also compliant with **DICE**_{1.1}, and vice versa. We will say that **DICE**_{2.2} *specializes* **DICE**_{1.2}: any action compliant with **DICE**_{2.2} is also compliant with **DICE**_{1.2}, but the reverse does not hold.

To represent such entities and their connections, we need to introduce relations of directedness and compliance between informational entities and actions, and explain their connection with the relations of parthood, synonymy and specialization illustrated above. We also need to represent when such instructions direct *successfully* such actions, or when they merely attempt to direct them. Finally, we need to differentiate successful and *maximal* direction, e.g., **DICE**_{1.1} successfully directing the part of g_1 during which Bond pours the first 2 cl of gin, but maximally directing g_1 .

2.2. Background

This section will describe some relevant former work for the analysis of directedness, showing their limitations and how our present work can complement them.

2.2.1. Information Artifacts in Ontology

There are few proposals addressing the ontological nature of informational artifacts such as recipes. The Informational Artifact Ontology (IAO) [1] is based on the Basic Formal Ontology (BFO) [2]. In this framework, informational entities are called “information content entities” (ICE), which have the property of *being about* something. ICEs can be concretized in some qualities, such as a pattern of ink on a paper, or a mental quality in a cognitive system. An important subclass of ICE is **Directive information entity**, which encompasses in particular **Action specification**, which aims at directing actions. However, there is to date no formalized relation of directedness that would relate action specifications with the actions they direct. It is especially important to introduce such a relation for ontologies based on BFO, such as the biomedical ontologies of the OBO Foundry. For example, it is important to be able to relate prescriptions of drugs, prescriptions of laboratory tests [3] or surgery instructions with the actions they direct.

Such directive informational entities could also be introduced in other upper ontologies. For example, in DOLCE [4], they might be categorized as a non-agentive social object, but DOLCE doesn’t propose either any relation resembling directedness.

Informational objects called “representations” are also addressed in YAMATO [5]. Representations can be realized by a variety of entities. In particular, procedures are realized by actions. But procedures do not appear to have the identity criteria for directive informational entities discussed below in Section 3.1, and, although lacking a formal characterization that would enable to define it unambiguously, it seems the relation “**realization_of**” in YAMATO is more related to the notion of compliance than to the notion of directedness.

We will in the following use the neutral term “**Directive information content entity**” (abbreviated “**DICE**”) referring to an informational entity that could direct actions. The formalization we propose can presumably be adapted in various upper ontologies.

2.2.2. Languages for Process Specification

In engineering and conceptual modelling, several representation frameworks have been proposed to specify the dynamic aspects of systems. The theory called Process Specification Language (PSL) represent “activities” in the context of system interoperability in the manufacturing domain [6][7][8]. It evolved into a modular ontology formalized in Common Logic (and OWL) as well as an ISO standard [9].

Activities in PSL may have zero or more “activity occurrences” (events or processes, including, but not limited to, actions [10]), to which they are related with a binary relation named “**occurrence_of**”. Occurrences are situated in time while activities are not, but subactivities of activities can be temporally ordered. PSL is organized around a core ontology of time and events. The **occurrence_of** relation differs in several ways from the directedness relation we are addressing here. First, activity occurrences are not restricted to actions. Second, this relation appears to be one of type-token. Therefore, activities are reified types or classes, without any characteristics of informational entities (as, e.g., having author and addressee, epistemic and deontic effects, physical concretizations...). Moreover, activity occurrences are all exact occurrences of their type,

and so are by definition successful. Attempts are considered in PSL as interrupted sequences of subactivity occurrences; there is no space for failure in the execution of an atomic activity.² So, PSL does not provide the kind of relation we are looking for between DICE and the actions they direct (or attempt to direct). It nevertheless encompasses useful features, in particular with respect to the mereological and temporal structure of both activities and activity occurrences.

BPMN is a major framework used to represent industrial processes and their workflows. It is not an ontology, but there are proposals to analyze its ontological foundations [11] or to partially integrate within domain ontologies [12]. However, crucially for us, within BPMN there is no notion of informational object. In addition, the distinction between the types of processes and their occurrences is taken care of by a semantic interpretation external to the notation language. As a result, there is not much to take inspiration there for the present paper, concerned with axiomatizing directedness between DICES and actions. Similar observations can be made for another important language for representing dynamic systems, UML activity diagrams in conceptual modelling [13]. Of course, extensions of the present work to account for the semantic contents of DICES are likely to build on such rich and elaborate representation frameworks in the future.

3. Framework

We will formalize the axioms in FOL, omitting universal quantifiers for free variables. We will admit in the universe of discourse particulars only. Symbols and formulas are written in bold.

3.1. The Identity of Informational Entities

We must first clarify that in our framework, the identity of an informational entity (and in particular, of a DICE) derives from the speech act that created it (for a theory of discourse based on this assumption, see the Segmented Discourse Representation Theory or SDRT [14]). Consider for example **DICE₃** (see Figure 1), another very similar recipe of martini, in a different book, created independently of **DICE₁** by a different author. **DICE_{1,2}** and **DICE_{3,1}** are not the same entity, as they were created by two different speech acts, in different discursive contexts. However, they have two things in common. First, they are constituted by the same sentence (the same succession of words). Second, their semantic contents is the same action type.

A crucial aspect of the semantic contents of a DICE like **DICE₁** is the temporal ordering of the action types referred to by its parts **DICE_{1,1}**, **DICE_{1,2}** and **DICE_{1,3}**. Indeed, when executing **DICE₁**, the shaking should occur after the pourings, something captured among DICE parts through discourse relations in a theory like SDRT. But action types are independent of speech acts, and could be combined temporally in various ways, as seen with **DICE₁** and **DICE₃** whose semantic contents are different temporal arrangements of the same action types. That there are different “sums” of these three action types shows that the mereology on action types cannot be a classical extensional mereology. PSL does include a “subactivity” relation to decompose activities into

² There is some level of non-determinism captured in occurrence trees, but this helps accounting for underspecified temporal ordering of subactivities and for alternative ways of accomplishing an activity.

subactivities, and assume it is a partial ordering [8], but does not claim it is a full-fledged mereological relation. In fact, the very notion of mereology on types, or universals, is problematic. There is no consensus on the existence of “structural universals” [15], as they face critical issues such as that of having a part “several times over” [16]. As far as we know, the PSL literature is silent with respect to how to account for multiple subactivity links, such as when the same atomic activity of making one step is repeated in the complex activity of walking.

On the contrary, mereology on DICES is extensional. There is no other DICE than **DICE₁** that is only composed by the parts **DICE_{1.1}**, **DICE_{1.2}** and **DICE_{1.3}**. In particular, there is no other DICE that has as parts **DICE_{1.1}** and **DICE_{1.2}** with the former following the latter, just as there is no alternative body of mine with my two hands swapped. We will use a classical mereology [17], with the parthood relation **part_of** and the associated **overlaps** relation. Parts of a DICE are related by discourse relations, some of which imply temporal constraints on the action types in their semantic contents [14].

In this paper, we will concentrate on DICES and their connections with actions, rather than on the sentences that constitute those DICES, on the semantic contents of DICES in terms of action types, or on the discourse relations between DICE parts and their semantic consequences on the temporal order of action types, all of which is left for future extensions of this work.

3.2. Directedness

There are two important cases of directedness to distinguish. Suppose for example that Bond is attempting to make a Martini by following **DICE₁**. At t_0 , he attempts to perform the recipe through his action **a₀**, but gets the proportion wrong: we will say that **DICE₁** “a-directs” (where “a” stands for “attempt”) **a₀**, and write this **a-directs(DICE₁, a₀)**. Later at t_1 , Bond attempts again to perform the recipe through his action **m₁** (mentioned above), and succeeds: we will say that **DICE₁** “successfully directs” **m₁**, and write this **s-directs(DICE₁, m₁)**. On this understanding, if a DICE successfully directs an action, then it attempts to direct this action – but the reciprocal implication does not hold, since an attempt can fail: **s-directs(d, a) → a-directs(d, a)**. This paper will clarify the intuition behind those two relations **a-directs** and **s-directs**, and which axioms they satisfy. The relation **a-directs** (and therefore **s-directs** too) has the class **DICE** as domain, and a class we can name **Action** as range:

$$\mathbf{a-directs(d, a) \rightarrow DICE(d) \wedge Action(a)}$$

3.3. Agents, Intentions and Compliance

We will not enter here into any detailed investigation of the ontology of actions. We will make the following hypotheses: a) several agents can constitute a larger agent (e.g., two humans dancing constitute one agent); b) the mereological sum of several actions made by the same agent is also an action; c) all actions are intentional (see [18] for a discussion). We will not formalize intentions though, since our main goal is to connect informational entities with actions (because of their private, mental character, we typically have less data about the intentions of agents than about the action specifications they are supposed to follow, or about the actions that they indeed performed). We nevertheless suppose that for a DICE to **a-direct** an action, we need: 1) the cognitive system of the agent representing in some way this DICE (this could be analyzed by the DICE being

concretized by a mental quality of the agent, if one follows IAO's ontology); 2) this representation leading to an intention to perform an action as described; 3) and this intention leading to a subsequent action (that can be compliant or not with the instruction, depending on whether it is successful or not). As we said above, we will not represent the notion of intention here; however, the relation of directedness takes into account such intentions.

We will also make use of a relation of "compliance" between an action and a DICE, that we will write **compliant(a,d)**. This is not a relation of direction, but rather a relation independent of any intentions that the agent of the action may have had and so of the possibly different DICE he may have followed or not. As such, it is akin to the token-type relation "**occurrence_of**" used in PSL, although DICES are not action types.

4. Proposal

4.1. Max-directing

In the use case presented above, we have: **s-directs(DICE₁, m₁)**; **s-directs(DICE_{1.1}, g₁)**; **s-directs(DICE_{1.2}, v₁)**; **s-directs(DICE_{1.3}, s₁)**. Moreover, since **g₁**, **v₁** and **s₁** are all essential steps in making martini, we assume that they are also directed by the whole **DICE₁**: **s-directs(DICE₁, g₁)**; **s-directs(DICE₁, v₁)**; **s-directs(DICE₁, s₁)**. (Note that this would not be true in a framework like PSL, which uses a relation **occurrence_of** that is of a type-token sort; and this is also not true for the notion of compliance: **g₁** is not compliant with **DICE₁**, but only with its part **DICE_{1.1}**.)

One proposition, inspired by [19], would be to state that if **DICE₁** successfully directs an action, then this action is an instance of **Martini_making**. However, this statement would conflict with **s-directs(DICE₁, g₁)** and **s-directs(DICE₁, v₁)**, since **g₁** and **v₁** are not instances of **Martini_making** (rather, they are proper parts of **m₁**, which is an instance of **Martini_making**).

To avoid this problem, we can introduce, on top of the relation **s-directs**, the relation **max-directs**, meaning "maximally successfully directs", connecting a DICE with a compliant action it successfully directs. We can then state:

$$\mathbf{max-directs(DICE_1, a) \rightarrow Martini_making(a)}$$

and similar axioms connecting **DICE_{1.1}** and **Gin_pouring**, **DICE_{1.2}** and **Vermouth_pouring**, etc. Thus, we have **max-directs(DICE₁, m₁)** but **DICE₁** does not max-direct **g₁** nor **v₁** (it only s-direct them).

A DICE **max-directs** an action if, by definition, the DICE **a-directs** this action, and this action is compliant with this DICE:

$$\mathbf{max-directs(d, a) \equiv_{def} a-directs(d, a) \wedge compliant(a, d)}$$

Moreover, if **d max-directs a**, then **d** successfully directs **a** and **d** does not direct anything larger (in the mereological sense) than **a**:

$$\mathbf{max-directs(d, a) \rightarrow}$$

$$\mathbf{(s-directs(d, a) \wedge \forall b ((s-directs(d, a) \wedge overlaps(a, b)) \rightarrow part_of(b, a)))}$$

Note that one cannot speak of a "maximal direction" for a mere attempt that would not be successful, since an attempted action can be basically anything, as long as the agent has the intention to realize the action described by the relevant DICE.

In particular, this distinction between the relations **max-directs** and **s-directs** can account for directive entities that are followed for some time but not fully realized. Suppose that at t_2 , Bond pours 4 cl of gin in the shaker (g_2) but then receives an urgent call at t_3 and has to leave to save the world; thus, he never finishes making this martini. Then **s-directs**(**DICE**₁, g_2) although there is no instance of **Martini_making** maximally directed by **DICE**₁ of which g_2 is a part. Therefore, a DICE can successfully direct some action **a** even if there is no action maximally directed by this DICE of which **a** is part³.

One could also think that if a DICE s-directs some action, then there exists some part of this DICE that max-directs this action. However, this is not true. For example, the instruction ‘CBC’ (‘complete blood count’) on a laboratory test prescription could s-direct more than 10 different tests (hematocrit, hemoglobin, etc.); however, there is no part of ‘CBC’ that max-directs a hematocrit test, a hemoglobin test, etc.⁴

4.2. Synonymy between DICES

As mentioned earlier, **DICE**_{1.1} and **DICE**_{2.1} are synonymous: we write **synonymous_with**(**DICE**_{1.1}, **DICE**_{2.1}) and assume that **synonymous_with** is reflexive, symmetric and transitive: it is an equivalence relation (note that two DICES constituted by the same succession of sentences might be different, if created by two different speech-acts; that would be a trivial case of synonymy).

It is important to be able to connect a directed action with the exact DICE that directed it. As a matter of fact, various DICES may lead to different risk of errors, even if they are synonymous (one might e.g. be more difficult to understand than the other). We define synonymy as related to compliance⁵:

$$\text{synonymous_with}(d_1, d_2) \equiv_{\text{def}} \forall a (\text{compliant}(a, d_1) \leftrightarrow \text{compliant}(a, d_2))$$

Suppose that Vesper Lynd reads **DICE**_{2.1} and decides to verse 4 cl of gin (g_3). Then we have **max-directs**(**DICE**_{2.1}, g_3), the same way we had **max-directs**(**DICE**_{1.1}, g_1). However, **DICE**_{1.1} does not direct g_3 (**DICE**_{1.1} does not cause the apparition of an intention in Lynd’s mind that leads to g_3), g_3 is merely compliant with **DICE**_{1.1}: **compliant**(g_3 , **DICE**_{1.1}) (and **compliant**(g_3 , **DICE**_{2.1})). For the same reason, **DICE**_{2.1} does not direct g_1 but we have **compliant**(g_1 , **DICE**_{2.1}). However, all actions compliant with **DICE**_{1.1} (and **DICE**_{2.1}, since they are synonymous) are instances of **Gin_pouring**:

$$\text{compliant}(a, \text{DICE}_{i.1}) \rightarrow \text{Gin_pouring}(a) \text{ (for } i=1 \text{ or } 2\text{)}^6$$

4.3. Specialization of a DICE by a DICE

Suppose that Bond reads **DICE**_{2.2} and consequently pours slowly 1cl of vermouth in the shaker – that’s the action v_2 . Then we have: **max-directs**(**DICE**_{2.2}, v_2). Since Bond did not represent in his cognitive system **DICE**_{1.2}, it did not direct v_2 . This is not because of

³ The distinction between **max-directs** on the one hand and **s-directs** and **a-directs** on the other hand enables to capture the notion of interruptability of a procedure without relying on complex occurrence trees as in PSL.

⁴ There could be, however, a synonymous DICE that has such parts – see below the discussion on synonymy.

⁵ Our use of synonymy on DICES is not a trivial extension of the standard linguistic notion applying to lexical items. We define it here on the basis of compliance only. Other choices could have been made, taking the syntactic, semantic and pragmatic structure of the DICES into account.

⁶ With this kind of axioms and the link between **max-directs** and **compliant**, **max-directs** (**DICE**₁, **a**) \rightarrow **Martini_making**(**a**) as mentioned above becomes a theorem.

the slow character of v_2 : it is only because Bond did not perform v_2 with the intention of following $DICE_{1.2}$. As a matter of fact, $DICE_{1.2}$ can direct vermouth pourings which are of any speed. On the other hand, $DICE_{2.2}$ can only direct slow vermouth pourings.

However, there is a connection between $DICE_{1.2}$ and $DICE_{2.2}$. We will say that $DICE_{2.2}$ “specializes” $DICE_{1.2}$ and write **specializes**($DICE_{2.2}$, $DICE_{1.2}$). This relation can be expressed in terms of compliance: indeed, the class of actions that are compliant with $DICE_{2.2}$ is a subclass of the class of actions that are compliant with $DICE_{1.2}$:

$$\mathbf{specializes}(d, d') \equiv_{\text{def}} \forall a (\mathbf{compliant}(a, d) \rightarrow \mathbf{compliant}(a, d'))$$

This definition implies that the relation **specializes** is reflexive: any DICE specializes itself (under a large understanding of the term “specializes”; one can also introduce the relation **strictly specializes** to capture a strict, non-reflexive understanding of the term “specializes”). It is also transitive. However, it is not symmetrical: $DICE_{2.2}$ specializes $DICE_{1.2}$, but $DICE_{1.2}$ does not specialize $DICE_{2.2}$. It is also not antisymmetrical: $DICE_{1.1}$ and $DICE_{2.1}$ specialize each other, but they are not identical: they are synonymous, which implies that they share the same compliant actions. Indeed, we obtain as a theorem that two DICES are synonymous iff they specialize each other:

$$(\mathbf{specializes}(d, d') \wedge \mathbf{specializes}(d', d)) \leftrightarrow \mathbf{synonymous_with}(d, d')$$

5. Discussion

Now that the essential formal notions of directedness have been introduced, we can discuss their connection with parthood, synonymy, compliance and specialization.

5.1. DICES part of a DICE

The fact that $DICE_1$ directs not only m_1 , but also g_1 , v_1 and s_1 suggests that if a DICE successfully directs an action, then a larger DICE (by a mereological relation) also successfully directs this action; and the same holds for attempts to direct. That is, with $x = 's'$ or $'a'$, we would have the following axiom:

$$(\mathbf{x-directs}(d, a) \wedge \mathbf{part_of}(d, d') \wedge \mathbf{DICE}(d')) \rightarrow \mathbf{x-directs}(d', a)$$

This axiom brings about a clarification on the relation **part_of** between DICES. As a matter of fact, it seems wrong that the mereological sum of $DICE_1$ and $DICE_3$, namely the mereological sum of the first and the last Martini recipes, also directs m_1 . This intuition is captured by the identity conditions of DICES essentially relying on speech acts as explained in Section 3.1. Since there is no (complex) speech act leading to a DICE whose parts are exactly $DICE_1$ and $DICE_3$, their mereological sum simply is not a DICE. The speech act identity condition for informational entities on a DICE entails that its parts should be created by (sub)speech acts and with the intention that these parts be related (through discourse relations) into a whole discourse directing actions towards a common goal. Obviously, two different recipes taken from two different books by two different authors are not parts of a whole discourse. The specification of those exact conditions that need to hold for two DICES to be related by the relation **part_of** is a complex issue, that should be addressed in future work, probably relying on a rich enough theory of discourse such as SDRT.

5.2. A Medical Use Case

We will now illustrate with a medical example of drug prescription why it is important to represent relations of directedness, synonymy and specialization in biomedical applied ontologies [20][21]. Suppose that on 2018/01/01, in Quebec, a doctor deems that her patient should take metoprolol for hypertension control until further notice. She then writes the instructions i_1 = ‘metoprolol 100 mg PO BID’ instructing her patient to take a drug with 100 mg of active ingredient metoprolol twice a day (‘BID’) per mouth (‘PO’) until further notice. If he takes metoprolol in such a way (action a_1), then i_1 s-directs a_1 .

Suppose instead that the patient loses the prescription, and goes back during the day to his doctor to get a new prescription. This time, the doctor writes i_2 = ‘metoprolol 100 mg per mouth twice a day’. Then i_2 is synonymous with i_1 (even if the patient may better understand i_2 than i_1). However, they do not direct the same actions: if the patient had forgotten what was written on the first prescription and takes the drug following i_2 , then i_2 directs this action, not i_1 .

Actually, the pharmacist will typically specialize the instruction i_2 further for the patient, with an instruction such as i_3 = ‘Apo-Metoprolol 50 mg, 2 tab orally 8 am and 2 tab orally 8 pm every day’. i_3 specializes i_2 : any action compliant with i_3 is also compliant with i_2 , but the reverse does not hold. Finally, i_2 maximally directs the patient’s drug-taking until e.g. the patient receives a new instruction to stop taking metoprolol, but merely successfully directs the drug-taking by the patient of one dose of metoprolol in the morning of 2018/03/15.

6. Conclusion and Future Work

We have proposed bases for the representation of directedness in ontologies. Intuitively, for a DICE to a-direct an action, three conditions (at least) should be satisfied: 1) this DICE is represented in the cognitive system of an agent (which could be formalized, following IAO, as the concretization of the DICE by a mental quality of the agent); 2) it leads to an intention to perform this action; 3) and this intention leads to an action. We have introduced a taxonomy of relations of directedness: attempt to direct (a-directs); successfully directs (s-directs); and maximally directs (max-directs). We have analyzed the connections between those notions of directedness. We have introduced the relations of synonymy and specialization, and defined them in terms of compliance. The relation of synonymy is an equivalence relation, and the relation of specialization is reflexive and transitive.

Future work should address essential points such as a more detailed investigation in the ontology of actions and intentions, as well as the temporal order in which actions specified by instructions should be realized. In particular, this will require to analyze the different kinds of relations that can hold between various parts of a DICE, in light of theories such as SRDT, and relate them with some formal framework specifying processes (such as PSL, BPMN, UML activity diagrams...) in order to characterize the semantics of some specific discourse relations. The connection between directive aspects (that we addressed here) and normative aspects (whether an action is permitted, obligatory, forbidden or recommended) should also be investigated. Two challenges related to each other would be representing the direction of non-actions, such as the kind of entity that would be directed by a DICE ‘Do not smoke’; and representing the notion of contradiction between DICES, such as when a doctor writes to his patient ‘Stop

metoprolol’ after two years of prescription, when realizing that her patient start reacting badly to this drug. Finally, an ontological characterization of the notion of intention might be helpful for use in e.g. robotics. In particular, one would need to characterize the link between the representation of a DICE and the apparition of a corresponding intention; and the link between an intention and an action to which it leads. Like for other cognitive attitudes such as beliefs [22], dispositional characterization of intention might be developed.

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