

States, Events, and Truth-makers

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Abstract. In the last decade, the debate about the *ontological foundations* of reified temporal logics (RTLs) has been relatively quiet, even though we think some problems still exist. In this paper, we identify some of these problems and propose (partial) solutions to them in a FOL framework. *States* are here characterized (at the syntactic level) as truth-makers of propositions—they reify *true* propositions—and *events* are built from states. These choices make the event-state distinction much crisper than the one characterized in terms of the (meta-)predicates HOLDS vs. OCCURS, which are necessary in RTLs but not in our theory. We also offer some epistemological arguments in favor of this choice.

Keywords. time, change, events · constitution, identity · cognition and language

1. Introduction

In the 90s, Galton [1] first, and Vila and Reichgelt [2] later, start criticizing the so-called *reified temporal logics* (RTLs) [3,4,5,6,1,7,2]—the most known being the *situation calculus* [8] and the *event calculus* [9]²—from an ontological point of view. One of the main problem they point out concerns the ontological nature of the *reified* entities. Reification—a technique nowadays relatively common in knowledge representation [12] and conceptual modeling [13]—allows one to introduce entities that denote propositional terms in the domain of quantification. Usually, two kinds of reified entities are distinguished in RTLs: *fluents* (or *states*) and *events*. Fluents and events are related to instants (or intervals) of time through some ‘meta-predicates’. The most common ones are $\text{HOLDS}(f,t)$, which stands for ‘the fluent f is true at time t ’, and $\text{OCCURS}(e,t)$, which stands for ‘the event e occurs (happens) at time t ’.

Galton, Vila and Reichgelt noted that the reified events are actually event *types*, as the same event can re-occur several times (analogously for fluents). This contrasts with the view on events usually adopted in philosophy and linguistics [14], where events are considered as *tokens*. Those authors follow this tradition and consider event-*tokens* instead of event-*types*. We agree with these criticisms, but we think that (i) some aspects of the proposed solutions are not completely satisfactory—the solution proposed by Vila and Reichgelt is discussed in detail in Section 3.2—and (ii) there are additional ontological problems that have never been taken into account. In this work, we identify some

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²[10] and [11] are good overviews.

of these problems and discuss alternative ways to address them. Methodologically, our investigation is guided by the RTLs, however the resulting framework provides an analysis of the ontological nature of states and events in a FOL setting (avoiding then the introduction of an *ad hoc* semantics for meta-predicates). Our approach has three main characteristics. First, in contrast to the usual strategy followed by RTLs, in our framework, states are not reifications of propositional terms. Our states exist in time as objects do and they correspond to (but are not) *true* propositions. When a proposition is true, a corresponding state exists and vice versa (Section 2). Our approach is then consistent with one of the main philosophical view that assumes states to be the *truth-makers* of propositions, what exists in the world that makes propositions (linguistic entities) true [15]. Second, our states and events are completely specified. Differently from the (neo-) Davidsonian approaches, we provide explicit identity conditions for them (Section 2). Third, our events are *built* from states, that is, they group states according to a definitory unity criterion. Section 4 considers two alternative constructions: (i) events as mereological sums of *instantaneous* states, and (ii) events *supervening* or *emerging* from persisting states. This last option allows for a conceptual or cognitive perspective on emergence, where events(-types) are seen as a compact and cognitively-oriented tool to understand the ‘world’s dynamics’.

2. The Basic Framework

We consider 3 disjoint *basic categories*: *time* (TM), *object* (OB), and *state of affairs*, or simply *state*, (ST). We leave open if TM-instances, called *times*, are punctual or extended atomic entities. Time is linear and discrete (the *precedence* relation is noted \leq). Objects—also called *substances*, *endurants*, or *continuants*—are wholly present at every time they exist, e.g., tables, persons, bits of stuff. States correspond to—using the terminology of Kim [16]—*exemplifications* by objects of (contingent) properties at a time, i.e., a state corresponds to the fact that an object (several objects) has a given property (are in a given relation) at a given time. E.g., Luca’s being 180cm high now, Luca’s being enrolled in the University of Trento now.

The framework is formally characterized as follows. Both objects and states exist in time (a1)-(a2), where $\varepsilon_t x$ stands for “ x exists at time t ”.³ States are covered by a *finite* set $\bar{\mathcal{P}}$ of unary predicates (a3) that, intuitively, individuate all the states that correspond to the exemplification of the same property or relation. The atemporal primitives $-\circ_i$ hold between objects and states (a4) and identify the i th object involved in the state (a5)—the i th *participant*—that necessarily exists when the state exists (a6) and (d1). By (d3)⁴, we define n -ary participations—where α is the maximal *finite* arity of ST-instances (that is also the number of $-\circ_i$ primitives). For each $\bar{P} \in \bar{\mathcal{P}}$, an axiom with form (a7) sets to n the number of participants in all the \bar{P} -states—the *arity* of \bar{P} -states. (a8) is the identity criterion for states: temporally overlapping (d2) states belonging to the same type and having the same participants are identical. Intuitively, at any time, the same objects cannot exemplify the same relation in two different ways. (a8) allows the introduction of (d4)—where \imath is a description operator *à la Russell*.⁵ It is then possible to introduce a

³We write $P_t x$ instead of $P(x, t)$ to highlight the time-argument.

⁴ x^n is a shortcut for x_1, \dots, x_n .

⁵ $\psi(\imath x(\phi(x)))$ is equivalent to $\exists x(\phi(x) \wedge \forall y(\phi(y) \rightarrow y=x) \wedge \psi(x))$.

set \mathcal{D} of *descriptions* that are in a 1-1 relation with the predicates $\bar{P} \in \bar{\mathcal{P}}$. The description relative to the predicate $\bar{P} \in \bar{\mathcal{P}}$ is noted \mathbf{p} . As (a8) does not apply to states of different type, it is possible to have $\mathbf{p}_t x^n \neq \mathbf{q}_t x^n$ (states do not reduce to tuples). Unlike Kim's *identity condition*— $[x, P, t] = [y, Q, t']$ if and only if $x = y$, $P = Q$, and $t = t'$ ($[x, P, t]$ corresponds to $\mathbf{p}_t x$)—our framework allows for both (i) $\mathbf{p}_t x^n = \mathbf{q}_t x^n$ with \mathbf{p} different from \mathbf{q} , i.e., the predicates in $\bar{\mathcal{P}}$ do not necessarily partition ST, and thus states may belong to several types; and (ii) $\mathbf{p}_t x^n = \mathbf{p}_{t'} x^n$ with $t \neq t'$, i.e., states can persist through time.

- d1** $x \otimes y \triangleq \forall t(\varepsilon_t x \rightarrow \varepsilon_t y)$ (temporal inclusion)
- d2** $x \otimes y \triangleq \exists t(\varepsilon_t x \wedge \varepsilon_t y)$ (temporal overlap)
- d3** $x^n \multimap s \triangleq \bigwedge_{1 \leq i \leq n}(x_i \multimap_i s) \wedge \bigwedge_{n < i \leq \alpha} \neg \exists x(x \multimap_i s)$
- d4** $\mathbf{p}_t x^n \triangleq \exists s(\bar{P}s \wedge \varepsilon_t s \wedge x^n \multimap s)$ (state description)
- a1** $\varepsilon_t x \rightarrow \text{TM}t \wedge (\text{OB}x \vee \text{ST}x)$
- a2** $\text{OB}x \vee \text{ST}x \rightarrow \exists t(\varepsilon_t x)$
- a3** $\text{ST}s \leftrightarrow \bigvee_{\bar{P} \in \bar{\mathcal{P}}} \bar{P}s$
- a4** $x \multimap_i s \rightarrow \text{OB}x \wedge \text{ST}s$
- a5** $x \multimap_i s \wedge y \multimap_i s \rightarrow x = y$
- a6** $x \multimap_i s \rightarrow s \otimes x$
- a7** $\bar{P}s \rightarrow \exists x^n(x^n \multimap s)$
- a8** $\bar{P}s \wedge \bar{P}s' \wedge s \otimes s' \wedge \bigwedge_{1 \leq i \leq \alpha} \forall x(x \multimap_i s \leftrightarrow x \multimap_i s') \rightarrow s = s'$
- a9** $P_t x^n \leftrightarrow \exists s(\bar{P}s \wedge \varepsilon_t s \wedge x^n \multimap s)$

The usual method to avoid state-reification, the *method of temporal arguments* (MTA) [2], consists of the introduction of a time as an additional argument of (some of) the predicates and functions in the vocabulary. For instance, TIRED_x becomes $\text{TIRED}_{t,x}$. While state-reification and MTA are usually considered as alternative methods, here we try to connect them in an explicit way. We think that this move has three advantages. First, the link between states and propositions can be clearly stated at the syntactic level. This enables a better characterization of the nature of states. Second, meta-predicates like HOLDS and OCCURS (and their *ad-hoc* semantics [5,2]) are not necessary. Third, primitive predicates (on objects) can be directly axiomatized without recurring to HOLDS as required, for instance, in the Event Calculus, e.g., $\text{HOLDS}(\text{on}(x, y), t) \rightarrow \neg \text{HOLDS}(\text{on}(y, x), t)$.

More technically, our idea is to reify into states *temporally qualified and closed* atomic FOL propositions (about objects). Let \mathcal{V} be the extra-logical vocabulary of the FOL theory under consideration and $\mathcal{P} \subset \mathcal{V}$ be the set of predicates with one argument of type TM and all the other arguments of type OB. We assume that all the predicates in \mathcal{P} are *temporally contingent*—i.e., $P_t x \wedge \varepsilon_{t'} x \wedge t \neq t' \rightarrow P_{t'} x$ is *not* provable—i.e., *kinds* like ‘being a person’ or ‘being an electron’, as well as ε , are excluded from \mathcal{P} .⁶ We also assume \mathcal{P} to be *finite* and in a 1-1 relation with types of states in $\bar{\mathcal{P}}$. $P \in \mathcal{P}$ indicates the predicate associated with $\bar{P} \in \bar{\mathcal{P}}$, i.e., \bar{P} -states are reifications of P -atomic propositions.

(a9) formalizes the link between propositions and states. There is a unique state that satisfies the condition $\bar{P}s \wedge \varepsilon_t s \wedge x^n \multimap s$, it is $\mathbf{p}_t x^n$. Consequently, $\mathbf{p}_t x^n$ exists—in terms of \exists , not ε —only when $P_t x^n$ holds, i.e., states reify only *true* propositions; their existence contributes to how the world is. This closely corresponds to Kim's *existence*

⁶For kinds like ‘being a person’, it is usually assumed that their ‘truth-makers’ are the persons themselves, i.e., no states exist in correspondence with kinds (see [15]). Similarly for atemporal relations among objects. Here, we adopt this view. However, our framework can be adapted to include temporally necessary predicates.

condition: “the state $[x, P, t]$ exists if and only if substance x has property P at time t ” [16].⁷ Vice versa, non atomic closed formulas with existential or universal quantifiers do not introduce states but only (existential) constraints on them. In particular, existential quantifiers, as well as disjunctions and negations of atomic propositions, introduce a sort of *indeterminism*: different configurations of the world can make them true.

3. Eventualities

We extend our basic framework to cope with a deeper comparison with RTLs and to have the formal tools to represent events (Section 4). We introduce (i) a new category called, following [17], *eventuality* (EV), that subsumes ST (a10); and (ii) a parthood relation, $x \sqsubseteq y$, standing for “ x is part of y ”. Usual mereological notions are defined in (d5)-(d9). We consider an atomic classical extensional mereology closed under sum: parthood holds only between eventualities (a11), it implies temporal inclusion (a12), it is reflexive, antisymmetric, transitive, and atomic (a13), it satisfies the *strong supplementation principle* (a14), and it is closed under sum (a15). In this theory, eventualities are uniquely decomposable into atoms (see [18]). Sometimes we write $x+y$ to refer to the z such that $z \Sigma xy$. (a16) enforces states and mereological atoms to coincide. Hence EV is the closure of ST under mereological sum: states are the building blocks of eventualities.

- d5** $x \sqsubseteq y \triangleq x \sqsubseteq y \wedge x \neq y$ (*proper part*)
- d6** $x \overline{\sqsubseteq} y \triangleq \exists z(z \sqsubseteq x \wedge z \sqsubseteq y)$ (*overlap*)
- d7** $x \Sigma y^n \triangleq \forall w(w \overline{\sqsubseteq} x \leftrightarrow (w \overline{\sqsubseteq} y_1 \vee \dots \vee w \overline{\sqsubseteq} y_n))$ (*sum*)
- d8** $\Lambda x \triangleq \text{EV}x \wedge \neg \exists y(y \sqsubseteq x)$ (*atom*)
- d9** $x \wedge \sqsubseteq y \triangleq \Lambda x \wedge x \sqsubseteq y$ (*atomic part*)
- a10** $\text{ST}x \rightarrow \text{EV}x$
- a11** $x \sqsubseteq y \rightarrow \text{EV}x \wedge \text{EV}y$
- a12** $x \sqsubseteq y \rightarrow x \otimes y$
- a13** $\exists y(y \wedge \sqsubseteq x)$
- a14** $\neg x \sqsubseteq y \rightarrow \exists z(z \sqsubseteq x \wedge \neg z \overline{\sqsubseteq} y)$
- a15** $\text{EV}x \wedge \text{EV}y \rightarrow \exists s(s \Sigma xy)$
- a16** $\Lambda x \leftrightarrow \text{ST}x$

With a slight abuse of notation, (d10) extends ε to eventualities. The participants in an eventuality at a time t are the participants in at least one of the states that compose it and exist at t (d11). (d12) just abstracts from time. Hence, the participants in the part participate also in the whole. A non standard notion of *temporal slice* is defined in (d13): even though an eventuality has a unique temporal slice at any time it exists, it may have the same temporal slice at different times. This is the case with persisting states (atoms).

- d10** $\varepsilon_t e \triangleq \exists s(s \wedge \sqsubseteq e \wedge \varepsilon_t s)$
- d11** $x \rightarrow_t e \triangleq \bigvee_{1 \leq i \leq \alpha} \exists s(s \wedge \sqsubseteq e \wedge x \rightarrow_i s \wedge \varepsilon_t s)$
- d12** $x \rightarrow e \triangleq \exists t(x \rightarrow_t e)$
- d13** $x \parallel_t y \triangleq \forall z(z \sqsubseteq x \leftrightarrow \varepsilon_t z \wedge z \sqsubseteq y)$

⁷While Kim’s properties are in the domain of quantification, we have a 1-1 relation between \mathcal{P} and $\tilde{\mathcal{P}}$.

3.1. Types of Eventualities

Eventualities can be classified according to their behavior with respect to their temporal extensions, participants, and atomic components. An eventuality is *instantaneous*, $\langle i \rangle \text{EV}$, if it exists at a unique time (d14) and it is *convex*, $\langle c \rangle \text{EV}$, if it exists over a convex, with respect to time-precedence \leq , set of times (d15). *Dissective* eventualities, $\langle d \rangle \text{EV}$, are sums of states of the same type (d16), while for *homogeneous* ones, $\langle h \rangle \text{EV}$, all their *temporal slices* are states of the same type (d17). Homogeneity is stronger than dissectivity, since it requires that at every time only a state compose the eventuality. For instance, if $\varepsilon_t s \wedge \varepsilon_t s' \wedge s \neq s' \wedge \bar{P}s \wedge \bar{P}s'$, then $\langle d \rangle \text{EV}(s+s')$ but $\neg \langle h \rangle \text{EV}(s+s')$. An eventuality is *stable*, $\langle s \rangle \text{EV}$, if it is dissective and all its parts have the same participants (in the same order) (d18).

The previous definitions can be concatenated as in (d19), e.g., $\langle c, h \rangle \text{EV}$ individuates convex homogeneous eventualities. *Maximality constraints* can be added (d20). Maximally homogeneous eventualities are the sum of all the states of the same type, while maximally stable ones are the sum of all the states of the same type that have the same participants. $m \langle s \rangle \text{EV}$ s are abstractions of states (of one type) from time, while $m \langle h \rangle \text{EV}$ s are abstractions from time *and* participants. States are homogeneous and stable, but neither convex—nothing rules out intermittent atoms—nor maximally stable—nothing excludes the sum of two different instantaneous atoms s and s' from being stable.

- d14** $\langle i \rangle \text{EVE} \triangleq \text{EVE} \wedge \exists! t(\varepsilon_t e)$
d15 $\langle c \rangle \text{EVE} \triangleq \text{EVE} \wedge \forall t_0 t_1 t(\varepsilon_{t_0} e \wedge \varepsilon_{t_1} e \wedge t_0 \leq t \leq t_1 \rightarrow \varepsilon_t e)$
d16 $\langle d \rangle \text{EVE} \triangleq \bigvee_{\bar{p} \in \bar{\mathcal{P}}} \forall s(s \sqsubseteq e \rightarrow \bar{P}s)$
d17 $\langle h \rangle \text{EVE} \triangleq \bigvee_{\bar{p} \in \bar{\mathcal{P}}} \forall t(\varepsilon_t e \rightarrow \exists s(s \Vdash_t e \wedge \bar{P}s))$
d18 $\langle s \rangle \text{EVE} \triangleq \langle d \rangle \text{EVE} \wedge \forall s s'(s \sqsubseteq e \wedge s' \sqsubseteq e \rightarrow \bigwedge_i \forall x(x \dashv\vdash_i s \leftrightarrow x \dashv\vdash_i s'))$
d19 $\langle x, y \rangle \text{EVE} \triangleq \langle x \rangle \text{EVE} \wedge \langle y \rangle \text{EVE}$
d20 $m \langle x \rangle \text{EVE} \triangleq \langle x \rangle \text{EVE} \wedge \neg \exists e'(\langle x \rangle \text{EVE}' \wedge e \sqsubset e')$

3.2. Comparison with RTLs

In RTLs, *fluents* and *states* are usually represented as total functions⁸ applied to objects, e.g., respectively, **tired**(john) and **tired**(john, t).⁹ Differently, in our framework, the existence of john does not entails the one of **tired** _{t} (john), assuming **tired** $\in \mathcal{D}$. Our rationale for avoiding total functions is that total functions force states to be in the domain of quantification even if they do not hold; e.g., the state **tired**(john, t') s.t. $\neg \text{HOLDS}(\text{tired}(\text{john}, t'))$ is in the domain of quantification.¹⁰ Actually, for every time and object in the domain, there will be a **tired**-state. Similarly for fluents. This seems to contradict the Kim's *existence condition*. Contrariwise, our states correspond only to true propositions; HOLDS does not make sense for them, they just exist in time. While states (fluents) seem reifications of temporal (atemporal) *propositions*—they have a linguistic

⁸Functions are noted in bold, constants in typewriter type.

⁹States were introduced to account for the criticisms originally raised in [1] regarding the fact that fluents are reifications of types instead of tokens. States are then represented as total functions where at least one of the arguments is a time point or an interval.

¹⁰HOLDS(f, x^t, t) means that the fluent f, x^t holds (is true) at t . Concerning states, as the state-function f has already a temporal argument, there is no need to temporally qualify HOLDS, e.g., HOLDS(**tired**(john, t)). Some approaches consider a time interval or a couple of time points [2] as arguments of HOLDS.

nature—our states can be seen as *truth-makers* of propositions [15], i.e., what exists ‘in reality’ that makes propositions true.¹¹

The Token-Reified-Logic (TRL) [2] also suffers from the issue just discussed. However, TRL solves some problems of RTLs: it assumes event-tokens (instead of event-types) and proposes a clear semantics for HOLDS and OCCURS. TLR represents states by means of functions that have two (possibly equal) instants as arguments—the start and the end of the state—e.g., **tired**(john, 3pm, 4pm) meaning “John’s being tired from 3pm to 4pm”. In TRL, the fluent counterpart can be specified by means of the function TYPE from states (events) to *functions* from couples of times to states (events). For instance, TYPE(**tired**(john, 3pm, 4pm))(t₁, t₂) selects the state **tired**(john, t₁, t₂). TYPE is a sort of lambda abstraction from the temporal extension, but not from the function (e.g., **tired**) and the participants (e.g., john). Now, we show how some ontological assumptions in TRL can be formulated in our framework. States are convex and satisfy (f1): given a state $s_1 = \mathbf{f}(x^n, t_s, t_e)$, for all the subintervals of $[t_s, t_e]$, e.g. $[t_1, t_2]$, there exists a different state of the same type and with the same participants: $s_2 = \mathbf{f}(x^n, t_1, t_2)$. TRL provides no structural relation between states. Indeed, it seems reasonable to assume that (i) the functions **f** correspond to our descriptions; (ii) the temporal inclusion of states generated by the same function and participants is parthood (e.g., s_2 is part of s_1); and (iii) states with form $\mathbf{f}(x^n, t, t)$ are atoms. Given these assumptions, the notion of state in TRL can be characterized in our framework by adding (a17) and assuming states to be $\langle c, h, s \rangle$ EV-instances. Yet, we can write $3\text{pm} \leq t \leq 4\text{pm} \rightarrow \exists x(x = \mathbf{tired}_t \text{john})$ without committing to specific persistence conditions of states or to how many states exist. Because our states correspond to *true* propositions (so they necessarily hold at some time), fluents and TYPE can be only approximated by summing up all the states of a given type with the same participants, i.e., $m\langle s \rangle$ EV-instances. We can also abstract from participants: $m\langle d \rangle$ EV-instances are the sums of all the states of a given type, independently of their participants.

$$\mathbf{f1} \text{ HOLDS}(\mathbf{f}(x^n, t_s, t_e)) \wedge t_s \leq t_1 \leq t_2 \leq t_e \rightarrow \text{HOLDS}(\mathbf{f}(x^n, t_1, t_2))$$

$$\mathbf{a17} \ \Lambda s \rightarrow \langle i \rangle \text{EV } s$$

4. Events

Almost all the reified-theories distinguish *states* from *events* (CLIMB [19] is one exception).¹² States *hold* or *are true*, while events *occur* or *happen*. Both states and events are represented by means of total functions, e.g., for all x, y, t_s, t_e , **on**(x, y, t_s, t_e) is usually considered as a state, while **stab**(x, y, t_s, t_e) as an event. Given **on**(x, y, t_s, t_e), for all the subintervals of $[t_s, t_e]$, there exists a different **on**-state involving x and y , i.e., **on**(x, y, t_1, t_2) \neq **on**(x, y, t_3, t_4) if and only if $t_1 \neq t_3$ or $t_2 \neq t_4$. The same holds for events. The difference between states and events is characterized by means of the primitives HOLDS (for states) and OCCURS (for events) through (f1) (see the previous Section) and (f2).

$$\mathbf{f2} \text{ OCCURS}(\mathbf{p}(x^n, t_s, t_e)) \wedge t_s \leq t_1 \leq t_2 \leq t_e \rightarrow \neg \text{OCCURS}(\mathbf{p}(x^n, t_1, t_2))$$

$$\mathbf{f3} \text{ P}_i x^n \wedge j \sqsubseteq i \rightarrow \text{P}_j x^n$$

$$\mathbf{f4} \text{ P}_i x^n \wedge j \sqsubset i \rightarrow \neg \text{P}_j x^n$$

¹¹Note, however, that we do not commit to the ontological primacy of states with respect to propositions, only a correspondence between states and *true* propositions is assumed.

¹²We consider here the states introduced in [2], even though similar arguments apply to fluents.

In a non reified framework that follows MTA, (f1) and (f2) seem to closely correspond to (temporal) *homeomericity* (f3) and *anti-homeomericity* (f4) (where i and j are intervals and \sqsubseteq is parthood). In (f3), one could reduce the truth of $P_i x^n$ to the truth of *all* the $P_t x^n$ with $t \sqsubseteq i$, i.e., the truth-makers of $P_i x^n$ would make also true $P_i x^n$. Vice versa, according to (f4), there are no $t \sqsubseteq i$ where $P_t x^n$ is true, as the relation P between the objects x^n holds only at the whole interval. One needs then to understand what are the truth-makers of $P_i x^n$ in this second case. One possibility, the one we develop here, is to assume that $P_i x^n$ is reducible to a complex formula that involves atomic predicates holding over subintervals of i .¹³ P is a sort of *emergent* property [20], a property with a complex *structure* whose truth *depends* on the truth, during i , of simpler properties. We assume that this never holds for the predicates in \mathcal{P} that, even when extended to intervals, are supposed to satisfy (f3). The reduction of predicates satisfying (f4) to complex (diachronic) formulas allows us to see the entities that correspond to their truth, that we call *events*, as temporal entities with a complex structure, sort of *trajectories* across states.

A *narrative* or, let us say, a movie can be seen as a sequence of temporally labeled snapshots or frames. The content of each frame, the way the world is at a given time, may be captured by a complex (synchronic) formula belonging to the FOL-theory under development. In our framework, we can associate a frame with temporal label t to the set of states that exist at t .¹⁴ Vice versa, in general, events correspond to complex diachronic formulas, to set of states that exist at different times, therefore they require sequences of frames to be taken into account. Events have a conceptual role: they offer an abstract and dynamically-oriented point of view on narratives. From an *epistemological* or *perceptual* perspective, states may be seen as ‘time stamped data’, ‘basic observations’, ‘sensory atoms’, or, in a more subjective way, as ‘qualia’ (see [21]). Perception organizes sensory outputs by synchronically or, using memory, diachronically grouping them in units that allow us to interact with the world in a quick and fruitful way (see [22] for an introduction and [23] for perception of events). Similarly, states can be organized by *grouping* them into events that help us to understand the dynamics of the world in a cognitive-friendly fashion. Events can be reduced to mereological sum of states only when we assume instantaneous states (Section 4.1) or a perdurantist view. Otherwise, one needs to see events as higher level entities [24] and to allow them to change their *constituent*-states or to cease to exist even when these states continue to exist (Section 4.2). This sort of dichotomy is not new and originated lively philosophical discussions around the notion of material constitution (see [25]). The view that events are the result of a state-grouping is analogous to the one developed in [26], where *courses of events* are partial functions from space-time regions to sets of *facts*, i.e., true or false propositions. The framework proposed by [26] is more abstract than ours; however, the idea that events are at higher level of abstraction with respect to states is already present.

4.1. Events from Instantaneous States

We consider here instantaneous states: $STx \rightarrow \langle i \rangle EVx$. In this case, the temporal slices of persisting eventualities are always proper parts of them and pure perdurantism can be

¹³Another possibility is to assume that the truth of $P_i x^n$ depends on the truth of other predicates that holds before or after i .

¹⁴The axioms that characterize the predicates in \mathcal{P} correspond to (possibly complex) existential generic dependencies between states, i.e., they can be seen as the *laws* that regulate the world.

pursuit. Note that if ON and STAB belong to \mathcal{P} , both $\text{ON}_t xy$ and $\text{STAB}_t xy$ correspond to states. By putting STAB in \mathcal{P} , the developer decided that the existence of STAB-instances can be acquired looking at a single frame, no dynamics or structure is present in them. This choice can be motivated by a coarse time-*granularity*, frames could be seen as ‘short movies’ in this case. STAB-instances can be involved in dependence or causation relations as all the other states, no special behavior is attributed to them *a priori*.

At this point, we could accept as events all non-atomic eventualities, or, more strongly, all the persisting eventualities (including stable ones). The user has the possibility to *filter* the eventualities by defining some specific types of events according to her needs and the expressive power of the FOL-theory under construction. These types of events correspond to some structural constraints among the component states. In this perspective, event-types correspond to patterns, regularities, or trajectories identifiable in the sequences of the states of the world and, ultimately, in the world itself.

4.2. Events from Persisting States

We consider here maximal stable states: $\text{ST}x \leftrightarrow \text{m}(s)\text{EV}x$. This hypothesis entails that, given the objects x^t , a unique state corresponds to $\text{P}_t x^t$ whatever t . Less restrictive assumptions for states, e.g., $(s)\text{EV}x$ or $(s)\text{EV}x \wedge \text{m}(c)\text{EV}x$, are possible. We focus on the strong one because, from a cognitive standpoint, it parallels the re-identification of a single state in all the frames where $\text{P}_t x^t$ holds, a quite realistic hypothesis. In this case, states can be seen as persisting entities that are wholly present at different times, sort of *endurants*. Because of that, to build complex entities from states, one incurs in all the usual problems linked to material constitution and change (see [25]). In [27], Galton avoids committing to *processes* as endurants; we follow him and leave this question aside for our states.

To address these problems, we endorse a simplified version of the theory of levels introduced in [24]. We assume that events— $\text{EVN}x$ stands for ‘ x is an *event*’—are higher level entities grounded (at a time) on eventualities— $x <_t y$ stands for ‘the eventuality x fully grounds the event y at t ’, i.e., ‘ y owes its existence at t to x ’s existence at t ’. Events do not have temporal parts, but they can change their ground through time. The primitives EVN and $<$ are characterized by axioms (a18)–(a26) and definitions (d21)–(d23). Accordingly, events are in time and when they exist, they are fully grounded exactly on one eventuality. Moreover, partial grounding (d21) implies the existence of a disjoint (partial) ground (a25) (a sort of supplementation principle). (a26) is the identity condition for events: two events are identical if (i) they are temporally co-extensional and (ii) they coincide at all the times (i.e., at every time they exist, all the states that partially ground one event partially ground also the other and vice versa). This explains in which sense events are *built* from states. One can exclude events that are temporally co-extensive with, and always grounded on, a single eventuality by introducing (f5) as axiom. Due to lack of space, we cannot compare our theory with Galton’s processes *composing* events [27].

- d21** $x <_t y \triangleq \exists z(z <_t y \wedge x \sqsubset z \wedge \varepsilon_t x)$ (partial grounding)
- d22** $x \sqsubseteq_t y \triangleq \text{EVN}x \wedge \forall z(z <_t x \rightarrow z <_t y)$ (temporary part)
- d23** $x \equiv_t y \triangleq x \sqsubseteq_t y \wedge y \sqsubseteq_t x$ (coincidence)
- a18** $\text{EVN}x \rightarrow \neg \text{EV}x \wedge \neg \text{TM}x \wedge \neg \text{OB}x$
- a19** $x <_t y \rightarrow \text{EV}x \wedge \text{EVN}y$
- a20** $x <_t y \rightarrow \varepsilon_t x \wedge \varepsilon_t y$
- a21** $\text{EVN}x \rightarrow \exists t(\varepsilon_t x)$

- a22** $\text{EVN}x \wedge \varepsilon_t x \rightarrow \exists y(y <_t x)$
a23 $x <_t y \wedge z <_t y \rightarrow x = z$
a24 $x <_t y \wedge z \sqsubset x \rightarrow \varepsilon_t z$
a25 $x <_t y \rightarrow \exists z(z <_t y \wedge \neg z \checkmark x)$
a26 $\text{EVN}x \wedge \text{EVN}y \wedge \forall t(\varepsilon_t x \rightarrow x \equiv_t y) \wedge \forall t(\varepsilon_t y \rightarrow x \equiv_t y) \rightarrow x = y$
f5 $\text{EVN}x \rightarrow \neg \exists s(\forall t(\varepsilon_t x \rightarrow s <_t x) \wedge \forall t(\varepsilon_t s \rightarrow s <_t x))$

4.3. Changes

Related to the notions of state and event is the notion of change. There is no much agreement in what is a change, but it is useful to distinguish changes *in objects* from the more general notion of changes as transitions between states. Problems arise when trying to circumscribe the “scope” of a change: what seems a change may not be a change, if a wider scope is taken. Lombard [28] addresses them through the notion of *quality space* assuming that (basic) changes are *movements* of objects through quality spaces. Another problem is if changes are in time (“when changes occur?”). For Galton [17], changes are *instantaneous transitions*. He claims that such transitions do not occur at any time, but *between* times. Consequently, he includes these ‘interfaces’ among the temporal entities. Our framework can be conservatively extended to accommodate both positions.

4.4. Partially Specified Events

In our framework, both eventualities and events are fully specified. For instance, the existential conditions (a3) and (a7) together with the unicity conditions (a5) and (a8) assure that when there is a state, its type and all its participants must be determined. For instance, by assuming that **STAB** (binary) and **STAB_WITH** (ternary) are both in \mathcal{P} , in our framework one necessarily has $\mathbf{stab}_{,xy} \neq \mathbf{stab_with}_{,xyz}$, because the two states have different participants. Similarly, in the case of events (see (a21), (a22), (a23), and (a26)). First of all, note that there are approaches in linguistics that are closer to ours. For instance, Dowty [29] represents n -ary verbs by $(n+1)$ -ary predicates and adjuncts are distinct predicates, conjoined with the verb-predicate. Here, predicates have a fixed arity, and therefore what said before about existential and identity conditions holds. Second, in a neo-Davidsonian context, one can add constraints like $\mathbf{STABBING}(e) \rightarrow \exists i(\mathbf{INSTRUMENT}(e, i))$. However, these constraints individuate only the *necessary* participants. Third, by rejecting (a22) (and (a26)), we could allow partially described events. However, we would pay the same price of neo-Davidsonian approaches, we would lose the identity condition for events.

5. Conclusion

We introduced an ontologically clean framework that does not lack expressive power with respect to the investigated RTLs. We showed the irreducibility of events to mereological sums of persisting states; however the question about the nature of events remains open. In particular, our framework could be criticized because of the lack of a real dynamics. Our world may be seen as a big collection of static entities, of states. We suggested that the dynamics is in us. We build events and changes, we perceive them, we use them to communicate and represent the world. For Galton [27], there must

be something in reality that serves as explanation of how events *emerge* from static configurations. Galton explains such emergence in terms of *processes*; other authors refer to *dispositions*. However, for Wittgenstein, “The world is the totality of facts” [30], where facts are true states of affairs, what resembles our states. Here, our concern was to define events, not to explain the possible reasons of their emergence. Indeed this is a very interesting topic that merits a deeper analysis that we leave for future work.

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