Event Ontology based on Four-Dimensionalism

Yasuo NAKAYAMA

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1. Introduction

Donald Davidson (1980) developed an event-based semantics. According to Davidson, we can quantify over events as well as things. In this paper, we extend this view and formalize an ultimate form of event-based ontology. Not only do we accept events as concrete objects and consider things as special kinds of events, but we also interpret the whole four-dimensional universe as the maximal event and all concrete objects as parts of the universe. Using this framework, it is easy to see that this event-based ontology is compatible with both perduarantism[1)] and eternalism[2)].

In this paper, we propose an axiomatic theory for *Four-Dimensional Event Ontology* (4EO). This theory is based on *General Extensional Mereology* (GEM) for (four-dimensionally extended) events. It turns out that 4EO is a very expressive framework. We then develop an event-based ontology that interprets things as four-dimensionally extended events. When we interpret the history of a thing as a four-dimensionally extended event, we can describe its states and changes by ascribing certain properties to its temporal parts.

2. Arguments for Event-based Ontology

There are different concepts of events. In this paper, we assume the existence of the four-dimensional universe and identify an event through its spatio-temporal location in the universe. Events exist as parts of the universe, which is the maximal event. However, in order to refer to an event, we need a (four-dimensional) sortal or a (four-dimensional) mass predicate that characterizes types of referred events. Things can be interpreted as a special kind of events. For example, we can interpret a human as the whole life of an individual person. In other words, we can identify a human with the whole spatio-temporal extension of this individual person. In this case, the term "human" is a sortal that picks out such a spatio-temporal extension.

It is clear that this ontological view presupposes the eterrnalism. It is also clear that this view is compatible with a four-dimensional mereology. For, according to this view, all concrete entities are events (in the broad sense) and all events are four-dimensionally extended. In four-dimensionalism, there are a *worm theory and a stage theory*[3]. Our view belongs to a worm theory. We assume that an event can be identified as a four-dimensionally extended object by using a linguistic device such as a sortal. At first, the whole four-dimensional event of a cretin type is identified. After that, we can talk about its temporal parts. For example, when we refer to the whole life of Arthur N. Prior, we can talk about his student time. In this sense, the (four-dimensional) whole is ontologically more fundamental than its temporal parts. In Section 5 of this paper, we point out that this ontological view is not identical with our epistemological view. However, this kind of discrepancy between ontology and epistemology can be also found in many mathematical systems based on the classic logic and therefore nothing unusual. Our common understanding of objects might have its source in both our ontological and our epistemological view.

In ordinary language, we use expressions for physical objects and events. Semantically, both kinds of reductionism seem possible. In this paper, we reduce physical objects to events. One of aims of this paper is to show how to describe physical objects as four-dimensional events[4].

3. Formal Frameworks for Event-based Ontology

In this section we develop the *Four-Dimensional Event Ontology* (4EO). 4EO is based on *General Extensional Mereology* (GEM), *Theory for Temporal Objects* (TTO), and *Four-Dimensional Theory for Events* (4TE)[5].

3.1 The General Extensional Mereology

The General Extensional Mereology is a standard theory of mereology (Casati and Varzi 1999: Chapter 3; Varzi 2016). In the following description, (X.A*n*) indicates an axiom and (X.D*n*) indicates a definition. We use P as the part relation, which is the primitive relation in mereology.

(GEM.A1) [Reflexive Law] $\forall x\, P(x, x)$.

(GEM.A2) [Asymmetric Law] $\forall x\, \forall y\, (P(x, y) \wedge P(y, x) \rightarrow x = y)$.

(GEM.A3) [Transitive Law] $\forall x\, \forall y\, \forall z\, (P(x, y) \wedge P(y, z) \rightarrow P(x, z))$.

(GEM.D1) [Overlap] $\forall x\, \forall y\, (O(x, y) \leftrightarrow \exists z\, (P(z, x) \wedge P(z, y)))$.

(GEM.D2) [Underlap] $\forall x\, \forall y\, (U(x, y) \leftrightarrow \exists z\, (P(x, z) \wedge P(y, z)))$.

(GEM.D3) [Proper Part] $\forall x\, \forall y\, (PP(x, y) \leftrightarrow (P(x, y) \wedge \neg P(y, x)))$.

(GEM.D4) [Over-crossing] $\forall x\, \forall y\, (OX(x, y) \leftrightarrow (O(x, y) \wedge \neg P(x, y)))$.

(GEM.A4) [Strong Supplementation] $\forall x\, \forall y\, (\neg P(y, x) \rightarrow \exists z\, (P(z, y) \wedge \neg O(z, x)))$.

(GEM.A5) [Fusion] $\exists x\varphi \rightarrow \exists z\, \forall y\, (O(y, z) \leftrightarrow \exists x(\varphi \wedge O(y, x)))$, for any φ.

(GEM.D5) [Sum] $\sigma x\varphi = \iota z \forall y\, (O(y, z) \leftrightarrow \exists x(\varphi \wedge O(y, x)))$, for any φ.

(GEM.D6) [Product] $\pi x\varphi = \sigma z \forall x(\varphi \rightarrow P(z, x))$, for any φ.

(GEM.D7) [Sum of two individuals] $\forall x\ \forall y\ (x+y = \sigma z\ (P(z, x) \vee P(z, y)))$.

(GEM.D8) [Product of two individuals] $\forall x\ \forall y\ (x\times y = \sigma z\ (P(z, x) \wedge P(z, y)))$.

(GEM.D9) [Subtraction] $\forall x\ \forall y\ (x - y = \sigma z\ (P(z, x) \wedge \neg O(z, y))$.

(GEM.D10) [Complement] $\forall x(\sim x = \sigma z(\neg O(z, x)))$.

(GEM.D11) [Universe] $U = \sigma x(P(x, x))$.

(GEM.D12) [Lambda] $\forall x((\lambda y\ \varphi(y))x \leftrightarrow \varphi(x))$, for any φ.

In this paper, we deal with two GEMs, a GEM for temporal objects and a GEM for events.

3.2 The Theory for Temporal Objects

Now, we define the *Theory for Temporal Objects* (TTO). We use T, T_1, T_2, T_3, … as variables for temporal objects.

(TTO.A1) GEM for temporal objects.

(TTO.D1) [Time Point] $\forall T_1\ (\mathrm{TimePoint}(T_1) \leftrightarrow \forall T_2\ (P(T_2, T_1) \rightarrow T_2 = T_1))$. (A time point is a minimal temporal object.)

(TTO.A2) $\forall T_1\ (\mathrm{TimePoint}(T_1) \vee \exists T_2\ (P(T_2, T_1) \wedge \mathrm{TimePoint}(T_2)))$. (All temporal parts contain time points as their parts.)

(TTO.D2) [Relativization for Time Points]

[1] $\forall t\ \phi(t) \leftrightarrow \forall T\ (\mathrm{TimePoint}(T) \rightarrow \phi(T))$.

[2] $\exists t\ \phi(t) \leftrightarrow \exists T\ (\mathrm{TimePoint}(T) \wedge \phi(T))$.

(TTO.D3) $U_T = \sigma T\ P(T, T)$. (U_T is the fusion of all temporal objects.)

(TTO.D4) $\forall T\ (\mathrm{INT}(T) \leftrightarrow \forall t_1\ \forall t_2 \forall t_3\ (P(t_1, T) \wedge P(t_2, T) \wedge t_1 < t_3 \wedge t_3 < t_2 \rightarrow P(t_3, T)))$. (An interval is a continuous temporal object.)

We use t, t_1, t_2, t_3, … as variables for time points. Now, we introduce axioms for the simple B-theory[6)]. The simple B-theory says that atomic times are linearly ordered.

(TTO.A3) [Irreflextivity] $\forall t \neg\, t < t$.

(TTO.A4) [Transitivity] $\forall t_1 \forall t_2 \forall t_3\ ((t_1 < t_2 \wedge t_2 < t_3) \rightarrow t_1 < t_3)$.

(TTO.A5) [Comparativity] $\forall t_1\, t_2\ (t_1 < t_2 \vee t_1 = t_2 \vee t_2 < t_1)$.

Now, we can prove Proposition 1.

[Proposition1]

(TTO.P1) [Extensionality with repect to Time Points] $\forall T_1\ \forall T_2\ (\forall t(P(t, T_1) \leftrightarrow P(t, T_2)) \rightarrow T_1 =$

T_2). (If T_1 and T_2 are composed of the same time points, then $T_1 = T_2$.)

(TTO.P2) $\forall T\, T = \sigma t\, \mathrm{P}(t, T)$. (Every temporal object is composed of time points which are its parts.)

(TTO.P3) $\forall T\, \mathrm{P}(T, \mathrm{U}_T)$. (Every temporal object is a part of U_T.)

(TTO.P4) $\forall t\, \mathrm{P}(t, \mathrm{U}_T)$. (Every time point is a part of U_T.)

(TTO.P5) $\sigma t\, \mathrm{P}(t, t) = \mathrm{U}_T$. (The fusion of all time points is identical with U_T.)

Proof. We show (TTO.P1) by induction. Suppose T_1 is a time point. Then, the claim holds because of the reflectivity of P. Next, we assume that the claim holds for T_a. We set $T_b = T_a + t_b$ and $T_c = T_a + t_c$. Suppose that $\forall t\, (\mathrm{P}(t, T_b) \leftrightarrow \mathrm{P}(t, T_c))$. Then, $t_b = t_c$. Thus, because of (GEM.D7), $T_b = T_c$. Hence, (TTO.P1) holds. (TTO.P2) follows from (TTO.P1). (TTO.P3) follows from (GEM.A1), (TTO.A1) and (TTO.D3). (TTO.P4) follows from (TTO.P3) and (TTO.D2). (TTO.P5) follows from(TTO.P2) and (TTO.D3). Q.E.D.

3.3 The Four-Dimensional Theory for Events

Now, we introduce the *Four-Dimensional Theory for Events* (4TE). We use E, E_1, E_2, E_3, … as variables for events[7]. In 4TE, P and *exist* are primitive relations.

(4TE.A1) GEM for events.

(4TE.A2) Theory for Temporal Objects (TTO)

(4TE.A3) [Existence of Events 1] $\forall E\, \exists T\, exist(E, T)$. (Every event exists in some time.)

(4TE.A4) [Existence of Events 2] $\forall E_1\, \forall E_2\, \forall T\, ((\mathrm{P}(E_2, E_1) \wedge exist(E_2, T)) \rightarrow exist(E_1, T))$. (If E_2 is a part of E_1 and E_2 exists in T, then E_1 exists in T.)

(4TE.D1) [Instamtaneous Event] $\forall E\, (\text{Inst-event}(E) \leftrightarrow \exists^{=1} t\, exist(E,t))$. (An instantaneous event is an event that exists exactly at one time point.)

(4TE.D2) [Relativization for atomic events] We use e, e_1, e_2, e_3, …as variables for instantaneous events.

[1] $\forall e\, \phi(e) \leftrightarrow \forall E\, (\text{Inst-event}(E) \rightarrow \phi(E))$.

[2] $\exists e\, \phi(e) \leftrightarrow \exists E\, (\text{Inst-event}(E) \wedge \phi(E))$.

(4TE.D3) [Existence Time] $\forall T \forall E\, (T = exist\text{-}time(E) \leftrightarrow \forall t\, (\mathrm{P}(t, T) \leftrightarrow \exists e\, (exist(e, t) \wedge \mathrm{P}(e, E))))$. ($T = exist\text{-}time(E)$ iff (if and only if) for every time position t, [t is a part of T iff there is an instantaneous event e at t that is a part of E].)

(4TE.D4) [Temporal Part] $\forall E_1 \forall E_2\, (\mathrm{TP}(E_1, E_2) \leftrightarrow \forall e\, (exist(e, exist\text{-}time(E_1)) \rightarrow (\mathrm{P}(e, E_1) \leftrightarrow \mathrm{P}(e, E_2))))$. ($E_1$ is a temporal part of E_2 iff for every e that exists in the existence time of E_1, [e belongs to E_1 iff e belongs to E_2]).)

(4TE.D5) [Proper Temporal Part] $\forall E_1\, \forall E_2\, (\mathrm{PTP}(E_1, E_2) \leftrightarrow (\mathrm{TP}(E_1, E_2) \wedge \neg\, \mathrm{TP}(E_2, E_1)))$.

(4TE.D6) [Universe] $\mathrm{U}_E = \sigma E\, \mathrm{P}(E, E)$. (The universe U_E is the maximal event. It is identical with the whole history of the universe.)

(4TE.A5) [Partial Definition of *temporal part* (*tp*)] $\forall T \forall E_1$ ($exist(E_1, T) \rightarrow \forall E_2$ ($tp(E_1, T) = E_2 \leftrightarrow$ (TP$(E_2, E_1) \wedge T = exist\text{-}time(E_2)$)))). (If E_1 exists in T, then [the *temporal part* of E_1 in T is E_2 iff [E_2 is a temporal part of E_1 and T is the existence time of E_2]].)

(4TE.D7) [Simultaneity] $\forall e_1 \forall e_2$ ($simultaneous(e_1, e_2) \leftrightarrow exist\text{-}time(e_1) = exist\text{-}time(e_2)$).

Proposition 2 can be derived from these axioms and definitions.

[Proposition 2]

(4TE.P1) [Extensionality with respect to Instantaneous Events] $\forall E_1 \forall E_2$ ($\forall e$(P$(e, E_1) \leftrightarrow$ P$(e, E_2)) \rightarrow E_1 = E_2$). (If E_1 and E_2 are composed of the same instantaneous events, then $E_1 = E_2$.)

(4TE.P2) $\forall E\ E = \sigma e$ P(e, E). (Every event is composed of instantaneous events which are its parts.)

(4TE.P3) $\forall e\, \exists^{=1} t\ exist(e,t)$. (Every instrantaneous event exists at a unique time point.)

(4TE.P4) $\forall E$ P(E, U_E). (Every event is a part of the universe.)

(4TE.P5) $\forall e$ P(e, U_E). (Every instrantaneous event is a part of the universe.)

(4TE.P6) σe P$(e, e) = U_E$. (The fusion of all instrantaneous events is identical with the universe.)

Proof. (4TE.P1) can be proved in the same way as (TTO.P1). (4TE.P2) follows from (4TE.P1). (4TE.P3) follows from (4TE.A3), (4TE.D1) and (4TE.D2). (4TE.P4) follows from (GEM.A1), (4TE.A1), and (4TE.D5). (4TE.P5) follows from (4TE.P4), and (4TE.D2). (4TE.P6) follows from (4TE.P2), and (4TE.D5). Q.E.D.

Now, we can define tenses as relations between a time point and an event.

(4TE.D8) [Past Tense for Instantaneous Events] $\forall e \forall t_1$ ($Past(t_1, e) \leftrightarrow \exists t_2(exist(e, t_2) \wedge t_2 < t_1)$). ($e$ is *past* at t_1 iff there is a time point t_2 such that e exists at t_2 and t_2 is earlier than t_1.)

(4TE.D9) [Present Tense for Instantaneous Events] $\forall e \forall t$ ($Present(t, e) \leftrightarrow exist(e, t)$). ($e$ is *present* at t iff e exists at t.)

(4TE.D10) [Future Tense for Instantaneous Events] $\forall e \forall t_1$ ($Future(t_1, e) \leftrightarrow \exists t_2(exist(e, t_2) \wedge t_1 < t_2)$). ($e$ is *future* at t_1 iff there is a time point t_2 such that e exists at t_2 and t_1 is earlier than t_2.)

(4TE.D11) [Past Tense for Events] $\forall E \forall t$ ($Past(t, E) \leftrightarrow \forall e$(TP$(e, E) \rightarrow Past(t, e)$)). ($E$ is past in t iff all instrantaneous events that are temporal parts of E are past at t.)

(4TE.D12) [Present Tense for Events] $\forall E$ ($Present(t, E) \leftrightarrow \exists e$(TP$(e, E) \wedge Present(t, e)$)). ($E$ is present in t iff there is an instrantaneous event that is a temporal part of E and is present at t.)

(4TE.D13) [Future Tense for Events] $\forall E(Future(t, E) \leftrightarrow \forall e(\mathrm{TP}(e, E) \rightarrow Future(t, e)))$. ($E$ is future in t iff all instrantaneous events that are temporal parts of E are future at t.)

We define *spatial part* as part relation between instantaneous events.

(4TE.D12) [Spatial Part] $\forall e_1 \forall e_2 (\mathrm{SP}(e_1, e_2) \leftrightarrow \mathrm{P}(e_1, e_2))$. ($e_1$ is a *spatial part* of e_2 iff e_1 is a part of e_2).

(4TE.D13) [Spatial Proper Part] $\forall e_1 \forall e_2 (\mathrm{SPP}(e_1, e_2) \leftrightarrow (\mathrm{SP}(e_1, e_2) \wedge \neg \mathrm{SP}(e_2, e_1)))$. ($e_1$ is a *spatial proper part* of e_2 iff e_1 is a spatial part of e_2 and e_2 is not a spatial part of e_1).

3.4 The Four-Dimensional Event Ontology

As the first step, we define *mereological predicates* as predicates that are applicable to mereological sums.

(4EO.A1) All axioms and definitions of 4TE.

(4EO.D1) [Mereological Predicate] F is a *mereological predicate* iff F satisfies the following condition: $\forall E_1 \forall E_2 ((\mathrm{F}(E_1) \wedge \mathrm{F}(E_2)) \rightarrow (\mathrm{F}(E_1{+}E_2) \wedge (\neg \mathrm{P}(E_1, E_2) \rightarrow \mathrm{F}(E_1 - E_2))))$.

(4EO.D2) [Part Relation for F] $\forall E_1 \forall E_2 (\mathrm{P}_{[\mathrm{F}]}(E_1, E_2) \leftrightarrow (\mathrm{F}(E_1) \wedge \mathrm{F}(E_2) \wedge \mathrm{P}(E_1, E_2)))$.

(4EO.D3) [F-sentence] φ is a F-sentence iff $\exists E\, \varphi(E) \wedge \forall E\, (\varphi(E) \rightarrow \mathrm{F}(E))$.

(4EO.D4) [Overlap for F-objects] $\forall E_1 \forall E_2 (\mathrm{O}_{[\mathrm{F}]}(E_1, E_2) \leftrightarrow \exists E_3 (\mathrm{P}_{[\mathrm{F}]}(E_3, E_1) \wedge \mathrm{P}_{[\mathrm{F}]}(E_3, E_2)))$.

(4EO.D5) [Underlap for F-objects] $\forall \mathrm{x} \forall \mathrm{y} (\mathrm{U}_{[\mathrm{F}]}(\mathrm{x}, \mathrm{y}) \leftrightarrow \exists \mathrm{z} (\mathrm{P}_{[\mathrm{F}]}(\mathrm{x}, \mathrm{z}) \wedge \mathrm{P}_{[\mathrm{F}]}(\mathrm{y}, \mathrm{z})))$.

(4EO.D6) [Proper Part for F-objects] $\forall \mathrm{x} \forall \mathrm{y} (\mathrm{PP}_{[\mathrm{F}]}(\mathrm{x}, \mathrm{y}) \leftrightarrow (\mathrm{P}_{[\mathrm{F}]}(\mathrm{x}, \mathrm{y}) \wedge \neg \mathrm{P}_{[\mathrm{F}]}(\mathrm{y}, \mathrm{x})))$.

(4EO.D7) [Over-crossing for F-objects] $\forall \mathrm{x} \forall \mathrm{y} (\mathrm{OX}_{[\mathrm{F}]}(\mathrm{x}, \mathrm{y}) \leftrightarrow (\mathrm{O}_{[\mathrm{F}]}(\mathrm{x}, \mathrm{y}) \wedge \neg \mathrm{P}_{[\mathrm{F}]}(\mathrm{x}, \mathrm{y})))$.

We can show that General Extensional Mereology (GEM) holds for F-objects, when F is a mereological predicate.

[Proposition 3] $\mathrm{P}_{[\mathrm{F}]}$ is a reflexive, asymmetric and transitive relation for F-objects.

Proof. To show the reflextivity of $\mathrm{P}_{[\mathrm{F}]}$, it is sufficient to show $\forall E\, (\mathrm{F}(E) \rightarrow \mathrm{P}_{[\mathrm{F}]}(E, E))$. However, this holds because of (4EO.D2) and the reflextivity of P. In the same way, we can prove the asymmetry and the transitivity of $\mathrm{P}_{[\mathrm{F}]}$. Q.E.D.

[Proposition 4] If F is a mereological predicate, then the axiom for strong supplementation and the axiom for fusion hold for F-objects. Namely, the following sentences hold:

(4EO.P1) [Strong Supplementation for F-objects] $\forall E_1 \forall E_2 ((\mathrm{F}(E_1) \wedge \mathrm{F}(E_2)) \rightarrow (\neg \mathrm{P}_{[\mathrm{F}]}(E_2, E_1) \rightarrow \exists E_3 (\mathrm{F}(E_3) \wedge \mathrm{P}_{[\mathrm{F}]}(E_3, E_2) \wedge \neg \mathrm{O}_{[\mathrm{F}]}(E_3, E_1))))$.

(4EO.P2) [Fusion for F-objects] If φ is F-sentence, then $\exists E_2$ $(\mathrm{F}(E_2) \wedge \forall E_3$ $(\mathrm{F}(E_3) \rightarrow (\mathrm{O}_{[\mathrm{F}]}(E_3, E_2)$ $\leftrightarrow \exists E_1$ $(\varphi(E_1) \wedge \mathrm{O}_{[\mathrm{F}]}(E_3, E_1)))))$.

Proof. Suppose that F is a mereological predicate. To show (4EO.P1), suppose that $\mathrm{F}(E_a) \wedge \mathrm{F}(E_b)$ $\wedge \neg \mathrm{P}_{[\mathrm{F}]}(E_b, E_a)$. We set $E_c = E_b - E_a$. Then, from (4EO.D1), $\mathrm{F}(E_c)$. Because of (GEM.D9), we have $\mathrm{P}(E_c, E_b) \wedge \neg \mathrm{O}(E_c, E_a))$. Thus, $\mathrm{F}(E_c) \wedge \mathrm{P}_{[\mathrm{F}]}(E_c, E_b) \wedge \neg \mathrm{O}_{[\mathrm{F}]}(E_c, E_a)$. Hence, (4EO.P1) holds. Now, to show (4EO.P2), suppose that φ is F-sentence. Because of (GEM.A5), we have $\exists E_2 \forall E_3$ $(\mathrm{O}(E_3, E_2) \leftrightarrow \exists E_1$ $(\varphi(E_1) \wedge \mathrm{O}(E_3, E_1)))$. We define $E_d = \sigma E_3 \exists E_1$ $(\varphi(E_1) \wedge \mathrm{O}_{[\mathrm{F}]}(E_3, E_1))$. Then, because of (4EO.D1), we have $\mathrm{F}(E_d)$. It also holds: $\forall E_3$ $(\mathrm{F}(E_3) \rightarrow (\mathrm{O}_{[\mathrm{F}]}(E_3, E_d) \leftrightarrow \exists E_1$ $(\varphi(E_1) \wedge \mathrm{O}_{[\mathrm{F}]}(E_3, E_1))))$. Thus, (4EO.P2) holds. Q.E.D.

We distinguish sortals and mass predicates. For example, "human" is a sortal and "water" is a mass predicate.

(4EO.D8) [Atomic F-Object] $\forall E_1$ $(\mathrm{atom}_{\mathrm{F}}(E_1) \leftrightarrow (\mathrm{F}(E_1) \wedge \neg\exists E_2$ $(\mathrm{PP}(E_2, E_1) \wedge \mathrm{F}(E_2)) \wedge \neg\exists E_2$ $(\mathrm{PP}(E_1, E_2) \wedge \neg\mathrm{F}(E_2) \wedge \mathrm{F}(E_1{+}E_2))))$. ($E_1$ is F-atomic iff E_1 is a minimal F-object).

(4EO.D9) [Sortal] F is a s*ortal* iff F is a mereological predicate that satisfies the following condition: $\forall E_1$ $(\mathrm{atom}_{\mathrm{F}}(E_1) \vee ((\mathrm{F}(E_1) \wedge \neg\, \mathrm{atom}_{\mathrm{F}}(E_1)) \rightarrow \exists E_2$ $(\mathrm{P}(E_2, E_1) \wedge \mathrm{atom}_{\mathrm{F}}(E_2))))$. (F is a sortal iff [F is a mereological predicate and every F-object consists of F-atomic objects].)

(4EO.D10) [Noun] $[\mathrm{F}] = \sigma E$ $\mathrm{F}(E)$. ([F] is the maximal F-obhect.)

(4EO.D11) [Sortal Term] [F] is a sortal term iff F is a sortal.

(4EO.D12) [Mass Predicate] F is a *mass predicate* iff F is a mereological predicate that satisfies the following condition: $\forall E_1$ $\forall E_2$ $((\mathrm{F}(E_1) \wedge \mathrm{PP}(E_2, E_1)) \rightarrow \mathrm{F}(E_2))$. (F is a mass predicate iff [F is a mereological predicate and every F-object is dividable into smaller F-objects].)

According to Grandy (2016), there are three characterizations of *sortal*.

(1a) A sortal tells us what essence of a thing is.

(1b) A sortal tells us how to count things of that kind, which requires knowing which things are different and which are the same.

(1c) A sortal tells us when something continues to exist, and when it goes out of existence.

In this paper, we distinguish *substance sortals* and *phase sortals*. Both are kinds of sortals. We interpret that *substance sortals* satisfy (1b) and (1c). This view is in agreement with the view of Strawson (1959) (Grandy 2016: Section 3.1). A phase sortal satisfies only characterization (1b). A substance sortal is a sortal that is used for individuation of objects. Thus, a substance sortal is more fundamental than phase sortal[8)].

(4EO.D13) [Phase Sortal] F is a phase sortal iff there is a substance sortal G such that $\forall E_1(\mathrm{F}(E_1) \rightarrow \exists E_2\,(\mathrm{G}(E_2) \wedge \mathrm{PTP}(E_1, E_2)))$. (For every F-object E_1, there is a G-object E_2 such that E_1 is a proper temporal part of E_2.)

"cat" is a substance sortal, while "kitten" is a phase sortal. The term "cat" is used to identify an object, while the term "kitten" is used to characterize a temporal part of a cat. Kitten is a phase sortal, because when a cat matures it ceases to be a kitten but it does not go out of existence (Grandy 2016: Section 4).

It is commonly accepted that there are two kinds of objects, namely *things* and *events*. However, in this paper, we consider all objects are events in the broad sense. A typical example of a thing is a desk and a typical example of an event in the narrow sense is a concert. A concert is performed by musicians during a time interval. We can refer to the whole concert and talk about its temporal parts. We propose to take the same view for a desk. A desk is spatio-temporally extended and we consider the whole four-dimensional extension of the desk as an individual desk.

We propose to relativize IS-A and INSTANCE-OF relations by sortals.

(4EO.D14) [IS-A Relation for F] If [A] and [B] are sortal terms and F is a sortal, then IS-A relation is defined as follows: $\text{IS-A}_{[\mathrm{F}]}([\mathrm{A}], [\mathrm{B}]) \leftrightarrow \mathrm{P}_{[\mathrm{F}]}([\mathrm{A}], [\mathrm{B}])$.

(4EO.D15) [INSTANCE-OF Relation for F] If [A] is a proper noun, [B] is a sortal term, and F is a sortal, then INSTANCE-OF relation is defined as follows: $\text{INSTANCE-OF}_{[\mathrm{F}]}([\mathrm{A}], [\mathrm{B}]) \leftrightarrow (\mathrm{P}_{[\mathrm{F}]}([\mathrm{A}], [\mathrm{B}]) \wedge \mathrm{atom}_{\mathrm{F}}([\mathrm{A}]))$.

We can explain the notion of counting by the cardinality of sortal objects, which can be recursively defined as follows.

(4EO.D16a) [Cardinality 1] $\forall E_1\,(\mathrm{atom}_{\mathrm{F}}(E_1) \rightarrow \mathrm{cd}_{\mathrm{F}}(E_1) = 1)$. (The F-cardinality of a F-atomic event is 1.)

(4EO.D16b) [Cardinality 2] $\forall E_1\ \forall E_2\ \forall n\ ((\mathrm{cd}_{\mathrm{F}}(E_1) = n \wedge \mathrm{atom}_{\mathrm{F}}(E_2) \wedge \neg\mathrm{O}_{[\mathrm{F}]}(E_1, E_2)) \rightarrow \mathrm{cd}_{\mathrm{F}}(E_1+E_2) = n+1)$. (If the F-cardinality of E_1 is n, E_2 is F-atomic, and E_1 and E_2 do not overlap each other, then the F-cardinality of E_1+E_2 is $n+1$.)

The temporal homogeneity characterizes the internal structure of events in the narrow sense. This notion can be defined in the same way as the general homogeneity (See (4EO.D12) and (4EO. D17)).

(4EO.D17) [General Homogeneity] An object denoted by [F] is *generally homogeneous* iff F is a mass predicate.

(4EO.D18) [Temporal Homogeneity] An object denoted by [F] is *temporally homogeneous* iff it holds: $\forall E_1 \forall E_2 ((F(E_1) \land PTP(E_2, E_1)) \to F(E_2))$. (Every proper temporal part of a F-object is F).

Many authors classify events into four classes, namely *achievements, accomplishments, activities* and *states*. We can characterize achievements as instantaneous events, namely it holds: if *E* is an achievement, then *E* is an instantaneous event. If an event is an activity or a state, then the event is temporally homogeneous. An accomplishment can be interpreted as a fusion of an activity and an achievement. Casati and Varzi (2015) appropriately characterizes these four classes of events:

> An *activity*, such as John's walking uphill, is a homogeneous event: its sub-events satisfy the same description as the activity itself and has no natural finishing point or culmination. An *accomplishment*, such as John's climbing the mountain, may have a culmination, but is never homogeneous. An *achievement*, such as John's reaching the top, *is* a culminating event (and is therefore always instantaneous). And a *state*, such as John's knowing the shortest way, is homogeneous and may extend over time, but it makes no sense to ask how long it took or whether it culminated. (Casati and Varzi 2015: Section 2.1)

Predicates of achievements and accomplishments are phase sortals. This is shown by the fact that achievements and accomplishments can be counted. We can illustrate the ontological view of this paper by the following two taxonomical schemas (See Figure 1 and Figure 2).

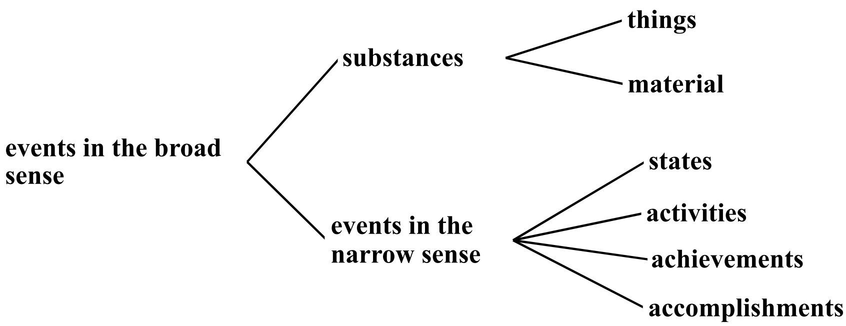

Figure 1. Ontological Taxonomy

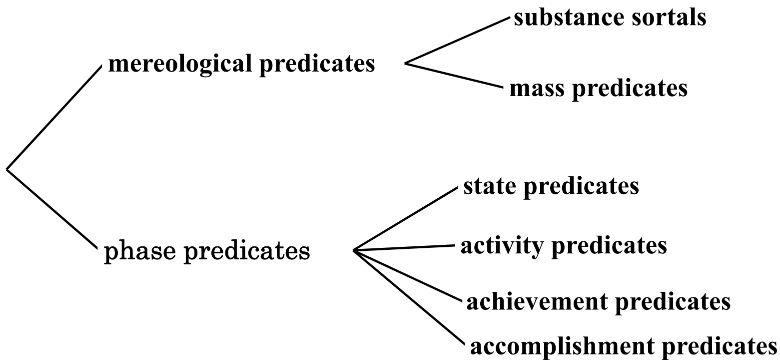

Figure 2. Taxonomy of expressions

4. Some Applications of Four-Dimensional Event Ontology

There are different forms of four-dimensionalism. Usually, worm theory and stage theory are distinguished (Sider 2001). Many metaphysicians accept that events are four-dimensionally extended. Because we claim that all concrete objects are events, it is natural to accept four-dimensionalism for concrete objects.

We propose to identify things with four-dimensionally (extended) events that are picked out by substance sortals. For example, a person is identified with the whole life of the person. As a result, we can easily describe the biology of a person in 4EO. As an example, let us take the life of English philosopher, J. M. E. McTaggart. We assume that *McTaggart* denotes the whole life of McTaggart. We also assume that *London* refers to a four-dimenisonal object.

(2a) "McTaggart was born in London in 1866."

$\exists E$ (TP(E, *McTaggart*) $\wedge$ *born*(E) $\wedge$ P(E, *London*) $\wedge$ P(*exist-time*(E), *year*(1866)) $\wedge$ *Past*(*now*, E)).

(2b) "McTaggart was born in 1866 and died in 1925. "

$\exists E_1$ $\exists E_2$ (TP(E_1, *McTaggart*) $\wedge$ *born*(E_1) $\wedge$ P(*exist-time*(E_1), *year*(1866)) $\wedge$ *Past*(*now*, E_1) $\wedge$ TP(E_2, *McTaggart*) $\wedge$ *die*(E_2) $\wedge$ P(*exist-time*(E_2), *year*(1925)) $\wedge$ *Past*(*now*, E_2)).

(2c) "McTaggart studied philosophy at Trinity College, Cambridge from 1885 to 1888."

$\exists E$ (TP(E, *McTaggart*) $\wedge$ *study*(E, *philosophy*, *Trinity-College*) $\wedge$ P(*Trinity-College*, *Cambridge*) $\wedge$ P(*exist-time*(E), *years*(1885-1888)) $\wedge$ *Past*(*now*, E)).

(2d) "McTaggart published the first volume of *The Nature of Existence* in 1921."

$\exists E$ (TP(E, *McTaggart*) $\wedge$ *publish*(E, *first*(*NatEx*)) $\wedge$ P(*exist-time*(E), *year*(1921)) $\wedge$ *Past*(*now*, E)).

In these descriptions, we assume that the indexical *now* refers to the speaker time. For example, when these sentences are uttered by A at time t_1, we interpret $now = t_1$. We can also say that *born*, *die*, and *publish* are relations that express accomplishments and *study* expresses an activity.

5. Four-Dimensional Epistemology

The Four-Dimensional Event Ontology (4EO) expresses an ontological position. We propose to combine 4EO with a four-dimensional epistemology, because we think that the appearance of peculiarity of 4EO comes from a lack of an appropriate epistemology[9)].

The epistemology for 4EO can be characterized through (3a), (3b), (3c), (3d), and (3e).

(3a) Agents are four-dimensional objects. Thus, they are parts of the universe.
(3b) Every agent belongs to a reference frame.
(3c) When an agent exists at a time point, he can make an observation at the time point.
(3d) The *present* for a temporal part of an agent is the time point at which he can make an observation.
(3e) The set of observations made by an agent continuously expands until his death. This expansion of the observation set expresses the dynamic aspect of time.

This epistemological view of 4EO can be characterized as an *internal view of the universe*. According to these theses, agents exist in the universe as four-dimensional objects. A *temporal part of an agent* can observe certain events at a time point. It follows from (3d) that a temporal part of an agent can make an observation *only in the present*. Thus, the present has this *epistemological* superiority. However, the present has no *ontological* superiority[10)].

Now, let us assume that $OS(A, t)$ be the set of observations that have been made by the agent A until time point t. If A is alive at time point t_1 and t_2 and $t_1 < t_2$, then $OS(A, t_1) \subseteq OS(A, t_2)$. This is because every past event remains as a past event. Thus, every past observation remains as an element of the set of observations. Hence, the observation set monotonically increases[11)].

On one hand, from the epistemological viewpoint, any model of the eternalism is mere theoretical constructions and not empirically provable. For no future event is directly observable. The epistemological view corresponds to the internal view, because observations are always made from the internal view. On the other hand, from the viewpoint of an observer, the future is unknown. Thus, the universe experienced by an observer has the structure of the *growing universe theory*, although these experiences do not justify the growing universe theory interpreted as an ontological thesis.

Observation apparatuses are spatiotemporally located in the universe and we may replace observers through observation apparatuses. Thus, not the agency itself but the internal locality of an observation is important for epistemological considerations.

6. Four-Dimensional Indexicalism

According to Merricks (1995), the indexicalism (the indexical view of the present) claims that the present time is simply one time among many and that being present is simply being this time. Here, I combine the indexicalism with 4EO and propose the *Four-Dimensional Indexicalism* (4DI) (see Nakayama 2012b).

According to 4DI, an observer makes an observation in a *spatiotemporal part of the universe*. By the way, this is the view supported by the relativity theory. The *present* is a time point where an observer makes observations. According to 4EO, an action is an event and an event is a four-dimensional entity.

When act_1 is an action, we denote the agent of the action by $agent(act_1)$. Then, we can define truth conditions for tensed sentences as follows:

(4a) The statement "I *am* tired" produced by an utterance act_1 is true iff there is a four-dimensional object E such that [E is a temporal part of $agent(act_1)$ & E is tired & the utterance time is a part of the occurrence time of E], namely $\exists E\ (\mathrm{TP}(E, agent(act_1)) \wedge tired(E) \wedge \mathrm{P}(exist\text{-}time(act_1), exist\text{-}time(E)))$.

(4b) The statement "I *was* tired" produced by an utterance act_1 is true iff there is a four-dimensional object E such that [E is a temporal part of $agent(act_1)$ & E is tired & the utterance time is before the occurrence time of E], namely $\exists E\ (\mathrm{TP}(E, agent(act_1)) \wedge tired(E) \wedge exist\text{-}time(act_1) < exist\text{-}time(E))$.

(4c) The statement "I will be tired" produced by an utterance act_1 is true iff there is a four-dimensional object E such that [E is a temporal part of $agent(act_1)$ & E is tired & the utterance time is after the occurrence time of E], namely $\exists E\ (\mathrm{TP}(E, agent(act_1)) \wedge tired(E) \wedge exist\text{-}time(E) < exist\text{-}time(act_1))$.

Note that the standard semantic treatment of indexicals proposed by Kaplan is quite abstract (Kaplan 1989), while the above formulation can describe how the values of contextual information are determined. 4DI interprets context as *context of an utterance*. The context gives information for evaluation of uttered sentences, because an utterance takes place in a particular spatio-temporal part of the universe. This is why the tensed view becomes necessary for interpretation of tensed sentences.

7. Concluding Remarks

In this paper, we have proposed a formulation of four-dimensional event-based ontology. We have also demonstrated how to combine this ontology with a four-dimensional epistemology. A formal description of sortals in a mereological framework was recently proposed in Nakayama (2009). In this paper, we have improved this approach and combined sortals with an event-based ontology.

Ontological studies tend to focus on things. In this paper, we have shown more general ontology that includes both things and events as particulars. In this framework, the universe is defined as the maximal event and all other concrete objects are considered as parts of the universe. The proposed framework, the *Four-Dimensional Event Ontology* (4EO), clarifies metaphysical presuppositions and semantics of natural languages. By introducing a four-dimensional epistemology, we could describe not only static but also dynamic aspects of human activities.

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Notes

1)According to Hawley (2015), perdurantists believe that ordinary things like animals, boats and planets have temporal parts (things persist by ‘perduring’).

2)Eternalists claim that objects from both the past and the future exist just as much as present objects and that temporal location matters not at all when it comes to ontology (Markosian 2016).

3)For the distinction between the worm theory and the stage theory, see Sider (2001). David Lewis and W.V.O. Quine are advocators of the worm theory and T. Sider supports the stage theory.

4)A part of discussions in this paper is based on Nakayama (2012a, 2013, 2015).

5)It is also possible to define time as a sum of (simultaneous) events. This kind of formulation is sketched in Nakayama (2009: Chapter 2).

6)This notion of B-theory comes from McTaggart's distinction between A series and B series (McTaggart 1927). See Poidevin and Macbeath (1993), Mellor (1998), and Nakayama (2005, 2015).

7)In this paper, we use two-sorted logic. However, in general, many-sorted logic is reducible to the First-Order Logic by relativization. We consider temporal objects as instrumental objects. Thus, in this paper, only events in the broad sense are considered as concrete objects.

8)Substance sortals are sortals that Wiggins (1967) regards as crucial. A phase sortal typically only applies to some temporal parts of an object. See Grandy (2016: Section 4).

9)The discussion in Section 5 and 6 is based on Nakayama (2014b).

10)The presentism claims the ontological superiority of the present. However, we accept only the epistemological superiority of the present and deny its ontological superiority.

11) For this discussion, see Nakayama (2014a).

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Event Ontology based on Four-Dimensionalism

Yasuo Nakayama

Donald Davidson (1980) developed an event-based semantics. According to Davidson, we can quantify over events as well as things. In this paper, we extend this view and formalize an ultimate form of event-based ontology. Not only do we accept events as concrete objects and consider things as special kinds of events, but we also interpret the whole four-dimensional universe as the maximal event and all concrete objects as parts of the universe. Using this framework, it, is easy to see that this event-based ontology is compatible with both perduarantism and eternalism.

In Section 3 of this paper, we define an axiomatic theory for *Four-Dimensional Event Ontology* (4EO). This theory is based on *General Extensional Mereology* (GEM) for (four-dimensionally extended) events. We then develop an event-based ontology that interprets things as four-dimensionally extended events. When we interpret the history of a thing as a four-dimensionally extended event, we can describe its states and changes by ascribing certain properties to its temporal parts.

A formal description of sortals in a mereological framework was recently proposed by Nakayama (2009). In this paper, we improve this approach and combine a theory of sortals with an event-based ontology. It turns out that 4EO is a very expressive framework and can be applied to the formal representation of sentences in natural languages (See Section 4 and 6).

Ontological studies tend to focus on things. In this paper, we describe more general ontology that includes both things and events as particulars. In this framework, the universe is defined as the maximal event and all other concrete objects are considered as parts of the universe. The proposed framework, 4EO, clarifies metaphysical presuppositions and the semantics of natural languages (See Section 5). By introducing a four-dimensional epistemology, we can describe not only static but also dynamic aspects of human activities.