An Ontology of the Aspectual Classes of Actions

Robert Trypuz[1,2]
trypuz@loa-cnr.it
Laure Vieu[2,3]
vieu@irit.fr

[1] *Università di Trento*
[2] *Laboratorio di Ontologia Applicata, ISTC, CNR, Trento*
[3] *Institut de Recherche en Informatique de Toulouse, CNRS*

Abstract

It is well known that verb phrases can be classified into lexical *aspectual classes*, the most popular ones being: activity (e.g., *run*), state (e.g., *sit*), accomplishment (e.g., *climb a mountain*) and achievement (e.g., *reach the summit*). Although existing formal theories and logics of actions only consider telic actions, that is, accomplishments and/or achievements, all four categories do contain verbs describing agentive and intentional eventualities, i.e., actions. In this paper, we show how these aspectual classes, seen as eventuality types can be incorporated into a formal ontology of action—OntoSTIT+. We also show how the famous imperfective paradox is solved in this theory, which illustrates its expressive power.

Keywords: action, ontology, aspectual classes, imperfective paradox

1 Introduction

In the middle of the twentieth century, linguists studying aspect started distinguishing lexical *aspectual classes* of verbs and verb phrases, also called *aktionsarten* [14, 6]. The most popular ones are four, and are named after Vendler: activity (e.g., *run, eat*), state (e.g., *know, be sick, sit*), accomplishment (e.g., *drown, eat an apple, climb a mountain*) and achievement (e.g., *realize, reach the summit*).[1]

Aktionsart, or lexical aspect, should be distinguished from the grammatical aspect of a sentence. In most Indo-European languages, the later is grounded on the distinction between perfective tenses (e.g., simple past in English, *I run*) and imperfective tenses (e.g., past progressive, *I was running*). Both aktionsart and grammatical aspect characterize the relation of what a verb phrase denotes with respect to time or the temporal flow. And linguistic studies early showed that the combination of lexical aspect with grammatical aspect is constrained in certain ways. For instance, the imperfective aspect cannot apply to achievements: **I am realizing*.

The work on aspect inspired many philosophers of language and formal semanticists who saw the deep relationship aktionsart has a with the ontological classification of *eventualities* or *perdurants*, the temporal entities verb phrases refer to in a Davidsonian semantics, and proposed formal characterizations of these classes [9, 4, 8, 15]. In particular, Mourelatos noticed that the verb classification into activity, performance (which groups accomplishment and achievement together) and state "obviously falls under an ontological trichotomy of wider scope, viz. process-event-state" [9]. Verb phrases describe eventualities, so they can be seen as denoting types of eventualities. Aspectual classes of verbs can then be treated as larger, ontological, classes of eventualities. Nevertheless, this is a simplification as grammatical aspect also plays a role. The famous *imperfective paradox* [4, 2] brings some light into this interaction. Both activity and accomplishment verbs can take the progressive form (imperfective), but one should be able to explain why the progressive of an activity verb entails the perfect form (*I was running* entails *I ran*), whereas the progressive of an accomplishment verb does not entail it (*I was running home* does not entail that *I ran home*).

In this paper, we are interested in showing how aspectual classes, seen as eventuality types, as well as the imperfective/perfective distinction can be incorporated into an ontology of action. As far as we know, aspectual classes have not been applied to any theory of action. In fact, in most theories and logics of action, actions are, usually implicitly, considered as restricted to telic actions, i.e., performances. This is the case in PDL [5], Situation Calculus [11] and the so-called logics of agency [3, 10, 1]. The same appears in the top-level ontologies SUMO[2] and OpenCyc[3], where the concept of action is restricted to those actions which are purposeful, so neither activities nor states are taken into account. However, if an action is to be defined as "what an agent can intentionally do", a standard definition in philosophy of action, it is clear that activities like running, or states like sitting, also count as actions. Our goal is to fill this gap and present a formal ontology of action which includes a classification of actions motivated by the aspectual classes. For this purpose we extend the ontology of action, called OntoSTIT+ [12], with four sub-sorts: activity, culminated process, culmination, and state, corresponding to the four aspectual classes of, respectively, activity, accomplishment, achievement, and state.

In what follows, we first summarize the properties of eventualities associated to each of the four aspectual classes, that have been discussed in the literature. Then, after having briefly described OntoSTIT+, we show how all these properties —and the four new sub-sorts of action— can be characterized in OntoSTIT+ . Finally, we show how the imperfective paradox is solved, which demonstrates the expressive power of OntoSTIT+.

2 Semantic properties of the aspectual classes

Because of our ontological aims, we here disregard the standard linguistic tests characterizing the aspectual classes to focus on semantic properties which have an ontological import. The main parameters involved in distinguishing these classes from the point of view of their relation with time are: having (or being) a culmination point, being downward homogeneous, and being cumulative.

Activities (e.g., *running, writing, eating*) are atelic, they do not require any terminal point, climax or culmination, i.e., they are not internally related to any climax. Activities are "homogeneous down to a certain limit in size" [4], i.e., some temporal parts of an activity are also activities of the same type. For instance, some, but not all, temporal parts of a running count as a running. In fact, I need to do at least a few steps in order to describe my behavior as running, one step is not enough. In addition, activities are cumulative, i.e., two immediately successive instances of an activity of the same type make up an activity of the same type. For instance, two successive runnings (of the same agent) make up a single running.

States (e.g., *loving, sitting, being on the top of Chegul*) have most in common with activities, they are also without climax, cumulative and homogeneous. But their homogeneity is "perfect", i.e., it is not constrained by any limit in size. Thus for instance, any temporal part of a loving is also a loving. States are necessarily extended, they have a non-null duration: to be on top of the Chegul it is not enough to pass through the top of the Chegul.

Accomplishments (e.g., *eat an apple, drawing a circle*) are telic, they have a climax. An accomplishment is sometimes called *culminated process* [8], because it has a particular culmination and a particular process (activity) associated with it. Additionally, contrary to activities and states, accomplishements are anti-homogeneous and anti-cumulative.

Achievements (e.g., *reaching the top, winning a race*) are pure climax, they "capture either the inception or the climax of an act" [9]. An achievement is sometimes called a *culmination* [8]. Achievements are temporally atomic, therefore also anti-homogeneous and anti-cumulative. Like accomplishments, achievements are not independent entities, as they are the culmination of some activity.

3 Aspectual classes in OntoSTIT+

3.1 The framework

3.1.1 Introduction to OntoSTIT+

OntoSTIT+ [12] is a sorted first-order logic whose domain contains agents (ag), moments (m), histories (h), intervals (i), action tokens (t), action courses (c) and arbitrary non-temporal entities (e), which includes the subsort ag (see Figure 1). The language includes a set of primitive predicates Δ_+ establishing relations between individuals of the first six sorts, a set of primitive predicates, Π_+ over individuals of the last sort e, intended to describe the states of affairs that hold at a moment m and a history h (in short, at an *index* m/h), a set of predicates Θ of basic action types linking action tokens to their participants (of e), two sets of predicates $\Omega\Theta$ and $\Gamma\Theta$ describing respectively the expected outcomes and the preconditions associated to a basic action type, and finally, three sets of predicates Θ_{all}, $\Omega\Theta_{all}$, $\Gamma\Theta_{all}$, and for all action types, basic or not, their expected outcomes and their preconditions.[4] Bold, lowercase serif letters stand for constants.

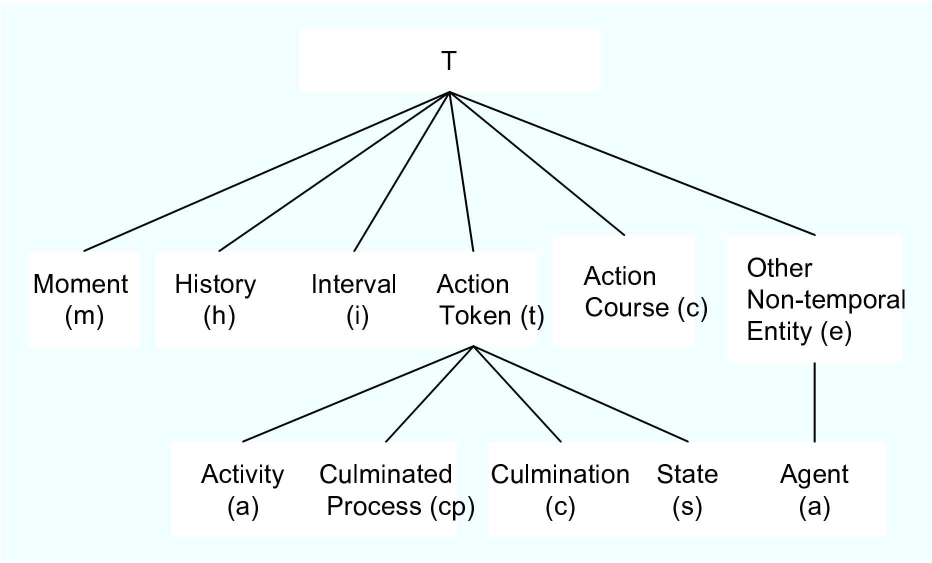

Figure 1: Hierarchy of sorts in OntoSTIT+

As OntoSTIT+ is the extension of a first-order equivalent of Chellas's "seeing to it that" logic of agency [3, 1], it is grounded in a branching time structure made of moments and histories which grasps the indeterminacy of the future. Histories are maximal chains of moments, and correspond to the possible temporal courses of the world. Intervals are convex stretches of histories. Any interval i has a beginning moment ($Beg(m, i)$) and an ending moment ($End(m, i)$) which are unique. $Inc(i, i')$ ($PInc(i, i')$) stands for the (proper) inclusion of the interval i in i'. $At(i)$ means interval i is atomic or degenerated, i.e. i is such that its beginning and its end are the same moment.

In OntoSTIT+, actions are considered as having a duration and as being non-deterministic. This means that action *tokens* may unfold into different action *courses* on histories that branch during their execution. Action tokens and courses are dependent on each other so that for each action token t there is at least one action course c which is a course of it ($CO(c, t)$) and for each action course there is exactly one *action token* which it is a course of. Each action course c runs through ($RT(c, i)$) a unique interval i. Obviously, all courses of a same action token start at the same moment, i.e., their intervals begin at the same moment, but they may have different durations. $BAct(m, c)$ and $EAct(m, c)$ stand respectively for the beginning and end of the action course c. We assume that one and only one basic action type A_i from Θ applies to each action token. An action course is *successful* if and only if the expected-outcomes predicate ($OA_i \in \Omega\Theta$) associated with the basic action type of its action token holds at the end. So, the same action token might have successful courses on certain histories and unsuccessful courses on others.

3.1.2 Aspectual classes in OntoSTIT+

The four aspectual classes are introduced in OntoSTIT+ by means of the addition of four sub-sorts of the sort t: activity (a), culminated process (cp), culmination (c) and state (s)—see Figure 1. All the properties of the aspectual classes discussed above are implemented in OntoSTIT+ with axioms discussed in the next subsection. We also discuss a few additional properties there.

Θ, the set of predicates of basic action types, is now $\Theta = \Theta^a \cup \Theta^{cp} \cup \Theta^c \cup \Theta^s$ and $\Omega\Theta$, the set of predicates describing the expected outcomes associated to an action type, is now $\Omega\Theta = \Omega\Theta^a \cup \Omega\Theta^{cp} \cup \Omega\Theta^c \cup \Omega\Theta^s$. Sets Θ^a, Θ^{cp}, Θ^c, Θ^s are respectively the sets of activity, culminated process, culmination and state basic action types, where: $\Theta^a = \{A_1^a, A_2^a, ...A_k^a\}$ (each element A_i^a of Θ^a is of sort $\mathsf{a} \times \mathsf{e}^{n_i}$, $n_i \geq 1$)—Θ^{cp}, Θ^c, Θ^s are characterized in a similar way—and $\Omega\Theta^a$, $\Omega\Theta^{cp}$, $\Omega\Theta^c$ and $\Omega\Theta^s$ are the finite sets of predicates describing the expected outcomes associated to (in a one-to-one mapping with), respectively, Θ^a, Θ^{cp}, Θ^c and Θ^s.

Examples of sentences involving verbs belonging to all aspectual classes and their semantic interpretation in OntoSTIT+ involving the corresponding basic action type predicates are presented in the table below.[5]

Aktionsart	**Sentence**	**Formula**
Cul. Process	I eat the apple	$\exists t^{cp} Eat^{cp}(t^{cp}, \mathbf{me}, \mathbf{apple})$
State	I sit on the chair	$\exists t^s Sit^s(t^s, \mathbf{me}, \mathbf{chair})$
Activity	I run	$\exists t^a Run^a(t^a, \mathbf{me})$
Culmination	I reach the summit of K2	$\exists t^c Reach^c(t^c, \mathbf{me}, \mathbf{summit\text{-}K2})$

Table 1: Verb phrases and basic action types.

3.1.3 A few definitions

The two following definitions characterize the inclusion of two action courses of the same action token:

(CInc) $CInc(c,t,c') \triangleq CO(c,t) \wedge CO(c',t) \wedge \exists i,i'(RT(c,i) \wedge RT(c',i') \wedge Inc(i,i'))$ [*Inclusion of courses*]

(CPInc) $CPInc(c,t,c') \triangleq CO(c,t) \wedge CO(c',t) \wedge \exists i,i'(RT(c,i) \wedge RT(c',i') \wedge PInc(i,i'))$ [*Proper inclusion of courses*]

We also need to introduce the relation of subsequence between sequences (e.g., $\overrightarrow{x}$, $\overrightarrow{y}$, ...) that are arguments of elements of the set Θ (e.g., $A_i^c(t^c, \overrightarrow{x})$). By $\overrightarrow{x} \preccurlyeq \overrightarrow{y}$ we mean that a sequence $\overrightarrow{x}$ is a subsequence of $\overrightarrow{y}$.

3.2 Characterizing the four classes

We will now get into the axioms and theorems describing properties of action tokens of each of the four aspectual classes. When they involve arbitrary predicates of Θ, these actually are schemas.

3.2.1 Activity

As seen in Section 2, activities are homogeneous "down to a certain limit". To capture this fact, we will use the OntoSTIT+ feature of having non-deterministic actions, i.e., that action courses can be successful or not. So, we will not say that a too short temporal part of a running is not a course of a running, we will just say that it is an unsuccessful one. To characterize the limit in homogeneity of activities, we state that for each course c of an activity token, there is always an unsuccessful course *c'* of the same token which is prolonged by c or equal to c:

(Av1) $CO(c,t^a) \rightarrow \exists c'(CInc(c',t^a,c) \wedge \neg Su(c'))$ [*Successfulness-down-to-a-certain-limit*]

For instance a particular *running* course is successful only if an agent does several steps, let's say more then five. Thus some subcourses of a successful running course, these for which an agent does five or less steps, are unsuccessful.

From (Av1) it follows that all successful activity courses are not atomic, i.e., they do not run through atomic intervals:

(TAv1) $CO(c, t^a) \wedge RT(c, i) \wedge Su(c) \rightarrow \neg At(i)$ [*Anti-atomic*]

Activities are homogeneous, in the sense that for any proper sub-interval of the interval of any course of any token of a given type, there is a (possibly different) token of the same type which has a course running through this sub-interval. Obviously, this course may be unsuccessful. In a way, (Av2) captures the fact that at all moments of the execution of an activity (but the last), the agent keeps deciding to pursue that activity.

(Av2) $CO(c, t^a_1) \wedge RT(c, i) \wedge A^a_i(t^a_1, \overrightarrow{x}) \wedge PInc(i', i) \wedge Beg(m, i') \wedge \neg End(m, i)$
$\rightarrow \exists c', t^a_2(CO(c', t^a_2) \wedge RT(c', i') \wedge A^a_i(t^a_2, \overrightarrow{x}))$ [*Homogeneity*]

(Av3) expresses the fact that the successful activities are extensible. If I have already been running successfully for half an hour, I can keep running further and this extension is already successful:

(Av3) $CInc(c, t^a, c') \wedge Su(c) \rightarrow Su(c')$ [*Extensible*]

Activities are also cumulative. Two courses of two tokens of the same basic action type, which meet, can be summed:

(Av4) $CO(c, t^a_1) \wedge CO(c', t^a_2) \wedge A^a_i(t^a_1, \overrightarrow{x}) \wedge A^a_i(t^a_2, \overrightarrow{x}) \wedge BAct(m', c) \wedge EAct(m, c)$
$\wedge BAct(m, c') \wedge EAct(m'', c') \rightarrow \exists c''(CO(c'', t^a_1) \wedge BAct(m', c'') \wedge$
$EAct(m'', c''))$ [*Cumulative*]

3.2.2 Culminated Process

Contrary to activities, a successful cumulative process (accomplishment) is not extensible, i.e., a course of a culminated process which is prolonged, disregarding whether this longer course is successful or not, cannot be successful:

(CP1) $CPInc(c, t^{cp}, c') \rightarrow \neg Su(c)$ [*Non-Extensible*]

Culminated processes also are anti-homogeneous. In fact, we have a stronger requirement: in the middle of a course of a token, it is impossible to start a second token of the same type, and with the same participants: I cannot start climbing the K2 while I'm already in the middle of the ascent. Anti-homogeneity is a consequence of this no-overlap constraint.

(CP2) $CO(c, t^{cp}_1) \wedge RT(c, i) \wedge A^{cp}_i(t^{cp}_1, \overrightarrow{x}) \wedge BAct(m, c) \rightarrow \neg\exists c', t^{cp}_2(CO(c', t^{cp}_2)$
$\wedge BAct(m', c') \wedge A^{cp}_i(t^{cp}_2, \overrightarrow{x}) \wedge InI(m', i) \wedge m' \neq m)$ [*No-Overlap*]

As an additional the consequence of (CP2) we obtain that the culminated processes are not cumulative, i.e., any two courses of two different tokens of culminated process of the same basic action type, which meet, do not make up a third:

(TCP1) $CO(c, t_1^{cp}) \wedge CO(c', t_2^{cp}) \wedge A_i^{cp}(t_1^{cp}, \overrightarrow{x}) \wedge A_i^{cp}(t_2^{cp}, \overrightarrow{x}) \wedge BAct(m', c) \wedge EAct(m, c) \wedge BAct(m, c') \wedge EAct(m'', c') \rightarrow \neg\exists c''(CO(c'', t_1^{cp}) \wedge BAct(m', i'') \wedge EAct(m'', i''))$ [*Anti-Cumulative*]

Activity associated with a culminated process. To capture the other properties of culminated processes, i.e., their dependence on activities, we need to introduce the concept of activity associated with a culminated process. We do so with $\Upsilon\Theta^{cp} = \{(AA_1^{cp})^a, (AA_2^{cp})^a, ...\}$, a subset of predicates of Θ_{all} associated (in a one-to-one mapping with) to Θ^{cp}, and with the set $\Omega\Upsilon\Theta^{cp} \subseteq \Omega\Theta_{all}$, the predicates for the expected outcomes associated to $\Upsilon\Theta^{cp}$. Each $(AA_i^{cp})^a$—in short AA_i^{cp}—is associated to A_i^{cp} and is of sort $\mathsf{a} \times \mathsf{e}^{n_i}$, $n_i \geq 1$. Intuitively AA_i^{cp} is an activity type associated to the culminated process type A_i^{cp}. But the AA_i^{cp} are not basic activity types, and, although all tokens of type AA_i^{cp} are activities, we do not have $\Upsilon\Theta^{cp} \subseteq \Theta^a$. Actually, tokens of type AA_i^{cp} may be of different basic activity types from the set Θ^a (e.g., once I might cross the street by way of walking, and in another occasion I might do it by way of running). Obviously, not all basic types of activity can be predicated of a token of the activity type associated with a given culminated process type culminated process (e.g., I cannot cross the street by way of swimming).

For example consider my walking on High Street. This action is an activity. During this walking I decide to cross High Street. My crossing High Street is not an activity, it is a culminated process which is *constituted* by my walking. I'm walking when I'm crossing the street.

The courses of a token of an activity type AA_i^{cp} have the same temporal extension as the courses of the token of type A_i^{cp} it corresponds to. In fact, the link between tokens of associated activities and culminated processes is one of *constitution*. We here adopt the characterization of constitution from [7, p. 34], where "$K(x, y, t)$" stands for "x constitutes y during t". $K(c, c', i)$, where c and c' are two courses, implies $RT(c, i) \wedge RT(c', i)$. So, the activity constitutes the culminated process, i.e., the culminated process depends on the activity (see Figure 2):

(CP3) $A_i^{cp}(t^{cp}, \overrightarrow{x_1}) \rightarrow \exists t^a, \overrightarrow{x_2}(AA_i^{cp}(t^a, \overrightarrow{x_2}) \wedge \forall c, i(CO(c, t^{cp}) \wedge RT(c, i) \rightarrow \exists c'(CO(c', t^a) \wedge RT(c', i) \wedge K(c', c, i)))$, where $\overrightarrow{x_2} \preccurlyeq \overrightarrow{x_1}$
[*Dependence of Cul. Process on Activity*]

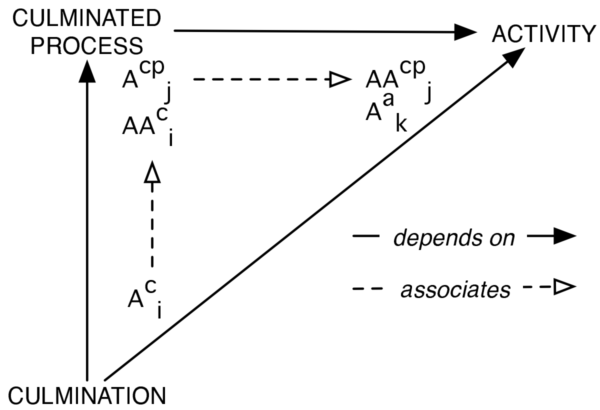

Figure 2: Dependency and association between basic action types.

Reciprocally, these special activities (but not all activities), by construction, also depend on some culminated process:

(Av5) $AA_i^{cp}(t^a, \overrightarrow{x_1}) \rightarrow \exists t^{cp}, \overrightarrow{x_2}(A_i^{cp}(t^{cp}, \overrightarrow{x_2}) \wedge \forall c, i(CO(c, t^a) \wedge RT(c, i) \rightarrow \exists c'(CO(c', t^{cp}) \wedge RT(c', i) \wedge K(c, c', i)))$, where $\overrightarrow{x_1} \preccurlyeq \overrightarrow{x_2}$
[*Dependence of Associated Activity on Cul. Process*]

Taking into account (CP3) and (Av5), it can be said that a culminated process and its associated activity are mutually dependent. This dependency will be explored in solving the imperfective paradox (see Section 4).

If the culminated process is successful then the associated activity constituting it is also successful. For instance, if I did successfully cross the street, then I did walk, or run, or whatever basic activity type was the type of the token associated to my crossing.

(CP4) $Su(c) \wedge CO(c', t^a) \wedge RT(c', i) \wedge AA_i^{cp}(t^a, \overrightarrow{x_1}) \wedge K(c', c, i) \rightarrow Su(c')$
[*Dep. of success. of Activ. on success. of Cul. Process*]

The opposite, obviously is not true. I can have walked successfully and yet have not succeeded in crossing the street.

From (TAv1), (CP3), and (CP4), it follows that successful culminated processes are not atomic:

(TCP2) $CO(c, t^{cp}) \wedge RT(c, i) \wedge Su(c) \rightarrow \neg At(i)$ [*Anti-Atomic*]

3.2.3 Culmination

Culminations (i.e., achievements) are atomic:

(C1) $CO(c, t^{c}) \wedge RT(c, i) \rightarrow At(i)$ [*Atomic*]

Each culmination is dependent on a culminated process, i.e., whenever there is a course of the culmination there is also a course of the culminated process which is associated with it. In fact, we here again need to introduce associated types of actions, in a similar way as we did above. $\Upsilon\Theta^c = \{(AA_1^c)^{cp}, (AA_2^c)^{cp}, ...(AA_k^c)^{cp}\}$ is a subset of predicates of Θ_{all} associated with (in a one-to-one mapping with) Θ^c and $\Omega\Upsilon\Theta^c \subseteq \Omega\Theta_{all}$ is the corresponding set of predicates describing their expected outcomes. $(AA_i^c)^{cp}$ —in short AA_i^c— is associated with A_i^c and it is of sort $\mathsf{cp} \times \mathsf{e}^{n_i}$, $n_i \geq 1$. Intuitively AA_i^c is the type of culminated process associated to the culmination A_i^c (for example climbing the hill and reaching the top of it). Contrary to associated activities, it is not so clear that there could be many ways of realizing such an associated culminated process. In other words, it could well be that these actually are basic types, i.e., that $\Upsilon\Theta^c \subseteq \Theta^{cp}$. We do not want to take issue on this point here, and leave the question open.

The expected outcomes of both the culmination and the associated culminated process hold simultaneously: $OA_i^c(m, h, \overrightarrow{x}) \leftrightarrow OAA_i^c(m, h, \overrightarrow{x})$.

(C2) expresses the fact that culminations depend on culminated processes (see Figure 2):

(C2) $A_i^c(t^c, \overrightarrow{x}) \rightarrow \exists t^{cp}(AA_i^c(t^{cp}, \overrightarrow{x}))$
[*Dependence of Culmination on Cul. Process*]

3.2.4 State

States, as activities, are extensible and, contrary to activities, are homogeneous without any limit. Therefore, in our interpretation, states are always successful:

(S1) $CO(c, t^{s}) \rightarrow Su(c)$ [*Successfulness*]

This means that, provided that the preconditions hold and thus that the state can start, trying to realize a state cannot fail further on, contrary to trying to do some activity or accomplishment.

However, because of this, to capture the idea that states are extended, we need to resort to another solution than for activities. A state course might be atomic only if it has some extension, i.e., a course that prolongs it:

(S2) $CO(c, t^s) \wedge RT(c, i) \wedge At(i) \rightarrow \exists c' \ CPInc(c, t^s, c')$ [*Extension*]

(S2) allows to consider a very first moment of a longer state action as a state action itself.

As activities, states are cumulative (S3) and homogeneous (S4):

(S3) $CO(c, t_1^s) \wedge CO(c', t_2^s) \wedge A_i^s(t_1^s, \overrightarrow{x}) \wedge A_i^s(t_2^s, \overrightarrow{x}) \wedge BAct(m', c) \wedge EAct(m, c) \wedge BAct(m, c') \wedge EAct(m'', c') \rightarrow \exists c''(CO(c'', t_1^s) \wedge BAct(m', i'') \wedge EAct(m'', i''))$ [*Cumulative*]

(S4) $CO(c, t_1^s) \wedge RT(c, i) \wedge A_i^s(t_1^s, \overrightarrow{x}) \wedge PInc(i', i) \wedge Beg(m, i') \wedge \neg End(m, i) \rightarrow \exists c', t_2^s(CO(c', t_2^s) \wedge RT(c', i') \wedge A_i^s(t_2^s, \overrightarrow{x}))$ [*Homogeneity*]

4 Dealing with the Imperfective Paradox

We now show that in OntoSTIT+, the imperfective paradox, as described above (Section 1), can be solved. This solution requires that both aktionsart and the progressive form of a verb have their counterparts in the ontology. As detailed above, aspectual classes of actions correspond to subsorts of action tokens. Now we posit that a progressive statement is a statement about a specific action course of an action token.[6] More precisely, because the progressive means "being-in-the-middle" of an action we will always associate a progressive sentence with a course c^{prog} of some activity token t^a which is prolonged by a course of the same token. Dependently on whether the progressive sentence is the progressive of an activity or a culminated process verb, the token t^a, which c^{prog} is a course of, is either of the activity type (A_i^a) itself or of the activity type associated with the culminated process type (AA_i^{cp}). We thus assume that progressive statements are of the form:

(Prog) $\exists c^{prog}, t^a, c, \overrightarrow{x}(CPInc(c^{prog}, t^a, c) \wedge Su(c^{prog}) \wedge (A_i^a(t^a, \overrightarrow{x}) \vee AA_i^{cp}(t^a, \overrightarrow{x}))$ [*Progressive Statement*]

Let's start with activities, and let's see whether from the sentence a) *I was running*, we can infer b) *I ran*. The semantics of sentence a) is the existence of course c^{prog} of a token t^a. t^a is of basic action type $Run^a \in \Theta^a$, i.e., $Run^a(t^a, \mathbf{me})$, since the verb "run" belongs to the aspectual classe activity:

(E1) $\exists c^{prog}, c, t^a(CPInc(c^{prog}, t^a, c) \wedge Su(c^{prog}) \wedge Run^a(t^a, \mathbf{me}))$

The fact that *I ran*, i.e., that the course c^{prog} is successful, follows directly from E1.

Now for culminated processes, on the other hand, we need to show, e.g., that from c) *I was crossing the street* we do not get d) *I crossed the street*. "Cross-the-street" is a basic culminated process type and its progressive corresponds to the activity associated with it:

(E2) $\exists c^{prog}, c, t^a(CPInc(c^{prog}, t^a, c) \wedge Su(c^{prog}) \wedge ACross\text{-}the\text{-}street^{cp}(t^a, \mathbf{me}))$

Now, the question is not whether c^{prog} is successful, as before, but whether a course c^{cp} —of a token t^{cp}, such that $Cross\text{-}the\text{-}street^{cp}(t^{cp}, \mathbf{me})$— constituted by c^{prog} is a successful course. The existence of a course c^{cp} constituted by c^{prog} is guaranteed by (Av5). Since c^{prog} is properly included in the other course, there is a prolongation of it which constitutes another course c' of a token t^{cp}. c' may be successful or not. What is essential is the fact that since in turn c' prolongs c^{cp}, from (CP1) it follows that c^{cp} is not successful. Thus from the fact that c^{prog} is successful we cannot infer that c^{cp} is successful as well; c) does not entail d) which was to be proved.

In fact, from c) we can infer that *I did not cross the street, yet.* This sentence follows from the fact that the progressive form applied to a culminated process implies that there is always a course of the culminated process token, which is constituted by the "progressive" course and which is unsuccessful:

(T) $\exists c^{prog}, c, t^a, \overrightarrow{x_1}(CPInc(c^{prog}, t^a, c) \wedge Su(c^{prog}) \wedge AA_i^{cp}(t^a, \overrightarrow{x_1}))$
$\rightarrow \exists c^{prog}, c', i, t^{cp}, \overrightarrow{x_2}(K(c^{prog}, c', i) \wedge CO(c', t^{cp}) \wedge A_i^{cp}(t^{cp}, \overrightarrow{x_2}) \wedge \neg Su(c'))$

The formula (T) is a theorem of OntoSTIT+. Its proof goes as follows:

Proof 1

1. $\exists c^{prog}, c, t^a, \overrightarrow{x_1}(CPInc(c^{prog}, t^a, c) \wedge Su(c^{prog}) \wedge \mathrm{AA}_i^{cp}(t^a, \overrightarrow{x_1}))$ *assump.*

2. $CPInc(\mathbf{c^{prog}}, \mathbf{t^a}, \mathbf{c}) \wedge Su(\mathbf{c^{prog}}) \wedge \mathrm{AA}_i^{cp}(\mathbf{t^a}, \overrightarrow{\mathbf{x_1}})$ $\exists E$

3. $CO(\mathbf{c^{prog}}, \mathbf{t^a}) \wedge CO(\mathbf{c}, \mathbf{t^a}) \wedge \exists i, i'(RT(\mathbf{c^{prog}}, i) \wedge RT(\mathbf{c}, i') \wedge PInc(i, i')) \wedge Su(\mathbf{c^{prog}}) \wedge \mathrm{AA}_i^{cp}(\mathbf{t^a}, \overrightarrow{\mathbf{x_1}})$ *CPInc:2*

4. $CO(\mathbf{c^{prog}}, \mathbf{t^a}) \wedge CO(\mathbf{c}, \mathbf{t^a}) \wedge RT(\mathbf{c^{prog}}, \mathbf{i}) \wedge RT(\mathbf{c}, \mathbf{i'}) \wedge PInc(\mathbf{i}, \mathbf{i'}) \wedge Su(\mathbf{c^{prog}}) \wedge \mathrm{AA}_i^{cp}(\mathbf{t^a}, \overrightarrow{\mathbf{x_1}})$ *∃E:3*

5. $AA_i^{cp}(t^a, \overrightarrow{x_1}) \rightarrow \exists t^{cp}, \overrightarrow{x_2}(A_i^{cp}(t^{cp}, \overrightarrow{x_2}) \wedge \forall c, i(CO(c, t^a) \wedge RT(c, i) \rightarrow \exists c'(CO(c', t^{cp}) \wedge RT(c', i) \wedge K(c, c', i)))$ *Av5*

6. $\exists t^{cp}, \overrightarrow{x_2}(A_i^{cp}(t^{cp}, \overrightarrow{x_2}) \wedge \forall c, i(CO(c, \mathbf{t^a}) \wedge RT(c, i) \rightarrow \exists c'(CO(c', t^{cp}) \wedge RT(c', i) \wedge K(c, c', i)))$ *MP:4,5*

7. $A_i^{cp}(\mathbf{t^{cp}}, \overrightarrow{\mathbf{x_2}})$ *∃E:6*

8. $\forall c, i(CO(c, \mathbf{t^a}) \wedge RT(c, i) \rightarrow \exists c'(CO(c', \mathbf{t^{cp}}) \wedge RT(c', i) \wedge K(c, c', i)))$ *∃E:6*

9. $CO(\mathbf{c^{prog}}, \mathbf{t^a}) \wedge RT(\mathbf{c^{prog}}, \mathbf{i}) \rightarrow \exists c'(CO(c', \mathbf{t^{cp}}) \wedge RT(c', \mathbf{i}) \wedge K(\mathbf{c^{prog}}, c', \mathbf{i}))$ *∀E:8*

10. $\exists c'(CO(c', \mathbf{t^{cp}}) \wedge RT(c', \mathbf{i}) \wedge K(\mathbf{c^{prog}}, c', \mathbf{i}))$ *MP:4,9*

11. $CO(\mathbf{c'}, \mathbf{t^{cp}}) \wedge RT(\mathbf{c'}, \mathbf{i}) \wedge K(\mathbf{c^{prog}}, \mathbf{c'}, \mathbf{i})$ *∀E:10*

12. $CO(\mathbf{c}, \mathbf{t^a}) \wedge RT(\mathbf{c}, \mathbf{i'}) \rightarrow \exists c'(CO(c', \mathbf{t^{cp}}) \wedge RT(c', \mathbf{i'}) \wedge K(\mathbf{c}, c', \mathbf{i'}))$ *∀E:8*

13. $\exists c'(CO(c', \mathbf{t^{cp}}) \wedge RT(c', \mathbf{i'}) \wedge K(\mathbf{c}, c', \mathbf{i'}))$ *MP:4,12*

14. $CO(\mathbf{c''}, \mathbf{t^{cp}}) \wedge RT(\mathbf{c''}, \mathbf{i'}) \wedge K(\mathbf{c}, \mathbf{c''}, \mathbf{i'})$ *∃E:13*

15. $CO(\mathbf{c'}, \mathbf{t^{cp}}) \wedge RT(\mathbf{c'}, \mathbf{i}) \wedge CO(\mathbf{c''}, \mathbf{t^{cp}}) \wedge RT(\mathbf{c''}, \mathbf{i'}) \wedge PInc(\mathbf{i}, \mathbf{i'})$ *∧I 11,14*

16. $CO(\mathbf{c'}, \mathbf{t^{cp}}) \wedge CO(\mathbf{c''}, \mathbf{t^{cp}}) \wedge \exists i, i'(RT(\mathbf{c'}, i) \wedge RT(\mathbf{c''}, i') \wedge PInc(i, i'))$ *∃I:15*

17. $CPInc(\mathbf{c'}, \mathbf{t^{cp}}, \mathbf{c''})$ *CPInc:16*

18. $\neg Su(\mathbf{c'})$ *MP: CP1 and 17*

19. $K(\mathbf{c^{prog}}, \mathbf{c'}, \mathbf{i}) \wedge CO(\mathbf{c'}, \mathbf{t^{cp}}) \wedge A_i^{cp}(\mathbf{t^{cp}}, \overrightarrow{\mathbf{x_2}}) \wedge \neg Su(\mathbf{c'})$ *∧I:11,7,18*

20. $\exists c^{prog}, c', i, t^{cp}, \overrightarrow{x_2}(K(c^{prog}, c', i) \wedge CO(c', t^{cp}) \wedge \mathrm{A}_i^{cp}(t^{cp}, \overrightarrow{x_2}) \wedge \neg Su(c'))$ *∃I:19*

5 Conclusion

In this paper we have shown how the aspectual classes can be integrated into a formal ontology of action. OntoSTIT+ appears to be expressive enough for capturing all properties of the aspectual classes which have been described in the literature.

Actions in the activity and state classes—which have not been seriously taken into account in formal action theories up to now—can now come into play. In fact, the constitution link between a culminated process and its associated activity may help in practical reasoning, something action theories are used for. We pointed out that OntoSTIT+ allows for different tokens of the same basic culminated process type to be constituted by action tokens of different activity types. The choice of the constituting activity actually corresponds to the choice of the way or manner of acting.

OntoSTIT+ can also be seen as a rich ontology of time and action to be used in formal semantics for the interpretation of natural language sentences. Our solution of the imperfective paradox in which the logical form corresponding to progressive sentences was introduced shows the relevance of such a choice.

Future work will be dedicated to the integration of both OntoSTIT+ extensions, the present extension to aspectual classes, and the second one to mental attitudes which is also described in these proceedings [13].

Notes

[1]Although very popular and largely used, there is no complete consensus on this classification. Variations exist in the number of relevant classes, in names, as well as in definitions, which at times focus on linguistic behaviour (e.g., taking or not the progressive) and at other on semantic and ontological aspects.

[2]http://suo.ieee.org/

[3]http://www.opencyc.org/

[4]We do not want to investigate here which action types are basic and which are not. We just assume that only one basic action type applies to a given token action. So if one takes *run* to be a kind of *move*, *move* will not be a basic type.

[5]These formulas obviously are a simplification as, for instance, they do not include the contribution of the tense.

[6]We here focus on the application of the progressive to activity and accomplishment verbs, on which the imperfective paradox is built. We therefore disregard the case of those special stative verbs which do take the progressive, as *to sit*.

References

[1] N. Belnap, M. Perloff, and M. Xu. *Facing the future: agents and choices in our indeterminist world*. Oxford University Press, 2001.

[2] P. Blackburn, C. Gardent, and M. de Rijke. On rich ontologies for tense and aspect. In Jerry Seligman and Dag Westerstahl, editors, *Logic, Language and Computation, I. (CSLI Lecture Notes, 58.)*, pages 77–92. Stanford, California: Center for the Study of Language and Information, 1996.

[3] B. F. Chellas. *The logical form of imperatives*. Perry Lane Press, Stanford, CA., 1969.

[4] D. Dowty. The effects of aspectual classes on the temporal structure of discourse: semantics or pragmatics? *Linguistics and Philosophy*, 9:37–61, 1986.

[5] D. Harel, D. Kozen, and J. Tiuryn. *Dynamic Logic*. MIT Press, 2000.

[6] A. Kenny. *Action, Emotion and Will*. New York, The Humanities Press, Inc., 1963.

[7] C. Masolo, S. Borgo, A. Gangemini, N. Guarino, A. Oltramari, and L. Schneider. The WonderWeb Library of Fundational Ontologies and the DOLCE ontology. WonderWeb Deliverable D18, Final Report (vr. 1.0. 31-12-2003). Technical report, LOA-ISTC, 2003.

[8] M. Moens and M. Steedman. Temporal Ontology and Temporal Reference. *Computational Linguistics*, 14(2):15–28, 1988.

[9] A. P. D. Mourelatos. Events, processes, and states. *Linguistics and Philosophy*, 2:415–434, 1978.

[10] I. Pörn. *The Logic of Power*. Blackwell, Oxford, 1970.

[11] Raymond Reiter. *Knowledge in Action: Logical Foundations for Specifying and Implementing Dynamical Systems*. The MIT Press, 2001.

[12] N. Troquard, R. Trypuz, and L. Vieu. Towards an ontology of agency and action: From stit to ontostit+. In *Proceedings of the Fourth International Conference FOIS 2006, Baltimore, Maryland (USA), November 9-11*, pages 179–190, 2006.

[13] Robert Trypuz, Emiliano Lorini, and Laure Vieu. Solving bratman's video game puzzle in two formalisms. In *Logic and Philosophy of Knowledge, Communication and Action 2007 (LogKCA-07)*, 2007.

[14] Z. Vendler. Verbs and times. *Philosophical Review*, 46:143–160, 1957.

[15] H. J. Verkuyl. Aspectual classes and aspectual composition. *Linguistics and Philosophy*, 12(1):39–94, February 1989.