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Causatives and Mixed Aspectual Type

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1. Introduction

The core idea of algebraic approaches to aspect classification (Dowty 1979, Krifka 1989a) is to classify sentences (or their denotations) into classes such as accomplishments (atelics) and activities (telics) using semantic characterizations which refer to part-whole structure of intervals or events. The sentences in (1) are in the activity group, and the sentences in (2) are in the accomplishment group.

(1) a. Solange ran northward.
b. Solange slept.
c. Solange drank wine.
c. The room grew warmer.

(2) a. Solange ran ten blocks.
b. Solange recited Verse 1.
c. Solange drank a glass of wine.
d. The room grew 10 degrees warmer.

In the approach of Krifka (1989a), which is my starting point, tenseless sentences denote sets of events. For instance, (3)a denotes a set of events, which can be verbalized as "the set of events of Solange running". (3)b denotes another set of events, which happens to be a subset of the first one.

(3) a. Solange run.
b. Solange run northward.

Events are individuals in the model, and they are ordered by a part-whole relation $\sqsubseteq$, with $c \sqsubset d$ defined as $c \sqsubseteq d \wedge c \neq d$. It is characteristic of activity sentences that their denotations include "nested" pairs of events, which are pairs $\{c,d\}$ such that $c \sqsubset d$. For instance, suppose that one morning Solange ran northward along 10th Avenue from 23rd Street. Let m be the event of her running (on that occasion) from 23rd St. to 25th St., and let m_{24} be the event of her running (on that occasion) from 24th St. to 25th St. Then it is natural to assume models where the event m_{24} is a proper part of m ($m_{24} \sqsubset m$) and where both m_{24} and m are elements of the denotation of the tenseless clause (3)b. If so, the denotation of (3)b includes a nested pair $\{m_{24},m\}$ as a subset.

Related to the part-whole relation on events is the hypothesis that the set of events has a semi-lattice structure, with a join operation which is written $\sqcup$. A development of this idea is found in Krifka (1989a), with Krifka (1989b, 1992) covering the same ideas in shorter form. As usual in the definition of a lattice structure in terms of a partial order,

$d \sqcup e$ is defined to be the least upper bound for the set {d,e}, and such least upper bounds are assumed to exist.

To illustrate the join operation, let m_{23} be the event of Solange running from 23rd St. to 24th St. The run from 23rd St to 25th is formed as the join of the two subevents, $m=m_{23} \sqcup m_{24}$.

The semi-lattice structure is used to define *cumulativity* of predicates of events. A predicate P is cumulative iff for any c and d, if P(c) and P(d) then $P(c \sqcup d)$. For instance, let P be the denotation of (3)a, which is the set of events of Solange running. As applied to this case, the condition says that if c is an event of Solange running and d is an event of Solange running, then $c \sqcup d$ is an event of Solange running. This is certainly intuitive for contiguous events like m_{23} and m_{24}. Krifka constructs an axiomatic theory in which it is proved that the denotation of (3)a, (3)b, and a variety of other activity predicates are cumulative. Cumulativity is suggested as the best theoretical construction of the notion of activity predicate.

This theory is applied directly in the semantics of durative *for*-adverbs. As illustrated in (4) and (5), these adverbs can modify activity sentences, but not accomplishment sentences.

(4) a. Solange ran northward for five minutes.
b. Solange slept for five minutes.
c. Solange drank wine for five minutes.

(5) a. *Solange ran six blocks for five minutes.
b. ? Solange wrote a sentence on the blackboard for five minutes.
c. ? Solange drank a glass of wine for five minutes.

The constraint is imposed by putting a presupposition of cumulativity in the semantics of *for*-adverbs (Krifka 1989a, p. 167):

(6) Where P is a property of events and Q is a property of time intervals, the denotation of [P for Q]
(i) is undefined, if P is not cumulative;
(ii) is the set of events e such that P(e) and $Q(\tau(e))$, otherwise.

In the definition, a temporal phrase like *two minutes* is assumed to contribute a property of time intervals Q, the set of time intervals which are two minutes long. τ is an operator which maps an event to its temporal projection. (7) shows how this is expressed using a measure function (Krifka 1989b).

(7) $\lambda i[\mathbf{minute}(i)=2]$

This paper is concerned with applying this theory to motion verbs and their causatives, and to similar change-of-state verbs. The major concerns are (i) to derive the aspectual properties of predicates using a compositional semantics, (ii) to clarify a phenomenon of certain causatives having a mixed activity/accomplishment character, and (iii) to motivate and define a revised theoretical notion of activity. In Abusch (1985, 1986) I discussed (ii), using the framework of Dowty (1979), but the formal results were not conclusive. The present paper uses Krifka's results, which provides a framework for (i). The paper also incorporates an approach to path prepositional phrases from Cresswell (1985).

2. Motion verbs and their causatives

The predicates in (8) describe motion of the individual denoted by the subject along a path described by a prepositional phrase. In (8)a the root verb is the motion predicate, while in the remaining cases (8)b-c the root verb provides a manner of motion predication.

(8) a. The ship moved towards the reef.
b. The drums rolled onto the highway.
c. Solange's sled slid along the path.

For verbs with a manner of motion root as in (8)b-c, Levin and Rappaport (1992) suggested a representation which includes a motion predicate and a manner of motion predicate which takes its name from the root verb. I will assume that the motion predicate (which I write as **go**) takes an event and a path of motion as arguments, with **go**(e,p) understood as 'e is an event of motion along path p'.[1] If the theme of motion is added with a theta role **theme**, this gives us the representation (9)b for the path motion sentence (9)a.[2]

(9) a. A sled slid towards a ravine.
b. ∃x∃y∃e∃p[**sled**(x) ∧ **ravine**(y) ∧ **go**(e,p) ∧ **slide**(e) ∧ **theme**(e,x) ∧ **toward**(p,y)]

The manner of motion predicate is **slide**. When the root verb is the motion predicate, the representation is the same, except that the manner of motion predicate is dropped:

(10) a. A sled moved towards a ravine.
b. ∃x∃y∃e∃p[**sled**(x) ∧ **ravine**(y) ∧ **go**(e,p) ∧ **theme**(e,x) ∧ **toward**(p,y)]

As pointed out in Verkuyl (1972), path motion predicates are activities or accomplishments, depending on the path predicate. This is illustrated in (11). With the path predicate *northward*, we have an activity predicate, as indicated by compatibility with *for two minutes,* and incompatibility with *in two minutes*. With the path predicate *100 feet*, the data are reversed, showing that *roll 100 feet* is an accomplishment.

(11) a. The drum rolled northward for two minutes.
b. *The drum rolled 100 feet for two minutes.
c. *The drum rolled northward in two minutes.
d. The drum rolled 100 feet in two minutes.

For the semantic analysis of paths, I will take the approach of Cresswell (1985), who treats paths as functions from points of time to areas of space:

> Formally, it will turn out most convenient to make a path p a function from moments of time so that where t is an interval and m a moment within that interval (i.e. $m \in t$), p(m) is the space occupied by the path at m.
>
> Cresswell (1985, p.103)

The same path construction is found in Verkuyl (1978); see also Verkuyl (1993, Ch. 10).

The path construction makes it possible to define the semantics of *northward*, *100 feet*, *towards the ravine*, and similar adverbs and prepositional phrases as predicates on paths. Where p and q are two paths whose domains are contiguous intervals, one can also form the combination of the two paths (written $p \sqcup q$) as the set-theoretic union of the functions.

The aspectual dependency in (11) can now be analyzed as follows. The path predicate *northward* is cumulative, in that if p and q are contiguous paths, and each of them is directed northward, then their combination $p \sqcup q$ is also a path directed northward. To show that *roll northward* is cumulative, we need to assume that the event-predicate **roll** is cumulative, and that the relation **go** has the summativity property (12).[3]

(12) $\forall d \forall e \forall p \forall q[\mathbf{go}(d,p) \wedge \mathbf{go}(e,q) \rightarrow \mathbf{go}(d \sqcup e, p \sqcup q)]$

(12) says that if p is the path of motion for the event d, and q is the path of motion for the event e, then the path of motion for the combined event $d \sqcup e$ is the combined path $p \sqcup q$.[4] With these assumptions, one can prove that the predicate *roll northwards* is cumulative, which explains the compatibility with the *for*-durative adverb in (11)a. The proof is given in the appendix.

Next consider the transitive path motion constructions in (13). The moving object (i.e. the theme of motion, in theta-role terminology) is expressed as the object, and the subject expresses a causing event, or an individual participating in a causing event. Notice each sentence in (13) entails the corresponding intransitive sentence in (14). In a theta-role framework, this makes it natural to analyze the transitive logical form as having an additional cause theta role added as a conjunct. I will assume a theta role **cause** when the subject denotes an event and a theta role **causer** when the subject denotes an ordinary individual. This gives us the representations in (15) for the examples in (13).

(13) a. An explosion rolled a drum towards a ravine.
b. A woman rolled a drum towards a ravine.

(14) A drum rolled towards a ravine.

(15) a. $\exists d \exists x \exists y \exists e \exists p[\mathbf{explosion}(d) \wedge \mathbf{drum}(x) \wedge \mathbf{ravine}(y) \wedge \mathbf{cause}(e,d) \wedge \mathbf{go}(e,p) \wedge \mathbf{theme}(e,x) \wedge \mathbf{toward}(p,y)]$

b. $\exists z \exists x \exists y \exists e \exists p[\mathbf{woman}(z) \wedge \mathbf{drum}(x) \wedge \mathbf{ravine}(y) \wedge \mathbf{causer}(e,z) \wedge \mathbf{go}(e,p) \wedge \mathbf{theme}(e,x) \wedge \mathbf{toward}(p,y)]$

Notice that the formula **cause**(e,d) expresses a theta role of the event e; this means that it should be verbalized as “the cause of e is d” or “d causes e,” not “e causes d.”

With these representations, the valid inference from (13)a or (13)b to (14) has a simple predicate logic proof where the first and fourth conjuncts inside the existential quantifier in (15)a or (15)b are dropped, to obtain the representation of (14), which is (16).

(16) $\exists x \exists y \exists e \exists p[\mathbf{drum}(x) \wedge \mathbf{ravine}(y) \wedge \mathbf{go}(e,p) \wedge \mathbf{theme}(e,x) \wedge \mathbf{toward}(p,y)]$

In Abusch (1985), I pointed out that causatives inherit the aspectual type of their intransitive counterparts. In (17), this is illustrated with a *for*-durative adverb testing for an activity aspectual type.

(17) a. The drum rolled northward for two minutes.
b. Sandy rolled the drum northward for two minutes.
c. *The drum rolled 100 feet for two minutes.
d. *Sandy rolled the drum 100 feet for two minutes.

The analysis of this in Abusch (1985) used Lewis's (1973a,b) counterfactual analysis of the causation relation, and also built on Dowty (1979)'s application of that analysis to the semantics of natural language causatives. This led to certain difficulties and gaps in attempted proofs, due to the complexity of the counterfactual semantics. Here I will rework that analysis by treating the cause relation as a theta role, as already shown above, rather than as a relation between propositions which is defined in terms of a counterfactual. I will also adopt the strategy of hypothesizing summativity properties for theta roles, and assume that the **cause** and **causer** theta roles satisfy the summativity axioms in (18).[5]

(18) a. $\forall d \forall e \forall d' \forall e'[\mathbf{cause}(e,d) \wedge \mathbf{cause}(e'd') \rightarrow \mathbf{cause}(e \sqcup e', d \sqcup d')]$

b. $\forall x \forall e \forall x' \forall e'[\mathbf{causer}(e,x) \wedge \mathbf{causer}(e'x') \rightarrow \mathbf{cause}(e \sqcup e', x \sqcup x')]$

One can now prove that causative predicates such as those used in (13) are cumulative predicates of events. The appendix gives a predicate-logic proof of the cumulativity of *x push y northward*. Cumulativity then predicts compatibility with *for*-durative adverbs, as explained in section 1.

3. Causatives of change of state verbs

Now I want to apply the same ideas to the causatives of change-of-state verbs. As shown in (19)a and (20)a, certain intransitive change of state verbs have activity readings.[6] Examples (19)b and (20)b show that the corresponding causatives also have activity readings.

(19) a. The image changed for two minutes.
b. The technician changed the image for two minutes.
(20) a. The room temperature increased for two minutes.
b. The open flame increased the room temperature for two minutes.

In Abusch (1985), following a suggestion of Dowty (1979, p. 90), I developed an approach to these activity readings which was based on the vagueness of predicates such as *dark*. It relied on quantification over resolutions of the vagueness of the predicate, inside the scope of the *for*-durative adverb. It now seems to me that this analysis is not plausible for the full variety of predicates, because *change* and *increase*, for instance, are not vague. Here I will employ an analysis which is based on the treatment of motion predicates in the previous section.

The verbs *change*, *increase*, and *darken* do not describe ordinary physical motion. However, dimensions like temperature and darkness can be regarded as one-dimensional spaces, and color and the distribution of colors in the pixels of a computer screen can be regarded as multidimensional spaces. Change of state verbs can then be treated as describing motion in these abstract spaces. This allows us to apply Cresswell's construction, where a path is a function from moments in an interval to positions in a space, and introduce paths in the logical forms of change predicates. (21)b is directly based on the motion representation (9). For simplicity, I represent *the temperature$_3$* with a free variable x_3.

(21) a. The temperature$_3$ increased gradually.

b. $\exists e \exists p[\mathbf{go}(e,p) \wedge \mathbf{increase}(e) \wedge \mathbf{theme}(e,x_3) \wedge \mathbf{gradual}(p)]$

c. $\exists e \exists p[\mathbf{go}(e,p) \wedge \mathbf{theme}(e,x_3) \wedge \mathbf{increase}(p) \wedge \mathbf{gradual}(p)]$

The adverb *gradual* is analyzed as a predicate on the path, analogous to the path predicate **toward** in (9). In (21)b, **increase** is a predicate on the event, but it is semantically natural to treat it as a predicate on the path instead, as shown in (21)c.

If we assume such logical forms for change predicates, we can apply the analysis of the aspectual type of motion predicates with no modification at all, except for the range of the path functions (i.e. one of the abstract spaces, instead of ordinary physical space). Cumulativity of the predicate *increase gradually* follows from the assumption that the one-place predicates **increase** and **gradual** are cumulative, and the two-place relations **go** and **path** are summative. To show that the transitive predicates used in (19)b and (20)b are cumulative, as before we need to assume that the **cause** theta role is summative.

A recent analysis of incremental-change verbs such as *increase*, *rise*, and *darken* is given by Hay, Kennedy, and Levin (1999). Instead of basing the representation of these verbs on path motion, their analysis uses logical forms which represent degrees.

4. Initiation scenarios

I have outlined an analysis of the motion and change verbs and their causatives which explains the aspectual type of the non-causative verbs, and the fact that the aspectual type is inherited by the causative form. The analysis also captures the fact that the causative forms entail corresponding non-causative forms.

But the last advantage is accompanied by an oddity. The reason that (23)a entails (22)a on my analysis is that the set of events (23)b is a subset of the set of events (22)b. In other words, any event of her rolling it northward is an event of it rolling northward. Similarly, the reason that (25)a entails (24)a is that (25)b is a subset of (24)b: any event of the technician changing the image is an event of the image changing. The analysis identifies a causation-of-motion or causation-of-change event with a motion/change event.

(22) a. it_2 rolled northward

b. . $\lambda e \exists p[\textbf{go}(e,p) \wedge \textbf{roll}(e) \wedge \textbf{theme}(e,x_2) \wedge \textbf{path}(e,p) \wedge \textbf{northward}(p)]$

(23) a. she_3 rolled it_2 northward

b. $\lambda e \exists p[\textbf{go}(e,p) \wedge \textbf{roll}(e) \wedge \textbf{causer}(e,x_3) \wedge \textbf{theme}(e,x_2) \wedge \textbf{path}(e,p) \wedge \textbf{northward}(p)]$

(24) a. it_2 changed

b. $\lambda e \exists p[\textbf{go}(e,p) \wedge \textbf{theme}(e,x_2) \wedge \textbf{change}(p)]$

(25) a. he_3 changed it_2

b. $\lambda e \exists p[\textbf{go}(e,p) \wedge \textbf{causer}(e,x_3) \wedge \textbf{theme}(e,x_2) \wedge \textbf{change}(p)]$

This identification is not obviously unsatisfactory, but it does place constraints on the kind of event models we can work with. In particular, if one thinks that the set of participants in the event should be uniquely recoverable from the token event, then there is a problem. The technician should be a participant in an event of the technician changing the image (i.e. an event in the extension of *the technician change the image*), but not in an event of the image changing (i.e. an event in the extension of *the image change*), and so the two events must be different.

The worry about the identification of causative and non-causative events can be sharpened into an actual defect by considering modification by time adverbs. It is standardly assumed that *in*-durative adverbs measure the temporal extent of accomplishments. If causative events are identified with non-causative events, then there can be no difference in temporal extents. The examples (26)-(27) show that this is potentially problematic.

(26) a. The temperature changed by five degrees in ten minutes.

b. The super changed the temperature by five degrees in ten minutes.

(27) a. The temperature changed by five degrees in twenty minutes.

b. The super changed the temperature by five degrees in twenty minutes.

Suppose your office is cold, and you ask the super to fix the problem. Knowing exactly what to do, he sets the thermostat in a certain way, releases air from valves in the radiators, and performs other heating-technical manipulations. In the first ten minutes that he is working, there is no change in the room temperature. Then as he continues to work for another ten minutes, the temperature goes up five degrees. Which of the sentences in (26)-(27) is true in this situation? (26)a is clearly true. (26)b seems false, because it took the super twenty minutes to do the job. (27)a seems either false, or uninformative by comparison with (26)a. (27)b is true. These data suggest that the change event should be distinguished from the causation-of-change event, so that they can have different temporal measures.

Here is another scenario. Consider a contest (a Scottish traditional sport) in which the participants are supposed to roll a large tree trunk down a hill as far as possible and in as little time as possible. After the start pistol is fired, this can be done by just pushing it steadily with one's body, or by constructing elaborate systems of poles and wedges at the top of the hill which give the log a mighty push, whereupon the log rolls along the course by itself. The sentence (28)a is non-specific about whether Cyrus followed the steady-pushing strategy, or the initiation strategy in which all his effort is concentrated at the start. The sentence can be true in either case.

(28) a. Cyrus rolled the log_3 40 feet.

b. $\exists e \exists p[\mathbf{causer}(e,\mathbf{cyrus}) \wedge \mathbf{theme}(e,x_3) \wedge \mathbf{roll}(e) \wedge \mathbf{go}(e,p) \wedge \mathbf{foot}(p)=40]$

(28)b gives a representation for (28)a which includes a measure function on the path, capturing the modifier *40 feet*. (29)a is the intransitive counterpart of (28)a, and (29)b is its event-semantic representation.

(29) a. The log_3 rolled 40 feet.

b. $\exists e \exists p[\mathbf{theme}(e,x_3) \wedge \mathbf{roll}(e) \wedge \mathbf{go}(e,p) \wedge \mathbf{foot}(p)=40]$

Consider an occasion where Cyrus used the initiation strategy: he spent 100 seconds getting the log moving, and then it moved without his intervention for 50 seconds. Which of the sentences in (30)-(31) are true?

(30) a. The log rolled 40 feet in 50 seconds.
b. Cyrus rolled the log 40 feet in 50 seconds.

(31) a. The log rolled 40 feet in 150 seconds.
b. Cyrus rolled the log 40 feet in 150 seconds.

(32) a. The log rolled 40 feet in 100 seconds.
b. Cyrus rolled the log 40 feet in 100 seconds.

Of the intransitive sentences, (30)a is clearly true. (31)a is either false or uninformative relative to (30)a. (32)a strikes me as false, or uninformative and oddly arbitrary. Of the transitive sentences, I think one can think of both (31)b and (32)b as true. (30)b seems false to me, though the intuition isn't entirely clear. Some of these intuitions are not entirely clear or systematic; for instance a reviewer is not sure that (30)b should be called false. But taking (30)-(32) together, it is clear and systematic that there are differences in truth value or status between the a. examples and the corresponding b. examples. This is unexplained on a theory which identifies the rolling event with the causation-of-rolling event, because on such a theory the temporal extent of the rolling event and the causation-of-rolling event must be the same.[7]

Similar data for frame temporal adverbs were discussed in Abusch (1985). When a frame adverb like *on Sunday* modifies a clause with causative meaning, both the causing activity and the change must fall within the frame picked out by the adverb in order for the sentence to be true. Assume that (33)a,b are to describe a scenario where John killed Slinky (who was a snake) by shooting. John's shooting is the causing event, and Slinky's dying is the change of state event.

(33) a. John killed Slinky on Saturday.
b. John killed Slinky on Sunday.

b. John killed Slinky on the weekend.

Suppose the shooting occurred on Saturday, and the resulting death on Sunday. (33)c is an adequate description of the scenario, but (33)a and (33)b are not. This can be attributed to a requirement that both the cause and effect events fall within the interval designated by the frame adverb. This falls out if *kill* is given a causative semantics, with a killing event composed of a cause d and an effect e, because if d⊔e falls within a given period, than so do d and e individually.

These data demonstrate a problem with identifying causation of motion/change events with motion/change events. The problem with the representation is that the causation predicate is treated as an intersective modifier of the change/motion predicate, rather than as an operator which introduces a new causative event.

A definition in Dowty (1979) is relevant here. Although he doesn't discuss examples like (30)-(33), the definition he provides for his cause operator in the fragment at the end of his book (1979, rule 15, p. 353) covers such cases. Dowty's CAUSE operator is analyzed in terms of Lewis's definitions of causal dependence, which is defined in terms of counterfactuals. It is Dowty's temporal addition to the definition of [φ CAUSE ψ] which is relevant to my discussion. The CAUSE operator is a bi-sentential operator where φ is a proposition describing the cause, and ψ is a proposition describing the result. The definition requires that if [φ CAUSE ψ] is true at an interval i, then φ is true at some subinterval of i, and ψ is also true at some subinterval of i. This covers the frame adverb data (33), and also the *in*-adverb data (30)-(32).

Adapting Dowty's subinterval conditions to event-semantic terms, one could require that a motion-causation event e should have a causing event d and a motion event m as subparts. I will go a bit further than this, and say that the complex event is the join of the two constituent events. The representation is exemplified in (34)b, which is the property of events denoted by the tenseless clause (34)a. The event variable d designates the causing event and the event variable m designates the motion event; d causes m, and the causative event e is stipulated to be the join of d and m.

(34) a. A woman push a sled northward.

b. λe∃x∃y∃d∃m∃p [**woman**(x) ∧ **sled**(y) ∧ e=d⊔m ∧ **cause**(d,m) ∧ **push**(d,x,y) ∧ **go**(m,y,p) ∧ **northward**(p)]

Here I have also dropped theta-role theory, and replaced it with a representation which includes three-place relations. The formula **push**(d,x,y) is understood as 'd is an event of x pushing at y' and the formula **go**(m,y,p) is understood as 'm is an event of y moving along path p'. Notice also that the agent x is not a direct argument of a cause relation. Instead x is an argument of the root relation **push**, and the event argument of **push** is also an argument of **cause**. I also changed the order of arguments of **cause**, so that **cause**(d,m) is read as "d causes m".

This representation addresses the problems with *in*-durative and frame adverbs. When an *in*-durative adverb modifies (34)a, it will measure the size of the complex event corresponding to the variable e, rather than the motion event m. Let's go back to the example scenarios. In the log-rolling scenario, (31)b is predicted to be the most accurate description out of the three causative options (30)b, (31)b, and (32)b. In the temperature scenario, (27)b is predicted to be more accurate than (26)b. This agrees much better with intuitions than the single-event semantics.

Does the new causative semantics have the right aspectual properties? We need to show that it predicts the interaction between path predications and aspectual types, and that the aspectual type of a non-causative is inherited by the causative. For reasons of space, I will not cover all the individual cases. Instead, the appendix gives a proof in the multiple-event causative semantics that *x push y northward* is cumulative.

5. Mixed aspectual type

Let's look at a variant of the temperature scenario. Imagine a computer-hacking contest where the contestants are supposed to change the image on a computer screen on the other side of the country in as little time as possible, by executing commands, guessing passwords, releasing destructive worms, or whatever. Any change at all on the target screen counts as success. Sentence (35) can describe a successful round of the contest.

(35) Cyrus changed the image in 16½ minutes.

This hacking-scenario is like the earlier initiation scenarios, except that the motion/change event is very short. Cyrus spends nearly all of the 16½ minutes on his hacking activity, and at the end, there is a short event of the screen changing. This is just a variation in the temporal size of the causing and motion/change events, so it is not surprising that (35) falls under the multiple-event causative semantics. A model where it is true will contain an event d of which Cyrus is the agent (this is his typing and programming activity) and an event m which is an event of the screen changing, with m caused by d and the combined event d⊔m having a temporal extent of 16½ minutes. These constraints are stated in (36), where y corresponds to the image.

(36) $e = d \sqcup m \wedge \mathbf{cause}(d,m) \wedge \mathbf{agent}(d,Cyrus) \wedge \mathbf{go}(m,y,p) \wedge \mathbf{change}(p) \wedge \mathbf{minute}(e) = 16½$

(35) has the syntactic structure (37)a, with the *in*-adverb modifying the tenseless sentence (37)b. This tenseless sentence denotes the property of events (37)c. In the previous section, I said that properties of events named by lambda-expressions with this syntactic form are cumulative; so (37)c is cumulative. On the theory of durative adverbs we are currently assuming, it follows that the modifier could be a *for*-adverb rather than an *in*-adverb. The reason is that, on our assumptions, *for*-adverbs denote functions which are defined exactly on the cumulative predicates of events.

(37) a. [Past [[Cyrus change the image] [in 16½ minutes]]]
b. Cyrus change the image.
c. $\lambda e \exists d \exists m \exists p[e = d \sqcup m \wedge \mathbf{cause}(d,m) \wedge \mathbf{agent}(d,Cyrus) \wedge \mathbf{go}(m,y,p) \wedge \mathbf{change}(p)]$

But in fact, a version of (35) with a *for*-adverb is odd in this scenario:

(38) #Cyrus changed the image for 16½ minutes.

This problem is recorded in (39).

(39) Problem 1

In certain scenarios*,* *for*-durative adverbs can not modify predicates of events which are cumulative according to the multiple-event causative semantics.

Here is an elaboration of the hacking scenario. Suppose that after taking control of the trans-continental computer, changing the image, and thereby winning the round, Cyrus can change the image continuously by moving his mouse around. After winning, he does this for five minutes, as a kind of victory lap. This is described by (40).

(40) After winning, Cyrus changed the image for five minutes, to celebrate.

Here we do find the tenseless sentence (37)b being modified by a *for*-adverb. To construct a model for this example, suppose that during the five-minute celebratory interval, Cyrus makes small mouse motions $d_1,\ldots,d_n$, with each d_i causing a corresponding image change m_i. For any i we have:

$$\exists p_i[\mathbf{agent}(d_i,\mathbf{Cyrus}) \wedge \mathbf{cause}(d_i,m_i) \wedge \mathbf{go}(m_i,y,p_i) \wedge \mathbf{change}(p_i)].$$

In other words for each i, $d_i \sqcup m_i$ is in the set of events (37)c. Using cumulativity, we can establish that the complex event $(d_1 \sqcup m_1) \sqcup \ldots \sqcup (d_n \sqcup m_n)$ is also an element of the set of events (37)c. So, there is an event which has a temporal extent of five minutes and is an element of the set of events denoted by the tenseless sentence (37)b, and that set of events is cumulative. This gives us an adequate analysis of (40), on Krifka's theory (as described in Section 1) that a *for*-durative adverb is a measure modifier, with a presupposition of cumulativity. This is a good result. The problem is that, by similar reasoning, (38) should be good in the non-extended scenario.

The comparison between (38) and (40) shows that, to determine whether a *for*-adverb can be used, it is not sufficient to check general algebraic properties of the predicate (i.e. the VP meaning) such as cumulativity. Somehow, the acceptability of the *for*-adverb depends on whether particular events in the extension of the predicate have a "local" accomplishment character, or a "local" activity character. This is a second and more conceptual problem:

(41) Problem 2

Whether a *for*-adverb is usable depends on local properties of the model involving token events, not on general algebraic properties of the argument predicate of events.

The sense of "local" has to be explained, because in the theory of aspectual type I am assuming, the opposition between activities, accomplishments, and states is a classification of properties of events, not of token events. Being an activity is, precisely, something which is true of properties of events, not token events.

Is there a counterpart of Problem 2 with *in*-adverbs? Suppose we analyzed *in*-adverbs in the same way as *for*-adverbs, with a presupposition about the aspectual type of the argument, for instance non-cumulativity or non-quantization. Then there would be a similar problem, because (as a description of our scenario) sentence (42)a is good, but sentence (42)b is bad.

(42) a. Cyrus won by changing the image in 16½ minutes.
b. After winning, he changed the image in 5 minutes.

I think this contrast makes a point, though in fact Krifka (1989a) gives a different analysis of *in*-adverbs which says that *in*-adverbs merely order an event inside an interval and measures that interval, without any presupposition.

6. Non-quantized application

In the hacking scenario, there is a sense in which Cyrus's celebratory image-changing had an activity character. For any i, $d_i \sqcup m_i$ is an event of Cyrus changing the image, and so is the compound event $(d_1 \sqcup m_1) \sqcup \ldots \sqcup (d_n \sqcup m_n)$. Since $d_i \sqcup m_i$ is properly included in $(d_1 \sqcup m_1) \sqcup \ldots \sqcup (d_n \sqcup m_n)$, there is a pair of events, both of which are in the extension of *Cyrus change the image*, with one properly included in the other. As was mentioned in the introduction, this nesting of instances is characteristic of activity predicates.

In a similar way, the initial image-changing event $d \sqcup m$, which won Cyrus the round in 16½ minutes, does not have an activity character, because it includes no proper sub-events which are also events of Cyrus changing the image.

Problem 1 arises when we assume a semantics for *for*-adverbs which stipulates a presupposition of cumulativity as the aspectual constraint imposed by the adverb, with no other presupposition or entailment related to part-whole structure. Even though $d \sqcup m$ contains no proper sub-events which are events of Cyrus changing the image, it is in the extension of *Cyrus change the image*, that set is cumulative, and $d \sqcup m$ has temporal extent 16½ minutes. This predicts that (38) should be true and acceptable in the initial version of the hacking scenario (without the celebration), which it is not.

I think Problem 2 indicates that *for*-adverbs have a sub-event or sub-interval implication. This was originally proposed by Bennett and Partee (1978), and Dowty (1979) gave the following interval semantics for *for*-adverbs.[8] Note that (ii) entails that φ is true at i itself.

(43) Dowty's semantics
[φ for Q] is true with respect to the interval i iff

(i) Q(i),

(ii) for any $j \sqsubseteq i$, φ is true w.r.t. j.

Let k be the 16 ½ minute interval which covers Cyrus's hacking activity, and the image-change at the end. According to definition (43), in order for (44)a to be true with respect to k, (44)b must be true with respect to every subinterval of k which is not a point. For instance, (44)b would have to be true with respect to the first ten minutes of k. Since that ten minute interval includes no image-change, in any reasonable model (44)b is not true with respect to that ten-minute interval, and so we predict that (44)a is false. This is what we want.

(44) a. Cyrus change the image for 16 ½ minutes
b. Cyrus change the image

Notice how strong (43) is. It requires that φ is true at *every* subinterval of i which is not a point. This is perhaps already implausible in the interval semantics, and it becomes more so in the event semantics. In my model for the hacking scenario, I said that $d \sqcup m$ was an event of Cyrus changing the image. But d is a proper subevent of $d \sqcup m$, and it is reasonable to assume that d is *not* an event of Cyrus changing the image. If so, the property of events denoted by *Cyrus change the image* does not satisfy an event counterpart of the subinterval property. [9]

This example is a reason not to adopt a sub-event implication which is stated as a universal quantification of events. One alternative is to use a universal quantification over intervals, as in Dowty's definition:

(45) Universal sub-entailment stated with intervals
The event e is in the extension of [P for Q] iff
(i) e is in the extension of P,
(ii) $\tau(e)$ is in the extension of Q, and
(iii) for any subinterval j of $\tau(e)$ such that j is not a point, there is an event d such that P(d), and $\tau(d) = j$.

I prefer to investigate a weaker sub-event entailment with an existential character, rather than a universal one. Consider the definition of non-quantized application in (46). For P to NQ-apply to e, P must apply to e, and there must be some sub-event d of e such that P also applies to d.[10] Notice that in this case P has a nested pair {d,e} in its extension, something which is characteristic of activity predicates. The definition is local, because it refers to both P and a particular e.

(46) Non-quantized application
P NQ-applies to e iff
(i) P(e) and
(ii) for some d, $d \sqsubseteq e$ and P(d)

The next step is to incorporate non-quantized application into the semantics of for-adverbials. One possibility is to keep the cumulativity presupposition of Krifka's definition (6), while replacing ordinary application with NQ-application.

(47) Semantics of *for* with cumulativity presupposition and existential sub-event entailment.
[[P for Q]] presupposes that P is cumulative, and is true of e iff
(i) Q(τ(e)) and
(ii) P NQ-applies to e.

According to (47), an event e in the extension of *Cyrus change the image for 15 minutes* has a proper sub-event d which is in the extension of *Cyrus change the image*. This does not hold for d⊔m in the hacking scenario, so we capture the fact that (38) is not true in that scenario.

I have the feeling that (47) is a redundant mixture of two analyses, because the cumulativity presupposition and the sub-event entailment are similar aspectual conditions. This suggests the possibility of removing the cumulativity presupposition, to eliminate the redundancy. I think this is attractive, because in some cases cumulativity seems unmotivated. Consider an event d of Solange walking along 10^{th} Avenue from 23^{rd} St to 42^{nd} St. in 1987, and another event e of Solange walking along the 2^{nd} floor hallway of Morrill Hall from the Linguistics office to the Russian office in 2004. To someone who knows the geographical facts, it is natural to assume models in which d and e are each in the extension of *Solange walk northward*. A cumulativity condition on the extension of *Solange walk northward* forces us to assume models where the complex event *d⊔e* is also in the extension of *Solange walk northward*, even though d and e are separated by 17 years, and by 200 miles in the East-West direction.[11] I think there is no motivation for this, except for the desire to make the extension of *Solange walk northward* cumulative, in order to agree with the cumulativity theory of activityhood.

(48) is a version of (47) with the cumulativity presupposition dropped.

(48) Semantics of *for* with existential sub-event entailment.
[[P for Q]] is true of e iff
(i) Q(τ(e)) and
(ii) P NQ-applies to e.

(49) Cyrus changed the image for 16½ minutes.

Let us look at the application of (47) and (48) to (49). If as I have been assuming the denotation of *Cyrus change the image* is cumulative, the cumulativity presupposition in (47) is satisfied. The sub-event entailment present in both (47) and (48) fails, because there is no sub-event of d⊔m which is also an event of Cyrus changing the image. In other words, the denotation of *Cyrus change the image* does not NQ-apply to d⊔m, and so it is predicted that (49) is false, whether (47) or (48) is used as the semantics of *for*.

Notice that, even if *for* has a cumulativity presupposition, (49) does not come out as a presupposition failure, because (on my assumptions) the argument predicate is cumulative. This actually seems satisfactory, because the negated sentece (50) strikes me as true, confirming the hypothesis that (49) is false.

(50) (On that occasion) Cyrus didn't change the image for 16 ½ minutes.

In my analysis, stating the sub-event implication as a presupposition instead of as an entailment is hardly a significant option, because the event argument gets existentially quantified by the semantics of tense. This makes it difficult to satisfy the presupposition, except by locally accommodating it.[12]

The problem or possible problem with the presupposition-less definition (48) comes with straightforward accomplishments. (51)a is a standard accomplishment clause. Both the positive and negative sentences with the modifier *for 10 minutes* are bad.

(51) a. Cyrus type 10,000 key strokes.
b. ?? (On that occasion) Cyrus typed 10,000 key strokes for 10 minutes.
c. ?? (On that occasion) Cyrus didn't type 10,000 key strokes for 10 minutes.

I have to say that this is because the sub-event entailment fails regardless of the particular circumstances, because *Cyrus type 10,000 key strokes* is necessarily quantized. If follows that the positive sentence is necessarily true, and the negative sentence is necessarily false. On this story, the oddity of (51)b and (51)c is caused by necessary uninformativeness of the statements. I don't know if having to make this analytical move is an disadvantage of the analysis (48), or an interesting consequence which tells us something about possible semantic/pragmatic sources of unacceptability.

Either of the definitions (47)-(48) solves Problem 1 by incorporating a sub-event entailment into the semantics of *for*, instead of (or in addition to) the cumulativity presupposition. What about Problem 2, which is the problem of the acceptability of *for*-adverbs being sensitive to local properties of models, rather than just general algebraic properties such as cumulativity? As a matter of technical detail, this problem is solved also, because the sub-event entailment is imposed for a particular event, not as a general algebraic constraint on the argument of the *for*-adverbial.

Here is a more conceptual and general version of Problem 2. In talking about algebraic approaches to aspect such as Dowty (1979) and Krifka (1989)a,b we are used to thinking about the theories as providing us with a classification of properties of events or intervals into activity properties, accomplishment properties, and stative properties. We are used to thinking of data regarding *for*-adverbs and *in*-adverbs as being reduced to this classification. This way of talking and thinking no longer seems totally appropriate, because it seems that certain change-motion causatives have mixed properties of activities and accomplishments, in a way which is sensitive to properties of individual token events.

One option for a response is the following. After trying out a variety of possibilities, researchers on aspect have discovered that cumulativity of properties of events is the best reasonably simple theoretical reconstruction of the notion of "activity" we originally abstracted from a group of empirical tests. Our linguistic analysis indicates that the property of events denoted by *Cyrus change the image* is a cumulative property of events. Therefore it is an activity property, in the theoretical sense we have decided to adopt.

The unacceptabily or falsity of (38) as a description of certain scenarios happens to have to do with part-whole relations between events. But it does not indicate that *Cyrus change the image* does not denote an activity property. Instead, the unacceptability (or rather falsity) comes from an implication of *for*-adverbs which is independent of the activity/accomplishment classification.

This response separates the semantic theory of activityhood from one of its main empirical motivations. Certainly, one of the main things a theory of aspectual type as applied to English is supposed to accomplish is to account for compatibility of durative adverbs with verbal predicates. Ideally, a theoretical notion of activity predication should cover all cases of this.

Another response is to adopt an alternative theoretical definition of activityhood which refers to individual events, in addition to properties of events. NQ-application is such a notion, and it (instead of cumulativity) can be hypothesized as the best theoretical construction of activityhood. The major difference from standard algebraic aspect classifications is that in hypothesizing NQ-application as the theory of activityhood, we are classifying predications P(e), not properties P.

7. Divisive-cumulative application

I have some concern that NQ-application is too weak as an aspectual condition for *for*-durative adverbs. I think there might be predications P(e) which have an accomplishment-like character by linguistic criteria, but which nevertheless are non-quantized applications because e has a subevent in the extension of P, for reasons independent of P really being an activity predicate.

Here is an example given by Mats Rooth. In third grade, as part of an education in the new math, he learned a method for division which (in contrast to the familiar long-division algorithm) allows the user to make numerous free choices in how to proceed, while still being a correct division algorithm. The algorithm in part involves solving division problems as sub-problems of division problems. For instance in computing the quotient 125 / 5 = 25 one might (or might not) compute a quotient 25 / 5 = 5. It is natural to say that this maps onto the part-whole relation on events, so that a model for such a computation would contain an event e of dividing 125 by 5, which has a proper sub-event d of dividing 25 by 5. This configuration is summarized in (52).

(52) e: event of John dividing 125 by 5

$d \sqsubset e$

d: event of John dividing 25 by 5

The choices in the algorithm are so free that, in principle, it would be possible that in computing the quotient 91 / 7 = 13, John computed the same quotient 91 / 7 = 13 as a sub-problem. A model for this scenario has the following events and relations:

(53) e: event of John dividing 91 by 7

$d \sqsubset e$

d: event of John dividing 91 by 7

The events e and d are different events; for instance they differ in that the temporal projection of d (say 20 seconds) is shorter than the temporal projection of e (which I will assume is 160 seconds). The computation d should be thought of as just another sub-problem which is involved in the computation e. It might be that John did not notice he was solving the same problem twice. Or maybe he wanted to demonstrate his understanding of the new division method by performing an intentionally complex computation.

In this scenario, the free choices allowed in the new division algorithm have a role. The event d need not have a proper subevent which is also an event of dividing 97 by 7, because in the new division method, there are many ways to compute this quotient. So there is no problem of an infinite regress.

Let P be the property of events denoted by the clause (54). P NQ-applies to e in (53), because d satisfies the sub-event entailment. In other words, according to the analysis using NQ-application, the predication P(e) has an activity character. And yet, intuitively, the scenario does not license sentence (55)a. Instead, the sentence (55)b with an in-adverbial is appropriate, indicating that the predication P(e) has an accomplishment character.

(54) John divide 91 by 7.
(55) a. ?? John divided 91 by 7 for 160 seconds.
b. John divided 91 by 7 in 160 seconds.

The analysis (48) predicts that (54)a is a true description of the scenario (53), with d satisfying the sub-event entailment of *for 160 seconds*.

This example suggests that, if one wants to leave out the cumulativity presupposition in the semantics of *for*, the sub-event implication has to be strengthened somehow. As a matter of theoretical intuition, I think the event e in (53) does not qualify as an activity instance of *John divide 91 by 7*, because there is only one sub-event which is also in the extension of the predicate, and because the big event e can not be formed as a sum of events which are also in the extension of the event predicate.

I will explore the hypothesis that in an activity predication P(e), a version of cumulativity is in fact in effect, restricted to a group of subevents of e. (56) is a definition of *divisive-cumulative* application which says that P is cumulative for a set A of subevents of e. Cumulativity is however restricted to temporally contiguous events, by means of the overlap condition in clause (iii). The subset of A which is summed is described as the set of events which overlap the interval i, capturing temporal contiguity. The overlap relation is written $\circ$.

(56) Divisive-cumulative application

P DC-applies to e iff there is a set A of events such that

(i) $\bigsqcup A = e$

(ii) each event d in A is a proper sub-event of e

(iii) for any interval i such that $\exists d[d \in A \wedge \tau(d) \circ i]$,

$P(\bigsqcup\{d|\ d{\in}A \wedge \tau(d) \circ i\})$,

(iv) A has at least “several” elements.

I have in mind the following picture. There is a set A of subevents of e, say A={a,b,c}. The members of A have the property P, and so do the events which are formed by joining temporally contiguous elements of A. With A={a,b,c}, the events $a{\sqcup}b$, $b{\sqcup}c$, $a{\sqcup}c$, and $a{\sqcup}b{\sqcup}c$ can be formed as joins; let us assume that of these $a{\sqcup}c$ is not selected in (iii) because of lack of temporal contiguity. We then obtain $P(a{\sqcup}b)$, $P(b{\sqcup}c)$, and $P(a{\sqcup}b{\sqcup}c)$ by the restricted cumulativity condition. The last condition is deliberately vague: A must contain at least “several” elements. Condition (ii) rules out the trivial case of A containing e.[13]

In the new-division scenario (54), the denotation of (54) does not DC-apply to the larger event e, because e can not be formed as a join of subevents which are also in the extension of the predicate.

Because the definition of DC-application refers to an individual event, it is possible for P to DC-apply to one event e in the extension of P, but not to DC-apply to another event e’ in the extension of P. This is my analysis of the hacking scenario. The property denoted by *Cyrus change the image* DC-applies to the celebration event $(d_1{\sqcup}m_1) \sqcup \ldots \sqcup (d_n{\sqcup}m_n)$ but it does not DC-apply to the event $d{\sqcup}m$ which won the round for Cyrus. In the celebration scenario, the right value for A is $\{d_1{\sqcup}m_1,\ldots,d_n{\sqcup}m_n\}$.

DC-application is my local definition of activityhood, which refers both to a property P and an event e. It is interesting that it combines aspects of the subinterval property which was suggested by Bennett and Partee (1978), Taylor (1977), and Dowty (1979) with aspects of cumulativity, which was used by Krifka (1989a,b) as his notion of activity. The elements of A are sub-events of e, and they are required to have the property P. So there is a sub-event entailment, similar to the subinterval property. The condition (iii) is related to cumulativity in that it runs “upwards”, and (ignoring the restriction to contiguous events) it requires that the restriction of P to events generated from A is cumulative.

Definition (57) incorporates divisive-cumulative application into the semantics of *for*-adverbs.

(57) e is in the extension of [P for Q] iff
  (i) $Q(\tau(e))$ and
  (ii) P DC-applies to e.

As with NQ-application, the sub-event conditions are stated as entailments, and the example below comes out false in the winning scenario, rather than odd in some other way. Again, I think the result is satisfactory in this case.

(58) Cyrus changed the image for 16 ½ minutes (and thereby won the round).

The new division scenario and problem is related to the issue raised in Zucchi and White (1996), but I think not closely. They discuss (59)a, which seems to indicate that (59)b is an accomplishment.

(59) a. ?? John wrote a sequence for ten minutes.
b. John write a sequence.

However, they argue, an event e of John writing the sequence of letters *abcdefg* does have a proper subevent e' which is also an event of John writing a sequence, for instance the event of him writing the sequence of letters *bcde* on the same occasion. I think Zucchi and White are right that this problem should be solved in the syntax-semantics interface, essentially by giving the existential quantification wider scope than the for-adverb. As a consequence, in the compositional structure for (59)a, *for ten minutes* does not modify a predicate John-write-a-sequence incorporating an existential quantifier over sequences, or the equivalent.[14] My analysis requires the same conclusion, because John-write-a-sequence would DC-apply to the event e, so there would be no way of ruling out (59)a semantically.[15]

I suppose that if (54) was compositionally similar to the sentences in (60), Zucchi and White's analysis would apply to it. But I do not see any reason to think that (54) has an indefinite quantifier which would take scope over other operators.

(60) a. John computed a quotient of 91 and 7.
b. John made a division of 91 by 7.

8. Alternative lexical-semantic analyses

In the arguments about mixed aspectual type, the aspectual conditions associated with temporal measure adverbs, and the local character of aspectual distinctions, the lexical-semantic analysis from sections 2 and 3 is important, because it allows us to reason with an axiomatic theory in making claims about the part-whole structure in extensions of predicates. I don't think these arguments would be convincing if instead of using the axiomatic lexical-semantic theory, I had appealed to poorly-founded intuitions about what models can be like.

Could it be possible to make the same general points, using a different lexical-semantic analysis of motion and change verbs and their causatives? This is perfectly conceivable, and in fact this is what I tried to do in Abusch (1985), using the analyses of change verbs and causatives from Dowty (1979). As I mentioned in section 3, Dowty's analysis of process inchoatives relied on vagueness of an underlying stative predicate, such as *dark* in the case of *darken*. If one tries to apply this to the lexical material I have discussing, one has to hypothesize vague one-place predicates underlying *move* and *change*.[16] Next one would have to explain what the vagueness of these supposed one-place predicates consists in. I suspect this would involve construction some kind of hidden two-place predicate. The approach seems artificial and unpromising as a general strategy. But maybe for some verbs, the vagueness approach could be combined with the causative semantics and the general approach I have proposed here.

Perhaps more generally viable is the approach to change verbs in Hay, Kennedy, and Levin (1999), which uses an ontology of degrees. It seems conceivable that a degree analysis would be preferable to a path analysis for some verbs, and that the results obtained in sections 5-7 could be derived also in this setting. Or perhaps when one worked out degree and path analyses of the same verbs and modifiers, one would find out that the two analyses are equivalent.

In Abusch (1985a,b) I used the analysis of causative verbs from Dowty (1979), which is based on the analysis of causation and counterfactuals in Lewis (1973a,b). The cause relation in Dowty relates two propositions, rather than two events as in section 3, and is defined in terms of a counterfactual. Using these hypotheses, in Abusch (1985a) I investigated the cumulative and subinterval properties of causative predicates in relation to algebraic properties of their non-causative sources, and was able to obtain only some weak results. Though this could be a result of the complexity of the counterfactual semantics, the arguments need to be re-examined to check whether the counterfactual cause relation could be used in combination with the definition of activities suggested in section 7.

Are the results in the theory of aspect which I obtained here an argument for treating causation in lexical semantics as a relation between events, rather than a relation between propositions defined in terms of a counterfactual? Maybe yes, but it has to be admitted that the counterfactual semantics is a substantive semantics for causation, in contrast to the semantics used in this paper, which just stipulates a cause relation between events and an axiom of summativity. It is not surprising that it is easier to obtain results with the second strategy.

The idea that there is interaction between path elements and the aspect of predicates is not a new one. Some important earlier work is Verkuyl (1972, 1993) and Jackendoff (1991, 1996). The account in Jackendoff (1996) is not concerned with the aspect of causatives or with mixed aspectual type, but it has the same aims as section 2 and the appendix, since it relates aspectual properties of predicates to algebraic properties of path components in semantic representations. However, his analysis is different in substance from what has been discussed here, because he draws the distinction between processes (atelics) and accomplishments (telics) at the level of token events, rather than properties of events as in the approach assumed here (see e.g. p. 324 and p. 352 of Jackendoff (1996)). If I understand Jackendoff correctly, in his account process events have temporal projections which do not include their upper bounds. By means of a mathematical notion of continuity, it is determined that path and event components also do not include their bounds. I am skeptical about this way of making the telic/atelic distinction. I think it is an unsuccessful or at best arbitrary mathematical reconstruction of the intuition that an event in the extension of a process predicate could have extended forward in time, while remaining in the extension of the predicate (for this intuition, see Jackendoff 1996 p 307). I don't see why this should be any less true of temporally closed events or intervals than of open ones. Instead the intuition --- which I think has a real foundation --- follows from the fact that processes can have nested pairs of events or intervals in their extensions, while accomplishments do not. Extending an event forward in time produces, on the assumption that both the original event and the extended one are in the predicate extension, a pair of events in a part-whole relation which are both in the predicate extension. This could only happen for a process (i.e. atelic) predicate, on an approach which defines processhood in terms of part-whole structure in the extension of predicates.[17] This being so, it is not necessary to rely on a distinction between intervals which are closed above (i.e. contain their least upper bounds) and intervals which are open above (i.e. do not contain their least upper bounds).

Although I borrowed an analysis of paths from Cresswell (1985), I deliberately ignored some of the points Cresswell makes about events and paths, in order to work with Krifka's event analysis. Cresswell (1985) argues that if one has a semantic analysis with individuals and time intervals, paths and events can be constructed mathematically, so one does not need to represent them as individuals in the model. This conflicts with my assumption that events are individuals in the model, and possibly with the idea that event arguments are represented in syntax. It would be interesting to try to rework my analysis of motion verbs in Cresswell's framework. I think this would work for the motion predicates, but it is unclear how to proceed with the cause relation.

9. Conclusion

Here is a summary of my analysis.

(i) Intransitive motion/change verbs have a decomposed representation which includes a path variable.
(ii) It follows from algebraic assumptions about primitive relations that cumulativity of the decomposed motion/change predicate co-varies with summativity of path predications.
(iii) Causative motion/change verbs have a decomposed representation which introduces a complex event defined as the join of cause and effect events, embeds the intransitive representation, and includes a **cause** relation between the cause and effect events.
(iv) It follows from algebraic assumptions about primitive relations that the cumulativity of the causative predicate co-varies with cumulativity of the intransitive predicate.
(v) The best theoretical construction of activityhood is divisive-cumulative application, rather than cumulativity.
(vi) Certain causation of motion/change predicates sometimes apply to events divisive-cumulatively, and sometimes not. Thus they have a mixed activity/accomplishment character, sensitive to properities of a particular event.
(vii) In general, aspectual distinctions such as activity vs. accomplishment are classifications of predications P(e), rather than of properties of events P.

As mentioned in (iii) a causative motion/change event is analyzed as the join $d \sqcup m$ of a cause event d and a motion event m. When d precedes (or mostly precedes) m and $d \sqcup m$ has a substantial temporal extent, this produces predications which have accomplishment-like character. In particular, because of the sub-event entailment associated with (v), a true predication $P(d \sqcup m)$, where $Q(\tau(d \sqcup m))$, can not be extended with a *for*-durative adverb to a true predication $for(Q)(P)(d \sqcup m)$.

My most novel claims are (vi) and (vii). Some causative predicates have mixed activity/accomplishment character. They are true of some events in an activity way (i.e.

divisive-cumulatively), and of other events in a non-activity way. This was supported both empirically and by the lexical-semantic analysis of motion/change predicates and causatives. I would like to emphasize this point: I did not just say that there was empirical reason to say that event predicates such as the denotation of *Cyrus change the image* have a mixed activity/accomplishment character, I stated a lexical semantics (which I think is plausible on other grounds) which entails that they do have a mixed activity-accomplishment character.

If (vi) is correct, there is no absolute distinction between activity predicates and accomplishment predicates, contrary to what is assumed in other algebraic approaches to aspect classification, and contrary to an implicit or explicit assumption of nearly all work on aspectual classes.

Appendix

Cumulativity of *y roll northward* on theta-role semantics

1. $\lambda e \exists p[\mathbf{roll}(e) \wedge \mathbf{go}(e,p) \wedge \mathbf{theme}(e,y) \wedge \mathbf{northward}(p)](c)$ premise
2. $\lambda e \exists p[\mathbf{roll}(e) \wedge \mathbf{go}(e,p) \wedge \mathbf{theme}(e,y) \wedge \mathbf{northward}(p)](d)$ premise
3. $\exists p[\mathbf{roll}(c) \wedge \mathbf{go}(c,p) \wedge \mathbf{theme}(c,y) \wedge \mathbf{northward}(p)]$ 1, λ-conversion
4. $\exists p[\mathbf{roll}(d) \wedge \mathbf{go}(d,p) \wedge \mathbf{theme}(d,y) \wedge \mathbf{northward}(p)]$ 1, λ-conversion
5. ~~Show~~: $\exists p[\mathbf{roll}(c \sqcup d) \wedge \mathbf{go}(c \sqcup d,p) \wedge \mathbf{theme}(c \sqcup d,y) \wedge \mathbf{northward}(p)]$ $\exists$D
6. | $\mathbf{roll}(c) \wedge \mathbf{go}(c,p_1) \wedge \mathbf{theme}(c,y) \wedge \mathbf{northward}(p_1)$ ass. 3
7. | $\mathbf{roll}(c)$ 6, $\wedge$E
8. | $\mathbf{go}(c,p_1)$ 6, $\wedge$E
9. | $\mathbf{theme}(c,y)$ 6, $\wedge$E
10. | $\mathbf{northward}(p_1)$ 6, $\wedge$E
11. | ~~Show~~: $\exists p[\mathbf{roll}(c \sqcup d) \wedge \mathbf{go}(c \sqcup d,p) \wedge \mathbf{theme}(c \sqcup d,y) \wedge \mathbf{northward}(p)]$ $\exists$D
12. | | $\mathbf{roll}(d) \wedge \mathbf{go}(d,p_2) \wedge \mathbf{theme}(d,y) \wedge \mathbf{northward}(p_2)$ ass. 4
13. | | $\mathbf{roll}(d)$ 12, $\wedge$E
14. | | $\mathbf{go}(d,p_2)$ 12, $\wedge$E
15. | | $\mathbf{theme}(d,y)$ 12, $\wedge$E
16. | | $\mathbf{northward}(p_2)$ 12, $\wedge$E
17. | | $\mathbf{roll}(c \sqcup d)$ 7, 13, cumulativity of **roll**
18. | | $\mathbf{go}(c \sqcup d, p_1 \sqcup p_2)$ 8, 14, summativity of **go**
19. | | $\mathbf{theme}(c \sqcup d,y)$ 9, 15, 1-cumulativity of **theme**
20. | | $\mathbf{northward}(p_1 \sqcup p_2)$ 10, 16, cumulativity of **northward**
21. | | $\mathbf{roll}(c \sqcup d) \wedge \mathbf{go}(c \sqcup d, p_1 \sqcup p_2) \wedge \mathbf{theme}(c \sqcup d,y) \wedge \mathbf{northward}(p_1 \sqcup p_2)$ 17-20, $\wedge$I
22. $\lambda e \exists p[\mathbf{roll}(e) \wedge \mathbf{go}(e,p) \wedge \mathbf{theme}(e,y) \wedge \mathbf{northward}(p)](c \sqcup d)$ 5, λ-conversion

Cumulativity of *x push y northward* on theta-role semantics

1. λe∃p[**push**(e) ∧ **causer**(e,x) ∧ **go**(e,p) ∧ **theme**(e,y) ∧ **northward**(p)](c) premise
2. λe∃p[**push**(e) ∧ **causer**(e,x) ∧ **go**(e,p) ∧ **theme**(e,y) ∧ **northward**(p)](d) premise
3. ∃p[**push**(c) ∧ **causer**(c,x) ∧ **go**(c,p) ∧ **theme**(c,y) ∧ **northward**(p)] 1, λ-conversion
4. ∃p[**push**(d) ∧ **causer**(d,x) ∧ **go**(d,p) ∧ **theme**(d,y) ∧ **northward**(p)] 2, λ-conversion
5. ~~Show~~: ∃p[**push**(c⊔d)∧ **causer**(c⊔d,x) ∧ **go**(c⊔d,p) ∧ **theme**(c⊔d,y) ∧ **northward**(p)] ∃D
6. | **push**(c) ∧ **causer**(c,x) ∧ **go**(c,p_1) ∧ **theme**(c,y) ∧ **northward**(p_1) ass. 3
7. | **push**(c) 6, ∧E
8. | **causer**(c,x) 6, ∧E
9. | **go**(c,p_1) 6, ∧E
10. | **theme**(c,y) 6, ∧E
11. | **northward**(p_1) 6, ∧E
12. | ~~Show~~: ∃p[**push**(c⊔d)∧ **causer**(c⊔d,x) ∧ **go**(c⊔d,p) ∧ **theme**(c⊔d,y) ∧ **northward**(p)] ∃D
13. | | **push**(d) ∧ **causer**(d,x) ∧ **go**(d,p_2) ∧ **theme**(d,y) ∧ **northward**(p_2) ass. 4
14. | | **push**(d) 13, ∧E
15. | | **causer**(d,x) 13, ∧E
16. | | **go**(d,p_2) 13, ∧E
17. | | **theme**(d,y) 13, ∧E
18. | | **northward**(p_2) 13, ∧E
19. | | **push**(c⊔d) 7,14, cumulativity of **push**
20. | | **causer**(c⊔d,x) 8,15, 1-cumulativity of **causer**
21. | | **go**(c⊔d,p_1⊔p_2) 9,16, cumulativity of **go**
22. | | **theme**(c⊔d,y) 17,22, 1-cumulativity of **theme**
23. | | **northward**(p_2⊔p_2) 11,23, cumulativity of **northward**
24. | | **push**(c⊔d) ∧ **causer**(c⊔d,x) ∧ **go**(c⊔d,p_1⊔p_2) ∧**theme**(c⊔d,y) ∧ **northward**(p_2⊔p_2)
    19-23, ∧I
25. | | ∃p[**push**(c⊔d)∧ **causer**(c⊔d,x) ∧ **go**(c⊔d,p) ∧ **theme**(c⊔d,y) ∧ **northward**(p)]
    24, ∃I
26. λe∃p[**push**(e)∧ **causer**(e,x) ∧ **go**(e,p) ∧ **theme**(e,y) ∧ **northward**(p)](c⊔d)
    5, λ-conversion

Cumulativity of *x push y northward* on multiple-event causative semantics

1. $\lambda e \exists d \exists m \exists p[e=d \sqcup m \wedge \mathbf{cause}(d,m) \wedge \mathbf{push}(d,x,y) \wedge \mathbf{go}(m,y,p) \wedge \mathbf{northward}(p)](e_1)$ *premise*
2. $\lambda e \exists d \exists m \exists p[e=d \sqcup m \wedge \mathbf{cause}(d,m) \wedge \mathbf{push}(d,x,y) \wedge \mathbf{go}(m,y,p) \wedge \mathbf{northward}(p)](e_2)$ *premise*
3. $\exists d \exists m \exists p[e_1=d \sqcup m \wedge \mathbf{cause}(d,m) \wedge \mathbf{push}(d,x,y) \wedge \mathbf{go}(m,y,p) \wedge \mathbf{northward}(p)]$ 1, λ-conversion
4. $\exists d \exists m \exists p[e_2=d \sqcup m \wedge \mathbf{cause}(d,m) \wedge \mathbf{push}(d,x,y) \wedge \mathbf{go}(m,y,p) \wedge \mathbf{northward}(p)]$ 2, λ-conversion
5. ~~Show~~: $\exists d \exists m \exists p[e_1 \sqcup e_2 = d \sqcup m \wedge \mathbf{cause}(d,m) \wedge \mathbf{push}(d,x,y) \wedge \mathbf{go}(m,y,p) \wedge \mathbf{northward}(p)]$ $\exists$D
6. | $e_1=d_1 \sqcup m_1 \wedge \mathbf{cause}(d_1,m_1) \wedge \mathbf{push}(d_1,x,y) \wedge \mathbf{go}(m_1,y,p_1) \wedge \mathbf{northward}(p_1)$ ass. 3
7. | $e_1=d_1 \sqcup m_1$ 6 $\wedge$E
8. | $\mathbf{cause}(d_1,m_1)$ 6 $\wedge$E
9. | $\mathbf{push}(d_1,x,y)$ 6 $\wedge$E
10. | $\mathbf{go}(m_1,y,p_1)$ 6 $\wedge$E
11. | $\mathbf{northward}(p_1)$ 6 $\wedge$E
12. | ~~Show~~: $\exists d \exists m \exists p[e_1 \sqcup e_2 = d \sqcup m \wedge \mathbf{cause}(d,m) \wedge \mathbf{push}(d,x,y) \wedge \mathbf{go}(m,y,p) \wedge \mathbf{northward}(p)]$ $\exists$D
13. | | $e_2=d_2 \sqcup m_2 \wedge \mathbf{cause}(d_2,m_2) \wedge \mathbf{push}(d_2,x,y) \wedge \mathbf{go}(m_2,y,p_2) \wedge \mathbf{northward}(p_2)$ ass. 4
14. | | $e_2=d_2 \sqcup m_2$ 13 $\wedge$E
15. | | $\mathbf{cause}(d_2,m_2)$ 13 $\wedge$E
16. | | $\mathbf{push}(d_2,x,y)$ 13 $\wedge$E
17. | | $\mathbf{go}(m_2,y,p_2)$ 13 $\wedge$E
18. | | $\mathbf{northward}(p_2)$ 13 $\wedge$E
19. | | $\mathbf{cause}(d_1 \sqcup d_2, m_1 \sqcup m_2)$ 8,15, **cause** is cumulative
20. | | $\mathbf{push}(d_1 \sqcup d_2,x,y)$ 9,16, **push** is 1-cumulative
21. | | $\mathbf{go}(m_1 \sqcup m_2,y,p_1 \sqcup p_2)$ 10,17, **go** is 1,3-cumulative
22. | | $\mathbf{northward}(p_1 \sqcup p_2)$ 11, 18, **northward** is cumulative
23. | | $(d_1 \sqcup m_1) \sqcup (d_2 \sqcup m_2) = (d_1 \sqcup d_2) \sqcup (m_1 \sqcup m_2)$ commutativity and associativity of $\sqcup$
24. | | $e_1 \sqcup e_2 = (d_1 \sqcup d_2) \sqcup (m_1 \sqcup m_2)$ 23, 7, 14, substitution of equals
25. | | $e_1 \sqcup e_2 = (d_1 \sqcup d_2) \sqcup (m_1 \sqcup m_2) \wedge \mathbf{cause}(d_1 \sqcup d_2, m_1 \sqcup m_2) \wedge \mathbf{push}(d_1 \sqcup d_2,x,y) \wedge$
    $\mathbf{go}(m_1 \sqcup m_2,y,p_1 \sqcup p_2) \wedge \mathbf{northward}(p_1 \sqcup p_2)$ 24,19-22 $\wedge$I
26. | | $\exists d \exists m \exists p[e_1 \sqcup e_2 = d \sqcup m \wedge \mathbf{cause}(d,m) \wedge \mathbf{push}(d,x,y) \wedge \mathbf{go}(m,y,p) \wedge \mathbf{northward}(p)$ 25, $\exists$I
27. $\lambda e \exists d \exists m \exists p[e= d \sqcup m \wedge \mathbf{cause}(d,m) \wedge \mathbf{push}(d,x,y) \wedge \mathbf{go}(m,y,p) \wedge \mathbf{northward}(p)](e_1 \sqcup e_2)$
    5, λ-conversion

Notes

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[1] Levin and Rappaport (1992) make a distinction between a predicate **go** which entails change of location, and a predicate **move** which represents movement without any necessary change in location. My **go**, since it describes path motion, agrees with theirs.

[2] Here and later on, I put examples in the simple past tense, but ignore tense in the semantics.

[3] Summativity is the two-place version of cumulativity. This could be called cumulativity as well, though in the text I follow Krifka's terminology by calling it summativity. In the appendix, I need to refer to cumulativity properties of particular argument slots, with other slots kept constant. The cumulative slots are listed as prefixes. For instance, a three-place relation is 1,3-cumulative if it obeys the axiom

$\forall x_1 \forall x_2 \forall y \forall z_1 \forall z_2[\mathbf{R}(x_1,y,z_1) \wedge \mathbf{R}(x_2,y,z_2) \rightarrow \mathbf{R}(x_1 \sqcup x_2,y,z_1 \sqcup z_2)$.

[4] This is comparable to the summativity assumption about the patient theta role of verbs like *drink* which is discussed by Krifka (1989b).

[5] Notice the similarity to the summativity axiom for the path theta role.

[6] This was pointed out by Dowty (1979). See also Abusch (1985,1986) and Hay, Kennedy and Levin (1999).

[7] A reviewer points out that the periphrastic version (i) of (30)b is fine. I think this is because a syntactic bracketing (ii) is possible here; with this syntactic structure, [in 50 seconds] measures the motion event. This is confirmed by the fact that the syntactically awkward (iii), where the adverb is higher up and so measures the causative event, seems false as a description of the scenario we are discussing.

(i) Cyrus caused the log to roll 40 feet in 50 seconds.
(ii) Cyrus caused the log [to roll 40 feet in 50 seconds].
(iii) Cyrus, in 50 seconds, caused the log to roll 40 feet.

The reviewer also raises the question of whether the periphrastic causative should have the analysis proposed later in the section, where the causation-of-motion event is the join of the cause event and the motion event. To test this, one should contrast (32)b with (iv), and (31)b with (v).

(iv) Cyrus, in 100 seconds, caused the log to roll 40 feet.
(v) Cyrus, in 150 seconds, caused the log to roll 40 feet.

An informant I checked this with thinks example (iv) is fine, indicating that the event argument of the periphrastic causative is just the cause event.

[8] Because Dowty holds that processe formulas are not true at points, I think "such that j is not a point" should be added in (ii).

[9] Two options for the sub-event property are given in (i). The first one incorporates the divisiveness axiom from Krifka (1989b). The second option restricts the universal quantification to events whose temporal extent is not a point, following (43).

(i) Universal sub-event entailment

a. P for Q = $\lambda e[P(e) \wedge Q(\tau(e)) \wedge \forall d[d \sqsubset e \rightarrow P(d)]]$

b. P for Q = $\lambda e[P(e) \wedge Q(\tau(e)) \wedge \forall d[d \sqsubset e \wedge \neg \textbf{moment}(\tau(e)) \rightarrow P(d)]]$

In the hacking celebration scenario, the denotation of *Cyrus change the image* satisfies neither version, because $(d_1 \sqcup m_1) \sqcup \ldots \sqcup (d_n \sqcup m_n)$ is in the extension, d_1 is not in the extension, d_1 is a proper part of $(d_1 \sqcup m_1) \sqcup \ldots \sqcup (d_n \sqcup m_n)$, d_1 has temporal extent greater than a point, and we want $(d_1 \sqcup m_1) \sqcup \ldots \sqcup (d_n \sqcup m_n)$ to be in the extension of *Cyrus change the image for five minutes*.

10 It might be reasonable to add the condition $\tau(d) \sqsubset \tau(e)$ to the definition of NQ-application, requiring proper containment of temporal projections, in addition to proper containment of events.

11 I do not know how close to North-South the alignment of 10th Avenue and the Morrill Hall hallway are. For the purpose of the example, I assume that the hallway has a perfect north-south alignment at longitude 77 W, and that 10th Avenue has a perfect north-south alignment at longitude 74 W. It is significant for the intuition (or rather the absence of an intuition) about $d \sqcup e$ that the hallway and the Avenue are not in one line. If you continued northward along the line of 10th Avenue, at the latitude of Ithaca you would be in the vicinity of Albany, which is 200 miles east.

12 There could not be a projected presupposition that every e in the extension of P has a sub-event which is also in the extension of P (i.e. that P is non-quantized), because this is not true of the event which won the contest for Cyrus.

13 Maybe (ii) should be strengthened. One could say that the temporal length of an element of A could be maximally 1/n of the temporal length of e, to rule out the case of one element of A constituting nearly all of e.

14 I hope I am right about Zucchi and White's analysis here. They discuss two analyses, one with an ordinary existential quantifier, and another with a variable-like indefinite, in the sense of Discourse Representation Theory. But it seems to me that also the second version solves the problem with (59) in the syntax-semantics interface, by giving the indefinite scope over the for-adverbial.

15 As pointed out by a reviewer, there is also a similarity between Zucchi and White's problem with (59)a and my problem with (38), repeated below. In both cases, a predicate which appears to be a process by semantic criteria can not combine with a for-adverb.

(i) # Cyrus changed the image for 16 ½ minutes.

But in my analysis, (i) is in fact not a process predication, namely it is not a DC-application. According to Zucchi and White, if I understand them correctly, (59)b is a process predicate by semantic criteria, but the *for*-adverb does not get scope over the existential quantification, because of rules of the syntax-semantics interface. I find this convincing, because it seems clear that (59)b would be an activity property if it were a unitary piece of meaning, on any reasonable algebraic definition of activity. If this is right, (i) and (59)a are not examples of the same problem.

[16] I guess the supposed one-place predicates would be *be located* (underlying *move*) and something like *appear* underlying the use of *change* in *the image changed*.

[17] Here I am reasoning as if the right notion of processhood is non-quantization. But I think a similar point could be made in terms of divisive cumulativity.

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