Reanalyzing the complement coercion effect through a generalized lexical semantics for aspectual verbs

Abstract: Coercion verbs have been taken to include not only aspectual verbs like *begin*, *start*, and *finish* but also psychological verbs such as *enjoy*, *endure*, and *savor* and control verbs like *try* and *attempt*. Their unifying property has been assumed to be that they select for eventive complements (e.g. *John began/enjoyed reading the book/the meeting*). On this view, the composition of an entity-denoting expression with any coercion verb obligatorily gives rise to a type-mismatch, which can only be resolved by "coercing" the entity-denoting expression into an event-denoting expression. The experimental literature has presupposed such an event-selecting lexical semantics for all coercion verbs and interpreted processing and neurological phenomena as being reflexes of entity-to-event type-shifting.

Recent evidence on the processing properties of coercion verbs however shows that when distinct semantic subclasses of coercion verbs are isolated, out of the two main subclasses (aspectual and psychological verbs), only aspectual verbs trigger the expected processing profile (Katsika et al 2012, Utt., et al., Lai et al., 2014). Crucially, these results call into question the standard account for the increased processing cost observed and in doing so they also call into question the linguistic analysis that gives rise to such an account.

To address this issue, we focus on aspectual verbs and provide a new lexical semantic analysis of aspectual verbs. On this analysis, aspectual verbs lexically select for structured individuals – entities that can be construed as one-dimensional directed path structures (Krifka 1998) in some ontological dimension. This analysis has wide empirical coverage: it accounts for the full range of complements that aspectual verbs legitimately combine with in their transitive uses, and it does so without appealing to any coercive entity-to-event type-shifting operations. Finally, the analysis allows for a simpler, conceptually grounded interpretation of the observed processing cost as being a result of exhaustive lexical retrieval (on the verb) and ambiguity resolution (on the complement).

Keywords: aspectual verbs, lexical semantics, coercion, type-shifting, psycholinguistics

1. Introduction

What are "coercion verbs" and what is the process by which these verbs compose with entity-denoting complements? In this paper, we seek to answer these questions by focusing on the distribution and interpretation of aspectual verbs, one of the main subclasses within the coercion set, amenable to semantic investigation and the semantic subclass most robustly shown to trigger the "coercion effect". We show that a closer examination of the combinatorial behavior of aspectual verbs sheds light on three related issues: (a) their under-specified lexical semantics, (b) the compositional mechanism that allows them to combine successfully with entity-denoting complements and (c) the way this mechanism translates into a testable psychological process which captures the psycholinguistic and neurolinguistic evidence that has accumulated so far in this domain. We begin by presenting aspectual verbs in the context of the coercion literature.[1]

The literature on this topic has assumed that verbs like *begin* and *enjoy* carry selectional restrictions: their complements must be eventive (e.g. *John began reading the book/the meeting*) (Pustejovsky 1991, 1995; Jackendoff 1997). Evidence in support of this restriction comes from the observation that even in sentences where the complement of a coercion verb denotes an individual of the ordinary sort, only an eventive interpretation is available. For instance, in (1a), where the complement *the book* denotes an ordinary individual, the sentence is typically interpreted as describing a situation in which some event involving the book (e.g. reading or writing) is undertaken. Similarly in (1b), the sentence is understood as describing some event involving the cake. This phenomenon has been well-studied under the term **Complement Coercion**.

(1)   a. John <u>began</u> the book.   *reading, writing*

          b. Mary <u>finished</u> the cake   *eating, making*

          c. The carpenter <u>began</u> the table.   *building*

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[1]The term **coercion** is widely used to describe diverse phenomena in which it appears that interpretations are derived despite apparent semantic incongruity or mismatch between the combining expressions. The phenomena often considered under the coercion umbrella include mass-count nominals (nominal coercion) (e.g. Pustejovsky, 1995; Michaelis, 2005; Wiese & Maling, 2005), grammatical aspect (e.g., De Swart, 1998), and aktionsart (aspectual coercion) (e.g. Michaelis, 2003, 2004; Piñango et al., 1999; Todorova et al., 2000, Piñango & Zurif 2001, Piñango, 2003; Piñango et al., 2006), and our present focus, complementation (complement coercion) (e.g. Pustejovsky, 1991, 1995; Jackendoff, 1997; McElree et al 2001; Piñango & Zurif 2001; Traxler et al 2002; Traxler et al 2005; Pickering et al 2004; McElree et al., 2006, Katsika et al 2012, Utt et al 2013, Lai et al 2014).

Observations like these have motivated a process-based account that enables the building of interpretations associated with sentences like those in (1). The idea that the compositional process associated with complement coercion verbs is computationally costly *because it requires mismatch repair operations* was introduced in McElree et al (2001), the first real-time comprehension study of the phenomenon. Following this initial connection, the general schema of the account has been presented as follows: a set of verbs in the language, "coercion verbs", selects for event-denoting complements, i.e. their arguments must be of an eventive type. When they are combined with entity-denoting expressions, which are of the type of ordinary individuals, straightforward composition via functional application fails because the selectional restrictions of the verb are not satisfied by the complement. The resulting type-mismatch is resolved by the mechanism of complement coercion, which involves a semantic shift in the type of the entity-denoting expression, allowing it to be interpreted as denoting an event instead. Thus, type-shifting lets the selectional restrictions of the verb to be satisfied, which in turn allows for meaning composition to proceed via straightforward functional application. From a processing perspective, the crucial elements of this account are: type-mismatch triggered by failure of the complement to meet the selectional restrictions of the verb, subsequent failure of straightforward compositionality, and the repair of the mismatch via type-shifting.

The implications of this analysis for our understanding of the psychological basis of meaning composition have not gone unnoticed by the neuro- and psycholinguistic community. Two main factors, one general and one more specific, give rise to this interest: The general factor is that the coercion effect affords the unique possibility of isolating purely semantic composition, i.e. meaning changing operations with no overt morpho-syntactic reflexes. Coercion phenomena imply an inherently non-homomorphic relationship between syntax and semantics, and therefore can be used to probe for purely semantic processes.

The specific factor leading to neuro/psycholinguistic interest in complement coercion has to do with the nature of the linguistic analysis described above. Formally, type-coercion is implemented as involving the insertion of a type-shifting semantic operator that repairs an otherwise uninterpretable representation. This kind of analysis has at least three properties that make it viable as a testable psychological process:

(2)   a. The intuition behind the analysis is clear and the proposal is to a large extent theory-neutral. The phenomenon has, in fact, been couched in a variety of ways, all of them maintaining the basic "repair in the presence of a selectional mismatch" intuition.

b. The main mechanism used to explain the repair – type-shifting – is rooted in the grammar and has

been shown to be independently necessary for a variety of phenomena. This endows it with the necessary validity as a probe into linguistic composition.

c. The conceptualization of complement coercion as a mechanism of repair lends itself naturally to a complexity-based model of processing that is very much compatible with current processing approaches. On a complexity-based view, repair mechanisms of this sort are not only expected to be isolable (i.e., it is possible to calculate precisely *when* the mechanism is triggered during the process of comprehension), but they are also predicted to be taxing to the processing system, that is, they can be associated with computational cost.

Taken together, these properties of complement coercion make for a intuitively robust, linguistically motivated and psychologically viable phenomenon that could be subjected to experimental manipulation and testing. Such a phenomenon also offers a promissory note for understanding the psychological properties of meaning composition, a fundamental and elusive component of language function, as well as for the potential to bring together neuro- and psycholinguistic semantic modelling with lexical semantic analyses in a mutually informing manner. This aspiration has found its best expression in the number and methodological diversity of experimental studies published since the early 2000s, all demonstrating that the process of composing coercion verbs with entity-denoting complements is cortically localizable and associated with additional processing cost. These findings pertain, not purely to aspectual verbs, but to the larger set of "coercion" verbs, which includes aspectual, psychological, and some control verbs.

Table 1 below shows a summary of the main findings reported in the literature beginning with McElree et al (2001) and Piñango & Zurif (2001). Each row describes the nature of the task, the main observations reported, and the interpretation of the observed effect by the researchers. A sampling of the contrasting stimuli that were tested in these studies is given in the appendix. The numbers in the second column of the table link up to the corresponding examples in the appendix.

Table 1: Summary of experimental evidence on Complement Coercion until 2013

	Study/Task	*Contrast*	*Observation*	*Interpretation of effect*
1.	**McElree et al 2001** Self-paced reading	43	longer reading times for type-shifted complements	Cost due to enriched composition or type-shifting
2.	**Piñango & Zurif 2001** picture matching focal brain lesion (Aphasia)	44	Wernicke's aphasics performed significantly worse in coercion condition; Broca's at ceiling level in both conditions	Wernicke's area supports purely semantic composition
3.	**Traxler et al 2002** Self-paced reading Eye tracking	45	entity-denoting complements take longer to process; effect disappears with event-denoting NPs	Cost emerges from the generation of additional semantic structure
4.	**Lapata et al 2003** Sentence-completion and simulation	46	subject interpretation influences verbal interpretation	Both object and subject contribute to the coerced reading
5.	**De Almeida 2004** Self-paced reading	47	*No effect of coercion condition*	type-shifting involves pragmatic inferences
6.	**Pickering, McElree & Traxler 2005** Eye tracking	48	greater reading times for the coercion condition	cost attributed to online construction of eventive sense
7.	**Traxler et al 2005** Eye tracking	49	coercion effect disappears when context establishes intended interpretation	cost attributed to online construction of eventive sense
8.	**Pylkkänen & McElree 2007** Magnetoencephalography (MEG)	50	coercion (but not anomaly) elicits increased amplitudes in the AMF at 350-450 ms	cost due to type-shifting operation that adjusts complement meaning
9.	**Frisson & McElree 2008** Eye tracking		No distinction between weakly and strongly constrained interpretation	Results consistent with hypothesis that cost reflects online construction of sense
10.	**De Almeida & Dwivedi 2008** Reanalysis of experimental evidence		coercion cost present but delayed	Delayed cost due to syntactic restructuring
11.	**Baggio et al 2009** Event Related Potentials (ERP)	50	coercion gives rise to long-lasting negative shift; distinct from N400	Cost resulting from type-shifting or unification
12.	**Kuperberg et al 2009** Event Related Potentials (ERP)		coercion invokes an N400 no different in magnitude or scalp distribution from effect evoked by animacy violations	Cost reflects mismatch between selectional restrictions of verb and mismatching properties of incoming complement
13.	**Pylkkänen et al 2009** Magnetoencephalography (MEG)		AMF effect of coercion is elicited without a decision task	ventromedial prefrontal regions contribute to resolution of syntax-semantics mismatches (type-shifting)
14.	**Husband et al 2011** fMRI	51	coercion sentences activate left inferior frontal cortex more than control	Complex compositional operations like coercion elicit greater activity in left IFG
15.	**Piñango & Deo 2010** Reanalysis and integration of linguistic, psycholinguistic, and neurolinguistic evidence		Empirical domain of complement coercion is is ill-defined	Cost results from thwarted expectation and search for event in conceptual structure
16.	**Katsika et al 2012** Eye tracking	52	Aspectual verbs, but not psych verbs, with individual-denoting subjects exhibit coercion effect	The coercion effect must arise from the semantics of aspectual verbs only

The evidence accumulated over the decades has clearly shown that there is computational cost associated with the interpretation of sentences exhibiting complement coercion. This cost has been inferred on the basis of longer reading times (Studies 1, 3, 6), ERP effects such as an N400 (Study 12) or a long-lasting negative shift (Study 11), increased amplitude in the Anterior Midline Field (AMF) (Study 8, 13), and increased activation in the left inferior frontal cortex (Study 14).

The robustness of these experimental observations has given rise to the implicit assumption that the lexical semantics of the verbs that exhibit the complement coercion effect is fully understood. This is clear from the fact that very few of the experimental studies have provided explicit semantic or syntactic reasons for why particular verbs have been included as "coercion verbs" in building their stimuli. We suggest here that other than the paraphrase diagnostic no independent argument has been provided for the conclusion that coercion verbs form a unified and well-understood semantic class.

As evidence for non-unified behavior, one can consider some of the divergences in the experimental findings. For example, complement coercion elicits a clear ERP effect, yet, the evidence does not converge on the specific nature of the index: while Kuperberg et al (2009) report an index akin to an N400, Baggio et al (2009) report a long-lasting negative shift which they argue should *not* be interpreted as an N400. Moreover, the neurological evidence unpredictably reveals distinct loci of activity for this phenomenon: while Piñango & Zurif (2001) place the locus in the left posterior superior temporal cortex, Husband et al (2011) do so in the left inferior frontal cortex. Yet another locus is reported by Pylkkänen & McElree (2007), who uniquely associate it with a distinct cortical region: the ventromedial prefrontal cortex.

Further, Katsika et al (2012) report results that motivate a new path of inquiry in complement coercion. They argue that the coercion verbs tested in many of the prior studies resist a unified lexical semantic description and that semantic differences between verbs have been seriously neglected in the experimental evidence built up in previous studies. In their study, they select two clear semantically characterizable subsets of coercion verbs – aspectual verbs and psychological verbs, hypothesizing that the difference between the two should result in differing processing profiles.[2] The study reveals that when these verbs are tested by

[2]Even though it is the case that both *begin the book* and *enjoy the book* (classic stimuli used in these studies), can be paraphrased as *begin/enjoy doing some activity involving the book*, the meaning relation between the complement and the respective predicates is different: in the case of *begin*, *the book* is interpreted as an incremental theme that is created or consumed or otherwise incrementally affected in some implicit eventuality. However, in the case of *enjoy*, *the book* may be interpreted instead as a target of emotion. More generally, *enjoy* patterns like other psychological

separating them along a semantic dimension, there is differential processing cost *within* the class of coercion verbs – only aspectual verbs (e.g. *begin, finish*) exhibit cost, not psychological verbs (e.g. *enjoy, savor*). In the face of these diverging findings, the question re-emerges: How are coercion verbs to be semantically understood and what is the precise psycholinguistic nature of the coercion effect?

This paper is structured in service of answering this question: In §2 we describe the linguistic assumptions and diagnostics that gave rise to the stimulus choices in experimental approaches to complement coercion. In §3, we demonstrate that when the full range of the simple transitive uses of aspectual verbs is considered, these verbs cannot be reasonably analyzed as selecting for event-denoting complements. This finding directly calls into question the type-mismatch and type-repair interpretation of the coercion effect, making it in effect unviable. In §4 we propose an analysis that offers a unified account of both sentences like *John began the book* and sentences like *The chapter on global poverty begins the book* and *This is the little perch that officially begins the Appalachian trail*. On the analysis we propose, individuals may map onto one dimensional directed path structures (one-dimensional dpss) in the sense of Krifka (1998) along a range of dimensions, such as the temporal, the spatial, or the informational dimension. We call such one-dimensional dpss **axes** and entities that relate to such axes via homomorphic functions are called **structured individuals**. Aspectual verbs select for complements that are structured individuals in some dimension determined by a contextual axis. The full interpretation of sentences containing aspectual verbs is dependent on determining the specific dimension along which the complement denotation is structured. §5 explicates how these interpretations are derived for a range of cases, one of which is the coercion case. In §6, we consider some implications of this analysis and also sketch out a possible way in which it applies to aspectual verb sentences with non-finite verbal complements (e.g. *John began reading/to read the book*). In §7 we show how this analysis,gets rid of type-mismatch and coercion-based type-shifting, yet is still compatible with increased processing cost for what we call the **coercion-configuration**: sentences containing aspectual verbs with agentive subjects and entity-denoting complements. We attribute this cost to the determination of the dimension from the set of possibilities afforded by the interaction of the subject and complement denotations. Thus, a generalized semantics for aspectual verbs that comprises a mechanism

verbs, such as *love*, *fear*, *like* which may allow an eventuality-based paraphrase but do not always require it. So, for instance, a sentence like (*I hate this book* may, but does not necessarily, mean that *I hate reading/writing this book*). In parallel, *Mary enjoyed the extra bathroom* does not necessarily mean that *Mary enjoyed using the extra bathroom* since it is fully compatible with her never having used it.

for dimension specification allows for a lean but empirically comprehensive account of the basic facts of complement coercion.

2. The coercion effect: Linguistic basis and diagnostics

Starting with the first studies in McElree et al (2001) and Piñango & Zurif (2001), the set of verbs assumed to exhibit complement coercion because of their selectional restrictions is semantically quite heterogeneous:

(3)   *endure, begin, master, start, attempt, complete, expect, prefer, try, finish, resist, savor, enjoy, survive*

Following Pustejovsky (1991, 1995) and Jackendoff (1997), the linguistic diagnostic for assuming that the verbs in (3) select for event-denoting complements is the availability of an eventive paraphrase to a sentence in which the verbal complement is an entity-denoting expression. Thus, *savor* (4a-b) and *resist* (4c-d) are taken to select for event-denoting complements because sentences like (4a) and (4c) can be paraphrased as (4b) and (4d).

(4)   a. The cook *savored* the spice at the restaurant on the corner. (from McElree et al 2001)

b. The cook *savored* tasting the spice at the restaurant on the corner.

c. The dieter *resisted* the ice cream at her niece's birthday party. (from McElree et al 2001)

d. The dieter *resisted* eating the ice cream at her niece's birthday party.

To the best of our knowledge, stimuli generation for complement coercion studies over the past decade has depended entirely on this paraphraseability diagnostic, adding a few more verbs to the mix (*complete*, *continue*, *end*, *tolerate*, *favor*). In terms of their lexical meanings, the verbs in (3) include aspectual verbs (*start, finish, begin*), psychological verbs (*enjoy, prefer, resist, savor*) and some control verbs (*attempt, master, try, survive, expect*). Whereas it is clear that the diagnostic identifies the availability of eventive or VP complementation, it is unclear how this diagnostic captures a semantically unified class of predicates. For instance, none of the sentences in (5) can be paraphrased appropriately by using an explicit event-denoting VP complement. Neither do they seem to involve an interpretation in which the NP complement must be interpreted as denoting an unspecified activity involving the NP. It is true that savoring the taste of freedom (5a) entails tasting freedom and mastering the intricacies of a plane (5b) entails learning

8

about its intricacies. But there is no *a priori* reason as to why these entailments must indicate the presence of selectional restrictions on the arguments of the corresponding verbs.

(5) a. John savored the taste of freedom. *??tasting/experiencing/tasting the taste*

  b. The engineer mastered the intricacies of the plane. *??learning/knowing the intricacies*

  c. The philosopher preferred Kant to Hegel. *??reading/understanding Kant*

  d. . Peter survived his wife and children. *??living after his wife*

The possible availability of a paraphrase cannot therefore be taken as evidence for identical syntactic or semantic properties. In fact, there have been no concrete proposals to unify the class of verbs in (3) as a distinct semantic subclass with clear grammatical reflexes. Consider in contrast, lexical semantic classes like states, achievements, degree achievements, incremental theme verbs, etc. all of which exhibit unified grammatical behavior which is accounted for with concrete proposals about their event-structural and argument structural properties.

We propose here that it is no coincidence that coercion verbs have not been shown to be linguistically unifiable and that only aspectual verbs have been shown experimentally to exhibit the coercion effect (under the specific manipulation that separates aspectual from psychological classes). Connecting these two observations, we further propose that whatever the source of the coercion effect, it arises out of the behavior of aspectual verbs (at least in their transitive use). What is needed then is a unified analysis of aspectual verbs that includes the coercion configuration in addition to all the other attested transitive uses and that makes connections with independently motivated psycholinguistic metrics of cost. This the focus of the following sections.

3. Aspectual verbs and ordering relations

In this section, we show that the complement coercion hypothesis fails to explain the broader distributional and interpretational properties of aspectual verbs. The empirical facts supporting this hypothesis turn out to constitute only a small subset of the dataset relevant for determining aspectual verb semantics. When we examine the larger range of contexts in which these verbs appear (in simple transitive uses), the selectional restriction assumption turns out to be inaccurate. In their simple transitive uses, which we focus on here, aspectual verbs do not exclusively select for eventive complements and agentive subject-referents. A glimpse

9

of the relevant data is offered in (6). All examples given in this section and analyzed in the next section are web attested.

(6)   a. This is the famous perch that officially <u>begins</u> the Appalachian Trail.

        b. A little porcelain pot <u>finished</u> the row.

        c. Defoe (1661–1731) <u>begins</u> the list of writers of the period of people's influence...

        d. "Under The Sun" <u>ends</u> the album with the s-l-o-o-o-o-o-w-est Sab riff ever..

There is no construal of (6a) in which *the Appalachian trail* is "coerced" into an entity of an eventive type before combining with the aspectual verb. Neither is there a reading (at least not a salient one) in which the denotation of *the perch* is construed as an agent that somehow initiates an event. Likewise for the other examples. Not only is there no eventive complement (syntactically explicit or coerced) in these examples, but the sentences themselves are aspectually stative, and it is more accurate to say that they report configurational relations between individuals rather than causal relations between events.

A closer look at this kind of data reveals that the interpretations of sentences containing aspectual verbs systematically make reference to parthood relations between objects along a range of familiar (and, sometimes not so familiar) dimensions. The notions of 'part' and 'parthood' have been investigated closely in the semantic and philosophical literature and have been central to the mereological framework that underpins much work on the lexical semantics of verbs and aspectuality more generally in natural language. Mereology lays down general principles underlying the relationship between an entity and its constituent parts with no ontological restriction on the field of 'part'. To quote Varzi (2010), "the relata can be as different as material bodies, events, geometric entities, or spatio-temporal regions..., as well as abstract entities such as properties, propositions, types, or kinds." What is central to the mereological perspective is that the 'part' relation gives rise to a partial order – i.e. it is a reflexive, transitive, and asymmetric relation. We will discuss assumptions underlying the mereological framework in §4; here we restrict ourselves to informally supporting our empirical claim that the meanings of aspectual verbs come with no ontological restrictions, i.e. they allow reference to orderings in a variety of domains – both concrete and abstract. Although we identify the distinct domains that the relata belong to and characterize them in terms of distinct interpretations such as the spatial (§3.1), the temporal (§3.2), the individual (§3.4), and the informational (§3.5) ones, our intent is not to offer a taxonomy of *different* parthood relations in different ontological domains. On the other hand, we wish to stress the underlying unity in the observed data: regardless of the ontological domain

of the relata, the particular parthood relation associated with a given aspectual verb, remains invariant. The systematic use of aspectual verbs in invoking parthood relations casts serious doubt on any analysis of these verbs as carrying selectional restrictions about the ontological properties of their complements.

3.1. Ordering of spatial intervals

Consider the examples in (7). In each of these cases, the spatial extent of the subject denotation is interpreted as an initial/medial/final subpart of the spatial extent of the complement denotation. (7a), for example asserts that the spatial extent of the lock is at the end of a spatial path defined by the spatial extent of the canal. (7b) is similarly understood as asserting that the spatial stretch corresponding to the turn is the initial stretch of the final quarter-mile stretch in some race. In (7c), we construe the ear canal of the cat as having a spatial extent (which it obviously does) and locate the inferior portion of the cat's eardrum at the final subinterval of this extent.

(7)   a. At one end of Ford street is a lock that <u>ends</u> the canal.

        b. The final turn around a tall oak tree <u>begins</u> the quarter-mile stretch to the finish line.

        c. Third, the superior portion of cat eardrum lies along the ear canal wall while the inferior portion <u>ends</u> the canal at a 50 degree angle.

        d. This is the famous perch that officially <u>begins</u> the Appalachian Trail.

        Thus the interpretation of any of the sentences in (7) and the wider class of such sentences requires us to map individuals to their spatial extents and consider how these relate to each other.

3.2. Ordering of temporal intervals

In the sentences in (8), aspectual verbs are used to describe parthood relations between temporal intervals and their initial/medial/final subintervals. In (8a), for example, in saying that the thunderstorm began the morning, one means that the time interval corresponding to the thunderstorm is the initial subinterval of the time interval corresponding to the morning. In (8b), the complement, *the deadline*, is taken to refer to the interval over which submissions may be accepted with the punctual interval corresponding to the "actual deadline" (e.g. 11:59 P.M. on Friday) giving the right boundary of such an interval. The subject, *next week*,

refers to some final sub-interval of this extended deadline-interval.[3] Similarly, in (8d), the time interval of midnight is understood as the final subinterval of the time interval corresponding to the (24 hour) day. In (8e), the time at which the said configuration of our planetary neighbors obtains is understood as being the initial subinterval of the time corresponding to March.

(8)　　a. A thunderstorm <u>began</u> the morning.

　　　　b. Next week <u>finishes</u> the deadline to submit your paper.

　　　　c. The afternoon <u>began</u> the selection process with eight men and women questioned individually by Judge Jolene Kopriva.

　　　　d. You are correct, midnight <u>ends</u> the day.

　　　　e. A veritable line-up of our planetary neighbors <u>starts</u> the month of March

　　　So in interpreting sentences like those in (8) we are required to consider the temporal extents of the denotations of the arguments and parthood relations between these extents.

3.3. Ordering of events

There is a distinction to be made between events and spatial or temporal intervals. Following the standard literature, we will assume that events are a sort of individual and, like ordinary individuals, they are multi-dimensional objects occupying spatio-temporal regions (Bach 1986; Krifka 1998). Spatial and temporal intervals, in contrast, are unidimensional entities to which multidimensional objects can be mapped. The subevent relation can hold between event individuals along both spatial and temporal dimensions but is not reducible to just these two dimensions. Consider the examples in (9).

(9)　　a. A prayer <u>started</u> the banquet.

　　　　b. This conclusion <u>finished</u> the first day's activities and the staff adjourned.

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[3]A reviewer points out that the parthood relation for this example appears to be reversed. That is, "the deadline to submit the paper" is understood to be a subpart of "next week" rather than "next week" being a subpart of "the deadline." However, we believe that our interpretation, in which *the deadline* is construed as an interval with the punctual deadline as its right boundary is the more correct one. It is supported by the fact that punctual deadline is understood to be located on Friday (or some other conventionalized end-point to the week) rather than any arbitrary day – such as Tuesday or Thursday. (8c) can also be understood similarly.

c. What many remember most about Kilpatrick, the youngest person elected as mayor in the nation's history, at age 31, is that he lied on stand during a whistleblower lawsuit about an affair he had with his former chief of staff. The moment <u>began</u> his downfall.

In (9a), it is possible to map the denotations of both *the prayer* and *the banquet* to their temporal extent, but there seems to be an additional causal dimension to the relation between the two individuals – the prayer event is intended to mark the beginning of the banquet. In (9c), this causal dimension is even more salient. The lying event is understood to be the causal eventuality in the event of Kilpatrick's downfall. It is not enough to simply treat its temporal extent as being the initial subinterval of the interval corresponding to the downfall event. We therefore suggest that in this class of cases, we consider parthood relations between events, and the arguments are interpreted accordingly. In (9c) then, the event (of lying) culminating at the time referred to by *the moment* is understood as being the initial subevent of the downfall eventuality.

3.4. Ordering of individual atoms

Another class of cases is those in which the complement denotes a totally ordered set of ordinary individuals. Examples of such lexical expressions include *row*, *list*, *queue*, *menu*. In the sentences below, the complement denotation is construed as a set of ordinary individual atoms and the subject denotation is the initial or final element in such a set. The little porcelain pot in (10a) is construed as being the final element of the set of items displayed in the row of objects. In (10d), the menu is taken to be composed of several items that follow a particular order. Veal consommé with cheese pastry is the initial element of this ordered set.[4] This order also corresponds to a *temporal* ordering of events – the order in which the items on the menu are served, but that is derivative of the intrinsic structure of the menu.

(10) a. A little porcelain pot <u>finished</u> the row.

b. The little girl with glasses <u>began</u> the queue.

c. Defoe (1661–1731) <u>begins</u> the list of writers of the period of people's influence...

d. Veal consommé with cheese pastry <u>started</u> the menu for the year 1927.

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[4]The sentence is part of a description of the dinner served at the banquet for the Nobel Prize award ceremony of 1927.

3.5. Ordering of informational entities

In this class of cases, the aspectual verb is interpreted relative to some body of information construed as an ordered entity. The complements in each case map to some such structured set of informational content while the subject denotations map to the initial/medial/final parts of such sets. So (11a) conveys that the informational content of chapter one is the initial part of the informational content of the book, while (11b) conveys that the informational content of the lemma is the final part of the informational content of the proof.

(11)   a. Chapter 1 <u>begins</u> the book with a brief overview of what collective intelligence is and how it manifests itself in your application.

b. The next lemma <u>finishes</u> the proof.

c. The final stanza <u>finishes</u> the poem with a satirical stab at the people described above.

d. The penultimate stanza <u>continues</u> the poem's resonance, just in a different manner.

e. "Under The Sun" <u>ends</u> the album with the s-l-o-o-o-o-o-w-est Sab riff ever...

3.6. Other orderings

Further evidence that aspectual verbs involve reference to ordered structures comes from uses of these verbs where the dimensions along which the structure exists is more abstract than that of space, time, or pieces of text. Consider the example in (12a). What is conveyed by this sentence is that electromagnetic radiation of wavelength corresponding to the color black occurs at the initial and final subparts of an ordering of electromagnetic radiation corresponding to the visible spectrum by wavelength.[5] In (12b), the speaker considers the neighborhoods in Tokyo ordered by increasing social status and the relevant sentence conveys that the neighborhood corresponding to the number 4 is associated with incomes that are in the initial part of the range of middle class incomes.

(12)   a. Black <u>starts and ends</u> the visible spectrum.

b. Also, it is important to note that I have numbered the 6 neighborhoods based on social status (on a scale of 1 to 6): 1 is the poorest and the most dangerous of the neighborhoods, 4 <u>begins</u> the middle

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[5]Technically speaking, this is a false statement, since black is the absence of the wavelengths of the visible light spectrum and doesn't actually correspond to particular wavelengths within the spectrum.

class, and 6 is the wealthiest and safest of the neighborhoods.

c. Also, respondents were asked to assess what level of income <u>begins</u> the middle class.

d. This level <u>begins</u> the serious study of dance.

3.7. Summary

The range of examples discussed in this section make it clear that reference to ordered structures is fundamental to the lexical semantics of aspectual verbs. They also make it clear that any analysis of aspectual verbs that assumes that they select for event-denoting complements is not tenable given their actual range of occurrence. Given this, it would be undesirable to argue that the range of uses/readings of aspectual verbs all involve coercion, type-mismatch, and type-shifting operations forced by the narrow combinatorial possibilities of aspectual verbs. Instead, we take the more conservative position that any empirically adequate analysis of the lexical semantics of aspectual verbs should be neutral with respect to the ontological properties of the arguments they combine with. On that basis, we propose that the proper semantic treatment of these verbs relies on a notion that we have so far invoked only informally – contextually determined axes. §4 offers an analysis that formalizes how the axis argument is implicated in the interpretation of aspectual verbs.

4. The lexical semantics of aspectual verbs

4.1. Generalized axes

It has been noted that the meanings lexicalized in certain verb classes involve a systematic underspecification of the ontological dimension along which they can be interpreted. Gawron (2009) develops this core observation in his analysis of *extent verbs* which include degree achievements *rise, lengthen, increase* and verbs like *cover, extend, surround* in which the change described can obtain along the spatial dimension. The lexical semantics of these verbs therefore must generalize over paths in both temporal and spatial domains. The relevant examples are in (13).

(13)   a. The fog *extends* from the pier to the point. (Gawron 2009)

b. Freeway 101 *widens* between San Francisco and San Jose.

c. The valley *sinks* even further five miles ahead. (Koontz-Garboden 2011)

d. . The bridge *narrowed* from the midpoint of the canyon on. (Gawron 2009)

Deo, Francez, and Koontz-Garboden (2011, 2013) argue that Gawron's analysis is not fully adequate in capturing the full range of facts. The readings available to degree achievements requires an even further generalization of the dimensions along which change may be described to obtain. Examples like those in (14) illustrate the relevant readings of degree achievements. In (14a), for instance, the flatness of the divot of an individual *x* depends on the severity of the condition found in *x*, but no individual divot is said to undergo change. (14c), which introduces George Taylor's (1926) "hemline index", crucially makes no assertion about temporal or spatial changes in any particular hemline, but rather seems to assert that the rise and fall of the economy is correlated with the fall and rise respectively of the average length of hemlines.

(14) a. (In children with fetal alcohol syndrome) the divot or groove between the nose and upper lip *flattens* with increased prenatal alcohol exposure.

b. The median income *increases* with each additional level of education acquired.

c. When the economy is flourishing, hemlines *rise*, meaning one would see more miniskirts, and when the situation is deteriorating, hemlines *drop*, perhaps even to the floor.

Gawron, as well as Deo, Francez, and Koontz-Garboden analyze these sort of phenomena by introducing a **generalized axis** argument in defining the semantics of lexical predicates, where an axis is taken to be a linearly ordered set of entities in any ontological domain. Both degree achievements and other extent verbs describe incremental relations that hold between such a (contextually provided) axis and the participants of eventualities denoted by the verbs. We import this observation about generalization over dimensions in building our analysis of aspectual verbs within the mereological framework developed in Krifka (1998).

4.2. The mereological framework

Classical extensional mereology (CEM), the most commonly used system in natural language semantics, takes the notion of **part** to be central, either treating it as a primitive, or deriving it by taking the notion of **sum** as primitive.[6] Krifka (1998), starting from the latter position, develops algebraic structures that

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[6]Champollion and Krifka (2014) distinguish between the "order-theoretic" mereological perspective (which axiomatizes parthood) and the algebraic "lattice-theoretic" perspective, where the starting point is the sum operation that

facilitate the description of conceptual structures that underpin incremental relations between participants in a predication. These part structures are defined with full generality so as to be able to apply to individuals, times, events. The assumption is that all ontological domains – time, spatial paths, events, and objects – are characterizable by the same underlying algebraic structure. The lexical semantics of verbal predicates constrains relations between these domains; for instance incremental theme verbs relate parts of the object denotation and parts of the event to each other in a one-to-one mapping.

A subclass of the part structures that Krifka axiomatizes, **one-dimensional directed paths**, turn out to be very well-suited to capture the linguistic behavior of aspectual verbs. These can be defined incrementally, starting with defining the join semi-lattice structure characterizing each domain. A join semi-lattice is a tuple $\langle U, \oplus \rangle$, where U is a set of entities and $\oplus$ is the two-place *sum operation*. For any two elements $x, y \in U$, their sum (join) $x \oplus y \in U$ (i.e. U is closed under sum formation).[7] A part structure P is a join semi-lattice $\langle U, \oplus \rangle$ whose elements satisfy the *part* relation (15a), the *proper part* relation (15b), the *overlap* relation (15c), and the remainder principle (15d).[8]

(15)   a. $\leq$, the *part* relation, defined as: $\forall x, y \in U [x \leq y \rightarrow x \oplus y = y]$

       b. $<$, the *proper part* relation, defined as: $\forall x, y \in U [x < y \leftrightarrow x \leq y \wedge x \oplus y \neq y]$

       c. $\otimes$, the *overlap* relation, defined as: $\forall x, y \in U [x \otimes y \leftrightarrow \exists z \in U [z \leq x \wedge z \leq y]]$

       d. Remainder principle: $\forall x, y \in U [x < y \rightarrow \exists ! z [\neg [z \otimes x] \wedge x \oplus z = y]]$

A one-dimensional directed path structure D, the type of part structure relevant to aspectual verb semantics, is additionally constrained by the following conditions: It is a *convex*, *linear* structure, whose *adjacent* parts are *totally* ordered by the *precedence* relation.[9] Adjacency (∞) is a two-place relation; elements

is used to define the parthood relation.

[7] The sum operation is defined to be idempotent, commutative, and associative.

[8] Krifka (1998) defines all part structures as tuples of a set of entities, the sum operation, and the relevant relations that constrain the part-structure. So a part structure is a tuple $\langle U_P, \oplus_P, \leq_P, <_P, \otimes_P \rangle$, while a directed path structure (a subtype of part structures) is a tuple $\langle U_D, \oplus_D, \leq_D, <_P, \otimes_D \infty_D, P_D, C_D, D_D \rangle$. We assume this derivation of part structures from elements in the basic ontology but the notational aspect is kept to the minimum so as to facilitate readability.

[9] We only provide the most relevant axioms here and refer the reader to Krifka (1998) for the complete formal system that we are relying on. However, we do characterize the notions that are captured there in prose in the text.

of a part-structure that are externally connected and non-overlapping are in the adjacency relation. Convexity and linearity restricts us to those part structures (path structures) whose disjoint (non-overlapping) and non-adjacent parts are always connected by a unique convex element (16a-b).

(16)   a. $\forall x,y,z \in D[y,z \leq x \land \neg y \otimes z \land \neg y \infty z \to \exists! u \in D[u \leq x \land y \infty u \infty z]]$

   b. $\forall x,y,z \in U[\neg x \otimes y \land \neg x \infty y \to \exists z \in D[x \infty z \infty y]]$

The constraint on precedence ($\prec$), which is defined by the conditions in (17a-d), completes the definition of a directed path structure (dps). Precedence is irreflexive, asymmetric, and transitive (17a), holds only for non-overlapping elements (17b), and requires all pairs of non-overlapping parts to be in the precedence relation (17c).[10] Only parts of a dps can stand in the precedence relation to one another (17d).

(17)   a. $\forall x,y,z \in D[[\neg x \prec x] \land [x \prec y \to \neg y \prec x] \land [x \prec y \land y \prec z \to x \prec z]]$

   b. $\forall x,y \in D[x \prec y \to \neg x \otimes y]$

   c. $\forall x,y,z \in D[x,y \leq z \land \neg x \otimes y \to x \prec y \lor y \prec x]$

   d. $\forall x,y \in D[x \prec y \to \exists z \in D[x,y \leq z]]$

Finally, a one-dimensional dps is one that is totally ordered (18). That is, for each two convex, non-overlapping parts x,y, it holds that either x precedes y or y precedes x.

(18) $\forall x,y \in D[\neg x \otimes y \to x \prec y \lor y \prec x]$

One-dimensional dpss are observed and pragmatically constructed in diverse ontological domains. For instance, the temporal domain is a one-dimensional dps where $\prec$ is interpreted as temporal precedence. The (imaginary) line from New Haven to Boston is also a one-dimensional dps, where $\prec$ is interpreted as spatial precedence: the relation orders spatial points closer to New Haven as preceding those points that are closer to Boston. The same line going from Boston to New Haven, which is exactly the same set of spatial points (with the same ontologically given parthood structure) is a *different* one-dimensional dps in which $\prec$ orders points closer to Boston as preceding those that are closer to New Haven.[11] Similarly, where the Brooklyn Bridge "starts" depends on whether one is contemplating the question standing in Brooklyn or in

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[10]A reviewer notes that the first conjunct in (17a) is redundant since irreflexivity follows from asymmetry.

[11]See Gawron (2009) and Fong (1997) for a discussion of what Fong calls *diphasic locatives*, in which two perspectives might be taken on the same road differing in the directionality imposed on how the road is viewed.

Manhattan (and even then, one might take a different perspective). Krifka gives the examples of the text of a book as a dps, once we have a defined adjacency relation for it (for instance, considering the chapters of a book to be the adjacent parts of the book) and take $\prec$ to give us the order of these chapters relative to each other. We might also define the adjacency relation differently considering the pages of the book to be the adjacent parts and $\prec$ then gives us the precedence ordering on the page-parts of the book. As one of our reviewers notes perfectly, path structures in general "capture this odd domain that is part cognitive, part conventionalized: ways of grasping the world." The dps of time is given to us by the ontology – since both the parthood relation and precedence relation are fixed once and for all – given by the way we experience time. On the other hand, for the spatial domain, although the parthood relation remains ontologically fixed, precedence is a pragmatically given relation fixed in context by the perspective of the cognizer allowing us to construe the same spatial domain construed linearly (e.g. the Brooklyn Bridge) as corresponding to distinct one-dimensional dpss. The adjacency relation, furthermore, is often given by convention, and sometimes by pragmatic context. For instance, the week may be conventionally divided into day-length adjacent temporal parts, a street may be divided into block-length adjacent spatial parts, and a poem may be divided into stanza-length adjacent informational parts. A line of people waiting for a bus is a one-dimensional dps with a fixed precedence relation, given by what we conventionally take to be the "head" of the line, and adjacent parts consisting of individuals. This richness of the interaction between ontological structures, conventionalized structures, and contextual perspective is visible in the distribution and interpretation of aspectual verbs, to whose semantics we now turn.

Throughout the coming discussion, we assume four non-null, disjoint mereological domains in the ontology: $\mathscr{D}$, the domain of ordinary individuals, and $\mathscr{E}$, the domain of event individuals, both which form a part structure. The domain of spatial intervals $\mathscr{S}$ is also a part structure. In each of these three domains, the dpss that we discuss will be determined by linguistic and non-linguistic convention and context. The domain of temporal intervals $\mathscr{I}$ is assumed to be a one-dimensional dps as mentioned above.[12] Relatedly, $\mathscr{E}$ is subject to a precedence relation that is based on the temporal precedence relation on times. An event

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[12]Each of these mereological domains is associated with its own parthood relation, sum operation, and so on. Because we assume that these domains are disjoint, we will also generalize over the different relations and operations in each domain by forming their union (Champollion 2010: 23). The symbols for parthood ($\leq$, $<$) etc. will stand for the union of the parthood relation on events, on individuals, times, and spaces. This will allow us to express statements that generalize over the distinct mereological domains.

e is taken to precede another event e' iff the runtime of e (given by the temporal trace function τ) – $\tau(e)$, temporally precedes the runtime of $e' – \tau(e')$.

4.3. Connections between mereological domains

The ontological domains $\mathscr{D}, \mathscr{E}, \mathscr{I}$, and $\mathscr{S}$ are connected with each other by partial functions that map entities from one domain to entities in another domain. For instance, temporal and spatial trace functions map ordinary and event individuals to their temporal and spatial extent respectively, while thematic role functions relate individuals and events. The set of functions that are relevant to our purpose are those that map entities to one-dimensional dpss. Since time is an axis (a one-dimensional dps, the temporal trace function necessarily maps individuals and events to a one-dimensional dps (a temporal interval). As far as space is concerned, we will make the assumption that the spatial trace function also maps individuals and events to an axis (a spatial interval). For event individuals, this is a relatively standard assumption since the spatial trace of event individuals is the spatial path along which the eventuality obtains – a one-dimensional dps (Gawron 2009, Champollion 2010). For ordinary individuals, which often occupy a two- or three-dimensional spatial region, this interval is their spatial extent along their most salient spatial dimension, if they have one. In this assumption, we follow previous ideas and implementations from the literature. Jackendoff (1992) has proposed that an object (ordinary individual) can be decomposed into a hierarchical arrangement of spatial dimensions. For certain objects, like a river or a bridge or a road, the primary dimension is a line. Verkuyl & Zwarts (1992) interpret this notion of dimensionality of an object in terms of the spatial orderings that can be imposed on the material parts of that object. Objects like bridges and roads can be construed as one-dimensional in space, because they may be partitioned into a set of parts that are linearly ordered with respect to each other – slices of the bridge or the road that follow one another.[13] Fong (1997), in her analysis of directional locatives, also assumes that the spatial trace function returns one-dimensional spatial extents for objects that can be construed as being linearly ordered.

Before we move on to providing lexical entries for aspectual verbs, a terminological note is in order. Following the spirit of Gawron (2009) and Deo, Francez, and Koontz-Garboden (2011, 2013), we will use

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[13]Such a partition of material parts along a salient dimension is not easily available for an entity like a chair or a plate, which makes it much more difficult to construe such entities as spatially one-dimensional (and consequently constrains their use with aspectual verbs).

the term **axis** to refer to one-dimensional dpss in any ontological domain. Thus, in defining the notion of a **structured individual** below, we will make reference to axes onto which individuals are mapped. By this we simply mean that the individual is in a homomorphic relation to an (ontologically, conventionally, or pragmatically) given one-dimensional dps. The predicate **axis** is taken to be the set of all entities (temporal, spatial, material, or abstract) that are one-dimensional dpss. An axis is an element from this set.

4.4. Lexical entries for aspectual verbs

The notion of a **structured individual** is defined in (19). An individual x of any type τ is taken to be a structured individual relative to a function f of any type (τ, σ) iff $f(x)$ is an axis and f is a homomorphism from the part structure of x to the axis $f(x)$.

(19) $\forall x_\tau \ [\textbf{struct-ind}_{f_{\langle \tau, \sigma \rangle}}(x) \leftrightarrow [\textbf{axis}(f(x)) \wedge \forall x', x'' \leq x[x' \leq x'' \rightarrow f(x') \leq f(x'')]]]$

　　With these notions in hand, it is possible to analyze aspectual verbs as specifying relations between the subparts of the axis determined by their complement denotation. Specifically, we take aspectual verbs to select for structured individuals, modeling this selectional requirement as a lexical presupposition. The truth-conditional component of aspectual verbs requires that the subject denotation be mapped to some privileged subpart of the axis determined by the complement denotation. Intuitively speaking, sentences with aspectual verbs in their transitive uses are true if there is a way of construing the subject denotation as a subpart of the axis that is the construal of the complement denotation. The lexical entries for *begin*, *end* and *continue* that are given in (20a), (21a), and (22a) respectively, are intended to capture this intuition. The function f_c that maps the complement denotation to the axis comes from a constrained set of functions that we take to be lexically listed as part of the general meaning for this class of verbs. Which of these functions is applied to the complement denotation (i.e. the construal of the complement denotation) is determined in the context of utterance.

(20)   a. $[\![\text{begin}]\!] = \lambda x_\tau \lambda y_\sigma : \ \textbf{struct-ind}_{f_c}(x).\ \exists f'[f'(y) <_{\textit{small-init}} f_c(x)]$

　　　b. *Begin(x)(y)* is defined iff x is a structured individual with respect to the contextually determined function f_c. If defined, *begin(x)(y)* is true iff there is some function f' (possibly identical to f) such that $f'(y)$ is a "small" initial subpart of the axis $f_c(x)$.

(21)   a. ⟦end⟧ $= \lambda x_\tau \lambda y_\sigma :$ **struct-ind**$_{f_c}(x). \exists f'[f'(y) <_{small\text{-}fin} f_c(x)]$

b. *End(x)(y)* is defined iff *x* is a structured individual with respect to the contextually determined function f_c. If defined, *end(x)(y)* is true iff there is some function f' (possibly identical to f) such that $f'(y)$ is a "small" final subpart of $f_c(x)$.

(22)   a. ⟦continue⟧ $= \lambda x_\tau \lambda y_\sigma :$ **struct-ind**$_{f_c}(x). \exists f'[f'(y) <_{small\text{-}med} f_c(x)]$

b. *Continue(x)(y)* is defined iff *x* is a structured individual with respect to the contextually determined function f_c. If defined, *continue(x)(y)* is true iff there is some function f' (possibly identical to f) such that $f'(y)$ is a "small" medial (non-initial and non-final) subpart of $f_c(x)$.

We have said that aspectual verbs make reference to "small" initial, final, and medial parts of a contextual axis determined by the complement denotation. What counts as "small' in a particular context of use of an aspectual verb is determined partly by the properties of the complement denotation that provides the axis and partly by context. The axis, depending on whether it is a temporal, spatial, or material entity, may or may not be composed of discrete atoms (the smallest elements with respect to the part relation). If the axis is made up of such atoms (e.g. a row of sculptures or a queue of people waiting for a bus), a small part is most naturally understood to mean an atom – an individual sculpture or a person. Thus, in a sentence like *The porcelain pot finished the row*, we understand the porcelain pot to be the final atom in an axis composed of exhibits that are each atoms. In the case of any axis *a* that is not composed of such discrete elements – e.g. a temporal or a spatial interval (which are usually taken to be dense sets), a small part of *a* is a part whose measure does not exceed some contextual threshold relative to the measure of *a*. A small part of the spatial extent of a ribbon will be much smaller than a small part of the spatial extent of a bridge, which in turn, is expected to be smaller than a small part of the spatial extent of a river. Moreover, what counts as "small' may vary in context. A small initial part of a movie may be its opening shot from a cinematographer's perspective (*A shot of a boy turning on the television begins the movie*) or its opening scene (*A TV show about a boy with a stutter begins the movie.*)[14] While a shot of the television being turned on is a proper part of the scene showing the TV show, both count as small initial parts of the informational content corresponding to the movie and may be judged true in different contexts.

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[14]The movie being referred to is Andrei Tarkovsky's *Mirror* (1975).

Similarly, we may say that *'a' begins the sequence 'abcdefg'* if we take the sequence to be composed of letters that are the atoms of the axis. A small initial part is then the initial atom. We may also say *'ab' begins the sequence 'abcdefg'* and construe the sequence as composed of sub-sequences, in which case, *'ab'*, or even *'abc'* may count as small initial parts. The measure of the sequence would disallow any larger subparts (e.g. *'abcd'*, or *'abcde'*) from counting as small initial subparts of the sequence.[15]

To summarize, we take "smallness" to be a vague notion and what counts as a "small" part to be constrained by the structure and the measure of the axis, while also possibly being variable from context to context.

4.4.1. *Mappings to axes and Pustejovskian qualia structures*

The lexical semantics that we have proposed for aspectual verbs relativizes their interpretation to contextually determined functions that apply to the complement denotation to yield axial entities in different dimensions. These functions are maps between (and within) ontological domains and we take at least some subset of these to be listed as part of the lexical entries of aspectual verbs. The full interpretation of sentences containing aspectual verbs is dependent on determining the specific dimension along which the complement denotation is construed as a structured individual. That is, it depends on selecting a particular function that maps the complement denotation to an axis in some (possibly the same) ontological domain. The selection of an appropriate function is constrained by the lexical semantics of the complement denotation and determined in context.

For instance, consider an expression like *book*, which denotes an entity with a spatial and temporal extent as well as an abstract informational extent. An expression like *bridge*, which also denotes an entity with spatio-temporal extent, is further characterized by a salient spatial organization of its parts along its length. An expression like *queue* denotes an intrinsically totally ordered entity composed of atomic individual parts. We take it that such information about the possible dimensions along which entities may be construed as structured individuals e.g. the spatial, temporal, informational dimension of entities, or any intrinsic or conventionalized ordering of their part-structure is part of the lexical entries for each expression. It is this information that must be mined for selecting the function that is relevant to interpreting the mean-

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[15]We thank Chris Kennedy for providing the example and pointing out the need for explicating which parts are relevant in such judgments.

ing of aspectual verb sentences in a given context. Such a view of lexical meaning assumes a lexicon that is populated by atomic, yet, structured lexical entries, whose dimensional content must be accessible for composition with aspectual verbs and the contextual selection of the appropriate function that determines the axis.

This can be compared to the approach taken in Pustejovsky's Generative Lexicon (GL) framework (1991, 1995, and later) , which introduces an enrichment of lexical entries via semantic templates called *Qualia Structures*. This framework has been very influential in the coercion-based type-shifting analyses that were discussed in §1. Qualia are part of lexical meanings and constrain type-shifting operations, which allow for reinterpretations of entities to satisfy typing requirements that they may not otherwise satisfy. For instance, an expression like *book* has, as part of its qualia structure, a *telic* role, which invokes a reading event, and an agentive role, which invokes a writing event. Coercion operators access this substructure of meaning in order to semantically shift an entity-denoting expression like *book* to an event involving the book, such as reading or writing. The set of coercion operators that effect such a shift is determined by the lexical semantics, and in particular, the qualia structure associated with an expression.

Like the GL analysis, the present analysis too capitalizes on richer lexical structures and relies on the lexicalization of conceptual information (dimensional information) which is part and parcel of qualia structure. However, unlike the GL analysis, the present analysis relies on an independently motivated semantic class, the aspectual class. It places no selectional constraints on the verbs nor does it invoke coercion operators in accessing information from the qualia structures of complements in order to satisfy the type-requirement for events that these verbs are claimed to have. It is in these specific properties where the present analysis differs from the GL-based account. On our analysis, aspectual verbs select for structured individuals (event individuals are only one kind of structured individuals) and the satisfaction of this presupposition is not effected by coercion operators but rather by a constrained set of homomorphic functions that map individuals to their (axial) extents in different dimensions. Indeed, in the present analysis, complement coercion, no longer exists as a phenomenon. Thus, while the present analysis builds on a GL-based architecture by relying on richer and more structured information in the lexicon (by encoding, for instance the dimensions along which these individuals extend as part of the encoded lexical content of expressions), the content itself of the analysis differs radically from the GL-based one.

5. Deriving the interpretations of aspectual verb sentences

This section explicates how aspectual verbs combine with arguments of different semantic types to yield the range of interpretations observed in §3. In particular, we will consider two classes of cases – (a) those configurations in which the complement denotation and the subject denotation are mapped to the axis by **an identical function**; and (b) those configurations in which the complement denotation and the subject denotation are mapped to the axis by **non-identical functions**. The **coercion configuration** turns out to be a subclass of (b).

5.1. Mapping to axes via an identical function

In this class of cases, the subject denotation is construable as a subpart of the complement denotation and both map to the axis by the same function. The parthood relation holds between the two entities along the dimension established by the axis. Mapping to axes via an identical function takes place with a variety of dimensions. For expository purposes we only derive the spatial case here. However, the detailed analysis of the other attested cases from §3, which make reference to axes from other dimensions, can be found in Appendix B.

The cases of spatial parthood are those in which the individual denoted by the complement of the aspectual verb is structured along the spatial dimension. The relevant function in all spatial cases is the spatial trace function σ, which maps individuals to their extent on their most salient spatial dimension, if they have one. The general schema can be illustrated with the sentence in (23a), a simplified version of (6a). In this example, the axis $\sigma(a)$ corresponds to the spatial interval that is the one-dimensional extent or the length of the Appalachian trail. The sentence receives its compositional meaning thus:

(23)   a. This famous perch <u>begins</u> the Appalachian Trail.

  b. $[\![\text{begin}]\!] = \lambda x_\tau \lambda y_\sigma : \; \textbf{struct-ind}_{f_c}(x). \; \exists f'[f'(y) <_{small\text{-}init} f_c(x)]$

  c. $[\![\text{this famous perch}]\!] = p$

  d. $[\![\text{the Appalachian trail}]\!] = a$

  e. $[\![(23a)]\!]$ is defined iff $\textbf{axis}(\sigma(a)) \wedge \forall x', x'' \leq a[x' \leq x'' \rightarrow \sigma(x') \leq \sigma(x'')]$

   If defined $[\![(23a)]\!] = 1$ iff $\exists f'[f'(p) <_{small\text{-}init} \sigma(a)]$

That is, (23a) is defined iff a is a structured individual relative to σ. If defined, (23a) is true iff there is some function f' that maps the famous perch to an initial part of the axis that is $\sigma(a)$ – the one-dimensional spatial extent of the Appalachian trail. In this case, the function is exactly the same; if the spatial trace of this famous perch ($\sigma(p)$) corresponds to an initial part of the spatial trace of the trail, the sentence is judged true. It is easy to generalize this to the other cases in (7), all of which cases assume an identity between f_c, which maps the complement denotation to the axis and f', which maps the subject denotation to some proper subpart of the axis. Appendix B derives all the other cases.

5.2. Mapping to axes via non-identical functions

This class of cases differs from the previous one only in the fact that there is greater freedom in the choice of functions. Specifically, the subject and complement denotation of the aspectual verb get mapped to the same axis, yet to do so they do not resort to the same function. The observation here is that on the standard construal of the subject and complement denotations the former cannot be taken to be a subpart of the latter. The implication of this observation is that the parthood relation is exclusively established via the axis and the constituency relation between the subject and the object denotations is therefore weaker.

In what follows, we present two examples that make this observation more concrete. The first one, (24a), involves a temporal axis, while the second one is the coercion case.

Consider (8f), repeated in (24a). The complement *the month of March* is most naturally taken to denote a temporal interval – in our terms, an axis along the temporal dimension. The subject noun phrase denotes an eventuality, specifically, a configuration of planetary neighbors. The meaning of (24a) can be derived in the following way. Let the contextually determined function f_c be $f_{identity}$ – which simply maps an entity to itself.

(24) a. A veritable line-up of our planetary neighbors <u>starts</u> the month of March.

b. $[\![start]\!] = \lambda x_\tau \lambda y_\sigma :$ **struct-ind**$_{f_c}(x).\ \exists f'[f'(y) <_{small\text{-}init} f_c(x)]$

c. $[\![$a veritable line-up of planetary neighbors$]\!] = l$

d. $[\![$the month of March$]\!] = m$

e. $[\![(24a)]\!]$ is defined iff **axis**$(f_{identity}(m)) \land \forall x',x'' \le m[x' \le x'' \to f_{identity}(x') \le f_{identity}(x'')]$

If defined $[\![(24a)]\!] = 1$ iff $\exists f'[f'(l) <_{small\text{-}init} f_{identity}(m)]$

(24a) is true iff there is some function f' such that $f'(l)$ is a small initial subpart of the temporal interval denoted by the month of March. There is such a function, viz. f_{time}, the partial function that maps ordinary and event individuals to their temporal location. The sentence is true because the runtime of the eventuality of the lineup of the planetary neighbors is an initial subinterval of the March interval. (8a–c), which involve temporal axes, can all be derived by the schema above.

(25) contains another instance of this schema.

(25)   a. Then an uphill climb out of Porthoustock <u>begins</u> the inland route to Porthallow.

   b. This linear walk <u>continues</u> the route of the Eden Valley Walk from Edenbridge.

In both cases, the subject noun phrase most naturally denotes an eventuality while the complement denotes a spatial interval (on the assumption that a route is fundamentally a directed line of spatial points). The sentences can be interpreted if the contextually determined function is $f_{identity}$, that returns the spatial axis that is the complement denotation. There is a function f', the spatial trace function, σ, that when applied to the eventualities denoted by the subject noun phrases in (25), returns the spatial path along which the eventualities obtain. The sentences are true if these spatial paths are small initial and medial subparts respectively of the spatial axes denoted by the complements.

We finally turn to the **coercion configuration**, the configuration that gave rise to the erroneous assumption that aspectual verbs select exclusively for event-denoting complements. We analyze this configuration as a subclass of mapping via non-identical functions. The coercion configuration is semantically characterizable as one in which an aspectual verb combines with an animate agentive argument and an individual-denoting complement. Examples are in (26).

(26)   a. John began the book.

   b. The carpenter finished the table.

   c. The little girl started the queue.

   d. The dog began the bone.

The resulting reading is (often) one in which the animate subject referent is construed as the agent of some implicit dynamic eventuality. The functions that are relevant to understanding the coercion configuration are maps between the domain of ordinary individuals $\mathscr{D}$ and the domain of events $\mathscr{E}$. Specifically, we will introduce functions that are the inverse of thematic role functions. Thematic roles such as agent (or

initiator of an event) and patient/theme (undergoer of an event) map events to their individual participants. We will define inverse thematic functions as those that map pairs of individuals and times to the unique event that the individual bears a participant role to at that time in a given context. f_{ag_i} maps an individual to the unique event that they are an agentive participant of at the reference interval i in a given context. f_{th_i} maps an individual to the unique event that they are the patient/theme of at i in a given context.

(27)   a. $f_{ag_i}: \mathscr{D} \times \mathscr{I} \rightarrow \mathscr{E}$

   b. $f_{th_i}: \mathscr{D} \times \mathscr{I} \rightarrow \mathscr{E}$

Assuming these functions, the general analysis applies to the coercion case as follows: The salient reading for a sentence like (28a) is one in which the axis is construed as some event of which John and the book are participants. When f_c is taken to be f_{th_i}, the book gets mapped to the (contextually) unique event of which it is the theme. Then (28a) is defined iff f_{th_i} applied to the book yields an axis and iff f_{th_i} is a homomorphism from the parts of the book to parts of the axis. The truth-conditions of (28a) require there to be a function f' such that f' applied to John is a small initial part of f_{th_i}(the book) – i.e. there should be a map from John to a small initial part of the axial event. There is such a function f_{ag_i}. Thus, (28a) comes out true if the contextually unique event of which John is an agentive participant at a reference interval i is a small initial part of the unique event of which the book is a theme participant at i.

(28)   a. John began the book.

   b. $[\![\text{begin}]\!] = \lambda x_\tau \lambda y_\sigma :$ **struct-ind**$_{f_c}(x).\ \exists f'[f'(y) <_{small\text{-}init} f_c(x)]$

   c. $[\![\text{John}]\!] = j$

   d. $[\![\text{the book}]\!] = b$

   e. $[\![(28a)]\!]$ is defined iff **axis**$(f_{th_i}(b)) \land \forall x',x'' \le b[x' \le x'' \rightarrow f_{th_i}(x') \le f_{th_i}(x'')]$
      If defined $[\![(28a)]\!] = 1$ iff $\exists f'[f'(j) <_{small\text{-}init} f_{th_i}(b)]$

Thus, under this analysis, the coercion configuration is a case which arises when the subject and the complement denotation map to an eventuality (an eventive axis) by the inverse thematic functions f_{ag_i} and f_{th_i} respectively and the complement denotation is in a homomorphic relation to this eventuality.

Our analysis of coercion configuration sentences as involving the mapping of arguments to an eventive axis has further implications for their interpretation. In the following section, we discuss three such

implications – the incremental theme interpretation of complements in the coercion configuration (§6.1), the ambiguity of coercion configuration sentences (§6.2), and the aspectual differences between the coercion configuration and other aspectual verb sentences (§6.3). We then proceed to show in §6.4 how our lexical semantics for aspectual verbs is extendable to sentences in which these verbs have non-finite or gerundive complements (e.g. *John began reading the book/to read the book*).[16]

6. Implications and extensions

6.1. Incremental themes in the coercion configuration

The structured individual presupposition requires that the contextually determined f_c be a homomorphism from the part structure of the complement denotation to the part structure of the axis. This requirement constrains the properties of the eventuality that is construed as the relevant axis in the coercion configuration. Specifically, this eventuality must be one in which the part structure of the complement denotation is incrementally related to the course of the event – i.e. the complement of *begin*, *finish* etc. must be interpreted as an incremental theme argument of the implicit eventuality (Dowty 1991, Krifka 1992, 1998). A thematic relation between eventualities and objects is understood to be incremental iff whenever it holds between an eventuality and an object, every unique proper part of the object is understood to map onto a unique proper part of the eventuality. In the coercion configuration, the structured individual presupposition has the effect of restricting the range of f_{th_i} to eventualities with incremental theme participants.

This naturally accounts for an observation about the coercion configuration that has, to our knowledge, never been made before. The observation is that a sentence in the coercion configuration such as *John began the book* cannot make reference to any event in which *the book* cannot be construed incrementally, such as an event of John playing with the book or seeing the book (both non-scalar predicates). This incrementality constraint on the interpretation of the eventuality associated with aspectual verbs in the coercion configuration emerges as a purely stipulative constraint in a type-shifting, mismatch-repair approach to their semantics. On the current approach, in which the complement denotation is always required to be homomorphically related to an axis, the incremental constraint on the axial eventuality in the coercion configuration falls out as a direct consequence of the general analysis.

[16]All examples in §6 are constructed and not naturally occurring.

We should note here that the structured individual presupposition, while essentially correct, is still not general enough. Specifically, it fails to account for interpretations that intuitively seem to involve incremental change but where the change does not involve a part structure homomorphism between the complement denotation and the eventuality. Degree achievements are a case in point and their relation to incremental theme verbs has been discussed extensively in the literature on aspectual telicity (Kennedy and Levin 2008; Kennedy 2012). A sentence like *John began the soup* can plausibly be interpreted in the right context as describing a situation in which John began cooling or warming the soup, in addition to the more salient interpretations in which it describes the consumption or creation of the soup. The relevant homomorphism here is between an interval of degrees corresponding to the change in the warmth or coolness of the soup (accessed through the complement NP *the soup*) and the axial eventuality in which this change takes place. But on the current analysis, there is no direct way to construe the soup as a structured individual relative to an eventuality that corresponds to a degree achievement, since the notion is defined in exclusively in terms of the part structure of the complement denotation. We leave the development of a more precise analysis that can accommodate this pattern for later work.

6.2. *The ambiguity of coercion configuration sentences*

Consider the sentences in (29), which exemplify the coercion configuration (animate, agentive subject argument and individual-denoting complement).

(29)   a. The little girl began the queue.

         b. Beethoven began the list.

In each example, the axis can be taken to be an eventuality determined by applying f_{th_i} to the complement denotation and the subject referent can be mapped to the axial eventuality by f_{ag_i}. So (29a) can be paraphrased as *The little girl began forming the queue* and (29b) as *Beethoven began making the list.*

However, there is a non-agentive reading of the sentences in (29) in which the axis is not taken to be an eventuality. So (29a) can also be understood as describing the position of the little girl relative to the structure of the queue. (29b) has a reading in which Beethoven's name occurs at the beginning of a list, say, of Romantic-era composers, in alphabetical order, or in order of importance. The availability of these non-eventive readings even when the subject referents are arguably animate, sentient entities gives support to our claim that aspectual verbs do not carry a selectional restriction for eventive complements and that the

presence of an agentive, animate subject argument and an entity-denoting complement does not obligatorily give rise to an eventive interpretation.

Here is how our analysis accounts for the "non-coercion" reading of (29a). We assume that ordered sets of ordinary individuals denoted by expressions such as *row*, *list*, *queue* etc. are axes (one-dimensional dpss) and thus also satisfy the structured individual presupposition (see Appendix B (individual axes)). Let f_c be $f_{identity}$, mapping the complement denotation to itself. Presupposition satisfied, (29a) is true iff there is a function f' such that f' applied to the little girl is a small initial part of the queue. We can let f' be $f_{identity}$, and the sentence is true iff the little girl is the initial atom of the queue.

(30) a. $[\![\text{begin}]\!] = \lambda x_\tau \lambda y_\sigma : \textbf{struct-ind}_{f_c}(x). \exists f'[f'(y) <_{\textit{small-init}} f_c(x)]$

b. $[\![\text{The little girl}]\!] = g$

c. $[\![\text{the queue}]\!] = q$

d. $[\![(29a)]\!]$ is defined iff $\textbf{axis}(f_{identity}(q)) \wedge \forall x', x'' \leq q[x' \leq x'' \rightarrow f_{identity}(x') \leq f_{identity}(x'')]$
   If defined $[\![(29a)]\!] = 1$ iff $\exists f'[f'(g) <_{\textit{small-init}} f_{identity}(q)]$

A variation within this class of cases involves examples in which the subject referent undergoes reference transfer, as in the examples in (31).

(31) a. Mozart began the anthology of the Classical Period compiled by the Indiana University Music School.

b. Van Gogh finished the cycle of Impressionist exhibits organized at the MOMA last spring.

Similar to the cases in (29), the sentences in (31) are ambiguous between an agentive reading and a non-agentive reading. On the agentive reading, the sentences describe events initiated and completed by Mozart and Van Gogh respectively. However, on the non-agentive reading, the subject NPs *Mozart* and *Van Gogh* do not refer to the individuals Mozart and Van Gogh, but rather to pieces of music/art created by these individuals. On the assumption that animacy preferences are lexically encoded, the mechanism by which such constrained reference change occurs is metonymy – specifically, "producer-for-product" metonymy (Frisson & Pickering 2007, Piñango et al, 2014). This metonymic process is one of the differences between (29) and (31).

(31a), on the non-agentive reading, conveys that some selection from Mozart's work is a small, initial subpart (perhaps the initial piece) of the set of pieces compiled in the Anthology. (31b) conveys that

some selection of Van Gogh's work is a small final subpart of the MOMA Impressionist exhibits.

Such cases are naturally accounted for on our analysis, once metonymy is taken into account. In the case of (31a), the axis is the body of information corresponding to the anthology and the relevant function is $f_{content}$ (a partial function from $\mathscr{D} \to \mathscr{D}$) that maps an individual to the informational content associated with it (discussed also in appendix B (informational axes)). *Mozart* maps via metonymic transfer to some piece composed by Mozart, say $m+$. It is straightforward how the meaning of (31a) is derived once *Mozart* is taken to refer to a non-sentient, inanimate individual that is associated with informational content. (31a) is defined if the anthology is a structured individual on the informational dimension (i.e. the information contained in the anthology is an axis) and it is true iff there is a function f' that maps $m+$ (Mozart's work) to a small initial subpart of this informational axis. There is such an f', viz. $f_{content}$.

(32)   a. $[\![\text{begin}]\!] = \lambda x_\tau \lambda y_\sigma :$ **struct-ind**$_{f_c}(x). \exists f'[f'(y) <_{\text{small-init}} f_c(x)]$

    b. $[\![\text{Mozart}]\!] = m+$

    c. $[\![\text{the anthology}]\!] = a$

    d. $[\![(31a)]\!]$ is defined iff **axis**$(f_{content}(a)) \wedge \forall x', x'' \le a[x' \le x'' \to f_{content}(x') \le f_{content}(x'')]$
       If defined $[\![(32a)]\!] = 1$ iff $\exists f'[f'(m+) <_{\text{small-init}} f_{content}(a)]$

The point here is to show that the coercion configuration is multiply ambiguous and that the resolution of this ambiguity depends on the dimension along which the parthood relation is understood to obtain. As we will see in §7, this property will turn out to be implicated in the cost associated with the real-time comprehension of aspectual verbs in the coercion configuration.

6.3. Aspectual verbs and the eventive/stative contrast

It was observed in §5.2 that sentences in the coercion configuration are often understood eventively, i.e. they describe dynamic events in contrast to invariant stative parthood configurations described by other aspectual verb sentences. The contrast between the sentences in (33a-b) and (33c-d) reflects this aspectual distinction. In (33a), the frame adverb *yesterday* gives an interval within which the event of John finishing the book is contained. (33b) sounds odd because the chapter on poverty and the book are in a relatively invariant stative relation that is not restricted to the interval supplied by *yesterday*. Similarly, for (33c-d).

(33)   a. John finished the book yesterday.

b. ?A chapter on poverty finished the book yesterday.

c. Kim began the Appalachian trail yesterday.

d. ?That little perch began the Appalachian trail yesterday.

An even clearer distinction between the salient reading of the coercion configuration sentences and other aspectual verb sentences involves their interpretations when inflected in the present tense and the progressive aspect. Consider the contrasts in (34a-b).

(34)   a. The clarinet begins the second movement.

b. Kim begins the second movement.

(34a), a present tense sentence, describes a stative situation, the parthood configuration in which the musical content associated with the clarinet is an initial subpart of the musical content of the second movement. In contrast to stative predicates, eventive predicates in the simple present tense tend to receive habitual (rather than event-in-progress) interpretations. That (34b) is understood eventively is evidenced by the fact that it most saliently describes a generalization (habit or assignment of roles) about the musical performance of the second movement. Kim is understood to be the initiator of an event of performing the second movement (the clarinet player, for instance) and such events are understood to be regularly instantiated in time. Thus, the sentential predicate is interpreted eventively in the coercion configuration but statively elsewhere.

Eventive predicates are compatible with progressive aspect marking and give rise to an event-in-progress reading. Stative predicates, on the other hand, are often incompatible with progressive aspect marking (Dowty 1979; Deo 2009). The contrasts in (35) further indicates that coercion configuration and other aspectual verb sentences are aspectually different.

(35)   a. Kim is beginning the second movement.

b. ??The clarinet is beginning the second movement.

c. Shhh! Pay attention now...the clarinet is beginning the second movement.

(35a) describes an event in progress in which the second movement is performed with Kim as the agentive participant in this event. The sentence is acceptable. (35b), however, most saliently describes the structure of the second movement, and is odd with progressive marking. On the other hand, if understood

metonymically, where *the clarinet* denotes the clarinet player in a particular performance of the second movement, as in (35c), the sentence is entirely acceptable.

The contrast between eventive and stative readings of aspectual verb sentences is thus reflected in the grammar and must be addressed in relation to the general analysis proposed here. Based on the data above (and more below) we make the following empirical generalization: *Aspectual verb sentences are interpreted eventively just in case the axis determined by the complement denotation is an eventuality axis.* Axes in all other ontological domains give rise to a stative interpretation.

The coercion configuration straightforwardly falls under this generalization since it is a case where the subject and the complement denotation map to an eventuality (an eventive axis) by the inverse thematic functions f_{ag_i} and f_{th_i} respectively. Further evidence for this generalization comes from cases in which the subject and complement denotation directly denote eventualities (and thus map to an axial eventuality by $f_{identity}$) and cases in which subject denotation maps to the axial eventuality via the inverse thematic function f_{th_i}. These do not instantiate the coercion configuration but exhibit properties of eventive predicates – acceptability with short-duration frame adverbs, habitual/generic interpretation in the present tense, and acceptability with progressive marking. The behavior is illustrated in (36) and (37).

In (36), the subject and the complement both denote eventualities and the sentences describe a parthood relation between these eventualities. As the examples (36a–c) and (36d–f) show, the predicates are compatible with frame adverbs, give rise to a habitual/generic reading in the present tense, and are acceptable with progressive marking.

(36)   a. A discussion about the budget began/finished the Board meeting yesterday.

    b. A discussion about the budget begins/finishes the Board meeting.

    c. A discussion about the budget was just beginning/finishing the Board meeting when some Board members left.

    d. A plenary talk by a distinguished linguist finished the conference last week.

    e. A plenary talk by a distinguished linguist (usually) finishes the conference.

    f. A plenary talk by a distinguished linguist was finishing the conference when a fire broke out.

In (37), the subject denotes an entity while the complement denotes an eventuality. The subject argument gets mapped to the eventuality by the inverse thematic function f_{ag_i} (37a–c) or f_{th_i} (37d–f). Again,

the predicates are compatible with frame adverbs, give rise to a habitual/generic reading in the present tense, and are acceptable with progressive marking.

(37) a. John began the group presentation yesterday.

  b. John (always) begins the group presentations.

  c. John was beginning the group presentation when a fire broke out.

  d. A light papaya salad began the prix fixe meal yesterday.

  e. A light papaya salad begins the prix fixe meal.

  f. A light papaya salad was just beginning the prix fixe meal when we had to rush out because of an emergency.

    We take the data observed here to indicate that an eventive reading of aspectual sentences depends on an eventuality axis in the interpretation of these sentences. The aspectual contrast within this class is a consequence of ontological differences within axes – all types of axes other than eventuality axes give rise to a stative, non-dynamic interpretation.

6.4. Aspectual verbs with non-finite verbal complements

The discussion in this section so far has explored how our analysis bears on certain interpretive properties of aspectual verb sentences – both in the coercion configuration and not. We have focused throughout this paper on the transitive uses of aspectual verbs in which both the subject and the complement are syntactically NPs (DPs). However, aspectual verbs can syntactically combine with non-finite verbal complements, as in the examples in (38).

(38) a. John began/started reading/to read the book.

  b. Mary continued eating/to eat the apple.

  c. Tom finished painting the fence.

    A truly unified analysis of aspectual verbs would extend to these cases and derive them without any extra assumptions or modifications. We are indeed able to do this if we assume that both kinds of non-finite verbal complements (*V-ing NP* and *to V NP*) can denote events. That is, we need to assume that the

complement *reading the book* in (38a) denotes the contextually unique event of reading the book.[17] The full

derivation is then straightforward. In (39a), we notate the event individual denoted by *reading the book* as r.

(39a) is defined iff $f_{identity}$ applied to r yields an axis (i.e. an event with ordered subevents). We let f_c be the

identity function. The truth-conditions of (39a) require there to be a function f' such that f' applied to John

is a small initial part of $f_{identity}(r)$ – i.e. there should be a map from John to a small initial part of the axial

event. There is such a function f_{ag_i}. Thus, (39a) comes out true if the contextually unique event of which

John is an agentive participant at a reference interval i is a small initial part of the contextually unique event

of reading the book.

(39)   a. John began reading the book.

b. $[\![\textbf{begin}]\!] = \lambda x_\tau \lambda y_\sigma : \ \textbf{struct-ind}_{f_c}(x). \ \exists f'[f'(y) <_{\textit{small-init}} f_c(x)]$

c. $[\![\text{John}]\!] = j$

d. $[\![\text{the book}]\!] = b$

e. $[\![\text{reading the book}]\!] = \iota e[\textbf{read}(e) \wedge \textbf{theme}(e,b)]$ (abbreviated to r)

f. $[\![(39a)]\!]$ is defined iff $\textbf{axis}(f_{identity}(r)) \wedge \forall x',x'' \leq r[x' \leq x'' \rightarrow f_{identity}(x') \leq f_{identity}(x'')]$

If defined $[\![(39a)]\!] = 1$ iff $\exists f'[f'(j) <_{\textit{small-init}} f_{identity}(r)]$

7. Accounting for the processing cost of aspectual verbs

In §4 we have offered an explicit lexical semantic analysis of aspectual verbs – an analysis that not only

captures their distribution in the coercion configuration but also accounts in a unified way for the full range

of parthood based readings exhibited in the transitive uses of these verbs. This analysis states that the

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[17]The full compositional analysis of how the non-finite verbal complements come to denote an event individual

(rather than an event predicate or a function from ordinary individuals to sets of events) would need to be worked

out precisely, but we believe that such an exercise would not require any unusual semantic or syntactic assumptions.

Crucially, the analysis given here takes it that there are three types of syntactic complements of aspectual verbs that

have eventive reference – event-denoting NPs (*meeting, lecture*), event-denoting non-finite VPs (*to V NP*), and event-

denoting gerundive VPs (*V-ing NP*). The treatment of each of these cases is identical in that the complements denote

structured individuals and the sentences establish parthood relations between initial, medial, or final subevents of an

axial eventuality and the larger structured eventuality.

selectional properties of aspectual verbs should be characterized in terms of structured individuals – entities that can be construed as having a totally ordered part structure that is homomorphic to an axis along some dimension. It is this lexical presupposition that determines how the verb successfully composes with its subject and complement.

Whereas the "type-mismatch and repair via type-shifting" view of the coercion configuration sentences proposed a ready-made measure of complexity, type-shifting, as the source of the observed increased processing cost, the present analysis has no comparable mechanism. So, if there is a processing cost associated with coercion configuration sentences, as the experimental research on complement coercion has robustly shown, what could possibly account for the existence of this cost? Before we propose an account of the processing profile of aspectual verbs, we resummarize the basic psycholinguistic observations. In §2 we noted that out of the sets of verbs used in complement coercion experiments (where the "coercion set" is understood as that composed of verbs that are not semantically unifiable beyond the paraphraseability diagnostic), only aspectual verbs (in contrast to psychological verbs, the other major semantically coherent verb class tested) have been shown to elicit the expected processing effect (Katsika et al. 2012, Utt et al. 2013, Lai et al., 2014)). As mentioned earlier, two properties have been systematically reported in connection to the processing of the coercion configuration: 1) the coercion effect is expressed as cost, that is, comprehending sentences containing the coercion configuration requires more processing resources (measured as longer reading time, greater electrical activity) than interpreting a minimal counterpart, and 2) the cost observed takes some time to fully develop, that is, its full effect is not observed at the licensing point but sometime after (i.e. after the entity-denoting complement has been heard/read).

7.1. Processing cost results from the presence of semantic ambiguity

Our analysis treats sentences containing aspectual verbs as manifesting a semantic ambiguity that comes from the dependence of the interpretation on the nature of the function applied to the complement denotation. On the analysis, truth conditions of *all* aspectual verb sentences, including the coercion configuration set, can only be determined after the relevant function has been chosen. Moreover, these sentences can receive multiple interpretations which, crucially, are mutually incompatible. This means that the interpretation of a coercion configuration sentence entails two processes that are potential sources of cost: 1) the exhaustive activation of all possible functions that are lexically encoded in these verbs, and 2) the determination of the

specific dimension from the conceptual structure of the complement (informational, temporal, spatial etc...) that determines how the axis is to be established. There are at least three clear advantages to this approach to accounting for the observed cost:

a. The account makes use of independently motivated sources of cost. In the mismatch and repair approach the notion that type-shifting would be a source of cost, although intuitive, had no independent basis in previous real-time processing studies. By contrast, lexical load and ambiguity resolution have been shown independently to be metrics of complexity (e.g., Shapiro et al., 1989, Rayner & Frazier, 1990, respectively)

b. The account grounds interpretation in independently motivated properties of conceptual structure – the extents of entities along distinct ontological dimensions and one-dimensional axial entities. In doing so it gives the analysis cognitive validity.

c. The account places the work of composition on the mechanisms of the grammar, while maintaining the general-purpose nature of the processor. So, on this account, the processor is not sensitive to *specific* grammatical details of composition such as type-mismatch and type-shifting, but is instead susceptible only to coarser-grained information such as presence of ambiguity and lexical load, factors that emerge from the grammatical set-up but which are not necessarily grammatical in themselves.

In sum, we propose that it is the combination of two processes – exhaustive activation of functions that are maps between ontological domains (**at the verb**) and dimension determination (**at the complement**) – that is the source of the cost observed in the comprehension of coercion configuration sentences. [18]

We note at this point that the indeterminacy at the level of dimension is quite distinct from the kind that arises in identifying the particular activity that connects the subject referent to the structured individual denoted by the complement. In the sentence *John began the book*, even after f_{θ_i} is determined to be the relevant function, it could be argued that the sentence still exhibits an ambiguity with respect to whether the

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[18]We have focused on the processing profile of the coercion configuration because this happens to be the only experimentally studied subclass of aspectual verb sentences. However, as has been shown, our analysis extends to a whole family of related constructions for which experimental predictions are straightforward but which are yet to be tested (although see Lai et al., 2014 for one particular elaboration involving a contrast with general psychological verbs such as *love* and *like*.)

implicit eventuality is one of reading or writing or restoring or decorating the book. But such ambiguity does not appear to contribute to the processing cost. Previous work has explicitly shown that the locus of the processing cost resides NOT in the process of *selecting* a particular action (retrieving a specific activity) but in *inferring* the presence of an eventive sense in the meaning of coercion sentences (Traxler et al 2005, Frisson & McElree 2008). Specifically, Traxler et al. found that the cost persists even when previous context disambiguates the intended implicit activity. The former is treated as an extra-sentential inference whose full resolution is not required for the immediate interpretation of the sentence (see Frazier & Rayner, 1990 for an experimental exploration of this distinction). Accordingly, its presence entails no processing cost. Our explanation is entirely in agreement with that view: we do not attribute the cost observed to determining any specific implicit activity but rather to retrieving the aspectual verb with all its functions specified, and to identifying the dimension along which the complement is structured, without which the VP cannot be interpreted.

Our account of the observed processing profile of aspectual verbs with agentive subject referents makes two general predictions: 1) the cost of interpretation will always occur given the requirement of exhaustive activation and of dimension determination regardless of the complement, and 2) the cost can be attenuated if the intended dimension can be gleaned from the preceding context and/or if the complement denotation reduces the dimension-selection ambiguity by providing a salient dimension along which the axis can be established. That is, if contextual information is provided that cues the processor to a specific intended dimension or directly to an axis, the ambiguity will either disappear or become asymmetric enough in favor of the intended reading so that computational cost will decrease, sometimes enough to remain undetectable.

Interestingly previous work has already shown that these predictions are likely to be borne out once the predicate set is limited to aspectual verbs. For example, Traxler et al. 2002 compare coercion verbs (again, not limited to aspectual verbs) with entity-denoting complements *began/enjoyed the book* with coercion verbs with event-denoting complements *began/enjoyed the fight*. The motivation for the comparison is that if coercion verbs select for events, the two conditions should contrast such that cost is only observed in the condition with the entity-denoting complement. And indeed that is the result reported.

Given our stance that a) only aspectual verbs exhibit the coercion effect, and b) aspectual verbs do not have a selectional restriction, this is a potentially puzzling result. However, we interpret this result as follows: The difference in processing cost observed does not reflect a categorical distinction but a difference

in degree of cost: in the event-denoting condition, the eventive complements *fight/dance/lecture* present the processor with an eventuality which is by definition a structured individual. The cost associated with dimension determination is therefore eliminated, which leads to a difference in observed processing cost relative to the counterpart condition containing the entity-denoting complement

Another example of results that potentially support our analysis is Traxler et al (2005). This study describes four experiments examining the impact of previous context on the magnitude of the processing cost associated with coercion sentence comprehension. The first two of those experiments tested the impact of a related activity context on the comprehension of a coercion-containing target sentence (subsequently presented). The results from Experiments 1 & 2 show that introducing such a related activity in the previous context e.g., *been building in the suburbs* does not attenuate the coercion effect in a subsequent sentence e.g., *began a condominium* as compared to neutral context e.g., *been looking for new jobs*.

(40) a. The contractor had **been building** in the suburbs   (event context)

b. The contractor had **been looking** for new jobs   (neutral context)

c. That spring, he **began a condominium** next to the shopping center.   (coercing target)

Our analysis predicts this finding in the following way: even though an activity salient in a given context can ultimately be the axial eventuality to which the complement denotation is homomorphically mapped, this mapping depends on the selection of the appropriate function in context. The presence of an activity in a previous context does not necessarily predict the dimension along which the complement in the subsequent coercion configuration sentence will be interpreted. From the processing perspective, this means that in the target sentence, when the complement of the aspectual verb is reached, the dimension along which *that complement* can be construed as a structured individual must still be determined. And it is this process of determining the relevant dimension, in addition to the exhaustive retrieval of all the functions stored in the aspectual verb that is predicted by our analysis to be the basis of the processing cost.

Notably, this possibility of priming for a structured individual is subsequently addressed in Traxler et al.'s experiments 3 & 4 where they compare the reading time of sentences such as those in (42) when they are preceded respectively by contexts such as those in (41).

(41) a. *Context-1 Coerced:* The contractor began a condominium in the spring.

b. *Context-2 Control:* The contractor built a condominium in the spring.

(42) a. *Target-1 Coerced:* After he <u>began</u> the condominium next to the mall, he won a big contract for another project.

b. *Target -2 Control:* After he <u>built</u> the condominium next to the mall, he won a big contract for another project.

The study reports a difference in reading time between (42a) and (42b) – (42a) > (42b) – and only for the predicted region in the context sentences. In the target sentence by contrast, the difference in reading time, and presumably the processing cost, is reported to be no longer reliably detectable.

Whereas these findings have been unexpected under all previous repair-based accounts, our analysis captures them naturally: The introduction of the aspectual verb in the context sentence (compare the difference between (41a) and (41b) by definition causes dimensional ambiguity (from the complement) resulting in predictable differential cost between (41a) and (41b). However, in the subsequent target sentence contrast – (42a) and (42b) – the impact of the ambiguity from the expression must disappear or significantly lessen because the interpretation has already been biased, presumably in the direction of the eventive dimension, triggered by the presence of the animate-denoting subject. Hence, significantly lesser or no cost is predicted, and indeed, no cost is observed.

8. Concluding remarks

In this paper, we have examined the phenomenon of complement coercion by undertaking an explicit lexical semantic analysis of the class of aspectual verbs. This class has been identified to be at the core of the coercion effect and it has been shown to reliably elicit computational cost. This paper had two goals a) to analyze the lexical semantics of aspectual verbs, and b) to connect the analysis to a proper account of the processing cost observed.

We have offered an analysis of aspectual verbs according to which they are lexically specified as combining with structured individuals (i.e. entities that map to one-dimensional axes in any ontological dimension via a constrained set of functions). This analysis is supported empirically by the broad range of arguments that aspectual verbs successfully combine with and the nature of interpretations that such combinations give rise to. The analysis also naturally accounts for certain constraints on the interpretation

of complements in the coercion configuration – they must be interpreted as incremental themes. It also is able to account for the contrast between eventive and stative readings of aspectual sentences as being rooted in the nature of the axis – only eventuality axes give rise to eventive interpretations.

The processing outcome of our observations and analysis is that the assumption that these verbs select for event-denoting arguments – which has been the backbone of all complement coercion experimental studies to date – is not tenable. This, in turn, means that the cost reported in experimental work cannot be attributed to the repair of mismatches induced by individual-denoting complements. Instead, we interpret the observed processing effect as the result of a semantic ambiguity that emerges from the requirement of determining the dimension along which the complement denotation is structured and the exhaustive retrieval of all the necessary functions encoded in the verb which facilitate the mapping between the complement denotation and the axis.

As we close, we note that our analysis makes use of general logical and conceptual notions – entities are understood to extend in different ontological dimensions and such extents are sometimes (construable as) axial. There is no purely formal non-conceptually grounded machinery (such as type-shifting) invoked for specific operations. The analysis and the view within which it is couched offers a way of addressing the question of whether the language system and its processing machinery distinguishes between ontological dimensions as it composes concepts. The semantico- conceptual behavior of aspectual verbs suggests that no such distinction is necessary. We leave it for future research to articulate the processing and neurological implications of this generalizing outcome.

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Appendix A: A sampling of contrasts tested in complement coercion studies

(43) **McElree et al 2001 (self-paced reading)**

    a. The author was <u>starting</u> the book in his house on the island.   **coerced**

    b. The author was <u>writing</u> the book in his house on the island.   **control 1**

    c. The author was <u>reading</u> the book in his house on the island.   **control 2**

(44) **Piñango & Zurif 2001 (picture-matching and focal brain lesions)**

    a. The boy <u>began</u> the book.   **coerced**

    b. The boy <u>began</u> reading/writing the book.   **control**

(45) **Traxler et al 2002 (self-paced reading; eye-tracking)**

    a. **Experiment 1**

      i. The secretary <u>began</u> the memo about the new office policy.

      ii. The secretary <u>typed</u> the memo about the new office policy.

      iii. The secretary <u>read</u> the memo about the new office policy.

    b. **Experiments 2&3**

      i. The boy <u>started</u> **the fight** after school today.   **eventive NP**

      ii. The boy <u>started</u> **the puzzle** after school today.   **individual NP**

iii. The boy <u>saw</u> **the fight** after school today.   **Control**

(46) **Lapata et al 2003 (sentence completion)**

a. Der Student/Autor/Peter <u>begann</u> das Buch ...

b. The student/author/Peter <u>began</u> the book ...

(47) **De Almeida 2004 (self-paced reading)**

The secretary <u>began/typed/read</u> the memo long before it was due.

(48) **Pickering et al 2005 (eye tracking)**

a. The carpenter <u>began</u> the table during the morning break.   **coerced**

b. The carpenter <u>built</u> the table during the morning break.   **preferred**

c. The carpenter <u>sanded</u> the table during the morning break.   **non-preferred**

d. The carpenter <u>began building</u> the table during the morning break.   **full-VP preferred**

(49) **Traxler et al 2005 (eye tracking)**

a. *Context-1 Coerced:* The contractor began a condominium in the spring.

b. *Context-2 Control:* The contractor built a condominium in the spring.

c. *Target-1 Coerced:* After he <u>began</u> the condominium next to the mall, he won a big contract for another project.

d. *Target -2 Control:* After he <u>built</u> the condominium next to the mall, he won a big contract for another project.

(50) **Pylkännen & McElree, 2007 (MEG) and Baggio et al. 2009 (ERP)**

a. The journalist <u>began</u> the article before his coffee break.   **coerced**

b. The journalist <u>astonished</u> the article before his coffee break.   **anomalous**

c. The journalist <u>wrote</u> the article before his coffee break.   **neutral**

(51) **Husband et al 2011 (fMRI)**

a. The novelist <u>began</u> the book before break.   **coerced**

b. The gymnast <u>attempted</u> the beam in competition.

c. The toddler <u>enjoyed</u> the cupcake before napping.

d. The novelist <u>wrote</u> the book before break.   **control**

e. The gymnast <u>walked</u> the beam in competition.

f. The toddler <u>ate</u> the cupcake before napping.

(52)   **Katsika, Braze, Deo, and Piñango 2012 (Eye tracking)**

a. The new interns, Alexandra and John, loved to read novels.   **context**

b. John was <u>beginning</u> a book when the secretary announced the meeting.   **aspectual**

c. John was <u>enjoying</u> a book when the secretary announced the meeting.   **psychological**

d. John was <u>shelving</u> a book when the secretary announced the meeting.   **control**

Appendix B: More cases of mapping to axes via identical functions

Temporal axes: The temporal cases (illustrated in (8d) and other sentences in (8)) are those in which the complement denotation is understood to be structured along the temporal dimension. *midnight* and *day* are kind referring expressions in (53a) and directly denote (kinds of) temporal intervals. We can make sense of the sentence by assuming that the relevant function is simply the identity function $f_{identity}$. That is, f_c is resolved to $f_{identity}$ and the existential statement about f' is satisfied by $f_{identity}$. The sentence is then true when the kind of interval denoted by *midnight* is a small final subpart of the kind of interval denoted by *the day*.

(53)   a. Midnight <u>ends</u> the day.

b. $[\![\text{end}]\!] = \lambda x_\tau \lambda y_\sigma : \textbf{struct-ind}_{f_c}(x). \exists f'[f'(y) <_{\textit{small-fin}} f_c(x)]$

c. $[\![\text{midnight}]\!] = m$

d. $[\![\text{the day}]\!] = d$

e. $[\![(53a)]\!]$ is defined iff **axis**$(f_{identity}(d)) \wedge \forall x', x'' \leq d[x' \leq x'' \rightarrow f_{identity}(x') \leq f_{identity}(x'')]$

If defined $[\![(53a)]\!] = 1$ iff $\exists f'[f'(m) <_{\textit{small-fin}} f_{identity}(d)]$

Eventive axes: In the case of (9a) (repeated as (54a)), and other examples of the kind, the subject denotation and the complement denotation are most naturally understood to denote events. We take the axis to be an ordered set of subevents of the larger banquet event. Taking both f_c and f' to be the identity function, the sentence is true when the prayer event is a small initial subpart of the structured event individual denoted by *the banquet*.

(54)   a. A prayer <u>started</u> the banquet.

   b. $[\![start]\!] = \lambda x_\tau \lambda y_\sigma :$ **struct-ind**$_{f_c}(x). \exists f'[f'(y) <_{\textit{small-init}} f_c(x)]$

   c. $[\![a\ prayer]\!] = p$

   d. $[\![the\ banquet]\!] = b$

   e. $[\![(54a)]\!]$ is defined iff **axis**$(f_{identity}(b)) \wedge \forall x', x'' \leq b[x' \leq x'' \rightarrow f_{identity}(x') \leq f_{identity}(x'')]$

   If defined $[\![(54a)]\!] = 1$ iff $\exists f'[f'(p) <_{\textit{small-init}} f_{identity}(b)]$

Individual axes: Ordered sets of ordinary individuals denoted by expressions such as *row*, *list*, *queue* etc. are axes (one-dimensional dpss) and thus also satisfy the structured individual presupposition. Like the eventive and the temporal cases, the sentences like those in (10) can be straightforwardly derived by letting f_c and f be the identity function.

(55)   a. A little porcelain pot <u>finished</u> the row.

   b. $[\![start]\!] = \lambda x_\tau \lambda y_\sigma :$ **struct-ind**$_{f_c}(x). \exists f'[f'(y) <_{\textit{small-init}} f_c(x)]$

   c. $[\![a\ little\ porcelain\ pot]\!] = p$

   d. $[\![the\ row]\!] = r$

   e. $[\![(55a)]\!]$ is defined iff **axis**$(f_{identity}(r)) \wedge \forall x', x'' \leq r[x' \leq x'' \rightarrow f_{identity}(x') \leq f_{identity}(x'')]$

   If defined $[\![(55a)]\!] = 1$ iff $\exists f'[f'(p) <_{\textit{small-fin}} f_{identity}(r)]$

Informational axes: The informational parthood reading arises when the axis is some set of informational content structured by both parthood and precedence. Let $f_{content}$ be a partial function from $\mathscr{D} \rightarrow \mathscr{D}$ that maps an individual to the informational content associated with it. For many objects that carry informative

content, (e.g. books, movies, CDs, playlists, letters, pages) this content can be construed as an axis (i.e. a one dimensional path). But not all objects that may be associated with informational content are saliently associable with structured informational content (e.g. signboards, blackboards, hard drives). Thus, an individual associated with informational content in $\mathscr{D}$ can be said to be a structured individual along the informational dimension only if $f_{content}$ is an axis.

Consider the sentence in (56a) as an illustration. Let f_c and f' be taken to be $f_{content}$. The informational content corresponding to the album is an axis since the informational parts of the album are totally ordered. (56a) is true when the informational content associated with "under the sun" is the minimal final part of the ordered informational content associated with the album.

(56)   a. "Under The Sun" <u>ends</u> the album.

        b. $[\![\text{end}]\!] = \lambda x_\tau \lambda y_\sigma : \ \textbf{struct-ind}_{f_c}(x). \ \exists f'[f'(y) <_{\textit{small-fin}} f_c(x)]$

        c. $[\![\text{Under the sun}]\!] = u$

        d. $[\![\text{the album}]\!] = a$

        e. $[\![(56a)]\!]$ is defined iff $\ \textbf{axis}(f_{content}(a)) \wedge \forall x',x'' \leq a[x' \leq x'' \rightarrow f_{content}(x') \leq f_{content}(x'')]$

          If defined $[\![(56a)]\!] = 1$ iff $\exists f'[f'(p) <_{\textit{small-fin}} f_{content}(b)]$

Examples like those in (11) contrast in acceptability with sentences like those in (57) below where the informational content associated with the complement denotation is not structured. It is much harder, although possible, to construe the information associated with the complements as an axis and we believe that this is the source of the acceptability contrast.

(57)   a. ?The next lemma <u>ends</u> the blackboard.

        b. ?The paper on environmental degradation <u>begins</u> the usb-stick.

        c. ?A female figure <u>begins</u> the restroom sign.

Other cases: In addition to the familiar dimensions of space, time, events, and information, there appear to be specialized ones whose information must be lexically encoded in the lexical entries of particular expressions. For instance, in a sentence like (58a), one may construe the relevant axis as being some open interval or range of electromagnetic radiation that contains the visible color spectrum, ordered by wavelength. Let us

call the set of all electromagnetic radiations A_{er}.[19] f_c is understood to be f_{wl}, a function that assigns to each interval on the visible color spectrum its range of wavelengths. For instance, it assigns to the violet part of the spectrum a wavelength range of between 380 and 420 nanometers and to the orange part of the spectrum, a wavelength range of between 590 and 625 nanometers. *Black* is taken to denote those parts of the spectrum that correspond to the color black (technically the non-visible edges of the color spectrum). The existential component of the assertion is satisfied by letting f' also be f_{wl}. (58a) will be true on this analysis because f_{wl} assigns to these intervals of electromagnetic radiation wavelengths that are the the initial and the final subintervals of the range of wavelengths corresponding to the visible spectrum.

(58)   a. Black <u>starts and ends</u> the visible spectrum.

   b. $[\![black]\!] = b$

   c. $[\![the\ visible\ spectrum]\!] = v$

   d. $[\![(58a)]\!]$ is defined iff $\mathbf{axis}(f_{wl}(v)) \wedge \forall x', x'' \leq v[x' \leq x'' \rightarrow f_{wl}(x') \leq f_{wl}(x'')]$
   If defined $[\![(58a)]\!] = 1$ iff $\exists f'[f'(b) <_{small\text{-}init} f_{wl}(v)] \wedge [f'(b) <_{small\text{-}fin} f_{wl}(v)]$

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[19]For the typical human eye, the visible range is waves of length between 380 and 750 nanometers. We assume that the axis is an open interval including its endpoints so that we are able to make sense of the quite easily understandable sentence (58a). Technically the color black is associated with wavelengths beyond the visible color spectrum.