

Temporal Forces and Type Coercion in Strings

Derek Kelleher

Trinity College Dublin
Dublin 2
Ireland
kellehdt@tcd.ie

Tim Fernando

Trinity College Dublin,
Dublin 2,
Ireland.
Tim.Fernando@cs.tcd.ie

Carl Vogel

Trinity College Dublin,
Dublin 2
Ireland.
vogel@cs.tcd.ie

Abstract

Durative forces are introduced to Finite State Temporality (the application of Finite State Methods to Temporal Semantics). Punctual and durative forces are shown to have natural representations as fluents which place certain constraints on strings. These forces are related to previous work on stative explanations of aspectual classification. Given this extended ontology, it is shown how type coercion can be handled in this framework.

1 Introduction

In recent years, a novel use of Finite State Methods has been their application to the field of Temporal Semantics (Fernando, 2014). Finite sets of temporal propositions (called fluents) are treated as symbols of an alphabet, with strings capturing the temporal ordering of these propositions. Fluents in the same box are taken to hold at the same time, and fluents in subsequent boxes are taken to hold at subsequent times. For example, the untensed event “reach the top” can be represented as a simple state change from (–at-the-top) to (at-the-top):

$$\boxed{\text{–at-the-top}} \mid \boxed{\text{at-the-top}} \quad (1)$$

Since Vendler (1957), it has been common to classify verbs/predicates/events into one of four aspectual types: states, activities, accomplishments, and achievements. The classification into these four different categories is based on whether an event is positive or negative for two binary features. The first feature is whether it can occur in the progressive. The second is whether it is telic (having a natu-

ral end-point) or not. Activities occur in the progressive and are non-telic:

- John was walking.

Accomplishments occur in the progressive and are telic:

- John walked a mile.

Achievements do not occur in the progressive and are telic:

- John won the race.

States do not occur in the progressive and are non-telic:

- John loved Mary.

Dowty (1979) took states to be the primitive entity, and operators were proposed that acted on states to give the other classes. More recently, a fifth class known as semelfactives or points has been added to the traditional four-fold classification.

A more recent approach to verbs known as Degree Achievements, such as “cool”, posits that properties such as telicity/durativity are based on scales that a property of an argument of the verb moves along. In the case of “the soup cooled”, the temperature of the soup moves negatively along a temperature scale. Viewing the temperature of the soup as a state, this approach can be seen to be in the same vein as Dowty’s, with observations of changes in state being the main factor in determining aspectual category.

However, this approach seems unsatisfactory in certain cases. There are punctual events where the start state is identical to the end state (“blink”), and durative events where it is extremely difficult to identify a natural scale that a property of the verb argument moves along (“beat a man”).

From early on, the notion of “force” has played a part in aspectual classification, with Dowty (1979) distinguishing between states and activities by whether they could occur as complements of “force”:

- #John forced Harry to know the answer
- John forced Harry to run

This paper introduces durative forces to Finite State Temporality (hereafter referred to as FS-Temporality¹), and builds upon the use of punctual forces in Fernando (2008). Forces are shown to have natural interpretations as fluents (though having different properties to stative fluents). Stative consequences (if any) are spelt out using string constraints. Durative forces are related to the semantic scales of Hay et al. (1999) and Beavers (2013), giving an explanation for durative phenomena based on scales in terms of forces.

Interest in computational approaches to aspectual phenomena is increasing in light of Van Lambalgen and Hamm (2008), where a first-order formalism, the Event Calculus, also using forces as part of its ontology, is implemented using logic programming. Finite state methods complement this approach, with well understood decidability properties, reducing references to the real line to regular languages.

Some events, typically classified as one type, can behave as another type in certain circumstances. For instance, accomplishments can be coerced into activities when combined with the progressive. This suggests a form of type coercion (Moens and Steedman, 1988). Cooper (2012) discusses the idea of “semantics in flux”, proposing that meaning be analyzed “in terms of structured objects that can be modified”. In this spirit, the phenomenon of type coercion is analyzed using strings.

2 Fluents and Strings

Fluents are taken to be primitives in FS-Temporality, with strings being drawn from an alphabet consisting of finite sets of fluents. These fluents are temporal propositions, interpreted relative to intervals. A satisfaction relation \models relates fluents to intervals, with

¹Though the abbreviation FST will be used in subscripts. It is hoped that no confusion will arise with “Finite State Transducers”.

$$I \models \phi \quad (2)$$

indicating that the fluent ϕ is true over the interval I .

Given a set Φ of fluents, the alphabet Σ can be formed by taking 2^Φ , the power set of Φ , consisting of all subsets of Φ (including the empty set). As an example, take $\Phi = \{a, b\}$. The alphabet $\Sigma = \{\{\}, \{a\}, \{b\}, \{a, b\}\}$. To increase legibility, the curly braces surrounding fluents are replaced with boxes, giving $\Sigma = \{\square, \boxed{a}, \boxed{b}, \boxed{a, b}\}$.

The set of fluents is divided into three basic types, representing states, punctual occurrences, and continuous occurrences. These fluents will have certain properties reflecting the different temporal behaviour of these entities.

If a fluent ϕ is homogeneous then whenever it is true of an interval, it is true of every subinterval of that interval:

$$I \models \phi \implies (\forall I' \sqsubseteq I) I' \models \phi \quad (3)$$

If a fluent ϕ is quantized then whenever it is true of an interval, it is not true of any proper subinterval of that interval:

$$I \models \phi \implies (\neg \exists I' \sqsubset I) I' \models \phi \quad (4)$$

If a fluent ϕ is ψ -causative then whenever ϕ is true of an interval, and there is no $\neg\psi$ -causative fluent true of that interval, ψ is true of a subsequent interval:

$$(\forall I) I \models \phi \text{ and } I \not\models F[\neg\psi] \text{ implies } (\exists I')(I \text{ m } I' \text{ and } I' \models \psi) \quad (5)$$

If a fluent ϕ is ψ -causative (for some fluent ψ) then it is said that ϕ is a force for ψ . If a fluent ϕ is $\neg\psi$ -causative (for some fluent ψ) then it is said that ϕ is a force against ψ .

That ϕ is a force for ψ can be written as $\phi:F[\psi]$, and $F[\psi]$ can be written in place of ϕ when we are solely concerned with its causative property. That ϕ is a force against ψ can be written as $\psi:F[\neg\psi]$.

If a fluent ϕ is inertial then whenever ϕ holds of an interval and no fluent that is a force against ϕ holds of that same interval, then ϕ holds of some subsequent interval:

$$\begin{aligned}
(\forall I)I \models \phi \text{ and } I \not\models F[\neg\phi] \\
\text{implies } (\exists I')I \text{ m } I' \text{ and } I' \models \phi \\
(6)
\end{aligned}$$

As mentioned above, given these four properties of fluents, we can distinguish between three types of fluents: stative fluents (type s_{FST}), punctual occurrence fluents (type e_{FST}), and durative occurrence fluents (type f_{FST}). Stative fluents are intuitively homogeneous, inertial, and non-causative. If John loves Mary for a month, he loves her for every part of that month (homogeneity). If John knows a fact today, he will know the fact a week later, unless something causes him to forget it (inertial). A state holding does not entail that subsequently another state will hold, or cease to hold (non-causative).

Unlike states, where there is no change over an interval they hold of, occurrences mark change. A punctual occurrence fluent indicates a change over an interval it holds of. A punctual occurrence fluent is quantized, non-inertial, and can be causative or non-causative. If the fluent is causative, then not only does it mark change, it specifies the results of that change. The importance of this distinction (between simply marking change, and specifying the results) can be seen in the distinction between achievements and semelfactives.

An achievement is typically thought to be a punctual occurrence, resulting in some new state holding. For instance, the achievement “reach the top” (of, say, a mountain) results in the state of being at the top of the mountain. A semelfactive, or point, makes no such commitment to a consequent state. It is difficult to imagine what state results from prototypical examples of semelfactives, such as “sneeze” or “blink”.

Dowty explained achievements in terms of states by positing an operator BECOME that operates on a state. $\text{BECOME}(\phi)$ is true at time t if ϕ was false before t , and true after it. The achievement “reach the top” then becomes $\text{BECOME}(\text{at-the-top})$. Semelfactives resist a stative explanation such as this, because they have no salient results.

Allowing event fluents which mark change

and possibly specify the consequences of that change solves this problem:

- Achievement: $\boxed{e, \neg\phi \mid \phi}$
- Semelfactive: \boxed{e}

It may seem strange to associate a punctual occurrence with an interval. However, Comrie (1976) notes that punctuality is a matter of perspective, describing a video of a cough (typically thought of as punctual) slowed down so that the cough now has duration. Here, punctuality is a structural notion, and not a strictly temporal one. Punctual occurrences are viewed as having no internal structure, while durative/continuous occurrences do.²

A continuous/durative occurrence also marks change over an interval, but may be part of a larger change. For instance, walking (if the distance/time is unspecified) may be broken up into multiple stages of walking, and these substages can be repackaged together into a larger walking. Punctual occurrences mark the entire change, and cannot be broken up and repackaged in the same manner. This has linguistic consequences in terms of telicity. Durative occurrence fluents are therefore homogeneous in contrast to the quantized nature of punctual occurrence fluents, though like punctual occurrence fluents, they are non-inertial and can be causative or non-causative.

Since Moens and Steedman (1988), it has been common to associate a complex structure based on contingency/causation with events. An event nucleus is an “association of a goal event or ‘culmination’ with a ‘preparatory process’ by which it is accomplished, and a ‘consequent state’ which ensues”. So “climb a mountain” is made up of a preparatory process of a “climb”, a culmination “reach the top” and a consequent state “at the top”. This structure can be formalized as a string using three functions (proc, cul, and cons), which act on fluents of type e_{FST} and return fluents of all three types:

- proc: $e_{FST} \rightarrow f_{FST}$. Associates an event fluent representing a punctual change,

²The second author holds a different view, being of the opinion that the distinction drawn here between structural and temporal notions can be avoided by an appropriate choice of fluents and the use of stutterless strings.

with a durative force fluent representing its preparatory process.

- **cul**: $e_{FST} \rightarrow e_{FST}$. Associates an event fluent representing a punctual change, with another event fluent, also representing a punctual change, the culmination of the event. For example, $\text{cul}(\text{climb-a-mountain}) = \text{reach-the-top}$. From this it is clear why punctuality is taken to be a structural rather than a temporal notion. “Climb a mountain” and “reach the top of the mountain” are both punctual occurrences, but with vastly different temporal spans.
- **cons**: $e_{FST} \rightarrow s_{FST}$. Associates an event fluent representing a punctual change, with a stative fluent representing its consequent state. Essentially, for fluent e_1 of type e_{FST} , $\text{cul}(e_1)$ is causative and a force for $\text{cons}(e_1)$.

The contingency/causal structure can be captured through string constraints. Fernando (2006) defines a constraint:

$$L \implies L' \quad (7)$$

as the set of strings such that whenever $s \supseteq \square^n L \square^m$, then $s \supseteq \square^n L' \square^m$.

\supseteq is the relation “subsumes”, defined as follows: If s and s' are strings, where $s = \alpha_1 \dots \alpha_n$ and $s' = \beta_1 \dots \beta_k$ we say $s \supseteq s'$ iff $n = k$, and for every i , $\alpha_i \supseteq \beta_i$. So every symbol of s contains all the fluents (information) of the corresponding symbol of s' , and possibly more.

An example may make this concept clearer. The constraint $\boxed{\phi} \implies \boxed{\psi}$ says that if a string contains two consecutive boxes that can be subsumed by the language on the left hand side of the above implication, then in that string, those two boxes must be subsumed by the sequence on the right-hand side of the implication, i.e. any string that has ϕ in a box must have ψ in the next box. So the string $\boxed{\chi} \boxed{\phi} \boxed{\psi}$ meets this constraint, but the string $\boxed{\phi} \boxed{\chi} \boxed{\psi}$ does not.

The following constraints relate both $\text{proc}(e)$ to $\text{cons}(e)$, with $\text{cul}(e)$ acting as a mediator between the two:

$$\boxed{\text{cul}(e)} \boxed{\text{proc}(e)} \implies \emptyset \quad (8)$$

Constraint (8) says that no string can have a box containing $\text{cul}(e)$ immediately followed by a box containing $\text{proc}(e)$, formalizing the constraint that $\text{cul}(e)$ ends $\text{proc}(e)$. Of course it is possible for a process to continue after a culmination, leading to a further culmination. Take the example of “climbing” where the second highest peak is reached. The climbing process will continue after this culmination until a new culmination of reaching the highest peak occurs. This can be avoided by positing two different events for “climbing to the second highest peak”, and “climbing the mountain” (the highest peak). Representing these two different event by fluents e_1 and e_2 respectively, the preparatory process of climbing to the second highest peak will be $\text{proc}(e_1)$, while the preparatory process of climbing to the highest peak will be $\text{proc}(e_2)$. Obviously, these processes are the same until the second highest peak is reached, but the culmination of reaching that peak will terminate $\text{proc}(e_1)$, but not $\text{proc}(e_2)$.

$$\boxed{\text{cul}(e)} \implies \boxed{\text{cons}(e)} \quad (9)$$

Constraint (9) says that if any box contains $\text{cul}(e)$, it must be immediately followed by a box containing $\text{cons}(e)$, formalizing the constraint that $\text{cul}(e)$ causes $\text{cons}(e)$.

It is not proposed that all fluents resulting from applications of these functions will have a linguistic realization. It is doubtful that $\text{proc}(\text{cul}(\text{cul}(\text{cul}(\text{reach the top}))))$ makes any sort of cognitive or linguistic sense. And as mentioned before, semelfactives have no salient consequent state. Either $\text{cons}(\text{cough})$ would have no value, or could have some consequence of coughing as a value, with lack of salience equating to lack of a causal constraint between $\text{cul}(\text{cough})$ and $\text{cons}(\text{cough})$.

As noted above, telicity is one of the diagnostic criteria for aspectual classification. The difference between “walking” (activity), and “walking a mile” (accomplishment) is that “walking a mile” has a natural end-point (reaching the end of the mile). In stative accounts this would usually be represented as a transition from a state of not having walked a distance of a mile, to a state of having walked a distance of a mile. As in the case of achievements vs. semelfactives, this can be given a

causative explanation, an event being telic if it has a causative constraint such as (9) associated with it. So telicity is explicable in terms of fluents and string constraints.

From here on, these punctual and durative fluents, previously called occurrences, will be called forces. The initial reluctance to do so stems from the expectation that a force must be a force for or against some stative fluent. The lack of consequences of a punctual occurrence such as “sneeze” may seem to argue against associating it with a force. However, it is assumed here that if there has been an “occurrence”, whether the stative effects of this are stated or not (due to lack of salience for example), then a force has caused this. The difference between forces which specify the resulting stative change, and those that do not, is brought out using string constraints.

3 Continuous Forces and Scales

Kennedy and Levin (2008) propose that the behaviour of incremental theme verbs (“eat”), degree achievements (“cool”), and directed motion verbs (“ascend”) arises from one shared element of their meanings: a measure of the degree to which an object changes relative to some scalar dimension over the course of an event. Under this analysis, verbs based on gradable adjectives like “cool” directly lexicalize measure functions which (given an object and a time) return a value of a degree on a scale. In the case of “cool”, this is likely to be a degree on a temperature scale.

Fernando (2014) encodes this idea in string form, by defining a stative fluent “deg < d” as:

$$I \models \text{deg} < d \iff (\forall r \in I) \text{deg}(r) < d \quad (10)$$

meaning that every degree in the interval is less than d. Another stative fluent “deg_↓” is defined as:

$$\exists x(\text{deg} < x \wedge \text{Prev}(x \leq \text{deg})) \quad (11)$$

holding of an interval if the degree of that interval is less than some degree x, but the degree of the previous interval was greater than that degree x (i.e. the degree has fallen going from one interval to the next).

Defining an operator on fluents $[\sqsupseteq]$ as:

$$I \models [\sqsupseteq]\phi \iff (\forall I' \sqsubseteq I) I' \models \phi \quad (12)$$

and letting the start of an hour be marked by x, and the end of an hour by hour(x), “the soup cooled in an hour” can be represented by the string:

$$\boxed{x \mid [\sqsupseteq]\text{deg}_{\downarrow} \mid \text{hour}(x), [\sqsupseteq]\text{deg}_{\downarrow}} \quad (13)$$

As in the punctual case (Achievements vs. Semelfactives), a stative account of durative change is not always satisfactory. Beavers (2013) uses the idea of a “force recipient” from Hovav and Levin (2001) to make aspectual classifications. Various linguistic tests are diagnostic of whether a force causes change or not:

- What happened to the lamp is that John rubbed it.
- #What happened to the lamp is that John saw it.
- John rubbed the lamp but nothing changed about it.

Beavers classifies “rub” as having the potential for change, positing the existence of a “latent scale”. That the lamp in the above example could undergo change can be seen in the following example:

- John rubbed the lamp clean.

The combination of “happening” and “seeing” is not always problematic. For instance, “What happened to the password is that John saw it”. But seeing a password seems to go hand in hand with changing a password, and is perhaps viewed as being a force for that change, or at least part of the force.

As well as the possibility of undergoing change, Beavers makes aspectual classifications based on the complexity of the underlying scale, with a simplex scale having two subparts, and a complex scale having more than two subparts. Punctuality of an event is seen as resulting from an object undergoing change along a simplex scale, while durativity is seen as resulting from an object undergoing change along a complex scale.

Beaver’s analysis fails when applied to verbs such as “sit”, typically thought of as states, but unlike most states, able to appear in the progressive. Firstly, note that sitting can be seen as application of a force:

- What happened to the chair is that John sat on it (Here the durative act of sitting is meant, rather than the punctual initial act of sitting down).
- ?John sat on the chair and nothing changed about it

The latter may be acceptable for a hard, wooden chair, but unacceptable for a soft armchair that sags under the weight of a person sitting in it.

The potential change a chair can undergo while being sat on is therefore along a simplex scale, going from its initial state to a sagging state during the initial event of being sat upon. The following durative event of sitting causes no change whatsoever. The question arises as to how the progressive applies to this durative sitting, when the progressive is thought to require multiple “stages” (Landman, 1992). Given this, it seems the notion of a continuous force is necessary to explain when the progressive can occur.

It is interesting to note that these “stative” verbs that can appear in the progressive coincide with what Maienborn (2007) calls “Davidsonian” states, in contrast to “Kimian” states (predicates such as “tall”). Key properties of these two different types of states are given, Davisonian states being perceptible, and locatable in space and time, while Kimian states are neither perceptible nor locatable in space (though they are locatable in time). It is possible these properties can be related to forces, and their spatiotemporal nature.

Durative forces can be related to semantic scales in the string approach using string constraints:

$$\boxed{\text{proc}(e)} \implies \boxed{\text{deg}_\downarrow} \quad (14)$$

essentially saying that when $\text{proc}(e)$ holds (for example a “cooling”), deg_\downarrow will hold in the next box (the temperature will have fallen). The above treatment gives no information

about the actual degrees of the soup while it is undergoing change.

Certain functions describing change will have an end-point or maximum/minimum. This may be contextually given, as Fernando assumes, or may be a natural feature of the scale against which change is measured. Closed scales (such as “smooth”) have a natural maximum/minimum, complete smoothness in this case (Solt, 2015). Fluents deg_{max} and deg_{min} can be defined, that are true whenever the maximum/minimum of an underlying continuous change function is reached.

Viewing $\text{proc}(e)$ as the force which causes the change along the semantic scale means that $\text{cul}(e)$ both ends the force and causes the maximum/minimum to be reached. This is formalized in the following constraint:

$$\bullet \boxed{\text{proc}(e), \text{cul}(e)} \implies \boxed{\text{deg}_{max}}$$

4 Aspectual Types

Now that the properties of the different fluent types, and the various string constraints that can be formed from them, have been given, it is possible to give an account of the five aspectual types: semelfactives, achievements, accomplishments, activities, and states. Each of these will consist of a set Σ of fluents, along with a set C of constraints that must be applied to any language that has Σ as part of its alphabet. While in practice the fluents used would have relevant names (the fluent “cough” representing a cough), here, general fluents such as e, f , and s will be used, where e is understood to be a fluent of type e_{FST} , and similarly for the others.

- Semelfactive: $\Sigma = \{e\}$, $C = \emptyset$
- Achievement: $\Sigma = \{e, \text{cons}(e)\}$, $C = \{\boxed{e} \implies \boxed{\text{cons}(e)}\}$
- Activity: $\Sigma = \{f, \text{deg}_\downarrow\}$, $C = \{\boxed{f} \implies \boxed{\text{deg}_\downarrow}\}$. Here the fluent deg_\downarrow is optional, along with the constraint.
- Accomplishment: If viewed punctually then the same representation as an achievement. If viewed duratively then $\Sigma = \{f, \text{deg}_\downarrow, e, \text{deg}_{max}\}$, $C = \{\boxed{f} \implies \boxed{\text{deg}_\downarrow}, \boxed{e} \implies \boxed{\text{deg}_{max}}\}$

- State: $\Sigma = \{s\}$, $C = \{\boxed{s} \implies \boxed{s} + \boxed{F[\neg s]}\}$. This constraint encodes the inertial property of stative fluents, indicating that if the state s holds in a box, it will continue to hold in the next box, unless the first box contained a force that caused it to not hold (The “+” sign being interpreted as disjunction).

5 Type Coercion

Aspectual classification is not static. In certain contexts, an event typically classified as one type may shift and be interpreted as being of a different type. This phenomenon is known as type coercion in an analogy with a similar phenomenon in programming languages.

In FS-Temporality, an event is assigned to a certain type based on two criteria: what fluents are used to describe it; and the temporal/causal relationship between these fluents, given by string constraints. Examples of this have already been seen, with the difference between Achievements and Semelfactives being that Achievements have consequences described by stative fluents, which are related to the force that caused them through string constraints.

A number of different cases of type coercion are given below. These can be accounted for in FS-Temporality through changes in the underlying alphabet (the fluents which describe the event), and the application or deletion of string constraints (the causal/temporal relation between fluents).

At this point it is convenient to introduce inverse functions for *proc*, *cul*, and *cons*, returning the perfective event of which they are the preparatory process, culmination, and consequent state. For instance $\text{cul}^{-1}(\text{reach-the-top}) = \text{climb-the-mountain}$. As with the *proc*, *cul*, and *cons*, the inverse functions may not return a linguistically coherent value. However, in the following examples, it is assumed that they do.

5.1 Achievements \rightarrow Accomplishments

As pointed out by Moens and Steedman (1988), the progressive applies to a process (activity), or culminated process (accomplishment), which conflicts with the following:

John was reaching the top (15)

“Reach the top” is usually seen as a culmination (achievement), punctual with an associated consequent state. The progressive coerces this culmination into a culminated process by adding a preparatory process, and focussing on this.

Taking reach-the-top as a fluent of type e_{FST} , the preparatory process of this is $\text{proc}(\text{reach-the-top})$. This can be added to the set of fluents under consideration. It is a fluent of type f_{FST} , so is homogeneous, inertial, and may be causative. String constraints can be applied which relate $\text{proc}(\text{reach-the-top})$ to $\text{cul}(\text{reach-the-top})$ and $\text{cons}(\text{reach-the-top})$ (which would presumably be *at-the-top*). As a durative force, it can occur in the progressive.

5.2 Semelfactives \rightarrow Activities

Typically, the progressive can only apply to activities and accomplishments, focussing on their preparatory processes. Achievements and semelfactives, not having preparatory processes, should be infelicitous with the progressive. However, contrary to expectations, the progressive can occur with semelfactives, and as Pulman (1997, p. 9) notes, with achievements under special circumstances.

- John was sneezing.

The most common view (Moens and Steedman, 1988, p. 17) of how the progressive can apply to semelfactives, such as “sneeze” is that they are coerced through iteration into becoming a series of sneezes, and thus a process. In string form this is represented by:

$$\boxed{e} \boxed{e} \boxed{e} \dots \quad (16)$$

as opposed to:

$$\boxed{e} \quad (17)$$

This does not work for achievements as $\boxed{e, \neg\phi} \boxed{\phi}$ iterated becomes:

$$\boxed{e, \neg\phi} \boxed{e, \neg\phi, \phi} \boxed{e, \neg\phi, \phi} \dots \quad (18)$$

with ϕ and $\neg\phi$ appearing in the same box leading to a contradiction.

The special circumstance given by Pulman is the slowing down of time to a scale where the punctual Achievement is viewed as having duration. From this, a preparatory process can be identified, and the progressive applied to it. For instance, the sentence:

- John was sneezing when Mike punched him

could suggest two different scenarios: John was sneezing multiple times when Mike punched him, or that John sneezed once, and the punch landed mid-sneeze.

The example of slowing down a cough to view its internal structure suggests that the *proc* function can be applied to Semelfactives to give a fluent (of type f_{FST}) representing their internal, durative structure (as a durative force). This fluent *proc*(*e*) would hold whenever *e* holds, but in contrast to *e*, can hold over an interval that contains multiple instances of *e*. So the strings:

- $e|e|e \dots$
- $proc(e)|proc(e)|proc(e)$
- $proc(e)$

can all hold of the same interval (the latter two can hold of the same interval due to the homogeneity of fluents of type f_{FST}).

Therefore, both Pulman’s special coercion and Moens and Steedman’s iterative coercion can be captured by replacing the fluent *e* in the alphabet with *proc*(*e*), a durative force fluent that the progressive applies to.

5.3 Accomplishments \rightarrow Activities

Moens and Steedman discuss the case of an accomplishment being coerced into an activity in the presence of the progressive:

$$\text{Roger was running a mile} \quad (19)$$

Note that “Roger was running a mile” does not entail that “Roger ran a mile”, but does entail that “Roger ran”. This is known as the imperfective paradox, and is evidence that the progressive is being applied to the preparatory process and not the accomplishment as a whole.

For this coercion to happen, the culmination and consequent state must be “stripped off”, leaving the preparatory process.

In FS-Temporality, this is achieved by applying the function *proc* to *e*, and deleting the constraints:

- $cul(e)|proc(e) \implies \emptyset$
- $cul(e) \implies cons(e)$

ensuring that the preparatory process of “walking” is not asserted to have ended and caused some consequent state to hold.

6 Conclusion

Previous approaches to Temporal Semantics using Finite State Methods based on stative change have been augmented with the addition of forces. Fluents representing both punctual and durative forces have been shown to have different properties to fluents representing states. Fluents of all three types are necessary to represent the event nucleus of Moens and Steedman in string form. Both telicity and the distinction between achievements and semelfactives have been shown to be explicable in terms of whether a force is associated with a resulting state, a distinction captured through constraints on strings.

The introduction of durative forces has added to the representation of semantic scales by strings, explaining the aspectual classification of durative events where no stative change takes place. Where stative change can be observed, forces can be related to this change through string constraints.

A “bottom up” approach has been taken to type coercion, where types come about through choice of fluents and applicability of string constraints. Various different coercions are shown to be implementable in a finite state framework. Given that instances of types are invariably represented as strings, this unified approach will feed into future work on the effect of types on simple narrative structure, and the possibility of representing this using Finite State Methods.

References

- John Beavers. 2013. Aspectual classes and scales of change. *Linguistics*, 51(4):681–706.
- Bernard Comrie. 1976. *Aspect: An introduction to the study of verbal aspect and related problems*, volume 2. Cambridge university press.
- Robin Cooper. 2012. Type theory and semantics in flux. *Handbook of the Philosophy of Science*, 14:271–323.
- David R Dowty. 1979. *Word meaning and Montague grammar: The semantics of verbs and times in generative semantics and in Montague’s PTQ*, volume 7. Springer Science & Business Media.
- Tim Fernando. 2006. Finite-state temporal projection. In *Implementation and Application of Automata*, pages 230–241. Springer.
- Tim Fernando. 2008. Branching from inertia worlds. *Journal of Semantics*, 25(3):321–344.
- Tim Fernando. 2014. Incremental semantic scales by strings. *EACL 2014*, page 63.
- Jennifer Hay, Christopher Kennedy, and Beth Levin. 1999. Scalar structure underlies telicity in “degree achievements”. In *Proceedings of SALT*, volume 9, pages 127–144.
- Malka Rappaport Hovav and Beth Levin. 2001. An event structure account of english resultatives. *Language*, 77(4):766–797.
- Christopher Kennedy and Beth Levin. 2008. Measure of change: The adjectival core of degree achievements. *Adjectives and adverbs: Syntax, semantics and discourse*, pages 156–182.
- Fred Landman. 1992. The progressive. *Natural language semantics*, 1(1):1–32.
- Claudia Maienborn. 2007. On davidsonian and kimian states. In I Comorovski and K von Heusinger, editors, *Existence: Syntax and Semantics*, pages 107–130. Kluwer, Dordrecht.
- Marc Moens and Mark Steedman. 1988. Temporal ontology and temporal reference. *Computational linguistics*, 14(2):15–28.
- Stephen G Pulman. 1997. Aspectual shift as type coercion. *Transactions of the Philological Society*, 95(2):279–317.
- Stephanie Solt. 2015. Measurement scales in natural language. *Language and Linguistics Compass*, pages 14–32.
- Michiel van Lambalgen and Fritz Hamm. 2003. Intensionality and coercion. *Intensionality. ASL Lecture Notes in Logic, AK Peters*.
- Michiel Van Lambalgen and Fritz Hamm. 2008. *The proper treatment of events*. John Wiley & Sons.
- Zeno Vendler. 1957. Verbs and times. *The philosophical review*, pages 143–160.