Formal Semantics of English Sentences with Tense and Aspect

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Abstract

As common expressions in natural language, sentences with tense and aspect play a very important role. There are many ways to encode their contributions to meaning, but I believe their function is best understood as exhibiting relations among related eventualities (events and states). Accordingly, contra other efforts to explain tense and aspect by appeal to temporal logics or interval logics, I believe the most basic and correct way to explain tense and aspect is to articulate these relations between eventualities. Building on these ideas, I will characterize a formal semantics – Event-State Semantics (ESS) – which differs from all formal semantics based on temporal logics; in particular, one with which sentences with tense and aspect can be adequately explained, including molecular sentences and those with adverbial clauses.

0. Introduction

Derczynski and Gaizauskas (2013) assert that natural language is the most important tool for conveying temporal information. A necessary part of language is temporal ordering, through which speakers can discuss change, describe what happened, and communicate plans for what will happen.

Unlike other theories of tense and aspect, according to this monograph, relations among eventualities are more basic than temporal information in natural language. Altshuler (2016) considers eventualities denote events and states. And the central thesis is that people can discuss change, describe what has happened and communicate plans for what will happen without appealing to temporal ordering or temporal information.

Eventualities include events and states. I acknowledge an ontological distinction between events and states, but, just the same, events and states are both widely used in semantics and pragmatics.

Standardly, events correspond to activities, processes or changes; and states to static conditions. Whereas "John broke a bowl." denotes an event, "John was sleeping." denotes a state. I presuppose that when people cognize an event they cognize its parts as states. Under this presupposition, an event should be treated as a chain of states rather than a chain of events. It is hard to demarcate events, but still it is not hard to discriminate their parts, such as the begin of an event, the processes of an event, the end of an event and the effect of an event, and so, events should not be constructed out of a set of sub-events. Accordingly, parts of an event should be static.

Another reason for invoking states as the essential ingredients of events is that I don't want to use the notion of an (sub)event in order to define *event*, which would end up in a circular definition.

Since relations among eventualities are essential for communication, they must be expressible in all natural languages. Every natural language has its own way to encode such relations; for example, syntactic elements, such as tense and aspect, and semantic rules for molecular phrases and adverbial clauses in English.

Many researchers have devised theories to explain tense and aspect in English (Bennett & Partee 1978; Davidson 2001; Parsons 1990; Prior 1967; Moszkowski 2012). All their ideas are couched in temporal logic, or I should say, in a time model (Konur 2008; Dowty 1979). A time model is constructed with time points or time intervals from a domain set. But most temporal logics are not expressive enough to capture all our intuitions about the meaning contribtuions of tense and aspect; this is particularly clear in interval logics (Konur 2006). So, for example, according to temporal logics, all the sentential truths should correspond to a time point set. Such theories can only explain sentences with a simple tense or aspect which express a single event or state. Call them atomic eventuality sentences. But indefinitely many other sentences have more complicated eventualities' constructions that can't be explained in temporal logic. Some of them don't require time points, and so, these sentences cannot be explained in temporal logic. For example,

(1) I didn't turn off the stove.
(2) He smiles when you praise him.

Example (1) does not mean there is no time point in the past at which I turn off the stove, nor does it mean there is a time point in the past at which I didn't turn off the stove. Thus, the meaning of this sort of sentence cannot be explained in temporal logic. Likewise, Example (2) means no matter when you praise him, an event will follow of his smiling. The event corresponding to "you praise him" may occur at any moment. It cannot be located at certain time points.

Atomic event sentences contain only one verb, or in other words, atomic event sentences describe a single event. As Lepore and Ludwig (2003) noted, verbs fall into different kinds. One includes event verbs. The atomic event sentences have event verbs. Here is a complete list of the atomic event sentences built up out of the verb 'to walk' in English. For example,

(3a) John walks to school.
(3b) John walked to school.
(3c) John will walk to school.
(3d) John said he would walk to school.
(3e) John is walking to school.
(3f) John was walking to school.
(3g) John will be walking to school then.
(3h) John would be walking to school.
(3i) John had walked to school then.
(3j) John has walked to school.
(3k) John will have walked to school then.
(3l) John would have walked to school then.
(3m) John has been walking to school.
(3n) John had been walking to school then.
(3o) John will have been walking to school then.
(3p) John would have been walking to school then.

Molecular event sentences are those which contain two or more verbs. These sentences describe relations among events and states. Here are samples of molecular events sentences.

(4) John was walking across the street when the truck hit him.
(5) John left after Mary left.
(6) I will take shower before you go home.
(7) John has been living here for ten years since he was born.

My aim here is to explore the formal meaning of atomic-event sentences and molecular-events sentences, especially molecular-events sentences.

1. Background

Before presenting my own analyses of these sorts of sentences, it is necessary to explore how other theories fail. Only then will the advantages of my own account become clear. There are several theories about the formal meaning of atomic-event sentences: three well known and influential accounts are Prior (1967) Temporal Logic, interval semantics from Bennett and Partee (1978), and Reichenbach (1947) tense structure.

Temporal Logic (TL)

Prior defines four temporal modal operators with meanings as follows:

P "It has at some time been the case that …"
F "It will at some time be the case that…"
H "It has always been the case that…"
G "It will always be the case that…"
$P\varphi \equiv \neg H \neg \varphi$, $H\varphi \equiv \neg P \neg \varphi$, $F\varphi \equiv \neg G \neg \varphi$, $G\varphi \equiv \neg F \neg \varphi$

Syntax:

The set of formulae of TL can be recursively defined by:
$\varphi ::= p \mid \perp \mid \neg\varphi \mid \varphi \vee \phi \mid G\varphi \mid H\varphi$

Semantics:

A temporal frame $\mathcal{T} = < T, < >$
A temporal model $M_{TL} = <T, <, V>$.
M_{TL} is a time model for a set of atomic propositions PROP.

T is the set of time instants, < is the binary relation between time instants, and V is a valuation which assigning to every $p \in$ PROP a time instants set. $V(p) \subseteq T$.

An interpretation of PROP in the temporal frame $\mathcal{T}$ assigns a truth value to every atomic proposition at every time instant, which is a mapping I: T×PROP →{true, false}.

A formula's truth of TL at a certain time instant t in a certain model M is defined inductively as follows:

$M, t \models p$ iff $t \in V(p)$, for $p \in$ PROP.
$M, t \models \neg\phi$ iff it is not the case that $M, t \models \phi$.
$M, t \models \varphi \vee \phi$ iff $M, t \models \varphi$ or $M, t \models \phi$.
$M, t \models H\varphi$ iff $M, t' \models \varphi$ for all the time instants t' such that t' < t.
$M, t \models G\varphi$ iff $M, t' \models \varphi$ for all the time instants t' such that t < t'
(Prior 1967).

The problem with Tense Logic is that it cannot explain sentences with aspect.

(8) I didn't turn off the stove.
(9) When I was in the room, Dave ate the cookie.
(10) When I was in the room, Dave was eating the cookie.

If I say that the formal explanation of example (8) is $M, t \models \neg\phi$ and ϕ is the corresponding proposition of "I turn off the stove", $M, t \models \neg\phi$ means at time instant t, I didn't turn off the stove. Whereas example (8) is trying to say I didn't turn off the stove at any time after I turn on the stove. It's not the same.

If I say "when I was in the room" refers to a certain time instant t, ϕ denotes the proposition of "Dave eats the cookie", then example (9) and example (10)'s explanations are below:

$$M, t \models P\phi$$

There is no difference between example (9) and example (10) in Tense Logic (Bennett & Partee 1978).

Interval Semantics

In order to capture the meaning of progressive aspect in formal semantics, Bennett and Partee offer a formal explanation based on interval semantics (Bennett & Partee 1978).

Syntax:
As Bennett and Partee don't mention syntax in their paper, I will introduce syntax partly based their analysis.

$$A ::= p \mid \bot \mid \neg\varphi \mid \varphi\vee\phi \mid Prog\varphi \mid P\varphi \mid F\varphi$$

Semantics:

$$M = < [T], < >$$

Let T be real numbers. T is to be regarded as the set of moments of time. Let $<$ be a simple ordering of T. I is an interval of T if and only if $I \subset T$ and for any $t_1, t_3 \in I$ such that $t_1 \leq t_3$ if t_2 is such that $t_1 \leq t_2 \leq t_3$ then $t_2 \in I$.

Let [T] be the set of all intervals of T expect the empty interval.

Let I, I’ be members of [T], I < I’ if and only if for all t in I and t’ in I’, t < t’.

(11) John eats the fish.

According to Bennett and Partee, simple present tense sentences have two senses: reportive sense and nonreportive sense. Reportive sense means this sentence refers to only one event; nonreportive sense means this sentence refers to a set of events of the same kind. Only nonreportive sense can be analyzed in interval semantics (Bennett & Partee 1978).

Suppose example (11) in the nonreportive sense is true at interval I. The event of John’s eating the fish is to be regarded as having occurred during interval I. If interval I has an initial point, then the event started at the point. If interval I has a final point, then the event stopped at the point.

The notion of a sentence being true at an interval of time leads to a natural analysis of the progressive tense [Progϕ] is true at interval I if and only if there exists an interval I’ such that I $\subset$ I’. I is not a final subinterval of I’, and ϕ is true at I’.

The simple past tense [Pϕ] is true at interval I if and only if I is a moment of time, Pϕ refers to an interval I’ and there exists a subinterval of I’, I”, such that I”[<] I and ϕ is true at I”.

The simple future tense [Fϕ] is true at interval I if and only if I is a moment of time, Fϕ refers to an interval of I’ and there exists a subinterval of I’, I”, such that either I is an initial point for I” or I [<] I” and ϕ is true at I”.

The past progressive tense [(P-Progϕ] is true at interval of I if and only if I is a moment of time, P-Progϕ refers to an interval of I’, and there exists a moment of time t such that t is a member of I’ and t [<] I and Progϕ is true at t (Bennett & Partee 1978).

Example (9) and example (10) can be explained properly in model M.

(9) When I was in the room, Dave ate the cookie.

“Dave ate the cookie” is true at interval I (“when I was in the room”) if and only if I is a moment of time, “Dave ate the cookie” refers to an interval I’ and there exists a subinterval of I’, I”, such that I”[<] I and “Dave eats the cookie” is true at I”.

(10) When I was in the room, Dave was eating the cookie.

“Dave was eating the cookie.” is true at interval I (“when I was in the room”) if and only if I is a moment of time, "Dave was eating the cookie." refers to an interval of I', and there exists a moment of time t such that t is a member of I' and t [<] I and "Dave is eating the cookie." is true at t.

Even with these additions, there are still some sentences that famously can't be explained in interval logic.

(11) Mary was drawing a circle.
(12) Mary drew a circle.

"Mary was drawing a circle" is true at interval I if and only if I is a moment of time, "Mary was drawing a circle." refers to an interval of I', and there exists a moment of time t such that t is a member of I' and t [<] I and "Mary is drawing a circle" is true at t. If "Mary is drawing a circle" is true at t, then according to Partee's theory, there exists an interval I' such that t $\subset$ I'. t is not a final subinterval of I', and "Mary draws a circle" is true at I', which means there is a "circle" already at I'. But there could be a case that "Mary was drawing a circle" and "she stopped before she finished", then there would be no "circle" at all. "Mary draws a circle" can't be true at I.

Example (11) doesn't entail example (12) all the times. Because even if Mary doesn't finish the circle, I can still say "Mary was drawing a circle" is true. But according to interval logics, example (11) must entail example (12).

Reichenbach's tense structure

In order to describe the tenses of verbs, Reichenbach (1947) offers a three-point framework in "The Tenses of Verbs". The three points are speech point, event point and reference point. Reichenbach uses these point and their relations to give descriptions of tenses. This framework can define the tense meaning with formally describing. Wolfgang Klein published a book featured a updated version of Reichenbach's theory in 1994. For this reason, we call it R(eichenbach)-K(lein) Theory.

Defination of tense and aspect

With these three abstract points, we can also define the rules for temporally arranging events which are related by these verbs(Derczynski & Gaizauskas 2013).

Speech Time(S), Reference Time(R), and Event Time(E)

Simple present	Simple past	Present perfect	Past perfect
S=R=E	R<S, E=R	R=S, E<R	R<S, E<R
I see him.	I saw him.	I have seen him.	I had seen him.

The model of RK Theory

Tense contributes information regarding the ordering relationship between the Utterance Time and the Topic Time.

a. 'Past Tense' = TT precedes UT
b. 'Present Tense' = TT is UT

Aspectual describes the relationship between the Topic Time and the Event Time.

a. 'Perfective Aspect' = TT contains ET
b. 'Imperfective Aspect' = ET contains TT

In this model, 'times' are also considered as primitives, but both relatable via the ordering relation '<' and the contentedness relation '⊂'.

Model

$\mathcal{M} = < D, I, <, \subset >$

D is the domain of entities, I is the set of times, < is an ordering relation on I, and ⊂ is a containment relation on I.

'g' is a variable assignment, 't' is a 'time of evaluation'. Thus, we use the parameterized interpretation function ' $[[\ ]]^{M,g,t}$'.

$$[[\ PAST_i\ ]]^{\mathcal{M},g,t} = g(i) \quad \text{if } g(i) < t, \text{ otherwise undefined}$$
$$[[\ PRES_i\ ]]^{\mathcal{M},g,t} = g(i) \quad \text{if } g(i) = t, \text{ otherwise undefined}$$
$$[[\ PERF\ ]]^{\mathcal{M},g,t} = \lambda P_{<it>}\,.\ \lambda t.\ [\exists t'.\ t' \subset t \wedge P(t')\ ]$$
$$[[\ IMP\ ]]^{\mathcal{M},g,t} = \lambda P_{<it>}\,.\ \lambda t.\ [\exists t'.\ t \subset t' \wedge P(t')\ ]$$

Example Derivations

(12) Mary drew a circle.

$[[\text{Mary drew a circle.}]]^{\mathcal{M}, g, t}$

$\Rightarrow [[\text{PAST}_i\ [\text{PERF}[\text{Mary draw-a-circle}]]^{\mathcal{M}, g, t}$

$\Rightarrow ([[\text{PERF}]]^{\mathcal{M}, g, t}\ ([[\text{draw-a-circle}]]^{\mathcal{M}, g, t}\ ([[\text{Mary}]]^{\mathcal{M}, g, t})))([[\text{PAST}_i]]^{\mathcal{M}, g, t})$

$\Rightarrow ([[\text{PERF}]]^{\mathcal{M}, g, t}\ ([\lambda x.\ \lambda t.\ x \text{ draw-a-circle at } t\,](\text{Mary})))([[\text{PAST}_i]]^{\mathcal{M}, g, t})$

$\Rightarrow ([[\text{PERF}]]^{\mathcal{M}, g, t}\ ([\lambda t.\ \text{Mary draw-a-circle at } t\,]))([[\text{PAST}_i]]^{\mathcal{M}, g, t})$

$\Rightarrow ([\lambda P\langle it\rangle.\ \lambda t.\ [\,\exists t'.\ t' \subset t\ \&\ P(t')]]\ ([\lambda t.\ \text{Mary draw-a-circle at } t\,]))([[\text{PAST}_i]]^{\mathcal{M}, g, t})$

$\Rightarrow (\lambda t.\ [\,\exists t'.\ t' \subset t\ \&\ \text{Mary draw-a-circle at } t'\,]]([[\text{PAST}_i]]^{\mathcal{M}, g, t})$

$\Rightarrow \exists t'.\ t' \subset [[\text{PAST}_i]]^{\mathcal{M}, g, t}\ \&\ \text{Mary draw-a-circle at } t'\,]$

$\Rightarrow \exists t'.\ t' \subset g(i)\ \&\ \text{Mary draw-a-circle at } t'$ (if $g(i) < t$; undefined otherwise)

There is some time t' that g(i) contains (where g(i) must be in the past), and

'Mary draw a circle' is true at t'.

(11) Mary was drawing a circle.

$[[\text{Mary was drawing a circle.}]]^{\mathcal{M}, g, t}$

$\Rightarrow [[\text{PAST}_i\ [\text{PERF}[\text{Mary draw-a-circle}\ ]]^{\mathcal{M}, g, t}$

$\Rightarrow ([\lambda P\langle it\rangle.\ \lambda t.\ [\,\exists t'.\ t \subset t'\ \&\ P(t')]]\ ([\lambda t.\ \text{Mary draw-a-circle at } t]))([[\text{PAST}_i]]^{\mathcal{M}, g, t})$

$\Rightarrow \exists t'.[[\text{PAST}_i]]^{\mathcal{M}, g, t} \subset t'\ \&\ \text{Mary draw-a-circle at } t']$

$\Rightarrow \exists t'.\ g(i) \subset t'\ \&\ \text{Mary draw a circle at } t'$ (if $g(i) < t$; undefined otherwise)

There is some time t' that contains g(i) (where g(i) must be in the past), and 'Mary draw a circle' is true at t'(Matthewson 2006).

(11) Mary was drawing a circle.
(12) Mary drew a circle.

According to this model, example (11) must entail example (12) too. Problem is still unsolved.

2. Event-State Semantics (ESS)

The main purpose of constructing Event-State Semantics is that I want to create a new formal semantics which can explain tense and aspect sentences without time. As a new method compared to temporal logics, if Event-State Semantics can capture all the tense and aspect sentences' meaning, it must have enough expressive power to explain the molecular sentences.

As I already saw, Temporal Logic can only explain tense and aspect sentences with time points. There are many tense and aspect sentences which do not make reference to time points. One kind of such sentence is those with conjunctions. However, ESS does offer an adequate semantics for these sentences.

Events are anything that can happen, such as what already happened, what is happening and what will happen. Alternatively, events can be decomposed into a chain of states, such as a beginning state, a progressive state, an ending state, and an effect state, and an ordering on that collection.

States themselves can be the recognized result of objects, they can also be the recognized result of events and states.

For example, "This apple is red." refers to a state about one object. "John is walking." refers to a state about event. "Being a student is happy." refers to a state about state.

Syntax for Tense and aspect Language—Ls

Ls is the language based on first order logic. It is used to represent the tense/aspect sentences in English. Let $\mathcal{A}$ be the domain. $\mathcal{A}$ is the set of individuals. All the eventualities are individuals. The specific mappings between individuals refer to the aspect of sentences. The certain relations between individuals refer to the tense of sentences.

Based on these properties of tense/aspect sentences, Ls should contain variables, constants, functions and predicates. That's why I decide to use predicate logic as the tool of representing tense/aspect sentences' meaning.

Variables: $x_1, x_2, x_3, \dots$

Event variables: $e_1, e_2, e_3, \dots$

State variables: $s_1, s_2, s_3, \dots$

As some functions can only be used on event individuals, the domain of ESS should have at least two kinds of individuals: one is suitable for these functions, the other is not. According to the definition of eventuality, the domain of ESS can be divided into two parts: event set and state set. There should be two kinds of variables too.

Some other functions can be used on all individuals. Then I also need variables which domain is the whole set of individuals.

Constants: N

There is one individual constant N, which refers to the state of speaker's uttering, or I can say "now". I presuppose all the sentences are uttered by speakers. Thus the state of uttering is indispensable in Ls.

Althsuler and Stojnic (2016) argue that the meaning of "now" should not be linked to any time, but rather to the most prominent state. I restrict the boundary of Ls to un-conversation discourse. All the sentences should be one speaker's utterance. The purpose of such restriction is to simplify the formal meaning of "now", as different speaker holds the different prominent state. One speaker can guarantee there is only one prominent state. That makes it possible to define "now" as a constant.

Functions: f

ing, hv, hv-ing, begin, end, effect

The functions in Ls could be more if needed. They are all partial functions, which are mapping eventuality to state.

"*ing*" refers to the progressive aspect, "*hv*" refers to the perfective aspect, "*hv-ing*" refers to the progressive-perfective aspect. These three aspects are indicated in sentences with grammar label, while the other three are not. The references of "*begin*", "*end*" and "*effect*" do not correspond to any grammar index, but they are essential for explicating tense/aspect sentences' meaning. "*begin*" refers to the start state of an event, "*end*" refers to the finish state of event, "*effect*" refers to the influence of an event. The last three aspects do not show in grammar, but they do take places in sentences' meaning.

I choose the six functions as they are the most common view aspects in English. Different language may have different aspects. Even the same language may have different aspects in different historical periods. Suppose one day people care about the preparation of an event, I should definitely add it into the function set.

Predicates:

Unitary predicates (P_1): P, Pr, F

Binary predicates (P_2): WHEN, AFTER, BEFORE, …

According to the analysis above, tense should be unitary predicates. "P" refers to the past tense, "Pr" refers to the present tense, and "F" refers to the future tense.

I agree with Bennett and Partee (1978) that simple present tense sentences have reportive sense and nonreportive sense. What's more, I presuppose all the tense sentences should have two senses: reportive sense and nonreportive senses. Tense sentence is the event sentence without aspect.

(13) John walks to school.
(14) John walked to school.
(15) John will walk to school.

These three sentences are all have reportive sense and nonreportive sense. Example (13) can mean "John" walks to school every day, it can also mean "John" walk to school now. Example (14) can mean "John" used to walk to school before, it can also mean "John" walked to school one time before now. Example (15) can mean "John" will walks to school every day in the future, it can also mean "John" will walk to school one time in the future.

Like Partee did, I only analyze the nonreportive sense of these sentences in this paper.

The binary predicates refer to the conjunctions such as "when", "after", "before". ESS presupposes the conjunctions of sentences indicate the relations of eventualities, which are binary predicates here.

Connectives:

$\neg$, $\rightarrow$.

Terms: t

event variables; state variables; individual constants; $f_n(t_1, t_2, t_3, \ldots, t_n)$

Well Formed Formulas:

$P_n(t_1, t_2, t_3, \ldots, t_n)$; if α is a well formed formula, then $\neg\alpha$ is a well formed formula too; if α, β are well formed formulas, then $\alpha \rightarrow \beta$ is a well formed formula too.

Semantics

The structure of Event-State Semantics' domain consists of an event set and a state set.

$\mathcal{F}$ = <$\mathcal{A}$, !, ≤ , B, E, C>.

$\mathcal{A}$ is an unempty set; ! is a individual constant; ≤ is partial order relation in $\mathcal{A}$. B, E and C are partial functions: $\mathcal{A} \rightarrow \mathcal{A}$.

$\mathcal{M}$ = <$\mathcal{A}$, !, ≤, B, E, C, σ> is model, σ is an interpretation function from varies set to domain $\mathcal{A}$.

Domain

$\mathcal{A} = \mathcal{E} \cup \mathcal{S}$, $\mathcal{E}$ denotes the event set; $\mathcal{S}$ denotes the state set. $a \in \mathcal{A}$, $e \in \mathcal{E}$, $s \in \mathcal{S}$. The symbol "!" denotes an important state, which means "now". That is to say, "now" is considered as a special state in Event-State structure. Every sentence has a close relation with this special state. For any e, $\sigma(e) \in \mathcal{E}$; for any s, $\sigma(s) \in \mathcal{S}$; $N^{\mathcal{M}} = !$.

Functions B, E, C

B: $\mathcal{E} \rightarrow \mathcal{S}$
E: $\mathcal{E} \rightarrow \mathcal{S}$
C: $\mathcal{E} \rightarrow \mathcal{S}$

B(e) means the begin of e. E(e) means the end of e. C(e) means the influence of e.

According to Event-State structure, the start, the finish and the influence of event are all states. There is a certain kind of event whose start state is equal to its finish state (B(e) ≡ E(e)). I call them instant events. Every event should have a start state and a finish state.

Basic relations

$a \leq a'$

Defined relations

$a \equiv a'$ if and only if $a \leq a'$ and $a' \leq a$.
$a < a'$ if and only if $a \leq a'$ and not E(a) ≡ B(a').
$a \mid a'$ if and only if E(a) < B(a').
$a - a'$ if and only if E(a) ≡ B(a').

$a \subseteq a'$ if and only if B(a') $\leq$ B(a) and E(a) $\leq$ E(a').
$a \subset a'$ if and only if B(a') $<$ B(a) and E(a) $<$ E(a').

These relations are based on $\leq$. They can help us to define the aspects' formal meaning more conveniently.

Rules

There are several rules should be committed in model $\mathcal{M}$.

RL 1: For every $e \in E$, B(e) $\leq$ E(e) $\leq$ C(e).
RL 1 means the begin of e must happens prior than the end of e, and the end of e must happens prior than the effect of e.
RL 2: For every $e \in E$, If E(e) $\in \mathcal{M}$, then B(e) and $e \in \mathcal{M}$.
RL 2 means if the end of e holds at model $\mathcal{M}$, the begin of e and e itself must hold at model $\mathcal{M}$ too.
RL 3: For every $e \in E$, If E(e), B (e) $\in \mathcal{M}$, then $e \in \mathcal{M}$.
RL 3 means if the begin and the end of e both hold at model $\mathcal{M}$, the event e must hold at $\mathcal{M}$.
RL 4: For every $e \in E$, If C(e) $\in \mathcal{M}$, then E(e) $\in \mathcal{M}$.
RL 4 means if the effect of e holds at model $\mathcal{M}$, the end of e must hold at model $\mathcal{M}$. According to RL 2, the begin of e and the event e also hold at model $\mathcal{M}$ too.

Explanation of functions in ESS

If $(begin(\mathrm{e}_1))^{\mathcal{M}} = s$, then there is an $e_1 \in \mathcal{M}$, $(\mathrm{e}_1)^{\mathcal{M}} \equiv e_1$, $s \equiv$ B(e_1).
If $(end(\mathrm{e}_1))^{\mathcal{M}} = s$, then there is an $e_1 \in \mathcal{M}$, $(\mathrm{e}_1)^{\mathcal{M}} \equiv e_1$, $s \equiv$ E(e_1).
If $(effect(\mathrm{e}_1))^{\mathcal{M}} = s$, then there is an $e_1 \in \mathcal{M}$, $(\mathrm{e}_1)^{\mathcal{M}} \equiv e_1$, $s \equiv$ C(e_1).
If $(hv(\mathrm{e}_1))^{\mathcal{M}} = s$, then there is an $e_1 \in \mathcal{M}$, $(\mathrm{e}_1)^{\mathcal{M}} \equiv e_1$, $s \subseteq$C(e_1).
If $(ing(\mathrm{e}_1))^{\mathcal{M}} = s$, then there is an $e_1 \in \mathcal{M}$, $(\mathrm{e}_1)^{\mathcal{M}} \equiv e_1$, B($e_1$) $\leq s <$ E(e_1), not B(e_1) $\equiv$ E(e_1).
If $(hv\text{-}ing(\mathrm{e}_1))^{\mathcal{M}} = s$, then there is an $e_1 \in \mathcal{M}$, $(\mathrm{e}_1)^{\mathcal{M}} \equiv e_1$, B($e_1$) $< s <$ E(e_1).

Explanation of formulas in ESS

For model $\mathcal{M}$, event e and formula A, if A is true on model $\mathcal{M}$ under event e (mostly e is the utterance event !), then $\mathcal{M}, e \models A$.

$\mathcal{M}, e \models F(t)$ iff if there is a such that $(t)^{\mathcal{M}} = a$, then $e \mid a$, $a \in \mathcal{A}$.
$\mathcal{M}, e \models P(t)$ iff there is a such that $(t)^{\mathcal{M}} = a$, $a \mid e$, $a \in \mathcal{A}$.
$\mathcal{M}, e \models Pr(t)$ iff there is a such that $(t)^{\mathcal{M}} = a$, a and e happen simultaneously, $e \subseteq a$, $a \in \mathcal{A}$.
$\mathcal{M}, e \models WHEN(t_1, t_2)$ iff $B(t_1)^{\mathcal{M}} \subseteq (t_2)^{\mathcal{M}}$ or $B(t_2)^{\mathcal{M}} \subseteq (t_1)^{\mathcal{M}}$.
$\mathcal{M}, e \models \neg \varphi$ iff $\mathcal{M}, e \not\models \varphi$.
$\mathcal{M}, e \models \varphi \to \phi$ iff $\mathcal{M}, e \models \neg\varphi$ or $\mathcal{M}, e \models \phi$.

Conjunctions

Conjunction is a common way to express the relation among events/states. For example, "when". There are several ways to use "when" in English.

(16) He smiles when you praise him.
(17) I hate myself when I look like this.
(18) Your mother will bawl you out when she sees this mess.
(19) You should turn it over when eating a whole cooked fish.
(20) He mudded himself when running in the rain.
(21) When he brought Mary her drink she gave him a big smile.
(22) He looked aside when I spoke to him.
(23) I had been gardening for ten years when I met the Gills.

Event-State Models treats conjunctions as binary relations between events and states. The capital forms are binary predicates in Event-State Model.

The normal meaning of example (16) should be that "you praise him" happens first, then "he smiles" happens next. Someone agrees that "you praise him" is the reason of why "he smiles". According to Asher's DRT, the reason should happen before the result, which means the end of x_1 is no later than the begin/start of x_2. $(x_2)^{\mathcal{M}} - (x_1)^{\mathcal{M}}$.

In example (17), "when" indicates the relation of simultaneity. The moment "I" realize that "I look like this", "I" begin to "hate myself", and it keeps on going until "I" stop "look like this". The main event/state and the subordinate event/state start and end at almost the same moment. $(x_1)^{\mathcal{M}} \equiv (x_2)^{\mathcal{M}}$.

Example (18) and example (16) have part of the same meaning of "when", $(x_2)^{\mathcal{M}} - (x_1)^{\mathcal{M}}$. The difference is that main event of example (18) is marked with future tense, which means $! \mid (x_1)^{\mathcal{M}}$. With the two conditions I can obtain a result that $! \mid (x_2)^{\mathcal{M}}$.

Both example (19) and example (20)'s subordinate events/states are in the form of gerund (V-ing). I believe that gerund is the evidence to support idea that people talk about events as entities in language or mind. All the V-ing forms have the same meaning in Event-State Semantics, which are non-instant states. The main events/states of example (19) and example (20) are both instant states. Based on their own natures, I can get their relations, $(x_1)^{\mathcal{M}} \subseteq (\mathit{ing}\ x_2)^{\mathcal{M}}$.

Example (21), example (22) and example (16) have the same meaning of "when".

Example (23) is different from all others. The main event/state in example (23) is instant, while the subordinate event/state is not. That's why the relation of these two events/states is explained as below: $(x_2)^{\mathcal{M}} \subseteq (\mathit{hv\text{-}ing}\ x_1)^{\mathcal{M}}$.

The examples' explanations are below.

(16a) $\mathcal{M}, ! \models Prx_1 \wedge Prx_2 \wedge WHEN(x_1, x_2)$
$! \equiv (x_2)^{\mathcal{M}}$ [1], $! \equiv (x_1)^{\mathcal{M}}$, $(x_2)^{\mathcal{M}} - (x_1)^{\mathcal{M}}$ [2]

(17a) $\mathcal{M}, ! \models Prx_1 \wedge Prx_2 \wedge WHEN(x_1, x_2)$
$! \equiv (x_1)^{\mathcal{M}},\ ! \equiv (x_2)^{\mathcal{M}},\ (x_1)^{\mathcal{M}} \equiv (x_2)^{\mathcal{M}}$

(18a) $\mathcal{M}, ! \models Fx_1 \wedge Fx_2 \wedge WHEN(x_1, x_2)$
$! \mid (x_1)^{\mathcal{M}},\ ! \mid (x_2)^{\mathcal{M}}$ and $(x_2)^{\mathcal{M}} - (x_1)^{\mathcal{M}}$

(19a) $\mathcal{M}, ! \models Prx_1 \wedge Pr(\mathit{ing}\ x_2) \wedge WHEN(x_1, \mathit{ing}\ x_2)$
$! \equiv (x_1)^{\mathcal{M}},\ ! \subseteq (\mathit{ing}\ x_2)^{\mathcal{M}},\ (x_1)^{\mathcal{M}} \subseteq (\mathit{ing}\ x_2)^{\mathcal{M}}$

(20a) $\mathcal{M}, ! \models Px_1 \wedge Pr(\mathit{ing}\ x_2) \wedge WHEN(x_1, \mathit{ing}\ x_2)$
$(x_1)^{\mathcal{M}} \mid !,\ (\mathit{ing}\ x_2)^{\mathcal{M}} \mid !$ and $(x_1)^{\mathcal{M}} \subseteq (\mathit{ing}\ x_2)^{\mathcal{M}}$

(21a) $\mathcal{M}, ! \models Px_1 \wedge Px_2 \wedge WHEN(x_1, x_2)$
$(x_1)^{\mathcal{M}} \mid !,\ (x_2)^{\mathcal{M}} \mid !$ and $(x_2)^{\mathcal{M}} - (x_1)^{\mathcal{M}}$

(22a) $\mathcal{M}, ! \models Px_1 \wedge Px_2 \wedge WHEN(x_1, x_2)$
$(x_1)^{\mathcal{M}} \mid !,\ (x_2)^{\mathcal{M}} \mid !$ and $(x_2)^{\mathcal{M}} - (x_1)^{\mathcal{M}}$

(23a) $\mathcal{M}, ! \models P(\mathit{hv\text{-}ing}\ x_1) \wedge Px_2 \wedge WHEN(\mathit{hv\text{-}ing}\ x_1, x_2)$
$(\mathit{hv\text{-}ing}\ x_1)^{\mathcal{M}} \mid !,\ (x_2)^{\mathcal{M}} \mid !$ and $(x_2)^{\mathcal{M}} \subseteq (\mathit{hv\text{-}ing}\ x_1)^{\mathcal{M}}$

To sum up all the meanings of "when", I can get the conclusion below:

$$\text{If } \mathcal{M}, ! \models WHEN(x_1, x_2), \text{ then } B(x_1)^{\mathcal{M}} \subseteq (x_2)^{\mathcal{M}} \text{ or } B(x_2)^{\mathcal{M}} \subseteq (x_1)^{\mathcal{M}}.$$

1 $! \subseteq (x1)^{\mathcal{M}}$, $B(x1)^{\mathcal{M}} \equiv E(x1)^{\mathcal{M}}$, so $! = (x1)^{\mathcal{M}}$.

2 $! \equiv B(x1)^{\mathcal{M}} \equiv E(x1)^{\mathcal{M}}$, $! \equiv B(x2)^{\mathcal{M}} \equiv E(x2)^{\mathcal{M}}$, so $E(x1)^{\mathcal{M}} \equiv B(x2)^{\mathcal{M}}$, which is $(x1)^{\mathcal{M}} - (x2)^{\mathcal{M}}$

3. The difference between Reichenbach and Event-State Semantics

According to Reichenbach's theory, all the tense and aspect expressions correspond to events' or times' relations; while in Event-State Semantics, tense is considered as events' relations, and aspect is a function mapping events onto states.

Under TimeML, each verb has both tense and aspect features, which take values from three "tenses" (PAST, PRESENT and FUTURE) and four "aspects" (NONE, PERFECTIVE, PROGRESSIVE and PERFECTIVE_PROGRESSIVE), and the event obtains a start and finish points E_s and E_f. According to Event-State Semantics, the event's start and finish should be functions which map events onto states. That is to say, the start and finish are aspects of events too.

Under TimeML, the event's start and finish should be points. While according to Event-State Semantics, they are functions, which means they can be used compounded. It is not necessary to say that all the starts and finishes of events are points. For some certain situations, a start of an event can be an intersection, unless the event is instant event.

(24) John began to drive (P(*begin*(α)). He was going to turn on the engine (P(*begin*(β)).

I do not find a sentence which use compounded aspects such as $(begin(begin(\alpha)))^{\mathcal{M}}$, but in example (24), α and β are not independent events, actually β = *begin*(α). That is to say the second sentence can be rewrite as P(*begin*(*begin*(α))).

Example Derivations

(11) Mary was drawing a circle.
$\mathcal{M}, ! \models P(ing(\alpha))$
iff there is s such that $(ing(\alpha))^{\mathcal{M}} = s$, $s \mid !$, $s \in \mathcal{A}$.
iff there is an $(\alpha)^{\mathcal{M}} \in \mathcal{A}$, $B((\alpha)^{\mathcal{M}}) \leq s \leq E((\alpha)^{\mathcal{M}})$, and not $B((\alpha)^{\mathcal{M}}) \equiv E((\alpha)^{\mathcal{M}})$, $s \mid !$, $s \in \mathcal{A}$.

(12) Mary drew a circle.
$\mathcal{M}, ! \models P\alpha$
iff there is a such that $(\alpha)^{\mathcal{M}} = a$, $a \mid !$, $a \in \mathcal{A}$.

The formal meaning of 2.2.2 doesn't entail 2.2.3 anymore in ESS, as $ing(\alpha))^{\mathcal{M}} \mid !$ do not entail $(\alpha)^{\mathcal{M}} \mid !$.

4. Conclusion

In this paper, I list three different theories of temporal logic: tense logic, interval semantics and RK Theory's model. Each one of them has their own advantage and the lack of expressive power.

The English sentences with tense can be expressed in Tense logic, but the sentences with aspect cannot be distinguished from the one does not have aspect, such as example (9) and example (10).

(9) When I was in the room, Dave ate the cookie.
(10) When I was in the room, Dave was eating the cookie.

Interval logic can show the precise difference between the sentences with aspect and the one does not have aspect, but according to Interval logic, there must be an implication relation between some sentences, such as 15 and 16, while in natural language they do not have any implication relation.

(11) Mary was drawing a circle.
(12) Mary drew a circle.

However, the implication relation between example (12) and example (11) is still presupposed in RK Theory's model.

In order to eliminate the improper presuppose, and capture the precise meaning of the sentences with tense and aspect, I construct a new semantics based on events and states- Event-State Semantics (ESS).

I defined the syntax and semantics of tense/aspect English sentences, gave explanation of tense/aspect sentences with propositions and some valid formulas in Event-State Semantics.

I also compared RK theory's model with the Event-State Semantics. They have the similar idea about the event relation, but also have different idea about the model's individuals and the different view of tense and aspect.

As an expansion of first-order logic, Event-State Semantics adds the individuals, functions and predicates to express the meaning of tense/aspect sentences. Based on Event-State Structure, Event-State Semantics presume that the basic relations in the world should be the relation between eventualities. As the result of cognizing the real world, tense/aspect sentences should also present the relations among eventualities other than time points. That's the most important component of Event-State Semantics, and it does have the expressive capacity to reveal the meaning of tense/aspect sentences without pointing certain time points.

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