Event-State Semantics: The Formal Semantics of English Temporal Sentences

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Abstract

In English, the expressions related to time are not only tense, but also aspect. They are two dimensions of English time expressions, which form a variety of temporal dimension. Tense logic, interval semantics and RK theory did some formal semantic explanations for time expression. How to apprehend the temporal dimension and construct a comprehensive explanation of tense and aspect is a challenge in formal semantics. Event-State Semantics gave up the absolute time frame of tense logic and construct a relative time frame with events and states as the basic elements. In this framework, 16 types of English tense-aspect sentences are formally described.

Motivation

There are various expressions about time in natural languages. Take English as an example, in grammar, there are tenses and aspects. With the two dimensions of tense and aspect, there are more combinations (see Table 1).

Following the development of modal logic, Prior put forward tense logic (Prior 1967). which takes F, P, G, H as temporal operators, gives characterization of the temporal dimension by composing a temporal framework of T nonempty points in time and a partial order relation (Gabbay & Guenthner 2002). Tense logic can only deal with the second column of Table 1. By the combination of tense operators, it can go far beyond the 4 cases, such as PFPP, FFPFPF... But these are not combinations that are actually appeared in natural language. Table 1 lists 16 situations that are common in English, and the corresponding sentences are hereinafter referred to as tense-aspect sentences. The description of the temporal dimension remains unexplored.

In order to describe the tenses of verbs, Reichenbach proposed the three-positions structure. He selected three time points and their relationships to represent tenses or aspects (Reichenbach 1947). Klein compiled an explanatory table of the three-position structure (see Table 2)(Klein 1994). According to RK theory, the semantic meaning of aspects are determined by the relationship between speaking time (ST) and event time (ET). In the subsequent development of the RK theory, the successors gradually formed grammatical and semantic representations (Mathewson, 2006), and gave formal semantic interpretations of the tense-aspect sentences in Table 2 (Derczynski & Gaizauskas 2013). Compared with tense logic semantics, RK theory can not only deal with the simple present tense and the simple past tense under the general aspect, but also with the present perfect tense and the past perfect under the perfect aspect. By comparison with Table 1, it can be found that RK theory does not cover all cases, and there are still gaps, such as no explanation of the continuous and the perfect aspect.

Davidson proposed Event Semantics. Event semantics is based on first-order logic, takes action verbs as predicates, and takes the elements of the event, such as the subject, the object, and the event itself, as arguments of the verb (Davidson 1967). Event semantics is an important theoretical branch of semantics, which has lots of subsequent development, such as subatomic semantics (Parsons 1990). The formal method chosen by event semantics does not preserve the tense-aspect feature of the sentence. For example, let event e be Jones buttered the toast. Under event semantics, BUTTER(j, the toast, e) can be obtained. Past tense ed is not reflected in it. Therefore, it fails to construct the formal expression related to the tenses. Lexical semantics also contributes to the classification of events. Based on the temporal characteristics of verbs, lexical semantics divides verbs into four categories: state verbs, activity verbs, achievement verbs and accomplishment verbs (Vendler 1957; 1967). On this basis, the sentences are divided into event sentences, state sentences and process sentences. Similar to event semantics, lexical semantics does not construct formal characterizations of tense-aspect sentences. Although event semantics, lexical semantics and their subsequent studies do not directly deal with tense-aspect sentences, their relevant studies such as the definition of the event concept have great theoretical significance for the semantic analysis of tense-aspect sentences.

In order to describe the formal semantics of progressive expressions, Bennett and Partee proposed interval semantics. They gave relevant explanations for tense-aspect phenomena (Bennett & Partee 1978). Compared with the semantics of time set plus order relation in temporal logic, interval semantics introduces the concept of time set subset. It makes interval semantics can deal with some aspects

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aspect / tense	**simple**	**continuous**	**perfect**	**perfect continuous**
present	Simple present tense* (1-1)	Present continuous tense* (1-2)	Present perfect tense* (1-3)	Present perfect continuous tense (1-4)
past	Simple past tense* (2-1)	Past continuous tense (2-2)	Past perfect tense (2-3)	Past perfect continuous tense (2-4)
future	Simple future tense* (3-1)	Future continuous tense (3-2)	Future perfect tense (3-3)	Future perfect continuous tense (3-4)
past future	Simple past future tense (4-1)	Past future continuous tense (4-2)	Past future perfect tense (4-3)	Past future perfect continuous tense (4-4)

Table 1: The combinational expressions of tense and aspect in the two dimensions of time in English

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

Table 2: Table comparing tense and aspect interpretations in three place structure

in language. For example, progressive-related tense-aspect sentences. However, the semantic interpretation of other aspects, such as perfect and perfect progressive, is still not constructed. Till now, the major theories, such as temporal logic, three-place structure semantics in RK theory, event semantics, interval semantics, only formed some explanations from their own perspectives, but failed to construct a unified explanation for all tense-aspect sentences. Wenyan Zhang and Beihai Zhou (2023) proposed event-state semantics, in which sentences are divided into simple sentences and compound sentences. Due to space limitation, only 5 cases of simple sentences are given. This research extends the work to compound sentences, giving formal semantics for all 16 cases. Consider the examples below.

e.g.1: John is a coward when he meets the big dog.

e.g.2: While Jane is singing, Mary is doing her homework.

e.g.3: Sue has lived here since she was born.

e.g.4: John became a soldier after 911.

e.g.5: John will leave after dinner.

e.g.6: John was walking to school when Mary left.

e.g.7: John had eaten 5 cookies before the school bus finally came.

e.g.8: John will be walking to school when Mary leaves.

e.g.9: John will have learned 12 units by the end of this term.

e.g.10: John has been crying for the whole ceremony.

e.g.11: John had been studying English for the whole class before he entered the college.

e.g.12: John will have been working for three weeks before he got the master degree.

e.g.13: John said that Bob would go home.

e.g.14: Mary thought Sam would be sleeping when Bob came back.

e.g.15: John said Sam would have finished his homework when Bob came back.

e.g.16: Mary thought Sam would have been doing his homework when Bob came back.

These are the tense-aspect sentences of all 16 cases, and they are all compound sentences, that is, they all have components indicating the referenced event or state, such as prepositional phrases or adverbial clauses. These sentences can be divided into three categories:

(1) e.g.1 - e.g.9, a sentence with an event or state of common reference .

(2) e.g.10 - e.g.12, correspond to three cases under the perfect continuous aspect, with reference events or states related to the length of events or states.

(3) e.g.13 - e.g.16, there are four cases in the past future state, all related to indirect statements. Such cases are complex and often have multiple or more points of reference, especially the speaking event itself.

These 3 types of tense-aspect sentences are also called reference sentences, event length sentences, and indirect statements, respectively. In Event-State Semantics, the semantic interpretation of these three types of 16 tense-aspect sentences can be constructed.

Analysis

Basic Views

Tense logic semantics, RK theory, interval semantics, and the later developed semantics (M. Moens & M. Steedman 1998) differ in the understanding and specific interpretation of tense-aspect phenomena, but there is one thing in common, that is, the default or presupposition of the existence of an independent abstract time frame. All events occur in this abstract time frame. This time frame also becomes the basic device for explaining the phenomenon of tenses and aspects. This point is most typical in the semantics of temporal logic.

In the abstract, the above views are the embodiment of Newtonian physics absolute view of time and space. The absolute view of time and space assumes that everything in the world exists in an abstract space-time framework, in terms of time, events start, proceed, and end. However, natural language is evolved with the development of human society. Will people have such an absolute view of time and space, and form language expressions about time under such a view of time and space? It needs to be verified.

We propose an alternative hypothesis. In the absence of the absolute view of time and space brought by physics, people have time-related expressions in natural language, usually according to the state of an event or time, resulting in the tense-aspect phenomenon in language. The core feature is taking a specific event or state as the temporal reference for another event.

In this way, we take the view that do not presuppose time frames, but only select the order relations between events or states, to explain tense-aspect phenomena in natural language. This view only needs to presuppose the existence of various events and states in the model, which can be called the relative view of time.

Basic Concepts

Events, Status and Facts A semantic model suitable for the interpretation of English tense-aspect sentences should include three types of objects: events, states, and time-independent facts. These three types of objects are hereinafter referred to as situations.

The term "event" refers to anything that happens, not only what has happened, but also what will happen in the future. Events are generally procedural in nature, expressed as "start - proceed - end" (Lewis 1986). Events that have a complete start-proceed-end process are ordinary events. There are also some events that end as soon as they start, there is no ongoing process, such events are instantaneous events. For example, the beginning and end of an event are also considered to be events, and if an event begins and ends with the same event, then such an event is an instantaneous event. It follows that the beginning and end of an event are also instantaneous events.

"State" refers to the condition of things, such as *Sam is a student* , this is Sam's state; It also includes the situation of the event, for example, *Sam is reading a book*, is a time when the event is in progress. Like events, states have a beginning and an end. The difference is that states do not have a process. According to the perception and understanding of the state, the state maintains the same character from beginning to end, unlike the course of events, which do not have the same moment. In other words, the middle part between the beginning and the end of a state is considered "homogeneous", so states are generally considered to have no "process".

Some facts are independent of time, and such facts may be called time-independent facts or simply facts. Sentences expressing these facts are usually presented in the simple present tense. Currently, there are two types of time-independent facts: (1) facts in the mathematical world; (2) Some facts about abstract concepts. The truth value of a fact does not depend on time.

Prototype, original sentence and actual sentence Because John slept many times throughout his life, “John sleep” constitutes a distinct event class. There is no English sentence that expresses such an event class, which is hereinafter referred to as "JOHN SLEEP" and called the prototype. The prototype itself has no tense or aspect expression and can be regarded as the name of the event class, similar to the general name. If we start from the prototype and want to express a sleep, we can take the method of marking the prototype, such as

$(johnsleep)_1$,$(johnsleep)_2$, ...,$(johnsleep)_n$

to refer to a certain event. A string such as "$(johnsleep)_n$" is hereafter referred to as the original sentence. However, in reality, people do not express events in this way, but use other events or states as reference points to determine which sleep is referred to, such as

e.g.17: John was sleeping when Sam came in. (The event of Sam came in is the reference point)

e.g.18: John is going to sleep as soon as the moon rises. (The event of the moon rises is the reference point)

e.g.19: John is sleeping.

As there is a certain reference point, the original sentence also has the corresponding tense deformation. From the prototype to the real sentence, it is also explained from a side that the expression of English sentence tense is essentially to clarify the event that the sentence refers to.

Station, point of speech, reference point, speech event According to Event-State Semantics, there are four elements that affect the temporal phenomenon of natural language: station, point of speech, reference point, speech event. For the same speech event or state, the tense or aspect of the final sentence will be different due to various positions or reference points.

Reference point is the event/state corresponding to the part of the sentence that expresses the reference. Not all sentences have the reference part. Consider the following example:

e.g.20: A (John says:) Bob will go home.

B (Sam says:) John said that Bob would go home.

In natural language expression, the speaker's speech or sentence generation is also an event, and also participates in the formation of the sentence as a reference point. For this purpose, two special reference points need to be considered, namely, speech point and site.

Speech point refers to the position of the speaker, such as in the present to speak about the past, or in a certain position in the past to speak about the future. Speech point has similarities with Reichenbach's "speech time", but in the relative time frame, speech point refers to speech events, rather than time.

"Bob will go home" is always a sentence said by a speaker, maybe John. This sentence has its own speech point. For e.g.20, the speech point is now. E.g.20 can also be said by someone else, maybe Sam. In this case, the speaker needs to be stated, thus giving rise to e.g.20. Similarly, e.g.20 has its own speech point, but the difference is that e.g.20 also includes the speech point of sentence e.g.20. The speech point of e.g.20 is not the point of e.g.20, but the relative position of the speaker of e.g.20 as stated by e.g.20. Such a position is called a site.

In the event-state structure of the objective world, standing at a point x, referencing an event or state, expressing an event or state, forming an event or state sentence, or determining whether an event sentence (or state sentence) is valid, is a complete formal semantic representation mode of a common tense-aspect sentence.

Behind the four elements of station, speech point, reference point and speech event are: (the speaker) standing position, (the relayed subject) position, language and the event-state structure of the objective world. These four aspects jointly determine the tense-aspect sentence that the sentence finally presents. Consider the following example:

e.g.21: Mary thought Sam would have been doing his homework when Bob came back.

The semantics expressed in e.g.21 are that, taking now as the station, through taking Mary's thinking as the point of view, e.g.21 expresses the state that Sam will be in writing homework when Bob comes back, where Sam will be in the state of writing homework is the speech event.

In general, we believe that the relative sequence of events and states in the world, the speech event, the reference event, the point of view expressed by the sentence and the relevant station, these elements determine the formation of the tenses and aspects sentences all together. In turn, they also constitute the basic elements for the interpretation of the semantics of such sentences.

Reference Sentences Reference sentences refer to the sentences with reference words. Reference words in English refer to time adverbials guided by time preposition phrases or conjunctions, which have a rich variety. In addition to the simple present tense, the tenses and aspects expressed by other simple sentences, such as the simple past tense, the simple future tense, the present continuous tense, and the present perfect tense, can also be expressed by reference sentences. The four tenses and aspects phenomena, such as the past continuous tense, the past perfect tense, the future continuous tense, and the future perfect tense, can only be expressed by reference sentences. Compared with the event/state expressed by simple sentences, there is nothing special about the reference event/state. The reference event/state also elements in the event-state model, so it can be found in the discourse domain of the event-state model, without expanding the event-state model. In general, there are three ways to express the reference event/state in sentences:

First, preposition + event noun. For example, John became a soldier after 911.

Second, preposition + time noun. For example, John will leave at May 5th 2017.

Third, conjunction + clause. For examples, Jack will have broken all the glass when you find him.

For the first way, the symbol representing event name is added to the formal language g ("911" refers to the 911 event). For the second way, the constant symbol t representing such things as "May 5th 2017" is added. For the sake of simplicity, we don't deal with such cases temporarily. Common prepositions similar to "after" and "at" include "before", "since"," by the end of", etc. For the third way, we add the symbols of formal language [WHX], [WIX] to represent conjunctions and clauses. Common conjunctions similar to "when" and "while" include "then" and etc. [WHX] in WH represents the conjunction while X represents the clause while leading. [WIX] handles similar cases in the same way.

Reference sentences also need to express the status and relationship between the main event/state and the reference event/state. In order to reflect the differences between the reference event/state and the main event/state, a new symbol @ is added to the event-state model to represent "as a reference event/state". The key is the difference in status.

Event length sentences If the events or states referred to in the reference sentences are some "points", that is, reference points, then there is a kind of sentences, their reference events or states need to be a process or interval of length. In English, that is, the completion progressive tense sentences (the first three lines in Column 4, Table 1).

e.g.10 takes "the whole ceremony" as a reference.

e.g.11 takes "the whole class" as a reference.

e.g.12 takes "three weeks" as a reference.

Such a process or interval generally has a certain length. In English, prepositional phrases indicating the length of events/states are usually used as references for such sentences, so we named such sentences "event-length sentences". Event-length sentences are usually used in the completion progressive tense. The complete progressive statement not only needs to point out the progress of the event, but also needs to emphasize the duration of the progress. This leads to the need for the event/state length element. We add words corresponding to event nouns and symbols indicating the length of event/state to formal language. $\mathscr{L}_{\mathrm{S}}$.

Indirect Speech Consider the following example:

(1)Bob will go home.

(2)(John says:) Bob will go home.

(3)John said: "Bob will go home".

(4)John said that Bob would go home.

(5)(Sam says:) John said that Bob would go home.

(6)Sam said that John said that Bob would go home.

(1) is a common sentence, which is also denoted as ξ. A sentence is always spoken by a speaker. Let's say that is said by John, namely (2). At this time, "John said..." is hidden behind ξ and can be regarded as the background. (3) and (4) are direct quotation and indirect quotation about (2). There are two points to be noted: (a) no matter what quotation is, it is necessary to raise the element "John said..." from the position of background to the sentence under discussion. (b) The difference is that direct quotation does not need to change the tense and aspect of the cited sentence; indirect quotation needs to adjust the tense and aspect of the cited sentence. According to the above analysis, assuming that (4) is said by Sam, there can be (5) and (6). It shows that the process of speaking and quoting can be carried on continuously in theory. It also adds complexity to the description of the phenomenon of indirect speech.

We believe that the key is to see that the utterance of a sentence is also an event, so that the utterance of a sentence can be used as a reference point in the background and also as an object to be talked about in the foreground.

Suppose that there are Bob and John in a world, the sentence "John said that Bob would go home." is true, which can be denoted as

$\mathcal{M}, x \models$ John said that Bob would go home.

There exists a certain speech event of John, in which John actually says "Bob will go home". Such a speaking event can be denoted as

S_{John}: Bob will go home

Then there is

$\mathcal{M}, x \models$ John said that Bob would go home, if and only if, there exists e, e happens before x, $e = S_{John}$: Bob will go home.

Correspondingly, "John said that Bob would go home" is false at x in $\mathcal{M}$, that is, there is no such e, e occurs before x, and $e = S_{John}$: Bob will go home.

Event-State Semantics

Table 1 exhibits 16 common English tense-aspect phenomena, which are also affected by sentence combination. Some appear in single sentences, some appear in complex sentences with time adverbial clauses, and some only appear in sentences with indirect speech. Single sentences do not contain clauses in grammar, which are divided into two categories, simple single sentence, and complex single sentence. Complex single sentence refers to single sentences with time unit or event length adverbial, while simple single sentence does not contain the above sentence components. Simple single sentence is the most basic type, and the tense or aspect involved are present simple, past simple, future simple, present continuous, and present perfect. In order to describe these temporal phenomena, we propose Event-State Semantics.

Formal language $\mathscr{L}_{\mathrm{S}}$

Initial symbols

1. $\xi_1, \xi_2, \xi_3, ...$ (ordinary event sentence variable)
2. $\zeta_1, \zeta_2, \zeta_3, ...$ (instantaneous event sentence variable)
3. $s_1, s_2, s_3, ...$ (state sentence variable)
4. $p_1, p_2, p_3, ...$ (time-independent fact sentence variable)
5. N (state sentence constant)
6. $\neg, \rightarrow$ (classical logical conjunction: negation, implication)
7. Ing, Hv, ft, pt (temporal operators: proceeding, completing, future, past)

7* Hv-Ing-for (temporal operator: completing progressive)

8. F,P (temporal operators: future, past)
9. (,) (technical symbol, left and right parenthesis)
10. $l_1, l_2, l_3, ...$ (event/state length variable)
11. $g_1, g_2, g_3, ...$ (event noun variable)
12. AF, BF, BY, WH, WI, SI, DU (compound word)
13. [ ] (reference mark)
14. S: (paraphrase symbol)

Propositional constant

In language $\mathscr{L}_{\mathrm{S}}$, a propositional constant symbol N correspond to the special instantaneous event mentioned above i.e., "now". N refers to the event/state of "now", that is, the event of "express". All sentences are closely related to the event of "express". The choice of each specific tense/aspect type is determined by the relationship between the relevant event/state and the event of "express".

$\mathscr{L}_{\mathrm{S}}$-formula

Event formula $\alpha ::= \xi|\zeta|$Ing$\xi|$Hv$\epsilon|$ft $\epsilon|$pt $\epsilon|$ Hv-Ing-for ϵ,

in which ϵ means ζ (instantaneous event), ξ (ordinary event) or S: φ (relayed event).

State formula $\varphi ::= N|s|Fs|Ps|F\alpha|P\alpha|[\mu X]\alpha|$ $F([\mu X]\alpha)|P([\mu X]\alpha)$ (μ can be AF BF BY WH WI SI or DU.)

Formula of fact $A ::= p|\varphi|\neg A|A \rightarrow A$

Examples of formulas:

φ, $\varphi \rightarrow \psi$, N, [WI Ing ξ] Ing ξ_1, Hv-Ing-for(ξ, l), [SI ϵ] Hv-Ing-for(ξ, l), pt(S: φ), ft(S:φ), ...

S:φ Such formulas are regarded as pointing to a specific speaking event (noted as ζ_1, $\zeta_1 = S : \varphi$ in the event-state frame, it (ζ_1) can be combined with ft, ed and other tense/aspect operators.

Formal semantics

Definition 1 $\mathcal{F}^S = \langle \mathcal{A}, !, B, E, \preccurlyeq, C, L, >, ||\ || \rangle$ is an $\mathscr{L}_{\mathrm{S}}$-frame, also called event-state frame, if and only if $\mathcal{F}^S$ is an ordered group satisfying the following conditions:

$\mathcal{A} = \mathcal{E} \cup S \neq \phi$; where $\mathcal{E}$ is called the event domain, and $\mathcal{S}$ is called the state domain.

$! \in \mathcal{S}$. B and E are mappings from $\mathcal{E}\cup\mathcal{S}$ to $\mathcal{E}\cup\mathcal{S}$ satisfying the following conditions: for any $\alpha \in \mathcal{E} \cup \mathcal{S}$, BB($\alpha$)=B($\alpha$), EB($\alpha$)=B($\alpha$), BE($\alpha$)=E($\alpha$),EE($\alpha$)=E($\alpha$);

is a binary relation satisfying the following conditions:

(1) for any $\alpha \in \mathcal{E} \cup \mathcal{S}$, $B(\alpha) \preccurlyeq E(\alpha)$;

(2) let $\mathcal{H} = \{B(\alpha) : \alpha \in \mathcal{E} \cup \mathcal{S}\} \cup \{E(\alpha) : \alpha \in \mathcal{E} \cup \mathcal{S}\}$. $\preccurlyeq$ is a binary relation in $\mathcal{H}$ that satisfiesfies the following conditions: for any $h_1, h_2, h_3 \in \mathcal{H}, h_1 \preccurlyeq h_1$; if $h_1 \preccurlyeq h_2$ and $h_2 \preccurlyeq h_3$ then $h_1 \preccurlyeq h_3$.

C is a mapping from $\mathcal{E}$ to $\mathcal{S}$, called an influence function, satisfying $B(\alpha) \preccurlyeq B(C(\alpha))$ and $E(\alpha) \preccurlyeq E(C(\alpha))$.

$L \neq \phi$, L is called the (event/state) length set;

$>$is a partial order relation on L;

|| || is a mapping from $\mathcal{A}$ to L (|| ||: $\mathcal{A} \rightarrow$ L) , called an event/state length mapping.

Definition 2 Let $\mathcal{F}^S = \langle \mathcal{A}, !, B, E, \preccurlyeq, C, L, >, ||\ || \rangle$ is an $\mathscr{L}_{\mathrm{S}}$-frame, x, y are elements in $\mathcal{A}$, the relations below are ordered relations.

$x \equiv y$, if and only if, $x \preccurlyeq y$ and $y \preccurlyeq x$.

$x \prec y$, if and only if, $x \preccurlyeq y$ and $x \equiv y$.

$x \mid y$, if and only if, $E(x) \preccurlyeq B(y)$ and $E(x) \preccurlyeq B(y)$

x - y,if and only if, $E(x) \equiv B(y)$.

$x \preccurlyeq y$, if and only if, $B(y) \preccurlyeq B(x)$ and $E(x) \preccurlyeq E(y)$.

$x \Subset y$, if and only if, $B(y) \prec B(x)$ and $E(x) \prec E(y)$.

$x \Cap y$, if and only if, $B(x) \preccurlyeq B(y)$ and $E(x) \preccurlyeq E(y)$.

Definition 3 $\approx$ is a binary relation on L; for any $l_1, l_2 \in L$, if $l_1 \approx l_2$,if and only if, $l_1 > l_2$ and $l_2 > l_1$.

Definition 4 Let $\mathcal{F}^S$ be an $\mathscr{L}_{\mathrm{S}}$-frame, ϵ is ordinary event sentence variable, ζ instantaneous event sentence variable, s state sentence variable, p time-independent fact sentence variable, l event/state length variable, $S : \varphi$ is a described event variable, σ is a assignment on $\mathcal{F}^S$, if σ is a mapping satisfying the following conditions:

$\sigma(\xi)=e, e\in\mathcal{E}$
$\sigma(\zeta)=e^*, e^*\in\mathcal{E}^*$
$\sigma(s)=\mathrm{s}, \mathrm{s}\in\mathcal{S}$
$\sigma(p)=1$ or 0 , one and only one of the two must be present. $\sigma(l)=1, 1\in$ L
$\sigma(\mathrm{S}:\varphi)=e, e\in\mathcal{E}$

Definition 5 $\mathcal{M}^{\mathrm{S}}=\langle\mathcal{F}^{\mathrm{S}},\sigma\rangle$ is an $\mathscr{L}_{\mathrm{S}}$-model, also called an event-state model, if and only if, $\mathcal{F}^{\mathrm{S}}$ is a $\mathscr{L}_{\mathrm{S}}$-frame, σ is a assignment on $\mathcal{F}^{\mathrm{S}}$.

Convention Let $\mathcal{F}^{\mathrm{S}}=\langle\mathcal{A},!,\mathrm{B},\mathrm{E},\preccurlyeq,\mathrm{C},\mathrm{L},>,\|\ \|\rangle$. The model on $\mathcal{F}^{\mathrm{S}}$ is $\mathcal{M}^{\mathrm{S}}=\langle\mathcal{F}^{\mathrm{S}},\sigma\rangle$ also denoted as $\langle\mathcal{A},!,\mathrm{B},\mathrm{E},\preccurlyeq,\mathrm{C},\mathrm{L},>,\|\ \|,\sigma\rangle$. For convenience, $\mathcal{F}^{\mathrm{S}}$ is denoted as $\mathcal{F}$ and $\mathcal{M}^{\mathrm{S}}$ similarly denoted as $\mathcal{M}$.

Notation Under any model $\mathcal{M}=\langle\mathcal{F},\sigma\rangle$, for any $\mathscr{L}_{\mathrm{s}}$ variable $u=\varepsilon, s, p, u^{\mathcal{M}}=\sigma(u)$.

Definition 6 Let $\mathcal{M}=\langle\mathcal{F},\sigma\rangle$ be any $\mathscr{L}_S$-model, where $\mathcal{F}=\langle\mathcal{A},!,\mathrm{B},\mathrm{E},\preccurlyeq,\mathrm{C},\mathrm{L},>,\|\ \|\rangle$, $\mathcal{A}=\mathcal{E}\cup\mathcal{S}$, x, y are elements in $\mathcal{A}$.

(1) $\mathcal{M}, x\vDash N$, if and only if, $x=!$.
(2) $\mathcal{M},\mathrm{x}\vDash p$, if and only if, $p^{\mathcal{M}}=1$.
(3) $\mathcal{M},\mathrm{x}\vDash s$, if and only if, $\mathrm{x}\Subset s^{\mathcal{M}}$.
(4) $\mathcal{M}, x\vDash\zeta$, if and only if, $\zeta^{\mathcal{M}}\Subset x$.
(5) $\mathcal{M},\mathrm{x}\vDash\mathrm{pt}\varepsilon$, if and only if, $\varepsilon^{\mathcal{M}}\mid\mathrm{x}$.
(6) $\mathcal{M},\mathrm{x}\vDash\mathrm{ft}\varepsilon$, if and only if, $\mathrm{x}\mid\varepsilon^{\mathcal{M}}$.
(7) $\mathcal{M},\mathrm{x}\vDash\mathrm{P}s$, if and only if, there is y, $\mathrm{y}\mid\mathrm{x}, \mathcal{M},\mathrm{y}\vDash s$.
(8) $\mathcal{M},\mathrm{x}\vDash\mathrm{F}s$, if and only if, there is y, $\mathrm{x}\mid\mathrm{y}, \mathcal{M},\mathrm{y}\vDash s$.
(9) $\mathcal{M},\mathrm{x}\vDash\mathrm{F}\varphi$, if and only if, if $s/\zeta\in\mathcal{M}$, then $\mathrm{x}\prec s/\zeta, \mathcal{M}, s/\zeta\models\varphi$.
(10) $\mathcal{M},\mathrm{x}\vDash\mathrm{P}\varphi$, if and only if, there is $s/\zeta\in\mathcal{M},\mathrm{x}\mid s/\zeta$, and $\mathcal{M}, s/\zeta\models\varphi$.
(11) $\mathcal{M},\mathrm{x}\vDash\mathrm{Ing}\,\xi$, if and only if, $\mathrm{x}\subset\xi^{\mathcal{M}}$, x is e or s.
(12) $\mathcal{M},\mathrm{x}\vDash\mathrm{Hv}\xi$, if and only if, $\xi^{\mathcal{M}}\mid\mathrm{x}$, and $\mathrm{x}\Subset\mathrm{C}\left(\xi^{\mathcal{M}}\right)$.
(13) $\mathcal{M},\mathrm{x}\vDash\neg A$, if and only if, $\mathcal{M},\mathrm{x}\nvDash A$.
(14) $\mathcal{M},\mathrm{x}\vDash A\rightarrow B$, if and only if, $\mathcal{M},\mathrm{x}\nvDash A$ or $\mathcal{M},\mathrm{x}\vDash B$.
(15) $\mathcal{M},\mathrm{x}\vDash\mathrm{S}:\varphi$, if and only if, there is $e, e\mid\mathrm{x}$, and $e=(\mathrm{S}:\varphi)^{\mathcal{M}}$.
(16) $\mathcal{M},\mathrm{x}\vDash[\mathrm{BY}g]$Hv-Ing-for (ξ,l), if and only if, $@g^{\mathcal{M}}:\left(g^{\mathcal{M}}\Subset\xi^{\mathcal{M}}\right),\mathrm{x}\subset\xi^{\mathcal{M}}, l^{\mathcal{M}}\approx\left(B\left(\xi^{\mathcal{M}}\right), g^{\mathcal{M}}\right)$.
(17) $\mathcal{M},\mathrm{x}\vDash[\mathrm{WI\ Ing}\,\xi]\,\mathrm{Ing}\,\xi_1$, if and only if, $@\,\mathrm{Ing}\,\xi^{\mathcal{M}}:(\mathrm{Ing}\,\xi_1)^{\mathcal{M}}\Subset\xi^{\mathcal{M}},\mathrm{x}\Subset(\mathrm{Ing}\,\xi)^{\mathcal{M}}$.
(18) $\mathcal{M},\mathrm{x}\vDash[\mathrm{WH}\varepsilon]\varepsilon_1$, if and only if, $@\ \varepsilon^{\mathcal{M}}:\varepsilon^{\mathcal{M}}\Subset\varepsilon_1^{\mathcal{M}}$), $\mathrm{x}\Subset\varepsilon^{\mathcal{M}}$.
(19) $\mathcal{M},\mathrm{x}\vDash[\mathrm{AF}\varepsilon]\varepsilon_1$, if and only if, $@\ \varepsilon^{\mathcal{M}}:\left(\varepsilon^{\mathcal{M}}\prec\varepsilon_1^{\mathcal{M}}\right),\mathrm{x}\Subset\varepsilon^{\mathcal{M}}$.
(20) $\mathcal{M},\mathrm{x}\vDash[\mathrm{BF}\varepsilon]\varepsilon_1$, if and only if, $@\ \varepsilon^{\mathcal{M}}:\left(\varepsilon_1^{\mathcal{M}}\prec\varepsilon^{\mathcal{M}}\right)$.
(21) $\mathcal{M},\mathrm{x}\vDash[\mathrm{BF}\varepsilon]\mathrm{Hv}\xi$, if and only if, $@\ \varepsilon^{\mathcal{M}}:\left((\mathrm{Hv}\xi)^{\mathcal{M}}\prec\varepsilon^{\mathcal{M}}\right)$.
(22) $\mathcal{M},\mathrm{x}\vDash[\mathrm{BF}\varepsilon]$Hv-Ing-for (ξ,l), if and only if, $@\ \varepsilon^{\mathcal{M}}:\left((\text{Hv-Ing-for}(\xi,l))^{\mathcal{M}}\prec\varepsilon^{\mathcal{M}}\right)$.
(23) $\mathcal{M},\mathrm{x}\vDash[\mathrm{DU}g]\xi$, if and only if, $@\ g^{\mathcal{M}}:\left(\xi^{\mathcal{M}}\Subset g^{\mathcal{M}}\right)$.
(24) $\mathcal{M},\mathrm{x}\vDash[\mathrm{DU}g]\mathrm{Hv}\xi$, if and only if, $@\ g^{\mathcal{M}}:\left(\xi^{\mathcal{M}}\Subset g^{\mathcal{M}}\right)$.
(25) $\mathcal{M},\mathrm{x}\vDash[\mathrm{SI}\zeta]\mathrm{Hv}\xi$, if and only if, $@\ \zeta^{\mathcal{M}}:\left(\zeta^{\mathcal{M}}-\xi^{\mathcal{M}}\right)$.
(26) $\mathcal{M},\mathrm{x}\vDash[\mathrm{SI}\zeta]$Hv-Ing-for$(\xi,l)$, if and only if, $@\ \zeta^{\mathcal{M}}:\left(\zeta^{\mathcal{M}}-(\text{Hv-Ing-for}(\xi,l))^{\mathcal{M}}\right)$.
(27) $\mathcal{M},\mathrm{x}\vDash\mathrm{P}([\mu\mathrm{X}]\alpha)$, if and only if, there is $\mathrm{y}\in\mathcal{M},\mathrm{y}\mid\mathrm{x},\mathcal{M},\mathrm{y}\vDash[\mu\mathrm{X}]\alpha$.
(28) $\mathcal{M},\mathrm{x}\vDash\mathrm{F}([\mu\mathrm{X}]\alpha)$, if and only if, there is $\mathrm{y}\in\mathcal{M},\mathrm{x}\mid\mathrm{y},\mathcal{M},\mathrm{y}\vDash[\mu\mathrm{X}]\alpha$.

Definition 7 Let A be any formula, $\mathcal{M}$ is $\mathscr{L}_{\mathrm{S}}$-model. For any $\mathrm{x}\in\mathcal{A},\mathcal{M},\mathrm{x}\vDash A$ is called A is true at x in $\mathcal{M}$.

The formal semantic interpretation

Reference sentence

Refer to 1-1 1-2 1-3 2-1 2-2 2-3 3-1 3-2 3-3 in table 1.

Present simple tense e.g.1 John is a coward when he meets the big dog. (1-1)

In formal language $\mathscr{L}_{\mathrm{S}}$, e.g.1 is expressed as $[\mathrm{WH}\zeta]\xi$.

$$\mathcal{M},!\models[\mathrm{WH}\zeta]\xi$$

If and only if, there is $e\in\mathcal{M}, e\equiv!, @\zeta^{\mathcal{M}}:\zeta^{\mathcal{M}}\Subset\xi^{\mathcal{M}}, e\Subset\zeta^{\mathcal{M}}$. as ζ is instant event argument, we have $e\equiv\zeta^{\mathcal{M}}$.

That is, there is $e\in\mathcal{M}, e\equiv!, @\zeta^{\mathcal{M}}:\zeta^{\mathcal{M}}\Subset\xi_1^{\mathcal{M}}, e\equiv\zeta^{\mathcal{M}}$.

Present continuous tense e.g.2 While Jane is singing, Mary is doing her homework. (1-2)

In formal language $\mathscr{L}_{\mathrm{s}}$, e.g.2 is expressed as $[\mathrm{WI\ Ing}\,\xi]\,\mathrm{Ing}\,\xi_1$.

$\mathcal{M},!\vDash[\ \mathrm{WI\ Ing}\,\xi]\,\mathrm{Ing}\,\xi_1$

If and only if, $@\,\mathrm{Ing}\,\xi^{\mathcal{M}}:(\mathrm{Ing}\,\xi_1)^{\mathcal{M}}\Subset\xi^{\mathcal{M}},!\Subset(\mathrm{Ing}\,\xi)^{\mathcal{M}}$.

Present perfect tense e.g.3 Sue has lived here since she was born. (1-3)

In formal language $\mathscr{L}_{\mathrm{S}}$, e.g.3 is expressed as $[\mathrm{SI}\zeta]\mathrm{Hv}\xi$.

$$\mathcal{M},!\vDash[\mathrm{SI}\zeta]\mathrm{Hv}\xi$$

If and only if, $@\ \zeta^{\mathcal{M}}:\zeta^{\mathcal{M}}-\xi^{\mathcal{M}},!\Subset\zeta^{\mathcal{M}}$
as ζ is instant event argument, we have $!\equiv\zeta^{\mathcal{M}}$.

Past simple tense e.g.4 John became a soldier after 911. (2-1)

In formal language $\mathscr{L}_{\mathrm{S}}$, e.g.4 is expressed as $\mathrm{P}\left([\mathrm{AF}\zeta]\zeta_1\right)$.

Then there is $\mathcal{M},!\models\mathrm{P}\left([\mathrm{AF}\zeta]\zeta_1\right)$

If and only if, there is $e\in\mathcal{M}, e\mid!$, and $\mathcal{M}, e\vDash[\mathrm{AF}\zeta]\zeta_1$.

If and only if, there is $e\in\mathcal{M}, e\mid!, @\zeta^{\mathcal{M}}:\left(\left(\mathrm{E}\left(\zeta^{\mathcal{M}}\right)\Subset\zeta_1^{\mathcal{M}}\right)\vee\left(\mathrm{B}\left(\zeta^{\mathcal{M}}\right)\Subset\zeta_1^{\mathcal{M}}\right)\right), e\Subset\zeta^{\mathcal{M}}$.

As ζ,ζ_1 are instant event arguments, we have $\zeta^{\mathcal{M}}=\mathrm{B}\left(\zeta^{\mathcal{M}}\right)=\mathrm{E}\left(\zeta^{\mathcal{M}}\right),\zeta_1^{\mathcal{M}}=\mathrm{B}\left(\zeta_1^{\mathcal{M}}\right)=\mathrm{E}\left(\zeta_1^{\mathcal{M}}\right)$, then we have $\left(\ \zeta_1^{\mathcal{M}}\Subset\zeta^{\mathcal{M}}\ \right)\vee\left(\ \zeta_1^{\mathcal{M}}\Subset\zeta^{\mathcal{M}}\ \right)$, which is $\zeta_1^{\mathcal{M}}\equiv\zeta^{\mathcal{M}}; e\Subset\zeta^{\mathcal{M}}$, then $e\equiv\zeta^{\mathcal{M}}$.

That is, there is $e\in\mathcal{M}, e\mid!, @\zeta^{\mathcal{M}}:{\zeta_1}^{\mathcal{M}}\equiv\zeta^{\mathcal{M}}, e\equiv\zeta^{\mathcal{M}}$.

Simple future tense e.g.5 John will leave after dinner. (3-1)

In formal language $\mathscr{L}_{\mathrm{S}}$, e.g.5 is expressed as $\mathrm{F}\left([\mathrm{AF}\zeta]\xi_1\right)$.

$$\mathcal{M}, ! \vDash \mathrm{F}\left([\mathrm{AF}\zeta]\xi_1\right)$$

If and only if, there is $e \in \mathcal{M}, ! \mid e$ and $\mathcal{M}, e \vDash [\mathrm{AF}\zeta]\xi_1$.

If and only if, there is $e \in \mathcal{M}, ! \mid e, @\zeta^{\mathcal{M}} : \left(\left(\mathrm{E}\left(\zeta^{\mathcal{M}}\right) \Subset \xi_1{}^{\mathcal{M}}\right) \vee \left(\mathrm{B}\left(\zeta^{\mathcal{M}}\right) \Subset \xi_1{}^{\mathcal{M}}\right)\right), e \Subset \zeta^{\mathcal{M}}$.

As ζ s instant event argument, we have $e \equiv \zeta^{\mathcal{M}}$.

That is, there is $e \in \mathcal{M}, ! \mid e, @\zeta^{\mathcal{M}} : \left(\mathrm{E}\left(\zeta^{\mathcal{M}}\right) \Subset \xi_1{}^{\mathcal{M}}\right) \vee \left(\mathrm{B}\left(\zeta^{\mathcal{M}}\right) \Subset \xi_1{}^{\mathcal{M}}\right), e \equiv \zeta^{\mathcal{M}}$.

Past Continuous tense e.g.6 John was walking to school when Mary left. (2-2)

In formal language $\mathscr{L}_{\mathrm{S}}$, e.g.6 is expressed as $\mathrm{P}\left([\mathrm{WH}\zeta]\,\mathrm{Ing}\,\xi_1\right)$ $\mathcal{M}, ! \vDash \mathrm{P}\left([\mathrm{WH}\zeta]\,\mathrm{Ing}\,\xi_1\right)$.

If and only if, there is $e \in \mathcal{M}, e \mid !$ and $\mathcal{M}, e \vDash [\mathrm{WH}\zeta]\,\mathrm{Ing}\,\xi_1$.

If and only if, there is $e \in \mathcal{M}, e \mid !, @\zeta^{\mathcal{M}} : \zeta^{\mathcal{M}} \Subset \xi_1^{\mathcal{M}}, e \Subset \zeta^{\mathcal{M}}$.

Since ζ is an instantaneous event variable, there is $e \equiv \zeta^{\mathcal{M}}$.

That is, there is $e \in \mathcal{M}, e \mid !, @\zeta^{\mathcal{M}} : \zeta^{\mathcal{M}} \Subset \xi_1^{\mathcal{M}}, e \equiv \zeta^{\mathcal{M}}$.

Past perfect tense e.g.7 John had eaten 5 cookies before the school bus finally came.

In formal language $\mathscr{L}_{\mathrm{S}}$, e.g.7 is expressed as $\mathrm{P}\left([\mathrm{BF}\varepsilon]\mathrm{Hv}\varepsilon_1\right)$

$$\mathcal{M}, ! \models \mathrm{P}\left([\mathrm{BF}\varepsilon]\mathrm{Hv}\varepsilon_1\right)$$

If and only if, there is $e \in \mathcal{M}, e \mid !$ and $\mathcal{M}, e \vDash [\mathrm{BF}\varepsilon]\mathrm{Hv}\varepsilon_1$.

If and only if, there is $e \in \mathcal{M}, e \mid !, @\varepsilon^{\mathcal{M}} : \mathrm{C}\left(\varepsilon_1{}^{\mathcal{M}}\right) \prec \varepsilon^{\mathcal{M}}, e \Subset \varepsilon^{\mathcal{M}}$.

Future continuous tense e,g,8 John will be walking to school when Mary leaves. (3-2)

In formal language $\mathscr{L}_{\mathrm{S}}$, e.g.8 is expressed as $\mathrm{F}([\mathrm{WH}\zeta]\,\mathrm{Ing}\,\xi_1)$

$$\mathcal{M}, ! \vDash \mathrm{F}\left([\mathrm{WH}\zeta]\,\mathrm{Ing}\,\xi_1\right)$$

If and only if, there is $e \in \mathcal{M}, ! \mid e$ and $\mathcal{M}, e \vDash [\mathrm{WH}\zeta]\,\mathrm{Ing}\,\xi_1$.

If and only if, there is $e \in \mathcal{M}, ! \mid e, @\zeta^{\mathcal{M}} : \zeta^{\mathcal{M}} \Subset \xi_1^{\mathcal{M}}, e \Subset \zeta^{\mathcal{M}}$.

Since ζ is an instantaneous event variable, there is $e \equiv \zeta^{\mathcal{M}}$.

That is, thereis $e \in \mathcal{M}, ! \mid e, @\zeta^{\mathcal{M}} : \zeta^{\mathcal{M}} \Subset \xi_1^{\mathcal{M}}, e \equiv \zeta^{\mathcal{M}}$.

Future perfect tense e.g.9 John will have learned 12 units by the end of this term.(3-3)

In formal language $\mathscr{L}_{\mathrm{S}}$, e.g.9 is expressed as $\mathrm{F}([\mathrm{BY}g]\mathrm{Hv}\varepsilon)$ $\mathcal{M}, ! \models \mathrm{F}([\mathrm{BY}g]\mathrm{Hv}\varepsilon)$

If and only if, there is $e \in \mathcal{M}, ! \mid e$ and $\mathcal{M}, e \vDash [\mathrm{BY}g]\,\mathrm{Hv}\varepsilon$. (g refers to the end of this term.)

If and only if, there is $e \in \mathcal{M}, ! \mid e, @g^{\mathcal{M}} : \varepsilon^{\mathcal{M}} \prec g^{\mathcal{M}}, e \Subset g^{\mathcal{M}}$.

Event-length sentences

Refer to 1-4 2-4 3-4 in table 1.

Present perfect continuous tense e.g.10 John has been crying for the whole ceremony. (1-4)

In formal language $\mathscr{L}_{\mathrm{S}}$, e.g.10 is expressed as Hv -Ing-for (ξ, l).

$\mathcal{M}, ! \models$ Hv-Ing-for (ξ, l)

If and only if, $! \Subset \xi^{\mathcal{M}}$ and $\left\|\xi^{\mathcal{M}}\right\| > l$.

Past perfect continuous tense e.g.11 John had been studying English for the whole class before he entered the college. (2-4)

In formal language $\mathscr{L}_{\mathrm{S}}$, e.g.11 is expressed as $\mathrm{P}([\mathrm{BF}\varepsilon]$Hv-Ing-for $(\xi, l))$ $\mathcal{M}, ! \models \mathrm{P}([\mathrm{BF}\varepsilon]$Hv-Ing-for $(\xi, l))$

If and only if, there is $\mathrm{x} \in \mathcal{M}, \mathrm{x} \mid !$ and $\mathcal{M}, \mathrm{x} \vDash [\mathrm{BF}\varepsilon]$ Hv-Ing-for (ξ, l).

If and only if, there is $\mathrm{x} \in \mathcal{M}, \mathrm{x} \mid !$ and $@\varepsilon^{\mathcal{M}} : \left(\xi^{\mathcal{M}} \prec \varepsilon^{\mathcal{M}}\right), \mathrm{x} \subset \xi^{\mathcal{M}}, l^{\mathcal{M}} \approx \left(B\left(\xi^{\mathcal{M}}\right), \varepsilon^{\mathcal{M}}\right)$.

Future perfect continuous e.g.12 John will have been working for three weeks before he got the master degree. (3-4)

In formal language $\mathscr{L}_{\mathrm{S}}$, e.g.12 is expressed as $\mathrm{F}([\mathrm{BF}\varepsilon]$Hv-Ing-for $(\xi, l))$.

$\mathcal{M}, ! \models \mathrm{F}([\mathrm{BF}\varepsilon]$Hv-Ing-for $(\xi, l))$

If and only if, there is $\mathrm{x} \in \mathcal{M}, ! \mid \mathrm{x}$ and $\mathcal{M}, \mathrm{x} \vDash [\mathrm{BF}\varepsilon]$ HvIng-for (ξ, l).

If and only if, there is $\mathrm{x} \in \mathcal{M}, ! \mid \mathrm{x}$ and $@\varepsilon^{\mathcal{M}} : \left(\xi^{\mathcal{M}} \prec \varepsilon^{\mathcal{M}}\right), \mathrm{x} \subset \xi^{\mathcal{M}}, l^{\mathcal{M}} \approx \left(B\left(\xi^{\mathcal{M}}\right), \varepsilon^{\mathcal{M}}\right)$.

Indirect Speech

Refer to 4-1 4-2 4-3 4-4 in table 1.

Past Future Simple tense e.g.13 John said that Bob would go home. (4-1)

In formal language $\mathscr{L}_{\mathrm{S}}$, e.g.13 is expressed as $\mathrm{ptS} : \mathrm{Pft}\xi (= \mathrm{pt}(\mathrm{S} : \mathrm{ft}\xi))$.

$$\mathcal{M}, ! \models \mathrm{pt}(\mathrm{S} : \mathrm{ft}\xi)$$

Therefore, the semantic interpretation of the above indirect speech example is accordingly divided into two steps:

The first step is to give the semantic interpretation of the outer tense of the indirect speech when the present is taken as the reference, that is, $\mathcal{M}, ! \vDash \mathrm{pt}(\mathrm{S} : \mathrm{ft}\xi)$.

If and only if, $(\mathrm{S} : \mathrm{ft}\xi)^{\mathcal{M}} \mid !$.

The second step is to add the interpretation of the indirect speech part on the basis of the semantic interpretation of the first step,

$$\mathcal{M}, (\mathrm{S} : \mathrm{ft}\xi)^{\mathcal{M}} \models \mathrm{ft}\xi$$

That is, there is $\xi^{\mathcal{M}} \in \mathcal{M}, (\mathrm{S} : \mathrm{ft}\xi)^{\mathcal{M}} \mid \xi^{\mathcal{M}}$

Combining the first step and the second step, there is $\xi^{\mathcal{M}} \in \mathcal{M}, (\mathrm{S} : \mathrm{ft}\xi)^{\mathcal{M}} \mid \xi^{\mathcal{M}}$ and $(\mathrm{S} : \mathrm{ft}\ \xi)^{\mathcal{M}} \mid !$.

Past Future Continuous tense e.g.14 Mary thought Sam would be sleeping when Bob came back. (4-2)

In formal language $\mathscr{L}_{\mathrm{S}}$, e.g.14 is expressed as pt S:PF ([WHζ] Ing ξ) (= pt(S:F([WH ζ]Ing ξ)))

$$\mathcal{M}, ! \vDash \mathrm{pt}(\mathrm{S} : \mathrm{F}([\mathrm{WH}\zeta]\,\mathrm{Ing}\,\xi))$$

Therefore, the semantic explanation of the above indirect speech examples is divided into two steps accordingly:

The first step is to give the semantic explanation of the outer tense of the indirect speech when the present is taken as the reference, that is,

$$\mathcal{M}, ! \vDash \mathrm{pt}(\mathrm{S} : \mathrm{F}([\mathrm{WH}\zeta]\,\mathrm{Ing}\,\xi))$$

If and only if, $(\mathrm{S} : \mathrm{F}([\mathrm{WH}\zeta]\,\mathrm{Ing}\,\xi))^{\mathcal{M}} \mid !$.

Step 2: Add the explanation of the indirect speech part on the basis of the semantic explanation of the first step,

$$\mathcal{M}, (\mathrm{S} : \mathrm{F}([\mathrm{WH}\zeta]\,\mathrm{Ing}\,\xi))^{\mathcal{M}} \vDash \mathrm{F}([\mathrm{WH}\zeta]\,\mathrm{Ing}\,\xi$$

That is, there is $\zeta^{\mathcal{M}}, \xi^{\mathcal{M}} \in \mathcal{M}, (\mathrm{S} : \mathrm{F}([\mathrm{WH}\zeta]\,\mathrm{Ing}\,\xi)))^{\mathcal{M}} \mid ([\mathrm{WH}\zeta]\,\mathrm{Ing}\,\xi)^{\mathcal{M}}$.

That is, there is $\zeta^{\mathcal{M}}, \xi^{\mathcal{M}} \in \mathcal{M}, @\zeta^{\mathcal{M}} : \zeta^{\mathcal{M}} \Subset \xi^{\mathcal{M}}, (\mathrm{S} : \mathrm{F}([\mathrm{WH}\zeta]\,\mathrm{Ing}\,\xi))^{\mathcal{M}} \Subset \zeta^{\mathcal{M}}$.

Combine the first and second steps,

there is, $\zeta^{\mathcal{M}}, \xi^{\mathcal{M}} \in \mathcal{M}, @\zeta^{\mathcal{M}} : \zeta^{\mathcal{M}} \Subset \xi^{\mathcal{M}}, (\mathrm{S} : \mathrm{F}([\mathrm{WH}\zeta]\,\mathrm{Ing}\,\xi))^{\mathcal{M}} \Subset \zeta^{\mathcal{M}}$ and $(\mathrm{S} : \mathrm{F}([\mathrm{WH}\zeta]\,\mathrm{Ing}\,\xi))^{\mathcal{M}} \mid !$.

Past Future Perfect tense e.g.15 John said Sam would have finished his homework when Bob came back. (4-3)

In formal language $\mathscr{L}_{\mathrm{S}}$, e.g.15 is expressed as pt S:PF([BY g]Hvξ)(=pt(S:F([BYg]Hvξ))

$$\mathcal{M}, ! \vDash \mathrm{pt}(\mathrm{S} : \mathrm{F}([\mathrm{BY}g]\mathrm{Hv}\xi))$$

Therefore, the semantic explanation of the above indirect speech examples is divided into two steps accordingly:

The first step is to give the semantic explanation of the outer tense of the indirect speech when the present is taken as the reference, that is,

$$\mathcal{M}, ! \vDash \mathrm{pt}(\mathrm{S} : \mathrm{F}([\mathrm{BY}g]\mathrm{Hv}\xi))$$

If and only if, $(\mathrm{S} : \mathrm{F}([\mathrm{BY}g]\mathrm{Hv}\xi))^{\mathcal{M}} \mid !$

Second, add the explanation of the indirect speech part on the basis of the semantic interpretation of the first step,

$$\mathcal{M}, (\mathrm{S} : \mathrm{F}([\mathrm{BY}g]\mathrm{Hv}\xi))^{\mathcal{M}} \models \mathrm{F}([\mathrm{BY}g]\mathrm{Hv}\xi)$$

That is, there is $g^{\mathcal{M}}, \xi^{\mathcal{M}} \in \mathcal{M}, (\mathrm{S} : \mathrm{F}([\mathrm{BY}g]\mathrm{Hv}\xi)))^{\mathcal{M}} \mid ([\mathrm{BY}g]\mathrm{Hv}\xi)^{\mathcal{M}}$

That is, there is $g^{\mathcal{M}}, \xi^{\mathcal{M}} \in \mathcal{M}, @g^{\mathcal{M}} : \xi^{\mathcal{M}} \prec g^{\mathcal{M}}, (\mathrm{S} : \mathrm{F}([\mathrm{BY}g]\mathrm{Hv}\xi))^{\mathcal{M}} \Subset g^{\mathcal{M}}$.

Combine the first and second steps,

there is $\zeta^{\mathcal{M}}, \xi^{\mathcal{M}} \in \mathcal{M}, @g^{\mathcal{M}} : \xi^{\mathcal{M}} \prec g^{\mathcal{M}}, (\mathrm{S} : \mathrm{F}([\mathrm{BY}g]\mathrm{Hv}\xi))^{\mathcal{M}} \Subset g^{\mathcal{M}}$ and $(\mathrm{S} : \mathrm{F}([\mathrm{BY}\ g]\mathrm{Hv}\xi))^{\mathcal{M}} \mid !$.

Past Future Perfect Continuous tense e.g.16 Mary thought Sam would have been doing his homework when Bob came back. (4-4)

In formal language $\mathscr{L}_{\mathrm{S}}$, e.g.16 is expressed as pt S:PF([BFξ_1]Hv-Ing-for $(\xi, l)) (=$ pt (S:F([BFξ_1] Hv-Ing-for(ξ, l))))

$\mathcal{M}, ! \vDash \mathrm{pt}\,(\mathrm{S} : \mathrm{F}\,([\mathrm{BF}\xi_1]\,\text{Hv-Ing-for}(\xi, l)))$

Therefore, the semantic explanation of the above indirect speech examples is divided into two steps accordingly:

The first step is to first give the semantic explanation of the outer tense of the indirect speech when the present is taken as the reference, that is,

$\mathcal{M}, ! \vDash \mathrm{pt}\,(\mathrm{S} : \mathrm{F}\,([\mathrm{BF}\xi_1]\,\text{Hv-Ing- for }(\xi, l)))$

If and only if, $(\mathrm{S} : \mathrm{F}\,([\mathrm{BF}\xi_1]\,\text{Hv-Ing -for }(\xi, l)))^{\mathcal{M}} \mid !$

In the second step, the explanation of indirect speech is added on the basis of the semantic interpretation of the first step,

$\mathcal{M}, (\mathrm{S} : \mathrm{F}\,([\mathrm{BF}\xi_1]\,\text{Hv-Ing -for }(\xi, l)))^{\mathcal{M}} \models \mathrm{F}\,([\mathrm{BF}\xi_1]\,\text{Hv-Ing-for }(\xi, l))$

That is, there is $l^{\mathcal{M}}, \xi^{\mathcal{M}}, \xi_1{}^{\mathcal{M}} \in \mathcal{M}, (\mathrm{S} : \mathrm{F}\,([\mathrm{BF}\xi_1]\,\text{Hv-Ing -for }(\xi, l)))^{\mathcal{M}} \mid ([\mathrm{BF}\xi_1]\,\text{Hv-Ing-for }(\xi, l)^{\mathcal{M}}$.

That is, there is $l^{\mathcal{M}}, \xi^{\mathcal{M}}, \xi_1{}^{\mathcal{M}} \in \mathcal{M}, @\xi^{\mathcal{M}} : \xi^{\mathcal{M}} \prec \xi_1{}^{\mathcal{M}}, (\mathrm{S} : \mathrm{F}\,([\mathrm{BF}\xi_1]\,\mathrm{Hv} - \text{Ing -for }(\xi, \mathrm{l})\,)\,)^{\mathcal{M}} \subset \xi^{\mathcal{M}}$.

Combining the first and second steps,

there is $l^{\mathcal{M}}, \xi^{\mathcal{M}}, \xi_1{}^{\mathcal{M}} \in \mathcal{M}, @\xi^{\mathcal{M}} : \xi^{\mathcal{M}} \prec \xi_1{}^{\mathcal{M}}, (\mathrm{S} : \mathrm{F}\,([\mathrm{BF}\xi_1]\,\mathrm{Hv} - \text{Ing-for }(\xi, l)))^{\mathcal{M}}$

$\subset \xi^{\mathcal{M}}$ and $(\mathrm{S} : \mathrm{F}\,([\mathrm{BF}\xi_1]\,\mathrm{Hv} - \text{Ing-for }(\xi, l)))^{\mathcal{M}} \mid !$.

Conclusion

We mainly analyzed the formal semantic interpretation of reference sentence, event-length sentence, direct speech sentence and indirect speech sentence involving multiple reference events/states, covering sixteen kinds of tense/aspect phenomena, which including past future tense, past future perfect tense, past future continuous tense, and past future perfect continuous tense. Indirect speech sentences involve three reference events/states(including !), but these three reference events/states appear at different semantic levels: the "express" event ! has the largest scope, acting on the whole sentence; the third-person "express" event has a smaller scope, acting on the indirect speech; the remaining reference events/states within the indirect speech have the smallest scope, acting on the main event expressed in the indirect speech only. The scopes of these reference events/states are not the same.

Starting with formal explanations of five types of simple sentences, and then in the second step adding individual terms indicating event durations/time units as well as length-related formulas, together with elements such as indirect speech, reported events, and quoted events, the formal language $\mathscr{L}_{\mathrm{S}}$ achieves semantic interpretation of sixteen types of tense-aspect phenomena in two steps. Ultimately, all of these interpretations provide the relationships among the speech event, the reference event, and the main event. Analysis of the earlier example sentences shows that in most English sentences, there is only one speech event, but in some English sentences, the reference event is not unique. The semantic interpretation of tense-aspect sentences is thus effectively realized through the relationships between events/states and among events/states.

Referring to the summary table of tense-aspect phenomena in Table 1, so far, all sixteen types of tense-aspect sentences have been explained under the event-state model. The formal language $\mathscr{L}_{\mathrm{S}}$ is now able to express various tense-aspect sentence types, including simple sentences, reference sentences, event duration sentences, direct speech sentences, and indirect speech sentences, thus ultimately achieving the goal of fully representing all sixteen English tense-aspect sentence types in Table 1 within the framework of event-state semantics.

Data Availability All example sentences used in this text are sourced from publicly published textbooks and books. If needed, they can be obtained through online searches.

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