Frames in Formal Semantics

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Abstract. In his classic paper on frame semantics, Charles Fillmore says that it comes from traditions of empirical semantics rather than formal semantics. In this paper we will try to draw a closer connection between empirical and formal semantics and suggest that a notion of frame closely related to that found in FrameNet can be usefully exploited in formal semantics based on a particular type theory with records (TTR). We will first show how frames of this kind can be used to give a compositional semantics for verbs relating to Reichenbach's analysis of tense using speech, reference and event time. We will then revisit an old puzzle from Montague semantics relating to temperature and price. We will relate our solution to this puzzle to Fernando's string theory of events. Finally, we will consider some consequences of our analysis for the way in which agents acquire and modify word meaning as a result of exposure to linguistic input.

Keywords: frame semantics, type theory, lexical semantics, mathematical modelling.

1 Introduction

In his classic paper on frame semantics, Fillmore [12] says:

> Frame semantics comes out of traditions of empirical semantics rather than formal semantics. It is most akin to ethnographic semantics, the work of the anthropologist who moves into an alien culture and asks such questions as, 'What categories of experience are encoded by the members of this speech community through the linguistic choices that they make when they talk?' A frame semantics outlook is not (or is not necessarily) incompatible with work and results in formal semantics; but it differs importantly from formal semantics in emphasizing the continuities, rather than the discontinuities, between language and experience. The ideas I will be presenting in this paper represent not so much a genuine theory of empirical semantics as a set of warnings about the kinds of problems such a theory will have to deal with. If we wish, we can think of the remarks I make as 'pre-formal' rather than 'non-formalist'; I claim to be listing, and as well as I can to be describing, phenomena

H. Loftsson, E. Rögnvaldsson, S. Helgadóttir (Eds.): IceTAL 2010, LNAI 6233, pp. 103–114, 2010.

which must be well understood and carefully described before serious formal theorizing about them can become possible.

In this paper, we will make a connection between formal semantics and frame semantics by importing into our semantic analysis objects which are related to the frames of FrameNet.[1] Our way of doing this will be different from, for example, [1]. An important part of our proposal will be that we introduce semantic objects corresponding to frames and that these objects can serve as the arguments to predicates. We will use record types as defined in TTR (type theory with records, [2,3,5,13]) to characterize our frames. The advantage of records is that they are objects with a structure like attribute value matrices as used in linguistics. Labels (corresponding to attributes) in records allow us to access and keep track of parameters defined within semantic objects. This is in marked contrast to classical model theoretic semantics where semantic objects are either atoms or unstructured sets and functions. We will first give a brief intuitive introduction to TTR and show how it can be used to represent frames (Sect. 2). We will then show how we propose to represent the contents of verbs in a compositional semantics (Sect. 3). The use of frames here leads us naturally from the Priorean tense operators used by Montague to the Reichenbachian account of tense [22] preferred by most linguists working on tense and aspect which involves what we will think of as parameters for speech time, event time and reference time. The use of frames also leads us to a particular view of Partee's puzzle about temperature and price first discussed in [16] (PTQ, reprinted as Chap. 8 of [17]). We will discuss this in Sect. 4. Our solution to this puzzle relates to Fernando's ([9,11]) theory of events as strings of frames which we discuss in Sect. 5. Finally (Sect. 6), we will consider how our proposal can be used to talk about how agents can modify word meaning by adjusting the parameters of word contents. This relates to a view of word meaning as being in a constant state of flux as we adapt words to describe new situations and concepts. In Sect. 7 we draw some conclusions.

2 Using TTR to Represent Frames

Consider the frame `Ambient_temperature` defined in the Berkeley FrameNet[2] by "The Temperature in a certain environment, determined by Time and Place, is specified". Its core frame elements are given in (1).

(1) **Attribute.** The temperature feature of the weather
Degree. A modifier expressing the deviation of the Temperature from the norm
Place. The Place where it is a certain Temperature
Temperature. A quantity or other characterization of the Temperature of the environment
Time. The Time during which an ambient environment has a particular Temperature

[1] `http://framenet.icsi.berkeley.edu/`
[2] Accessed 25th Oct, 2009.

To make things of a manageable size we will not include all the frame elements in our representation of this frame. (We have also changed the names of the frame elements to suit our own purposes.) We will say that an ambient temperature frame is a record of type (2).

(2) $$\begin{bmatrix} \text{x} & : \textit{Ind} \\ \text{e-time} & : \textit{Time} \\ \text{e-location} & : \textit{Loc} \\ \text{c}_{\text{temp\_at\_in}} & : \text{temp\_at\_in(e-time, e-location, x)} \end{bmatrix}$$

We will call this type *AmbTemp*. It is a set of four fields each consisting of a *label* (to the left of the colon) and a type (to the right of the colon). A record of type *AmbTemp* will meet the following two conditions:

– it will contain *at least* fields with the same labels as the type (it may contain more)
– each field in the record with the same label as a field in the record type will contain an object of the type in the corresponding field of the record type. (Any additional fields with different labels to those in the record type may contain objects of any type.)

Types constructed with predicates such as 'temp_at_in' have a special status in that they can be *dependent*. In (2) the type in the field labelled '$\text{c}_{\text{temp\_at\_in}}$' depends on what you choose for the other three fields in the frame. Intuitively, we can think of such types formed with a predicate like 'temp_at_in' as types of objects which prove a proposition. What objects you take to belong to these types depends on what kind of theory of the world you have or what kind of application you want to use your type theory for. Candidates would be events, states or, in this case, thermometer or sensor readings. Types constructed with predicates are also used in representing the contents of verbs as we will see in Sect. 3.

3 A TTR Approach to Verbs in Compositional Semantics

Consider an intransitive verb such as *run*. The simplest way to think of this is as corresponding to a predicate of individuals. Thus (3) would represent the type of events or situations where the individual *a* runs.

(3) run(a)

However, as anybody who has thought about tense and aspect knows, we need to get time into the picture somewhere. If you look up *run* on FrameNet[3] you will find that on one of its readings it is associated with the frame `Self_motion`. Like many other frames in FrameNet this has a frame element `Time` which in

[3] Accessed 1st April, 2010.

this frame is explained as "The time when the motion occurs". This is what Reichenbach [22] called more generally *event time* and we will use the label 'e-time'. We will add an additional argument for a time to the predicate and create a frame-type (4).[4]

$$(4)\quad \begin{bmatrix} \text{e-time} : \textit{TimeInt} \\ \text{c}_{\text{run}} : \text{run}(a,\text{e-time}) \end{bmatrix}$$

For the type (4) to be non-empty it is required that there be some time interval at which a runs. We use *TimeInt* as an abbreviation for the type of time intervals, (5).

$$(5)\quad \begin{bmatrix} \text{start} : \textit{Time} \\ \text{end} : \textit{Time} \\ \text{c} : \text{start}<\text{end} \end{bmatrix}$$

No constraints are placed on when that time interval in (4) should be. Thus this frame type corresponds to a "tenseless proposition", something that is not available in the Priorean setup [18,19] that Montague employs where logical formulae without a tense operator correspond to a present tense interpretation. In order to be able to add tense to this we need to relate the event time to another time interval, normally the time which Reichenbach calls the speech time.[5] A past tense type anchored to a time interval ι is represented in (6).

$$(6)\quad \begin{bmatrix} \text{e-time} : \textit{TimeInt} \\ \text{c}_{\text{tns}} : \text{e-time.end}< \iota.\text{start} \end{bmatrix}$$

This requires that the end of the event time interval has to precede that start of the speech time interval. In order for a past-tense sentence *a ran* to be true we would need to find an object of both types (4) and (6). This is equivalent to requiring that there is an object in the result of merging the two types given in (7).

$$(7)\quad \begin{bmatrix} \text{e-time} : \textit{TimeInt} \\ \text{c}_{\text{tns}} : \text{e-time.end}< \iota.\text{start} \\ \text{c}_{\text{run}} : \text{run}(a,\text{e-time}) \end{bmatrix}$$

Suppose that we have an utterance u, that is, a speech event of type (8).

$$(8)\quad \begin{bmatrix} \text{phon} : \text{“a”}\frown\text{“ran”} \\ \text{s-time} : \textit{TimeInt} \\ \text{c}_{\text{utt}} : \text{uttered}(\text{phon},\text{s-time}) \end{bmatrix}$$

[4] Of course, we are ignoring many other frame elements which occur in FrameNet's `Self_motion` which could be added to obtain a more detailed semantic analysis.

[5] Uses of historic present tense provide examples where the tense is anchored to a time other than the speech time.

where "a"⌢"ran" is the type of strings of an utterance of *a* concatenated with an utterance of *ran*. Then we can say that the speech time interval ι in (7) is u.s-time. That is, the past tense constraint requires that the event happened before the start of the speech event. In a complete treatment both the type of the speech event (8) and the content (7) would be packeted together in a single sign type together with more information about syntax, HPSG style (see [4] for a preliminary indication of how this would look).

(7) is a type which is the content of an utterance of the sentence *a ran*. In order to obtain the content of the verb *ran* we need to create a function which abstracts over the individual *a*. Because frames will play an important role as arguments to predicates below we will not abstract over individuals but rather over frames containing individuals. The content of the verb *ran* will be (9).

(9) $$\lambda r{:}\big[\text{x}{:}\mathit{Ind}\big]\left(\begin{bmatrix}\text{e-time} : \mathit{TimeInt} \\ \text{c}_{\text{tns}} \quad : \text{e-time.end}< \iota\text{.start} \\ \text{c}_{\text{run}} \quad : \text{run}(r\text{.x,e-time})\end{bmatrix}\right)$$

4 The Puzzle about Temperature and Prices

Montague [16] introduces a puzzle presented to him by Barbara Partee:

> From the premises **the temperature is ninety** and **the temperature rises**, the conclusion **ninety rises** would appear to follow by normal principles of logic; yet there are occasions on which both premises are true, but none on which the conclusion is.

Exactly similar remarks can be made substituting *price* for *temperature*. Montague's solution to this puzzle in [16] was to analyze *temperature*, *price* and *rise* not as predicates of individuals as one might expect but as predicates of individual concepts. For Montague individual concepts were modelled as functions from possible worlds and times to individuals. To say that *rise* holds of an individual concept does not entail that *rise* holds of the individual that the concepts finds at a given world and time. Our strategy is closely related to Montague's. However, instead of using individual concepts we will use frames. By interpreting *rises* as a predicate of frames, for example, of type *AmbTemp* as given in (2) we obtain a solution to this puzzle.

(10) $$\lambda r{:}\big[\text{x}{:}\mathit{Ind}\big]\left(\begin{bmatrix}\text{e-time} : \mathit{TimeInt} \\ \text{c}_{\text{tns}} \quad : \text{e-time}= \iota \\ \text{c}_{\text{run}} \quad : \text{rise}(r\text{,e-time})\end{bmatrix}\right)$$

Note that a crucial difference between (9) and (10) is that the first argument to the predicate 'rise' is the complete frame r rather than the value of the x field which is used for 'run'. Thus it will not follow that the value of the x field (i.e. 90 in Montague's example) is rising. While there is a difference in the type of the argument to the predicates (a record as opposed to an individual), the type of the complete verb content is the same: $\left[\text{x}:\mathit{Ind}\right]\rightarrow\mathit{RecType}$, that is, a function from records of type $\left[\text{x}:\mathit{Ind}\right]$ to record types. This ability to use different types internally but still have the same overall type for the content of the word is convenient for compositional semantics.

But now the question arises: what can it mean for a frame to rise?

5 Fernando's String Theory of Events

In an important series of papers including [8,9,10,11], Fernando introduces a finite state approach to event analysis where events can be seen as strings of punctual observations corresponding to the kind of sampling we are familiar with from audio technology and digitization processing in speech recognition. When talking about the intuition behind this analysis Fernando sometimes refers to strings of frames in a movie (e.g. in [10]). But in many cases what he is calling a movie frame can also be seen as a frame in the sense of this paper as well. Thus an event of a rise in temperature could be seen as a concatenation of two temperature frames, that is, an object of type $\mathit{AmbTemp}^\frown\mathit{AmbTemp}$. We have seen a concatenation type previously in our characterization of a phonology type in (8). That is because phonological events are also to be seen as event strings in Fernando's sense. (11) shows a type of event for a rise in temperature using the temperature frame *AmbTemp* in (2).

(11)
$$\begin{bmatrix} \text{e-time}:\mathit{TimeInt} \\ \text{start}:\begin{bmatrix} \text{x}:\mathit{Ind} \\ \text{e-time=e-time.start}:\mathit{Time} \\ \text{e-location}:\mathit{Loc} \\ \text{c}_{\text{temp\_at\_in}}:\text{temp\_at\_in(start.e-time, start.e-location, start.x)} \end{bmatrix} \\ \text{end}:\begin{bmatrix} \text{x}:\mathit{Ind} \\ \text{e-time=e-time.end}:\mathit{Time} \\ \text{e-location=start.e-location}:\mathit{Loc} \\ \text{c}_{\text{temp\_at\_in}}:\text{temp\_at\_in(end.e-time, end.e-location, end.x)} \end{bmatrix} \\ \text{event=start}^\frown\text{end}:\mathit{AmbTemp}^\frown\mathit{AmbTemp} \\ \text{c}_{\text{incr}}:\text{start.x<end.x} \end{bmatrix}$$

Here we make use of *manifest fields* [7] such as

(12) $\left[\text{e-time=e-time.start}:\mathit{Time}\right]$

which restrict the type in the field to be a singleton type of the unique object represented after the equality sign. Thus (12) is syntactic sugar for

(13) $\left[\text{e-time}:\mathit{Time}_{\text{e-time.start}}\right]$

This uses a singleton type represented by $\mathit{Time}_{\text{e-time.start}}$. If some object a is of type T ($a : T$) then T_a is a type such that $b : T_a$ iff $b = a$. That is, we restrict the type to be the type of a unique particular object. It should also be noted that path names such as 'start.e-time' always begin at the root of the record type rather than the most local record type in which they occur. (11) is then the type of events where there is a rise in ambient temperature. An event e of this type will be of type rise(e.start,e.e-time). In fact we will make the stronger requirement that if r:*AmbTemp* and i:*TimeInt* then e:rise(r,i) iff e:(11), e.start=r and e.e-time=i.

6 Word Meaning in Flux

For all (11) is based on a very much simplified version of FrameNet's `Ambient_temperature`, it represents a quite detailed account of the lexical meaning of *rise* in respect of ambient temperature — detailed enough, in fact, to make it inappropriate for *rise* with other kinds of subject arguments. Consider price. The type of a price rising event could be represented by (14).

(14)
$$\left[\begin{array}{ll}
\text{e-time:}\,\mathit{TimeInt} & \\
\text{start:} & \left[\begin{array}{l}
\text{x:}\mathit{Ind}\\
\text{e-time=e-time.start:}\,\mathit{Time}\\
\text{e-location:}\mathit{Loc}\\
\text{commodity:}\mathit{Ind}\\
\text{c}_{\text{price_of_at_in}}\text{:price_of_at_in(start.commodity,}\\
\qquad\qquad\text{start.e-time, start.e-location, start.x)}
\end{array}\right]\\
\text{end:} & \left[\begin{array}{l}
\text{x:}\mathit{Ind}\\
\text{e-time=e-time.end:}\,\mathit{Time}\\
\text{e-location=start.e-location:}\mathit{Loc}\\
\text{commodity=start.commodity:}\mathit{Ind}\\
\text{c}_{\text{price_of_at_in}}\text{:price_of_at_in(end.commodity,}\\
\qquad\qquad\text{end.e-time, end.e-location, end.x)}
\end{array}\right]\\
\text{event=start}^\frown\text{end:}\mathit{Price}^\frown\mathit{Price} & \\
\text{c}_{\text{incr}}\text{:start.x<end.x} &
\end{array}\right]$$

(14) is similar to (11) but crucially different. A price rising event is, not surprisingly, a string of price frames rather than ambient temperature frames. The type of price frames (*Price*) is given in (15).

(15)
$$\left[\begin{array}{ll}
\text{x} & :\mathit{Ind}\\
\text{e-time} & :\mathit{Time}\\
\text{e-location} & :\mathit{Loc}\\
\text{commodity} & :\mathit{Ind}\\
\text{c}_{\text{price_of_at_in}} & :\text{price_of_at_in(commodity, e-time, e-location, x)}
\end{array}\right]$$

If you look up the noun *price* in FrameNet[6] you find that it belongs to the frame `Commerce_scenario` which includes frame elements for goods (corresponding to our 'commodity') and money (corresponding to our 'x'-field). If you compare the

[6] Accessed 8th April, 2010.

FrameNet frames `Ambient_temperature` and `Commerce_scenario`, they may not initially appear to have very much in common. However, extracting out just those frame elements or roles that are relevant for the analysis of the lexical meaning of *rise* shows a degree of correspondence. They are, nevertheless, not the same. Apart from the obvious difference that the predicate in the constraint field that relates the various roles involves temperature in the one and price in the other, price crucially involves the role for commodity since this has to be held constant across the start and end frames. We cannot claim that a price is rising if we check the price of tomatoes in the start frame and the price of oranges in the end frame.

This corresponds to a situation which is familiar to us from work on the Generative Lexicon [20,21] where the arguments to words representing functions influence the precise meaning of those words. For example, *fast* means something different in *fast car* and *fast road*, although, of course, the two meanings are related. There are two important questions that arise when we study this kind of data:

– is it possible to extract a single general meaning of words which covers all the particular meanings of the word in context?
– is it possible to determine once and for all the set of particular contextually determined meanings?

Our suspicion is that the answer to both these questions is "no". It seems that we are able to create new meanings for words based on old meanings to suit the situation that we are currently trying to describe and that there is no obvious requirement that all these meanings be consistent with each other, making it difficult to extract a single general meaning. Here we are following the kind of theory proposed by Larsson and Cooper [14,6]. According to such a theory the traditional meaning question "What is the meaning of expression E?" should be replaced by the following two questions relating to the way in which agents coordinate meaning as they interact with each other in dialogue or, more indirectly, through the writing and reading of text:

the coordination question Given resources R, how can agent A construct a meaning for a particular utterance U of expression E?

the resource update question What effect will this have on A's resources R?

Let us look at a few examples of uses of the verb *rise* which suggest that this is the kind of theory we should be looking at. Consider first that a fairly standard interpretation of *rise* concerns a change in location. (16) is part of the description of a video game.[7]

(16) As they get to deck, they see the Inquisitor, calling out to a Titan in the seas. **The giant Titan rises through the waves**, shrieking at the Inquisitor.

[7] `http://en.wikipedia.org/wiki/Risen\_(video\_game)`, accessed 4th February, 2010.

The type of the rising event described here could be something like (17).

(17)
$$\left[\begin{array}{ll}
\text{e-time}: & \textit{TimeInt} \\
\text{start}: & \left[\begin{array}{l}
\text{x}:\textit{Ind} \\
\text{e-time}=\text{e-time.start}:\textit{Time} \\
\text{e-location}:\textit{Loc} \\
\text{c}_{\text{at}}:\text{at(start.x,start.e-location,start.e-time)}
\end{array}\right] \\
\text{end}: & \left[\begin{array}{l}
\text{x}=\text{start.x}:\textit{Ind} \\
\text{e-time}=\text{e-time.end}:\textit{Time} \\
\text{e-location}:\textit{Loc} \\
\text{c}_{\text{at}}:\text{at(end.x,end.e-location,end.e-time)}
\end{array}\right] \\
\multicolumn{2}{l}{\text{event}=\text{start}^\frown\text{end}:\textit{Position}^\frown\textit{Position}} \\
\multicolumn{2}{l}{\text{c}_{\text{incr}}:\text{height(start.e-location)}<\text{height(end.e-location)}}
\end{array}\right]$$

This relies on a frame type *Position* given in (18).

(18)
$$\left[\begin{array}{ll}
\text{x} & : \textit{Ind} \\
\text{e-time} & : \textit{Time} \\
\text{e-location} & : \textit{Loc} \\
\text{c}_{\text{at}} & : \text{at(x,e-location,e-time)}
\end{array}\right]$$

(18) is perhaps most closely related to FrameNet's `Locative_relation`. (17) is structurally different from the examples we have seen previously. Here the content of the 'x'-field, the focus of the frame, which in the case of the verb *rise* will correspond to the subject of the sentence, is held constant in the string of frames in the event whereas in the case of rising temperatures and prices it was the focus that changed value. Here it is the height of the location which increases whereas in the previous examples it was important to hold the location constant.[8] This makes it difficult to see how we could give a single type which is general enough to include both varieties and still be specific enough to characterize "the meaning of *rise*". It appears more intuitive and informative to show how the variants relate to each other in the way that we have done.

The second question we had concerned whether there is a fixed set of possible meanings available to speakers of a language or whether speakers create appropriate meanings on the fly based on their previous experience. Consider the examples in (19).

(19) a. Mastercard rises
b. China rises

[8] We have used 'height(start/end.e-location)' in (17) to represent the height of the location since we have chosen to treat *Loc*, the type of spatial location, as a basic type. However, in a more detailed treatment *Loc* should itself be treated as a frame type with fields for three coordinates one of them being height, so we would be able to refer to the height of a location l as l.height.

While speakers of English can get an idea of the content of the examples in (19) when stripped from their context, they can only guess at what the exact content might be. It *feels* like a pretty creative process. Seeing the examples in context as in (20) reveals a lot.[9]

(20)
a. Visa Up on Q1 Beat, Forecast; **Mastercard Rises** in Sympathy
By Tiernan Ray
Shares of Visa (V) and Mastercard (MA) are both climbing in the aftermarket, reversing declines during the regular session, after Visa this afternoon reported fiscal Q1 sales and profit ahead of estimates and forecast 2010 sales growth ahead of estimates, raising enthusiasm for its cousin, Mastercard.
b. The rise of China will undoubtedly be one of the great dramas of the twenty-first century. China's extraordinary economic growth and active diplomacy are already transforming East Asia, and future decades will see even greater increases in Chinese power and influence. But exactly how this drama will play out is an open question. Will China overthrow the existing order or become a part of it? And what, if anything, can the United States do to maintain its position as **China rises**?

It seems like the precise nature of the frames relevant for the interpretation of *rises* in these examples is being extracted from the surrounding text by a technique related to automated techniques of relation extraction in natural language processing.

7 Conclusion

We have suggested that a notion of frame can be of use in an approach to formal semantics dealing with hard empirical questions of lexical semantics and linguistic processing. The important aspect of our analysis is that we have semantic objects corresponding to frames and allow these to be arguments to predicates. We have illustrated this with an old puzzle from formal semantics, the Partee puzzle concerning the rising of temperature. Our solution is very similar in strategy to that originally proposed by Montague. It differs in that we use frames where Montague used individual concepts.

The additional detail of the lexical semantic analysis obtained by using frames comes at a cost, however. It has as a consequence that there is not obviously a single meaning or even a small set of meanings associated with *rise*. Rather *rise* means something slightly different for temperatures and prices, objects rising in

[9] `http://blogs.barrons.com/stockstowatchtoday/2010/02/03/visa-up-on-q1-beat-forecast-mastercard-moves-in-sympathy/?mod=rss_BOLBlog`, accessed 4th February, 2010; `http://www.foreignaffairs.com/articles/63042/g-john-ikenberry/the-rise-of-china-and-the-future-of-the-west`, accessed 4th February, 2010.

location, not to mention countries as in *China rises*. This spread of meanings seems to be important if we are to draw the kinds of detailed inferences that speakers of a language are able to draw from these examples.

We have argued that there is no fixed set of meanings but rather that speakers of a language create meanings on the fly for the purposes of interpretation in connection with a given speech (or reading) event. This idea is related to the notion of *meaning potential* discussed for example in [15] and a great deal of other literature. While we have made no precise proposal for how speakers go about creating new situation specific meanings in this paper we believe that the kinds of structured semantic objects (such as frames) that we are proposing in this paper will facilitate an account of this. Our record types comprise a collection of fields (which can be used to correspond to frame elements). New meanings can be constructed from old ones by adding, subtracting or modifying such fields, thus providing possibilities for change that are not so obviously available in traditional possible world semantics based on functions from possible worlds and times to denotations.

Acknowledgements. This research was supported in part by VR project 2009-1569, Semantic analysis of interaction and coordination in dialogue (SAICD) and Swedish Tercentenary Foundation Project P2007/0717, Semantic Coordination in Dialogue (SemCoord). I am grateful to Jonathan Ginzburg and Staffan Larsson for discussion. Previous versions of this material have been presented at the seminar of the Centre for Language Technology in Gothenburg, the linguistics seminar of the Department of Philosophy, Linguistics and Theory of Science at the University of Gothenburg and the Grammar Festival organized by the Department of Swedish at the University of Gothenburg. I am grateful to the audiences on all these occasions for useful discussions and improvements.

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