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Rules for Converting Natural Language Text with Motion Verbs into TIL-Script

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Abstract. The paper deals with the rules for converting natural language text with *motion verbs* into TIL-Script, the computational variant of Transparent Intensional Logic (TIL). This function is part of the TILUS tool, which is now being worked on, and which will be used for the needs of appropriate textual information sources retrieval and natural language processing. Our work is currently starting on a module that allows the transformation of a particular subset of natural language texts describing journey descriptions into logical constructions. Hence, in this paper, we focused on the transformation rules for sentences containing *motion verbs* describing the agent's movement on the infrastructure. These rules are based on the utilization of Stanford typed dependencies representation and verb valency frames of *motion verbs*.

Keywords. Motion verbs, Stanford typed dependencies, Verb valency frames, Transparent Intensional Logic, TIL-Script, Conversion rules

1. Introduction

In this paper, we deal with the transformation rules for converting natural language text with *motion verbs* into TIL-Script. According to linguists, *motion verbs*, as implied by the term "motion", are verbs that describe movement. They are intransitive (they usually have no object), so they cannot be used in the passive voice. Common examples of motion verbs include for instance "go", "walk", "run", "swim" or "fly", etc. The goal is to develop a module of the TILUS tool that allows the transformation of a natural language text describing the journey into the TIL-Script logical constructions. From these constructions, the concrete representation of the journey can be later generated according to the heuristic. The future work is to convert this representation to a graph representing a topology. The paper is organized as follows.

In chapter 2, there is a brief introduction of TILUS modules and their main functions. TILUS presupposes that all the data are previously formalized in TIL-Script, the computational variant of Transparent Intensional Logic (TIL). We are currently working on the semi-automated conversion of natural language texts into TIL-Script. In the first phase of our work, we limited ourselves to the transformation of the sentence with *motion verbs*. This is the main problem we are dealing in this paper with. In chapter 3, there is an outline of how we utilize the Stanford dependencies relations and the theory of verb valency frames for the purpose of transformation rules which are specified in the following chapter 4. Concluding remarks on further research can be found in the last chapter 5.

2. A brief introduction to the TILUS tool

We are developing the TILUS tool for the needs of natural language processing via TIL-Script constructions. Our system currently presupposes that all the inputs are transformed into TIL-Script. We chose the TIL-Script based on TIL because its procedural semantics is close to natural language and have great expressive power. TIL was developed by Pavel Tichý who introduced its main principles in [1], the complete works from Tichý can be found in [2]. TIL has been further developed for example by M. Duží, P. Materna, B. Jespersen, J. Raclavský and a great deal of the TIL contemporary research can be found in [3]. The outcomes of this book are especially relevant to the inter alia conceptual modeling area. TIL-Script as well as TIL is hyperintensional, typed, a partial specification language with a ramified hierarchy of types.

TILUS has a number of modules. One of them is the module of logical deduction in order to be able to infer the conclusions of premises and verify the validity of arguments. The inferential mechanism is based on natural deduction. This module was introduced in [4], [5], and [6]. The second module is based on machine learning and serves as a search tool for relevant text sources. This module generates an *explication* in TIL-Script of an atomic concept. The term *explication* can be understood as a brief description of the sought term in a particular source text. We generate an explication from each source text and present it to the user of our application. The user then selects a particular *explication* based on their preferences and our system then recommends other possible relevant documents. This module was introduced in [7], [8], [9], [10], [11].

The theoretical framework for the recommendation module design is the method of association rules and the FCA theory, where the relevant documents are ordered according to their significance to the user, for more see [12]. First, we need to analyze textual natural language sources to obtain their logical formalization in TIL-Script constructions. The conversion from natural language to the TIL-Script is a rather demanding process and requires logical-linguistic analysis. Hence, all our contributions, published up to now, presumed cooperation with the Department of Computational Linguistics to obtain the conversion of text to the TIL-Script constructions. The set of relevant propositional constructions is then selected from the formalized set; namely, those where the concept to be explicated occurs.

Our work is currently starting on a module that allows the transformation of a natural language text describing the journey into the TIL-Script logical constructions. The journey through the city can be described as an ordered set of sentences. Each sentence describes one whole part of the journey, usually containing information about who, how, from where, towards where, along with what and for how long the referee moved. For simplicity, we will assume that the particular sentences describing consecutive parts of the path are mutually connected. Therefore, some of the missing information in the following sentence (i.e. for instance the starting point, etc.) can be taken from the previous sentence. From these constructions, the concrete representation of the whole journey is later generated according to the heuristic. This journey representation will serve after our future work as the input for the part based on geographic data which will generate the map topology from these constructions.

As mentioned earlier, all our contributions published up to now presumed cooperation with the Department of Computational Linguistics to obtain the conversion of text into TIL-Script constructions. Our main goal is to currently semiautomate the conversion of natural language text to TIL-Script constructions and build it within the TILUS. The general outline of the utilization of Stanford type dependencies relations for these purposes was introduced in [13]. We follow the basic ideas also in this paper where we focus on the transformation of sentences containing *motion verbs* which are substantial for describing a given path. However, we have found out that the use of Stanford type dependencies relations is not sufficient to be able to provide the transformation rules. Hence, in this paper, we additionally take into account the valency of *motion verbs*.

3. Stanford typed dependencies and the theory of verb valency frames as the basis of the conversion rules

The goal is to develop a module of the TILUS tool that allows for the transformation of natural language text describing a journey into logical constructions. The movement of agents along the trajectory is described by special types of verbs, so-called *motion verbs* that describe motion. From the linguistic point of view, they are intransitive which means they usually have no object. Hence, they cannot be used in the passive voice. Common examples of motion verbs, for the description of agents' movement along the trajectory, are for instance "go", "walk", "run", etc. Typical examples of sentences expressing movement along a route are for instance the following ones: *John is walking down Sapkowski Street from the town hall to the secondary school building*. *After 100 meters, John came to the cinema building*. *After another 100 meters, he came to the crossroads*. To design specific rules for converting these types of sentences into TIL-Script logical constructions, we used Universal Dependencies based on Stanford typed dependencies relations and the theory of verb valency frames.

The semantics of the respective verb is provided via its lexical valency frame. In general, verb valency is the ability of a verb to bind other formal units, i.e. words, which cooperate to provide its meaning completely. These units are so-called *functors* or *participants* or *thematic roles*. Thus the valency of a verb determines the number of arguments (participants) controlled by a verbal predicate. This ability of verbs results from their meaning rather than from formal aspects. More details on the theory of valency frames can be found, for instance, in [14] and [15]. Attention to lexical valency has to therefore be paid in order to build up an ontology independent of a used language. We shall proceed from the valency dictionaries and John Sowa's approach which provides the verb valency participants classification according to lexical valency. Consider the example of the sentence *John is going to Ostrava by train*. The activity *is going* has the following participants: the actor (*John*), the instrument of transport (*train*), and the final destination (*Ostrava*).

In order to obtain basic participants, which can be used in the specification of the journey and which concern the *motion verbs*, we are proceeding from two valency dictionaries, namely VALLEX (see in [16]) and Verbalex (see in [17]), and John Sowa's thematic roles (see in [18]). The following types of participants are connected with the motion verbs and are important to get an idea of the specific shape of the route:

Actor: agent of movement,
DIR1: from where,
DIR2: which way,
DIR3: where to,
Manner: in the case of direction description – to the right, to the left,

Ext: the transport measure as a distance - *100 meters* in sentences like *after 100 meters turn right*

DIR1 (from where), *DIR2* (which way), and *DIR3* (where to) are continuously updated in the journey description as the journey progresses. Hence, the translation into TIL-Script assumes a continuous sequence of path descriptions due to *DIR* transformation into other sentences.

From the logical point of view, we deal with the verb phrases expressing an agent's *activities* as denoting a function that is applied to its arguments. The application of verb valency frame theory for the agents' activities specification was first introduced in [19] and further developed in [20], [21], [22]. The number of arguments is controlled by the verb valency content. Dynamic entities relating to activities can be characterized by the special relationships in intensions between activities and their participants modelled as functions of TIL-Script. In our background theory (TIL) we view α-intensions as functions mapping possible worlds (of type ω) to a type β. The type β is frequently the type of a chronology of the elements of type α. These α-chronologies are, in turn, functions mapping time (of type τ) to the type α. Thus, α-intensions are usually mappings of type $(\omega \rightarrow (\tau \rightarrow \alpha))$, or in TIL notation $((\alpha\tau)\omega)$, $\alpha_{\tau\omega}$ for short and in TIL-Script notation ((α Time)World)). Another frequent type of intensions is the *property of individuals*, an object of type $(o\iota)_{\tau\omega}$, in TIL-Script notation (((Bool Indiv)Time) World). Consider for example the above-mentioned sentence *John is going to Ostrava by train*. Below, there are examples of the results of conversion from natural language to TIL instead of TIL-Script for reasons of greater familiarity with TIL.

Sentence 1: *John is walking down Sapkowski Street from the town hall to the secondary school building.*

$$\lambda w \lambda t[[{}^{\text{'}}DIR1_{wt}\ {}^{\text{'}}TownHall\ {}^{\text{'}}walking] \wedge [{}^{\text{'}}DIR2_{wt}\ {}^{\text{'}}SapkowskiStreet\ {}^{\text{'}}walking] \wedge$$
$$\wedge\ [{}^{\text{'}}DIR3_{wt}\ {}^{\text{'}}SecondarySchoolBuilding\ {}^{\text{'}}walking] \wedge [{}^{\text{'}}Act_{wt}\ {}^{\text{'}}John\ {}^{\text{'}}walking]]$$ [1]

Sentence 2: *After 100 metres, John came to the cinema building.*

$$\lambda w \lambda t[[{}^{\text{'}}DIR1_{wt}\ {}^{\text{'}}TownHall\ {}^{\text{'}}came] \wedge [{}^{\text{'}}DIR2_{wt}\ {}^{\text{'}}SapkowskiStreet\ {}^{\text{'}}came] \wedge$$
$$\wedge\ [{}^{\text{'}}DIR3_{wt}\ {}^{\text{'}}CinemaBuilding\ {}^{\text{'}}came] \wedge [{}^{\text{'}}Act_{wt}\ {}^{\text{'}}John\ {}^{\text{'}}came] \wedge [{}^{\text{'}}Ext_{wt}\ {}^{\text{'}}100m\ {}^{\text{'}}came]]$$

In order to generate these constructions automatically from natural language text, we decided to base our rules on Universal dependencies relations. Universal Dependencies (UD) is a framework for consistent annotation of parts of natural language texts across different human languages. It was designed to provide a straightforward description of grammatical relations for any user who could benefit from an automatic text understanding. UD is an open community effort with over 300 contributors producing nearly 200 treebanks in over 100 languages. It is a project which is developing cross-linguistically consistent treebank annotation for many languages, with the goal of

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[1] The construction in TIL-Script notation is the following:
\w\t [['DIR1@wt 'TownHall 'walking] and
['DIR2@wt 'SapkowskiStreet 'walking] and
['DIR3@wt 'SecondarySchoolBuilding 'walking]
and ['Act@wt 'John 'walking]].
Note the specific notation character @wt. This character expresses an intensional descent to the respective possible world and time to obtain the final value of this intension in this possible world and time.

facilitating multilingual parser development, cross-lingual learning, and parsing research from a language typology perspective. The annotation scheme is based on the evolution of (universal) Stanford dependencies see [23], Google universal part-of-speech tags, see [24], and the Interset interlingua for morphosyntactic tagsets, see [25]. The theoretical framework for the types of syntactic relations is Stanford dependencies which map straightforwardly onto a directed graph representation, in which the words in the sentence are nodes in the graph and the grammatical relations are edge labels. This representation contains approximately 50 grammatical relations and in [26], you can find the list of all the types with their specifications and natural language examples. Below are the most common types of grammatical relations connected with motion verbs.

- *acomp*: adjectival complement. An adjectival complement of a verb is an adjectival phrase that functions as a complement (like an object of the verb). Example: *She looks very beautiful*: acomp(beautiful, very).
- *advmod*: adverb modifier. An adverb modifier of a word is a (non-clausal) adverb or adverb-headed phrase that serves to modify the meaning of the word. Examples: *Genetically modified food*: advmod(modified, genetically), *less often*: advmod(often, less).
- *nsubj*: nominal subject. A nominal subject is a noun phrase which is the syntactic subject of a clause. The governor of this relation might not always be a verb: when the verb is a copular verb, the root of the clause is the complement of the copular verb, which can be an adjective or noun. Examples: *Clinton defeated Dole*: nsubj(defeated, Clinton), *The baby is cute*: nsubj(cute, baby).
- *pobj*: object of a preposition. The object of a preposition is the head of a noun phrase following the preposition, or the adverbs "here" and "there". (The preposition in turn may be modifying a noun, verb, etc.) Example: *I sat on the chair*: pobj(on, chair).
- *prep*: propositional modifier. A prepositional modifier of a verb, adjective, or noun is any prepositional phrase that serves to modify the meaning of the verb, adjective, noun, or even another preposition. In the collapsed representation, this is used only for prepositions with NP complements. Examples: *I saw a cat in a hat*: prep(cat, in), *I saw a cat with a* telescope: prep(saw, with), *He is responsible for meals*: prep(responsible, for).
- *prt*: phrasal verb particle. The phrasal verb particle relation identifies a phrasal verb and holds between the verb and its particle. Example: *They shut down the station*: prt(shut, down).
- *num*: numeric modifier. A numeric modifier of a noun is any number phrase that serves to modify the meaning of the noun with a quantity. Examples: *Sam ate 3 sheep*: num(sheep, 3), *Sam spent forty dollars*: num(dollars, 40).

These relations provide a straightforward description of grammatical relations in the analyzed text and in [13] we demonstrated how to extract some important semantic information from this Stanford typed dependencies representation. We can use the tools generating tag annotations based on Stanford typed dependencies, such as for instance, *Explosion* (for details, see the website [27]). This is a software company specializing in developer tools for artificial intelligence and natural language processing (NLP). They are the makers of spaCy (the leading open-source library for advanced NLP) and Prodigy (an annotation tool for radically efficient machine teaching).

In [13], we introduced the first motivation and general outline as to how to utilize the Stanford typed dependencies relations. In many cases, we are also able to detect the activity and its participants in general on the basis of Stanford typed dependencies relations. Let us look at the above-mentioned example of the sentence *John goes to Ostrava by train*. The verb valency participants of the activity *going* are the following: *John* is the agent of the activity, *Ostrava* is the final destination and the *train* is the instrument of transport. For comparison, Fig. 1 shows an annotation scheme for this sentence based on Stanford dependencies.

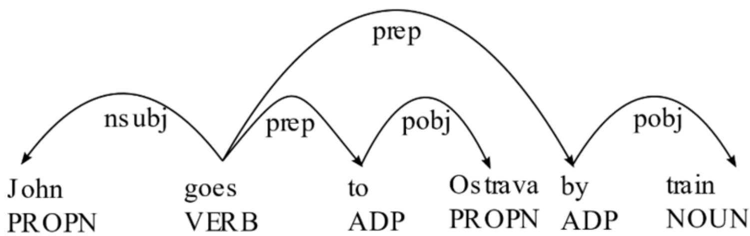

Figure 1. The Stanford dependencies annotation scheme for the sentence *John goes to Ostrava by train*.

We are able to recognize the activity determined by the verb and the agent of this activity that is determined by the proper name *John* and is in the relation *nsubj* with the verb. The terms *Ostrava* and *train* are detected as consecutive relations *prep* (preposition) and *pobj* (object of the preposition). Hence, we can recognize in an automated way via analysis of dependencies that these terms are the verb valency participants in general, but not the respective categories of these participants (destination, instrument). For this purpose, we also have to include world types and the specific word shape of the prepositions specifying the direction within the rules. In the following paragraph, there is a specification of the rules which is based on Stanford dependencies and verb valency frames for the conversion of natural language sentences containing *motion verbs* into TIL-Script.

4. Transformation rules

As mentioned above, our transformation rules are based on the use of Stanford dependencies and the theory of verb valency frames. In this chapter, we provide the specification of the substantial rules for the conversion of sentences with *motion verbs* to TIL-Script constructions. For the formal form of the rule, we take into account the respective type of relation according to Stanford dependencies, the respective type of word (i.e. noun, verb, preposition, etc.), and the specific word shape of the prepositions specifying the direction. We demonstrate these rules within concrete examples. At first, we give the example of the path description sentence, then we provide the output of this sentence tagged with Stanford dependencies. However, the types of participants are not the output of Stanford dependencies tagging. They are included in the pictures only for better orientation. Participant types are later assigned according to the respective rules of conversion to TIL-Script which are listed below. At the end of each example, there is the final construction of converted sentences. We present the constructions in TIL instead of TIL-Script for reasons of greater familiarity with TIL.

J^1: *John came from home to school down Main Street.*

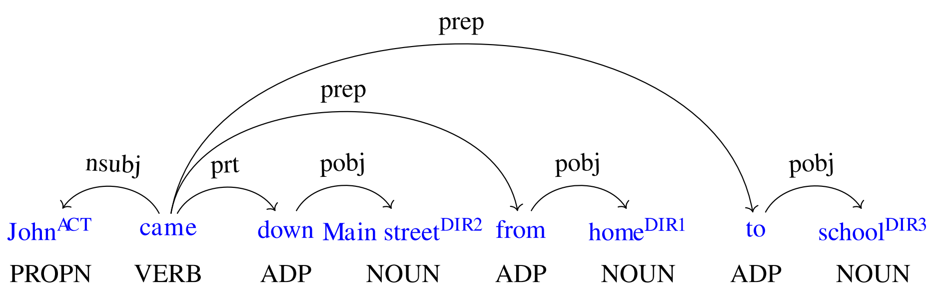

Figure 2. The Stanford dependencies annotation scheme for the sentence *John came from home to school down Main Street.*

J^2: *John came to a pub on Main Street.*

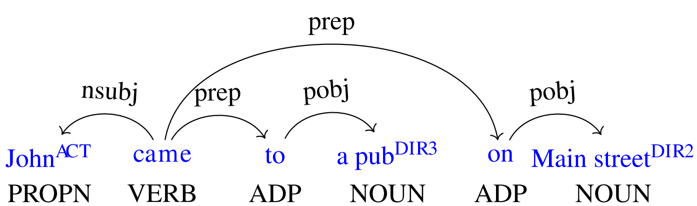

Figure 3. The Stanford dependencies annotation scheme for the sentence *John came to a pub on Main Street.*

- *Rules Actor, Dir1, Dir2, Dir3*[2]

RA: ***nsubj***(VERB(x), PROPN(y)) $\rightarrow \lambda w \lambda t[{}'ACT_{wt}\, y\, x]$

RD1: ***prep***(VERB(x), ADP(“*from*”)) $\wedge$ ***pobj***(ADP(“*from*”), NOUN(y)) $\rightarrow$ $\lambda w \lambda t[{}'DIR1_{wt}\, y\, x]$

RD2a: ***prt***(VERB(x), ADP(z)) $\wedge$ ***pobj***(ADP(z), NOUN(y)) $\rightarrow \lambda w \lambda t[{}'DIR2_{wt}\, y\, x]$

RD2b: ***prep***(VERB(x), ADP(“*on/through*”)) $\wedge$ ***pobj***(ADP(“*on/through*”), NOUN(y)) $\rightarrow \lambda w \lambda t[{}'DIR2_{wt}\, y\, x]$

RD3: ***prep***(VERB(x), ADP(“*to/onto*”)) $\wedge$ ***pobj***(ADP(“*to/onto*”), NOUN(y)) $\rightarrow$ $\lambda w \lambda t[{}'DIR3_{wt}\, y\, x]$

[2] For the respective form of rule to obtain particular participant, we consider the type of relation according to Stanford dependencies (in bold), word-class (capitals), and in some cases, the specific word shape of prepositions (in quotes).

The conversion of the sentence J[1], the rules applied: RA, RD1, RD2a, RD3:

$$\lambda w\lambda t[[{}^{\backprime}ACT_{wt}\,{}^{\backprime}John\,{}^{\backprime}Came] \wedge [{}^{\backprime}DIR3_{wt}\,{}^{\backprime}school\,{}^{\backprime}came] \wedge [{}^{\backprime}DIR1_{wt}\,{}^{\backprime}home\,{}^{\backprime}came] \wedge$$
$$\wedge [{}^{\backprime}DIR2_{wt}\,{}^{\backprime}MainStreet\,{}^{\backprime}came]]$$

The conversion of the sentence J[2], the rules applied: RA, RD1, RD2b, RD3:

$$\lambda w\lambda t[[{}^{\backprime}\mathrm{ACT}_{wt}\,{}^{\backprime}John\,{}^{\backprime}came] \wedge [{}^{\backprime}\mathrm{DIR3}_{wt}\,{}^{\backprime}pub\,{}^{\backprime}came] \wedge [{}^{\backprime}\mathrm{DIR2}_{wt}\,{}^{\backprime}MainStreet\,{}^{\backprime}came]]$$

J[3]: *After 100m John came to the pub on Main Street.*

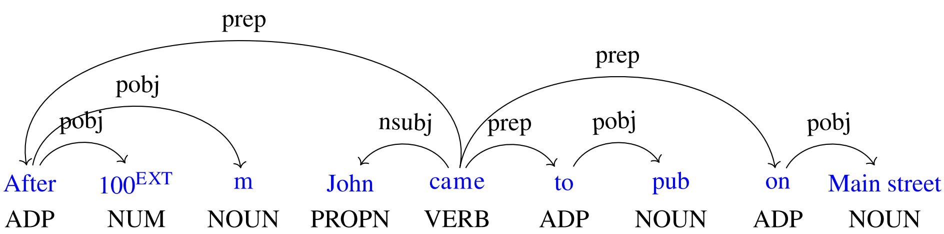

Figure 4. The Stanford dependencies annotation scheme for the sentence *After 100m John came to the pub on Main street.*

- ***Rule Extent***

RE: ***prep***(VERB(x),ADP("*after*")) ∧ ***pobj***(ADP("*after*"),NUM(y)) →

$\lambda w\lambda t[{}'EXT_{wt}\, y\, x]$

The conversion of the sentence J[3], the rules applied: RE, RA, RD3, RD2b:

$$\lambda w\lambda t[[{}^{\backprime}EXT_{wt}\,{}^{\backprime}100\,{}^{\backprime}came] \wedge [{}^{\backprime}ACT_{wt}\,{}^{\backprime}John\,{}^{\backprime}came] \wedge [{}^{\backprime}DIR3_{wt}\,{}^{\backprime}pub\,{}^{\backprime}came] \wedge$$
$$\wedge [{}^{\backprime}DIR2_{wt}\,{}^{\backprime}MainStreet\,{}^{\backprime}came]]$$

J[4]: *John turned right onto Havlicek Street.*

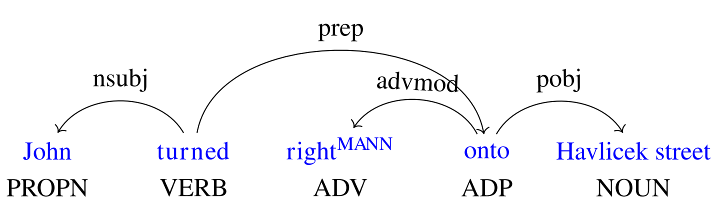

Figure 5. The Stanford dependencies annotation scheme for the sentence *John turned right onto Havlicek Street.*

- ***Rule Manner***

RM: ***prep***(VERB(x),ADP("*onto*")) ∧ ***advmod***(ADP("*onto*"),ADV(y)) →

$\lambda w\lambda t[{}'MANN_{wt}\, y\, x]$

The conversion of the sentence J[4], the rules applied: RE, RA, RD3, RM:

$$\lambda w \lambda t[[{}'ACT_{wt}\, {}'John\, {}'turned] \wedge [{}'MANN_{wt}\, {}'right\, {}'turned] \wedge$$
$$\wedge\ [{}'DIR3_{wt}\, {}'HavlicekStreet\, {}'came]]$$

The above-presented rules are substantial for the most commonly used *motion verbs* in the journey description. We are currently working on taking into account other verbs, and the phrasal connections that may appear in path descriptions. We also consider various possibilities of how the text refers to the transport instrument for the rule for determining the instrument of transport.

5. Conclusion and future work

In this paper, we have presented a proposal of rules for transforming natural language text with *motion verbs* into TIL-Script constructions. The rules are designed with respect to Stanford type dependencies and verb valency frames. From these constructions, the concrete representation of the whole journey is later generated according to the heuristic. In our future work, this journey representation will serve as the input for the part based on geographic data which will generate the map topology from these constructions.

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