Computational Onto-morphology for Modern Greek Derivation: from Ontolex-Morph to ell_schema Model

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Abstract

This article studies the embedding of morphological rules in ontologies with a particular reference to derivation. First, the core morphological approaches of word formation are shortly explained so that the modeling has a theoretical baseline. Then, the Ontolex-Morph is presented, a module of Ontolex to document and automate morphological information. Ontolex-Morph is used for representing and partly automate a Modern Greek derivation example and is shortly evaluated afterwards. In this framework, the ell_schema model is illustrated, an ontology based on the MMoOn, that has been developed to fully represent Modern Greek word formation, with a particular focus on derivation. After presenting the rule-based architecture of ell_schema, the study concludes with specific SPARQL CONSTRUCT query examples that operationalize the ontology's rules, turning it into a computational onto-morphological lexicon capable of automatically generating various derivational entities and their relationships.

Keywords

Linguistic Linked Data, Ontolex-Morph, ell_schema model, Modern Greek derivational morphology

1. Introduction

The LOD paradigm in recent decades has triggered the emergence of models to represent different aspects of language data [1, 2]. Language linked data (LLD) as called, have taken the form of lexica, linguistic annotation tools for corpora, linguistic data categories or linguistic resource metadata [2].

Between those models very few has been purposed for documenting morphological information. While the majority focus on descriptive and inflectional morphology [3, 4, 5], very few extend their coverage to derivation and compounding or incorporate morphological generative rules. Of those, the most prominent have been the latest version of OntoLex-Morph [6, 7] and the MMoOn [8]. The first has been planned to extend OntoLex-Lemon Core as a Morphology module and has also triggered an extension for derivational purposes in the LiLa ontology [9], a recent model for documenting Latin morphology.

In this article, in section 2, we briefly present the core morphological theories of word formation. In section 3, we illustrate and briefly review the latest version of Ontolex-Morph also by representing a MG derivational example. In section 4, we elaborate our ontological model for representing MG derivation, relating it to morphological theory. Finally, to exemplify it as a computational ontology, we run indicative SPARQL queries for automating derivational entities and their relationships.

2. Word formation theories

Among theories of word formation, we will refer to three of them that have been mostly cited. The Item-and-Arrangement (I-and-A), the Item-and-Process (I-and-P) and the Word-and-Paradigm (W-

SWODCH'26: International Workshop on Semantic Web and Ontology Design for Cultural Heritage, Workshop days of ISWC 2026, Bari, Italy.

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CEUR Workshop Proceedings ceur-ws.org ISSN 1613-0073

published 2026-11-09

CEUR-WS.org/Vol-4320/paper12.pdf

and-P) approaches along with the closely related word-based perspective of Construction morphology approach [10]. The I-and-A approach [11] corresponds to the concatenative, morphotactic or combinatorial morphology [12] and assumes that words are formed syntagmatically, i.e. by the alignment of affixes to the left (prefixation) or to the right (suffixation) of a base. Alternatively, such formations may be represented through successive morphological strata or levels [12, 13], whereby increasingly complex words are formed through successive morphological operations (cf. χορός > χορεύω > χορευτής > χορευτικός).

However, in I-and-P approach, words are not just formed by the simple concatenation of affixes, but morphemes go through morpho-phonological processes, i.e. allomorphy, that contribute to the resulting forms. Thus, in order for the derived noun καλλιεργη-τή-ς 'cultivator' to be formed, the appropriate allomorph stem-form καλλιεργη- from the source verb καλλιεργ-ώ 'to cultivate' is selected to which the derivational -τη- and the inflectional suffix -ς are appended. In even more complex and less productive cases, forms alter with no obvious reason due to diachrony or to morpho-phonological surroundings or even simplicity (υστερώ > καθυστερώ, ερωτώ > ρωτώ, κλέβω > κλοπή).

On the other hand, according to the W-and-P approach [14], words may also be formed paradigmatically because certain affixes are appended to base patterns. This can be represented by templates to which suitable processes are embedded (cf. 1, 2) [15]. In this approach, words are not related lexically but are pattern-based, i.e. a pair of words share the same paradigmatic system [16] (χορ-ός - χορ-εύω, γιατρ-ός - γιατρ-έυω). One more characteristic of this approach is that affixes do not possess separate lexical entries in the lexicon but "only exist as part of complex word and of abstract morphological patterns" (cf. 1, 2) [13, p. 10]. This approach is closely related to Construction Morphology (CxM), revolving around "constructions", which are conventionalized pairings of form and meaning [10]. An advantage of the approach is that it does not comprise linear or stratum- but network-based relationships. Additionally, the focus is on the content or the slot of a paradigm and not on the form, which gives the model predictability, accounting also for cases of double or triple affixation [17]. The problem is that it is highly declarative and descriptive, does not link to I-and-A approach or explicate the reason of form change.

1. [x]V → [x-er]N "one who Vs": dance → dancer
2. [x-ευ-ω]V → [x-ευ-τή-ς]N "one who Vs": χορεύω → χορευτής

3. Ontolex-Morph

According to the latest Draft Community Group Report[2] [18]: "OntoLex-Morph has been designed with the premise to make OntoLex-lemon applicable to morphologically rich languages of any type, supporting both fusional and agglutinating morphology, and thereby contributing to a truly multilingual web". This module extends and operates in combination with the Core model (Figure 1) and although it was initially developed primarily for extensional morphological description [7], lately has been extended to cover also intensional processes [6]. Namely, the module as it is now covers two core aspects of morphological information: a) descriptive morphology, that is all metadata related to morphs, words (either wordforms or lexical entries comprising simple lexemes, derivatives or compounds) and their structural or semantic relations and b) rule-based morphology accounting for the generation of new forms, either wordforms in inflection, derivatives in derivation and compounds in composition.

[2] https://ontolex.github.io/morph/.

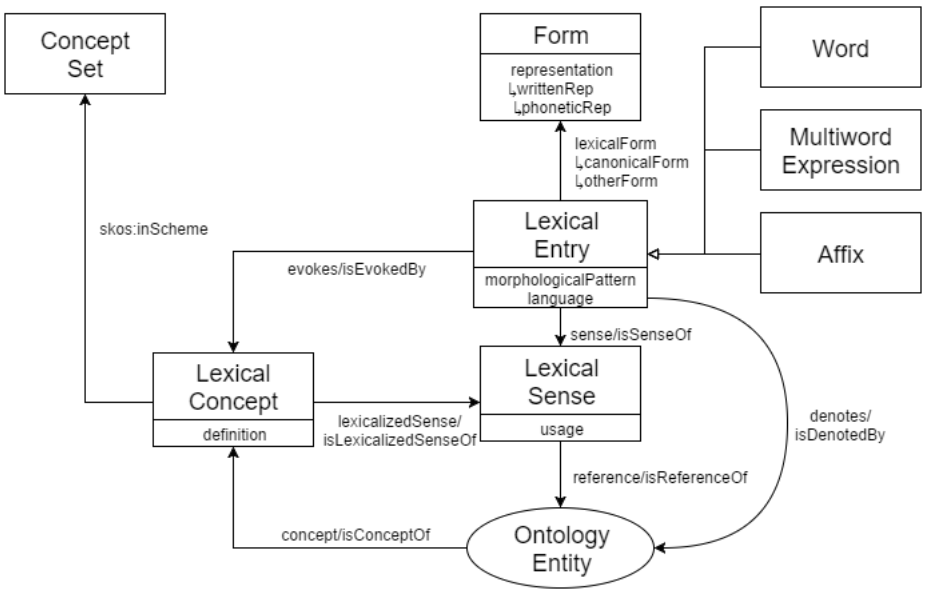


Figure 1: The architecture of Ontolex-Core module

3.1. Descriptive morphology

As we have already said, the Morph module (Figure 2) has been modeled upon the already established core schema (Figure 1). The heart-class is the Lexical Entry which has four subclasses, Morph, Word, Affix and MultiWordExpression. In this way, morphs also like words are handled as lemmas in the lexicon, a fact which aligns with the Lexicalist theory in morphology [12]. The Lexical entry class connects to the class Form via lexicalForm object property (OP). Its sub-property baseForm allows a Word to define its candidate base forms upon which derivation builds. Therefore, the model engulfs in the Form class instances of word-forms as well as of morphs. The Form class has also a baseType data property to mark the specific base type used in a word formation process and can consist (consistsOf) of Morph instances. For capturing grammatical semantics, both Morph and Form connect to the class Grammatical Meaning (via the grammaticalMeaning OP). Morph also has a baseConstraint property linked to a Grammatical Meaning instance, to capture specific grammatical characteristics of the stem or base that a derivational or inflectional morpheme can be combined with.

3.2. Rule-based morphology

In Figure 2, in terms of rule-based morphology, on the inflection level a Lexical Entry connects to an Inflection Class through the morphologicalPattern OP. In turn, an Inflection Rule class (subclass of the Rule class) connects to Inflection class via inflectionClass OP and to Inflection Slot class via inflectionSlot OP. A Rule is instantiated with an example, has grammaticalMeaning, involves a Morph class and is reified by specific replacement processes via the replacement OP linking to the Replacement class. On the derivation and compounding level, a general Lexical Relation class and its subclass, Word Formation Relation relate to Lexical entry. This relation extends its lexical components into source and target data properties. The Word Formation Relation is related via the wordFormationRule OP to the specific Word Formation Rule class (a subclass of the Rule class), either a Derivation or a Compounding Rule. A Word Formation Rule connects to the Lexical Entry instances it generates via the generates OP. Specific for compounding is the class Compound Relation and its subclass Compound Head that capture the specific lexical components of a compound.

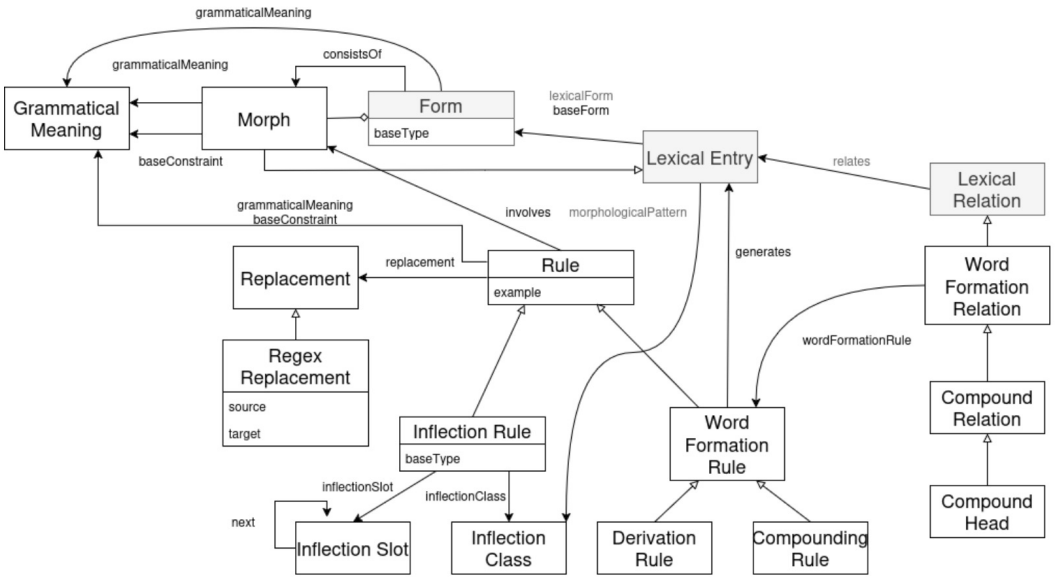


Figure 2: The Ontolex-Morph as depicted in the latest draft version

3.3. Ontolex-Morph evaluation analysis

Based on the examples of the latest Ontolex-Morph draft and the specified ontology ttl file [18], below we represent a lexical example from Modern Greek (MG). In MG derivation, it should be noted that usually derived words use an allomorph stem of the source word, if present. The model specifies that the property baseform may be used either for inflected or derived forms, so in our case the lexical entry :χορεύω_entry uses two different base types to represent inflected and derived forms.

```
:χορεύω_entry a ontolex:Word, ontolex:LexicalEntry ;
  rdfs:label "χορεύω"@el, "to dance"@en ;
  morph:baseForm [
    a ontolex:Form ;
    ontolex:writtenRep "χορεύ"@el ;
    ontolex:phoneticRep "xorév" ;
    morph:baseType "verbalBase_εύ1"
] ;
  morph:baseForm [
    a ontolex:Form ;
    ontolex:writtenRep "χορευ"@el ;
    ontolex:phoneticRep "xoref" ;
    morph:baseType "verbalBase_ευ2"
] .

:τής_rule a morph:DerivationRule ;
  morph:baseType "verbalBase_ευ2"
  morph:replacement [
    a morph:replacement ;
    morph:source "$" ;
    morph:target "τής"
    ] ;
  morph:involves :τή_suffix , :ς_suffix ;
  morph:generates :χορευτής_entry .
```

In the above example, we assign the specific base type of the source word to the rule that generates its derivative, ensuring that the rule operates on the appropriate base type of the source word in each case. In our example this is the phonological variant <xoref> of the homograph verbal base χορευ-. Then, the rule can generate the following:

```
:χορευτής_entry a ontolex:Word, ontolex:LexicalEntry ;
rdfs:label "χορευτής"@el, "dancer"@en  ;

:χορεύω-χορευτής a morph:WordFormationRelation ;
vartrans:source :χορεύω_entry ;
vartrans:target :χορευτής_entry ;
morph:wordFormationRule :τής_rule .
```

Overall, the model succeeds in associating a rule of a W-and-P approach with its components through the morph:baseType and the morph:involves properties and therefore to the I-and-A approach. By assigning specific base types to a word, the model aptly implies that these are morph variants (allomorphs). On the other hand, it should be noted that it focuses exclusively on automating word formation, but not base formation. If base forms could also be generated through the application of normalized rules, the derivational process would be more comprehensive and its intermediate stages more explicitly accounted for. Regarding rule representation, the Regex replacement process can be considered sufficiently effective for derivative generation; however, it remains primarily a computational mechanism rather than a theoretically motivated account of word formation. One final point to note is that the model and even LexInfo [4] do not define special types of suffixes, such as derivational and inflectional. This is crucial in MG morphological analysis as derivational suffixes have an extremely important role in word structures because they change stem category and transmit other grammatical and lexical or semi-lexical meanings [19]. By contrast, inflectional suffixes express solely grammatical functions like case, number, tense, voice, or paradigm. With Suffix class alone, it is not possible to discern and leverage the different qualities that each suffix type has. Nevertheless, the model offers clear potential for representing and computationally processing derivation, while adopting a top-down, language-agnostic approach to morphological data representation. As a matter of fact, it encourages the employment of the MMoOn ontology [8] for more complex morphological representations.

4. The ell_schema model

This research assumes that all three morphological approaches (I-and-A, I-and-P, and W-and-P) offer significant insights into morphological word-formation processes and that relevant aspects of each should therefore be integrated into a comprehensive representational model or graph. What is more, as already shown in Ontolex-Morph, an onto-morphological model ideally not only incorporates representational analysis but also is able to embed rules that mobilize word formation processes. Therefore, in our paradigm, we will elaborate on how insights from all three approaches can be modeled and integrated, with the aim of developing the ontology into a robust computational tool for MG word formation. As explained in earlier studies [20], because of Ontolex-Morph still unofficial status, we have chosen MMoOn as a complete and granular baseline ontology for extending our MG onto-morphological schema. Our model is based on morphological patterns as already provisioned in [21, 22] and in this study focuses on suffixation. More specifically, in Figure 3, where we have marked the new ell_schema classes in dark blue, Pattern is the core class of the model and can be divided into four types: a) a DerivationalPattern including two-word patterns (a source and a target) b) a WordPattern including a stem or a base pattern and an inflectional suffix c) a StemPattern including a stem or a base pattern and a derivational affix and d) a BasePattern including no other pattern or morph.

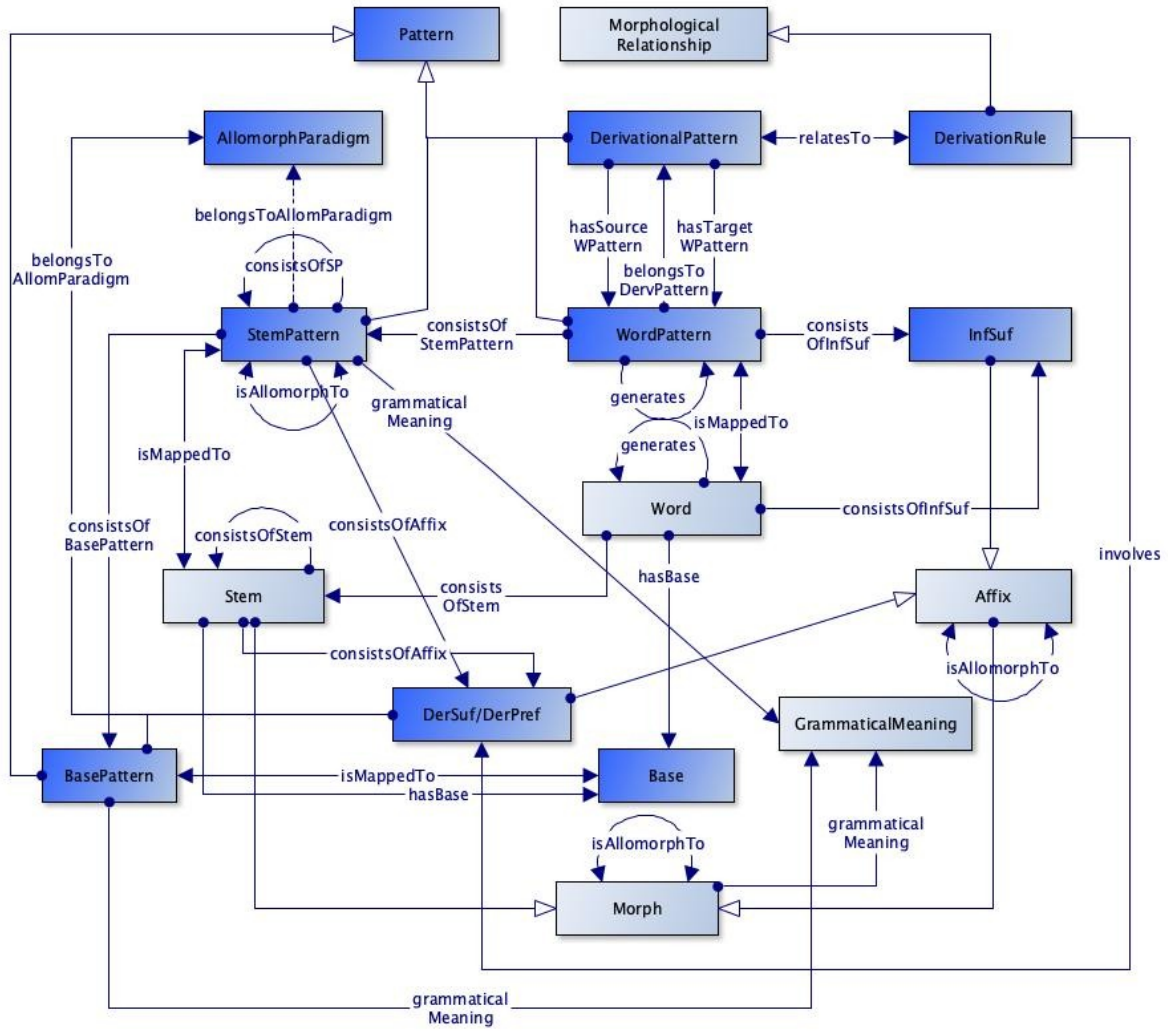


Figure 3: The rule-based architecture of ell_schema model

It should be noted that, following Ralli [12], the term Base is used in the model to denote the minimal, non-analyzable lexical starting point upon which all subsequent derivational processes are anchored and which, as in LiLa implementation [9], serves to connect all members of a word-formation family. For derivation, a DerivationalPattern stands at the top of the hierarchy linking to a source and a target WordPattern via the hasSourceWP and hasTargetWP object properties (OPs). This DerivationalPattern relates to a specific DerivationalRule that also involves a derivational affix when it comes to affixation, which is the most common MG derivational rule. A WordPattern generates another WordPattern mapped to the source-target word derivational sequence and consists of a Base or a StemPattern (via consistsOfStemPattern OP) and an inflectional suffix. This constituent StemPattern may consist of a derivational suffix or prefix and another StemPattern that is deconstructed likewise till it reaches a BasePattern. Both Base and StemPattern are the entities belonging to an AllomorphParadigm. In a certain AllomorphParadigm, each belonging Pattern can have 0 to n cognate allomorph Patterns. A single pattern or a cluster of allomorph patterns inherit allomorph and paradigm relations from their constituent derivational affixes. This way the model succeeds in linking allomorphy to derivation, which is principal in MG derivational theory. On the other hand, patterns are mapped to their lexical instances, via the symmetric OP isMappedTo, that is either bases, stems or words. Finally, each word and stem is linked to the base of the lexical family they are associated with (via hasBase OP) so that the appropriate derivational relations can be generated.

In Figure 4, we illustrate the dynamics of pattern modeling, with the higher-level word patterns X-ευ-τ-ικ-ός and X-ισ-τ-ικ-ός branching into lower-level patterns. Allomorphy between patterns or suffixes is depicted by red connecting lines. The symbol X represents the base of a pattern structure, i.e., the common lexical part of a lexical family, and is left unspecified so that the pattern can be generalized across different lexical instances. By contrast, when a stem pattern is decomposed into its base pattern(s), X is replaced by the corresponding base pattern(s), allowing each to be associated with the relevant derivational pathway. For example, the general stem patterns X-εύ1- and X-ευ2- may include different base patterns, such as the nominal pattern nX1.1, instantiated by χορ-, or the adjectival pattern aX1, instantiated by αγρι-, which are also constituents of the word patterns nX1.1-ός (χορ-ός 'dance') and aX1-ος (άγρι-ος 'angry') respectively. These base patterns give rise to the formations χορ-εύ1- > χορ-εύ1-ω 'to dance' and αγρι-εύ1- > αγρι-εύ1-ω 'to get angry' as well as to other formations. Importantly, however, a base that participates in a given derivational tree does not necessarily combine with all subsequent patterns within that tree. In the X-ευ-τ-ικ-ός tree, for example, another instantiation of nX1.1, γιατρ- occurs in γιατρ-εύ-ω, but does not give rise to *γιατρ-ευ-τή-ς or *γιατρ-ευ-τ-ικ-ός. Other restrictions may also apply between bases belonging to the same base pattern (e.g. nX1), for example, ρυθμ- combines with X-ισ-τ-ικ-ός derivational tree (ρυθμ-ισ-τ-ικ-ός < ρυθμ-ισ-τή-ς < ρυθμ-ίζ-ω < ρυθμ-ός) and not with X-ευ-τ-ικ-ός, whereas the reverse applies to χορ-, which participates in X-ευ-τ-ικ-ός (χορ-ευ-τ-ικ-ός < χορ-ευ-τή-ς < χορ-εύ-ω < χορ-ός) and not in X-ισ-τ-ικ-ός (Figure 4).

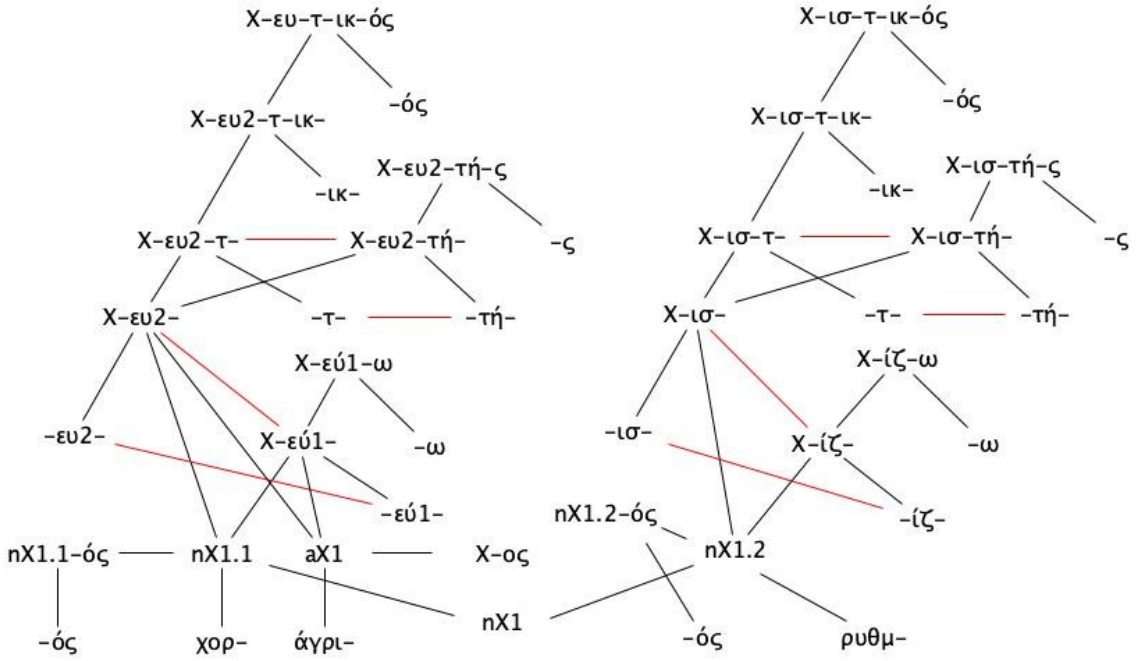


Figure 4: The branching of higher-level into lower level patterns

As a result, to prevent overgeneration, we can create in this case two specific base sub-pattern instances, nX1.1 and nX1.2, both related to nX1, to match each with the right derivational pattern tree (nX1.1=χορ-, nX1.2=ρυθμ-).

Despite the model's potential to overgenerate ungrammatical or possible formations, it should also be tested in a more controlled setting, i.e., a pipeline in which the rules are systematically matched against a substantial set of lexical entries, enabling a more comprehensive assessment of its usability and precision. On the whole, the model succeeds in integrating W-and-P, I-and-A and I-and-P approaches as: a) it is based on patterns b) patterns are deconstructed in whole-part

relationships and c) the whole process is justified by the association of allomorphs and the attribution to a specific rule. Another asset is that it differentiates between the linguistic and the language level, as patterns (linguistic) are mapped to lexical instances (language). By anchoring formal linguistic theory in empirical data, the model could be used as an exemplar framework to build robust and data-attested ontologies. Finally, it should be noted that the above design choices are provisional and may be revised over the course of this research.

4.1. SPARQL for automating derivation

Below, a series of SPARQL CONSTRUCT queries is given to automate the generation of various derivational entities and their relations. For each query, the corresponding input and output ontology triples are provided to illustrate the generation process. In this way, we preserve the ontology's descriptive function while offloading the computational processing to the SPARQL layer. The same example χορεύ-ω > χορευ-τή-ς represented previously in Ontolex-Morph e.g. is also analyzed here in order to highlight the different approaches. The ell_schema inventory current version can be reached at:

https://github.com/dis-ionio-gr-morphology/ell_schema/blob/main/inventory_versions/v1

The prefixes used in the ontology and SPARQL are the following:

```
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX owl: <http://www.w3.org/2002/07/owl#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>
PREFIX mmoon: <http://mmoon.org/core/>
PREFIX ell_schema: <http://mmoon.org/ell/schema/omg/>
PREFIX : <http://mmoon.org/ell/inventory/omg/>
```

Suffixed Stem Generation

INPUT

```
:X-ευ-τή- a ell_schema:StemPattern ;
   ell_schema:consistsOfDerSuf :_-τή-AL1_1_1 ;
ell_schema:consistsOfStemPattern :X-ευ2- ;
:X-ευ2- a ell_schema:StemPattern ;
   mmoon:isAllomorphTo :X-εύ1- ;
   ell_schema:isMappedTo :χορ-_-ευ-AL2_1_1 .
:χορ-_-ευ-AL2_1_1 a mmoon:Stem ;
   ell_schema:hasBase :b_xor ;
mmoon:orthographicRepresentation "χορευ" .
:_-τή-AL1_1_1 a ell_schema:DerSuf ;
   mmoon:orthographicRepresentation "τή" .
```

```
CONSTRUCT {
 ?stemIRI a mmoon:Stem ;
   mmoon:consistsOfStem ?stem ;
   ell_schema:consistsOfDerSuf ?affix ;
   mmoon:orthographicRepresentation ?generatedForm ;
   ell_schema:isMappedTo ?stemPattern2 ;
   ell_schema:hasBase ?base .
}
WHERE {
```

```
    ?stemPattern2 ell_schema:consistsOfDerSuf ?affix ;
    ell_schema:consistsOfStemPattern ?stemPattern1 .
    ?stemPattern1 ell_schema:isMappedTo ?stem .
    ?stem ell_schema:hasBase ?base ;
    mmoon:orthographicRepresentation ?stemForm .
    ?affix mmoon:orthographicRepresentation ?affixForm .
    BIND(
        CONCAT(STR(?stemForm), STR(?affixForm))
        AS ?generatedForm
    )
    BIND(
        IRI(CONCAT(
            "http://mmoon.org/ell/inventory/omg/",
            STRAFTER(STR(?stem), "omg/"),
            STRAFTER(STR(?affix), "omg/")
        ))
        AS ?stemIRI
    )
}
```

OUTPUT

```
:χορ-_-ευ-AL2_1_1_-τή-AL1_1_1 a mmoon:Stem ;
    mmoon:consistsOfStem :χορ-_-ευ-AL2_1_1 ;
    ell_schema:consistsOfDerSuf :_-τή-AL1_1_1 ;
    ell_schema:hasBase :b_xor ;
    ell_schema:isMappedTo :X-ευ-τή- ;
    mmoon:orthographicRepresentation "χορευτή" .
```

Suffixed Word Generation

INPUT

```
:X-ευ-τή-ς a ell_schema:WordPattern ;
    ell_schema:consistsOfInfSuf :_-ς ;
    ell_schema:consistsOfStemPattern :X-ευ-τή- .
:X-ευ-τή- a ell_schema:StemPattern ;
    ell_schema:consistsOfDerSuf :_-τή-AL1_1_1 ;
    ell_schema:isMappedTo :χορ-_-ευ-AL2_1_1_-τή-AL1_1_1 .
:χορ-_-ευ-AL2_1_1_-τή-AL1_1_1 a mmoon:Stem ;
    ell_schema:hasBase :b_xor ;
mmoon:orthographicRepresentation "χορευτή" .
:_-ς a  ell_schema:InfSuf ;
    mmoon:orthographicRepresentation "ς" .
```

```
CONSTRUCT {
  ?wordIRI a mmoon:Word ;
     mmoon:consistsOfStem ?stem ;
     ell_schema:consistsOfInfSuf ?affix ;
     ell_schema:isMappedTo ?wordPattern ;
     mmoon:orthographicRepresentation ?generatedForm ;
     ell_schema:hasBase ?base}
WHERE {
  ?wordPattern ell_schema:consistsOfStemPattern ?stemPattern ;
```

```
    ell_schema:consistsOfInfSuf ?affix .
  ?stemPattern ell_schema:isMappedTo ?stem ;
    ell_schema:consistsOfDerSuf ?derAff .
  ?stem mmoon:orthographicRepresentation ?stemForm ;
    ell_schema:hasBase ?base .
  ?affix mmoon:orthographicRepresentation ?affixForm .
  BIND(
      CONCAT(
          STR(?stemForm),
          STR(?affixForm)
      ) AS ?generatedForm
  )
  BIND(
      IRI(
          CONCAT(
              "http://mmoon.org/ell/inventory/omg/",
              STRAFTER(STR(?stem), "omg/"),
              STRAFTER(STR(?affix), "omg/")
          )
      ) AS ?wordIRI
  )}
```

OUTPUT

```
χορ-_-ευ-AL2_1_1_-τή-AL1_1_1_-ς a mmoon:Word ;
   mmoon:consistsOfStem :χορ-_-ευ-AL2_1_1_-τή-AL1_1_1 ;
   ell_schema:consistsOfInfSuf :_-ς ;
   ell_schema:isMappedTo :X-ευ-τή-ς ;
   mmoon:orthographicRepresentation "χορευτής" ;
   ell_schema:hasBase :b_xor .
```

Derivatives Generation (suffixation)

INPUT

```
:X-εύ-ω_X-ευ-τή-ς a ell_schema:DerivationalPattern ;
   ell_schema:hasSourceWP :X-ω ;
   ell_schema:hasTargetWP :X-ευ-τή-ς ;
   ell_schema:relatesTo :suffixation .
:χορ-_-εύ-AL1_1_1_-ωIS_AL1_1_1 a mmoon:Word ;
   ell_schema:isMappedTo :X-εύ-ω ;
   mmoon:orthographicRepresentation "χορεύω" ;
ell_schema:hasBase :b_xor .
:χορ-_-ευ-AL2_1_1_-τή-AL1_1_1_-ς a mmoon:Word ;
   ell_schema:isMappedTo :X-ευ-τή-ς ;
   mmoon:orthographicRepresentation "χορευτής" ;
   ell_schema:hasBase :b_xor .
```

```
CONSTRUCT {
  ?sourceWord ell_schema:generates ?targetWord .
  ?sourceWord mmoon:orthographicRepresentation ?sourceOrth.
  ?targetWord mmoon:orthographicRepresentation ?targetOrth .
  ?drvPattern ell_schema:relatesTo ?derivationRule .}
WHERE {
```

```
  ?drvPattern ell_schema:hasSourceWP ?sourceWP ;
     ell_schema:hasTargetWP ?targetWP .
  ?sourceWord ell_schema:isMappedTo ?sourceWP ;
     ell_schema:hasBase ?base ;
     mmoon:orthographicRepresentation ?sourceOrth .
  ?targetWord ell_schema:isMappedTo ?targetWP ;
     ell_schema:hasBase ?base ;
     mmoon:orthographicRepresentation ?targetOrth .
  ?drvPattern ell_schema:relatesTo ?derivationRule .
  FILTER(?sourceWord != ?targetWord)
}
```

OUTPUT

```
:χορ-_-εύ-AL1_1_1_-ωIS_SV1 a mmoon:Word ;
    ell_schema:generates :χορ-_-ευ-AL2_1_1_-τή-AL1_1_1_-ς ;
    mmoon:orthographicRepresentation "χορεύω" .
:χορ-_-ευ-AL2_1_1_-τή-AL1_1_1_-ς a mmoon:Word ;
    mmoon:orthographicRepresentation "χορευτής" .
:X-εύ-ω_X-ευ-τή-ς
    ell_schema:relatesTo :suffixation .
```

Declaration on Generative AI

The author(s) have not employed any Generative AI tools.

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