Functional Arabic Morphology

Principles of Design

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بذلك		P---------	PREP	*bi-*	about/by
		SD----MS--	DEM_PRON_MS	*ḏālika*	that
عن		P---------	PREP	*ʿan*	by/about
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الرسائل		N-------2D	DET+NOUN+CASE_DEF_GEN	*ar-rasāʾil-i*	the-messages
القصيرة		A-----FS2D	DET+ADJ+NSUFF_FEM_SG+ +CASE_DEF_GEN	*al-qaṣīr-at-i*	the-short
والإنترنت		C---------	CONJ	*wa-*	and
		Z-------2D	DET+NOUN_PROP+ +CASE_DEF_GEN	*al-ʾinternet-i*	the-internet
وغيرها		C---------	CONJ	*wa-*	and
		FN------2R	NEG_PART+CASE_DEF_GEN	*ġayr-i*	other/not-of
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Morphological theories can be classified along two dimensions (Stump 2001).

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Evidence favoring inferential–realizational theories over the others is given.

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An uncompounded word's morphological form is not distinct from its phonological form. *(Stump 2001:12)*

`DET+ADJ+NSUFF_FEM_SG+CASE_DEF_GEN` *(al-(qaṣīr-at))-i* ?? *((al-qaṣīr)-at)-i*

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Definition of lexemes can include the derivational root and pattern information if appropriate. Modeling of the written language as well as spoken dialects is expected to be methodologically identical.

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The lexicon of ElixirFM is derived from the open-source Buckwalter lexicon and from the PADT annotations. It is redesigned in important respects.

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data  ParaVerb  = VerbP Voice Person Gender Number
            | VerbI  Mood Voice Person Gender Number
            | VerbC                    Gender Number
    deriving Eq
```

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(c) definition of such format of the lexicon so that editing and understanding the data is not inappropriately difficult, and using such data markup whose syntax is either lightweight, or can be edited/verified with some automatic tools, or both

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FM Generic also provides functions for exporting and pretty-printing the linguistic model into XFST, Lexc, SQL, XML, LaTeX, ...

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Buckwalter Transliteration

يُولَدُ جَمِيعُ ٱلنَّاسِ أَحْرَارًا مُتَسَاوِينَ فِي ٱلْكَرَامَةِ وَٱلْحُقُوقِ. وَقَدْ وُهِبُوا عَقْلًا وَضَمِيرًا وَعَلَيْهِمْ أَنْ يُعَامِلَ بَعْضُهُمْ بَعْضًا بِرُوحِ ٱلْإِخَاءِ.

```
yuwladu jamiyEu  {ln~aAsi OaHoraArFA mutasaAwiyna fiy
{lokaraAmapi wa {loHuquwqi.  waqado wuhibuwA EaqolAF
waDamiyrFA waEalayohimo Oano yuEaAmila baEoDuhumo baEoDFA
biruwHi  {loIixaA'i.
```

يولد جميع الناس أحرارا متساوين في الكرامة والحقوق. وقد وهبوا عقلا وضميرا وعليهم أن يعامل بعضهم بعضا بروح الإخاء.

```
ywld jmyE AlnAs OHrArA mtsAwyn fy AlkrAmp wAlHqwq.  wqd
whbwA EqlA wDmyrA wElyhm On yEAml bEDhm bEDA brwH AlIxA'.
```

Notation of ArabTEX

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Yūladu ğamīʿu ’n-nāsi ʾaḥrāran mutasāwīna fī ’l-karāmati wa-’l-ḥuqūqi. Wa-qad wuhibū ʿaqlan wa-ḍamīran wa-ʿalayhim ʾan yuʿāmila baʿḍuhum baʿḍan bi-rūḥi ’l-ʾiẖāʾi.

```
\cap yUladu ^gamI‘u an-nAsi ’a.hrAraN mutasAwIna fI
     al-karAmaTi wa-al-.huqUqi.
\cap wa-qad wuhibUA ‘aqlaN wa-.damIraN wa-‘alayhim ’an
     yu‘Amila ba‘.duhum ba‘.daN bi-rU.hi al-’i_hA’i.
```

Encode Arabic

biruwHi {loIixaA'i ← بِرُوحِ آلْإِخَاءِ ← bi-rU.hi al-'i_hA'i

Implemented in Perl and available on CPAN as Encode-Arabic:

```
$encoded = encode "buckwalter", decode "arabtex", $decoded
$encoded = encode("buckwalter", decode("arabtex", $decoded))
```

Implemented in Haskell and available along with ElixirFM:

```
encoded = encode Buckwalter $ decode ArabTeX decoded
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encoded = (encode Buckwalter . decode ArabTeX) decoded
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[cmd] decode ArabTeX < decode.d | encode Buckwalter > encode.d
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biruwHi {loIixaA'i ← بِرُوحِ آلْإِخَاءِ ← bi-rU.hi al-'i_hA'i

Implemented in Perl and available on CPAN as Encode-Arabic:

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$encoded = encode "buckwalter", decode "arabtex", $decoded
$encoded = encode("buckwalter", decode("arabtex", $decoded))
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Implemented in Haskell and available along with ElixirFM:

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encoded = encode Buckwalter $ decode ArabTeX decoded
encoded = encode Buckwalter (decode ArabTeX decoded)
encoded = (encode Buckwalter . decode ArabTeX) decoded
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[cmd] decode ArabTeX < decode.d | encode Buckwalter > encode.d
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Morphology Disambiguation

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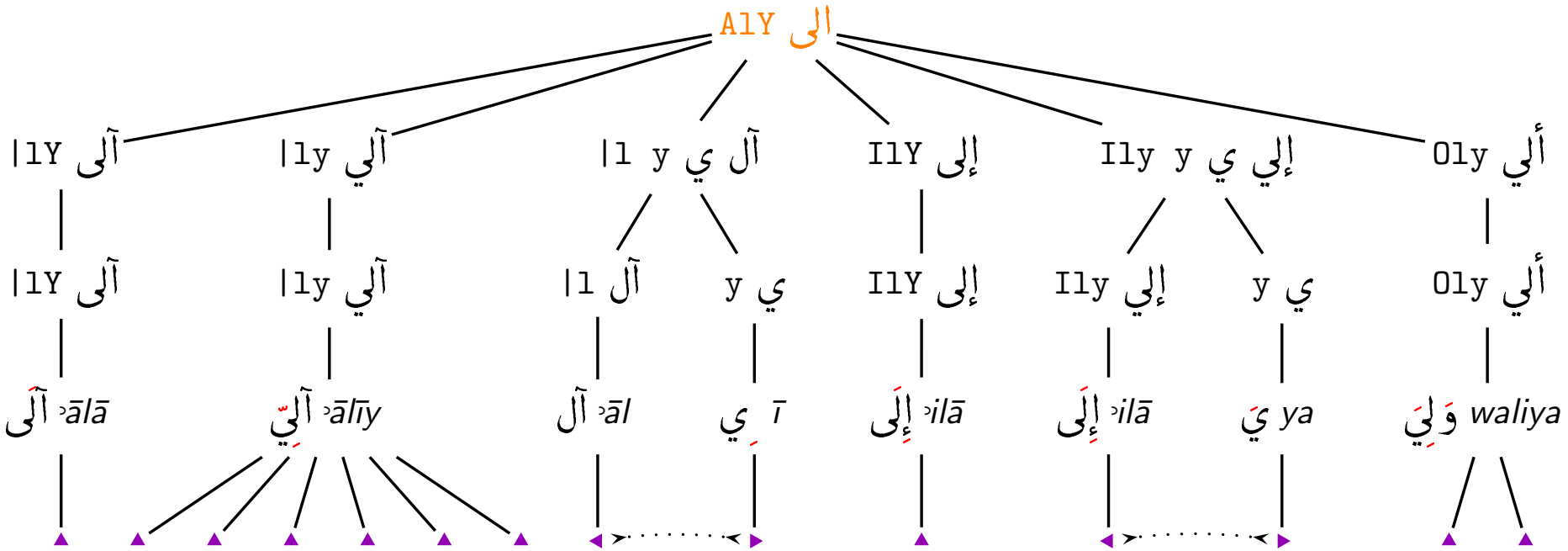
Linear Lists

Suppose you can list morphological analyses for a given input string ...

Morphs	Form	Token Tag	Lemma	Glosses per Morph
|laY+(null)	ʾālā	VP-A-3MS--	ʾālā	promise/take an oath + he/it
|liy˜	ʾālīy	A---------	ʾālīy	mechanical/automatic
|liy˜+u	ʾālīy-u	A-------1R	ʾālīy	mechanical ... + [def.nom.]
|liy˜+i	ʾālīy-i	A-------2R	ʾālīy	mechanical ... + [def.gen.]
|liy˜+a	ʾālīy-a	A-------4R	ʾālīy	mechanical ... + [def.acc.]
|liy˜+N	ʾālīy-un	A-------1I	ʾālīy	mechanical ... + [indef.nom.]
|liy˜+K	ʾālīy-in	A-------2I	ʾālīy	mechanical ... + [indef.gen.]
|l +	ʾāl	N--------R	ʾāl	family/clan +
+ iy	-ī	S----1-S2-	ī	+ my
IilaY	ʾilā	P---------	ʾilā	to/towards
Iilay +	ʾilay	P---------	ʾilā	to/towards +
+ ya	-ya	S----1-S2-	ya	+ me
Oa+liy+(null)	ʾa-lī	VIIA-1-S--	waliya	I + follow/come after + [ind.]
Oa+liy+a	ʾa-liy-a	VISA-1-S--	waliya	I + follow/come after + [sub.]

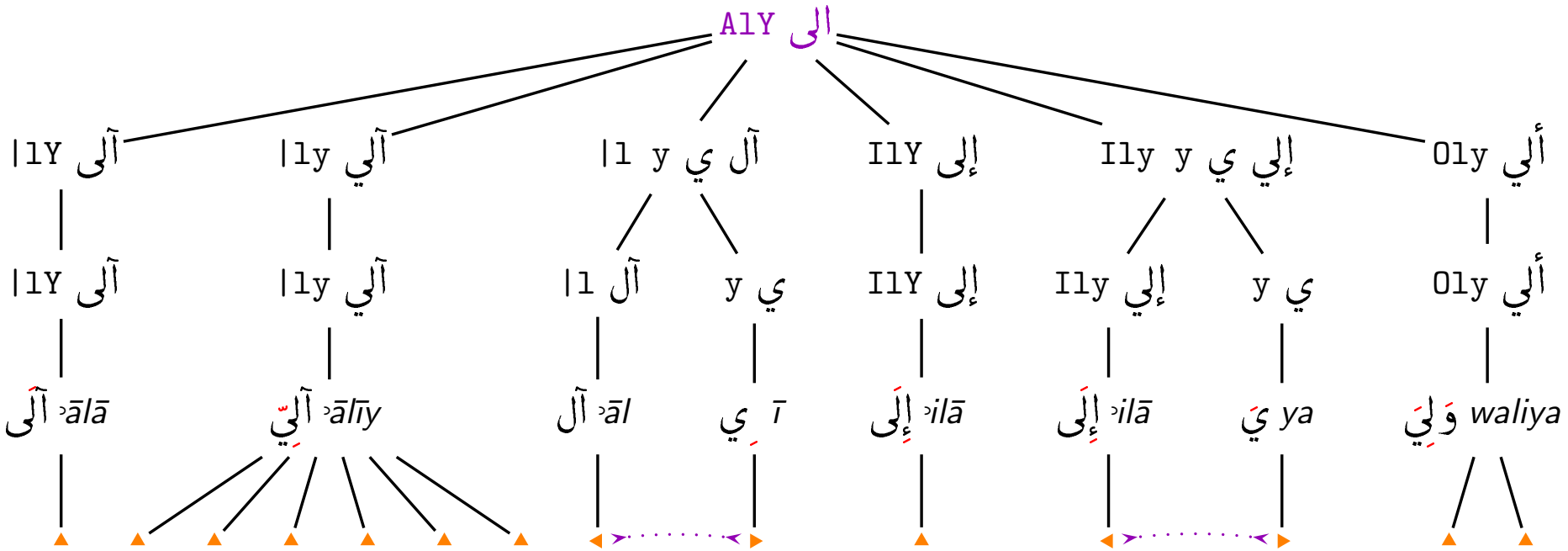
MorphoTrees

. . . organize the analyses into a hierarchy with the string as its root



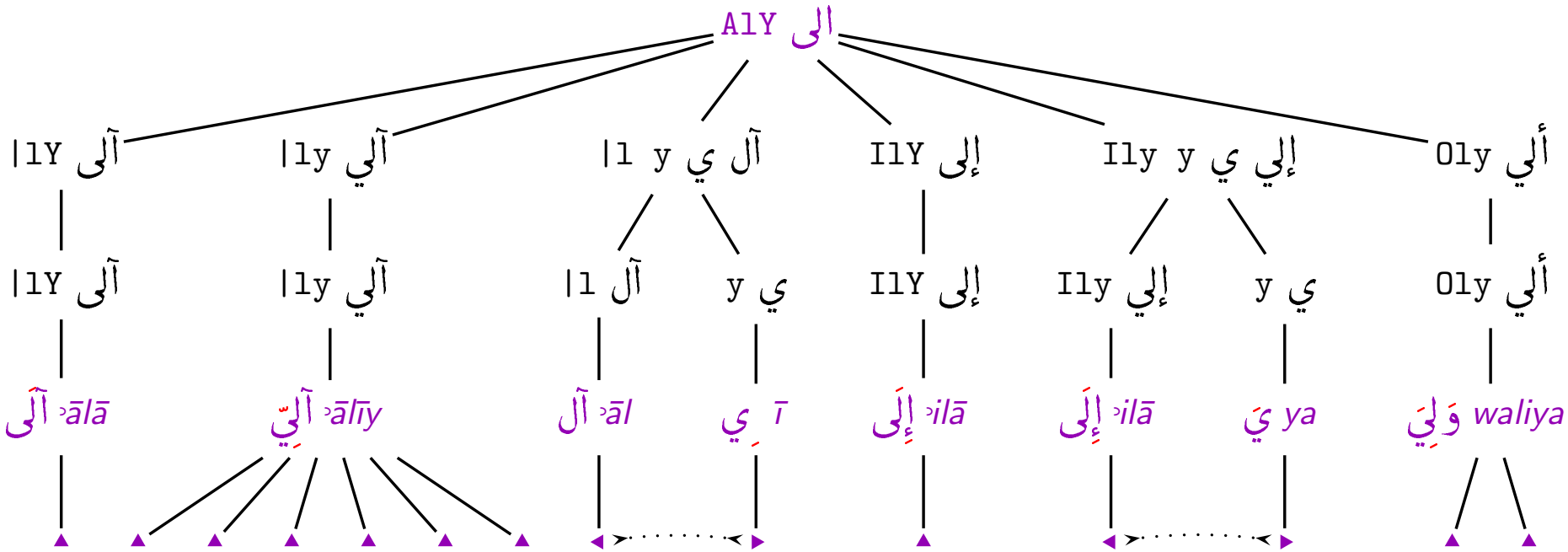
MorphoTrees

. . . organize the analyses into a hierarchy with the string as its root and the full tokens as the leaves



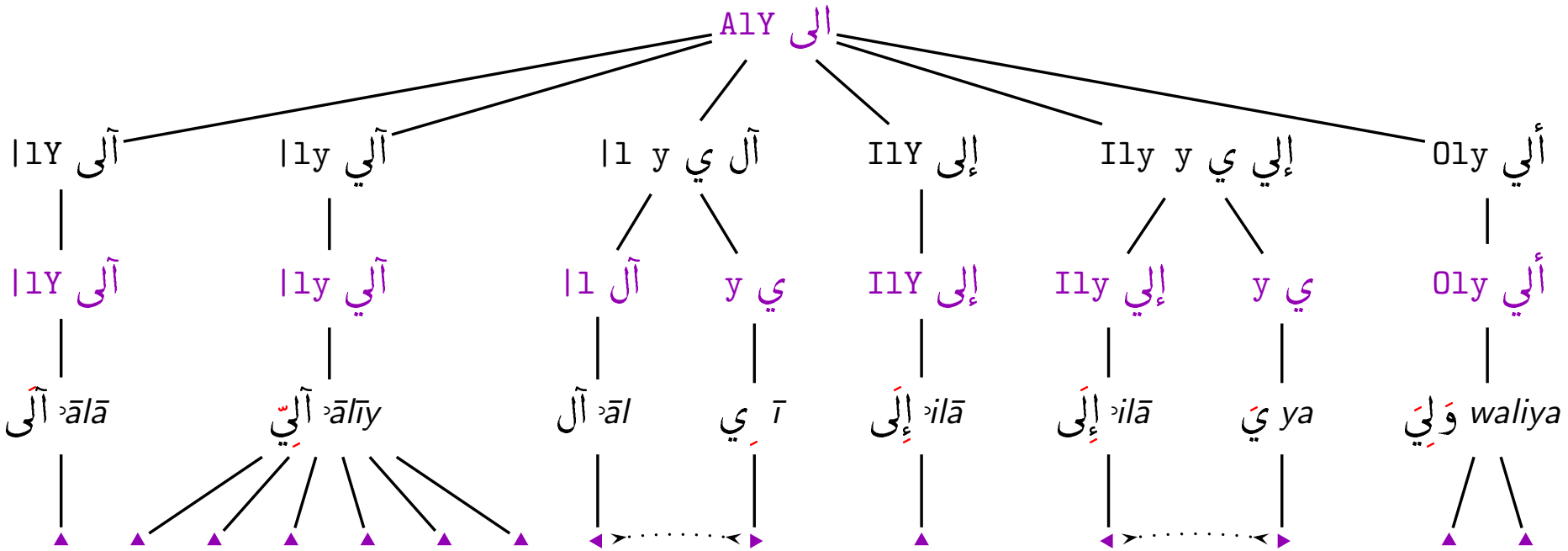
MorphoTrees

. . . organize the analyses into a hierarchy with the string as its root and the full tokens as the leaves, grouped by their lemmas



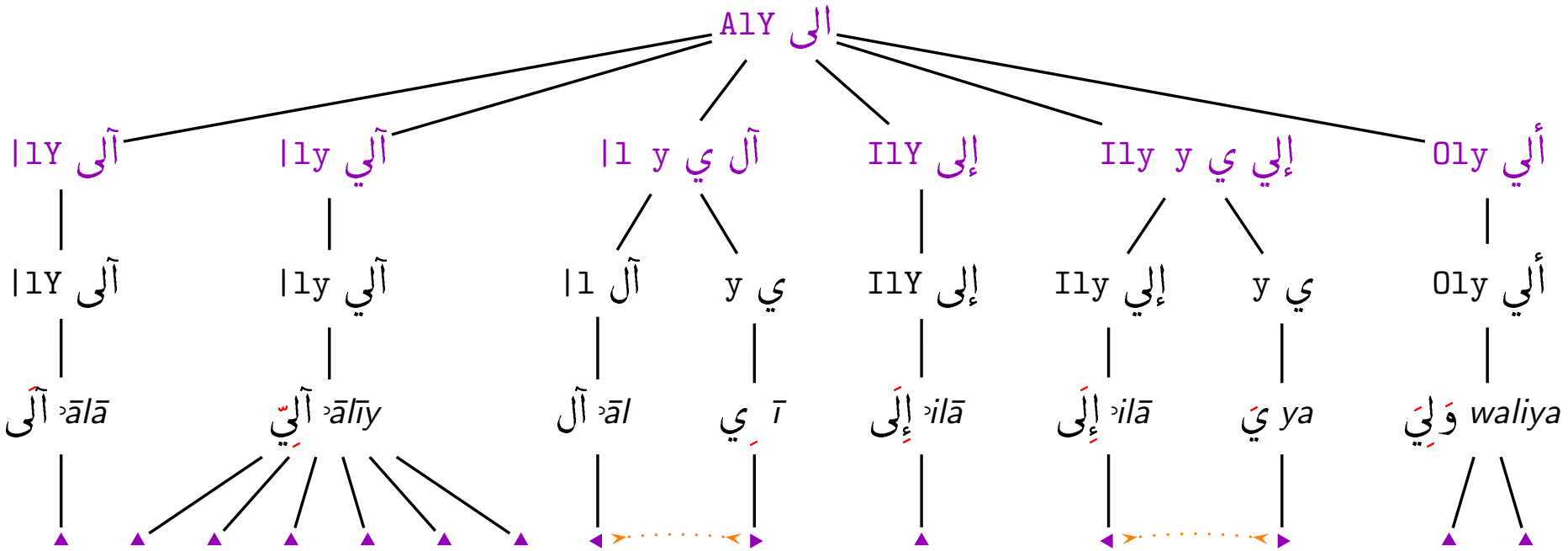
MorphoTrees

. . . organize the analyses into a hierarchy with the string as its root and the full tokens as the leaves, grouped by their lemmas, canonical forms

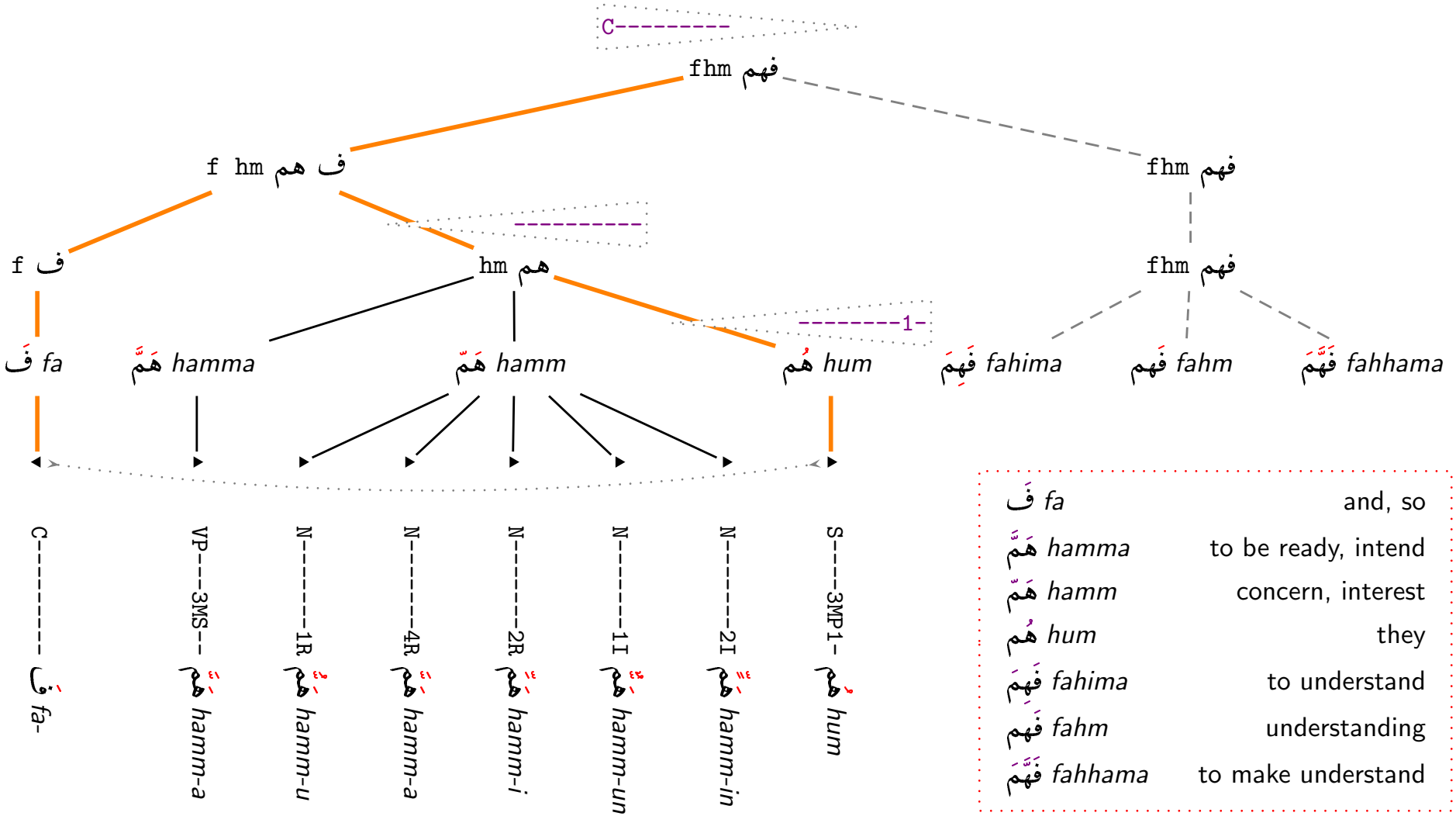


MorphoTrees

. . . organize the analyses into a hierarchy with the string as its root and the full tokens as the leaves, grouped by their lemmas, canonical forms and partitionings of the string into such forms:



Multi-Modal Annotation



فَ *fa*	and, so
هَمَّ *hamma*	to be ready, intend
هَمّ *hamm*	concern, interest
هُم *hum*	they
فَهِمَ *fahima*	to understand
فَهم *fahm*	understanding
فَهَّمَ *fahhama*	to make understand

Outline

1. Introduction
2. Morphological Theory
   - Incremental vs. Realizational
   - Lexical vs. Inferential
   - Functional Arabic Morphology
3. Implementation Design
   - ElixirFM
   - Paradigms, parameters, ...
   - Elixir Lexicon
   - FM Generic
4. Extensions
   - Encode Arabic
   - MorphoTrees
5. References

- Buckwalter, Tim. Buckwalter Arabic Morphological Analyzer 1.0. LDC catalog number LDC2002L49, ISBN 1-58563-257-0. 2002
- Forsberg, Markus and Aarne Ranta. Functional Morphology. Proceedings of ICFP 2004, pages 213–223. ACM Press. 2004
- Lagally, Klaus. ArabTeX: Typesetting Arabic and Hebrew, User Manual Version 4.00. Technical Report 2004/03, Fakultät Informatik, Universität Stuttgart. 2004
- Ljunglöf, Peter. Pure Functional Parsing. An Advanced Tutorial. Licenciate thesis, Göteborg University & Chalmers University of Technology. 2002.
- Smrž, Otakar and Petr Pajas. MorphoTrees of Arabic and Their Annotation in the TrEd Environment. Proceedings of the NEMLAR Conference 2004, pages 38–41. 2004
- Stump, Gregory T. Inflectional Morphology. A Theory of Paradigm Structure. Cambridge Studies in Linguistics. Cambridge University Press. 2001