Grammar Engineering for Language Documentation

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Acknowledgments

- Joint work with: Joshua Crowgey, Michael Goodman, Fei Xia, Sumukh Ghodke, Tim Baldwin, Rebecca Dridan, Robert Schikowski, Balthasar Bickel

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Introduction/Overview

- What is grammar engineering?
- What can grammar engineering do for language documentation?
- Case studies:
  - Lushootseed ([lut], Coast Salish, Salish, North America) morphophonology
  - Wambaya ([wmb], Mirndi, West Barkly, Australia) morphosyntax, treebanks
  - Chintang ([ctn], Kiranti, Tibeto-Burman, Nepal) automated grammar development from IGT

Computational tools for Linguistics

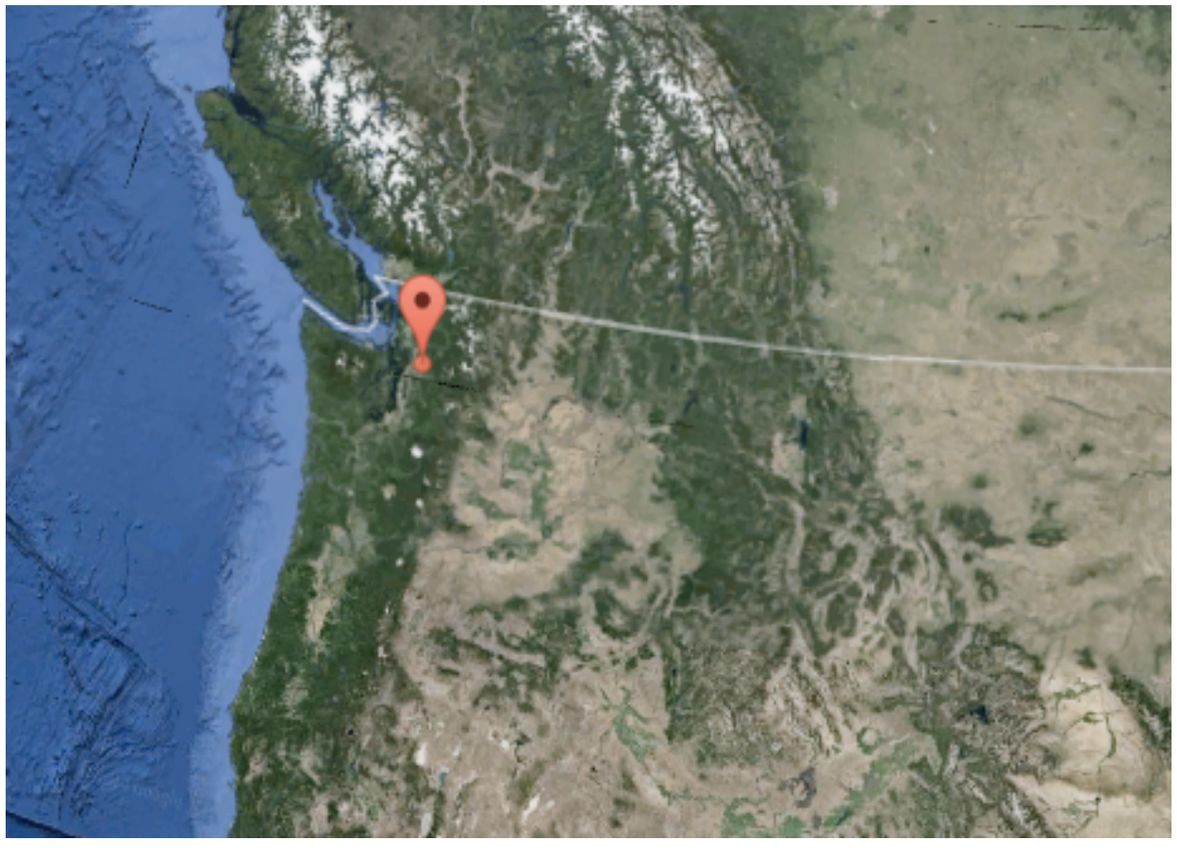
- MS Word
- Text editors
- Excel/spreadsheet software
- Local databases
- Web search
  - For examples
  - For resources (OLAC)
- Concordancer
- Praat
- ELAN
- Shoebox/Toolbox/FieldWorks
- POS tagger
- Morphological analyzer
- Syntactico-semantic parser

Grammar Engineering

- Creating machine-readable implementations of sets of linguistic rules
  - Phonological, morphological, syntactic and/or semantic
- Requires precise definitions of the rules: *formalized*, but not *formalist*
- Requires attention to interactions between the rules
- (Typically) separates declarative grammatical knowledge from procedural algorithms
- Facilitates testing of analyses: against test suites, against naturally occurring corpora
- Contrasts with (and complements): statistical modeling, hand annotation, pen-and-paper formalization

Case study #1: Lushootseed morphology (Work by Joshua Crowgey)

- Lushootseed [lut] is a Coast Salish language spoken in what is now Washington State, USA (Hess 1967)



Lushootseed morphology: Goal

- Create a morphophonological analyzer that relates surface forms (as transcribed) to segmented/regularized forms from Beck and Hess's IGT:

xʷiʔ	gʷəsəsaydubs	ʔə	tiʔəʔ	diʔəʔ
xʷiʔ	gʷə=s=ʔas-hay-dxʷ-b=s	ʔə	tiʔəʔ	diʔəʔ
NEG	SUBJ=NMLZ=STAT-known-CAUS-PASS=POSS.3SG	PREP	PROX	here
It is not known by the children.		Basket Ogress—ʔalatał Martin Sampson		

Lushootseed morhpology: tools

- Foma (Hulden 2009) implementation of xfst and lexc languages (Beesley & Karttunen 2003)

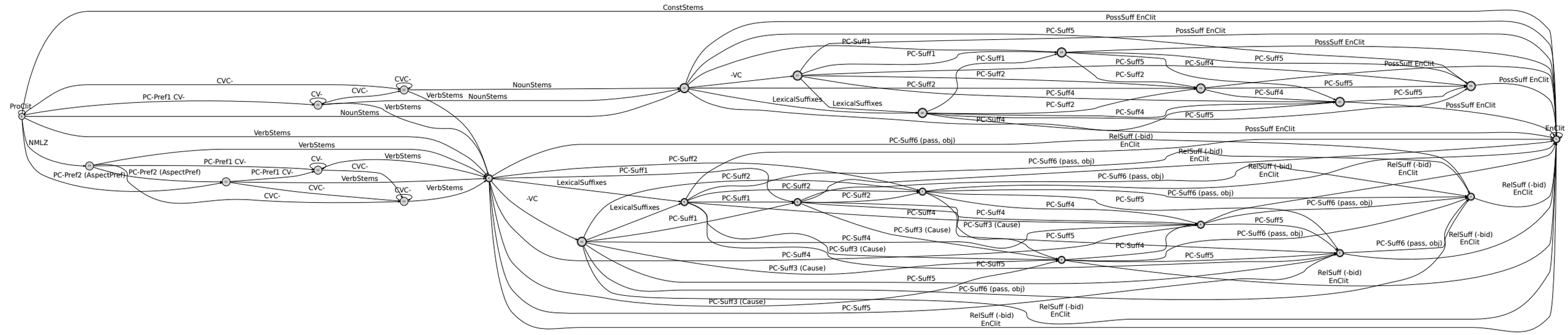
- lexc: morphotactics; define the set of possible underlying forms

- xfst: morphophonology: define the rules that relate underlying forms to surface forms

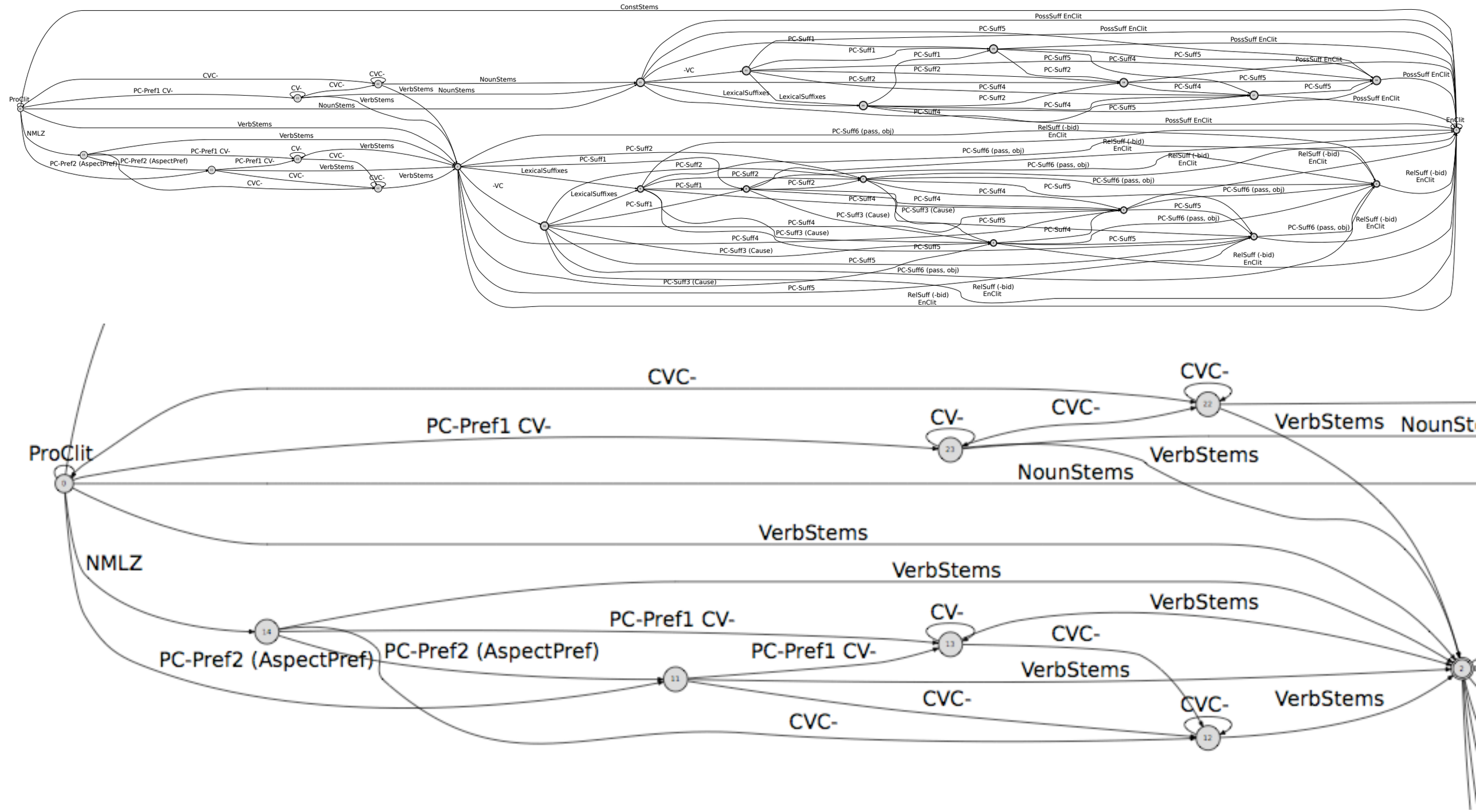
- lexc and xfst both define *finite state transducers* which can be composed into one complex (but efficient) transducer

- Both lexc and xfst use plain text declarations to define grammars, but these can be visualized as graphs

lexc: morphotactics



lexc: morphotactics



lexc: morphotactics

```
define PostRedV RED2* RED1* VerbStems (RED3);
define PostRedN RED2* RED1* NounStems (RED3);
define VPostpref1 (PCpref1) PostRedV (LSuff);
define NPostpref1 (PCpref1) PostRedN (LSuff);
define VPostAspect (AspectPref) VPostpref1;
define NPostsuff1 NPostpref1   (PCsuff1);
define VPostsuff1 VPostAspect (PCsuff1);
define NPostsuff2 NPostsuff1 (PCsuff2);
define VPostsuff2 VPostsuff1 (PCsuff2);
define VPostCausesuff1 VPostsuff2 (Causesuff1);
define VPostsuff4 VPostCausesuff1 (PCsuff4);
define NPostsuff4 NPostsuff2 (PCsuff4);
define VPostsuff5 VPostsuff4 (PCsuff5);
define NPostsuff5 NPostsuff4 (PCsuff5);
define VPostsuff6 VPostsuff5 (PCsuff6) (RelSuff);
define NPostsuff6 NPostsuff5 (poSuff);
define Iword NPostsuff6| (Nmlz) VPostsuff6;
define Word Iword | Const;
regex ProClit* Word EnClit*;
```

xfst: Phonological rules

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- Linguistic rule:

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- Linguistic rule: $u{=}? \rightarrow \varnothing \mid \{t, ɬ, ƛ\} \_\_\_ as\text{-}$

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- xfst source code: `u = ? -> 0 | [t|ƛ|ɬ] _ a s - ;`

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xfst: Phonological rules

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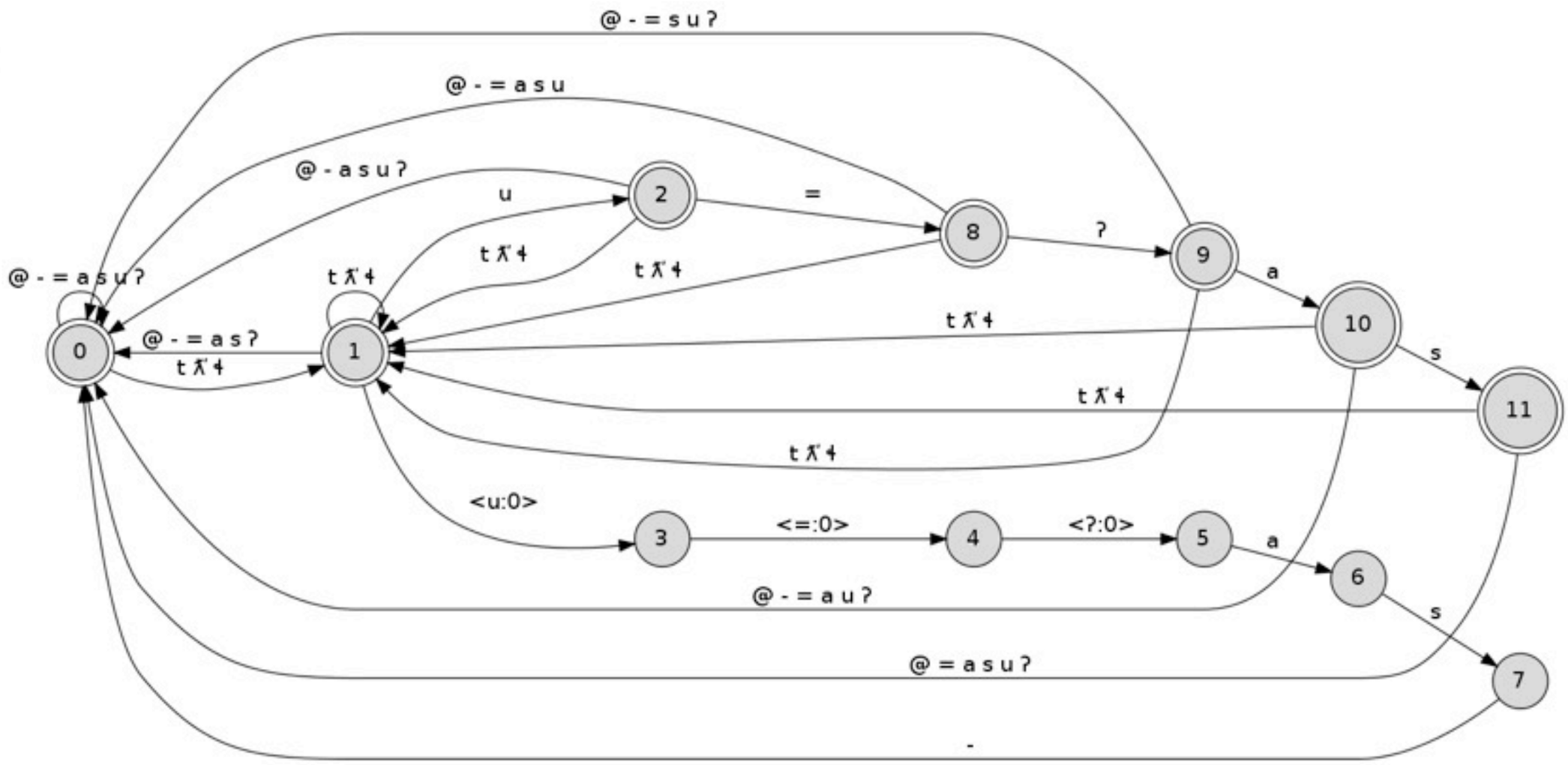

Lushootseed xfst: Development process and evaluation

- Development and evaluation data: Narratives from Beck and Hess (2014) *Tellings from Our Elders: Lushootseed syəyəhub.*

- Work with the narratives one at a time, until the FST has perfect coverage and no overgeneration:
    - for each surface form in the narrative, the FST should produce only legitimate underlying forms, including the one indicated
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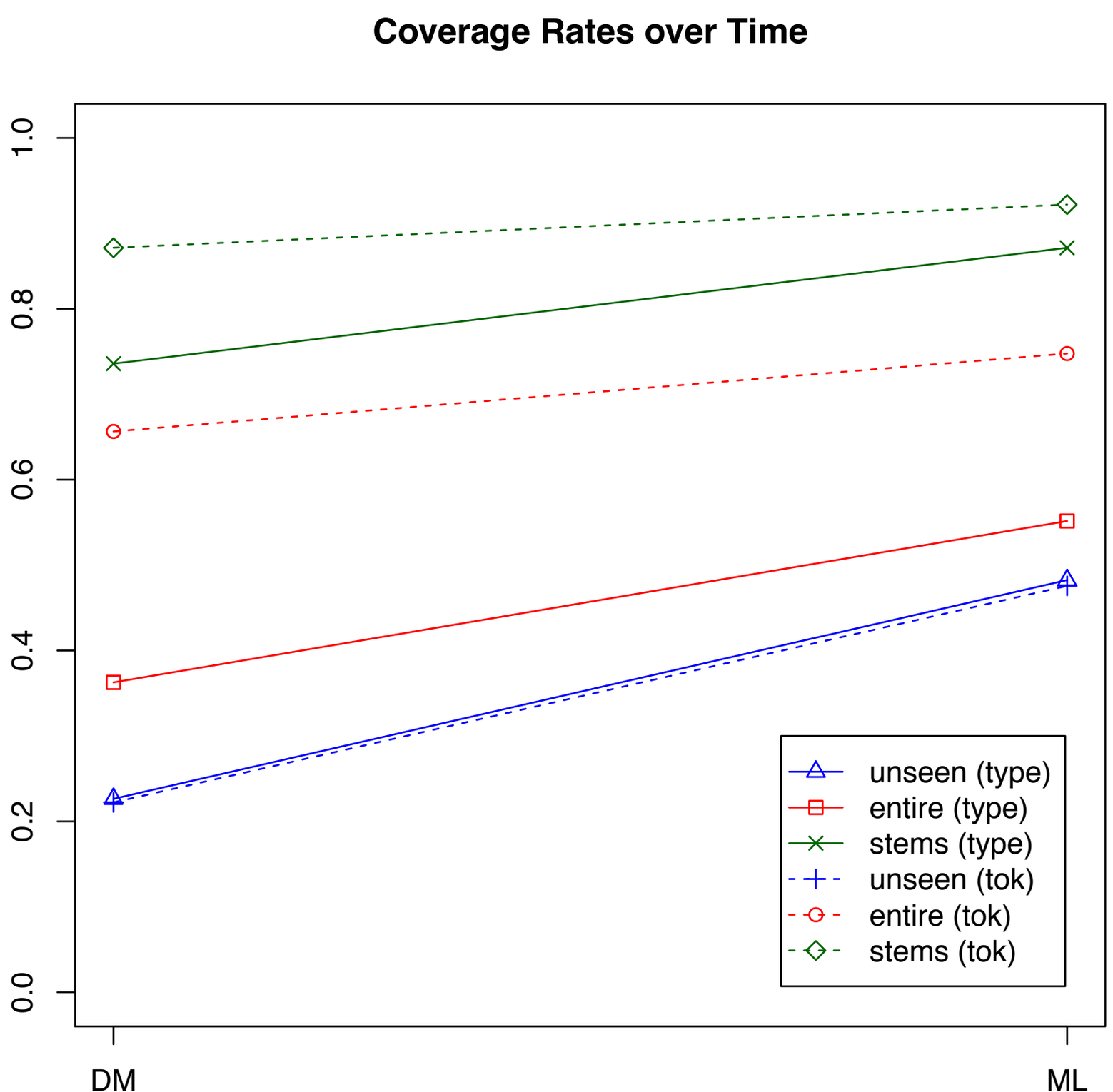
- Evaluate that version of the FST with the next narrative, and then repeat

Lushootseed FST: Evaluation so far



How does this help language documentation?

- Verification of analyses
- Identification of errors in glossing
- (Eventually) more rapid glossing of new texts
- More rapid identification of “new” phenomena in new texts

Case study #2: Wambaya morphosyntax

- Wambaya [wmb] is a Mirndi language spoken in the West Barkly Tablelands region (Northern Territory) of Australia (Nordlinger 1998; Green & Nordlinger 2004)

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Wambaya morphosyntax: Goal

- Create a grammar that analyses all 794 example sentences from Nordlinger 1998, associated each with an appropriate semantic representation

- Minimize ambiguity found by the grammar; especially avoiding unwarranted structures

- Test the grammar for generalizability on held-out text (narrative from Nordlinger 1998)

- Also: Test the applicability and usefulness of the LinGO Grammar Matrix (Bender et al 2002; Drellishak & Bender 2005)

Wambaya example: IGT

(Nordlinger 1998:223)

Wambaya example: IGT

(1) Ngaragana-nguja ngiy-a gujinganjanga-ni jiyawu
grog-PROP.IV.ACC 3.SG.NM.A-PST mother.II.ERG give
ngabulu.
milk.IV.ACC
‘(His) mother gave (him) milk with grog in it.’ [wmb]

(Nordlinger 1998:223)

Wambaya example: IGT

(Nordlinger 1998:223)

Wambaya example: semantic representation

$$\begin{bmatrix}
\text{LTOP} & \text{h1} \\
\text{INDEX} & \text{e2 (prop-or-ques, past)} \\
\text{RELS} & \left\langle \begin{bmatrix} \textbf{_grog_n_rel} \\ \text{LBL} \quad \text{h3} \\ \text{ARG0} \quad \text{x4 (3, iv)} \end{bmatrix}, \begin{bmatrix} \textbf{proprietive_a_rel} \\ \text{LBL} \quad \text{h5} \\ \text{ARG0} \quad \text{e6} \\ \text{ARG1} \quad \text{x7 (3, iv)} \\ \text{ARG2} \quad \text{x4} \end{bmatrix}, \begin{bmatrix} \textbf{_mother_n_rel} \\ \text{LBL} \quad \text{h8} \\ \text{ARG0} \quad \text{x9 (3sg, ii)} \end{bmatrix}, \right. \\
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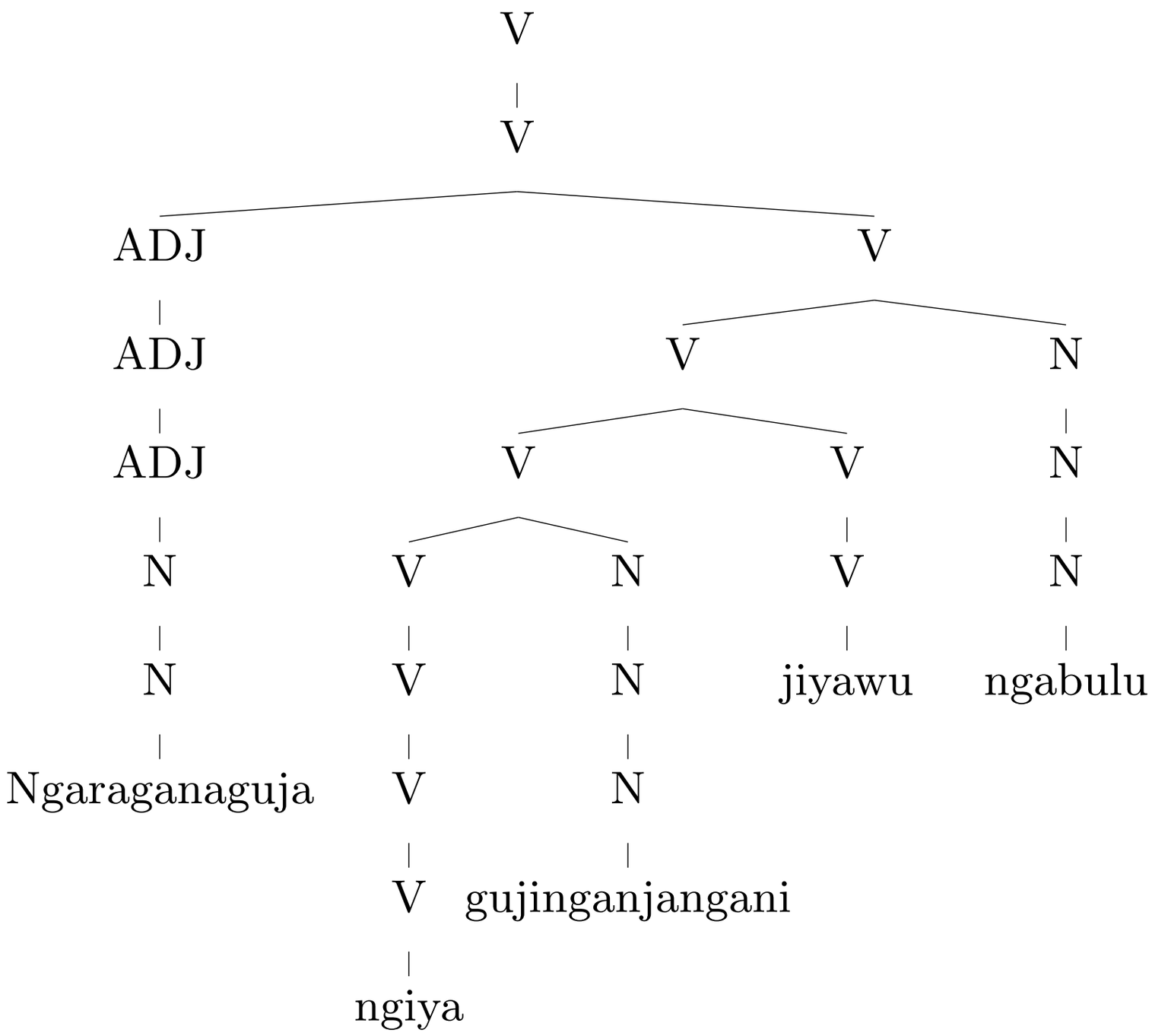
Wambaya example: Syntax tree

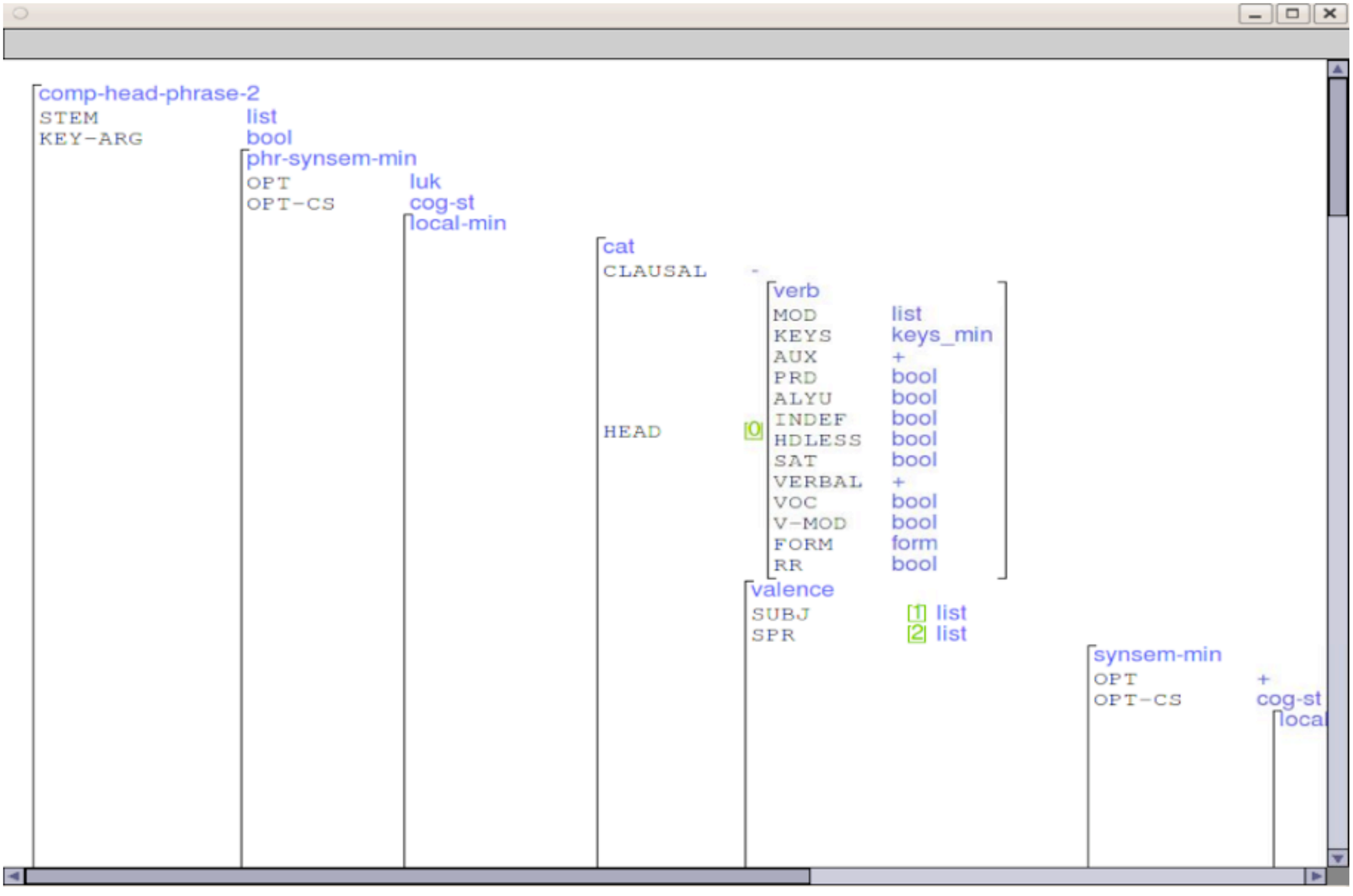


Definition of a grammar rule

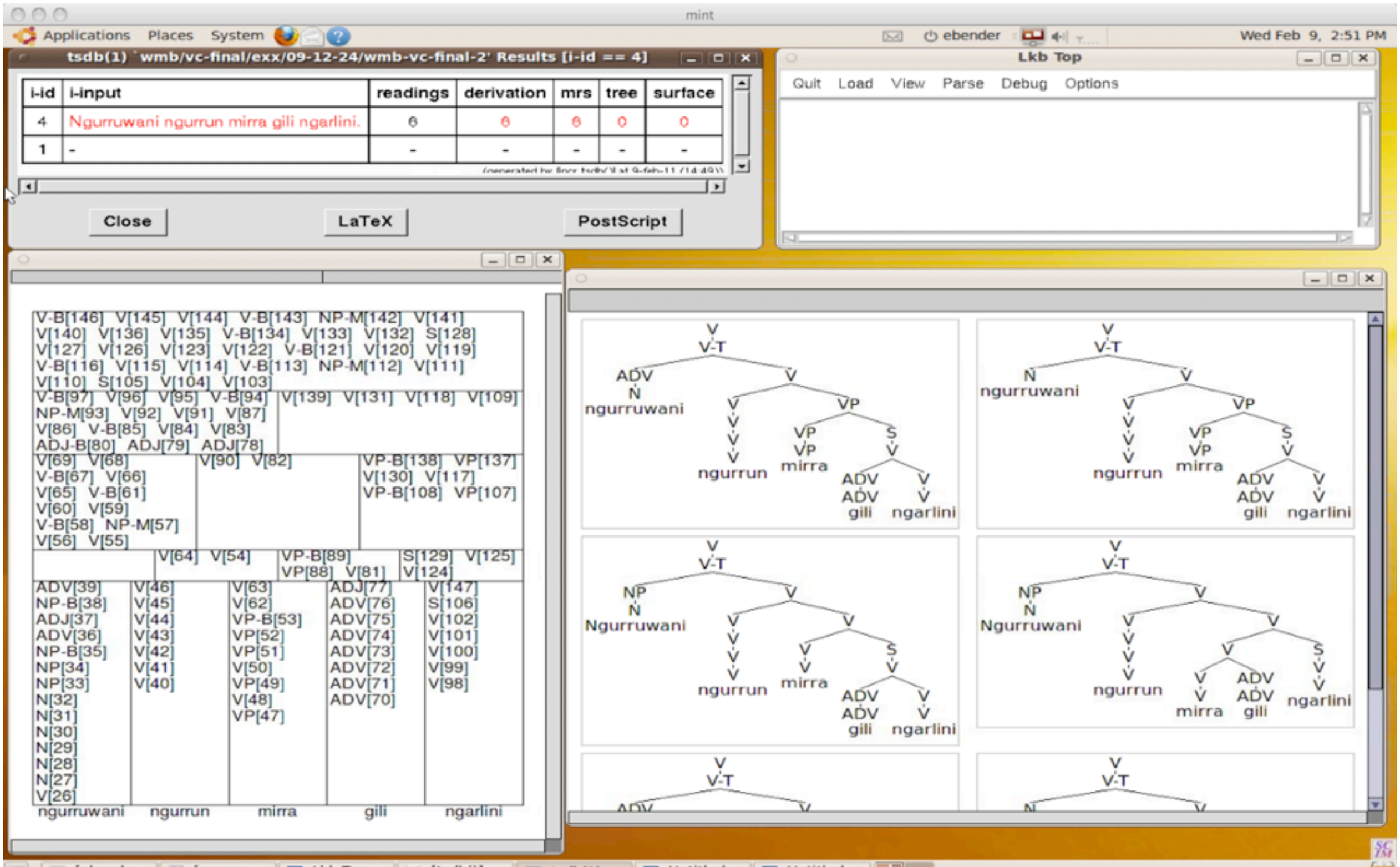
```
wmb-head-2nd-comp-phrase := non-1st-comp-phrase &
  [ SYNSEM.LOCAL.CAT.VAL.COMPS [ FIRST #firstcomp,
                REST [ FIRST [ OPT +,
                               INST +,
                               LOCAL #local,
                               NON-LOCAL #non-local ],
                       REST #othercomps ]],
    HEAD-DTR.SYNSEM.LOCAL.CAT.VAL.COMPS [ FIRST #firstcomp,
                     REST [ FIRST #synsem &
                                  [ INST -,
                                    LOCAL #local,
                                    NON-LOCAL #non-local ],
                            REST #othercomps ]],
    NON-HEAD-DTR.SYNSEM #synsem ].


head-comp-phrase-2 := wmb-head-2nd-comp-phrase & head-arg-phrase.
comp-head-phrase-2 := wmb-head-2nd-comp-phrase & verbal-head-final-
                      head-nexus.
```

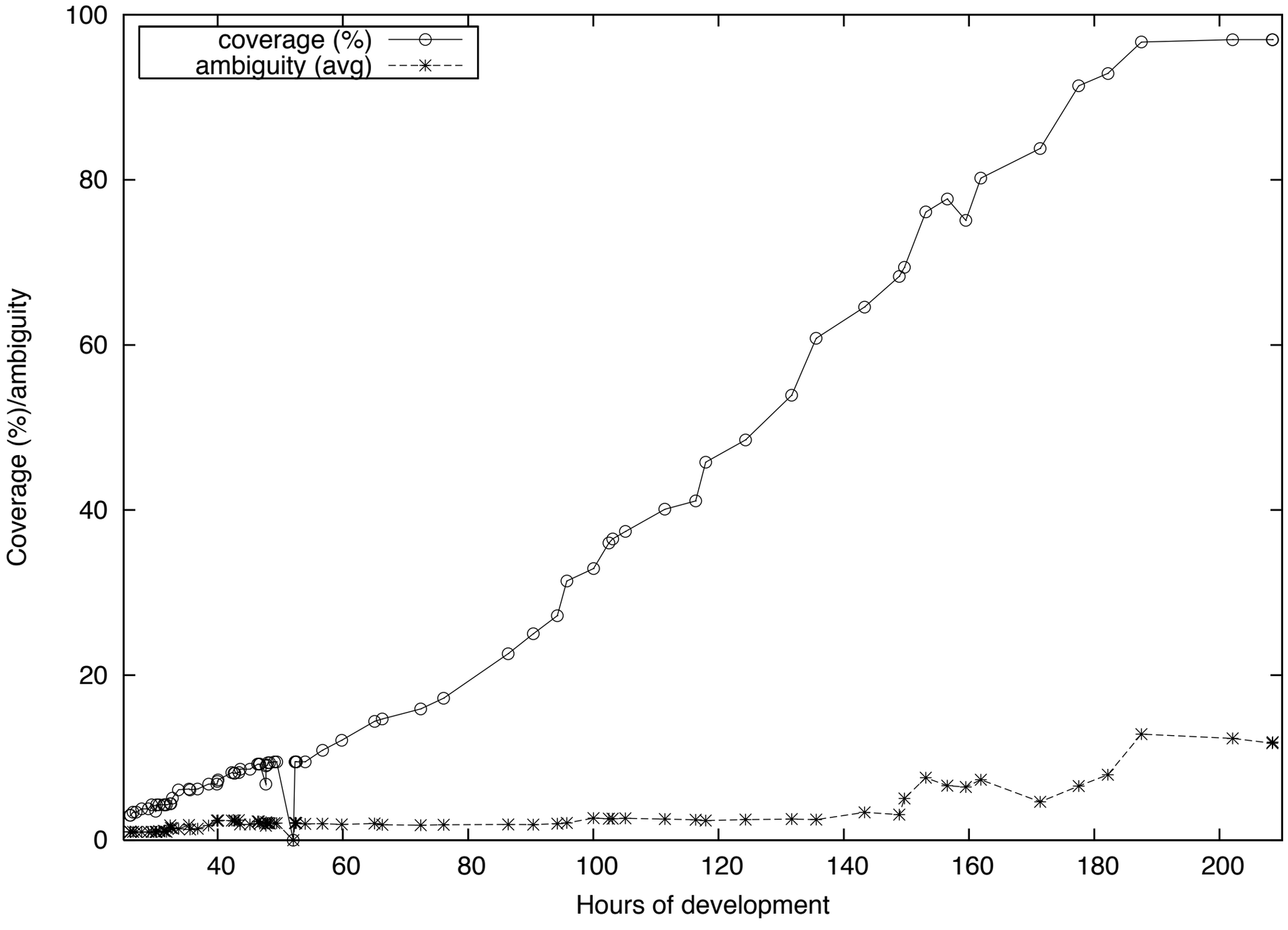
Inspecting a Grammar Rule



A Grammar Rule in Action



Wambaya grammar development



(Bender 2008)

Wambaya grammar evaluation (Bender 2008)

- Held out test data “The two Eaglehawks”
- 72 sentences (orig text: 92, removed 20 seen sentences)
- Run twice: before and after adding lexical entries and adjusting morphophonology only

	correct	parsed incorrect	unparsed	average ambiguity
Existing vocab	50%	8%	42%	10.62
w/added vocab	**76%**	8%	14%	12.56

Wambaya grammar parse selection

- Redwoods parse selection technology (Toutanova et al 2005) with Velldal's (2007) feature set

- Feature selection through 10-fold cross-validation on dev set

- Trained on parsed portion of dev set (732 items; 544 ambiguous)

- Test set results:

	Exact match
Random baseline	18.4%
Trained model	75.0%

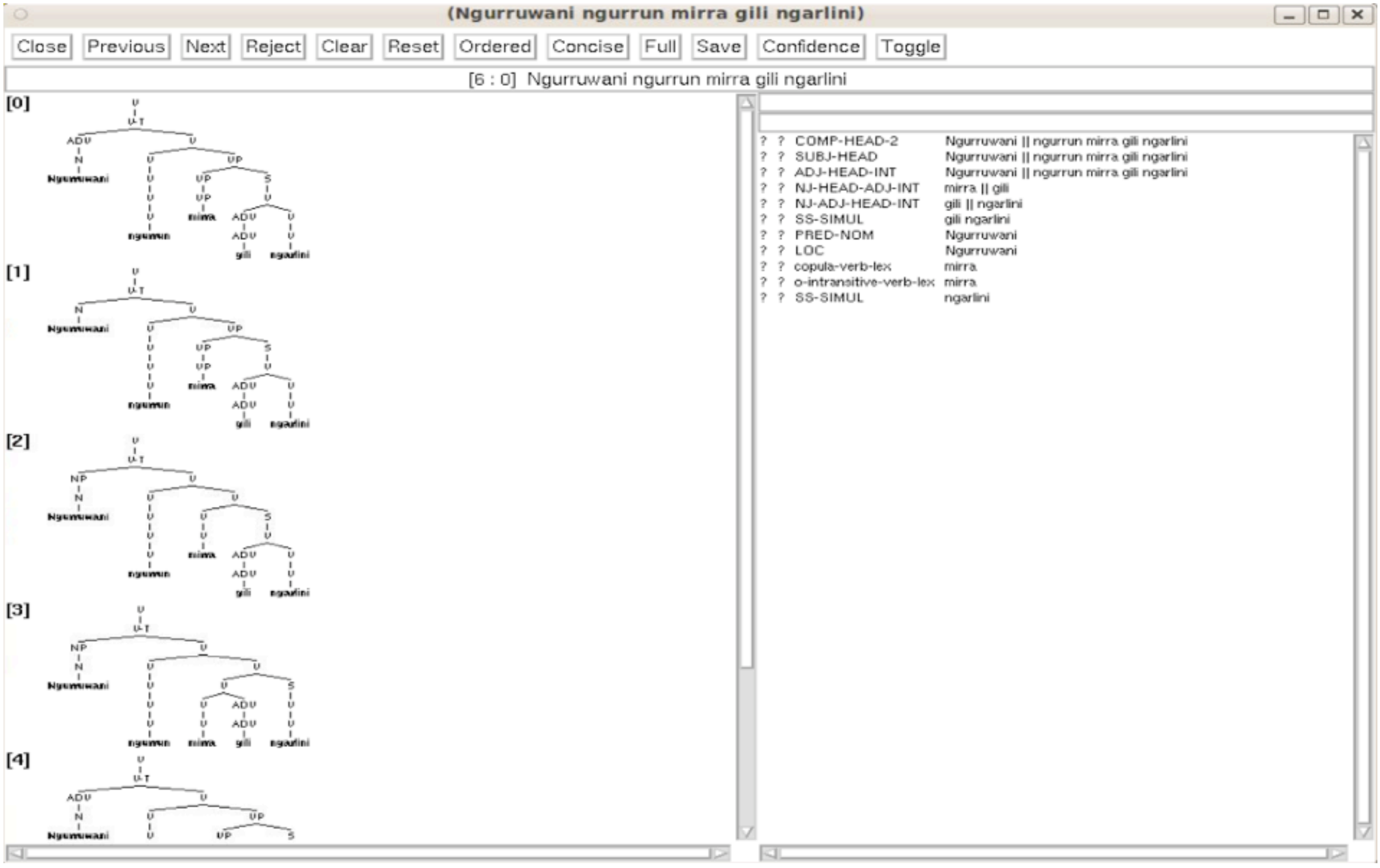
How does this help language documentation?

- Verification of analyses
- Identification of unhandled phenomena
- Processing of new text
- Treebanks

Treebanks

- Old-style (e.g., Penn Treebank, Marcus et al 1993): Develop extensive code book and hand-annotate tree structures for each item.
- New-style (e.g., Redwoods, Oepen et al 2004):
    - Process all items (typically utterances or sentences) with grammar
        - Select intended structure from among those provided by the grammar for each item --- assisted by calculation of discriminants
        - Indicate items with no correct analysis
        - Save decisions to rerun when grammar is updated
- Internally consistent treebanks, which can be updated easily as grammar is improved.

Redwoods Treebanking Tool



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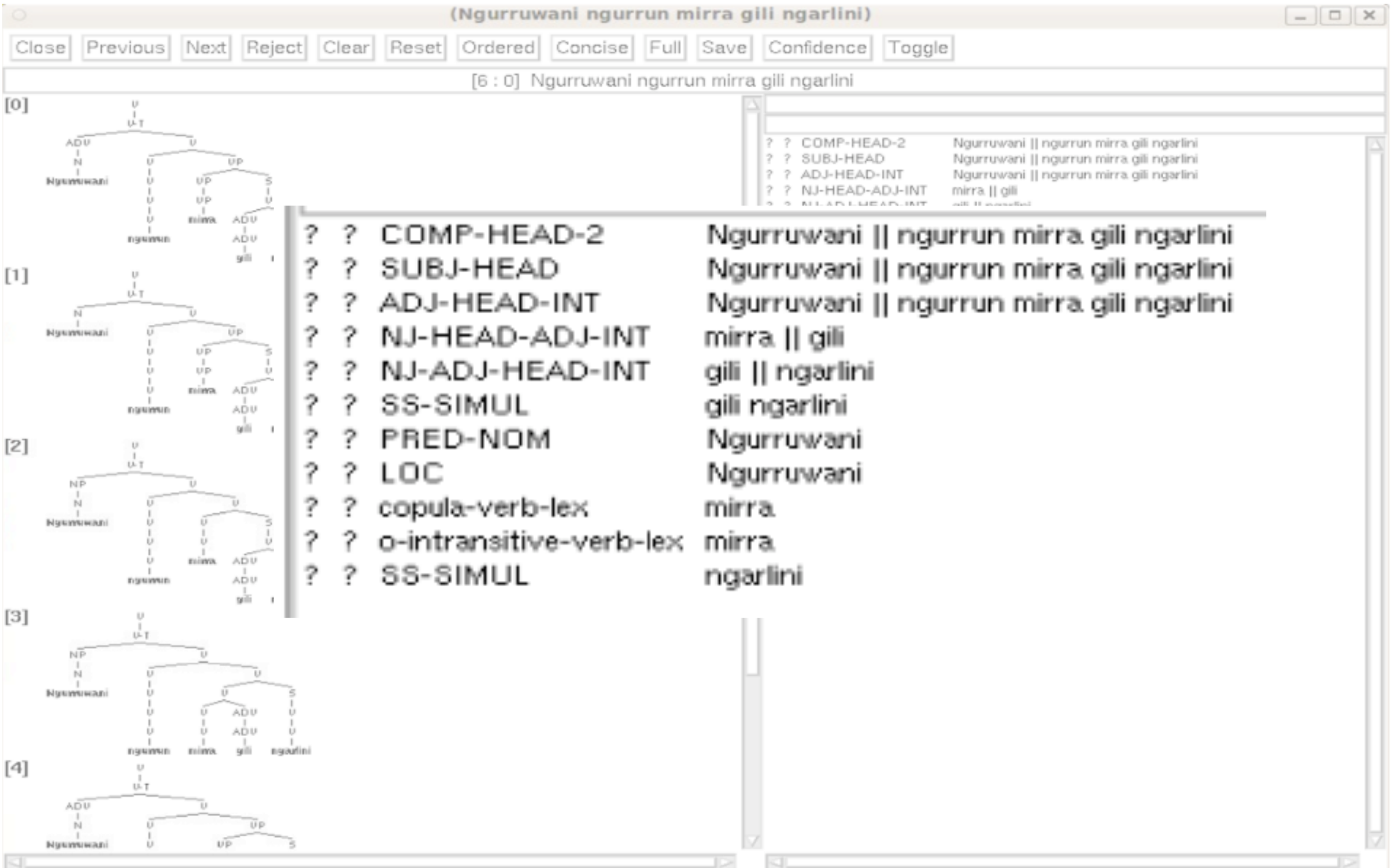


What Are Treebanks Good For?

- In Computational Linguistics:
    - Training parse-ranking models and other applications of machine learning
- In Language Description:
    - a set of searchable annotations
    - more detailed than IGT
    - more easily kept internally consistent than IGT
    - ... by no means a replacement for IGT!

Treebank Search (Ghodke and Bird 2010)

- Fast queries over large treebanks, including both PTB-style and Redwoods-style

- Sample query over Wambaya data:

  - Find sentences with a complement realized only by a modifier:

```
//DECL[//HEAD-COMP-MOD-2 AND NOT //HEAD-COMP-2
AND NOT //COMP-HEAD-2]
```

  - Find sentences with two overt arguments:

```
//DECL[//J-STRICT-TRANS-VERB-LEX AND
//HEAD-COMP-2 AND //HEAD-SUBJ]
```

Case study #3 Partially automated grammar development for Chintang

- Chintang [ctn] is a Kiranti (Tibeto-Burman) language spoken in Nepal (Bickel et al 2009)

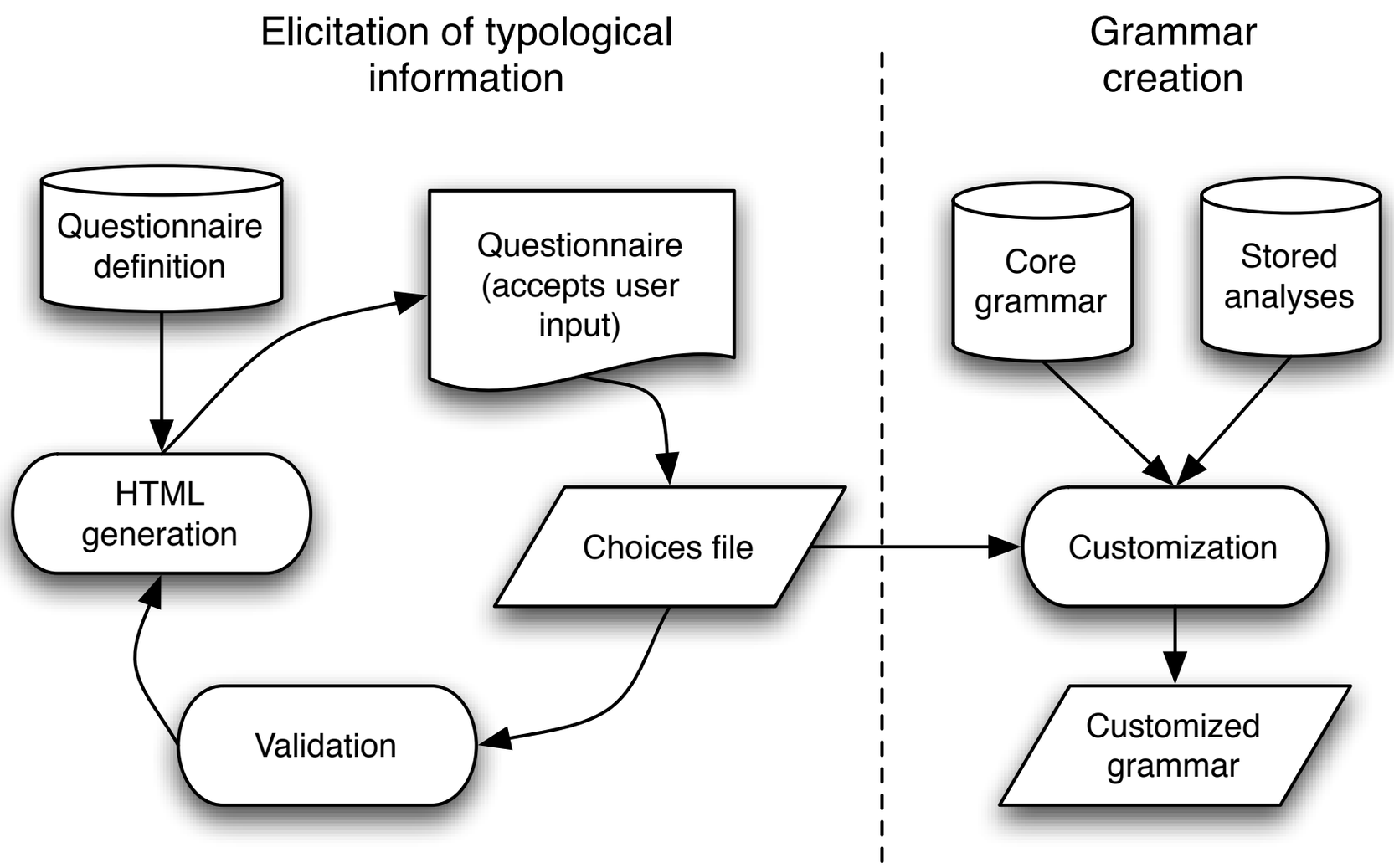
Partially automated grammar engineering: Overview

- LinGO Grammar Matrix, Grammar Matrix customization system
- ToolBox import
- Learning grammar specifications from IGT

The Grammar Matrix

- A repository of implemented analyses, including:
    - A core grammar with analyses of general patterns such as semantic compositionality
    - “Libraries” of analyses of cross-linguistically variable phenomena
    - Accessible via a web-based questionnaire
    - Produces working HPSG (Pollard & Sag 1994) grammars with Minimal Recursion Semantics (Copestake et al 2005), to spec

The Grammar Matrix



The Grammar Matrix:
http://www.delph-in.net/matrix

- * General Information
- * Word Order
- Number
- * Person
- Gender
- * Case
- Direct-inverse
- Tense, Aspect and Mood
- Other Features
- Sentential Negation
- Coordination
- Matrix Yes/No Questions
- Information Structure
- Argument Optionality
- ? Lexicon
- Morphology
- Import Toolbox Lexicon
- Test Sentences
- Test by Generation Options

Archive type: (•) .tar.gz ( ) .zip

Create Grammar | Test by Generation

View Choices File (right-click to download)

Upload Choices File: | Choose File | No file chosen

Implementation of Chintang Morphology (Bender et al 2012)

- Chintang boasts a fairly complex morphological system:

4 prefix slots + STEM + 12 suffix slots

- But then:
  - Prefix slots can freely reorder (Bickel et al 2007)
  - Prefix slots include one for ‘bipartite stems’
  - A single word can contain up to four verb roots, each hosting prefixes and suffixes
  - Complex morphophonology

Implementation of Chintang Morphology

- Focus on morpheme-segmented line of IGT, abstracting away from morphophonology

- 160 verbal lexical rules grouped into 54 position classes
    - Including duplicated prefix/suffix rules to handle the multi-root verbs

- 24 nominal lexical rules grouped into 6 position classes

- Elsewhere in the choices file, define values for case, tense/aspect/mood, person/number/gender

    - => Partial modeling of the syntactico-semantic effects of 131/160 rules

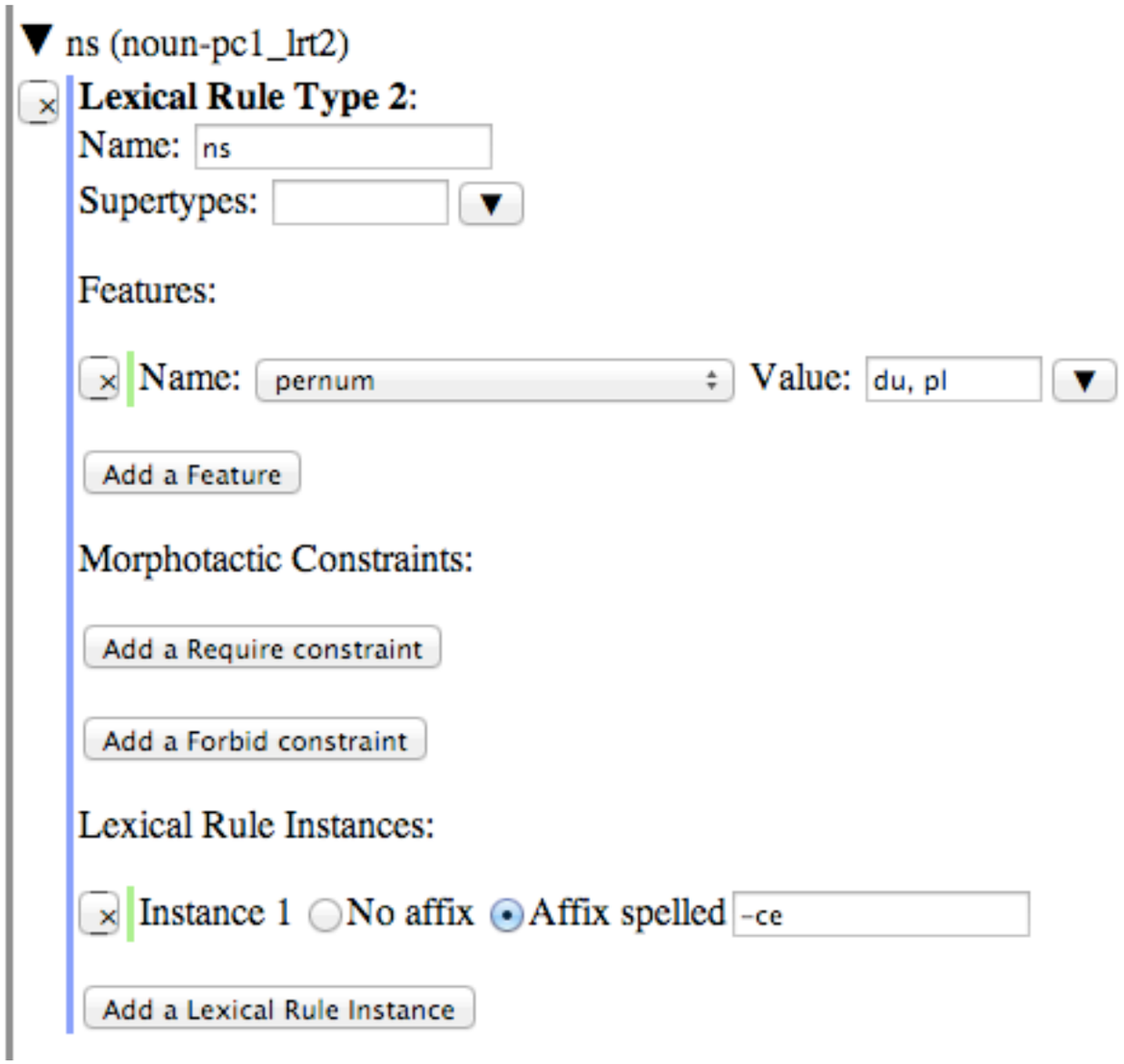
Chintang example

- Example test item (target is second line):

thupro	wassace	uyuwakte	pho
thupro	wassak-ce	u-yuŋ-a-yakt-e	pho
many	bird-NS	3NSS/A-live-PST-IPFV-IND.PST	REP

‘There lived many birds.’ [ctn] story_rabbit.005

Chintang morphosyntax: Sample noun lex rule



Chintang morphosyntax: Verb position classes

Verb Inflection

- neg-prefix (verb-pc1)
- 1st-person-object (verb-pc2)
- non-1st-subj (verb-pc3)
- act-ptcp (verb-pc4)
- suffix1 (verb-pc5)
- suffix2 (verb-pc6)
- suffix3 (verb-pc7)
- suffix4 (verb-pc8)
- suffix5 (verb-pc9)
- suffix6 (verb-pc10)
- suffix7 (verb-pc11)
- suffix8 (verb-pc12)
- suffix9 (verb-pc13)
- suffix10 (verb-pc14)
- suffix11 (verb-pc15)
- suffix12 (verb-pc16)
- suffix13 (verb-pc17)
- suffix14 (verb-pc18)
- suffix15 (verb-pc19)
- ?bps-prefix (verb-pc20)
- v2 (verb-pc21)
- suffix1-final (verb-pc22)
- suffix2-final (verb-pc23)
- suffix3-final (verb-pc24)
- suffix4-final (verb-pc25)
- suffix5-final (verb-pc26)
- suffix6-final (verb-pc27)
- suffix7-final (verb-pc28)
- suffix8-final (verb-pc29)
- suffix9-final (verb-pc30)
- suffix10-final (verb-pc31)
- suffix1-v2 (verb-pc32)
- suffix2-v2 (verb-pc33)
- suffix3-v2 (verb-pc34)
- suffix4-v2 (verb-pc35)
- suffix5-v2 (verb-pc36)
- suffix6-v2 (verb-pc37)
- suffix7-v2 (verb-pc38)
- suffix8-v2 (verb-pc39)
- suffix9-v2 (verb-pc40)
- suffix10-v2 (verb-pc41)
- v3 (verb-pc42)
- ntvz (verb-pc43)
- endoclitics (verb-pc44)
- act-ptcp-v2 (verb-pc45)
- non-1st-subj-v2 (verb-pc46)
- 1st-person-object-v2 (verb-pc47)
- neg-prefix-v2 (verb-pc48)
- endoclitics-v2 (verb-pc49)
- act-ptcp-v3 (verb-pc50)
- non-1st-subj-v3 (verb-pc51)
- 1st-person-object-v3 (verb-pc52)
- neg-prefix-v3 (verb-pc53)
- endoclitics-v3 (verb-pc54)

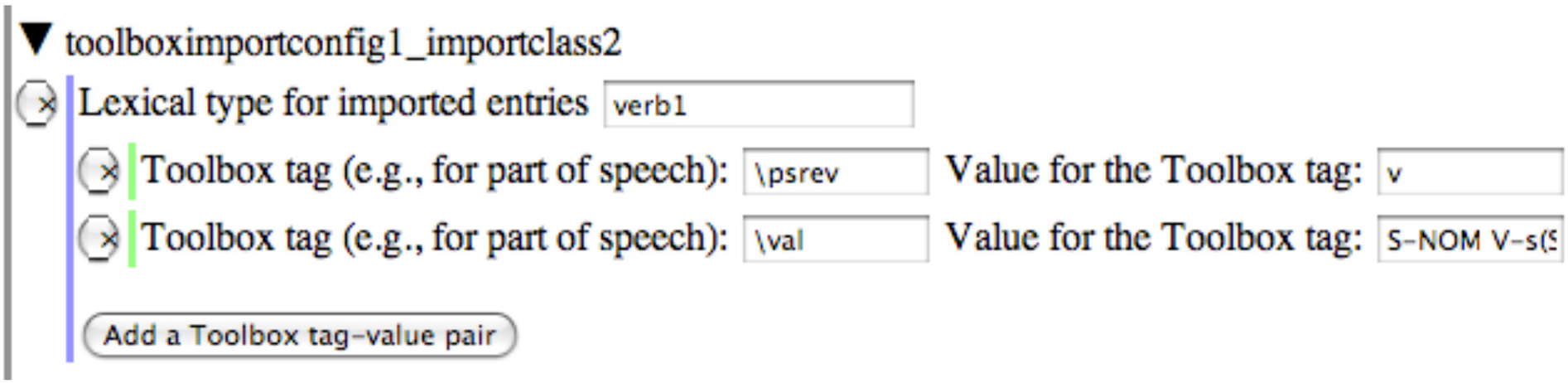
Reusing resources: Importing from Toolbox lexicon

- CPDP has a large Toolbox lexicon for Chintang
- stem forms
- alternate forms
- coarse-grained POS tag (drawn from a set of 30)
- syntactic valence (case for each argument)
- semantic valence (semantic role for each argument)
    - NB: valence information stored as a string

Chintang Toolbox lexicon

```
\lex kond
\id 179
\psrev v
\val A-ERG P-NOM V-a(A).o(P)
\ge search; look.for
\dt 22/Feb/2011
```

Import from Toolbox to Grammar Matrix



- verb1 is target type (defined as intransitive verb with normal case frame)
- \psrev is POS field; value here is ‘v’
- \val is valence field; value here is ‘S-NOM V-s(S)’
- ‘Add a Toolbox tag-value pair’ button makes unlimited tag-value constraints available
- Nothing in this set-up is Chintang-specific

Final import types: entries imported

- Common nouns: 4,741
- Native Chintang intransitive verbs: 282
- Borrowed Nepali intransitive verbs: 142
- Native Chintang transitive verbs: 285
- Borrowed Nepali transitive verbs: 190
- Total: 5,640/9,034 (62%) of all entries; 899/1,440 (62%) of the verbs
- Most frequent unimported POS tags: adverbs (866), adjectives (515), interjections (377), affixes (286)

Grammar Matrix lexical entry: source code

```
khad := trans-verb-lex &
   [ STEM < "kond" >,
     SYNSEM.LKEYS.KEYREL.PRED "_search;look.for_v_rel" ].

trans-verb-lex := erg-abs-transitive-verb-lex.

erg-abs-transitive-verb-lex := transitive-verb-lex &
   [ ARG-ST < [ LOCAL.CAT.HEAD noun &
                               [ CASE erg ] ],
              [ LOCAL.CAT.HEAD noun &
                               [ CASE abs ] ] > ].
```

$$
\begin{bmatrix}
\textit{trans-verb-lex} & & & & & & & & & & \\
\text{STEM} & \langle\ \textit{kond}\ \rangle & & & & & & & & & \\
\text{SYNSEM} & \begin{bmatrix}
\textit{lex-synsem} & & & & & & & & & & \\
\text{CAT} & \begin{bmatrix}
\textit{cat} & & & & & & & & & & \\
\text{HEAD} & \begin{bmatrix} \textit{verb} \\ \text{AUX} & - \\ \text{FORM} & \textit{form} \end{bmatrix} & & & & & & & & & \\
\text{VAL} & \begin{bmatrix}
\text{SUBJ} & \left\langle \boxed{0} \begin{bmatrix} \text{CAT} & \begin{bmatrix} \text{HEAD} & \begin{bmatrix} \textit{noun} \\ \text{CASE} & \textit{erg} \end{bmatrix} \end{bmatrix} \\ \text{CONT} & \begin{bmatrix} \text{INDEX} & \boxed{1} \end{bmatrix} \end{bmatrix} \right\rangle \\
\text{COMPS} & \left\langle \boxed{8} \begin{bmatrix} \text{CAT} & \begin{bmatrix} \text{HEAD} & \begin{bmatrix} \textit{noun} \\ \text{CASE} & \textit{nom} \end{bmatrix} \end{bmatrix} \\ \text{CONT} & \begin{bmatrix} \text{INDEX} & \boxed{9} \end{bmatrix} \end{bmatrix} \right\rangle
\end{bmatrix} \\
\text{CONT} & \begin{bmatrix}
\text{INDEX} & \boxed{14} \begin{bmatrix} \textit{event} \\ \text{TENSE} & \textit{tense} \\ \text{ASPECT} & \textit{aspect} \\ \text{MOOD} & \textit{mood} \end{bmatrix} \\
\text{RELS} & \left\langle \begin{bmatrix} \textit{arg12-ev-relation} \\ \text{PRED} & \textit{\_search;look.for\_v\_rel} \\ \text{ARG0} & \boxed{14} \\ \text{ARG1} & \boxed{1} \\ \text{ARG2} & \boxed{9} \end{bmatrix} \right\rangle
\end{bmatrix}
\end{bmatrix}
\end{bmatrix} \\
\text{INFLECTED} & \begin{bmatrix} \text{TRANSITIVE-VERB-FLAG} & + \end{bmatrix} & & & & & & & & & &
\end{bmatrix}
$$

Test data narratives

- 1,453 total word tokens
- Varied genres: biographical monologue, Pear Story (Chafe 1980), traditional story, recipe
- Example test item (target is second line):

thupro	wassace	uyuwakte	pho
thupro	wassak-ce	u-yuŋ-a-yakt-e	pho
many	bird-NS	3NSS/A-live-PST-IPFV-IND.PST	REP

'There lived many birds.' [ctn] story_rabbit.005

Lexical coverage results

Narrative	total		# analyzed		% analyzed		avg ambiguity	
	type	token	type	token	type	token	type	token
Durga_Exp	206	489	120	265	58	54	1.24	1.14
choku_yakkheng	152	331	89	184	59	56	1.26	1.20
pear_6-1	206	433	105	203	56	51	1.20	1.62
story_rabbit	85	200	43	69	51	35	1.37	1.23
All	568	1453	324	721	57	50	1.40	1.27

The AGGREGATION Project: Learning grammars from IGT?

- IGT contains a lot of linguistic analysis

jutta khet-a-ŋ-e
shoe buy-PST-1SS/P-IND.PST
'I bought a pair of shoes.' [ctn]

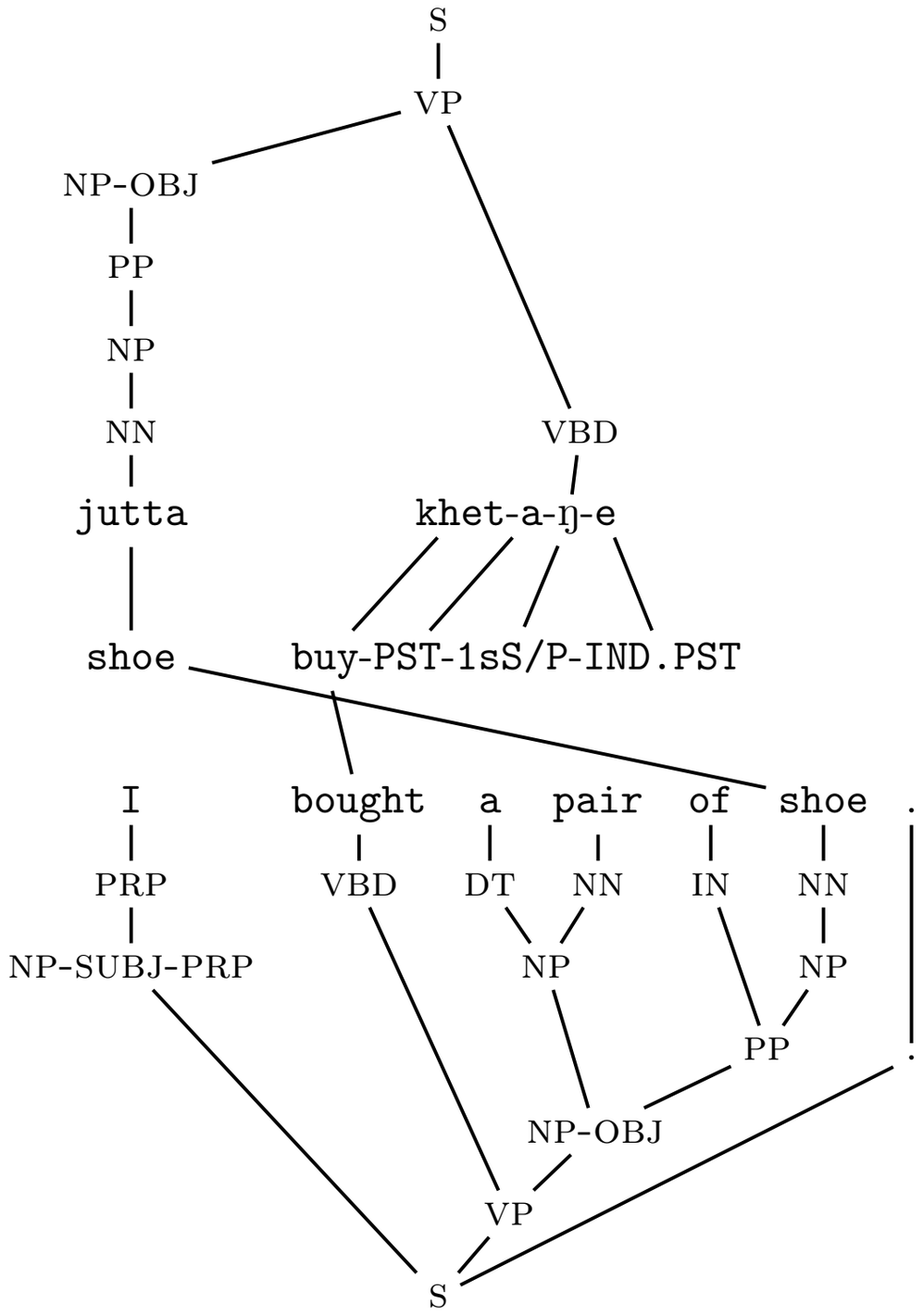
- The Grammar Matrix stores implemented analyses

- Can we write algorithms that extract information from IGT and distill it to a form that the Grammar Matrix can use?

(Bender et al 2013, 2014)

Extracting information from IGT

- Process English translation with parser for English
- Align translation to gloss, and gloss to source
- Project tree structure from English to source language (Xia & Lewis 2007)



Automatic creation of choices files

- Specification of word order and overall case system (Bender et al 2013)
- Specification of case frames for specific verbs (Bender et al 2014)
- Specification of case values for specific nouns (Bender et al 2014)
- Automatic extraction of stems and morphological rules (Wax 2014)

Extracted choices files

Choices file	# verb entries	# noun entries	# det entries
ORACLE	900	4751	0
BASELINE	3005	1719	240
FF-AUTO-NONE	3005	1719	240
FF-DEFAULT-GRAM	739	1724	240
FF-AUTO-GRAM	739	1724	240
MOM-DEFAULT-NONE	1177	1719	240
MOM-AUTO-NONE	1177	1719	240

Choices file	# verb affixes	# noun affixes
ORACLE	160	24
BASELINE	0	0
FF-AUTO-NONE	0	0
FF-DEFAULT-GRAM	0	0
FF-AUTO-GRAM	0	0
MOM-DEFAULT-NONE	262	0
MOM-AUTO-NONE	262	0

Evaluation of customized grammars

choices file	lexical coverage (%)		items parsed (%)		items correct (%)		average readings
	Training Data ($N = 8863$)						
ORACLE	1165	(13)	174	(3.5)	132	(1.5)	2.17
BASELINE	1276	(14)	398	(7.9)	216	(2.4)	8.30
FF-AUTO-NONE	1276	(14)	354	(4.0)	196	(2.2)	7.12
FF-DEFAULT-GRAM	911	(10)	126	(1.4)	84	(0.9)	4.08
FF-AUTO-GRAM	911	(10)	120	(1.4)	82	(0.9)	3.84
MOM-DEFAULT-NONE	1102	(12)	814	(9.2)	52	(0.6)	6.04
MOM-AUTO-NONE	1102	(12)	753	(8.5)	49	(0.6)	4.20
	Test Data ($N = 930$)						
ORACLE	116	(12.5)	20	(2.2)	10	(1.1)	1.35
BASELINE	41	(4.4)	15	(1.6)	8	(0.9)	28.87
FF-AUTO-NONE	41	(4.4)	13	(1.4)	7	(0.8)	13.92
FF-DEFAULT-GRAM	18	(1.9)	4	(0.4)	2	(0.2)	5.00
FF-AUTO-GRAM	18	(1.9)	4	(0.4)	2	(0.2)	5.00
MOM-DEFAULT-NONE	39	(4.2)	16	(1.7)	3	(0.3)	10.81
MOM-AUTO-NONE	39	(4.2)	10	(1.1)	3	(0.3)	9.20

How does this help language description?

- Rapid creation of precision grammars
    - => More quickly get to benefits identified earlier
- Maximize re-use of resources already created

Overview

- What is grammar engineering?
- What can grammar engineering do for language documentation?
- Case studies:
  - Lushootseed ([lut], Coast Salish, Salish, North America) morphophonology
  - Wambaya ([wmb], Mirndi, West Barkly, Australia) morphosyntax, treebanks
  - Chintang ([ctn], Kiranti, Tibeto-Burman, Nepal) automated grammar development from IGT

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