Generalizing patterns in Instrumented Item-and-Pattern Morphology

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Introduction: Item and Pattern Morphology

- Morphology is modeled directly in terms of surface alternations
- Term due to Blevins (forthcoming); preferable to the ambiguous 'Word and Paradigm'
- Consider French adjective paradigms:

Lexeme	M.SG	M.PL	F.SG	F.PL
LOCAL	lokal	loko	lokal	lokal
BANAL	banal	banal	banal	banal
GAI	gɛ	gɛ	gɛ	gɛ
LAID	lɛ	lɛ	lɛd	lɛd
RAIDE	ʁɛd	ʁɛd	ʁɛd	ʁɛd
PRÊT	pʁɛ	pʁɛ	pʁɛt	pʁɛ
NET	nɛt	nɛt	nɛt	nɛt
NIAIS	njɛ	njɛ	njɛz	njɛz
OBÈSE	obɛz	obɛz	obɛz	obɛz
ÉPAIS	epɛ	epɛ	epɛs	epɛs
EXPRESS	ɛkspʁɛs	ɛkspʁɛs	ɛkspʁɛs	ɛkspʁɛs

- Surface alternations between forms lead to opacities that are problematic for speakers.
- Classical phonological and morphological analyses do not model these opacities, but try to reduce them.

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- M.SG $\sim$ M.PL: two patterns
  1. $Xal \sim Xo$
  2. $X \sim X$
- This leads to uncertainty, as some M.SG in *-al* do not alternate.
- Thinking about morphemes (or processes) does not help address that uncertainty.

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- M.SG ∼ F.SG: numerous patterns
  1. $X \sim X$
  2. $X \sim Xd$
  3. $X \sim Xt$
  4. $X \sim Xz$
  5. $X \sim Xs$
- This leads to more uncertainty.
  - F to M: unpredictable C drop
  - M to F: unpredictable epenthesis
- Thinking about underlying representations does not help address that uncertainty.

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EXPRESS	ɛkspʁɛs	ɛkspʁɛs	ɛkspʁɛs	ɛkspʁɛs

- Item and Pattern Morphology focuses on modeling alternations themselves.
- We can then quantify how harmful opacity is.
- We do not try to infer abstract representations from which to reconstruct the surface forms.

☞ Not unfeasible or uninteresting, but a different enterprise.

Introduction: *Intrumented* IPa

- Instrumented Item and Pattern Morphology (IIPa)
  1. Based on large, machine-readable datasets (corpora or lexica)
     (e.g. Albright, 2002)
     - ★ Evaluating the prevalence of morphological phenomena is crucial
     - ★ Enough data to see correct generalizations despite Zipfian distributions
  2. Fully implemented analytic strategies
     (e.g. Albright, 2002; Stump and Finkel, 2013)
     - ★ Systematization of descriptive practice
     - ★ Cross-linguistic applicability
  3. Focus on quantitative methods
     (Ackerman, Blevins, and Malouf, 2009; Ackerman and Malouf, 2013)
     - ★ Gradience of morphological complexity
- See among others Bonami and Boyé (2014), Bonami and Luís (2014), Sims (2015), and Malouf (2016)

Introduction, 3

- This talk focuses on the notion of a pattern of alternation that is at the heart of current work in Instrumented IPa.
- The plan:
  1. Present key analytic techniques in Instrumented IPa
  2. Evaluate the importance of the choice of a particular classification of alternations
  3. Outline a new algorithm
  4. Present preliminary results on Zenzonpetec Chatino (Oto-Manguean)

Results in Instrumented Item and Pattern Morphology

Results in Intrumented IPa

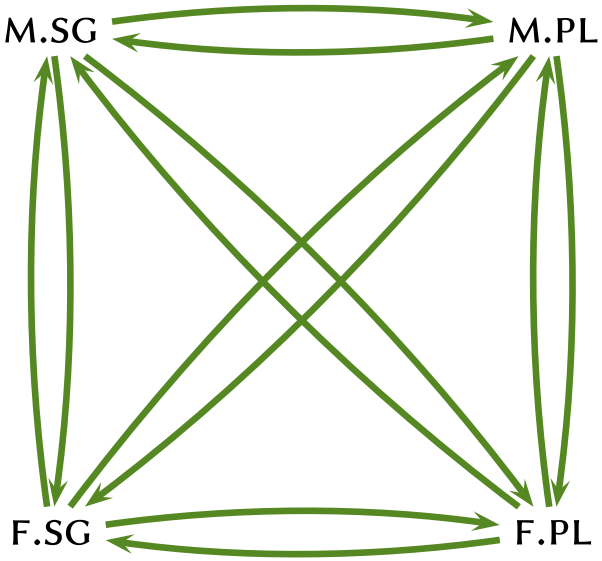
1. Evaluating the predictibility of inflectional paradigms
   1. Implicative entropy
   2. Principal part systems
2. Inflectional classification
   1. Inference of macro-classes
   2. Inflection systems as semi-lattices of classes

Predictivity in inflectional paradigms

When a speaker knows only one form of a lexeme, how hard is it to predict the others?

(Ackerman, Blevins, and Malouf (2009)'s Paradigm Cell Filling Problem)

Consider French adjectives:



- F.SG⇒F.PL is trivial
- M.SG⇒M.PL is easy but not trivial, see /lokal/∼/loko/ vs. /banal/∼/banal/
- F.SG⇒M.SG is harder, see /lɛd/∼/lɛ/ vs. /ʁɛd/∼/ʁɛd/
- M.SG⇒F.SG is hardest, see /gɛ/∼/gɛ/ vs. /lɛ/∼/lɛd/ vs. /njɛ/∼/njɛz/ vs. ...

Implicative entropy

Lexeme	M.SG	M.PL	alternation	M.SG class
LOYAL	lwajal	lwajo	*X*al ∼ *X*o	C1
BANAL	banal	banal	*X* ∼ *X*	C1
CALME	kalm	kalm	*X* ∼ *X*	C2
POLI	poli	poli	*X* ∼ *X*	C2

Data sample: French masculine adjectives

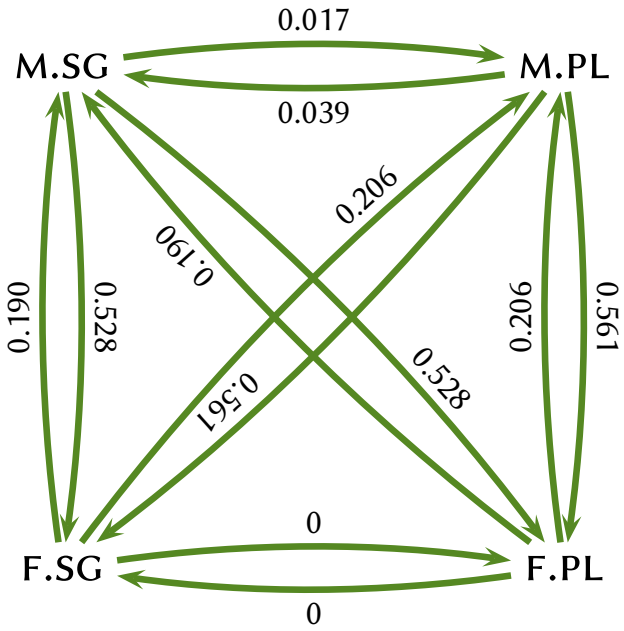
- For each pair of cells (A, B), over a set lexicon:
- Group lexemes by type of alternation: random variable $A \sim B$
- Group forms in A by shape, on the basis of which alternations these shapes are compatible with: random variable $A_{A\sim B}$
- The implicative entropy from A to B is the conditional entropy of patterns of alternation given input cell.

$$H(A \Rightarrow B) = H(A \sim B \mid A_{A\sim B})$$

- In our example:

$$H(\text{M.SG} \Rightarrow \text{M.PL}) = 0.5$$

Using implicative entropy



Average: 0.252

- Creole complexity

Language	Mauritian	French
Average	0.744	0.446
Minimum	0.563	0
Maximum	0.925	0.916

(Bonami, Boyé, and Henri, 2011)

- Prediction from multiple cells

	French	E. Portuguese
1 predictor	0.174	0.205
2 predictors	0.054	0.106
3 predictors	0.021	0.076

(Bonami and Beniamine, 2015)

Systems of principal parts

- Principal part system: a set of perfect predictor cells
- A traditional pedagogical tool
- Stump and Finkel (2013): Cardinality of the smallest such set is an indicator of the complexity of an inflection system.
- Can be deduced from implicative entropy
  - Set of cells from which implicative entropy to all other cells is 0

Language	1 cell	2 cells	3 cells
French conjugation	0	0	0
E. Portuguese conjugation	0	184	7884

Number of distinct categorical systems of principal parts

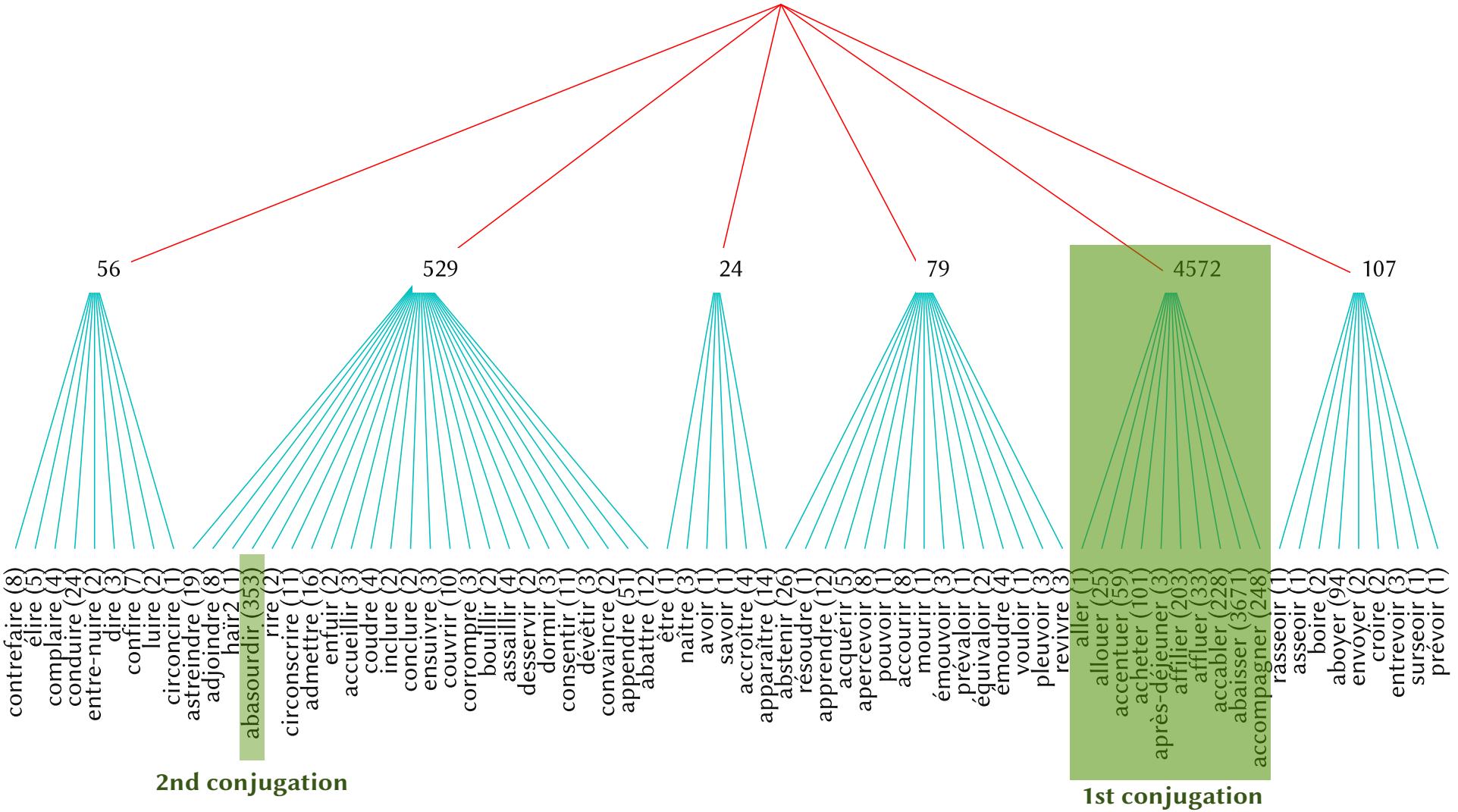
Inflectional classification

- Inflectional microclass: set of lexemes that share the exact same inflection strategies

  ...that is, exhibit the exact same patterns of alternation

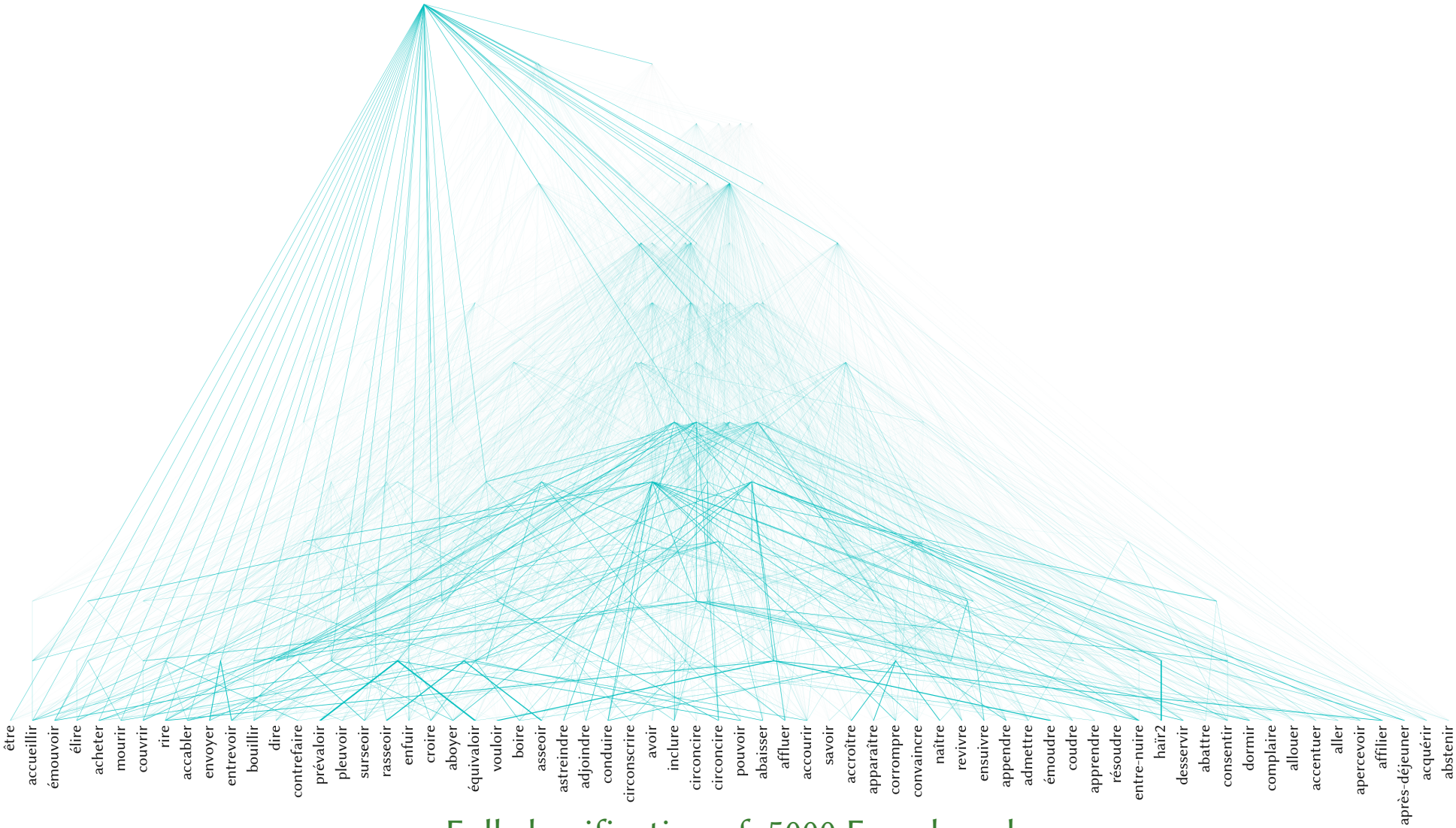
- Studying the structure of an inflection system is, to a large extent, studying the organization of its microclasses.
- Two current strategies:
  1. Infer macroclasses: a partition of the set of microclasses into maximally different subsets.
     - ★ Beniamine, Bonami, and Sagot (2015): group microclasses until the description length of the system stops decreasing
  2. Construct a semi-lattice of similarity between microclasses and examine its topology (Beniamine and Bonami, forthcoming)

Macroclasses: French conjugation



Semi-lattice: French conjugation

Representation of all sets of lexemes that share some inflectional characteristics

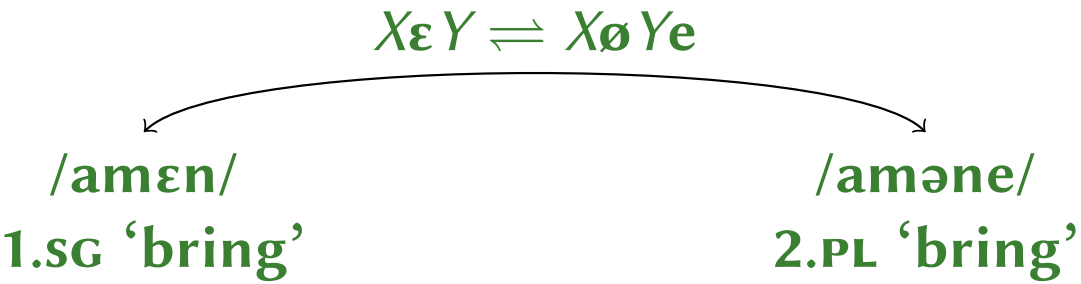


Full classification of 5000 French verbs

Pattern classification

The issue

- A crucial building block of the present enterprise is the choice of an algorithm for classifying alternations in paradigms.



- The choice of an algorithm influences all other calculations
- The algorithm should extract relevant generalizations in any language, without prior knowledge of that language's inflectional profile.
- This is the only route to unbiased typology.

Why it is not trivial

- Decisions cannot be taken locally for a single pair of alternants

A.Infix	
SG	PL
ba	baba
to	tabo
ri	rabi

B. Prefix	
SG	PL
ba	baba
to	bato
ri	bari

C. Suffix	
SG	PL
ba	baba
to	toba
ri	riba

D. Redup.	
SG	PL
ba	baba
to	toto
ri	riri

- Discontinuous alternations, e.g. in Standard Arabic

PFV.3SG	kataba	darasa	...
IPF.3SG	yaktubu	yadrusu	...

- Multidimensional alternations, e.g. in Zenzontepec Chatino

	‘break’	‘drench’	‘slide’	
POT	ku^{0}ki^{0}tę^{1}ʔ	ku^{0}ki^{0}li^{0}	ki^{0}ki^{0}li^{0}	...
CPL	nka^{0}ki^{1}tę^{2}ʔ	nka^{0}ki^{0}li^{0}	nku^{0}ki^{0}ti^{0}	...

Previous work

- Much previous work (e.g. Ackerman and Malouf 2013) ignores the issue and works from hand-designed classifications grammars.
- Most extant implemented proposals rely on local decisions with bias.
  - Sims (2015): only suffixation
  - Albright (2002): single change, bias:

    Suffixation > Prefixation > Stem-internal alternation (ablaut/infixation)
  - Bonami and Boyé (2014) and Bonami and Luís (2014): no stem-internal alternation, bias:

    Suffixation > Prefixation > Circumfixation
  - Bonami and Beniamine (2015): Suffixation + stem-internal alternation
- In this talk we evaluate a more general strategy, similar to that of Albright and Hayes (2006)

The algorithm: first steps

- For any pair of forms, find the set of alignments that minimize a weighted edit distance
  - Substitution weighted on the basis of phonological similarity (Frisch, Pierrehumbert, and Broe, 2004)
- Deduce a bidirectional pattern of alternation

	Alignment				Distance	Pattern
	b	a	b	a		
(i) Prefix	_	_	b	a	2	$\epsilon \rightleftharpoons$ ba / _ba
(ii) Suffix	b	a	_	_	2	$\epsilon \rightleftharpoons$ ba / ba_
(iii) Infix	b	_	_	a	2	$\epsilon \rightleftharpoons$ ab / b_a

SG	PL	Patterns
ba	baba	$\{\epsilon \rightleftharpoons$ ba / _ba, $\epsilon \rightleftharpoons$ ba / ba_, $\epsilon \rightleftharpoons$ ab / b_a$\}$
to	tabo	$\{\epsilon \rightleftharpoons$ ab / t_o$\}$
ri	rabi	$\{\epsilon \rightleftharpoons$ ab / r_i$\}$
su	sabu	$\{\epsilon \rightleftharpoons$ ab / s_u$\}$

The algorithm: last steps

- Fuse patterns with identical structural alternations

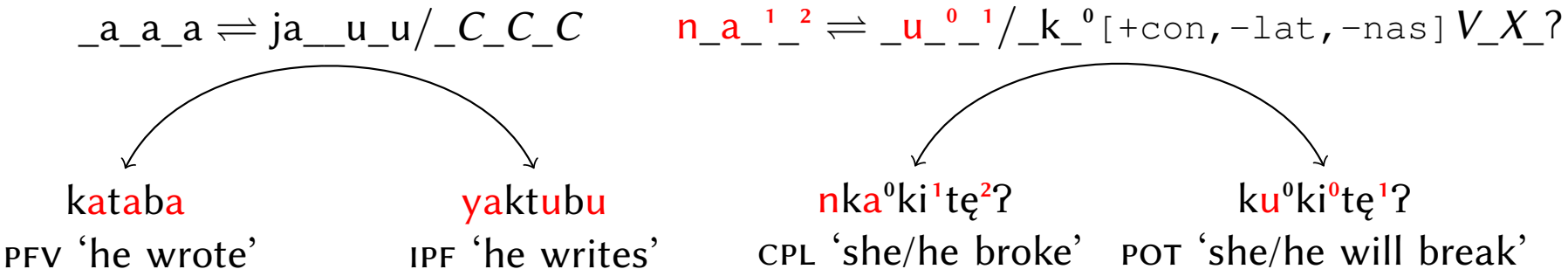
$$\left.\begin{array}{l} \epsilon \rightleftharpoons \text{ab / b\_a} \\ \epsilon \rightleftharpoons \text{ab / t\_o} \\ \epsilon \rightleftharpoons \text{ab / r\_i} \\ \epsilon \rightleftharpoons \text{ab / s\_u} \end{array}\right\} \Rightarrow \epsilon \rightleftharpoons \text{ab / } C\_V$$

- Score patterns using the harmonic mean of their coverage and accuracy
  - coverage: proportion of candidate lexemes for that pattern
  - accuracy: proportion of candidates actually instantiating the pattern
- For each lexeme, decide on the pattern with the highest score

Alignment					Pattern	Score
	b	a	b	a		
(i) Prefix	_	_	b	a	$\epsilon \rightleftharpoons$ ba / _ba	0.4
(ii) Suffix	b	a	_	_	$\epsilon \rightleftharpoons$ ba / ba_	0.4
(iii) Infix	b	_	_	a	$\epsilon \rightleftharpoons$ ab / b_a	1.0

Evaluation

- Qualitative: the algorithm does infer transfixation patterns



- Quantitative: we use 10-fold cross-validation to evaluate improvement in the inference of relevant generalizations

	Toy Arabic	French (pres. only)
Single contiguous change (Albright, 2002)	35%	94%
Suffix bias (Bonami and Beniamine, 2015)	35%	94%
Present algorithm	100%	94%

- Conclusion: the new algorithm corrects at least some of the limitations of those used by (Albright, 2002) and (Bonami and Beniamine, 2015)

Preliminary results on Zenzontepec Chatino

Zenzonpetec Chatino

- Zapotecan language (Oto-Manguean) with about 8.000 speakers
- Morphophonology documented by Campbell (2011, 2014, 2016)
- Paradigm collection available from the SMG *Oto-Manguean Inflectional Class Database* (Feist and Palancar, 2016)
- Verbs inflect for 4 aspects (and person/number).
- Dataset: paradigms of 370 non-compound verbs
- Inflection combines tone alternations and prefixation
- Ackerman and Malouf (2013) on Mazatec: orthogonal segmental and tonal marking leads to high numbers of inflection classes but has little effect on predictibility.
- We want to assess the situation in Z. Chatino, using our improved methodology.

Overall predictibility

- Implicative entropy by individual pair of cells:

	CPL	POT	HAB	PROG
CPL	—	0.399	0.395	0.283
POT	0.817	—	0.172	0.671
HAB	0.842	0.206	—	0.664
PROG	1.148	1.004	0.963	—

- Average implicative entropy by number of predictors:

Predictors	1	2	3
Average entropy	0.63	0.213	0.097

NB: the comparatively high numbers are likely to be due to a smaller dataset.

- No system of principal parts of cardinality < 4

Segmental inflection classes

- Campbell (2011) describes affixal and tonal inflection as mostly orthogonal.
  - 9 classes on the basis of prefixes:

Class	CPL	POT	HAB	PROG	Translation
Ac	nka^{0}se^{0}su^{0}	ki^{0}se^{0}su^{0}	nti^{0}se^{0}su^{0}	nte^{0}se^{0}su^{0}	'turn'
Au	nka^{1}ra^{2}	ku^{1}ra^{2}	ntu^{1}ra^{2}	nte^{1}ra^{2}	'hit'
At	nka^{0}te^{0}hę^{1}	tye^{0}hę^{1}	ntye^{0}hę^{1}	nte^{0}te^{0}hę^{1}	'have diarrhea'
A2	nkwi^{1}so^{2}ʔ	ki^{0}so^{1}ʔ	nti^{0}so^{1}ʔ	nte^{0}so^{1}ʔ	'pick'
Bc	nku^{0}hna^{2}	ki^{0}hna^{1}	nti^{0}hna^{1}	nte^{1}hna^{2}	'flee'
Bt	nku^{0}tye^{0}hna^{1}	tye^{0}hna^{1}	ntye^{0}hna^{1}	nte^{0}tye^{0}hna^{1}	'start'
By	nkya^{2}na^{1}	cha^{0}na^{0}	ncha^{0}na^{0}	nte^{0}ya^{2}na^{1}	'wilt'
Ca	ke^{2}ʔ	ka^{1}ke^{2}ʔ	nti^{1}ke^{2}ʔ	ncha^{0}ke^{1}ʔ	'cook'
C2	ya^{0}ku^{0}	ka^{0}ku^{0}	nta^{0}ku^{0}	ncha^{0}ku^{0}	'eat'

Campbell's affixal classes

- Multiple tonal patterns found with the same affixal class:

CPL	POT	HAB	PROG	Translation
ki^{0}nya^{0}xę^{0}ʔ	nti^{0}nya^{0}xę^{0}ʔ	nte^{0}nya^{0}xę^{0}ʔ	nku^{0}nya^{0}xę^{0}ʔ	'get angry'
ki^{0}la^{0}kwa^{1}	nti^{0}la^{0}kwa^{1}	nte^{0}la^{0}kwa^{1}	nku^{0}la^{0}kwa^{1}	'get counted'
ki^{0}ka^{0}ʔne^{0}	nti^{0}ka^{0}ʔne^{0}	nte^{0}ka^{2}ʔne^{1}	nku^{0}ka^{2}ʔne^{1}	'get beaten'
ki^{0}ki^{0}tę^{1}ʔ	nti^{0}ki^{0}tę^{1}ʔ	nte^{0}ki^{1}tę^{2}ʔ	nku^{0}ki^{1}tę^{2}ʔ	'get snapped'
ki^{0}su^{0}	nti^{0}su^{0}	nte^{0}su^{1}	nku^{0}su^{1}	'come off'
ki^{0}ti^{0}ta^{0}	nti^{0}ti^{0}ta^{0}	nte^{0}ti^{0}ta^{0}	nku^{0}ti^{0}ta^{1}	'get crushed'

Tonal patterns found for affixal class Bc

- Multiple affixal classes found with the same tone patterns:

Class	CPL	POT	HAB	PROG	Translation
Ac	nka^{0}xi^{0}ti^{0}	ki^{0}xi^{0}ti^{0}	nti^{0}xi^{0}ti^{0}	nte^{0}xi^{0}ti^{0}	'laugh'
Au	nka^{0}xi^{0}kwą^{0}	ku^{0}xi^{0}kwą^{0}	ntu^{0}xi^{0}kwą^{0}	nte^{0}xi^{0}kwą^{0}	'pull up'
Bc	nku^{0}ki^{0}ʔi^{0}	ki^{0}ki^{0}ʔi^{0}	nti^{0}ki^{0}ʔi^{0}	nte^{0}ki^{0}ʔi^{0}	'toast'
By	nkya^{0}ti^{0}ʔ	cha^{0}ti^{0}ʔ	ncha^{0}ti^{0}ʔ	ntya^{0}ti^{0}ʔ	'burn'
C2	ya^{0}la^{0}ʔ	ka^{0}la^{0}ʔ	nti^{0}la^{0}ʔ	ncha^{0}la^{0}ʔ	'hold'

Affixal classes found with default tone pattern

Assessing orthogonality

- Tone class can't be categorically predicted from affix class, and vice versa.
- However, tone and affixation are partly interpredictable.
  - Affixes ⇒ Tones:
    - ★ 53% of class C2 verbs use the default 'no tone' pattern
    - ★ 25% of class Au verbs do the same.
  - Tones ⇒ Affixes:
    - ★ 39% of verbs with a `(1)12` pattern in the completive fall in class Au
    - ★ 20% of verbs with a default 'no tone' pattern do the same.
  - ...
- To assess how interdependent the two classifications are, we compare 3 versions of the dataset:
  1. The fully specified data
  2. Only tonal information
  3. Only segmental information

How many patterns?

- If segmental and tonal inflection were fully independent, we would expect most combinations of segmental and tonal patterns to actually cooccur.

Cells	Segmental patterns	Tonal patterns	Possible combinations	Actual combinations
CPL∼HAB	31	24	184	76
CPL∼POT	28	21	205	73
CPL∼PROG	25	22	146	42
HAB∼PROG	29	24	197	70
POT∼HAB	21	4	63	22
POT∼PROG	19	20	119	59

☞ There is some amount of redundancy between the two dimensions of inflection.

Orthogonal prediction

- Asymetry: tone patterns are easier to predict from segmental patterns than the other way around.
  - Clearly related to the wider diversity of affixal patterns

H(affixal pattern | tone pattern)	1.726
H(tone pattern | affixal pattern)	0.996
H(tone pattern)	2.109
H(affixal pattern)	2.839

(Averages over 6 pairs of cells)

- However, when looking at implicative entropy
  - Predicting tone from tone is hardest
  - Predicting segments from segments is easier
  - Predicting both at the same time is barely more difficult

	Tones	Segments	Both
Average implicative entropy	1.01	0.619	0.630

☞ Focusing on tone alternations leads to overestimating the difficulty of inferring tone.

Conclusion

- In this talk:
  1. We have showcased *Instrumented Item and Pattern Morphology*, an emerging framework for the quantitative study of inflection systems.
  2. We have outlined a new algorithm for inferring patterns of alternations
  3. We have presented some preliminary results on orthogonal inflection in Zenzontepec Chatino
- Next steps:
  1. Use semi-lattice representations to assess in detail the interplay of tonal and affixal inflection in Chatino
  2. Extend this line of work to other Oto-Manguean languages, using the *Oto-Manguean Inflectional Class Database* (Feist and Palancar, 2016)
  3. General ambition: quantitative morphological typology. We are looking for more datasets!

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