# Description of the verbal morphology of Asama

## A realizational and implemented approach

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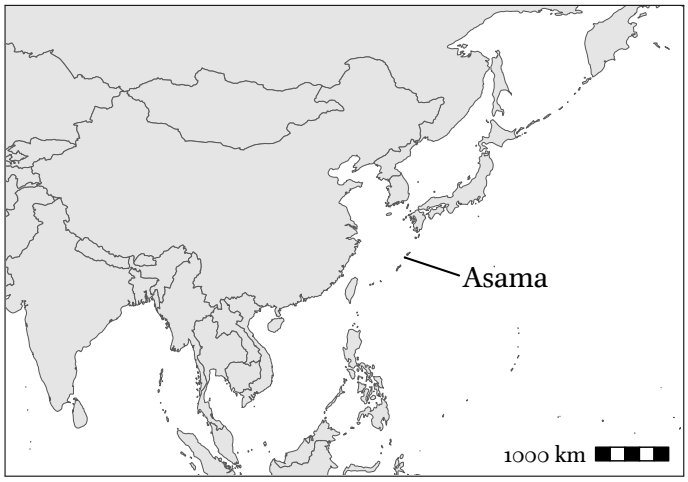
[1] Outline

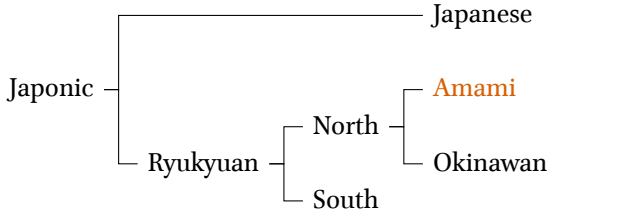
1. overview of the verb inflectional morphology of Asama, with a focus on non-canonical phenomena
2. computational implementation
3. complexity measures of implicative structure

## Introduction

[2] Asama

- endangered variety of Amami Ryukyuan
- spoken in the Asama village of Tokunoshima Island, Japan
- a few hundred of speakers, most > 70 years old
- SOV, dependent-marking
- word-tone, light vs. heavy syllables (CVV, CVC)




(Pellard 2015)

[3] Japonic verb morphology

- Japanese has a rather simple and almost canonical agglutinative morphology.
- some other Japonic languages are much more complex and opaque (Pellard & Yamada 2017; Lévêque 2017)

[4] Asama verb morphology exhibits several non-canonical phenomena

- stem allomorphy: segmental & suprasegmental (tone & vowel length)
- suffix allomorphy
- systematic overabundance
- multi-functional exponents

## Data & methods

[5] Data collection

- 50 full + 400 near-full inflectional verb paradigms
- data from published sources (Okamura et al. 2009; Uwano 2001)
- supplemented by data collected in the field by D. Lévêque (2018–2019)
- elicitation and natural texts

[6] Methods

*Formal description* Paradigm Function Morphology (PFM; Bonami & Stump 2016; Stump 2001; 2015; 2018)

*Computational implementation* finite-state transducers (FSTs, Beesley & Karttunen 2003; Hulden 2009)

*Quantitative analysis* information-theoretical complexity measures (Ackerman et al. 2009; Ackerman & Malouf 2013; Blevins 2013; Bonami & Beniamine 2016)

## The verb morphology of Asama

### *Non-canonical phenomena*

[7] Systematic overabundance

| | PROG.PST | |
|---|---|---|
| | #1 | #2 |
| 'to begin' | *hazɨmɨ́ɨtutan* H | *hazɨmɨ́tuutan* H |
| 'to be born' | *mˀaarɨ́ɨtutan* H | *mˀaarɨ́tuutan* H |

[8] Multi-functional exponents

| | IIMP | SEQ |
|---|---|---|
| 'to read' | *juum-í* LH | *juud-í* LH |
| 'to meet' | *oor-í* H | *oot-í* H |

[9] Overview of alternations

| | 'to sell' | 'to knit' | 'to take in charge' |
|---|---|---|---|
| NPST | *uju*i H | *amju*i H | *acɨkaju*i LH |
| CVB2 | *urug99sɨ* H | *amjug99sɨ* H | *acɨkarug99sɨ* LH |
| NEG | *uran* H | *aman* H | *acɨkaran* LH |
| DIMP | *uroo* H | *amoo* H | *acɨkaroo* LH |
| IIMP | *urɨɨ* H | *aamɨ* HL | *acɨkaarɨ* LH |
| CVB | *ui* H | *amii* H | *acɨkai* LH |
| DES | *uicjaahai* H | *amicjaahai* H | *acɨkaicjaahai* LH |
| PST | *utan* H | *adan* LH | *acɨkatan* LH |
| SEQ | *utɨɨ* H | *aadɨ* HL | *acɨkaatɨ* LH |
| PROG | *utui* LHL | *aadui* HL | *acɨkaatui* LHL |
| PROG.NEG | *utuuran* LHL | *aaduran* HL | *acɨkaaturan* LHL |

[10] Segmental alternations

| | 'to laugh' | 'to knit' | 'to die' |
|---|---|---|---|
| NPST | *waroju*i H | *amju*i H | *moisju*i H |
| CVB2 | *warorug99sɨ* H | *amjug99sɨ* H | *moisjug99sɨ* H |
| NEG | *waroran* H | *aman* H | *moisjan* H |
| DIMP | *waroroo* H | *amoo* H | *moisjoo* H |
| IIMP | *waroorɨ* H | *aamɨ* H | *moisjɨɨ* H |
| CVB | *waroi* H | *amii* H | *moisɨɨ* H |
| DES | *waroicjaahai* H | *amicjaahai* H | *moisɨcjaahai* H |
| PST | *warotan* H | *adan* LH | *moisjan* H |
| SEQ | *warootɨ* H | *aadɨ* HL | *moisjɨɨ* H |
| PROG | *warotui* H | *aadui* HL | *moisjui* H |
| PROG.NEG | *warotuuran* H | *aaduran* HL | *moisjuran* H |

[11] Vowel length alternations

| | 'to laugh' | 'to knit' | 'to take in charge' |
|---|---|---|---|
| NPST | *waroju*i H | ***a**mju*i H | *acɨ**ka**ju*i LH |
| NEG | *waroran* H | ***a**man* H | *acɨ**ka**ran* LH |
| DIMP | *waroroo* H | ***a**moo* H | *acɨ**ka**roo* LH |
| IIMP | *waroorɨ* H | ***aa**mɨ* HL | *acɨ**kaa**rɨ* LH |
| CVB | *waroi* H | ***a**mii* H | *acɨ**ka**i* |
| DES | *waroicjaahai* H | *a**m**icjaahai* H | *acɨ**ka**icjaahai* LH |
| SEQ | *warootɨ* H | ***aa**dɨ* HL | *acɨ**kaa**tɨ* LH |
| PROG | *warotui* H | ***aa**dui* HL | *acɨ**kaa**tui* LHL |
| PROG.NEG | *warotuuran* H | ***aa**duran* HL | *acɨ**kaa**turan* LHL |

[12] Tone alternations

| | 'to sell' | | 'to knit' | | 'to take in charge' | |
|---|---|---|---|---|---|---|
| NPST | *uju*i | H | *amju*i | H | *acɨkaju*i | LH |
| NEG | *uran* | H | *aman* | H | *acɨkaran* | LH |
| DIMP | *uroo* | H | *amoo* | H | *acɨkaroo* | LH |
| IIMP | *urɨɨ* | H | *aamɨ* | HL | *acɨkaarɨ* | LH |
| CVB | *ui* | H | *amii* | H | *acɨkai* | LH |
| DES | *uicjaahai* | H | *amicjaahai* | H | *acɨkaicjaahai* | LH |
| SEQ | *utɨɨ* | H | *aadɨ* | HL | *acɨkaatɨ* | LH |
| PROG | *utui* | LHL | *aadui* | HL | *acɨkaatui* | LHL |
| PROG.NEG | *utuuran* | LHL | *aaduran* | HL | *acɨkaaturan* | LHL |

## *A Paradigm Function Morphology (PFM) analysis*

[13] Non-canonical phenomena
- problematic for morpheme-based approaches → Word-and-Paradigm approach
- Paradigm Function Morphology (PFM)
  - one of the most carefully articulated and formalised theoretical framework of morphology
  - readily handles various non-canonical morphological phenomena
  - readily implementable (Karttunen 2003)
  - good empirical coverage of typologically diverse morphological systems
  - not committed to a particular syntactic framework

[14] Data sample

| | 'to laugh' | 'to knit' | 'to take in charge' |
|---|---|---|---|
| NPST | *waroju*i H | *amju*i H | *acɨkaju*i LH |
| CVB2 | *warorug99sɨ* H | *amjug99sɨ* H | *acɨkarug99sɨ* LH |
| NEG | *waroran* H | *aman* H | *acɨkaran* LH |
| IIMP | *waroorɨ* H | *aamɨ* HL | *acɨkaarɨ* LH |
| CVB | *waroi* H | *amii* H | *acɨkai* LH |
| SEQ | *warootɨ* H | *aadɨ* HL | *acɨkaatɨ* LH |
| PROG | *warotui* H | *aadui* HL | *acɨkaatui* LHL |

[15] PFM analysis

| | | |
|---|---|---|
| Rules of stem choice: | $X_V$, {} | $\rightarrow X$ |
| | $X_V$, {IIMP,SEQ} | $\rightarrow X$ː |
| | $X_{V,\text{ class }2,3}$, {PROG} | $\rightarrow X$ː |
| Block 1: | $X_V$, {NPST,CVB2} | $\rightarrow XT_1$ |
| | $X_{V,\text{class }1,3}$, {CVB2} | $\rightarrow XT_4$ |
| | $X_V$, {CVB} | $\rightarrow XT_3$ |
| | $X_V$, {NEG,HORT,IIMP} | $\rightarrow XT_4$ |
| | $X_V$, {SEQ,PROG NPST} | $\rightarrow XT_5$ |
| Block 2: | $X_V$, {NPST} | $\rightarrow XTui$ |
| | $X_V$, {NEG} | $\rightarrow Xan$ |
| | $X_V$, {CVB} | $\rightarrow Xii$ |
| | $X_V$, {SEQ,IIMP} | $\rightarrow Xɨ$ |
| Block 3: | $X_{V,\text{ class }1,2}$, {} | $\rightarrow X$ H |
| | $X_{V,\text{ class }2}$, {IIMP,SEQ,PROG} | $\rightarrow X$ HL |
| | $X_{V,\text{ class }3}$, {} | $\rightarrow X$ LH |
| | $X_{V,\text{ class }3}$, {PROG} | $\rightarrow X$ LHL |

[16] Two types of inflectional classes
- PFM analysis → segmental and suprasegmental alternations can be treated separately
- vowel length and tone assumed to be on an autosegmental tier
- behave independently from segmental alternations

[17] Segmental alternations

| $T_1$ | $T_2$ | $T_3$ | $T_4$ | $T_5$ |
|---|---|---|---|---|
| *bj* | — | *b* | *b* | *d* |
| *mj* | — | *m* | *m* | *d* |
| *gj* | — | *g* | *g* | *zj* |
| *kj* | — | *k* | *k* | *cj* |
| *kj* | — | *k* | *k* | *ccj* |
| *sj* | — | *s* | *sj* | *cj* |
| *sj* | — | *s* | *sj* | *sj* |
| *cj* | — | *c* | *t* | *ccj* |
| *j* | ∅ | ∅ | *r* | *t* |
| *j* | ∅ | *r* | *r* | *cj* |
| *j* | ∅ | *r* | *r* | *ccj* |
| *j* | ∅ | ∅ | *r* | *tt* |

Morphomic sets of forms (Aronoff 1994):
- $T_1$: NPST, NPST2, ...
- $T_2$: PROH
- $T_3$: CVB, DES, ...
- $T_4$: NEG, HORT, IIMP, ...
- $T_5$: SEQ, PST, PROG, ...

[18] Suprasegmental alternations

| Class | A | B | C |
|---|---|---|---|
| I1 | $RT_1X$ H | $RT_5X$ H | $RT_5X{:}Y$ H |
| I2 | $RT_1X$ H | $RT_5X$ H | $RT_5X$ H, $RT_5X{:}Y$ H |
| II1 | $RT_1X$ H | $RT_5X{:}$ H | $RT_5X{:}Y$ LHL |
| II2 | $RT_1X$ H | $RT_5X$ H | $RT_5X{:}Y$ LHL |
| III | $RT_1X$ LH | $RT_5X$ HL | $RT_5X$ HL |
| IV | $RT_1X$ LH | $RT_5X$ LH | $RT_5X$ LHL |
| V | $RT_1X$ HL | $RT_5X$ HL | $RT_5X$ HL |

[19] Suprasegmental alternations (example)

| Class | A: {NPST} | B: {SEQ} | C: {PROG} |
|---|---|---|---|
| I1 | $RT_1ui$ H | $RT_5i$ H | $RT_5ui$ H |
| I2 | $RT_1ui$ H | $RT_5i$ H | $RT_5ui$ H, $RT_5X{:}Y$ H |
| II1 | $RT_1ui$ H | $RT_5i{:}$ H | $RT_5ui$ LHL |
| II2 | $RT_1ui$ H | $RT_5i$ H | $RT_5ui$ LHL |
| III | $RT_1ui$ LH | $RT_5i$ HL | $RT_5ui$ HL |
| IV | $RT_1ui$ LH | $RT_5i$ LH | $RT_5ui$ LHL |
| V | $RT_1ui$ HL | $RT_5i$ HL | $RT_5ui$ HL |

## Computational implementation

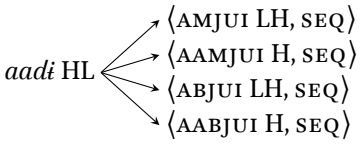
[20] Why an implemented description?
- "the insufficiency of paper-and-pencil linguistics" (Karttunen 2006)
- provide a maximally precise and explicit description
- helpful for testing hypotheses and for verifying the accuracy of the description
- allow to compute complexity measures

[21] Why FSTs?
- standard NLP tools
- can handle almost any morphological process (Koskenniemi 1983; Karttunen et al. 1992; Aksënova et al. 2016)
- bidirectional:
  *production* lexeme/root → inflected form
  *recognition* inflected form → lexeme/root
- many free, open-source and well documented implementations
- Foma free software (Hulden 2009)

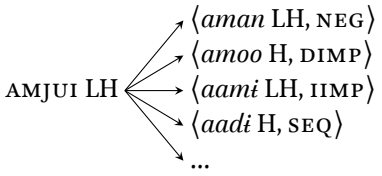
[22] FSTs
1. content paradigm cell $\langle L, \sigma \rangle$ → realised cell $w$

$$\langle \text{AMJUI LH, SEQ} \rangle \rightarrow aadi \text{ HL}$$

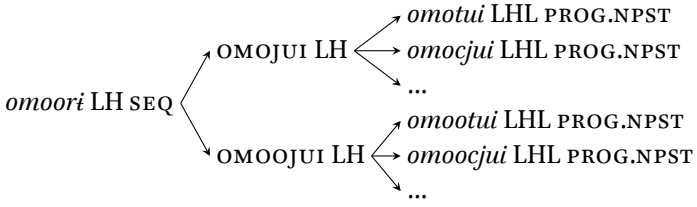
2. unlabeled form $w$ → all possible morphological analyses $\langle L, \sigma \rangle$




3. $L$ → full realised paradigm, i.e. a set of cells $\{\langle w, \sigma \rangle, \langle w', \sigma' \rangle, \ldots\}$)




[23] FST composition
- composition of 2 FSTs
- any (existing) given realised form → list of all possible realised forms of any other paradigm cell




## Implicative structure & complexity measures

[24] Implicative structure
- PFM: segmentation between stem and affixes
- implicative structure: no need to segment, whole forms are taken into account (Bonami 2014; Bonami & Luís 2015)
- including non-alternating parts helps reducing the uncertainty

[25] Segmental information reduces uncertainty
- segmental information:

$X_1 = X_{\{a,o,u\}}$
$X_2 = X_{\{i\}}$
$X_3 = X_{\{\{s,z,c\}i\}}$
$X_4 = X_{\{\{C\text{-}\{s,z,c\}i\}}$

- without knowledge:
  $[\textsc{npst} : Xjui \Rightarrow \textsc{cvb} : \left\{ \begin{array}{l} X\text{ː} \\ Xri\dot{\imath}\dot{\imath} \end{array} \right\}]$
- with knowledge:
  $[\textsc{npst} : X_4jui \Rightarrow \textsc{cvb} : X_4\text{ː}]$
  $[\textsc{npst} : X_3jui \Rightarrow \textsc{cvb} : X_3ri\dot{\imath}\dot{\imath}]$

[26] Length & syllable structure information reduce uncertainty

| Class | Length | Structure | Example | |
|---|---|---|---|---|
| I1 | $2\mu$ | (C)$V_iV_i$, (C)VCV | *warojui* H | 'to laugh' |
| I2 | $\geq 3\mu$ | — | *mʾaarijui* H | 'to be born' |
| II1 | $\leq 2\mu$ | (C)V, (C)VC]$_\sigma$, (C)Vi | *tubjui* H | 'to fly' |
| II2 | $2\mu$ | (C)VCV, (C)VN]$_\sigma$ | *asibjui* H | 'to play' |
| III | $\leq 2\mu$ | (C)V(N ∪ C)]$_\sigma$ | *umjui* LH | 'to ripen' |
| IV | — | ≠ (Cʔ)V(N ∪ C)]$_\sigma$ | *tuujui* LH | 'to go through' |
| V | $2\mu$ | $(C)V_iV_i$ | *mʾoojui* HL | 'to be' (honor.) |

- without knowledge:
  $[\textsc{npst} : Xjui\ \text{H} \Rightarrow \textsc{seq} : \left\{ \begin{array}{l} X\text{ː}T_5\dot{\imath}\ \text{H} \\ XT_5\dot{\imath}\dot{\imath}\ \text{H} \end{array} \right\}]$
- with knowledge:
  $X$ = (C)V $\Rightarrow [\textsc{npst} : Xjui\ \text{H} \Rightarrow \textsc{seq} : XT_5\dot{\imath}\dot{\imath}\ \text{H}]$
  $X$ = (C)VCV $\Rightarrow [\textsc{npst} : Xjui\ \text{H} \Rightarrow \textsc{seq} : X\text{ː}T_5\dot{\imath}\ \text{H}]$

[27] Entropy calculations & sources of uncertainty

*Paradigm Cell Filling Problem* "What licenses reliable inferences about the inflected (and derived) surface forms of a lexical item?" (Ackerman et al. 2009: 54)

*Shannon entropy* information quantity delivered by the source, used as a measure of uncertainty
$H(X) = -\sum_{x \in X} P(x) \log_2(P(x))$

*conditional Shannon entropy* how much does knowing a cell help predicting another?
$H(X|Y) = -\sum_{x \in X} \sum_{y \in Y} P(x,y) \log_2(P(x|y))$

[28] Distillation of 5 cells (areas of interpredictability; Stump & Finkel 2013)

| NPST | CVB | IIMP | SEQ | PROG.NPST |
|---|---|---|---|---|
| $RT_1ui$ H | $RT_3i\dot{\imath}$ H, $RT_4i\dot{\imath}$ H | $R\text{ː}T_4\dot{\imath}$ H | $R\text{ː}T_5\dot{\imath}$ H | $RT_5ui$ H |
| $RT_1ui$ H | $RT_3i\dot{\imath}$ H, $RT_4i\dot{\imath}$ H | $R\text{ː}T_4\dot{\imath}$ H | $R\text{ː}T_5\dot{\imath}$ H | $R\text{ː}T_5ui$ H, $RT_5ui$ H |
| $RT_1ui$ H | $RT_3i\dot{\imath}$ H, $RT_4i\dot{\imath}$ H | $RT_4i\dot{\imath}$ H | $RT_5i\dot{\imath}$ H | $RT_5ui$ LHL |
| $RT_1ui$ H | $RT_3i\dot{\imath}$ H, $RT_4i\dot{\imath}$ H | $RT_4\dot{\imath}$ H | $R\text{ː}T_5\dot{\imath}$ H | $RT_5ui$ LHL |
| $RT_1ui$ LH | $RT_3i\dot{\imath}$ LH, $RT_4i\dot{\imath}$ LH | $R\text{ː}T_4\dot{\imath}$ HL | $R\text{ː}T_5\dot{\imath}$ HL | $R\text{ː}T_5ui$ HL |
| $RT_1ui$ LH | $RT_3i\dot{\imath}$ LH, $RT_4i\dot{\imath}$ LH | $R\text{ː}T_4\dot{\imath}$ LH | $R\text{ː}T_5\dot{\imath}$ LH | $R\text{ː}T_5ui$ LHL |
| $RT_1ui$ HL | $RT_3i\dot{\imath}$ HL, $RT_4i\dot{\imath}$ HL | $RT_4\dot{\imath}$ HL | $RT_5\dot{\imath}$ HL | $RT_5ui$ HL |

[29] Unary implications

- knowledge of only one cell
- type frequencies of classes taken into account

| H(C\|R) | NPST | CVB | IIMP | SEQ | PROG.NPST |
|---|---|---|---|---|---|
| NPST | | 0.000 | 0.000 | 0.222 | 0.244 |
| CVB | 0.928 | | 0.085 | 0.300 | 0.559 |
| IIMP | 0.951 | 0.206 | | 0.222 | 0.529 |
| SEQ | 1.360 | 1.007 | 0.423 | | 0.322 |
| PROG.NPST | 1.244 | 0.942 | 0.421 | 0.000 | |

[30] Segmental alternations & uncertainty

- unary implications for segmental alternations
- full interpredictability between 2 zones
- entropy remains low because of the uneven frequencies of the segmental classes

| H(C\|R) | NPST | CVB | IIMP | SEQ | PROG.NPST |
|---|---|---|---|---|---|
| NPST | | 0.000 | 0.000 | 0.222 | 0.222 |
| CVB | 0.000 | | 0.000 | 0.222 | 0.222 |
| IIMP | 0.000 | 0.000 | | 0.222 | 0.222 |
| SEQ | 0.419 | 0.419 | 0.419 | | 0.000 |
| PROG.NPST | 0.419 | 0.419 | 0.419 | 0.000 | |

[31] Unpredictable segmental alternations

- H(SEQ|NPST):
  $[\textsc{npst} : Xjui \Rightarrow \textsc{seq} : \left\{ \begin{array}{l} Xt\dot{\imath} \\ Xtt\dot{\imath} \\ Xcj\dot{\imath} \end{array} \right\}]$
- H(CVB|PROG.NPST):
  $[\textsc{prog.npst} : Xdui \Rightarrow \textsc{cvb} : \left\{ \begin{array}{l} Xmii \\ Xbii \end{array} \right\}]$

[32] Neutralisation of vowel length

| H(C\|R) | NPST | CVB | IIMP | SEQ | PROG.NPST |
|---|---|---|---|---|---|
| NPST | | 0.000 | 0.000 | 0.222 | 0.244 |
| CVB | 0.928 | | 0.085 | 0.300 | 0.559 |
| IIMP | 0.951 | 0.206 | | 0.222 | 0.529 |
| SEQ | 1.360 | 1.007 | 0.423 | | 0.322 |
| PROG.NPST | 1.244 | 0.942 | 0.421 | 0.000 | |

- H(NPST|CVB):
  $[\textsc{cvb} : waroi\ (*warooi)\ \text{H} \Rightarrow \textsc{npst} : \left\{ \begin{array}{l} warojui\ H \\ waroojui\ H \end{array} \right\}]$
- H(NPST|IIMP):
  $[\textsc{iimp} : aci\dot{\imath}ki\dot{\imath}\ \text{LH} \Rightarrow \left\{ \begin{array}{l} \textsc{npst} : aci\dot{\imath}kjui\ \text{LH} \\ \textsc{npst} : acikjui\ \text{LH} \end{array} \right\}]$

[33] Neutralisation of tonal oppositions

| H(C\|R) | NPST | CVB | IIMP | SEQ | PROG.NPST |
|---|---|---|---|---|---|
| NPST | | 0.000 | 0.000 | 0.222 | 0.244 |
| CVB | 0.928 | | 0.085 | 0.300 | 0.559 |
| IIMP | 0.951 | 0.206 | | 0.222 | 0.529 |
| SEQ | 1.360 | 1.007 | 0.423 | | 0.322 |
| PROG.NPST | 1.244 | 0.942 | 0.421 | 0.000 | |

- H(NPST|IIMP):
  [IIMP : *uuti* (H=HL) ⇒ NPST : { *ucjui* LH / *uucjui* H }]
- H(PROG.NPST|SEQ):
  [SEQ : *aadi* (H=HL) ⇒ PROG.NPST : { *aadui* H / *aadui* HL }]

[34] Summary of the sources of uncertainty

| H(C\|R) | NPST | CVB | IIMP | SEQ | PROG.NPST |
|---|---|---|---|---|---|
| NPST | | | | V, S | V, S |
| CVB | V | | V | V, S | V, S |
| IIMP | V, T | V, T | | V, S | V, T, S |
| SEQ | V, T, S | V, T, S | V, S | | V, T |
| PROG.NPST | V, S | V, S | V, S | | |

(V = vowel length, T = tone, S = segment)

[35] Binary implications
- knowledge of two cells
- → identifying the principal parts of the system, i.e. the set of forms from which all the paradigm is predictable (Finkel & Stump 2007; Stump & Finkel 2013).

[36] Principal parts

| H(C\|R) | NPST | CVB | IIMP | SEQ | PROG.NPST |
|---|---|---|---|---|---|
| NPST | | 0.000 | 0.000 | 0.222 | 0.244 |
| {NPST,CVB} | 0.000 | | 0.000 | 0.222 | 0.250 |
| {NPST,IIMP} | 0.000 | 0.000 | | 0.222 | 0.250 |
| {NPST,SEQ} | 0.000 | 0.000 | 0.000 | | 0.023 |
| {NPST,PROG.NPST} | 0.000 | 0.000 | 0.000 | 0.000 | |

## Conclusions

[37] Conclusions
- PFM: clear framework for morphological description
- computational implementation with FSTs
  - explicitness and accuracy
  - enables complexity measures
- implicative structure with conditional entropy measures
  - identify phonological factors of uncertainty
  - identify the principal parts of the system
- future directions
  - more data for more coverage
  - Information-based Morphology (Crysmann & Bonami 2015): no need to introduce a radical, no need for rigid blocks of rules

## Abbreviations

CVB = converb, DES = desiderative, DIMP = direct imperative, HORT = hortative, IIMP = indirect imperative, IMP = imperative, NEG = negative, NPST = non-past, PROG = progressive, PROH = prohibitive, PST = past, SEQ = sequential.

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