The complexity of Weledeh verb paradigms

Gregory Stump
University of Kentucky
gstump@uky.edu

Raphael A. Finkel
University of Kentucky
raphael@cs.uky.edu

[*Dene Verb Paradigms Workshop, Toronto, ON, September 26-28, 2014*]

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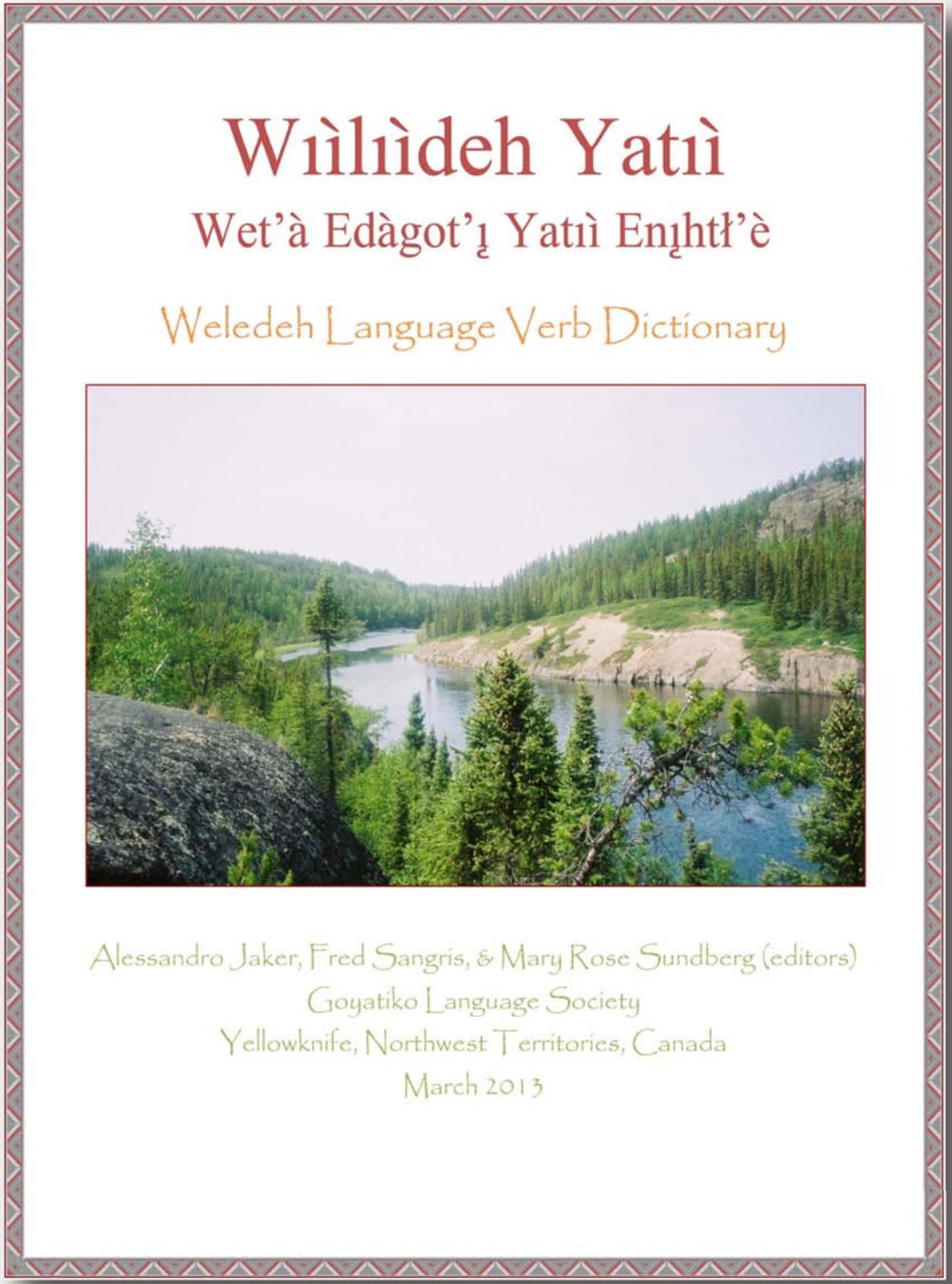
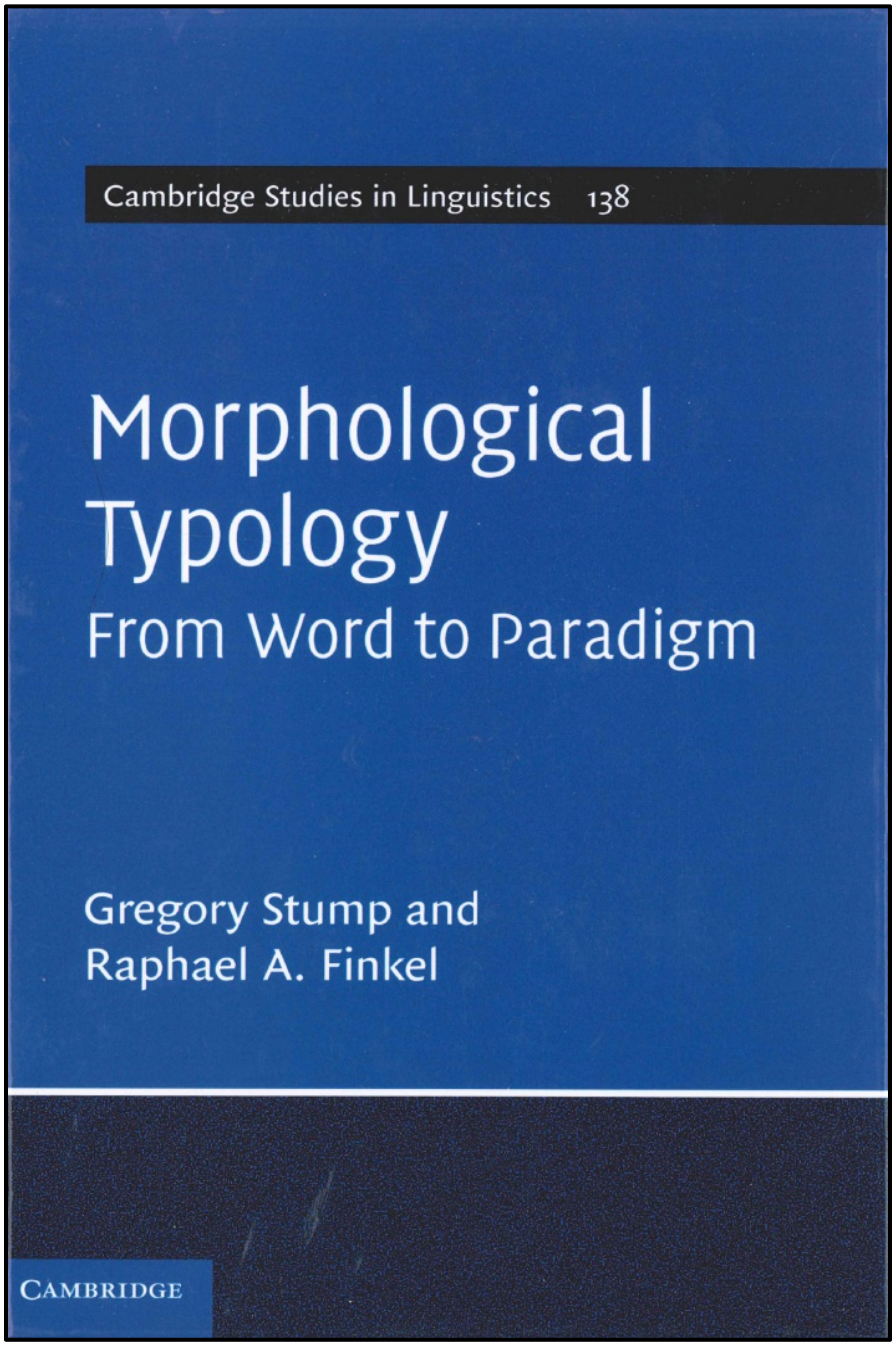
Conjugation of Weledeh *datło* ‘dance’

		Singular	Dual	Plural
Imperfective	**1st**	*dahtło*	*dałewìtło*	*dagots’ewho*
	2nd	*danetło*	*dałaahtło*	*dagaahwho*
	3rd	*datło*	*dałegetło*	*dagogewho*
Perfective	**1st**	*daehtło*	*dałiìtło*	*dagots’įįwho*
	2nd	*daįtło*	*dałaahtło*	*dagaahwho*
	3rd	*daetło*	*dałegeaatło*	*dagogįįwho*
Optative	**1st**	*dauhtło*	*dałuùtło*	*dagots’iiwho*
	2nd	*dauętło*	*dałewahtło*	*dagowahwho*
	3rd	*dautło*	*dałegiitło*	*dagogiiwho*



Many thanks to Alex Jaker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Gregory Stump and Raphael A. Finkel
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Outline

- What is implicative complexity?
- Measuring the complexity of inflection-class systems
- Typological variation in the complexity of inflection-class systems, with a focus on Weledeh
- Summary and conclusions

What is implicative complexity?

Informally, an inflectional system exhibits ***implicative complexity*** to the extent that it is difficult to predict a given word form from one or more other word forms in the same paradigm.

What is implicative complexity?

Informally, an inflectional system exhibits ***implicative complexity*** to the extent that it is difficult to predict a given word form from one or more other word forms in the same paradigm.

The factors that contribute to such complexity are of various kinds, making it desirable to employ a range of approaches to measuring their effects.

A hypothetical inflection-class system

System A

	pres	past	fut
I	**a**	**i**	**q**
II	**b**	**j**	**r**
III	**c**	**k**	**s**
IV	**d**	**l**	**t**
V	**e**	**m**	**u**
VI	**f**	**n**	**v**
VII	**g**	**o**	**w**
VIII	**h**	**p**	**x**

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VII	**g**	**o**	
VIII	**h**	**p**	

I – VIII inflection classes

a – x inflectional affixes

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	pres	past	fut
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II	**b**	**j**	**r**
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VI	**f**	**n**	**v**
VII	**g**	**o**	**w**
VIII	**h**	**p**	**x**

A maximally transparent system: Each individual affix is diagnostic of inflection-class membership.

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	pres	past	fut
I	**a**	**i**	**q**
II	**b**	**j**	**r**
III	**c**	**k**	**s**
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VI	**f**	**n**	**v**
VII	**g**	**o**	**w**
VIII	**h**	**p**	**x**

A maximally opaque system:
Inflection-class membership can only be determined by simultaneous reference to the exponents of ρ, σ and τ.

System F

	pres	past	fut
I	**a**	**c**	**e**
II	**a**	**c**	**f**
III	**a**	**d**	**e**
IV	**a**	**d**	**f**
V	**b**	**c**	**e**
VI	**b**	**c**	**f**
VII	**b**	**d**	**e**
VIII	**b**	**d**	**f**

Six hypothetical inflection-class systems

System A

	pres	past	fut
I	**a**	**i**	**q**
II	**b**	**j**	**r**
III	**c**	**k**	**s**
IV	**d**	**l**	**t**
V	**e**	**m**	**u**
VI	**f**	**n**	**v**
VII	**g**	**o**	**w**
VIII	**h**	**p**	**x**

System B

	pres	past	fut
I	**a**	**b**	**j**
II	**a**	**c**	**k**
III	**a**	**d**	**l**
IV	**a**	**e**	**m**
V	**a**	**f**	**n**
VI	**a**	**g**	**o**
VII	**a**	**h**	**p**
VIII	**a**	**i**	**q**

System C

	pres	past	fut
I	**a**	**i**	**k**
II	**b**	**i**	**l**
III	**c**	**j**	**k**
IV	**d**	**j**	**l**
V	**e**	**i**	**m**
VI	**f**	**i**	**n**
VII	**g**	**j**	**m**
VIII	**h**	**j**	**n**

System D

	pres	past	fut
I	**a**	**i**	**k**
II	**b**	**i**	**k**
III	**c**	**j**	**k**
IV	**d**	**j**	**k**
V	**e**	**i**	**l**
VI	**f**	**i**	**l**
VII	**g**	**j**	**l**
VIII	**h**	**j**	**l**

System E

	pres	past	fut
I	**a**	**e**	**i**
II	**b**	**e**	**j**
III	**c**	**f**	**i**
IV	**d**	**f**	**j**
V	**a**	**g**	**j**
VI	**b**	**g**	**i**
VII	**c**	**h**	**j**
VIII	**d**	**h**	**i**

System F

	pres	past	fut
I	**a**	**c**	**e**
II	**a**	**c**	**f**
III	**a**	**d**	**e**
IV	**a**	**d**	**f**
V	**b**	**c**	**e**
VI	**b**	**c**	**f**
VII	**b**	**d**	**e**
VIII	**b**	**d**	**f**

Seven measures of an inflection-class system's complexity

(a) the number of **distillations** the system has;

(b) the size of the system's **optimal static principal-part sets**;

(c) the density of the system's optimal static principal-part sets (given (a) and (b));

(d) the average size of **optimal dynamic principal-part sets** for the system's inflection classes;

(e) the density of the system's optimal dynamic principal-part sets for the system's inflection classes;

(f) the average **IC predictability** of the system's inflection classes; and

(g) the ***m*-system entropy**.

Seven measures of an inflection-class system's complexity

(a) the number of **distillations** the system has;

(b) the size [illegible] **sets**;

(c) the den[illegible] sets (gi[illegible]

(d) the ave[illegible] **sets** for[illegible]

(e) the density of the system's optimal dynamic principal-part sets for the system's inflection classes;

(f) the average **IC predictability** of the system's inflection classes; and

(g) the ***m*-system entropy**.

Each of these seven measures defines a dimension along which deviations from maximal transparency are observable.

Typological variation in the complexity of inflection-class systems

Twelve inflection-class systems

We compare Weledeh with the following systems:

Verbs in Comaltepec Chinantec	(Oto-Manguean; Mexico)
Nouns in Czech	(Slavic; Czech Republic)
Verbs in French	(Romance; France)
Verbs in Fur	(Nilo-Saharan; Sudan)
Verbs in Icelandic	(Germanic; Iceland)
Verbs in Koasati	(Muskogean; U. S.)
Verbs in Kwerba	(Tor-Kwerba; Indonesia)
Nouns in Lithuanian	(Baltic; Lithuania)
Verbs in Ngiti	(Nilo-Saharan; DR Congo)
Verbs in Palantla Chinantec	(Oto-Manguean; Mexico)
Nouns in Sanskrit	(Indic; India)
Verbs in Tuḷu	(Dravidian; India)

Plats

It is possible to compute the implicative characteristics of a lexeme's paradigm from a representation of the inflection-class system to which it belongs.

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We call a representation of this sort a ***plat***.

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A plat is a table in which

- each column is headed by a morphosyntactic property set;
- each row corresponds to an inflection class;
- the morphological expression of property set A in inflection class B is specified in the A column of the B row.

Conjugation of Weledeh *datło* ‘dance’

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Optative	**1st**	*dauhtło*	*dałuùtło*	*dagots’iiwho*
	2nd	*dauṭło*	*dałewahtło*	*dagowahwho*
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Perfective	**1st**	*daehtło*	*dałiìtło*	*dagots’ịịwho*
	2nd	*dạtło*	*dałaahtło*	*dagaahwho*
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	2nd	*danetło*	*dałaahtło*	*dagaahwho*
	3rd	*datło*	*dałegetło*	*dagogewho*
Perfective	**1st**	*daehtło*		*ts’ịịwho*
	2nd	*dạtło*		*ahwho*
	3rd	*daetło*		*gịịwho*
Optative	**1st**	*dauhtło*	*dałuùtło*	*dagots’iiwho*
	2nd	*dạutło*	*dałewahtło*	*dagowahwho*
	3rd	*dautło*	*dałegiitło*	*dagogiiwho*

themes

vs

distinguishers

IC	impSg1	impSg2	impSg3	impDu1	impDu2	impDu3
datło	htł	netł	tł	łewìtł	łaahtł	łegetł
datł’ı̨	h	ne	Ø	wì	ah	ge
dayeehke	weeh	wı̨ı̨h	yeeh	wìì	waah	yegeeh
deghaegwo	eh	ı̨	e	ì	ah	gee
dek’enaetse	ehtse	ı̨tse	etse	ìtse	ahtse	geetse
dek’enèetł’è	èeh	į̀ı̨	èe	ìì	àah	ègee
dek’enèyeetł’è	weeh	wı̨ı̨	yee	wìì	waah	yegee
detı̨	dehtı̨	dı̨tı̨	detı̨	dıìte	dahte	geete
det’è	deht’è	dı̨t’è	det’è	dıìt’è	daht’è	geet’è
dezè	deh	dı̨	de	dıì	dah	gee
e?à	eh?	ne?	e?	wìt’	ah?	ge?
e?į̀	eh?į̀	ne?į̀	e?į̀	wì?į̀	ah?į̀	ge?į̀
edè	ehdè	nedè	edè	wìdè	ahdè	gedè
edǫ	eh	ne	e	wì	ah	ge
edze	eh	ne	e	wì	ah	ge
eèhkw’ǫ	eèh	į̀ı̨h	eèh	ıì	aàh	egeèh
eèkw’o	eèh	į̀ı̨	eè	ıì	aàh	egeè

IC	impSg1	impSg2	impSg3	impDu1	impDu2	impDu3
datło	htł	netł	tł	łewìtł	łaahtł	łegetł
datł’ı̨	h	ne	Ø	wì	ah	ge
dayeehke	weeh	wı̨̀h	yeeh	wìì	waah	yegeeh
deghaegwo	eh	ı̨	e	ì	ah	gee
dek’enaetse	ehtse	ı̨tse	etse	ìtse	ahtse	geetse
dek’enèetł’è	èeh	į̀ı̨	èe	ìì	àah	ègee
dek’enèyeetł’è	weeh	wı̨̀ı̨	yee	wìì	waah	yegee
detı̨	dehtı̨	dı̨tı̨	detı̨	dıìte	dahte	geete
det’è	deht’è	dı̨t’è	det’è	dıìt’è	daht’è	geet’è
dezè	deh	dı̨	de	dıì	dah	gee
eʔà	ehʔ	neʔ	eʔ	wìt’	ahʔ	geʔ
eʔį̀	ehʔį̀	neʔį̀	eʔį̀	wìʔį̀	ahʔį̀	geʔį̀
edè	ehdè	nedè	edè	wìdè	ahdè	gedè
edǫ	eh	ne	e	wì	ah	ge
edze	eh	ne	e	wì	ah	ge
eèhkw’ǫ	eèh	į̀ı̨̀h	eèh	ıì	aàh	egeèh
eèkw’o	eèh	į̀ı̨̀	eè	ıì	aàh	egeè

Two approaches to building plats

(Sanskrit AŚVA ‘horse’)

	Nom	Voc	Acc	Ins	Dat	Abl	Gen	Loc
Sg	aśvas	aśva	aśvam	aśvena	aśvāya	aśvāt	aśvasya	aśve
Du	aśvau	aśvau	aśvau	aśvābhyām	aśvābhyām	aśvābhyām	aśvayos	aśvayos
Pl	aśvās	aśvās	aśvān	aśvais	aśvebhyas	aśvebhyas	aśvānām	aśveṣu

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Pl	aśvās	aśvās	aśvān	aśvais	aśvebhyas	aśvebhyas	aśvānām	aśveṣu

Distinguishers for a hearer-oriented plat

aśvas	aśva	aśvam	aśvena	aśvāya	aśvāt	aśvasya	aśve
aśvau	aśvau	aśvau	aśvābhyām	aśvābhyām	aśvābhyām	aśvayos	aśvayos
aśvās	ās	aśvān	aśvais	aśvebhyas	aśvebhyas	aśvānām	aśveṣu

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Du	aśvau	aśvau	aśvau	aśvābhyām	aśvābhyām	aśvābhyām	aśvayos	aśvayos
Pl	aśvās	aśvās	aśvān	aśvais	aśvebhyas	aśvebhyas	aśvānām	aśveṣu

Distinguishers for a hearer-oriented plat

aśvas	aśva	aśvam	aśvena	aśvāya	aśvāt	aśvasya	aśve
aśvau	aśvau	aśvau	aśvābhyām	aśvābhyām	aśvābhyām	aśvayos	aśvayos
aśvās	ās	aśvān	aśvais	aśvebhyas	aśvebhyas	aśvānām	aśveṣu

Distinguishers for a speaker-oriented plat

-s^{M}	– ^{M}	-m^{M}	-ina^{M}	-:ya^{M}	-:t^{M}	-sya^{M}	-i^{M}
-au^{M}	-au^{M}	-au^{M}	-:bhyām^{M}	-:bhyām^{M}	-:bhyām^{M}	-os^{M}	-os^{M}
-as^{M}	-as^{M}	-:n^{M}	-ais^{M}	-ibhyas^{M}	-ibhyas^{M}	-:nām^{M}	-iṣu^{M}

Two approaches to building plats

Here, we employ a **hearer-oriented** plat for Weledeh.

Try out our software for the analysis of plats:

http://www.cs.uky.edu/~raphael/linguistics/claw.html

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(All of the measurements given below were executed by means of this software.)

Measure 1 : Number of distillations

Two morphosyntactic property sets belong to the same **distillation** if and only if their exponence is interpredictable across all inflection classes.

Measure 1 : Number of distillations

A hypothetical plat

	ρ	σ	τ	υ	ϕ
I	**a**	**c**	**f**	**f**	**h**
II	**a**	**c**	**g**	**g**	**i**
III	**a**	**d**	**f**	**f**	**h**
IV	**b**	**d**	**g**	**g**	**i**
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VI	**b**	**e**	**g**	**g**	**i**

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IV	**b**	**d**	**g**	**g**	**i**
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VI	**b**	**e**	**g**	**g**	**i**

Measure 1 : Number of distillations

Two morphosyntactic property sets belong to the same **distillation** if and only if their exponence is interpredictable across all inflection classes.

The more distillations an inflection-class system has, the more complex it is.

Measure 1 : Number of distillations

Comaltepec Chinantec verbs	12
Czech nouns	13
French verbs	17
Fur verbs	9
Icelandic verbs	21
Koasati verbs	5
Kwerba verbs	4
Lithuanian nouns	9
Ngiti verbs	8
Palantla Chinantec verbs	11
Sanskrit nouns	13
Tuḷu verbs	7

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Sanskrit nouns	13
Tuḷu verbs	7
Weledeh verbs	27

Conjugation of Weledeh *datło* ‘dance’

		Singular	Dual	Plural
Imperfective	**1st**	*dahtło*	*dałewìtło*	*dagots’ewho*
	2nd	*danetło*	*dałaahtło*	*dagaahwho*
	3rd	*datło*	*dałegetło*	*dagogewho*
Perfective	**1st**	*daehtło*	*dałiìtło*	*dagots’įįwho*
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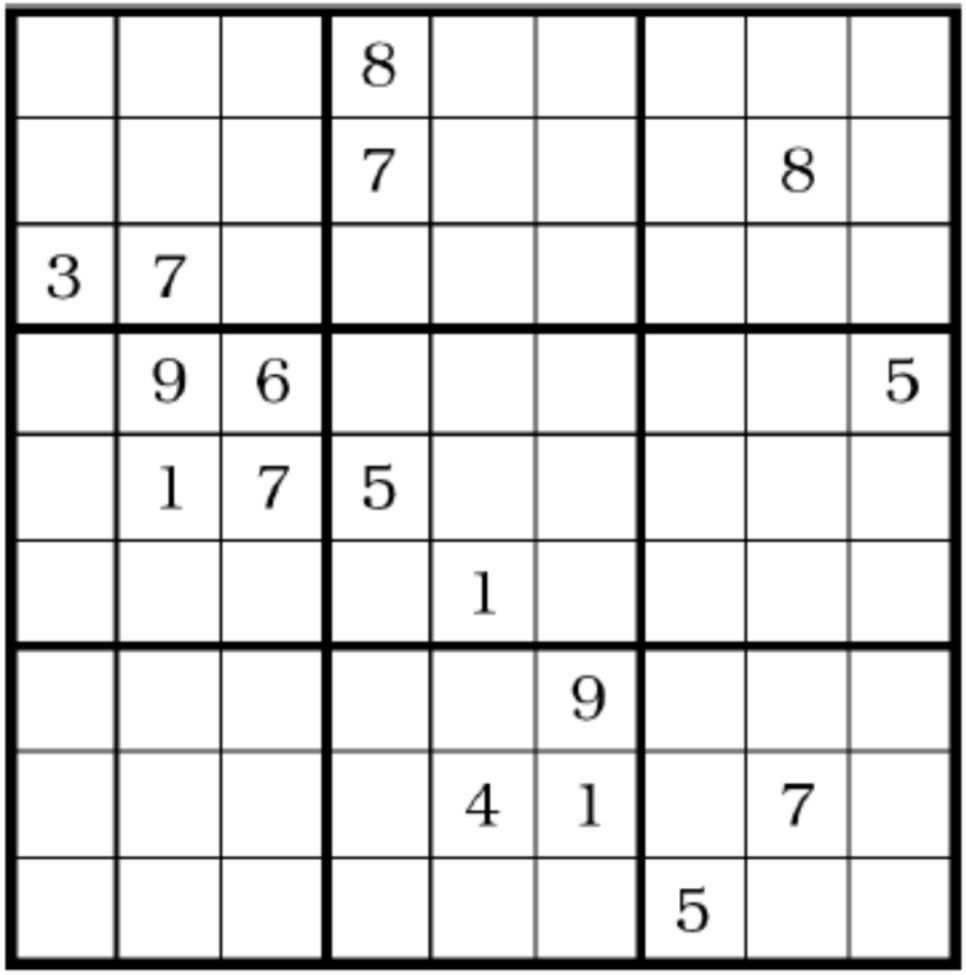
Optative	**1st**	*dauhtło*	*dałuùtło*	*dagots’iiwho*
	2nd	*daųtło*	*dałewahtło*	*dagowahwho*
	3rd	*dautło*	*dałegiitło*	*dagogiiwho*

Principal parts

Some measurements of an inflection-class system's complexity are based on the notion of **principal parts**.

Principal parts



Partial paradigm of Latin CAPERE ‘seize’

		Present	Past	Future	Infinitive
Infectum	1sg	***capiō***			***capere***
	2sg				
	3sg				
	1pl				
	2pl				
	3pl				
Perfectum	1sg	***cēpī***			
	2sg				
	3sg				
	1pl				
	2pl				
	3pl				

Partial paradigm of Latin CAPERE 'seize'

		Present	Past	Future	Infinitive
Infectum	1sg	***capiō***	*capiēbam*	*capiam*	***capere***
	2sg	*capis*	*capiēbās*	*capiēs*	
	3sg	*capit*	*capiēbat*	*capiet*	
	1pl	*capimus*	*capiēbāmus*	*capiēmus*	
	2pl	*capitis*	*capiēbātis*	*capiētis*	
	3pl	*capiunt*	*capiēbant*	*capient*	
Perfectum	1sg	***cēpī***	*cēperam*	*cēperō*	*cēpisse*
	2sg	*cēpistī*	*cēperās*	*cēperis*	
	3sg	*cēpit*	*cēperat*	*cēperit*	
	1pl	*cēpimus*	*cēperāmus*	*cēperimus*	
	2pl	*cēpistis*	*cēperātis*	*cēperitis*	
	3pl	*cēpērunt*	*cēperant*	*cēperint*	

Traditional principal parts of five Latin verbs

Conjugation	1sg present indicative active	Infinitive	1sg perfect indicative active	Perfect passive participle	Gloss
1st	*laudō*	*laudāre*	*laudāvī*	*laudātum*	'praise'
2nd	*moneō*	*monēre*	*monuī*	*monitum*	'warn'
3rd	*dūcō*	*dūcere*	*dūxī*	*dūctum*	'lead'
3rd (*-iō*)	*capiō*	*capere*	*cēpī*	*captum*	'take'
4th	*audiō*	*audīre*	*audīvī*	*audītum*	'hear'

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unique, uniform, optimal

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A set of principal parts for a lexeme L is a set of cells in L’s paradigm P from whose realization one can reliably deduce the realization of the remaining cells in P.

Two kinds of principal-part analysis

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Static principal parts

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Dynamic principal parts

In a dynamic principal-part scheme for an IC system, the optimal principal-part sets of lexemes belonging to distinct ICs may be different cells.

Measure 2 : Static principal-part number

An IC system's **static principal-part number** is its number of static principal parts on any optimal analysis.

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The higher an inflection-class system's static principal-part number, the more complex it is.

Measure 2 : Static principal-part number

Comaltepec Chinantec verbs	5
Czech nouns	5
French verbs	5
Fur verbs	5
Icelandic verbs	8
Koasati verbs	2
Kwerba verbs	1
Lithuanian nouns	3
Ngiti verbs	3
Palantla Chinantec verbs	6
Sanskrit nouns	4
Tuḷu verbs	2

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Measure 3 : Density of static principal-part sets

The **density of an IC system's static principal-part sets** is the ratio of actual to possible optimal static principal-part sets, given the system's number of distillations and the size of its optimal static principal-part sets.

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The lower the density of an IC system's static principal-part sets, the more complex it is.

Measure 3 : Density of static principal-part sets

	Number of optimal static principal-part sets		Density
	actual	possible	
Comaltepec Chinantec verbs	6	792	0.008
Czech nouns	6	1287	0.005
French verbs	5	6188	0.001
Fur verbs	4	126	0.032
Icelandic verbs	60	203490	< 0.001
Koasati verbs	1	10	0.100
Kwerba verbs	1	4	0.250
Lithuanian nouns	1	84	0.012
Ngiti verbs	6	56	0.107
Palantla Chinantec verbs	16	462	0.035
Sanskrit nouns	6	715	0.008
Tuḷu verbs	10	21	0.476

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Three optimal static principal-part analyses

(all orange and one blue)

		Singular	Dual	Plural
Imperfective	**1st**	*dahtłǫ*	*dałewìtłǫ*	*dagots'ewho*
	2nd	*danetłǫ*	*dałaahtłǫ*	*dagaahwho*
	3rd	*datłǫ*	*dałegetłǫ*	*dagogewho*
Perfective	**1st**	*daehtłǫ*	*dałiìtłǫ*	*dagots'ịịwho*
	2nd	*daịtłǫ*	*dałaahtłǫ*	*dagaahwho*
	3rd	*daetłǫ*	*dałegeaatłǫ*	*dagogịịwho*
Optative	**1st**	*dauhtłǫ*	*dałuùtłǫ*	*dagots'iiwho*
	2nd	*dauṭłǫ*	*dałewahtłǫ*	*dagowahwho*
	3rd	*dautłǫ*	*dałegiitłǫ*	*dagogiiwho*

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Measure 4 : Dynamic principal-part number

Comaltepec Chinantec verbs	1.84
Czech nouns	1.68
French verbs	1.25
Fur verbs	1.58
Icelandic verbs	1.56
Koasati verbs	1.00
Kwerba verbs	1.00
Lithuanian nouns	1.17
Ngiti verbs	1.60
Palantla Chinantec verbs	2.52
Sanskrit nouns	1.21
Tuḷu verbs	1.00

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The lower the average density of an IC system's optimal dynamic principal-part sets, the more complex it is.

Measure 5 : Density of dynamic principal-part sets

Comaltepec Chinantec verbs	20.3%
Czech nouns	21.8%
French verbs	42.2%
Fur verbs	17.3%
Icelandic verbs	23.9%
Koasati verbs	58.3%
Kwerba verbs	43.8%
Lithuanian nouns	50.0%
Ngiti verbs	23.8%
Palantla Chinantec verbs	10.5%
Sanskrit nouns	30.0%
Tuḷu verbs	38.1%

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Palantla Chinantec verbs	10.5%
Sanskrit nouns	30.0%
Tuḷu verbs	38.1%
Weledeh verbs	59.3%

Inflection-class (IC) predictability

Intuitively, the IC predictability of a lexeme L's IC is the fraction of adequate (though not necessarily optimal) dynamic principal-part sets among all nonempty subsets of cells in L's paradigm.

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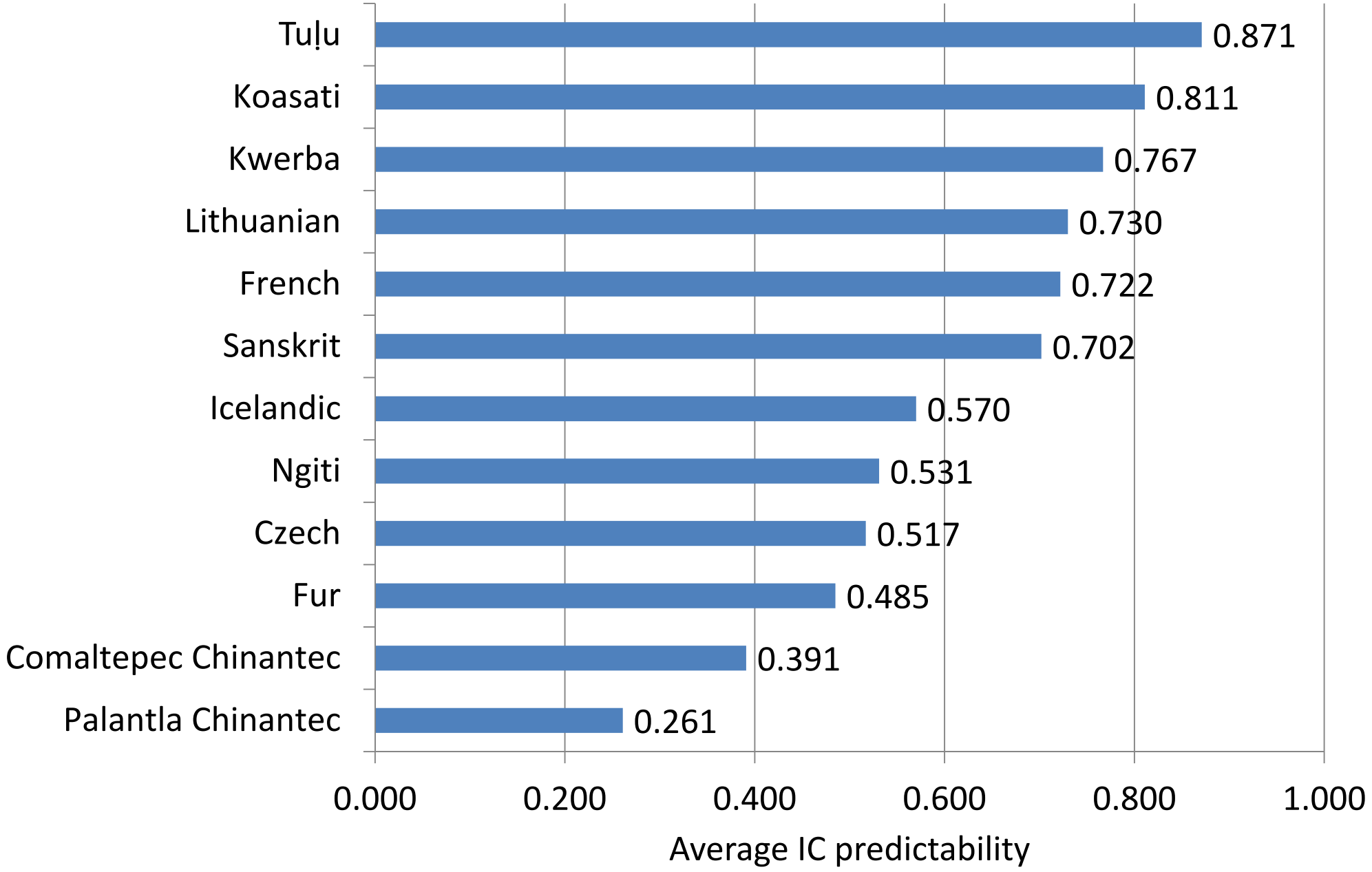
The lower the average IC predictability an IC system's inflection classes, the more complex it is.

Measure 6 : Average inflection-class predictability



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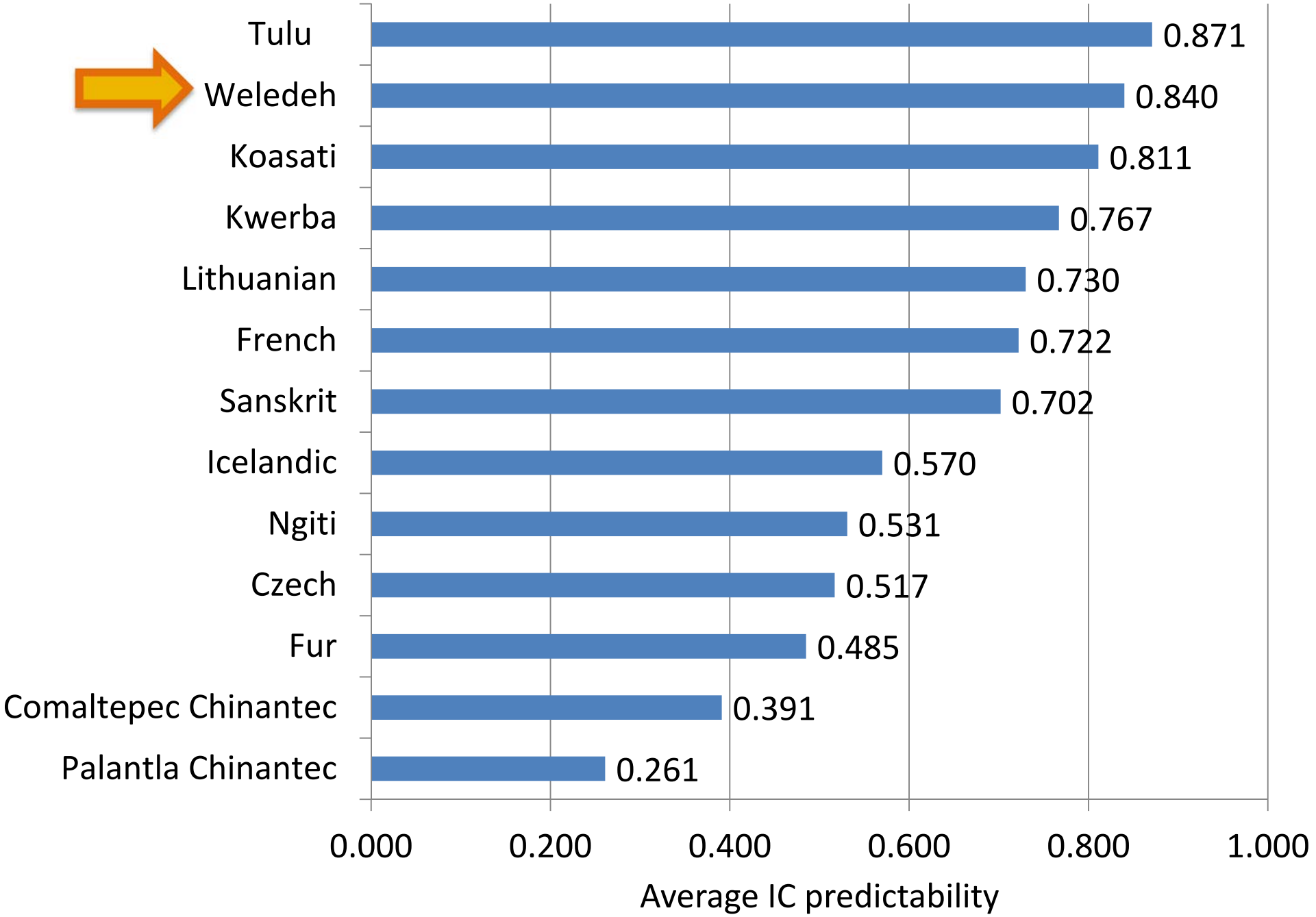

Measure 7 : Average *n*-MPS entropy

Entropy is an information-theoretic measure of uncertainty, first proposed by Claude Shannon in the mid-20th century.

Shannon, Claude E. 1948. A mathematical theory of communication. *Bell System Technical Journal* 27. 3, 379–423.

Shannon, Claude E. 1951. Prediction and entropy of printed English. *Bell System Technical Journal* 30.1, 50–64.

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If it has four equally probable realizations **a b c d**, the entropy of M is 2.

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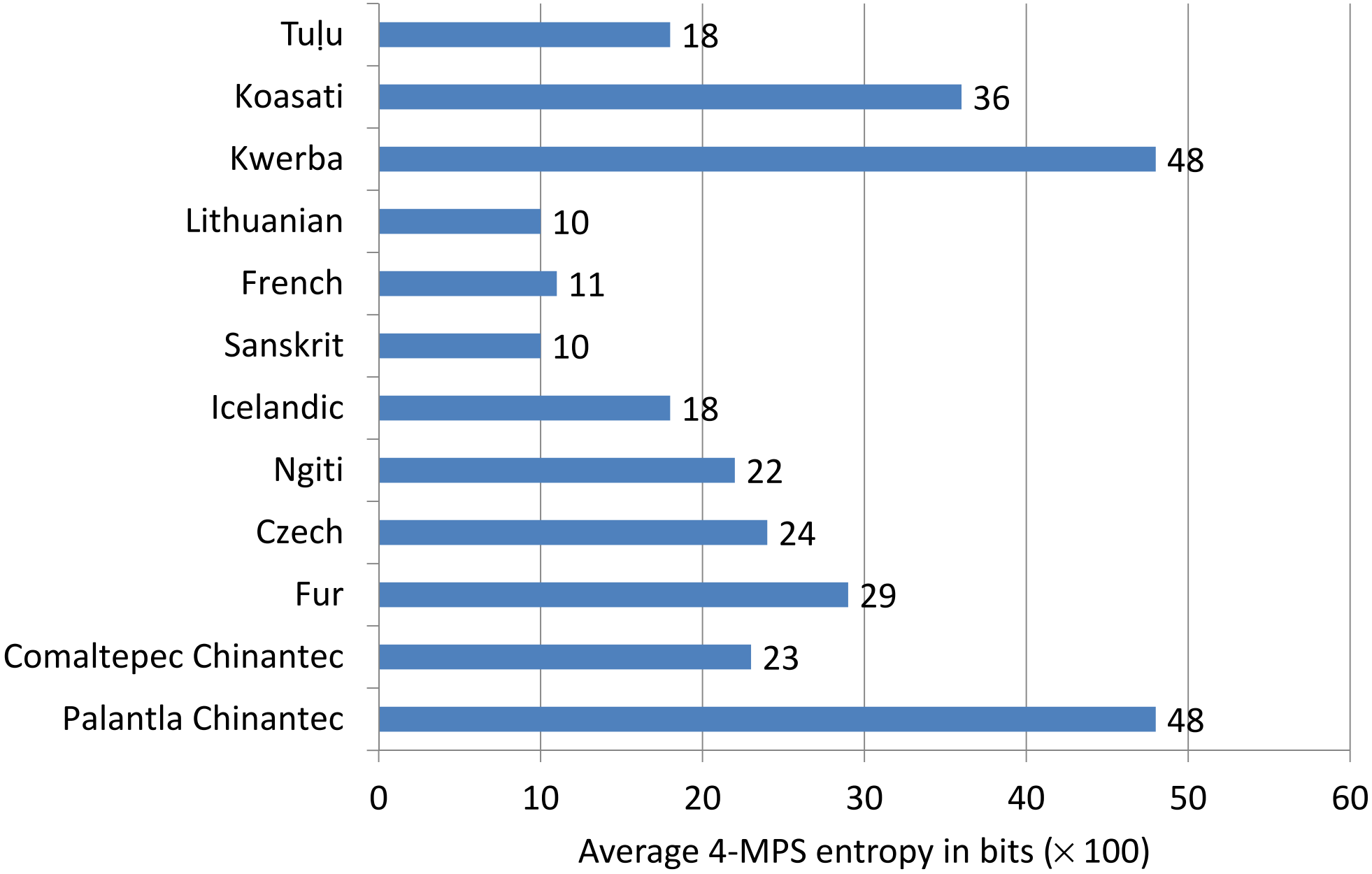

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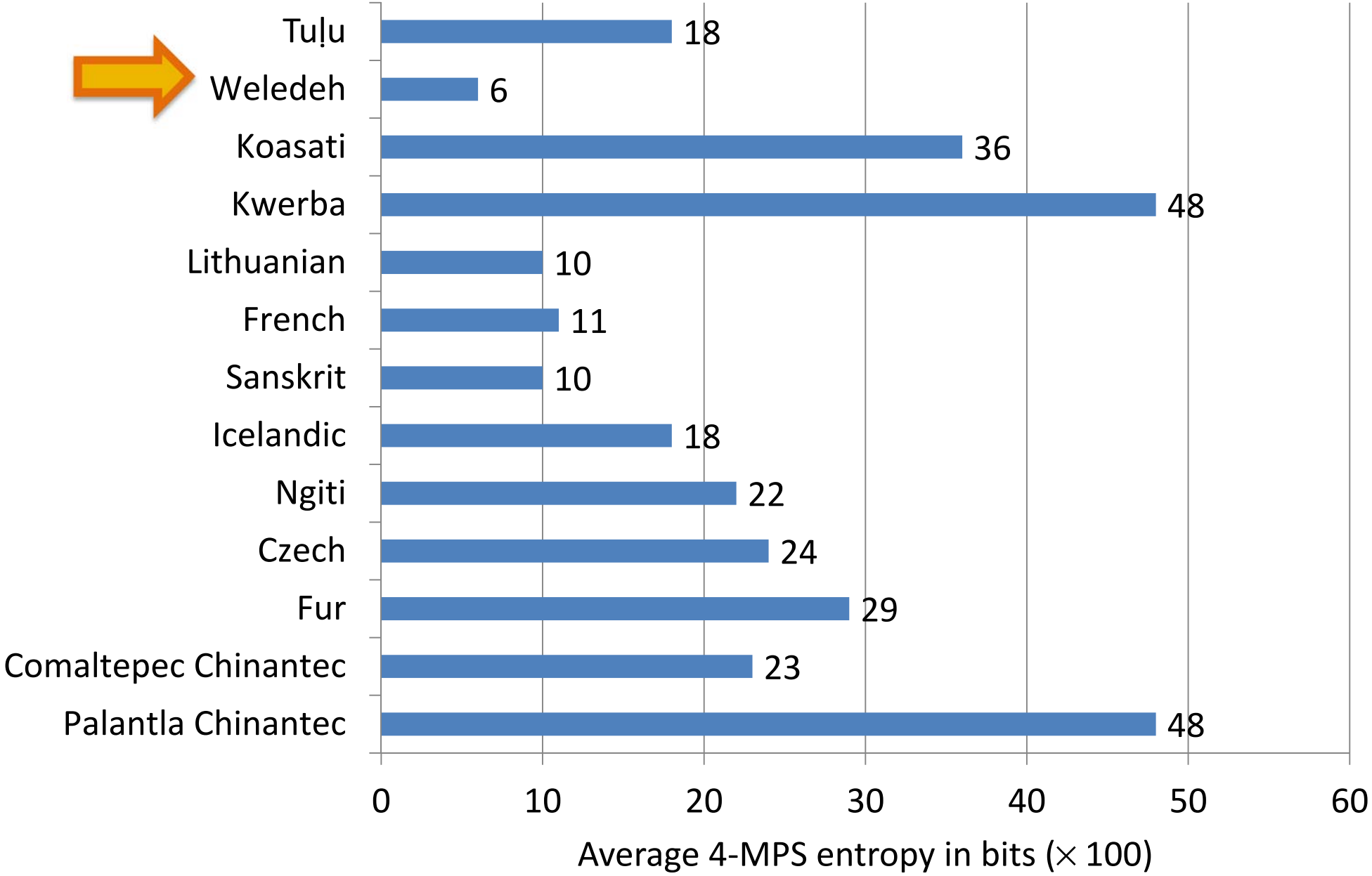

Summary and conclusions

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2. The optimal static principal part number is high, and the density of optimal static analyses is extremely low; yet, the optimal dynamic principal part number is low and the density of optimal dynamic analyses is very high. This shows that inflection-class membership can, in many paradigms, be deduced from a single diagnostic cell, but that the identity of this cell varies from one inflection class to another.

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3. The high IC predictability and the low entropy show that despite the fact inflection classes are very different, they are nevertheless alike in being highly predictable.

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We further anticipate that as we develop a speaker-oriented plat for Weledeh verbs (one in which the effects of sandhi processes and morphophonological alternations are factored out), we will likely get very different results:

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We further anticipate that as we develop a speaker-oriented plat for Weledeh verbs (one in which the effects of sandhi processes and morphophonological alternations are factored out), we will likely get very different results:

when a hearer-oriented plat is converted into a speaker-oriented plat,

- distinct inflection classes may collapse together (because sandhi-induced differences are factored out) and
- phonologically identical exponents may become different (because morphological boundaries and grammatical differences are explicitly represented).