Journal of Linguistics (2025), 1–29
doi:10.1017/S0022226725000052

Journal of Linguistics CAMBRIDGE UNIVERSITY PRESS

RESEARCH ARTICLE

System size and system complexity: A case study in Pamean nouns and verbs

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Received: 07 July 2023; **Revised:** 15 January 2025; **Accepted:** 18 November 2024

Keywords: complexity; morphology; Otomanguean; PCFP; type frequency

Abstract

Inflectional systems vary along multiple dimensions (number of members, size of paradigms, word class, integrative complexity, accidents of history, etc.). This makes it difficult to find significant correlations and causality relations between different properties, as attested systems usually differ in multiple ways at the same time, thus obscuring possible relations between individual variables. Here we analyze the relation between a system's size by number of members and its morphological complexity. We do so by exploring in detail, via quantitative methods, the cognate inflectional systems of Central Pame and Chichimec (Otomanguean, Mexico), whose inflecting nominal classes differ precisely mostly with regard to their size (i.e. number of members).

1. Introduction

The structure of inflectional systems is often seen as the interplay between storage and computation (e.g. Pinker 1997; Bertram, Schreuder & Baayen 2000; Baayen 2007). Given the highly irregular morphology of some paradigms (e.g. suppletion, Corbett 2007) and the extremely low frequency of many items and word forms in natural speech (Zipf 1932; Blevins, Milan & Ramscar 2017), what is memorized, and what is derived by rule must certainly coexist in language. These modules have come to be referred to as the LEXICON and the GRAMMAR, respectively, and their balance and interaction have long been major topics of research. The size and the complexity of a system naturally reflect this contrast: storage space is limited (i.e. 'small') but its contents are under no obligation to be systematic (i.e. can be 'complex'). Computation is open-ended (i.e. can be 'large') but must be tractable (i.e. 'simple'). This generates predictions about what inflectional systems should be like. All things equal, a smaller system should be allowed to be more complex than a larger one because, in principle, a larger portion of it could be memorized. The 'size' of an inflectional system, however, might refer to two completely independent dimensions: (a) the number of word forms in the paradigm and (b) the number of lexemes.

While some research has explored (a) (see Cotterell, Kirov, Hulden & Eisner 2019), we know of no research that has tackled (b). This constitutes the goal of this paper. Furthermore, we employ a novel methodology to uncover potentially causal dependencies between system size and system complexity. Rather than using a large cross-linguistic sample (like Cotterell et al. 2019), we approach this by zooming in on two closely related languages that, we argue, differ significantly only in the crucial factor we are interested in, namely system size. This focus on genetically related inflectional systems allows us to control for the various variables along which unrelated languages generally differ.

The remainder of this paper is structured as follows. Section 2 provides more details about the topics of inflectional system size and complexity and extant approaches to exploring their interaction. Section 3 describes the inflectional systems of Central Pame and Chichimec (Oto-Pamean, Otomanguean), which we rely on for the rest of the paper. Section 4 presents the concrete data and methods regarding how phonological forms were processed and why; Section 5 presents the quantitative results in detail. Section 6 discusses their significance in the theoretical and typological context. Section 7 wraps up the paper by summarizing its main findings and presenting avenues for future research.

2. Background

Hand in hand with the democratization of computing power, the past couple of decades have witnessed an increase in quantitative approaches to morphology (e.g. Stump & Finkel 2013, Cotterell et al. 2019). Regarding the exploration of paradigmatic structures, there has been a revived interest in what has come to be known as the Paradigm Cell Filling Problem (PCFP, Ackerman, Blevins & Malouf 2009), which asks how speakers are able to produce inflected forms that they have never encountered before. The morphological predictability relations within the paradigm (e.g. the fact that in Latin a form *mīsī* as the first person singular perfect active indicative of 'send' entails a form *mīserant* as the third-person plural pluperfect active indicative; see Pellegrini 2020) must be registered and actively used by language users of highly inflecting languages. Although notions like principal parts (e.g. *mittō, mittere, mīsī, mīssum* in the Latin verb above) have been used for a long time in the teaching of classical languages (see Finkel & Stump 2009), the popularization in the study of morphology of Information Theory and its core notion of Entropy (Blevins 2013) and also of Set Theory (Stump & Finkel 2013) and Graph Theory (Sims & Parker 2016) have made it possible, together with the constant increase of computing power, to explore these predictive relations in an objective, exhaustive, and replicable way.

A central concern of this work is the notion of COMPLEXITY (see Herce forthcoming for a summary of the state of the art). On this topic, multiple metrics have emerged, like conditional and unconditioned entropies, static and dynamic principal parts, cell predictiveness and predictability, etc. These various measures and notions are needed because inflectional systems are complex structures that cannot be reduced to any one single measure. Instead, different measures capture different aspects of an inflectional system's web of predictability. Alongside these newer measures of the 'integrative complexity' (Ackerman & Malouf 2013) of an inflectional system, the older 'enumerative complexity'

https://doi.org/10.1017/S0022226725000052 Published online by Cambridge University Press

metrics (number of inflection classes, number of cells, number of exponents, number of members, etc.) continue to be, of course, relevant and widely used.

These different aspects of an inflectional system need not be independent of each other. For example, larger paradigms (i.e. those with a greater number of word forms or cells) might require a greater level of regularity (i.e. lower integrative complexity, as measured for example by conditional entropies) to be learnable and usable by the human brain under conditions of finite and Zipfian input. Similarly, inflectional systems and word classes with more members might also be expected to have a greater need for predictability. The principle at work would be similar. Rote memorization must have some upper limit (see e.g. Miller 1956 on short-term memory and Landauer 1986 on long-term memory). Inflectional systems (see e.g. Wutung verbs [Marmion 2010] or Murrinh-Patha verbs [Mansfield 2016]) and word classes (e.g. adpositions [Herce 2024a], or pronouns [see Cysouw 2009]) that have fewer members would come closer to being contained entirely within that range where complexity has 'free rein'.

The exploration of these interdependencies and causality relations is complicated by the fact that unrelated inflectional systems usually vary along multiple dimensions simultaneously. Thus, the systems compared might differ not only in the variables of interest (e.g. number of cells and conditional entropies) but also in various other unrelated variables, such as the number of lexemes, their word class, the sociolinguistic history of the communities, etc. The latter then act as confounds that obscure correlations or dependencies between paradigm size and conditional entropies.

One approach to uncover these dependencies is to assemble a large enough sample of inflectional systems. This approach (taken for example by Cotterell et al. 2019) trusts that enough data will reduce to noise all the variation that is not due to the predictor variable at stake. The true (cor)relation between paradigm size and conditional entropies should thus surface as a statistically detectable signal from among this noise. Following this approach, Cotterell et al. find that systems in their sample may be large (in terms of number of distinct forms in the paradigm) or irregular (low interpredictability of forms) but not both, which suggests a tradeoff between system size and complexity. This approach provides insight into the nature of the tradeoff between size and complexity and will become increasingly powerful as the state of worldwide linguistic documentation improves. At present, it does have, however, important shortcomings, related, for example, to the genetic diversity of the sample. Almost half (79 of 167) of the languages in the largest available database of inflectional systems (Unimorph, Kirov et al. 2018) are Indo-European, and all of the ones with over 10,000 documented lexemes are either Indo-European (14) or Uralic (5). This is an important confound because most quantitative aspects of inflectional systems seem to be highly inheritable (Herce & Bickel forthcoming), which means that related systems should not count as independent data points. Idiosyncratic aspects of the best documented families could thus be mistaken for significant associations.

An alternative and complementary approach to uncovering these associations between different aspects of inflectional systems would be to narrow the focus, by looking at cognate systems that vary along discrete parameters. That way we can control for most of the variation that represented noise or confounds before. This is the approach we pursue here (see also Bonami & Henri 2010, Baechler 2016, and Di Garbo & de Souza 2023), whose focus, derived from the characteristics of the analyzed cognate systems, will be on the RELATION BETWEEN SYSTEM COMPLEXITY (under its various integrative and enumerative complexity senses) and the NUMBER OF LEXICAL ITEMS IN A WORD CLASS, a factor not previously investigated. We will explore their relationship by evaluating in detail the quantitative similarities and differences between the verbal and nominal inflectional systems of Chichimec (chic1272) and Central Pame (cent2145), which are highly inflecting Oto-Pamean languages spoken in North-Central Mexico. These two languages have similar systems of person-number inflection, and, in each language, this system is found with both nouns and verbs (for possessor and subject, respectively). In one point, though, there is a major difference: the word class of inflecting nouns in Chichimec contains a much smaller number of lexemes than the cognate one in Central Pame. This allows us to observe the effect of lexicon size both language-internally (comparing between nouns and verbs) and across languages (comparing Chichimec and Central Pame). Our study, thus, contributes to our understanding of complexity by considering languages and traits not previously investigated.

3. Inflection in Chichimec and Central Pame

Chichimec and Central Pame are related (Oto-Pamean) languages spoken in the Mexican states of Guanajuato and San Luis Potosí, respectively. Chichimec is spoken by around 800 people in Misión de Chichimecas, mostly by adults, and is hence classified as ‘shifting’ by Glottolog (Hammarström, Forkel, Haspelmath & Bank 2021). Central Pame is spoken by around 5,000 people in Santa María Acapulco and various smaller communities around it, where it is often still being acquired by children. It is classified as ‘threatened’ by Glottolog.

Although the estimates for their date of divergence differ widely (between 5500 BP by Josserand, Winter & Hopkins 1984 and 3600 BP by Kaufman 2006:819), the languages are certainly related and their inflectional systems are cognate, as they are structured in a completely parallel way that would be most unlikely to have emerged independently (see Bartholomew 1965). Verbal inflection in the two languages involves tense-aspect-mood (TAM) marking (six to eight categories) and agreement for person (1, 2, 3, INCL) and number (SG, DU, PL) of the subject (the S of intransitive verbs, A in transitives) and the person (1, 2, 3, INCL) and number (SG, DU, PL) of an object if there is one. Inflection involves interwoven prefixes, suffixes, stem alternations and tonal alternations, all of which fall into a large number of inflection classes. We rely on Angulo (1933) and Feist & Palancar (2019) for the Chichimec verb data and on Olson (1955) for the Central Pame verb data.

Illustrative partial paradigms can be found in Tables 1 and 2. The verbs ‘scold’ and ‘do so’ belong to different inflection classes in both languages, which means that they take different morphology for the expression of the same inflectional values. These are broken down by

Table 1. Present tense forms of two Chichimec verbs

	Chichimec ‘scold’ PRS			Chichimec ‘do so’ PRS		
	SG	DU	PL	SG	DU	PL
1.EX	é-tsó	é-tsó-mp	é-tsó-hų	tú-ʔę	tú-ʔę-mp	tú-ʔę-hų
1.INCL	-	é-tsó-s	é-tsó-n	-	tú-ʔę-s	tú-ʔę-n
2	kí-tʃo	kí-tʃo-s	kí-tʃo-n	sú-ʔę	sú-ʔę-s	sú-ʔę-n
3	é-tsó	é-tsó-s	é-tshó-r	ú-ʔę	ú-ʔę-s	ú-ʔę-r

https://doi.org/10.1017/S0022226725000052 Published online by Cambridge University Press

Table 2. Present tense forms of the cognate verbs in Central Pame

	Central Pame 'scold' PRS			Central Pame 'do so' PRS		
	SG	DU	PL	SG	DU	PL
1.EX	la-ttsú	ta-ttsú-bmʔ	ta-ttsú-bmʔ	to-ʔwḛ̂i̜	to-ʔwḛ̂i̜-bmʔ	to-ʔwḛ̂i̜-bmʔ
1.INCL	-	ta-ttsú-i	ta-ttsú-dn	-	to-ʔwḛ̂i̜	to-ʔwḛ̂i̜-dn
2	ki-ttʃû	ki-ttʃû-i	ki-ttʃû-dn	to-ʔwḛ̂i̜	to-ʔwḛ̂i̜	to-ʔwḛ̂i̜-dn
3	wa-ttsú	wa-ttsú-i	tsʔú	lo-ʔwḛ̂i̜	lo-ʔwḛ̂i̜	wa-tʔḛ̂i̜

Table 3. Breakdown of the Chichimec inflection class distinctions in Table 1

	prefixes		tone		stem	
	'scold'	'do so'	'scold'	'do so'	'scold'	'do so'
1	e-	tu-	HH	HL	tso	ʔḛ
2	ki-	su-	HL	HL	tʃo	ʔḛ
3SG/DU	e-	u-	HH	HL	tso	ʔḛ
3PL	e-	u-	HH	HL	tsho	ʔḛ

Table 4. Breakdown of the Central Pame inflection class distinctions in Table 2

	prefixes		tone		stem	
	'scold'	'do so'	'scold'	'do so'	'scold'	'do so'
1SG	la-	to-	H	F	ttsu	ʔwḛi̜
1DU/PL	ta-	to-	H	F	ttsu	ʔwḛi̜
2	ki-	to-	F	F	ttʃu	ʔwḛi̜
3SG/DU	wa-	lo-	H	F	ttsu	ʔwḛi̜
3PL	∅-	wa-	H	F	tsʔu	tʔḛi̜

prefix, tone, and stem in Tables 3 and 4. Inflection class distinctions are particularly prominent in prefixes (e.g. e- vs. tu- or la- vs. to- in the verbs above in the 1SG). In addition to this, tonal[1] and stem changes are also found, which can differ from one verb to the other. Notice with respect to tone, for example, that in both languages the verb 'scold' has an alternating tonal pattern (high-high ~ high-low in Chichimec; high ~ falling in Central Pame), while the verb 'do so' has fixed tone (high-low in Chichimec, falling in Central Pame). Regarding stem alternations, notice that the 3PL subject tends to be marked by a stem

[1] In Chichimec, every syllable can receive one of two tones: high, marked with an acute accent here (e.g. é, ó), and low, which is left unmarked. In Central Pame, stress and tone go together, with the stressed syllable receiving one of three tones: high, marked with an acute accent (e.g. é, ó); low, marked with a grave accent (e.g. è, ò); and falling, marked with a circumflex (e.g. ê, ô).

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different from the one found elsewhere but not in all verbs (see 'do so' in Chichimec) and not in the same way across verbs (with variously glottalization /ʔ/, aspiration /h/, and the addition of /t/ in the above verbs). Suffixes stand apart; these mark person-number and are invariant across both lexemes and TAM values, apart from relatively transparent morphophonological adjustments (e.g. Central Pame dual -i is absorbed by a stem ending in /i/ in 'do so'). Because of this, they do not interact with inflection class distinctions and will be ignored in the rest of this paper.

The inflectional morphological structure in Tables 1 and 2 is iterated, usually with different prefixes and often with different stem and tone alternation patterns, in other values of TAM, of which the present tense above (also known as real progressive) is one of six different values (real progressive, unreal progressive, real perfective, unreal perfective, potential, and neutral) in Central Pame and one of eight different values (present, anterior past, recent past, immediate past, future, potential, sequential, and negative) in Chichimec. These will not be presented here for lack of space, but their morphological traits can be consulted in the supplementary materials.

Nominal inflection in the two languages has many similarities with verbal inflection. It involves number (SG, DU, and PL) of the noun and agreement in person (1, 2, 3, INCL) and number (SG, DU, PL) with a possessor. Possessor agreement is expressed in a way closely resembling subject agreement on verbs within a particular TAM, i.e. by a complex assemblage of prefixes, stem alternations, and tonal changes, all of which distinguish a large number of inflection classes. We rely on Herce (2022) for the Chichimec data and on Gibson & Bartholomew (1979) for the Central Pame data.

As in verbs before, we see in Tables 5 and 6 that different nouns, in both Chichimec and Central Pame, make use of different morphological strategies to encode the same values, thus requiring us to recognize different inflection classes (see Tables 7 and 8). Also as with

Table 5. Forms of two Chichimec nouns (SG possessum)

	Chichimec 'belly'			Chichimec 'needle'		
	SG	DU	PL	SG	DU	PL
1.EX	ná-mba	ná-mba-ʔų	ná-mba-hų	ta-ʔí	ta-ʔí-ʔų	ta-ʔí-hų
1.INCL		ná-mba-s	ná-mba-n	-	ta-ʔí-s	ta-ʔí-n
2	u-ngʷá	u-ngʷá-s	u-ngʷá-n	kí-ʔi	kí-ʔi-s	kí-ʔi-n
3	ú-β̃a	ú-β̃a-s	ú-pʔa	ta-ʔí	ta-ʔí-s	ta-rʔí

Table 6. Forms of the cognate nouns in Central Pame (SG possessum)

	Central Pame 'belly'			Central Pame 'needle'		
	SG	DU	PL	SG	DU	PL
1.EX	na-mbâo	na-mbâ-bmʔ	na-mbâ-bmʔ	ta-ʔæ̀	ta-ʔæ̀-bmʔ	ta-ʔæ̀-bmʔ
1.INCL	-	na-mbâo-i	na-mbâo-dn	-	ta-ʔæ̀-i	ta-ʔæ̀-dn
2	ŋgo-wào	ŋgo-wào-i	ŋgo-wào-dn	ki-ʔæ̀	ki-ʔæ̀-i	ki-ʔæ̀-dn
3	ŋgo-mâo	ŋgo-mâo-i	ŋgo-bâ-pt	na-ʔæ̀	na-ʔæ̀-i	na-lʔæ̀-pt

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Table 7. Breakdown of the inflection class distinctions in Table 5

	prefixes		tone		stem	
	'belly'	'needle'	'belly'	'needle'	'belly'	'needle'
1	na-	ta-	HL	LH	mba	ʔi
2	u-	ki-	LH	HL	ngʷa	ʔi
3SG/DU	u-	ta-	HL	LH	β̃a	ʔi
3PL	u-	ta-	HL	LH	pʔa	rʔi

Table 8. Breakdown of the inflection class distinctions in Table 6

	prefixes		Tone		stem	
	'belly'	'needle'	'belly'	'needle'	'belly'	'needle'
1	na-	ta-	F	L	mbao	ʔæ
2	ŋgo-	ki-	L	L	wao	ʔæ
3SG/DU	ŋgo-	na-	F	L	mao	ʔæ
3PL	ŋgo-	na-	F	L	bao	lʔæ

verbs, inflectional differences involve prefixes (see e.g. na- and ta- in the 1SG in both languages), tones (notice a high-low tonal pattern in the 1SG of Chichimec 'belly', opposed to low-high in the same cell of 'needle'), and stems (e.g. no alternation in 'needle' except in the 3PL vs. more robust stem alternations in 'belly'). Suffixes, as in verbs, are stable across the lexicon and only predictable morphophonological adjustments occur at the contact between stem and suffix (e.g. *nambâ-bmʔ* above, rather than *nambâo-bmʔ*, due to the loss of a back rounded vowel adjacent to a bilabial consonant). They will be ignored through the rest of this paper.

The nominal morphological description provided above, however, applies only to a subclass of nouns in each language, which we will call here 'inalienable'.[2] Other nouns (i.e. 'alienables') behave very differently in that they do not show possessor agreement via prefixal, stem, and/or tonal changes but in an alternative way. In Chichimec (see e.g. 'tomato' in Table 9), alienable nouns are obligatorily preceded by one of four classifiers (the one in Table 9 being the most general one), which express the person and number of the possessor in ways analogous to the inalienable nouns of Table 5. In Central Pame, alienable nouns (see e.g. 'stone' in Table 9) take possessor suffixes only (-k for 1, -kʔ for 2, and -p for 3),[3] which are different from the possessor suffixes of inalienables (see Table 6). Overall, thus, in both languages, the morphological difference between the two classes is very pronounced (much

[2] This has been the term given to this class in previous publications (e.g. Lastra 2004), and we keep it here for convenience to refer to this highly inflecting class of nouns in the two languages. It must be noted, however, that the match with logically inalienable notions is far from perfect. Although most kin terms and body parts belong in this class, many do not (e.g. in Central Pame 'aunt' or 'chin'). Conversely, many logically alienable notions belong in the inalienable class (e.g. 'water', 'needle', 'flower', or 'salt' in either language).

[3] Continuing the parallels with verbal morphology, these have the same shape as object suffixes in verbs.

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Table 9. Expression of possession in the class of alienable nouns

	Chichimec ’tomato’			Central Pame ’stone’		
	SG	DU	PL	SG	DU	PL
1.EX	nantʔé embé̤	nantʔé-ʔų embé̤	nantʔé-hų embé̤	kotô-k	kotô-kʔŋ	kotô-kʔŋ
1.INCL	-	nantʔé-s embé̤	nantʔé-n embé̤	-	kotô-i-k	kotô-kŋ
2	útʔe émbe̤	útʔe-s embé̤	útʔe-n embé̤	kotô-kʔ	kotô-i-kʔ	kotô-kʔŋ
3	utʔé embé̤	utʔé-s embé̤	útsʔa émbe̤	kotô-p	kotô-p	kotô-pt

more so than between strong and weak verbs in Germanic) and immediately obvious in most inflected forms.

The rest of this paper will focus on the ’inalienable’ class (Tables 5–8). Crucially, in Chichimec this is a closed word class with around 160 members (see Herce 2022), while in Central Pame it is certainly a much larger one. In the extant documentation (Gibson & Bartholomew 1979, Gibson 1994b), around half of all nouns are of the inalienable class in Central Pame. Although a concrete number of nouns in Central Pame (or English for that matter) is difficult to estimate, it seems safe to say that any language should have at least thousands of nouns (see Dixon 2010:102). This means that the number of inalienable nouns in Central Pame should be over 1,000. This is the key difference central to the observations made in this paper.

Besides the number of members, other significant differences between the inalienable nouns in the two languages are hard to find. The two are (practically) identical regarding word class, paradigm size, the morphological devices and structures involved, etc. They also seem comparable regarding usage frequency. Although naturalistic corpora would need to be compiled and consulted for this, it is our impression that the average token frequencies of the members of the two subclasses could be indeed similar. Morphologically irregular subclasses in other languages, for example Germanic strong verbs, often lack a semantic core or motivation. Their synchronic membership is hence semantically arbitrary and merely the result of leveling (e.g. Eng. *help holp holpen* > *help helped helped*), with less frequent lexemes shifting more quickly over time than more frequent lexemes (Lieberman, Michel, Jackson, Tang & Nowak, 2007). A larger class of strong verbs in one language might be expected to be more morphologically regular than a smaller class of strong verbs in another not only due to its lower number of members but also, crucially, because of their lower average token frequency. The loss of members[4] of the inalienable class in Chichimec, however, does not seem to have come about primarily as a result of the regularization of less frequent nouns but rather as a result of the expansion of the possessive classifier system to more and broader semantic domains (see Herce 2022 for details). Thus, for example, the animal classifier in Chichimec applies to all animal-denoting nouns regardless of their frequency. The nouns that have been left behind in the inalienable class, therefore, were not

[4] Although this is not certain, it seems that the current ’inalienable’ class is the older one. This is suggested by the shared morphology in this class between Chichimec and Central Pame (see e.g. Tables 3 and 4) compared to the lack of agreement between the languages regarding the morphosyntactic behavior of the ’alienable’ class. If this is right, the ’inalienable class’ might have been losing members for a long time in both languages, with one of them (Chichimec) having simply progressed further along this path.

https://doi.org/10.1017/S0022226725000052 Published online by Cambridge University Press

necessarily the most frequent, but simply those that did not match the semantic domain of the novel possessive classifiers.

The general similarity of the inflectional systems of Chichimec and Central Pame observed in Tables 1–8 is perhaps unsurprising because, after all, they are cognate. The sociolinguistic characteristics of the communities must also have been identical until separation and quite similar from then until colonial times. Thus, given that the number of members in the inflecting noun classes has been the aspect that has diverged the most between the two languages, any quantitative complexity differences encountered between them could be, quite plausibly, causally related to it. The following subsection will present the datasets used and the processing choices adopted.

4. Datasets and methods

For a replicable quantitative assessment of inflectional system complexity, we need (i) large and reliable inflected lexica and (ii) a thorough description of how raw forms were processed (e.g. with regard to segmentation) and which analytical decisions were adopted and why. This subsection will be concerned with both of these goals.

As raw data, we need the word forms that make up paradigms. Ideally, we would have complete paradigms of as many lexemes as possible, with the word forms transcribed in phonological form. The availability of high-quality datasets for both languages was an important impetus to the present study. Chichimec verbs were originally documented by Angulo (1933) and have recently been further explored by Lastra (2018), Lizárraga Navarro (2018), Palancar & Avelino (2019), and Feist & Palancar (2021). The inflected lexicon at the Otom-Manguean Inflectional Class Database (Feist & Palancar 2015) provided the source of our data. Chichimec nouns were described originally by Angulo (1933). Other more recent research on the system includes Lastra (2004) and Herce (2022), which provides the source of the data analyzed in this paper when it comes to nouns. Central Pame verbs, in turn, were described, in the Tagmemic tradition, by Olson (1955), and later by Gibson (1994a). The former provides the data for this paper.[5] Central Pame nouns, in turn, were described by Gibson & Bartholomew (1979) and also by Gibson (1994b), which provides most of the data analyzed in this paper.[6]

The total number of lexemes analyzed here in each word class and language is provided in Table 10. As it shows, a comparable (and substantial) number of them have been assembled

Table 10. Size of the datasets

	Verbs	Nouns
Chichimec	168	159
Central Pame	126	191

[5] A larger dataset (Herce 2024b) has appeared since this paper was written.

[6] The first author of this paper supplemented these with the inflectional paradigms of Central Pame kin terms (collected in fieldwork in May 2022), which were absent from Gibson (1994b) and Gibson & Bartholomew (1979).

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for nouns and verbs in each language, which avoids any quantitative predictability differences due to different sample sizes. The available sample of Chichimec inalienable nouns (in gray) is exhaustive, or nearly so, hence closely approximating the overall size of the class, while the other classes have a much larger number of members.

Individual phonological forms in these datasets were all processed in the same way: prefixes and stems were segmented as in Tables 1 through 4, i.e. with prefixes always vowel final (or zero, see the 3PL.PRS of Central Pame 'scold' in Table 2) and stems always consonant-initial, including the complete consonant cluster after the prefix vowel. This segmentation choice (adopted for example in Palancar & Avelino 2019) is not the only logically possible one. Olson (1955) adopts a slightly different one by which some prefixes can finish in a nasal and by which most of the allomorphy of the 3PL is handled via prefixes (plus complex morphophonological operations). By doing this, he assigns more morphological ACTION to prefixes and less to stems.[7] Some reasons to prefer the former segmentation are given in Herce (2022), but the main reason why segmentation choices matter to us is that, for comparability, they need to be homogeneous across word classes and languages, which is why Olson's (1955) forms were RESEGMENTED here to match the choices adopted in the extant descriptions of the other inflectional systems.

Our segmentation, thus, leaves us with three logically independent layers within each inflectional system: prefixes (probably the most important one as judged by the number of distinct forms within a lexeme), stems, and tones, all of which contribute to the morphological discriminability of word forms. It is thus not the case that what happens in any of these layers is derivable from another. Values can be distinguished by any single one of these layers and by any combination of them concurrently.

As Table 11 shows, the prefix is what distinguishes, for example, the 1SG.PRS of 'take out' in Chichimec from its 2SG.PRS form. Tone (high-high vs. high-low) is the only thing that distinguishes 2SG.PRS from 2SG.ANTPST, and a different stem is what distinguishes for example 3SG.PRS from 3PL.PRS. Because of how we have proceeded with segmentation, any prefix could logically/phonotactically appear with any stem and with any tonal pattern. It will thus be an empirical matter to assess the degree of orthogonality of different subsystems in different languages and word classes. In addition to this, each subsystem can be readily compared with the equivalent one in the other language in search of differences and similarities.

As we mentioned in the introduction, inflectional systems (and subsystems) involve too many parameters to be reduced to a single metric. What we would like, instead, is a set of measures that captures different aspects of complexity. Stump & Finkel (2013) provide one such set of metrics and made a tool available to calculate all of them. This tool (presented in

Table 11. Partial paradigm of the Chichimec verb 'take out' (Feist & Palancar 2015)

	1SG	2SG	3SG	3PL
PRS	é-sí	kí-sí	é-sí	é-tʃĩ
ANTPST	tu-sí	kí-si	u-sí	u-tʃĩ

[7] Thus, what for Feist & Palancar (2015) is *ga-nha* '3SG.FUT.drink' and *ga-rha* '3PL.FUT.drink' would presumably be *gan-ha* and *gar-ha* for Olson.

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Stump & Finkel 2015 and accessible online at https://www.cs.uky.edu/~raphael/linguistics/analyze.html) can be used to obtain information about different aspects of an inflectional (sub)system. The list of metrics that we have surveyed in the rest of this paper is the following:

(i) Number of distillations
(ii) Number of exponents
(iii) Number of inflection classes
(iv) Number of signatures
(v) 4-MPS entropies
(vi) Conditional entropy of cell
(vii) Static principal parts
(viii) Density of static principal parts
(ix) Dynamic principal parts
(x) Density of dynamic principal parts
(xi) Adaptive principal parts
(xii) Entropy of inflection class
(xiii) Predictability of cell
(xiv) Predictability of inflection class
(xv) Predictiveness of cell
(xvi) Cell predictor number

A practical layperson's explanation of what all these measures refer to is provided in the Appendix. For mathematical formulae and technical details, we refer the reader to the original sources (Stump & Finkel 2013, 2015) and Brown (2018). Some of these metrics are enumerative complexity measures and others are of the integrative complexity kind. Each of these axes of variation can be quite unproblematically mapped onto a general dimension of 'complexity' (see Stump & Finkel 2013), which has been a prolific and contentious topic in recent years (see e.g. Miestamo 2008; Baerman, Brown & Corbett 2015; and Arkadiev & Gardani 2020). A system with more inflection classes, for example, must be considered more complex, all else being equal, than a system with fewer inflection classes. A system with a higher average conditional entropy must be seen as more complex than one with a lower average conditional entropy (this is so because entropy, the key notion of Information Theory [Shannon 1948] is a measure of uncertainty that is higher as uncertainty increases). We can hence also explore, at a general level, whether the Chichimec 'inalienable' nouns are more complex than the corresponding Central Pame noun class due to its smaller number of lexemes. We can also compare noun vs. verb inflection within each language and ask whether they differ on complexity metrics. At a finer-grained level, we can explore which aspects (i.e. variables i through xvi, and layers as explained in Section 2) appear to have been more or less affected and how. Results are reported in the following subsection.

5. Results

Each of the three inflectional layers in each of the four inflectional systems described in Section 4 and Table 6 was analyzed according to the various metrics (i) though (xvi). In verbal inflection, different TAMs were analyzed separately because of the better structural

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Table 12. Quantitative profile of nominal inflectional (sub)systems in the two languages. Gray shading indicates which language is more complex for each subsystem and metric

	CP Pref	Chic Pref	CP Stem	Chic Stem	CP Tone	Chic Tone
Distillations	4	4	4	4	4	4
Exponents	30	26	70	42	4	3
Inflection classes	33	53	111	82	25	19
Signatures	7	11	13	13	8	10
4-MPS entropy	84	115	116	112	113	107
Conditional entropy of cell	58	116	87	88	136	124
Static principal parts	4	4	3	4	4	4
Density of static princ. parts	1	1	1	1	1	1
Adaptive principal parts	2	3	3	3	3	4
Dynamic principal parts	1.39	1.74	1.54	1.66	2.24	2.63
Density of dyn. princ. parts	52.02	34.91	37.31	39.13	29	38.6
Entropy of inflection class	58	116	87	88	136	124
Predictability of cell	0.598	0.402	0.466	0.472	0.228	0.14
Predictability of infl. class	0.655	0.463	0.53	0.514	0.304	0.235
Predictiveness of cell	0.525	0.275	0.326	0.35	0.053	0.018
Cell predictor number	1.02	1.13	1.09	1.07	1.3	1.3

comparability to nominal possessor inflection and to be able to compare only cognate tenses to each other, which is what we do with nominal inflection.

Table 12 reports the results of the comparison of noun possessor inflection. In general, the most consistent difference between the two languages is found in the prefixes, where Chichimec (i.e. the smaller class) is almost consistently found to be more complex,[8] sometimes by a large margin (higher complexity has been indicated with gray shading in Table 12).[9] The overall complexity of the other inflectional layers (i.e. of stem alternations and tonal changes), by contrast, appears to be largely comparable across the two languages, with differences between them usually very small and both languages being the more complex one around half of the time. We can visualize these differences in Figure 1, where positive values represent complexity and negative values represent simplicity (we normalized, here and in Figures 2 and 3, all metrics to have 0 as the mean and a standard deviation of 1).

[8] We cannot lose sight of the fact that we are inspecting the morphological complexity of two noun (sub)classes and not of all nouns. Across all nouns, there could be little difference between the two languages in metrics sensitive to the type frequency of classes. In lay terms, the additional complexity of Chichimec inalienable nouns would be diluted more significantly among the morphologically invariant majority of alienables in that language. This does not invalidate our claims or results, as no difference in size (i.e. number of members) is expected between the noun classes as a whole in the two languages given that these have, probably, a similar size.

[9] Note that a higher number does not always correspond to more complexity. Higher density of principal parts (static or dynamic) makes a system simpler, not more complex, and the same applies to predictability and predictiveness. This has been taken into account as well when producing Figure 1.

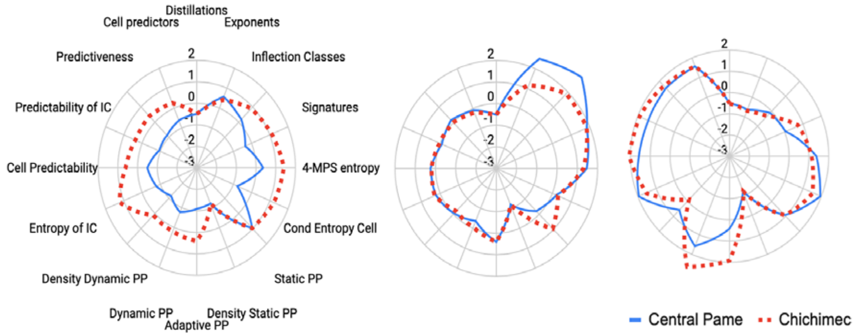

Figure 1. Multidimensional complexity of nominal inflectional layers: prefixes (left), stems (middle), and tones (right) in Central Pame and Chichimec.

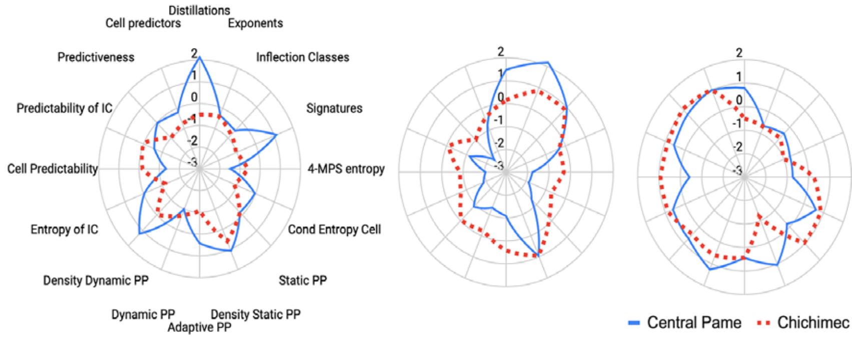

Figure 2. Multidimensional complexity of verbal inflectional layers: prefixes (left), stems (middle), and tones (right) in Central Pame and Chichimec. Present tense forms.

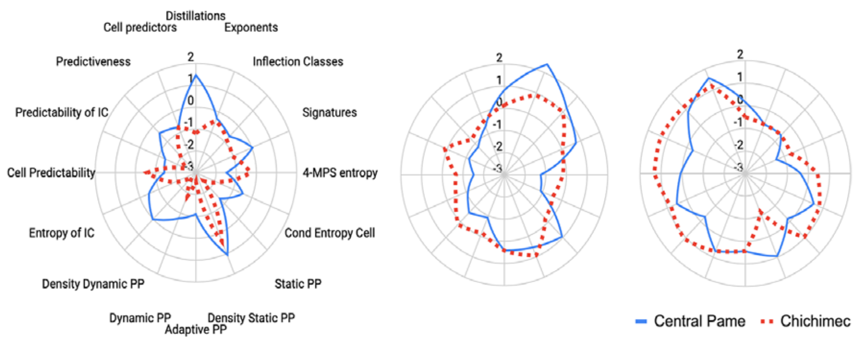

Figure 3. Multidimensional complexity of verbal inflectional layers: prefixes (left), stems (middle), and tones (right) in Central Pame and Chichimec. Past tense forms.

As advanced before, Figure 1 shows that Chichimec nominal prefixes (but not stems or tones) are significantly more complex than Central Pame ones. They are also very similar to stem alternations in their complexity profile in Chichimec but not in Pame.

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Table 13. Quantitative profile of verbal inflectional (sub)systems in the two languages. Gray shading indicates which language is more complex for each subsystem and metric

	Present / Real Progressive						Immediate Past / Real Perfective					
	CP Pref	Chic Pref	CP Stem	Chic Stem	CP Tone	Chic Tone	CP Pref	Chic Pref	CP Stem	Chic Stem	CP Tone	Chic Tone
Distillations	8	4	7	5	6	4	7	3	6	5	5	4
Exponents	10	9	63	35	4	3	11	9	68	36	4	4
Inflection classes	13	7	57	53	17	10	10	5	63	57	12	12
Signatures	11	5	7	7	6	5	8	5	10	8	4	6
4-MPS entropy	30	55	22	64	51	80	30	65	37	68	62	86
Conditional entropy of cell	79	47	27	59	98	105	67	27	49	67	95	103
Static principal parts	3	3	2	3	3	4	2	1	4	3	3	4
Density of static princ. parts	0.036	0.25	0.095	0.1	0.05	1	0.048	0.333	0.267	0.1	0.1	1
Adaptive principal parts	3	2	2	3	3	3	2	1	3	3	3	3
Dynamic principal parts	1.31	1.43	1.19	1.58	2.12	1.9	1.4	1	1.33	1.6	1.92	1.92
Density of dyn. princ. parts	20.33	36.9	48.2	37.36	27.06	30.83	36.19	73.33	45.03	34.21	40.83	21.53
Entropy of inflection class	79	47	27	59	98	105	67	27	49	67	95	103
Predictability of cell	0.754	0.545	0.88	0.666	0.587	0.347	0.768	0.617	0.787	0.634	0.502	0.279
Predictability of infl. class	0.603	0.514	0.692	0.53	0.437	0.393	0.717	0.886	0.693	0.502	0.567	0.317
Predictiveness of cell	0.363	0.548	0.789	0.546	0.204	0.142	0.448	0.733	0.593	0.508	0.192	0.132
Cell predictor number	1.07	1	1	1.04	1.23	1.23	1	1	1.02	1.05	1.3	1.25

Despite the inherited structural similarities, verbal inflection shows a somewhat different picture. Table 13 shows the same metrics of the cognate tenses Present (Chichimec) and Real Progressive (Central Pame), and Immediate Past (Chichimec) and Real Perfective (Central Pame). The overall complexity of verbal morphology (see Figures 2 and 3) appears to be similar in the two languages, both across layers and across tenses. It might even be Central Pame that shows somewhat higher overall complexity in prefixes, which is the opposite of what was observed in the nominal domain in Figure 1.

Approximating an overall system complexity, by averaging across normalized metrics and layers, we obtain that Chichimec nouns are the most complex inflectional system of all (0.608), followed, only at a distance, by Central Pame nouns (0.266). The Central Pame and Chichimec present come next (–0.125 and –0.134, respectively), and the Central Pame and Chichimec past appear as the simplest overall (–0.174 and –0.32, respectively) from among the analyzed ones.

Another aspect that could be analyzed is the amount of change between cognate (sub) systems. In terms of the cosine similarities[10] across metrics, the noun prefixes of Chichimec and Central Pame are the most divergent subsystems (–0.07), while noun stems and noun tones are the most similar ones (0.911 and 0.919, respectively). This remarkable asymmetry suggests that, as suggested by Bartholomew (1965) a lot more (independent) change seems to have occurred in noun prefixes than has occurred in noun stems or tones. The amount of change in verbal morphology varies between these extremes, with present tense prefixes most divergent (0.05), followed by past tense and present tense tone (0.353 and 0.388), past tense prefixes (0.565), and past and present tense stems as most similar (0.753 and 0.815). In the purely synchronic domain, another finding is the extraordinary similarity, within the same language, of the complexity profile of equivalent inflectional layers in different tenses (i.e. present in Figure 2 vs. past in Figure 3), which suggests that strong intraparadigmatic analogical pressures drive the isomorphy of different subparadigms within the same language.

So far in this subsection we have looked exclusively at cell-to-cell (i.e. paradigmatic) predictability. There are, however, other predictability relations that could be relevant to the comprehension (Balling & Baayen 2012; Geertzen, Blevins & Milin 2016), rather than the production complexity, of an inflectional system. From a syntagmatic perspective, for example, we can also measure the uncertainty in guessing the next segment in a word form, provided previous ones, or in guessing the lexeme that a form belongs to, or the morphosyntactic value that a form expresses (see also Herce 2022).

Table 14 provides these metrics for Central Pame and Chichimec inalienable nouns. It shows that, given the consonantal part of the prefix (e.g. the /n/ in ná-mba or the /ŋg/ in ŋgo-wào, see Table 5), it is more difficult to predict the vocalic part of the prefix in Chichimec (1.14 bits) than in Central Pame (0.89 bits). Given the whole prefix (i.e. /na/ or /ŋgo/ in the above forms), however, it is more difficult to predict the next segment (i.e. the first one of the stem) in Central Pame (3.24 bits) than in Chichimec (2.74 bits). This is so even though prefixes are typically somewhat longer in Central Pame. The difficulty in guessing the next stem segment from prefix+first segment of the stem is very similar in the two languages.

[10] Cosine similarity is a measure of the similarity of two sequences of numbers, in this case the vector of a dozen complexity values in Figures 1 through 3. Identical (or proportional) sequences have a cosine similarity of 1, orthogonal sequences have 0, and opposite sequences have –1.

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Table 14. Conditional entropies of column (e.g. lexeme) given row (e.g. whole prefix). Gray shading indicates which language is more complex for each aspect

	Central Pame			Chichimec		
	Next segment	Lexeme	Inflectional value	Next segment	Lexeme	Inflectional value
Consonantal part of the prefix	0.89	5.28	1.56	1.14	5.11	1.8
Whole prefix	3.24	4.74	1.18	2.74	4.36	1.42
Prefix plus first segment of stem	1.23	1.85	0.73	1.24	1.92	1.03

Parallel to this, the amount of lexical and morphosyntactic information encoded in the first segments also differs across the two languages. Looking at the predictability of the lexeme given progressively larger sets of word-initial segments, we can see that there is in general somewhat more lexical information (i.e. less lexeme uncertainty) at the beginning of a noun in Chichimec (5.11 bits, 4.36 bits) than in Pame (5.28 bits, 4.74 bits). Looking at the predictability of the inflectional value given the same word-initial segments, we can see that there is in general somewhat more morphosyntactic information (i.e. less inflectional value uncertainty) at the beginning of a noun in Central Pame (1.56 bits, 1.18 bits) than in Chichimec (1.8 bits, 1.42 bits). Chichimec nouns, thus, seem to encode more lexical information in their initial segments in contrast to Pame nouns, which encode more information about the inflectional value of the word.

6. Discussion

Language complexity has been traditionally a thorny issue in linguistic research. Until not so long ago, it was often assumed that because all languages need to perform similar functions, they should be expected to exhibit similar overall complexity. Thus, if one aspect or module of grammar simplifies, this needs to come at the cost of another one's complexification (Martinet 1955; Hockett 1958:180–181; Bentz, Gutierrez-Vasques, Sozinova & Samardžić 2022). Other research (Kusters 2008, Sinnemäki 2011) has cast doubt upon the validity of this so-called 'equicomplexity hypothesis'. At the same time and related to this, there has been an increased interest in measuring different dimensions of morphological complexity (e.g. Stump & Finkel 2013, Newmeyer & Preston 2014) and understanding what their limits are and how/whether they are correlated to each other and why (see Ackerman & Malouf 2013 and Cotterell et al. 2019).

As we discussed in the introduction, the study of correlations/tradeoffs between different aspects of inflectional systems (e.g. number of members in a word class and its morphological complexity) is complicated by the large number of logically unrelated aspects along which inflectional systems in different languages may differ at the same time as well as by the overrepresentation of languages from the better studied families, typically Indo-European, whose inflectional systems' traits are not independent. The comparison of minimally divergent cognate inflectional systems that we pursue in this paper is a promising

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avenue to sidestep some of these problems of comparison. Despite the considerable time depth, the two systems investigated here have diverged only minimally from each other structurally. Chichimec verbs have a few more morphological TAM distinctions, hence a slightly larger paradigm than their Central Pame equivalent, whose tenses will thus tend to be a bit more frequent on average as a result. Noun inflection, in turn, differs in the number of lexemes in the 'alienable' and 'inalienable' classes in the two languages. The highly inflecting inalienable noun class, in particular, appears to be a smaller one in Chichimec. The number of members in the Chichimec class is around 160 (exhaustively listed and analyzed in Herce 2022). The number of members in the Central Pame class is difficult to gauge in the absence of exhaustive dictionaries of the language, but, judged by their proportion in Gibson (1994b), must be above 1,000. These differences might be associated, causally, with changes in the morphological complexity measures we explored in this paper.

The most important finding presented in Section 5 is that Chichimec nominal prefixes, the ones in the smaller word class, are considerably more complex than the equivalent in related Central Pame across almost all metrics. At the same time, noun prefixes are the inflectional layer that, among all the subsystems and layers we have examined here, differs the most between the two languages. Because the two systems are cognate, this means that nominal prefixes must have changed the most diachronically, even if we were to remain agnostic as to the directionality of this change.[11] The greater simplicity/predictability of the class with more members makes sense intuitively in that it is here that the PCFP (Ackerman et al. 2009) is most relevant to language users, hence the need to find (productive) generalizations most acute.

Although the similarity of the two inflectional systems sidesteps many of the confounds that would hold between unrelated languages, other properties besides number of lexemes per se could be also entertained to be behind the morphological complexity differences plotted in Figure 1. One might wonder, for example, if differences could be driven not so much by the number of members of each class but by a difference in their average token frequency. Thus, for example, if we compare Germanic strong to weak verbs, we find that the smaller class (i.e. strong verbs) is the more complex one. A smaller class of strong verbs (e.g. in English) might also be morphologically more irregular than a larger class of strong verbs in a related language (e.g. Icelandic). The main reason for this might not be the number of members itself but rather the fact that infrequent strong verbs are the ones that tend to be regularized (i.e. become 'weak') more often (Lieberman et al. 2007). As lower-frequency verbs tend to shift to another class, the average frequency of the remaining verbs becomes higher, which means that morphological idiosyncrasies could be maintained better in the class with fewer members. A compatible explanation of the association between high frequency and morphological irregularity would be that high frequency may foster irregularity (Nübling 2011), due to processing preferences (earlier uniqueness points, see Balling & Baayen 2012) or the well-documented shortening associated with high frequency (see Gahl 2008 and Herce & Cathcart 2024). Although we lack the appropriate naturalistic corpora to explore the token frequencies of inalienable nouns in Chichimec and Central

[11] It is unclear whether we should jump to the conclusion that a reduction in the number of lexemes of the inalienable noun class in Chichimec generated a complexification of the predictive paradigmatic relations. The causality relation could also be the opposite if it was the complexification of the predictive relations that resulted in the inalienable noun class losing members (e.g. by favoring the more predictable marking of the possessor via classifiers).

Pame, our impression is that the situation is not analogous to that of Germanic strong vs. weak verb classes. We believe that the average frequencies of Chichimec and Pame inalienable nouns could be quite similar. This is because which nouns migrate into the uninflectable alienable class in Chichimec is more likely to be related to the semantic applicability of some of the expanding possessive classifiers rather than to the frequency of the nouns themselves (note that both Chichimec and Central Pame have seemingly very infrequent nouns in their inalienable classes: e.g. 'wing', 'steam', 'saliva', 'rattle', 'leather', 'ladder', 'gizzard', 'blister', etc. in the former, 'whip', 'umbrella', 'seed', 'ribbon', 'pepper', 'ink', 'fur', 'cherry', etc. in the latter. Thus, we believe that the number of members in each class, and not frequency, is the main distinguishing factor.

Another possible confound is derived from the general word order type of Chichimec (object-verb, OV) and Central Pame (verb-object, VO).[12] As is well known in the typological literature since Greenberg (1963), there is a strong cross-linguistic correlation between the order of a verb and its object and a language's proclivity toward prefixes or suffixes. In *The World Atlas of Language Structures Online* (WALS) (Dryer & Haspelmath 2013, features 26A [Dryer 2013a] and 83A [Dryer 2013b]), for example, VO languages are split in their preference for prefixes (51 strongly prefixing) or suffixes (93 strongly suffixing), while OV languages are almost exclusively suffixal (only 6 strongly prefixing compared to 269 strongly suffixing). How exactly these correlations become established is an active topic of debate (Are existing prefixes in OV languages more prone to disappearing? Or does the correlation emerge because new morphs in OV languages grammaticalize almost exclusively as suffixes because of the prevalent order of the words that give rise to them?). If we believe only the latter is the case (i.e. source constraints à la Cristofaro 2019), then we do not expect this to interfere with our Oto-Pamean data at all. If, instead, we believe cognitive pressures exist toward the uniformity of branching direction in syntax (see Temperley & Gildea 2018), then we could interpret the erosion of nominal inflectional prefixes in Chichimec as partially motivated by the disharmonic nature of prefixes in an OV language. We do not think this difference in basic word order between Chichimec and Central Pame can have a significant influence in our case due to two reasons. The first is that no analogous erosion of the prefixal slot is observed in Chichimec in the verbal domain. The second and more important one is that possessor inflection does not follow the general Greenbergian generalization we just mentioned. According, again, to WALS (features 57A [Dryer 2013c] and 83A [Dryer 2013b]), OV languages have a slight preference for prefixation (142 vs. 102), not suffixation, with regard to the location of pronominal possessive affixes, with VO languages preferring suffixation (209 vs. 82) instead. This would hence run completely against the observed development.

Chichimec and Central Pame nominal inflectional systems differ not only in their paradigmatic predictability (Figure 1) but also in their syntagmatic predictability (Table 10), i.e. in the difficulty of guessing the next segment in a word form given (an) earlier segment(s). Transition probabilities have been shown to be associated with morphological decomposition and segmentability (see e.g. Saffran, Aslin & Newport 1996; Hay & Baayen 2003; and Elsner, Johnson, Antetomaso & Sims 2020). In both our languages, we can observe a peak of uncertainty between the prefix and the stem as defined

[12] VO is found across Otomanguean and can be assumed to be the original order. Chichimec might be, in fact, the only SOV language in the whole family; this order, thus, is probably a recent development.

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in this paper in Section 3. This is expected and justifies a synchronic description in which there is a prefixal slot. This peak of uncertainty between prefix and stem, however, is more pronounced in Central Pame. Another difference displayed in Table 10 is that although neither language is canonically prefixal (morphosyntactic information only initially, lexical information later) nor suffixal (lexical information initially, morphosyntactic information later), the initial segments of Chichimec nouns provide more lexical and less morphosyntactic information than their Central Pame counterparts. In addition to this, while Central Pame nominal prefixes and stems show markedly different complexity profiles (see Figure 1), Chichimec's prefixal and stem inflectional layers are remarkably similar.

All these differences appear to point in the same direction. We argue that they reflect an incipient (or more advanced degree of) lexicalization of prefixal inflection in Chichimec inalienable nouns (i.e. the smaller class). A higher unpredictability and lower morphosyntactic informativity of the initial segments of Chichimec nouns as well as a smoother transition to stems amount to an erosion of precisely those traits that made them an entity separate from stems and inherently inflectional/grammatical in nature. Morphological theory needs to come to terms with the fact that morphological structure (e.g. the segmentability of a prefix and stem here) is gradient (see Hay & Baayen 2005). Both nominal inflectional systems are somewhere in the middle of this gradient between having a canonical prefixal slot and lacking any semblance of one. We believe that Chichimec inalienable nouns have simply progressed a little further toward the disintegration of the prefixal slot, and this, we argue, might be mostly the result of the smaller number of members in that class.

Another aspect of our results that deserves more discussion is the greater mutability of prefixes compared to other morphological layers like tonal or especially stem inflection. We found that almost all of the additional complexity we observe between Chichimec and Central Pame inalienable nouns occurs in the prefixal layer. This was also the case in the verbal domain in the past tense. The greater diachronic instability of the prefixal layer receives impressionistic confirmation from eyeballing prefixes and stems in cognate paradigms (e.g. Tables 1–4). There is little research to date on which types of inflection change faster; one reason for this may well be that stem and affix allomorphs are often mutually implicative, so that change in one subsystem cannot be assessed in isolation from the other. The paradigms examined here are remarkable in the relative independence of affixal and stem inflection, providing a rare opportunity to tease apart the dynamics. Our findings agree with recent research in other language families (see Herce 2021 on Kiranti), that stem alternation patterns appear to be more stable than affixes. Possible general explanations might involve the peripheral location of affixal relative to stem morphology, which might make it more vulnerable to changes involving the grammaticalization/univerbation of new morphs (Bybee & Newman 1995). The contrast between Chichimec and Central Pame noun classes, however, does not seem to be the product of grammaticalizations in either language but seems to be the result of a different incidence of analogical changes in affixes vs. stems. Stem alternations might hence be better indicators of language relatedness, especially when these are 'morphomic' (Aronoff 1994, Maiden 2018), i.e. not aligned to morphosyntactic or semantic values, hence unlikely to be found in the same or similar ways in unrelated languages. This follows from the general observation that shared morphological irregularity is one of the most reliable signals of relatedness (see e.g. Campbell 2003: 268–269, citing Meillet 1925).

Comparisons between nominal and analogous verbal inflectional subsystems might also reveal interesting principles of morphological architecture. The difference between nominal, present tense, and past tense systems' overall complexity (nouns >> present > past), for example, might be plausibly due to differences in each category's frequency in natural speech, with frequent forms accruing and/or preserving complexity and unpredictability while infrequent forms do not. Although suitable naturalistic corpora of these languages are woefully lacking, present tense forms will certainly be more frequent than past tense ones,[13] which translates into greater inflectional predictability of the less frequent tense, an effect/correlation we can observe in other languages too (e.g. in Latin and Romance present indicative vs. past, see Pellegrini 2020; Beniamine, Bonami & Luís 2021; and Herce & Pricop 2024). The differences in complexity between present (more complex) and past (less complex) and between Central Pame Real Perfective (more complex) and Chichimec Immediate Past (less complex) apply particularly to prefixes, suggesting again that this layer might be particularly sensitive to the amount of morphological irregularity it tolerates as a function of the characteristics of the input. Consider, with regard to this, that, as explained in Section 2, the Chichimec immediate past is only one of three different past tenses (it contrasts with a 'recent' and an 'anterior' past), while the Central Pame Real Perfective does not compete with others and is hence plausibly more frequent in naturalistic speech.

Another maybe more trivial observation in the comparison between nouns and verbs is that although in these languages, nominal possessor inflection and verbal subject inflection within individual TAMs runs quite parallel structurally, the various TAMs still resemble each other in their predictive complexities much more than they resemble nominal possessor inflection (see Figures 1–3). This suggests that the cognitive associations and analogies between the morphology in different tenses are, maybe unsurprisingly, stronger than the links between nominal and verbal inflection. Thus, structural divergences between nouns and verbs might not be resisted as strongly as those between different tenses within the same paradigm (note, for example, that prefixes sometimes distinguish SG, DU, and PL in the first and second person in verbs but never in nouns).

7. Conclusion

This paper has presented a quantitative analysis of the predictive complexities in related, minimally divergent inflectional systems. It presents an approach complementary to large cross-linguistic sampling (e.g. Cotterell et al. 2019) to investigate correlations and causal relations between different properties of an inflectional system. We do so by exploring the few areas where cognate systems differ and their possible associated properties. In this paper, we focused on the relationship between the number of members in a word class and its morphological complexity.

In the comparison between possessive inflection in inalienable nouns in Chichimec and Central Pame (related Oto-Pamean languages from Mexico), we find that the former contains substantially fewer members than the latter yet is very similar in all other respects. A quantitative analysis of nominal inflection, and verbal inflection for comparison, reveals

[13] The best we have is Hurch's (2022) collection of Central Pame texts, where there are 253 present tense tokens compared to 13 tokens of the past.

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that the smaller class, i.e. the one with fewer members, is substantially more complex than the larger one. Interestingly, however, this asymmetry is limited to prefixes, while inflectional stems and tones show comparable levels of overall complexity. Furthermore, the quantitative predictability profiles of stem and tonal inflection in the two languages are strikingly similar, which seems indicative of a high diachronic stability, in stark contrast to what is found in prefixes, which seems to be where evolutionary pressures have operated predominantly in the recent past.

With respect to syntagmatic predictability and the identification of lexeme and inflectional values from word beginnings, the two systems also show interesting differences, with the smaller class (i.e. Chichimec nouns) packing more lexical and less morphosyntactic information at the beginning of words (i.e. in the prefix slot) and having a lower peak of predictive uncertainty between prefix and stem. This suggests, along with the paradigmatic complexification mentioned in the previous paragraph, that the smaller class has moved more toward lexicalization (see Rhodes 1987) and maybe, ultimately, toward the elimination of the prefix slot. We argue that these effects are likely to be due to the reduced number of members of one class relative to the other, as we considered other potential causes (token frequency of members, and VO to OV word order change in Chichimec) less promising.

If we are right, we could therefore add number of members to the list of factors that have been argued in recent years to influence the morphological complexity of inflectional systems, i.e. to factors like sociolinguistic isolation, population size, dense and stable social networks (e.g. Lupyan & Dale 2010, Trudgill 2011, Nettle 2012), paradigm size (Cotterel et al. 2019), etc. Closed few-member classes in other languages (e.g. Wutung [Marmion 2010] or Murrinh-Patha [Mansfield 2016] verbs) are also often complex to a degree that larger classes cannot match. If complexity can be equated with the need to memorize, this means that the smaller a class is by number of members, the greater the role that memory tends to assume. What is striking in the Otomanguean data discussed here is that the difference is covert, since exponence looks much the same across both large and small classes. Beyond our concrete case, and beyond paradigms, this effect might extend for example to the syntactic properties of open vs. closed word classes, as members of the latter (e.g. adpositions) have been observed to be also much more syntactically heterogeneous (see Herce 2024a).

Future work could be aimed at exploring in more detail, and in other languages, the interrelations between properties, such as (average) token frequency, number of lexemes, and word class. These are all interrelated in a complex way: languages tend to have more nouns than verbs (see Polinsky 2005:429 and Dixon 2010:102), for example, which might be the reason that Seifart et al. (2018) find they tend to be pronounced at a slower rate cross-linguistically (i.e. because they are lower in token frequency, hence more informative and surprising, see Gahl 2008). It might also explain why Cotterel et al. (2019) find that nominal and verbal inflectional systems tend to have comparable levels of average i-complexity cross-linguistically, despite verbs having much larger paradigms on average.

To explore these and related questions we need more, larger, and more carefully curated inflected lexicons of understudied (preferably non–Indo-European) languages (see e.g. Cruz, Stump & Anastasopoulos 2020). We also need lexicons and grammars that explore, or at least do not disregard, synchronic variation (i.e. 'overabundance', see Thornton 2012), particularly in languages without a written tradition, since this has been claimed to reduce variation and slow down language change, possibly increasing

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complexity (Ferguson 1959). These resources can also constitute the yardsticks to evaluate children's performance in acquisition studies, which are also needed in typologically diverse languages (Moran, Schikowski, Pajović, Hysi & Stoll 2016; Engelmann, Granlund, Joanna Kolak, Szreder, Ambridge, Pine, Theakston & Lieven 2019) to understand how morphological systems with widely different characteristics are learned, and how different learning strategies and generalizations drive morphological evolution and generate the correlations (e.g. between number of lexemes and complexity of an inflectional system) that we observe synchronically.

Acknowledgments. Thanks are due to the editor and three anonymous reviewers of the *Journal of Linguistics*. The first author also gratefully acknowledges the financial contribution of Swiss National Science Foundation Spark grant #220720. The second author gratefully acknowledges the support of the Leverhulme Trust under grant RPG-2021-242 'Predicting language evolution: Analogy in morphological change'.

Conflict of interests. No conflicts of interest are reported.

Appendix. An explanation of inflection class complexity metrics

Inflectional systems are complex and multidimensional webs of morphological contrasts, which cannot be reduced to a single metric. Instead, different aspects of complexity are captured through separate measures. The simplest ones involve counting. This has been referred to as 'enumerative complexity' by Ackerman & Malouf (2013), which includes number of distinct exponents, number of inflection classes, number of paradigm cells, etc. Larger counts are associated with greater complexity.

Other measures, instead, capture the difficulty associated with the PCFP, i.e. how difficult it is for a language user to predict one form on the basis of others. Information theory and set theory metrics have been used over the past decade to measure different aspects of this so-called 'integrative complexity' (Ackerman & Malouf 2013). From this novel approach to organizational complexity, Stump & Finkel (2013) proposed 10 metrics. The same as count measures, different values can also be ranked in terms of complexity. We explain the rationale of these metrics in the rest of this subsection.

Distillations (i)

A distillation is a set of cells whose morphology is mutually predictable, either because it is identical (i.e. 'syncretic'), or because it contrasts predictably (i.e. always in the same way). To explain this and other metrics, a toy subset of the Central Pame verbal prefixes will be employed for illustration.

If we had an inflectional class system like the one in Table I, its five cells would be reduced to three distillations. The forms 1SG.PRS, 2SG.PRS, and 3PL.PRS would be part of the same distillation because there is a perfect bidirectional predictability relation between the three cells (e.g. a 1SG.PRS la- implies 3PL.PRS zero and vice versa). Inflectional systems, therefore, differ in their number of distillations, with the total number of cells constituting the logical upper limit and one the lower one. The rest of the metrics described in this subsection will be based on these distillations (i.e. {1SG.PRS, 2SG.PRS, 3PL.PRS},[14] 3SG.PRS, 2SG.PST in Table I).

Conditional entropy of cell (vi) and entropy of inflection class (xii)

Entropy is the core notion involved in the quantitative analysis of paradigm predictability. It measures uncertainty; in the context of paradigms, the uncertainty involved in predicting a form given different types or amounts of information, for example given another word form. No uncertainty results in entropy = 0. The uncertainty involved in a coin toss (i.e. a 50%–50% outcome) is reflected in an entropy = 1. Higher uncertainty (e.g. in guessing the

[14] In the rest of this subsection, this distillation will be referred to as 1SG.PRS for the sake of brevity. The isomorphic cells 2SG.PRS and 3PL.PRS can be safely ignored for the rest of the metrics.

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Table I. A subset of the Central Pame conjugation (prefixes only)

	1SG.PRS	2SG.PRS	3SG.PRS	3PL.PRS	2SG.PST
‘belittle’	la-	ki-	wa-	Ø	ni-
‘allow’	to-	la-	wa-	wa-	na-
‘become’	ti-	ti-	li-	li-	ni-
‘eat’	la-	ki-	Ø	Ø	ki-
‘carry’	la-	ki-	wa-	Ø	ni-
‘deceive’	ti-	ti-	li-	li-	ni-

Table II. A subset of the Central Pame conjugation

	1SG.PRS	3SG.PRS	2SG.PST
‘belittle’	la-	wa-	ni-
‘allow’	to-	wa-	na-
‘become’	ti-	li-	ni-
‘eat’	la-	Ø	ki-

number of a dice roll) results in higher entropy (in this case = 2.58). Stump & Finkel (2013) report these entropies multiplied by 100 (i.e. 0, 100, and 258, respectively).

Focusing on our toy example (reproduced more compactly as Table II, without predictable cells and verbs from the same class), we can calculate the entropy of one cell given another (also known as conditional entropy). Given a 1SG.PRS to- or ti- form we can predict the 3SG.PRS (wa- and li-, respectively) without uncertainty (i.e. entropy = 0). With the remaining forms (la-), however, the form of the 3SG.PRS can be either of wa- or 0- (i.e. a coin toss, entropy = 1). The overall conditional entropy of the 3SG.PRS given the 1SG.PRS is thus 0.5. The same calculation holds for the 1SG.PRS, given the 3SG.PRS, and between either cell and the 2SG.PST, hence the average conditional entropy of a cell is 0.5.

The entropy/uncertainty can also be calculated of inflection class membership. In the case of ’allow’, ’become’, and ’eat’, two of their three forms are unique to their class (e.g. to- and na- in ’allow’), hence revealing it without uncertainty (entropy = 0), while the third form (e.g. wa-) is shared with another class (entropy = 1). For these classes, thus, the average entropy is (0 + 0 + 1)/3 = 0.33. In the case of ’belittle’, no form reveals its class unambiguously (i.e. it only contains prefixes also found in another class), so a 50%–50% uncertainty remains for each form (i.e. entropy = 1). The average inflection class entropy is thus (0.33 + 0.33 + 0.33 + 1)/4 = 0.5. Higher entropy, applied to either inflection classes or to cells, can of course be equated with higher complexity.

n-MPS entropy (v)

n-MPS (morphosyntactic property set, essentially a technical term for what is more commonly known as a paradigm cell) entropy is the average conditional entropy of a cell given all sets of cells with up to *n* members. The larger the number of cells that are used for inference, the lower the remaining entropy/uncertainty. In our toy example, 0-MPS entropy is 1.5, 1-MPS entropy is 0.83, and 2-MPS entropy is 0.63. Sets larger than 2 yield the same measure, 0.63, because only 3 distillations can be found in our toy inflectional subsystem.

Static vs. dynamic vs. adaptive principal parts (vii, ix, xi)

Principal parts are those sets of cells from which the complete paradigm can be deduced. The best-known type of principal parts (e.g. from the pedagogy of classical languages like Latin) is the one Stump & Finkel (2013) refer to as

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'static', which consists of the same set of cells across all lexemes (e.g. *dominus dominī, rosa rosae, cornū cornūs*… i.e. NOM.SG and GEN.SG in every noun). In our toy example, no cell contains a distinct allomorph for every class; hence, two principal parts are needed (e.g. 1SG.PRS and 2SG.PRS).

Alternatively, principal parts may vary from one lexeme to another one, in which case the most informative cell(s) of each lexeme can be selected, in different ways. In the case of so-called 'dynamic' principal parts, three verbs in our toy example would 'have enough' with a single form: a 1SG.PRS to-, a 1SG.PRS ti-, and a 3SG.PRS 0- all identify their class unmistakable and can therefore predict the complete paradigm. In the verb 'belittle', by contrast, two forms would be minimally needed, since, as mentioned before, no single form is a class identifier. The average number of principal parts is thus ([1 + 1 + 1 + 2]/4) = 1.25. 'Adaptive' principal parts, in turn, represent an alternative method of identifying the most predictive forms in the paradigm. Here, cells are selected following an iterative branching process, by which one looks at the most informative cell first and then, depending on its allomorph, continues consulting other cells. In the case of our toy example, two cells would need to be minimally consulted; hence, there are two adaptive principal parts. In terms of the relationship between these measures and complexity, a higher number of principal parts is associated, of course, with greater complexity.

Density of static and dynamic principal parts (xiii, x)

What has not been mentioned in the previous subsection is that multiple sets of cells of the same size might allow us to predict the complete paradigm. Thus, not only the 1SG.PRS and 2SG.PRS allow us to predict the complete paradigm in our toy example; 1SG.PRS and 3SG.PRS and 2SG.PST and 2SG.PRS are equally adequate sets of static principal parts. Of the three possible 2-cell sets in our paradigm, all three are principal parts. This (three of three, 100% in our case) is what Stump & Finkel call 'density' of static principal parts

The same applies to dynamic principal parts. For the verb 'allow', for example, not only a 1SG.PRS to- but also a 2SG.PST na- can predict their class (i.e. two of three 1-cell sets are dynamic principal parts, i.e. 66.7% of them). The same applies to 'become' and 'eat'. For 'belittle', in turn, any two forms would suffice, i.e. three of three, 100% of 2-cell sets are dynamic principal parts. The average density of dynamic principal parts across all classes is thus (66.7 + 66.7 + 66.7 + 100)/4 = 75%. In terms of complexity, and unlike the other measures described here so far, a higher density of principal parts is associated with greater *simplicity*, since this is associated with more fully predictive sets of cells.

Cell predictability (xiii) and inflection class predictability (xiv)

A cell's predictability is the proportion of sets of other cells (of size n)[15] that reliably predicts that cell. On our toy example, in the verb 'allow', its 1SG.PRS to- can be reliably predicted (i.e. entropy = 0) from the 2-cell set (3SG.PRS and 2SG.PST), from half of the 1-cell sets (i.e. from the 2SG.PST, but not from the 3SG.PRS), and it cannot be predicted from a 0-cell set. The proportion of sets of cells (i.e. the predictability) of that form is hence 0.5 (2/4). The 3SG.PRS of 'allow' is more predictable in that both 1-cell sets (i.e. a 1SG.PRS and a 2SG.PRS) allow to predict wa- without uncertainty. Thus, three of the four possible sets allow us to predict that cell. Averaging across all classes and cells we can obtain the overall cell predictability, which in our toy example is 0.5 (i.e. 50% of all possible sets of cells).

An inflection class's predictability is also the proportion of sets of cells that allow a reliable prediction of inflection class membership. In our case, two of the three 1-cell sets allow to determine if a verb belongs to the conjugation of 'allow' (a 1SG.PRS or a 2SG.PST but not a 3SG.PRS) and all three 2-cell sets allow to identify if a verb belongs to this class. Overall, thus, five of six sets of cells (i.e. 0.833) allow perfect predictability. Averaging across classes we obtain the inflection class predictability for the whole system; 0.786. In terms of its association

[15] In a small paradigm, the very size of paradigms imposes a limitation to the maximum size of these sets (see also n-MPS entropy). In our case, it is pointless to consider sets of cells larger than two, because we only have three distillations. In the analysis of larger paradigms; however, larger numbers can be chosen. Stump & Finkel settle on size four, as a compromise between smaller sets (which will hardly ever predict the complete paradigm or never if they have four or more principal parts) and larger sets (which will almost always do so). We will also choose this number for comparability.

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with overall complexity, more predictability is, like density, associated with more SIMPLICITY because it corresponds to more straightforward predictive relations.

Cell predictiveness (xv)

Cell predictiveness is the opposite of predictability, that is, the proportion of forms in the paradigm that are perfectly predictable from the form in a given cell. In our toy example, a 1SG.PRS to- or ti- would allow perfect predictability of the 3SG.PRS, but a form la- would not. Overall, thus, half of the forms are predictable from the 1SG.PRS (i.e. predictiveness of this cell is 0.5). All cells are identical in this respect in our toy example, so the system average predictiveness is also 0.5. In terms of the relationship of this metric with complexity, higher predictiveness corresponds to more SIMPLICITY.

Cell predictor number (xvi)

This measure represents the average lowest number of forms needed to predict the form of a cell. In our example, this number is 1.08, as most forms in our example (all of the ones in 'allow', 'become', and 'eat') require reference to just one other form (e.g. 1SG.PRS to- can be predicted from a 2SG.PST na-), i.e. cell predictor number = 1, but 'belittle' does require sometimes multiple predictors (1.33 on average because a 2SG.PST na- or ki- allows to predict no la- in the 1SG.PRS, but a 2SG.PST ni- does require a second predictor; i.e. (1 + 1 + 2)/3 = 1.33. At the whole system level, (1 + 1 + 1 + 1.33)/4 equals 1.08. It must be mentioned that this number can dip below 1 when some distillation shows no allomorphy (e.g. if 2SG.PST were ni- across all verbs) because then 0 dynamic principal parts would allow one to predict one cell. Numbers above 1, in turn, signal Blur (Carstairs 1994), i.e. some inflection class(es) which, like 'belittle', have no class identifiers. Regarding system complexity, thus, a higher cell predictor number corresponds to more complexity.

Number of signatures (iii)

Number of signatures was not one of the complexity measures explored in Stump & Finkel (2013), as it is not an integrative but rather an enumerative complexity measure. It refers to the number of syncretism profiles found in the system. In our example, reproduced again below for convenience, 'belittle' (all cells different), 'allow' (3SG.PRS = 3PL.PRS), 'eat' (3SG.PRS = 3PL.PRS, and 2SG.PRS = 2SG.PST), and 'deceive' (3SG.PRS = 3PL.PRS, and 1SG.PRS = 2SG.PRS) all have different patterns of syncretism. The higher the number of these patterns (what is known as a 'signature'), the higher the complexity of the system, as the lack of isomorphism between classes makes it difficult to identify/learn cells to begin with (see Boyé and Schalchli 2019).

Number of exponents (i) and number of classes (ii)

Further enumerative complexity metrics are more straightforward and better known. The number of exponents (11 counting zero in our toy example) refers to the number of morphologically different morphs found in a system. The number of inflectional classes refers to how many types of lexemes exist by virtue of the morphs they take (i.e. 'become' and 'deceive' belong to the same class because they take the exact same prefixes: ti-, ti-, li-, li-, ni-; but 'eat' and 'carry' belong to different classes because some of their prefixes are different (e.g. ki- vs. ni- for the 2SG.PST).

Other measures

There is an open-ended number of measures that one can choose to explore as well as numerous variations and executive decisions one can take with respect to their exact operationalization. There is, as far as we can tell, no consensus nor an a priori way to decide between these in concrete cases (e.g. one could also/instead have looked at unconditioned entropies, or could have weighed entropies by the type frequency of different classes…). Here we have decided to focus on the integrative complexity metrics analyzed by Stump & Finkel (2013) along with the most straightforward enumerative complexity-type measures that can be calculated on their software. We leave further exploration of other possible metrics and their possible logical, mathematical and empirical correlations for future work.

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Cite this article: Herce, Borja, Baerman, Matthew and Parker, Jeff. 2025. “System size and system complexity: A case study in Pamean nouns and verbs.” *Journal of Linguistics*. doi:10.1017/S0022226725000052