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What learning Latin verbal morphology tells us about morphological theory

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Abstract
The Classical Latin verb has featured prominently in theoretical morphology. In particular, the notoriously unpredictable forms of the past participles that nevertheless show reliable syncretism with a semantically diverse set of deverbals challenge our notions about the relationship between form and meaning. The various treatments of this system disagree not only in their theoretical building blocks but also in their basic assumptions about what ought to be explained, which makes it difficult to properly evaluate them against one another. This paper aims to empirically motivate the prior assumptions about productivity and arbitrariness that drive these accounts. In applying insights developed for child language acquisition to a large Latin corpus, the theoretical frameworks are compared on equal footing. It becomes clear that the productive past participle forms do not line up well with the frequency-based assumptions of prior accounts and instead mirror the diachronic developments that the system underwent on its path to Romance. A new treatment is proposed to incorporate the acquisition results and to conform with diachronic outcomes. The methods developed here reveal explanatory gaps in the theories that had not previously been appreciated and emphasize the importance of quantitative evidence from a range of sources in future morphological analysis.

Keywords Morphology · Child language acquisition · Language change · Latin

1 Introduction

Latin features more prominently in the debates of theoretical linguistics than any other dead language. Within morphology, the notoriously unpredictable forms of Classical Latin verb have contributed many times to our understanding of the role of regularity in morphological systems and the theoretical nature of stems. The forms

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of the past participle are particularly varied, and they share their phonological forms, any irregularities or suppletion included, with a semantically diverse set of future active participles, agent, and event nouns, adverbs, and other deverbals, raising questions about the relationship between form and meaning. As such, analyses of the past participle have been put forth as positive evidence in favor of several disparate morphological frameworks (Matthews 1972; Lieber 1980; Mel'čuk 1982; Aronoff 1994; Embick 2000; Embick and Halle 2005; Steriade 2016; Calabrese 2020).

One common thread in prior treatments is the argumentation based on the role of regularity, or predictability, or listedness (the terminology will be clarified later) in the system. Such arguments from the proper degree of predictability versus arbitrariness have figured prominently in the literature as a distinguishing factor between different frameworks. One can trace a chain of of criticisms of this type from Aronoff (1994) arguing that Lieber (1980) requires excessive listing, to Embick and Halle (2005) arguing that their model contains fewer arbitrary relationships than Aronoff (1994), to Steriade (2016) who argues that her account can predict patterns that are rendered arbitrary for both Aronoff (1994) and Embick and Halle (2005). The details of these arguments will be elaborated upon later in the paper, but for now it suffices to say that parsimony drives many of the arguments in favor of one framework over the others.

One issue with building an argument on parsimony is that the proposed strengths of a new analysis in some framework are not always entailed by the framework. The morphological frameworks adopted in prior (and the present) work do allow arbitrary amounts of listing, so we need some consistent way to motivate what constitutes the most parsimonious amount of regularity in the system, in order to compare proposals on equal footing. Empirical coverage still reigns supreme, so part of this requires a consistent outlook on the data. However, prior accounts of the Latin verb have used different data sets and analysis methods ranging from corpus and lexicon searches (Steriade 2016) to dictionary counts (Aronoff 1994) to unspecified sources (Embick 2000; Embick and Halle 2005; Calabrese 2020). That said, a consistent data set is still not enough. The way we identify regularity in the Latin data should be motivated empirically and may come from considerations outside the theory itself. With a consistent data set and a consistent productivity metric, we reduce the degrees of freedom available to each model. Treatments that take the consistent data and metric into account may very well not be as elegant as the "optimal" solutions available to each framework, and this should tell us something useful about them.

This then requires a consistent and motivated way to characterize the irregularity, or listedness, or non-predictability. Motivation comes from a few sources. The first is diachrony. It is well-recognized that analogical change is related to productivity (Hare and Elman 1995; Hock 2003; Bybee 2010; Maiden 2013; *i.a.*) and that diachronic and synchronic theoretical analyses mutually inform one another (Lightfoot 1979; Kroch 1989, 1994; Niyogi and Berwick 1997; Yang 2000; Maiden 2013; *i.a.*). As 21st century researchers, we have a long view on the Latin and Romance verbal systems over which we observe a significant amount of analogical change (Laurent 1999; Maiden 2013). An adequate synchronic theory should predict these diachronic developments, or at the very least be conducive to them.

Child language acquisition provides a second source of evidence. Productivity, which drives analogical change, is a central focus in acquisition as well: all native

learners must determine language-specific productive patterns in their unique inputs (e.g., Pinker et al. 1987; Marcus et al. 1992; Clahsen and Rothweiler 1993; Orsolini et al. 1998; Yang 2016). Increasingly, computational approaches in learning and in the intersection between learning and change have allowed researchers to work out productivity from corpus data, even historical data (Baayen 1993; Hare and Elman 1995; Yang 2000; Albright 2005; Yang 2016).

These lines of evidence are particularly important in the study of Latin because we cannot rely on long since deceased native speakers' acceptability judgments. Acquisition and (indirectly) change constitute *second* and *third factors* in shaping the grammar (Chomsky 2005). Environmental variation in the input is contingent on the historical pathways that shape language up until synchronic study, and these "principles not specific to the faculty of language" include the principles of data analysis and developmental constraints which drive the process of language acquisition. To the extent that the goal of linguistic theory is explanatory adequacy, we have to take third factors seriously. That defines the primary goal of this paper. What can we learn about the relationship between Latin past participles and deverbals if theory is informed by and forced to account for acquisition and diachronic evidence, and what does this say about the theoretical frameworks themselves? An explanatorily adequate theoretical framework should comport with what is known of acquisition and change.

1.1 Contributions

This paper makes four contributions specific to Latin morphology which come together as a case study for the deep entwining of theory, acquisition, and diachrony in morphological analysis. They are summarized here. First, this work clarifies the ways in which the Latin past participle is related to other verb forms, specifies which past participle forms should be listed, and specifies which should be derived by productive generalization. Using the entirety of the Old and Classical Latin texts in the Perseus Catalogue (Smith et al. 2000) and the Tolerance Principle (Yang 2016), a psychologically motivated computational model of productivity learning, the following generalizations come to light. Taken together, this list provides an independent set of productive generalizations that a representational theory should match:

- Verbs with a long *ā* theme vowel (the traditional *1st conjugation*) productively form thematic past participles with that vowel (e.g., *amō* ∼ *amātus*), and those with the short-*i* theme vowel (the traditional *3rd-iō conjugation*), productively form bare past participles without a theme vowel (e.g., *capiō* ∼ *captus*). The theme vowel alone is not enough to productively determine any other past participle forms.
- More generalizations can be made with reference to the perfect. Verbs which manifest their theme vowel in their perfect forms (*-āvī*, *-ēvī*, or *-īvī*) show the same theme vowel in the past participle (e.g., *audīvī* ∼ *audītus*), those *3rd conjugation* verbs whose roots end in *-u* and have surface *-uī* perfects have past participles with a long *ū* (*soluere* ∼ *soluī* ∼ *solūtus*), and those with *s*-perfects productively form bare past participles with no overt theme vowel (*scripsī* ∼ *scriptus*).
- Perhaps counter-intuitively, no large class of verbs productively forms past participles with short *i* (*-itus*) despite it being among the most common forms in the language, particularly in the 2nd and 3rd conjugations.

Second, diachronic outcomes in Late Latin and Romance indicate long-term consequences of productivity and confirm the acquisition analysis. In particular, the lack of a productive generalization for the 3rd conjugation in general, lack of broadly productive short-*i* *-itus* and bare *-tus* past participles despite their high type frequencies, and the narrowly productive 3rd conjugation past participle in surface *-ū-* provide an empirically motivated account for two developments in Romance past participles: the anomalous rise of the Late Latin **-utu* past participle attested across much of Romance today and the loss of apparently productive reflexes of the Classical bare and short-*i* past participles.

Third, in motivating productivity by acquisition and change and holding that variable constant across competing morphological frameworks, it becomes possible to directly compare their predictions in a new way. The implications of the Tolerance Principle analysis are worked out for four accounts: Aronoff's (1994) lexeme-based account, the Embick (2000) and Embick and Halle (2005) Distributed Morphology (DM) treatment, Steriade's (2016) *Similarity-Based Syncretism* (SBS) account, and the Calabrese (2020) DM treatment. It becomes clear that SBS is not workable since it relies on a serious overestimation of the amount of regularity in the system. While the DM accounts yields correct surface forms, they struggle to encode the correct patterns of productivity and thus predict change inadequately. Finally, the lexeme-based treatment, which positions itself as a higher-level description of the data, has no issue in principle with handling these generalizations since it is willing to accept arbitrary form-meaning mappings, but it arguably fails to explain what motivates the mappings in the first place.

Fourth, I sketch out a theoretical account for the Latin past participles and related *t*-deverbals which operationalizes the results of the productivity analysis and provides a mechanism for the attested analogical changes. Previous accounts do not completely capture or motivate the productive relations between the relevant morphological categories, and the DM treatments fail in perhaps the most interesting way: they can produce the correct surface forms, but they require structural relationships that do not comport with the results of the acquisition model and make incorrect diachronic predictions. To put it another way, this formalism may yield the expected surface forms and nevertheless require unrealistic underlying representations. The *strong generative capacity* (Chomsky 1963) of these models is suspect. I argue that this is the price paid by the theory for its lack of stems as representational objects. To explicate this point, I propose a framework that is loosely inspired by DM but includes structures tantamount to stems. The results of the acquisition modeling are incorporated directly as constraints on the theoretical analysis, and it makes accurate diachronic predictions as a result.

1.2 Outline

The paper is laid out as a description of the synchronic and diachronic facts, followed by an analysis. Section 2 provides background on the relevant details about Latin and Romance verbs and is organized so that the reader may refer back to it as needed. Section 3 reviews key findings from the literature on morphological learning in child development and introduces the Tolerance Principle (Yang 2016), a quantitative model of productivity learning. It also describes the Latin data set that is analyzed.

Section 4 applies the Tolerance Principle to the corpus to work out which past participles are productively derived and evaluates the past participle and *t*-deverbal correspondence against the inherent sparsity of the corpus. Section 5 then summarizes four theoretical treatments in light of this analysis, namely the lexeme-based account from Aronoff (1994), where Latin is invoked to motivate a notion of stems; the Distributed Morphology accounts of Embick (2000) and Embick and Halle (2005), and of Calabrese (2020), which use the same data to argue against that notion of stems; and the Similarity-Based Syncretism treatment from Steriade (2016), which presents a phonology-based alternative to the shared assumptions between the previous accounts. Finally, taking stock of all of these results, Section 6 sketches what a stem-based treatment that accounts for both the diachronic evidence and acquisition results may look like and explicates its desirable properties. Section 7 concludes.

2 Latin past participles

This paper aims to provide a comprehensive morphological treatment of the forms of past participles and *t*-deverbals, and to that end it brings a wide range of synchronic and diachronic facts to bear on the problem. This section serves as a reference. It begins with a discussion of the Classical Latin inflectional paradigm with special attention to stem forms and the past participle in particular. Next, it summarizes the *t*-deverbals and related forms. Then turning to diachrony, it discusses key changes which the past participles and *t*-deverbals underwent on their way from Latin to Romance. Readers who are familiar with Classical Latin may wish to skip ahead to Sect. 2.3 and its discussion of the system's diachrony.

Classical Latin was a formal literary register of the language originally spoken by the Latins, an Italic ethnic group who were native to the plains of Latium (including the city of Rome) south of the Tiber River in modern Lazio, Italy. The Classical standard came into being during the 1st century BCE and seems to be based closely on the Vulgar Latin (spoken; from *vulgāris* 'common, usual') of the urban Roman elite of the time, though it contains some archaisms in phonology and vocabulary (Clackson and Horrocks 2011). The Vulgar Latin of the Classical period eventually developed into what is known as Late Latin and Proto-Romance, the common ancestor of the modern Romance languages. The Romance languages express shared innovations from Late Latin which are absent in Classical Latin, indicating that the Vulgar Latin on which Classical Latin is based continued to develop as a single Late Latin language (though with increasing regional variation; Laurent 1999; Adams 2007; Clackson and Horrocks 2011) for centuries before diversifying into the modern Romance family.

The adoption of Classical Latin as a literary standard obscures a degree of dialectal variation that must have always existed in the language, as evidenced by Old Latin epigraphy (Clackson and Horrocks 2011), and it served as the written standard for so long that Late Latin and the earliest Romance varieties are nearly unattested and must be reconstructed. Since dialectal variation existed and change was constantly unfolding behind the scenes, it is worth asking whether Classical sources can be investigated for our purposes. Fortunately, the answer turns out to be yes, because Latin verbal inflection, including that of the past participles, was stable from Old to Classical Latin

(Laurent 1999; Weiss 2020). In the relevant respects, Classical Latin was very similar to the spoken language of a particular time and place and therefore, living native speaker judgments aside, can be studied more or less like a spoken language today. We should, however, be cautious of Classical texts written by authors from Late Antiquity and the Medieval period who were native speakers of Late Latin, Romance, or other Mediterranean and European languages. This is particularly relevant to the past participles because they underwent significant changes during Late Latin after a long period of stability in the Old and Classical languages.

2.1 The conjugations, principal parts, and past participles

As far back as Priscian in the 6th century, Classical grammarians thought of verbs in terms of four forms or *principal parts* from which all the inflected forms of a verb could be determined. They classified the verbs themselves into four (and a half) classes or *conjugations* according to the forms of their first two principal parts. This descriptive characterization is quite useful, and the four principal parts are still provided in Latin grammars and dictionaries in use today (e.g., Allen and Greenough 1903; Glare 2012).[1] While they are meant as a purely descriptive tool and so may or may not be "real" in a cognitive sense, they actually do reflect meaningful patterns of Latin morphology: the conjugations relate to which *theme vowels* attach to the roots (Embick, 2000; or at least the present stem, cf., Aronoff, 1994), and the four principal parts line up with three recognizable stems. The first two principal parts, the present active indicative 1st person singular and present active infinitive, are associated with present stem (henceforth *Present*), the third, the perfect active indicative 1st person singular is associated with the perfect stem (henceforth *Perfect*), and the final, either the past (also called "perfect passive") participle or supine[2] is associated with the past participle stem (henceforth *PPtc*). The theme vowels and stems are provided in Table 1 along with several verbs as illustrative examples. Only a few verbs, including 'carry,' 'want,' and 'be' are so irregular or suppletive as not to figure into the system of conjugations.

The past participles are sometimes called passive participles because they are typically passive in meaning. However, since active past participles also exist, they will only be referred to as "past participles" here. The past participles of doponent verbs, whose finite forms are always passive despite having active meanings (e.g., *hortātus* 'having encouraged,' *locūtus* 'having spoken') have active past participles. The deponents are usually intransitive, having descended from Indo-European middle voice verbs, although some are clearly transitive with agent subjects (e.g., *aggredior* 'approach, attack'), so a reliable synchronic semantic generalization is elusive here. There are also some non-deponent verbs with active past participles *iūrātus* 'having sworn' (Embick 2000).

[1] I adopt the traditional practice of using the first principal part as the citation form when listing examples. Verbs are listed with additional forms as necessary to disambiguate conjugation for the reader.

[2] The supine inflects like a 4th declension noun, and is very nearly always identical to the past participle, so they are usually handled interchangeably. The only exception that I am familiar with is *lavō*, *-āre* 'wash' with past participle *lautus* and supine *lavātum*.

Table 1 Example "regular" and "irregular" non-deponent Latin verbs by conjugations and principal part with corresponding theme vowels and stems. Traditional Priscianic PPtc stems are bolded. *ThV* for "theme vowel"

Conj.	ThV	1st	2nd	3rd	4th	Meaning
		Present		Perfect	PPtc	
1st	***ā***	*amō*	*amāre*	*amāvī*	***amāt****us*	'love'
		sonō	*sonāre*	*sonuī*	***sonit****us*	'sound'
		stō	*stāre*	*stetī*	***stat****us*	'stand'
2nd	***ē***	*moneō*	*monēre*	*monuī*	***monit****us*	'warn'
		maneō	*manēre*	*mānsī*	***mānsus***	'remain'
		teneō	*tenēre*	*tenuī*	***tent****us*	'hold'
		fleō	*flēre*	*flēvī*	***flēt****us*	'weep'
		videō	*vidēre*	*vīdī*	***vīsus***	'see'
3rd	***e***	*legō*	*legere*	*lēgī*	***lēct****us*	'choose'
		pellō	*pellere*	*pepulī*	***puls****us*	'push'
		molō	*molere*	*moluī*	***molit****us*	'grind'
		serō	*serere*	*sēvī*	***sat****us*	'sow'
		serō	*serere*	*seruī*	***sert****us*	'join'
		petō	*petere*	*petī(v)ī*	***petīt****us*	'seek'
		solvō	*solvere*	*soluī*	***solūt****us*	'loosen'
		coquō	*coquere*	*coxī*	***coct****us*	'cook'
		tangō	*tangere*	*tetigī*	***tāct****us*	'touch'
		iungō	*iungere*	*iunxī*	***iūnct****us*	'join'
		bibō	*bibere*	*bibī*	–	'drink'
3rd *-iō*	***i***	*capiō*	*capere*	*cēpī*	***capt****us*	'take'
		faciō	*facere*	*fēcī*	***fact****us*	'make'
		rapiō	*rapere*	*rapuī*	***rapt****us*	'snatch'
4th	***ī***	*audiō*	*audīre*	*audīvī*	***audīt****us*	'hear'
		exciō	*excīre*	*excīvī*	***excit****us*	'summon'
		hauriō	*haurīre*	*hausī*	***haust****us*	'drain'
		feriō	*ferīre*	*ferīī*	–	'strike'
Irregular		*ferō*	*ferre*	*tulī*	***lāt****us*	'carry'
		volō	*velle*	*voluī*	–	'want'
		sum	*esse*	*fuī*	–	'be'

2.1.1 The range of stem forms

The verbs featured in Table 1 were chosen to emphasize the fact that the forms of the stems are not reliably predictable from one another. Merely sharing one or two stem patterns, a present infinitive in *-ere* or Perfect in *-uī*,[3] for example, does not guarantee that the other stems will share their form too. In practice though, some patterns are more consistent than others. The first conjugation is highly predictable, with the

[3] I do not normally segment endings into suffixes except when relevant. This is not a claim for a particular morphological decomposition.

overwhelming majority of verbs patterning like *amō*, while the 3rd conjugation is the least predictable. Considering the Perfect alone, the 3rd conjugation contains verbs with bare affixation (*bibō* ∼ *bibī*), vowel mutation in the root (*legō* ∼ *lēgī*), partial reduplication (*tangō* ∼ *tetigī*), an *-s-* suffix (*iungō* ∼ *iunxī* /juŋk-s-iː/), and an *-u-* suffix (*molō* ∼ *moluī*). A few 3rd conjugation verbs are variably attested with up to three distinct Perfects with different etymologies (*parcō* ∼ *pepercī*, *parsī*, *parcuī* 'spare'; Clackson and Horrocks 2011), and some which share a Present (e.g., *serō* 'sow' and *serō* 'join') nevertheless differ in the other stems. *Deponents*, those (usually intransitive) verbs which employ passive forms to express active meanings, lack a Perfect, instead using periphrastic constructions with the past participle and copula to express the perfect forms.

There is even more variety in possible PPtc forms, which inflect like 1st/2nd declension (*a*/*o*-stem) adjectives in *-a*, *-us*, *-um*. A few blatantly suppletive forms such as *ferō* ∼ *lātus* aside, a verb has several options. Most 1st and 4th, and a few 2nd conjugation verbs (e.g., *fleō* ∼ *flētus*) exhibit their theme vowel followed by *-t-* and case marking, but some show a short *-i-* instead of the theme vowel. This short *-i-* is present in all conjugations but is most common in the 2nd and 3rd. There are also a few 2nd conjugation verbs with roots of the form *Cav-* or *Cov-* with past participles in *-autus* or *-ōtus* < **-outos* (e.g., *faveō* ∼ *fautus* 'favor,' *moveō* ∼ *mōtus* 'move') and 3rd conjugation verbs with roots ending in *u*/*v*[4] with past participles in *-ūtus* (e.g., *solvō* ∼ *solūtus* 'loosen'), though these patterns all have exceptions as well.

Most other 2nd and 3rd conjugation verbs have "bare" athematic past participles lacking a vowel between the root and *-t-*, often with substantial effect on the form of the root. Most notably, if the root ends in a coronal obstruent (*d*, *t*, *s*), then the final segment of the root and PPtc *-t-* are replaced with *-s-*, either with compensatory lengthening of the root vowel (*videō* ∼ *vīsus* < Proto-Italic **wid-t-os* 'see'), or gemination *-ss-* (*sedeō* ∼ sup. *sessum* 'sit'). Most *s*-PPtcs are synchronically phonologically predictable, but there are exceptions (e.g., *pellō* ∼ *pulsus*). Bare past participles trigger a variety of other changes to the root, many of which are also phonologically predictable such as the devoicing of final obstruents (e.g., *scribō* ∼ *scriptus*) or low-to-mid raising of a low root vowel. Low vowel raising is typically seen in prefixed forms and corresponds to low-to-high raising in the Present, for example, compare unprefixed *faciō* ∼ *factus* 'do, make,' to *con-ficiō* ∼ *con-fectus* 'finish.' This and related processes seems to have been automatic in Old Latin but may or may not have been in the Classical language (Weiss 2020).

Laurent (1999) provides counts enumerated in Table 2, which finds the most frequent PPtc patterns for each conjugation in order to estimate the regularity of the PPtc forms. These are consistent with an earlier quantitative analysis in Aronoff (1994). If this most frequent pattern is treated as "regular," then the 1st conjugation is overwhelmingly regular, the 2nd and 4th are somewhat less so, and the 3rd is certainly not.

While useful at a glance, there are two problems with these conclusions. First, a simple majority of items sharing a pattern is not so much a well-motivated linguistic

[4]Conventionally written <u> in modern editions when it represents a vowel, off-glide (<au>, <eu>), or in <qu>, and <v> otherwise. Both were written with a single character <V> by the Romans.

Table 2 Percent of verbs by class exhibiting the most common PPtc pattern. Based on Laurent (1999, Table 1-1)

Conjugation	# Verbs	# Regular	% Regular	Ending
1st	360	345	96%	*-ātus*
2nd	120	90	75%	*-itus*/*-tus*
3rd	170	60	35%	*-itus*
4th	60	40	67%	*-ītus*

metric for regularity as it is a descriptive rule of thumb, and second, the 2nd conjugation count is actually the sum of two different patterns. An improved metric for regularity motivated by child language acquisition will be proposed in Sect. 3.

2.1.2 Missing past participles

In addition to the variety and unpredictability of inflected forms, many verbs simply do not have past participles. These may be grouped into two types: those which lack past participles due to semantics, and those which seem to be arbitrarily defective. The first type consists mainly of statives (*rubeō* 'be red' ← *rub-* 'red') and inchoatives (*rubescō*, *-ere* 'redden'), which constitute two large classes of derived verbs in the language. The second type seems limited to a small number of verbs in the 3rd and 4th conjugations including some of relatively high frequency including *bibō*, *-ere*, *bibī* 'drink' and *feriō*, *-īre*, *feriī* 'strike.' It is particularly unlikely that there is some semantic reason behind their defectiveness given that other verbs with essentially the same meaning do have past participles: *potō* ∼ *pōtus* 'drink,' *percutiō* ∼ *percussus* 'strike,' and *ictō* ∼ *ictus* 'strike,' for example.

2.2 The "*t*-deverbals"

2.2.1 The *t*-deverbal and past participle form correspondence

The Latin past participles share their form with several deverbals, refered to here as *t-deverbals* because they share the characteristic *-t-* of the PPtc. This form correspondence is very reliable though not quite inviolable. The *t*-deverbals adopt whatever irregularities manifest in the past participle with few exceptions. The *t*-deverbals are particular interesting because they are semantically diverse. Everything from result nouns to agent nouns to future active participles share their forms with the perfective, usually passive, past participle. Table 3 summarizes the *t*-deverbals and highlights the shared PPtc stem.[5]

2.2.2 *t*-deverbals without corresponding past participles

The form correspondence between the past participle and the various *t*-deverbals is quite robust, although there are a few well-known exceptions, such as *mortuus* 'dead'

[5]There are also some verbal derivatives, iteratives, intensives, frequentatives, and desideratives, which share their form with the PPtc (Laurent 1999: Sects. 2.4, 2.10), for example, *cantō*, *-āre* 'sing' ← *canō*, *-ere*, *cecinī*, *cantus* 'sing, recite.' These derived verbs are all 1st or 4th conjugation regardless of the conjugation of the base.

Table 3 Example *t*-deverbals with corresponding past participles, Priscianic PPtc stems bolded

Type	Ending	Present	Perfect	PPtc	Meaning	*t*-Deverbal	Meaning
Adverb	***-tim***	*stō*	*stetī*	***stat****us*	'stood'	***stat****im*	'immediately'
Agent	***-tor***	*doceō*	*docuī*	***doct****us*	'taught'	***doct****or, -is*	'teacher'
Event(1)	***-tiō***	*agō*	*ēgī*	***act****us*	'done'	***act****iō, -nis*	'action'
Event(2)	***-tus***	*sūmō*	*sūmpsī*	***sumpt****us*	'spent'	***sumpt****us, -ūs*	'expenditure'
FPtc	***-tūrus***	*currō*	*cucurrī*	***curs****us*	'run'	***curs****ūrus, -a, -um*	'about to run'
Result	***-tūra***	*scribō*	*scripsī*	***script****us*	'written'	***script****ūra, -ae*	'writing'

Table 4 Example non-verbal *t*-derivatives with corresponding nouns (in the nominative and genitive singular citation forms)

Nominal	Meaning	Type	*t*-Denom.	Meaning
fūr, -is	'thief'	Adverb	*furtim*	'stealthily'
paulus, -a, -um	'small'		*paulātim*	'bit by bit'
–, *vicis*	'time, change'		*vicissim*	'in turn'
vir, -ī	'man'		*virītim*	'per man'
senex, sen-is	'old'	Agent	*senātor*	'senator'
barba, -ae	'beard'	PPtc-like	*barbātus*	'bearded'
nāsus, -ī	'nose'		*nāsūtus*	'big-nosed'
turris, -is	'tower'		*turrītus*	'towered'

but *moritūrus* 'about to die,' and *sonitus* 'sounded' but *sonāturus* 'about to sound' (Laurent 1999: 18–19), or *favitor* 'favorer' which exists alongside *fautor* and PPtc *fautus* (Steriade 2016: ex. 23).[6] Verbs without past participles may nevertheless have *t*-deverbals, for example *calitūrus* 'about to be warm' from stative *caleō* 'be warm' and *futūrus* 'about to be' from the copula *sum*, *esse*, *fuī* (Aronoff 1994: Sect. 2.2). There are also *t*-forms derived from nominals. Their forms vary substantially. *-tim*-adverb denominals, for example, are attested with the theme vowels *ā* and *ī*, bare, and are built either on the root or the genitive singular. Several examples are summarized in Table 4.

The Latin past participle and its related forms pose many challenges for any theoretical analysis. At a superficial level, the forms of the past participle are highly varied and are often not predictable from the other forms of a verb (Table 1), but the degree of variability differs substantially from conjugation to conjugation (Table 2). At a deeper level, the observation that the semantically heterogeneous *t*-deverbals share their forms with the past participle (Table 3) challenges our assumptions about the relationship between form and meaning, as does the presence of the similar *t*-denominals.

[6] See Maiden (2013: Sect. 3) for a discussion of semantic relationships between the handful of non-corresponding *t*-deverbals.

2.3 Changes affecting the past participles and *t*-deverbals

2.3.1 The origins of the past participle and *t*-deverbals

The basic organization of the Latin verbal system was very different from that of Proto-Indo-European (Weiss 2020: Sects. 28, 36–39). Even the past participle did not exist as is. It seems to have developed from a family of deverbal nouns built on the suffix **-to-* which was then integrated into the verbal paradigm (Weiss 2020: Sect. 39.II). In fact, the *t*-deverbals are derived from several inherited endings, many of which are themselves built on **-to-* (Weiss 2020: Sects. 28–29). Regular sound changes that contributed to the irregularity of the past participle also applied to the *t*-deverbals, which kept them in correspondence.[7] Even the most suppletive verb *ferō*, *ferre*, *tulī*, *lātus* 'bring, carry' with *t*-deverbals in *lāt-* has its origins in Proto-Indo-European. The ancestor of its Present stem, PIE $*b^h er$-, only has a reconstructable imperfective stem. The Perfect and PPtc, including the *t*-deverbals, are instead derived from the root $*telh_2$- 'lift' (Ringe and Eska 2013: Chap. 8). The correspondence between the past participle and *t*-deverbal forms thus has diachronic origins. The major implication here for theoretical analysis of the correspondence is that the correspondence does not emerge primarily from processes active in the grammar of Classical Latin. Rather, the grammar need only maintain what was provided to the language diachronically. One point of complexity outside the present study's scope is that some *t*-deverbals were originally built on the Indo-European athematic stem and others were built on the thematic. Some of the Classical PPtc's unpredictability has its origin in this distinction, as the stems were leveled across various now-opaque derivational forms.

2.3.2 Past participles reworked on the basis of the perfect

Once established, the Latin verbal system was relatively stable for centuries, though individual forms did change periodically. These changes suggest that Perfects in *-uī* were productive and that Perfect stems were capable of influencing the form of the PPtc.

The Perfect showed signs of regularization in early Latin (Vincent 1978), with forms in *-uī* gradually replacing reduplicated forms inherited from the Indo-European perfect stem and *s*-Perfects inherited from the Indo-European *s*-aorist. In this light, verbs with multiple Perfects like *parcō* ∼ *pepercī*, *parsī*, *parcuī* (Sect. 2.1.1) can be seen as undergoing regularization, with the innovative productive form replacing two earlier competing forms. Furthermore, there is evidence that past participle forms were being reworked on the basis of the Perfect already in prehistoric Latin. For example, *spernō*, *-ere* ∼ *sprēvī*, *sprētus* 'separate, spurn,' and *cernō*, *-ere* ∼ *crēvī*, *crētus* 'separate, perceive' exhibit a long *ē* in the PPtc, apparently on the basis of the Perfect. These must have replaced earlier athematic zero-grade forms **spert-* and **cert-*. The latter is actually retained as an adjective *certus* 'certain' in Classical Latin (Laurent 1999). Additional examples include *s*-Perfect verbs which have *s*-PPtcs without

[7] Calabrese (2020: Sect. 6) provides a particularly detailed summary of these developments, which, while couched in a particular theoretical analysis, should also be of interest to historically-minded readers.

phonological motivation (e.g., *maneō*, *mānsī*, *mānsus* 'remain,' *mulgeō*, *mulsī*, *mulsus* 'milk'), for which it can argued that the *s* has analogized from the Perfect to the PPtc. The latter example is also attested with its expected bare *t*-past participle *mulctus*, likely suggesting only a weak analogical relationship.

2.3.3 The rise of **-utu* and decline of *-itus* and *-tus*

The verbal system underwent more substantial changes in the transition to Romance. Perhaps facilitated by the collapse of vowel length and the merger of short *i* with long *e* in most regions, there was also significant *metaplasm* or movement of items between conjugations, mostly with the 2nd and 3rd moving to the 4th (Laurent 1999: Sect. 2.6). There was an uptick in the coining of new derived intensive, frequentative, and iterative verbs which replaced older forms. These were consistently regular 1st conjugation verbs (e.g., *cantō*, *-āre*, *-āvī*, *-ātus* 'sing' < intensive of *canō*, *-ere*, *cecinī*, *cantus* 'sing, recite,' *cantitō*, *-āre*, *-āvī*, *-ātus* 'sing repeatedly' < frequentative of the same) (Laurent 1999: Sects. 2.4, 2.10). Most importantly here, there were significant changes to the forms of the past participle. Beginning in Late Latin, three past participle endings, **-atu* < *-ātus*, **-itu* < *-ītus* (not < *-itus*; see below), and **-utu* < *-ūtus* began to spread at the expense of bare *-tus* and *-itus* despite the latter's high frequency in the 2nd and 3rd conjugations. This is another example of the Perfect's relationship to the PPtcs, since it apparently spread first among verbs with *-uī* Perfects (Laurent 1999: Sect. 3).

The expansion of **-atu* and **-itu* can easily be accounted for in even a pre-theoretical account of analogical leveling because of their high frequencies, but the rise of **-utu* is more perplexing. Why *-ūtus*, which only existed for about twenty 3rd conjugation verbs, should have undergone analogical extension throughout the former 2nd and 3rd conjugations is not obvious, particularly given the much greater prevalence of bare *-tus* and *-itus* in those conjugations. Nevertheless, that is what happened.[8] The map in Fig. 1 illustrates the geographical extent of reflexes of *-ūtus* in modern Romance contrasted against reflexes of *-itus*. Strikingly, reflexes of *-ūtus* are

[8] It is possible to assign a very rough date to the spread of **-utu*, since the ending blocks the Second Palatalization in former 2nd/3rd conjugation verbs outside of Italy. For example, the descendants of Latin *placitus* reflect Late Latin **plac[k]-u-t-u* without palatalization. This can be seen in Catalan *plagut* /plə'gut/, Romanian *plăcut* /plə'kut/, and French *plu* /ply/ < Old French *pleüt*. The intervocalic deletion in French is the same as seen in Old French *seür* < *secūrus*, while expected French outcome of intervocalic /ki:/ would be <is> as in MF *voison* < OF *veisin* < *vīcīnus*, cf. Italian palatalized *vecino*. If palatalization had occurred before the analogical change, then all of these forms should have been palatalized by the now-lost short /i/. This dates the extension of **-utu* to the 4th century *at the latest*, well within the bounds predicted in this paper's assumption that the change occurred in a period where Vulgar Latin was still phonologically similar to the Classical standard.

As mentioned above, the Romance varieties of Italy show a different outcome: Standard Italian does show palatalization before *-uto* (*piasciuto* /pja'ʧuto/). There are two possible explanations for this. The first is that the analogical change happened after palatalization in Italy but before it everywhere else. While technically not impossible—changes do not spread instantly over a large geographical area and could have reached different places at drastically different times—this is untestable without a treasure trove of Late Latin sociolinguistic data. The second explanation is that Italian reflects a later case of analogical leveling. The paradigms of verbs like *piasciuto* show palatalization by regular sound change before /e/ and /i/ in every single form except for the past participle before /u/. It is not a stretch to suggest that a historical unpalatalized **piacuto* was levelled. Medieval texts are suggestive of this: Lopez et al. (1903) provide a 13th century Italian form *crescuto* for modern *cresciuto*. If the orthography is to be believed—a serious

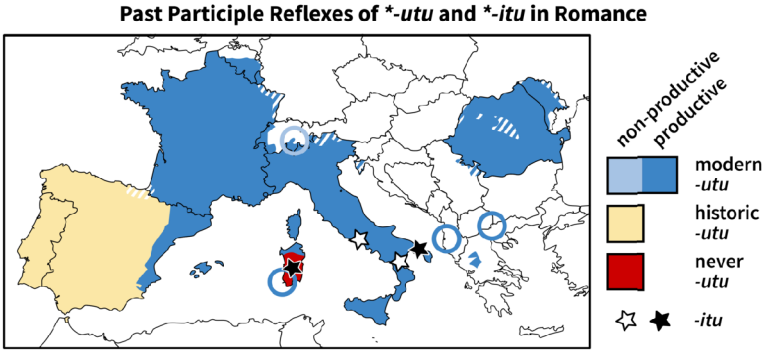


Fig. 1 The distribution of past participle reflexes of *-ūtus* and *-itus* in modern Romance. Reflexes of *-ūtus* productively form some past participles in most regions (dark blue), form some apparently unproductively in some dialects of Romansch (light blue), historically formed past participles in Iberia although they were already apparently unproductive by the Medieval era (light yellow), and never have in Sardinian (red). Unproductive reflexes of *-itus* still exist in some Southern Italian varieties (white stars), but only Sardinian and Apulian still productively form past participles in reflexes of *-itus* (black stars). Data compiled from Laurent (1999), especially Sect. 3. Circles highlight regions which are too small to shade (Color figure online)

attested everywhere except for Sardinian (red on the map). In most areas, the reflex is apparently productive today for some class of verbs (dark blue), and in many regions, it is apparently a default for the former 2nd and 3rd conjugations (e.g., Italian *-ere* verbs: *vendere* ∼ *vend**uto***, French *-re*: *vendre* ∼ *vend**u***, Catalan *-re*/*-er*: *vendre* ∼ *ven**ut*** 'sell,' contra Latin *vēnd**itus*** 'sold, on sale'). In others such as Romanian *vinde* ∼ *vând**ut***, it is productive for narrower classes. There are no verbs with *-ūtus* past participles in modern Portuguese, Spanish, and their close relatives, though they are attested both in Old Spanish and Old Portuguese (the yellow area in Fig. 1; e.g., Old Portuguese *ven**udo***). Remnants of Iberian *-udo* can still be found outside the verbal system, for example Spanish *men**udo*** 'tiny' < Latin *min**ūtus*** 'small, diminished,' and *ag**udo*** 'sharp' < Latin *ac**ūtus*** 'sharpened.' All Iberian *-udo* past participles were eventually replaced with *-ido* < *-ītus* (Laurent 1999: Sect. 4.7). Finally, past participle reflexes of *-ūtus* are present but apparently no longer productive in the Surselvan and Engadin dialects of Romansch spoken in far-southern Switzerland (Laurent 1999: Sect. 4.3).

The distribution of productive reflexes of *-itus* in modern Romance is far more restricted, present in only Sardinian and Apulian in southern Italy (the black stars in Fig. 1). There is evidence that *-itus* was previously productive in other parts of southern Italy as well, accounting for forms including Lucanian *bipp**eto*** and Neapolitan *vipp**eto*** < Late Latin **bib**i**tu*** rather than Standard Italian *bevuto* (the white stars in Fig. 1; Laurent 1999: Sect. 3.6). Its retention in Sardinian may be explained by the merger of /i/ and /iː/, which leveled the vowel quality in *-itus* and *-ītus* on the island, merging the short-*i* past participles into one of the productive classes. Elsewhere in Romance, /i/ merged with /eː/, and in most cases, /e/ (Loporcaro 2015: Sect. 2.4).

caveat with pre-standardized medieval spelling—this would serve as positive evidence for later analogical leveling towards palatalization in Italian.

What reflexes of bare *-tus* remain in Romance today have been relegated to irregular past participles or have been recast as adjectives. The irregulars are overwhelmingly high frequency items, for example, Italian *fatto*, French *fait*, Spanish *hecho* < *factus* 'done, made' and Italian *detto*, French *dit*, Spanish *dicho* < *dictus* 'said' (Laurent 1999: Sect. 6.6). The relationship between high frequency items and irregularity (or resistance to analogical leveling) is well-known (e.g., Bybee 1985; Baayen 1993; Bybee and Hopper 2001) and predicted by any reasonable model of analogical change. Many of these correspond to verbs with *s*-Perfects, including Italian *scritto* and Spanish *escrito* 'written' < *scriptus*, which retained an *s*-Perfect *escriss-* < *scrips-* in Old Spanish (Laurent 1999: 301). Some doublets exist in a few varieties, including Sicilian (predicative *ruttu* 'broken' < *ruptus* vs. passive and perfect AUX *rumputu* < **rumputu*), and Portuguese and Neapolitan (Maiden 2013). There is also evidence for an expansion of *s*-PPtcs in some Eastern Romance varieties, especially in Romania (Laurent 1999: Sect. 3).

2.3.4 The partial collapse of the *t*-deverbal correspondence

Some of the *t*-deverbals, including the future participle, have been totally lost in Romance. The remainder (particularly event and agent nouns) have gradually drifted away from the correspondence, slowly aligning with the present stem rather than the past participle when the two are distinct (Maiden 2013: Sect. 4). According to Steriade (2016), only inherited irregulars can have irregulars corresponding *t*-deverbals in Romance, which is consistent with the lack of a productive synchronic correspondence. When there is a difference between the past participle and the present stem in modern Romance, the *t*-deverbal generally shares a form with the present instead. This would suggest that Romance *t*-deverbals are productively built on the present rather than the past participle when the two differ (Maiden 2018: Chap. 7.4).

The decline of the correspondence has occurred at different rates across Romance, with Italian the most conservative standard variety, and Spanish the most innovative. Some inherited *t*-deverbals correspond as they did in Classical Latin (Italian *scritto* 'written' ~ *scrittore* 'writer' and Spanish *escrito* 'written' ~ *escritor* 'writer' < *scriptus* 'written' ~ *scriptor* 'writer'), while others have been regularized despite retained irregular past participles (Spanish *hecho* 'made, done' < *factus*, but regular *hacedor*, cf. infinitive *hacer*, Italian *fatto* < *factus*, but regular *facitore* replacing now-archaic or literary *fattore*).[9]

The theme vowel in Spanish agent nouns presents a strong illustration for the systematic realignment with the present to the exclusion of the past participle. Spanish has three conjugations corresponding to three theme vowels *-ar*, *-er*, and *-ir*, which surface distinctly in the infinitive and many present forms. It has three agent endings corresponding to the three theme vowels *-ador*, *-edor*, and *-idor*, however it only has two productive past participles: *-ado* < *-ātus* for *-ar* verbs, and *-ido* < *-ītus* for the other two. The agents of *-er* verbs thus transparently correspond to the present rather than the past participle (e.g., inf. *tener* 'hold,' pptc *tenido* 'held,' agent *tenedor* 'holder').

[9]Some of the remaining irregulars have regular doublets, for example, the expected regular Spanish agent noun *escribidor* 'scriptwriter' alongside *escritor* 'writer.'

3 Learning productive morphological patterns

There is a strong analogy to be drawn between the learning task which children face in working out the productivity of patterns their native languages and the task facing the linguist when working out theoretical analyses. But there is a more significant point to make here as well. The language faculty consists of more than just UG: it includes processing, tasks of language acquisition, and other properties not unique to the language faculty as well, as Chomsky has emphasized (Chomsky 2005). We should evaluate the merit of a theoretical analysis in an integrated perspective to the extent possible.

A significant body of results bearing on the acquisition of morphology has been published over the years. After reviewing the most important points, I turn to the Tolerance Principle (Yang 2016), a quantitative decision procedure in the sense of Chomsky (1957), derived from what is known about language development. Following that, I introduce the Latin data to work out in what ways it is amenable to this acquisition-inspired analysis. Readers who are familiar with the literature on morphology acquisition may wish to skip ahead to Sect. 3.3. The learning-based productivity analysis laid out in the next two sections will greatly clarify the divergent predictions of the lexeme-based, DM, and SBS analyses and will inform the sketch introduced at the end of this paper.

3.1 Productivity in morphological acquisition

Children clearly acquire productive morphological patterns early during their development, but these patterns are not learned instantaneously or all at once. Rather, productivity may ebb and flow as children continuously re-evaluate their hypotheses regarding their grammars (Ervin and Miller 1963; Pinker and Prince 1988). There is a significant asymmetry between regular and irregular patterns in language, which becomes evident through the analysis of child production errors: errant morphological productions are nearly always over-regularizations rather than over-irregularizations. This pattern has been observed in several languages: English (Marcus et al. 1992; Pinker 1999), German (Clahsen and Rothweiler 1993; Clahsen 1996), Spanish (Clahsen et al. 2002), and Italian (Orsolini et al. 1998), to name a few. For example, Clahsen et al. (2002) studied Spanish children's productions; 168 of 5,687 verb forms were innovative, but of those, all but three (98.2%) were over-regularizations. Patterns of over-regularization further reveal that productivity need not be all or nothing and global like English *-ed*, or entirely idiosyncratic like *go* ∼ *went*. In the Spanish, German, and Italian studies cited above, there is evidence of phonologically and semantically conditioned sub-regularities, for example, the presence of a specific theme vowel in Spanish (Clahsen et al. 2002), a specific root shape in Italian (Orsolini et al. 1998; Say and Clahsen 2002), or particular phonological and semantic conditions including gender in German (Clahsen 1996).

German also demonstrates that productivity is not simply a matter of majority type frequency: corpus and experimental evidence points to *-s* as the global default noun plural in German despite its low type frequency relative to unproductive and conditionally productive *-(e)n*, *-er*, *-e*, and ∅ (Clahsen 1996; Yang 2016; McCurdy

et al. 2020). This is the problem with the majority metric taken up by Aronoff (1994) and by Laurent (1999) in Table 2. Productivity has to be determined quantitatively, but it is not decided by simple numerical dominance.

Then again, not all minority patterns are productive either. The mere presence of a potential phonologically or semantically conditioned pattern, one that linguists classify and even naive adult speakers may perceive, does not guarantee it achieves a productive status in the grammar. Some of the less famous words from the classic wug study illustrate this. Berko (1958) prompted children to produce past tense forms for *gling* and *bing* with the expectation that they might mutate the stem vowel to *a* or *u* like *sing* ∼ *sang* or *sting* ∼ *stung*. That is not what happened. Only one child out of 86 produced the stem change, two applied both the stem change and *-ed*, and the rest resorted to *-ed* or simply could not answer. The success rate was far lower than for regular patterns such as *-ed*, *-s*, and *-ing*, suggesting that both mutating patterns are unproductive. This begins to make sense when looking at these verbs in the English lexicon. There are several *sing*-type and *sting*-type verbs, but they serve as exceptions to each other's patterns as do many verbs like *ding* ∼ *dinged*, and *bring* ∼ *brought*. Though English-speaking adults *can* produce forms like *glang* or *glung* and did in the Berko (1958) study, this is not what they usually do in practice. When new words enter the lexicon, they do so with *-ed* pasts (*ping* ∼ *pinged*, *Bing* ∼ *Binged*, and *bling* ∼ *blinged*).

3.2 The Tolerance Principle

The *Tolerance Principle* (TP; Yang 2016) is a type-based model which casts generalizations in terms of productivity in the face of exceptions. I adopt it here because it is as well-motivated by both psycholinguistic and computational principles and validated over several corpus and experimental studies. Crucially for the argument developed here, it is motivated by linguistic and cognitive factors outside of the problem at hand. Any other acquisition model that accurately models the acquisition process and the learning of productivity by native language learners could conceivably be substituted here to make the same general point.

A distinction between productive "regular" patterns and unproductive "irregular" exceptions is prominent in many theories of grammar, and has often been conceptualized in terms of Elsewhere Conditions (Anderson 1973; Kiparsky 1973; Aronoff 1976) in which irregulars have to be looked up in some way before defaulting to a regular pattern. By their very nature, irregulars have to be listed in some fashion, so even regulars have to be checked against the set of the set of irregulars before they can be inflected. Since it takes time to search down a list of exceptions before applying the elsewhere condition, an effect consistent with psycholinguistic findings in frequency-ranked lexical access (Murray and Forster 2004), a cost is established for representing patterns as long lists of lexical exceptions as opposed to shorter lists with elsewhere conditions. The more irregulars, the longer the lookup, which motivates the learner to establish productive patterns when it is more economical to do so. But regardless of the theory, a question then arises: how many exceptions is too many? At what point does it become better to list items and absorb the cost rather than form a productive generalization? This is where the TP comes in. It is fundamentally

a mathematical heuristic, a quantitative decision procedure. A child can hypothesize a generalization and then evaluate whether or not the number of exceptions to that generalization are too many to tolerate. If a generalization is reliable enough, it can enter the grammar as a productive pattern.

The TP is a binary function: either a generalization is productive over some scope, or it is not. All rules or generalizations are productive and all memorized lexical exceptions are non-productive by definition, so if a pattern is not productive, then it is not learned as a generalization, and vice-versa. It is up to each individual learner to determine whether patterns in the input are productive over a given domain or if they have to be memorized instead. As part of the learner's hypothesis evaluation, it necessarily occurs prior to the language-specific adult instantiation of the grammar, and so is highly influenced by surface forms which are transmitted to the learner as primary linguistic input. Learners proceed by postulating tentative generalizations over these forms projected onto a hypothesized grammar. They must be able to generate a wide range of hypothesized grammars constrained by the language faculty and the input since they cannot know a priori which will grammar will best accommodate the data.

More formally, the *tolerance threshold* is calculated as the number of exceptions below which it becomes more efficient to hypothesize a generalization than to list items.[10] To calculate this, the TP assumes that lexical access is correlated with frequency rank, so high frequency irregulars are accessed before lower frequency ones (Goodman et al. 2008), and items in the input follow long-tailed Zipfian frequency distributions (Zipf 1949) in which few items are well-attested and others are rarely tested in the input. Zipfian and other long-tailed distributions are quite common throughout language and are very prominent in lexical and inflectional frequencies (and indeed other domains as well, e.g., Miller 1957; Howes 1968; Jelinek 1997; Baroni 2005; Chan 2008; Yang 2013; Lignos and Yang 2018).

If the number of exceptions exceeds the tolerance threshold for a hypothesized generalization, then children can resort to memorization. If the exceptions fall below the threshold, they can learn the grammar that supports that generalization and memorize the exceptions. They can learn the generalization, handle the exceptions as needed, and consider a broader one to potentially subsume it. The threshold θ_N itself is determined by the number of lexical items N in the scope of the generalization and the number of exceptions e, the number of words learned so far that fit the conditions for the generalization but do not exhibit the pattern. (1) provides a formulation of the Tolerance Principle, and Fig. 2 provides a visualization of it. The tolerance threshold θ_N is defined as the number of known types that a generalization should apply to divided by its natural logarithm.

(1) **Tolerance Principle**
If R is a productive rule applicable to N candidates, then the following relation holds between N and e, the number of exceptions that could but do not follow R:

$$e \leq \theta_N \text{ where } \theta_N := \frac{N}{\ln N}$$

[10] See Yang (2016: 10, 144) for the full mathematical derivation.

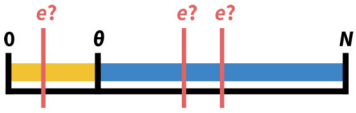


Fig. 2 Visualizing exceptions on a number line. e falls in the range $[0, N]$. If it lies below θ (gold/light), then there are tolerably few exceptions to the hypothesized generalization, so the learner should acquire it and memorize the exceptions. Otherwise, if e lies above θ (blue/dark), then there are too many exceptions to the generalization to tolerate, so the learner should resort to memorization instead

(a) Vocabularies grow over the course of development

(b) A pattern may fall into productivity

(c) A pattern may fall out of productivity

Fig. 3 **a**) Visualizing exceptions on a number line during individual development. N grows as the learner's vocabulary grows. θ grows more slowly because of how it is defined as a function of N. A learner's acquisition trajectory depends on how e grows relative to N. **b**) If θ grows more quickly than e, it is possible for a generalization that was non-productive early in an individual's development to become productive later. Here, e falls in the non-productive (blue/dark) zone earlier, but falls into the productive (gold/light) zone later. **c**) If e grows more quickly than θ for a given individual, it is possible for a pattern to fall out out of productivity over the course of development

One important property of the TP is that learners will adjust their decisions about productivity as they learn new vocabulary and their tolerance thresholds shift accordingly (Fig. 3a). This means that a generalization that is not productive in a learner's early development can potentially be rendered productive as that learner acquires more vocabulary (Fig. 3b). Alternatively, if the number of exceptions to a generalization grows faster than the vocabulary, as may happen when a learner is learning new words from a long tail of exceptions, a generalization that was productive early in development may fall out of productivity (Fig. 3c).

This falling in and out of productivity is empirically testable because children with over-productive grammars are expected to occasionally make over-production errors, as discussed above. These examples extend past morphology into syntax as phonology as well, as noted by Gropen et al. (1989), Bowerman and Croft (2008), and Yang (2016), among others. The TP has been successfully applied to problems across linguistics from phonology (Yang 2016; Sneller et al. 2019; Kodner and Richter 2020; Richter 2021) to morphology including the German noun plural patterns (Yang 2016, 2017; Gorman and Yang 2019; Msaka 2019; Björnsdóttir 2021), and syntax (Yang 2016; Yang and Montrul 2017; Pearl and Sprouse 2018; Irani 2019; Lee and Kodner 2020), among others; and it has also received backing from a growing body of experimental studies in morphological and syntactic learning (Schuler 2017;

Koulaguina and Shi 2019; Emond and Shi 2020). As a decision procedure embedded within computational learning models, it has achieved good performance in learning morphological systems in English, German, and Spanish (Payne et al. 2021; Belth et al. 2021).

3.3 Modeling typical Latin learners

Before calculating the productivity of the Latin past participles, we need to choose a corpus over which to apply the Tolerance Principle and make some practical decisions about how to process the data. Ideally, we could use a corpus of child-directed speech (CDS) like those available from the CHILDES project (MacWhinney 2000). But of course, that is out of the question for Latin (and for the vast majority of living languages!) so I instead turn to the online Perseus Catalogue of classical languages (Smith et al. 2000) instead.

A few properties of acquisition and early linguistic input facilitate corpus investigation of morphological acquisition. First, all children receive unique input yet exhibit remarkable uniformity in the patterns that they acquire (Labov 1972), even if the time course of acquisition is slightly advanced or delayed (Fenson et al. 1994; Maratsos 2000; Yang 2002). Second, the crucial role of type frequency: convergent results from a wide variety of research programs connect grammar learning to the *number of types* over which linguistic patterns are expressed in the input rather than the attestation of any particular lexical items (Aronoff 1976; MacWhinney 1978; Bybee 1985; Baayen 1993; Elman 1998; Pierrehumbert 2003; Yang 2016). Third, token frequency and availability: the relative age at which learners acquire vocabulary items is correlated with their *token frequencies* (Goodman et al. 2008) in the input. And fourth, small early vocabularies: the typical learner knows only a few hundred to a thousand words by around age three (Fenson et al. 1994; Hart and Risley 1995, 2003; Szagun et al. 2006). Since children are well on their way towards acquiring their languages' inflectional morphologies by that point, the bulk of grammar acquisition is undertaken on the basis of relatively few mostly high frequency items rather than large adult-like lexicons.

Since higher token frequency items tend to be acquired earlier, young learner's lexicons may be estimated by trimming off the less frequent items from CDS (Nagy and Anderson 1984; Yang 2016). Doing so yields approximations of "typical" children's lexicons which are the appropriate size and consist primarily of high frequency items. It has been demonstrated that for some research questions, one can reasonably substitute historical corpora for CDS, including Perseus for Latin, because the extraction procedure tends to remove corpus specific low-frequency items and closely approximate the distributions found in CDS (Kodner 2019, 2020). This is equivalent to using any large modern non-CDS corpus for the same purposes. This section will review some of the core findings about the relationship between Perseus and CDS before setting up the Latin analysis.

3.3.1 Estimating Latin learner knowledge from Perseus

The Perseus corpus contains roughly 3.5 million tokens of Old and Classical Latin text. In order to extract all of the verbs, the texts were scraped from the online edition

(which contain more text than could be downloaded directly), then they were lemmatized and then POS-tagged with scripts extended from the CLTK Python library (Johnson et al. 2016). Lemmatization is motivated by the finding that modern Spanish learners are capable of identifying person/number marking from an early age (Marrero and Aguirre 2003), and that young learners of both English (Brown 1973) and Spanish (Kvaal et al. 1988) already show an understanding of the semantics behind inflectional morphology, making it possible for them to identify and classify lemmas. These were sorted by token frequency as one would normally do with CDS and grouped without prepositional prefixes (e.g., FACIŌ: *faciō*, *conficiō*, *perficiō*, *officiō*, etc.), since verbs with these derivational prefixes very rarely differ in their PPtc patterns. [11] Perseus does not mark vowel length, so length was restored and Perfect and PPtc stems found by merging the lemma list with the principal parts provided with vowel length in Latin Wiktionary.[12] The result is a list of 1,292 unique verb lemmas and their principal parts derived from about 3.5 million tokens of Latin text composed between the 3rd century BCE and 2nd century CE inclusive. This is about three times larger than the data sets used in Aronoff (1994) and Steriade (2016). The full list is available as supplementary material.[13]

As an initial test, we can investigate how the Perseus-derived verb list compares to Laurent's (Table 2) in terms of the sizes and homogeneities of the conjugations.

[11] They often differ in short vowel raising, which will be treated here as a regular phonological process (Sect. 2.1.1).

[12] Accessed November 2018.

[13] The automatic frequency list extraction procedure comes with the usual caveats associated with this kind of task. The scope of the potential problems was found to be minor in each case, but they are important to discuss:

- All automatic POS-tagging and lemmatization has the potential to introduce errors. The main problem comes from homophonous inflected forms such as `volo` 'I want' or 'I fly,' which cannot easily be assigned to the correct lemma (but note, most members of the paradigms can be, e.g., `vult` 's/he wants' vs. `volat` 's/he flies'). The problem is exacerbated on Perseus data because it lacks vowel length annotation. This collapsed some forms such as `cecidi` which can reflect either *cecīdī* 'I struck, killed' or *cecidī* 'I fell.' Even so, there are only a few cases of homophony like this, so when these arose, the combined frequency count was applied to both verbs, and since the calculations here do not depend on the presence or absence of any particular verb, this decision does not affect the final calculations.
- Wiktionary, which was used to collect principal parts with vowel length, is built by a community of volunteers referencing standard dictionaries such as Lewis and Short (1966) and could contain transcription errors. A sample of about one hundred Wiktionary-provided principal parts was compared with entries in the Oxford Latin Dictionary (Glare 2012) in order to confirm their accuracy. There were only a few discrepancies, all of which would have stood out to any student of Latin. These were corrected, and all other suspicious entries were double checked. All in all, Latin Wiktionary is surprisingly accurate in this respect.
- There were some design decisions involved in removing derivational prepositional prefixes. Every derivational prefix was removed with only a few exceptions that were already opaque during the Classical era, including *prōmō* 'produce, bring to light' which was not decomposed into *prō+emō* (root: 'buy, acquire') and *vēndō* 'sell' which was not decomposed into *vēn-+dō* (root: 'give'). There were fewer than a dozen of these according to the author's non-native judgment.
- There are likely other errors and biases in the data as well. It is important to note though that this problem is not restricted to automatically collected corpora. Hand sampled data also suffers from biases introduced by the smaller data size and researchers' preconceived and perhaps subconscious notions of which pieces of data will be relevant.

Table 5 Percent of verbs exhibiting the two most common PPtc forms in each class. Highlighted values can be compared directly to Table 2

Conj.	# Verbs	Most freq		% Most Freq	Next Freq		% (Most + Next Freq)
1st	541	*-ātus*	528	97.6%	*-itus*	6	98.7%
2nd	65	*-itus*	25	38.5%	*-tus*	17	64.6%
3rd	215	*-tus*	69	32.1%	*-itus*	17	40.0%
4th	55	*-ītus*	34	61.8%	*-tus*	13	87.3%

Table 5 summarizes the top 1,000 most frequent verb lemmas.[14] The 1st and 3rd conjugations are the largest, with the 1st conjugation accounting for over half of all verbs with past participles. They are also the most and least homogeneous respectively. *-itus* and *-tus* are the most common past participle forms in the 2nd and 3rd conjugations and the second most common in the 1st and 4th. Most remaining verbs undergo some unpredictable stem mutation. Keep in mind that the 2nd conjugation count in Table 2 is the sum of two endings, so it should be compared to the rightmost column of Table 5.

So the Perseus corpus as processed here contains roughly the same distributions of conjugations and PPtc endings as expected from prior literature. What of its relationship to CDS? The most important property of a corpus when estimating child linguistic experience is the extent to which it captures type frequencies at a scale expected for child learners. English- and German-learning children know a few hundred, or a thousand words at most by age three (Hart and Risley 1995, 2003; Szagun et al. 2006), and only a fraction of those are verbs. Estimates for Adam and Sarah of the Brown corpus (Brown 1973) suggest that they knew about two hundred verbs at age three and just under four hundred at age five (Marcus et al. 1992: Chap. 5). With 1,292 verbs, the Perseus corpus is more than large enough. It also contains roughly the same number of verb types as widely studied corpora of CDS. The classic English CDS corpora—Brown, Brent, and MacWhinney—contain 1,042 verb types as parsed in Kodner (2019), which is quite close to the number for Perseus. For comparison, the Brown University Standard Corpus of Present-Day American English (not to be confused with the CHILDES Brown corpus), a classic NLP corpus drawn from several genres, contains 1,256 verb types. It is also shown in Kodner (2020) that the Latin corpus exhibits the same very sparse long-tailed distributions of inflectional categories and lemmas as are consistently found in CDS and in fact all corpora of reasonable size (Zipf 1949; Chan 2008; Lignos and Yang 2018).

All in all, the Perseus-derived verb list employed in this study is actually quite similar to what we would expect from a Latin CDS corpus if one existed. In addition to that, while not perfect, it is both larger and better characterized and verified than the corpora employed in the prior accounts discussed in Sect. 5.

3.3.2 Learning Latin

This section concludes with a explanation of how the Tolerance Principle is applied to the Latin data. The question at hand is whether some cue from the root or other

[14] Verbs without recorded past participles in this data set are overwhelmingly inchoatives in *-escere*. If no PPtc is in the input, it cannot serve as evidence either way. These were excluded from this calculation, which is why the second column does not sum to 1,000.

stems of a verb form as transmitted to a learner should lead that learner to internalize a productive generalization that renders some set of the past participles productive. The generalizations evaluated by the Tolerance Principle can be phrased in the terms of any of the theories described in Sect. 5, which renders it suitable as part of an integrated account of the language faculty and as a tool for comparing theories. For example, if one wants to ask whether 1st conjugation verbs should form past participles with the ending *-ātus*,[15] it could be phrased in several ways depending on the theoretical framework that is about to be employed: if a given $\sqrt{\text{ROOT}}$ selects 1st conjugation and the theme vowel is spelled out in finite forms, does that imply it will remain unadjusted in the PPtc? Or in a different framework, if /aː/ follows the root in the Present, will the PPtc show /aː/ in the same location?

As a concrete example, consider a child who currently knows $n = 500$ verbs in their Present and PPtc forms and is evaluating the following hypothesized rule for the grammar: "if theme vowel *ā* manifests after the root in the Present, then *ā* should appear after the same root form in the PPtc." Using the Tolerance Principle to evaluate the hypothesis, the child would ask whether the pattern holds with sufficient reliability to commit it to the grammar. The corpus is referenced to determine the learner's input. Scanning the verb list, a typical learner with verbal vocabulary size $n = 500$ knows $N = 211$ verbs with *ā* in the Present. All but 11 of those (e.g., *sonitus*) meet the generalization, so $e = 11$. The tolerance threshold for $\theta_{211} = 39.43$, and e is well under that, so the generalization is productive. We can conclude that 1st conjugation verbs, productively form PPtcs in *-ātus* at this vocabulary size. The grammar should handle these productively. The child then repeats this evaluation for every potential generalization that they postulate.

4 Productivity of the past participles and *t*-deverbals

This section calculates out and discusses the productivity of Latin PPtc derivation according to the Tolerance Principle as applied in Sect. 3.3.2 and discusses implications for the form correspondence between the past participle and *t*-deverbals. Section 4.1 evaluates the productivity of past participle patterns given evidence from other forms of a verb, and Sect. 4.2 evaluates the past participle to *t*-deverbal correspondence.

4.1 Productivity of the past participles

We begin by modeling typical Latin learners as they evaluate a range of hypothesized productive patterns for inclusion in their grammars. Following the principles discussed in Yang (2016), the child should test both broad generalizations such as productivity for an entire conjugation as well as narrower ones like productivity only

[15] In this section, PPtc endings are written as *-ātus*, *-itus*, *-sus*, etc., in the masculine nominative singular in keeping with the style of traditional grammars (and to avoid implying that they are supines). This format is a surface description of the linguistic input and does not imply a lack of segmentation or internal structure in the speaker's or listener's grammar. Children are able to distinguish an item's outermost endings as indicated in studies of Romance-learning children (Kvaal et al. 1988; Marrero and Aguirre 2003), so person/number and case/number marking do not factor into the analysis.

for roots meeting a certain phonotactic constraint. Standing in for the child, we consider broad productivity on the level of conjugations and narrower productivity on the basis of other patterns visible in the Present which have been suggested in the literature, e.g., (Weiss 2020: Sect. 39) in Sect. 4.1.1. Following that, productivity based on the form of the Perfect is evaluated in Sect. 4.1.2 since this is strongly suggested by diachronic evidence (Sects. 2.3.2–2.3.3). Finally, multiple possible operationalizations of the Steriade (2016) rhythmic correspondence are evaluated in Sect. 4.1.3. In the spirit of giving generalization its best shot, plausibly automatic phonological mutations discussed in Sect. 2.1 such as unstressed short vowel raising in prefixed verbs, compensatory vowel lengthening, final obstruent devoicing, and $t > s$ before coronal obstruents in bare PPtcs, and rhoticization do not count as exceptions in the analyses. Other mutations, including unexpected *s*-PPtcs, unexpected vowel mutations, and suppletives do count as exceptions.[16]

Since children may reevaluate their grammars many times as they develop (Sect. 3.1), and patterns may fall out of productivity as children mature (Fig. 3), the Tolerance Principle is applied here at three verbal vocabulary sizes: $n = 100$, which for Italian corresponds to learners around the age of three (D'Odorico and Fasolo 2007), $n = 500$, which is more like school age, and $n = 1{,}000$, which accounts for most of the verbs in Perseus and so must indicate a mature speaker. A kind of developmental trajectory can be loosely approximated this way.

4.1.1 Evidence from the present

The set of calculations presented in Table 6 concerns the traditional theme vowels identifiable in the Present stem. It immediately stands out that only the 1st and 3rd-*iō* conjugations have productive PPtc derivations conditioned on the theme vowel. While the majority of 4th conjugation verbs do indeed form their past participles in *-ītus*, it is not quite enough to render that derivation productive according to the Tolerance Principle. Importantly, even though *-tus* and *-itus* are quite common outside the 1st conjugation, their distribution is such that neither is productive according to these theme vowel generalizations. Plurality does not equal productivity and it is entirely possible for frequent patterns to fail the test. In all, just over half (the large majority of the 1st conjugation + 3rd-*iō*) of the thousand verbs tested have past participle forms which may be productively derived given their theme vowels or conjugation.

For this calculation, it has to be assumed that the model child knows an infinitive or other Present stem form that allows them to classify the verb into the correct conjugation. Some forms of 3rd and 4th conjugation verbs are ambiguous as to class, for example, the third person singular present active indicative of these conjugations

[16]The plausibly automatic stem mutations discussed in Sect. 2.1 only apply to bare past participles. In treating them as automatic, this analysis can only err by *over*-estimating the productivity of bare PPtc patterns. Empirically, this turns out to be an innocuous assumption: looking ahead to the results in Tables 6 and 8, all but two hypothetical bare PPtc derivations (3rd-*iō* and *-sī*-Perfect) are unproductive even with this potential advantage. None of the those phonological processes affect the 3rd-*iō* Presents and PPtcs or *-sī*-Perfect and PPtcs, so the assumption is safe there as well. Whether or not these phonological patterns were actually synchronically productive is also a question amenable to a Tolerance Principle analysis, but that paper is left for future work.

Table 6 Tolerability of past participle patterns by Present stem theme vowel corresponding to the traditional conjugations. (Bold/green) productive, (red) unproductive, (italicized/yellow) marginal cases within 1 of the tolerance threshold may be subject to variation, (white) calculation was not carried out because N is too small for the formula

Theme Vowel	PPtc	Example	At $n = 100$?	At 500?	At 1000?
(1st) *ā*	*-ātus*	*vocāre* ∼ *vocātus*	**N=17 (e=1)**	**221 (11)**	**541 (13)**
(2nd) *ē*	*-itus*	*habēre* ∼ *habitus*	16 (9)	55 (35)	65 (40)
(2nd) *ē*	*-s/tus*	*docēre* ∼ *doctus*	16 (14)	55 (42)	65 (48)
(3rd non-*iō*) *e*	*-itus*	*reddere* ∼ *redditus*	47 (46)	147 (136)	201 (185)
(3rd non-*iō*) *e*	*-s/tus*	*scribere* ∼ *scriptus*	47 (32)	147 (105)	201 (143)
(3rd *-iō*) *i*	*-s/tus*	*capiō* ∼ *captus*	**9 (1)**	**12 (2)**	**14 (3)**
(4th) *ī*	*-ītus*	*audīre* ∼ *audītus*	5 (3)	*27 (9)*	55 (21)
(4th) *ī*	*-s/tus*	*venīre* ∼ *ventus*	5 (2)	27 (20)	55 (42)
(3rd + 3rd-*iō*) *ī*	*-ītus*	(see above)	56 (33)	159 (107)	215 (146)
(4th + 3rd-*iō*)	*-s/tus*	(see above)	**14 (3)**	39 (22)	69 (45)
			⟶ Individual Development ⟶		
			"toddler"	"youth"	"adult"

all end in *-it*. The child must know some other form, such as the infinitive, to distinguish them. This may raise an issue for 3rd-*iō* verbs which show 3rd conjugation person/number marking in some Present stem inflections and 4th conjugation forms in others. A child who has yet to learn enough inflections of a given 3rd-*iō* verb may incorrectly classify it as 3rd or 4th. Two rows are added to the bottom of Table 6 to test the unlikely worst case scenario of a child somehow misclassifying all 3rd-*iō* verbs as either 3rd or 4th. This extreme case is only tolerable at $n = 100$.

Table 7 lists potential narrower generalizations based on Present stem forms which were suggested in the literature or appeared qualitatively promising when summarizing the data. Few of these narrower patterns manage to achieve productivity either, and only the pattern followed by *faveō* and *moveō* remains clearly tolerable for large vocabulary sizes. One of the hypothesized generalizations is right at the cusp of productivity in our data set: that of *solvere* ∼ *solūtus*. If any individual child's lexicon contained one fewer exception, it would have been rendered productive. These verbs are of particular interest because the reflex of *-ūtus* spread analogically in Late Latin (Sect. 2.3.3), but this class is small, only contributing 18 more productively derived past participles at most.

4.1.2 Evidence from the perfect

The form of the PPtc is more predictable from the form of the Perfect than from the form of the Present, as shown in Table 8. There exist productive derivations for both *-ātus* and *-ītus* past participles along with the small handful of *-ētus* in the 2nd

Table 7 Tolerability of Present stem form to past participle stem relationships. (Bold/green) productive, (red) unproductive, (italicized/yellow) marginal cases within 1 of the tolerance threshold may be subject to variation, (white) calculation was not carried out because N is too small for the formula

Present	PPtc	Example	At $n = 100$?	At 500?	At 1000?
-veō	*-autus/ōtus*	*favēo* ∼ *fautus*	N=1 (e=0)	**5 (0)**	**5 (0)**
-[velar]*eō*	*-s/tus*	*doceō* ∼ *doctus*	2 (1)	14 (9)	16 (11)
-[not velar]*eō*	*-itus*	*debeō* ∼ *debitus*	***9 (4)***	32 (19)	40 (24)
-[not velar]*eō*	*-s/tus*	*teneō* ∼ *tentus*	9 (8)	32 (24)	40 (28)
-vere	*-ūtus*	*solvere* ∼ *solūtus*	**7 (2)**	*22 (8)*	26 (8)
-{*ll*,*rr*}*ere*	-{*l*,*r*}*sus*	*currō* ∼ *cursus*	2 (2)	***6 (3)***	*7 (4)*
				⟶ Individual Development ⟶	

Table 8 Tolerability of perfect to past participle relationships. (Bold/green) productive, (red) unproductive, (italicized/yellow) marginal cases within 1 of the tolerance threshold may be subject to variation, (white) calculation was not carried out because N is too small for the formula

Perfect	PPtc	Example	At $n = 100$?	At 500?	At 1000?
-āvī	*-ātus*	*amāvī* ∼ *amātus*	***N*=15 (*e*=0)**	**204 (7)**	**490 (8)**
-īvī	*-ītus*	*dormīvī* ∼ *dormītus*	**5 (1)**	**22 (2)**	**46 (9)**
-ēvī	*-ētus*	*flēvī* ∼ *flētus*	**4 (1)**	**11 (3)**	*16 (6)*
-Vvī	*-Vtus*	(see above)	**24 (2)**	**237 (12)**	**552 (23)**
-uī	*-itus*	*valuī* ∼ *valitus*	19 (13)	66 (36)	90 (52)
-uī	*-s/tus*	*tenuī* ∼ *tentus*	19 (11)	66 (49)	90 (67)
-[velar]*uī*	*-s/tus*	*līquī* ∼ *līctus*	3 (1)	13 (10)	18 (13)
-[not velar]*uī*	*-itus*	*dēbuī* ∼ *dēbitus*	16 (11)	53 (29)	72 (42)
-[not velar]*uī*	*-tus*	*tenuī* ∼ *tentus*	16 (10)	53 (39)	72 (54)
-sī	*-s/tus*	*scripsī* ∼ *scriptus*	**15 (4)**	**51 (9)**	**70 (11)**
-sī	*-sus*	*mulsī* ∼ *mulsus*	15 (12)	51 (37)	70 (54)
bare	*-s/tus*	*lēgī* ∼ *lēctus*	24 (22)	56 (43)	68 (49)
-u-bare	*-ūtus*	*soluī* ∼ *solūtus*	4 (1)	14 (2)	**18 (2)**
				⟶ Individual Development ⟶	

conjugation.[17] In the 1st and 4th conjugations, the verbs with exceptional PPtcs tend to have *-uī* perfects, so *-āvī* and *-īvī* perfects serves as a more reliable evidence for the form of the PPtcs than the Present forms do. These can be further generalized to say that if the theme vowel surfaces in the Perfect, the same will surface in the PPtc. However, since the only theme vowels that surface in the Perfect are long, this productivity does not apply to *-itus* forms.

[17]Embick and Halle (2005) argue that the long vowel is retained in this class because it is part of the root and not a theme vowel, and that it is retained to achieve minimal root phonotactics. The theme vowel and root vowel analyses both produce the correct surface forms for these verbs, but note that there are many verbs with light monosyllabic roots counter to the proposed phonotactic constraint, including *st-ō*, *-ā-re* ∼ *sta-t-us*, *ser-ō*, *-e-re* ∼ *sa-t-us*, *ci-e-ō* ∼ *ci-t-us*, and *r-e-or* ∼ *ra-tus*.

s-Perfect verbs productively form bare PPtcs in *-s/tus*. These are a major source for remnant exceptional past participles in modern Romance (Sect. 2.3.3), which could suggest that they were productive at some point in the history of these languages. Traditional grammars further observe that otherwise unexpected *s*-Perfects often have *s*-PPtcs as well (e.g., *mulsī* ∼ *mulsus*, *mānsī* ∼ *mānsus*), however the implicational relationship turns out to be very weak in the Classical language. Only a minority of *s*-Perfect verbs have *s*-PPtcs, so the traditional description, while deserving of more investigation, appears to be unproductive.

Perhaps most surprisingly, there are no broadly productive past participle patterns for *-uī* perfects despite their high frequency outside the 1st conjugation. The broader implication here is that the athematic Perfects without a surface theme vowel (in *-uī*, *-sī*, or bare *ī*) do not reliably correspond to bare PPtcs. The traditional observation that a thematic Perfect productively correspond to a thematic PPtc and an athematic Perfect to an athematic PPtcs is only half true: only the long vowel thematics are productive according to this analysis.

The only predictable bare PPtcs are the aforementioned subset with corresponding *s*-Perfects and a small set with verb roots ending in *-u* (i.e., *tribu-ī* 'granted, yielded'). These form bare PPtcs ending in surface *-ūtus* with only two exceptions at $n = 1{,}000$: *linquō*, *-ere līquī*, *līctus* 'leave' and *ruō*, *-ere ruī*, *rutus* 'rush, collapse' with a short *u*. This is the only subset of the surface *-uī*-Perfect verbs with productive PPtcs.

To summarize quantitatively, if the form of the PPtc is predicted either from the form of the Present or Perfect, 664 verbs (528 1st conjugation + 5 *-veō* 2nd conjugation + 45 2nd and 4th conjugation with thematic Perfects + 11 3rd-*iō* + 59 verbs with *s*-Perfects + 16 productive *-ūtus* verbs) are productively derived, an improvement of 23% over the root and theme vowel alone.

4.1.3 Rhythmic correspondence

The final set of calculations investigates the productivity of the rhythmic correspondence between the Perfect and PPtc in the 2nd and 3rd conjugations as espoused in Steriade (2016). This is described as an OT constraint in Sect. 5.4, but for now it suffices to describe the correspondence as a matching of syllable counts in the Perfect and PPtc stems. The Perfect and PPtc stems including the theme vowel if overt, and should contain the same number of syllables.

Several variants of the rhythmic correspondence were tested, though most of these these did not make a difference in the TP calculation. A subset that had some effect is shown in Table 9. The most general formulation of the problem (σ) tests "PPtcs in the 2nd and 3rd conjugation are matched for number of syllables with Perfects, either bare *-tus* with predictable root mutations or *-itus*." This is not upheld at any vocabulary size. Alternatively, it could be the case that separate rhythmic correspondence rules were tolerable for monosyllabic (1σ) or polysyllabic Perfect stems (2σ) independently. This is not upheld either, although further conditioning on theme vowels shows some more interesting results. For 2nd conjugation verbs, polysyllabic Perfects correspond marginally with *-itus* at $n = 1{,}000$, but the monosyllabic pattern is not upheld, largely because of too many exceptional mutations. There is no pattern for the 3rd conjugation in general, but there is support for 3rd-*iō* where *-tus* is productive

Table 9 Tolerability of rhythmic correspondence patterns. (Bold/green) productive, (red) unproductive, (italicized/yellow) marginal cases within 1 of the tolerance threshold may be subject to variation, (white) calculation was not carried out because N is too small for the formula

Pres./ThV	Perfect	PPtc	Example	At $n = 100$?	At 500?	At 1000?
	σ	σ	[*vīd*]$\bar{\imath}$~[*vī*]*sus*, [*valu*]$\bar{\imath}$~[*vali*]*tus*	N=61 (e=28)	189 (84)	246 (109)
	1σ	1σ	[*vīd*]$\bar{\imath}$ ~ [*vī*]*sus*	38 (12)	111 (38)	140 (44)
	2σ	2σ	[*valu*]$\bar{\imath}$ ~ [*vali*]*tus*	23 (16)	78 (46)	106 (65)
(2nd) $\bar{e}$	1σ	1σ	[*rēs*]$\bar{\imath}$ ~ [*rī*]*sus*	5 (3)	24 (13)	27 (13)
(2nd) $\bar{e}$	2σ	2σ	[*tacu*]$\bar{\imath}$ ~ [*taci*]*tus*	**7 (2)**	**23 (6)**	*29 (9)*
(3rd) *e*	1σ	1σ	[*scrips*]$\bar{\imath}$ ~ [*scrip*]*tus*	*29 (9)*	81 (25)	106 (31)
(3rd) *e*	2σ	2σ	[*molu*]$\bar{\imath}$ ~ [*moli*]*tus*	14 (12)	52 (38)	73 (54)
(3rd-*iō*) *i*	1σ	1σ	[*coep*]$\bar{\imath}$ ~ [*coep*]*tus*	4 (0)	**6 (0)**	**7 (0)**
-uere	2σ+*u*	2σ+$\bar{u}$	[*statu*]$\bar{\imath}$ ~ [*statū*]*tus*	14 (10)	52 (29)	73 (43)
					⟶ Individual Development ⟶	

(cf. Table 6). In the interest of completeness, it was tested whether *-ūtus* PPtcs might count as the expected outcome for the rhythmic correspondence for *-vere* verbs instead of *-itus* (2σ+$\bar{u}$). This does not meaningfully alter the results either. Altogether, neither global *-itus* nor the rhythmic correspondence pattern is productive over the Perseus data set even though the correspondence holds for a large number of verbs.

4.2 Productivity of the *t*-deverbals

With a productivity analysis of the past participles complete, we can now begin to more fully explain the *t*-deverbal form correspondence. It is worth re-emphasizing that the correspondence is itself a diachronic accident (Sect. 2.3.1): the past participle and *t*-deverbals are etymologically related and were subject to the same sound changes, keeping the correspondence along the way. Thus, synchronic processes, whether acquisition or theory, need not explain the correspondence, just encode it and maintain it.

Acquisition is capable of bringing this accidental correspondence into the grammar. Laid out conceptually, the forms of most *t*-deverbals need to be inferred by the learner because they are unlikely to be attested in the input, and most of the *t*-deverbals that are attested do have a corresponding attested past participle for diachronic reasons. With these as evidence, the hypothesis "make the *t*-deverbals be like the PPtc," however that is ultimately implemented, is upheld more reliably than other options, far more than is required by the Tolerance Principle, so new forms are produced in correspondence with the past participle. It is then up to the grammar to encode the correspondence.

There are other hypotheses which a learner could entertain but can immediately be dismissed. First, it could be the case that all *t*-deverbals are built according to some default pattern (e.g., *-itūrus*, *-itor*, *-itim*, etc.) and then repaired to correspond with the past participle when necessary. However, a global default pattern is not possible here for the same reason it is impossible for the past participles: any candidate theme vowel would have far too many exceptions. Second, it could be that the form of the

Table 10 Past participle type frequencies relative to *t*-deverbals at least as frequent as the thousandth past participle. Many more verbs are attested as past participles than all *t*-deverbals combined. Most verb roots attested in a *t*-deverbal are also attested as a PPtc, and few are attested in any one of the *t*-deverbals alone

Category	# Freq ≥ 35	% Total	# This Only	% of Cat.	% of This Only
Past Part.	1006	75.9%	817	81.2%	89.6%
Adverb	18	1.4%	8	44.4%	0.9%
Agent	72	5.4%	20	27.7%	2.2%
Event	178	13.4%	54	30.3%	5.9%
FPtc	52	3.9%	13	25.0%	1.5%
Total	1326		912	68.8%	

t-deverbal is drawn from either the Present or Perfect stem then exceptional cases are learned. This correspondence trivially holds for most *ā*-stem and *ī*-stem verbs since most of them have past participles in *-ātus* and *-ītus* (Maiden 2018: Chap. 7), and these actually account for the majority of verbs (Tables 2, 5, 7, 8). The problem is that there are too many exceptions for a learner to acquire this pattern more generally for the same reason that the PPtc forms cannot be generalized in this way. Third, it could be the case that the form of the past participle is actually influenced by the *t*-deverbal rather than vice-versa. While both directions of influence are technically possible in practice, this direction cannot have been common. For any given verb, a learner was far more likely to hear a past participle and have to infer the corresponding unattested *t*-deverbal than vice-versa.

This is worked out quantitatively in Table 10 with forms collected from Perseus. This time, every inflected past participle and *t*-deverbal was collected.[18] The first question is one of raw type frequency. How many *t*-deverbals are there relative to past participles in the corpus? To determine this, the thousandth most frequent past participle was found, and then all *t*-deverbals with at least that frequency (= 35) were extracted. The past participles account for just over three quarters of all types. The next question is how often a learner would have to infer the form of one or the other. To do this, the previous list was filtered to find the number of verbs that are only expressed in exactly one PPtc category. Very nearly 90% of these verbs attest their PPtc stem just in the past participle with no attested *t*-deverbals in this large corpus, suggesting that a learner tasked with acquiring the language would overwhelmingly need to perform inference from the past participle to *t*-deverbals rather than from a *t*-deverbal to the past participle or other *t*-deverbals.

This leaves the child with one option for inferring the form of *t*-deverbals not attested in the input, to reference the form of the past participle. Referring back to Table 10, 414 verbs (1326 verbs attested PPtc in ≥ 1 categories – 912 verbs attested PPtc in exactly 1 category) have an attested past participle and at least one *t*-deverbal in Perseus, and all but a couple of these exhibit the correspondence. This passes the Tolerance Principle calculation with flying colors. Any acquisition model worth its salt should be able to learn it from this data!

Thinking in terms of data sparsity and the Tolerance Principle provides explanations for remaining edge cases. First, the presence of *t*-deverbals with verbs lacking

[18] Result nouns have forms identical to feminine future participles and the relatively rare *-tus* even nouns share forms with the past participle and supine, so they were grouped together.

past participles (e.g., fptc *calitūrus*, Sect. 2.2.2) is entirely unremarkable in an account where diachrony is doing most of the legwork. Young learners have no way of knowing *a priori* if any past participle not (yet) attested to them is actually gapped in the language or will be attested to them sometime in the future, so they must be willing to memorize attested *t*-deverbals for gapped verbs in the same way that they learn them for non-gapped ones. Second, the analysis allows for high frequency verbs whose past participles do not correspond to the *t*-deverbal as long as the child can learn both directly from the input. As it turns out non-corresponding pairs such as *mortuus* ∼ *moritūrus*, *sonitus* ∼ *sonātūrus*, and *lautus* ∼ *lavātum* are all attested in this high frequency data set and so have a chance at being memorized directly.

4.3 Diachronic predictions of productivity

Synchronic productivity is clearly related to diachronic analogical change (Hare and Elman 1995; Hock 2003; Bybee 2010; Maiden 2013: *i.a.*), and children, who are tasked with uncovering linguistic productivity, are well understood as agents of language change (Sweet 1899; Halle 1962; Kiparsky 1965; Anderson 1973; Baron 1977; Lightfoot 1979; Niyogi and Berwick 1996; Kroch 2001; Yang 2002; Cournane 2017; Kodner 2020: *inter alia*). The acquisition analysis carried out in Sect. 4 thus makes predictions about outcomes in the descendants of Latin. Before discussing those predictions, a caveat is in order. As argued in Kodner (2020), the primary point of interest for acquisition-driven models of change lies in the actuation of categorical changes to the grammar.

4.3.1 Learning, theory, and the Actuation Problem

In a standard breakdown of the process of population-level change as described by variationist sociolinguists, language change begins with *actuation*, defined here as the innovation and initial entrance movement of a change from an individual into the language of a speech community (Labov et al. 1972). Since actuation is contingent on so many factors, both inside and outside the linguistic system, it is impossible to know what the exact cognitive and environmental circumstances were at the moment that an innovation was made. It is impossible to answer with perfect certainly *why* any change was first actuated (*the Actuation Problem*, Weinreich et al. 1968). Nevertheless, armed with a cognitively motivated, quantitative, predictive model of productivity learning, we can approach the actuation point asymptotically. And when good sociolinguistic evidence is available in parallel with acquisition and theory, it is possible to make strong predictions regarding both acquisition and incrementation, as was done in the Yang (2016) study of "dative sickness" in Icelandic and the Sneller et al. (2019) study on recent changes in the Philadelphia short-*a* system.[19]

[19] *Incrementation* is the process by which an innovation spreads through the linguistic system once actuated. The study of incrementation is the bread and butter of variationist sociolinguistics. Unfortunately, the studies of acquisition and theory are both limited in what they contribute to the study of incrementation, since the progress of a change through the linguistic system and networks of speech communities is driven largely by sociolinguistic and extra-linguistic factors.

The Tolerance Principle as applied here is part of a predictive causal mechanism for analogical innovations. Given a specific sparse input sample, a pattern that is unproductive for an adult may be rendered productive for a child. This should yield over-regularizations (Xu and Pinker 1995) in child speech. From a diachronic perspective, over-regularization is the innovation of an analogical change.[20] It cannot, of course, tell us which plausible change will actually happen—the Actuation Problem, we cannot know the exact input sample that little Roman Drusilla or Livilla received in their moments of innovation or the precise structure of their immediate social networks—but it can tell us which paths of innovation were available and what circumstances could cause them.

4.3.2 Predictions for Latin and Romance

This productivity account of the past participles provides an explanation for the rise of Romance *-*atu*, *-*itu* < -*ītus*, and *-*utu* at the expense of -*itus* and -*tus*. The first two, *-*atu* and *-*itu*, are the most straightforward: they were productive endings with high type frequencies, and so could be expanded by over-regularization. The basis for the productivity of -*ītus* was weaker than for -*ātus*, but its numbers were bolstered by movement of items from the 2nd and 3rd conjugations (Sect. 2.3.3).

The retention of *-*atu* and *-*itu* was not surprising, unlike the spread of *-*utu*. As discussed in Sect. 4.1.2, 3rd conjugation verbs with roots ending in -*u* productively form PPtcs in surface -*ūtus*, and this generalization is tolerable both at small child-like and large adult-like vocabulary sizes. Notably, these are the only verbs with surface -*uī*-Perfects with predictable PPtcs despite the large size of that class. Productive patterns have an opportunity to spread as the base of analogical leveling through over-regularization at the expense of unproductive patterns, and -*ūtus* did indeed spread first among the -*uī* Perfects. In Late Latin, most former 2nd, 3rd, and 4th conjugation verbs were reformed with *-*itu* or *-*utu*.

The -*u*- in Romance reflexes of *-*utu* is analyzed as a theme vowel. This suggests the underlying mechanism of the leveling: Given the productivity of -*ūtus* in Latin and the productivity of long -*V:tus* PPtc forms, a child could achieve the same extensional pattern of productivity by treating -*ūtus* PPtcs as bare attached to roots ending in -*ū* (the conservative grammar) or as theme vowels -*ū*- (the innovative grammar). Similarly, the Perfects of these verbs could be analyzed conservatively as bare with

Specific outcomes in Modern Italian, Spanish, and Latin's other modern descendants are questions of incrementation: once productive *-*utu* was actuated, the severence of the past participle to *t*-deverbal correspondence was actuated, to what extend did these patterns spread? No theoretical or cognitive analysis of the Classical language can completely answer these questions. One would need access to centuries of sociolinguistic data from throughout the Roman and post-Roman world to do so.

But this is not to say that a theory of grammar cannot improve our understanding of incrementation in general. One famous example is the Constant Rate Effect (CRE), a constraint on the progress of surface-distinct but structurally related changes (Kroch 1989, 1994). Note though that the CRE does not tell us why or how rapidly a given change should increment. One must still appeal to sociolinguistic factors for a predictive causal mechanism.

[20]There is still an explanatory gap here. Once a child innovates a change, that change still must enter to population to be actuated. See Kodner (2020) for discussion of prior work on acquisition in the context of variation, a proposal for "sibling-induced change" as part of acquisition-driven actuation, and computational models providing proof of concept.

roots ending in *-ū* (e.g., *solu-ī* or innovatively as *-uī*-Perfects (e.g., *sol-u-ī*).[21] Both are plausible grammars, and both are acceptable hypotheses according to the quantitative measure applied here. A child who happened to acquire both innovative segmentations would then be in a position to extend a segmented *-ū-tus* and particularly to *-uī*-Perfects at first. Here we have a cause, the outcome of productivity learning, and a means, the re-segmentation of surface forms, to account for the actuation of the Romance pattern.

Without access to Late Latin and early Romance data, less can be said for sure about incrementation. Whatever happened, the conditions for the analogical extension of *-ūtus* must have been just right: the learners' input had to be conducive to the innovation, the learner had to hypothesize the innovative grammars, and the innovation had to have entered the local community. This is at least consistent with the incomplete geographic distribution of **-utu* in Romance (map, Fig. 1). Any slight differences in regional lexicons could have pushed tolerance over the edge and prevented the extension, and geographical and later political distance could have regionally hampered the incrementation of the change. In remote Sardinia in particular, the merger of /i/ and /iː/ would have introduced many **-itu* PPtcs into the 2nd and 3rd conjugations and may have prevented *-ūtus* from taking off even if it arrived.

Parallel to this, the productivity analysis predicts the decline of *-itus* and *-tus* as unproductive forms. They show the diachronic hallmark of unproductivity: reflexes of *-itus* and *-tus* have eroded over the centuries and survive today overwhelmingly among high frequency irregular verbs which benefited from the conserving effect of item frequency against analogical leveling (e.g., Bybee 1985; Baayen 1993; Bybee and Hopper 2001). From the perspective of acquisition, unproductive forms were not derived by rule and so were acquired inasmuch as they were reliably attested in the learners' input. It is further striking that *-tus* forms rather than *-itus* forms form the bulk of irregulars in modern Romance (Laurent 1999). The former were productive in Latin in some specific cases, but the latter were not. Thus, the former were preserved better than the latter. For a theoretical framework to be compatible with these patterns, it needs a way to encode the initial conditions of productivity and each of the innovative and conservative segmentations described in this section without falling back on post hoc solutions.[22]

[21] The innovative segmentations could both take advantage of vowel cluster reduction to maintain the same *-u*-final root form: UR *solū-u-ī* > SR *soluī*, UR *solū-ū-t-us* > SR *solūtus*.

[22] A related process may account for the collapse of the past participle and *t*-deverbal correspondence in Romance, where it now appears to hold productively between the Present and *t*-deverbals (Steriade 2016: Sect. 6.2.8.3; Maiden 2018: Chap. 7.4). In modern Romance, most past participles themselves share a stem form with their Presents because they are regular reflexes of **-atu*, **-itu*, and **-utu*. As a consequence, the only evidence for the past participle and *t*-deverbal correspondence in Romance would come from cases where the Present and past participle do not share a stem but the past participle and *t*-deverbals do. The fact that most *t*-deverbals are thus ambiguous in their derivation suggests a solution: even in Classical Latin, a correspondence with the Present trivially held between most 1st and 4th conjugation Presents and their *t*-deverbals in *-āt-* and in *-īt-* because it held between many of their Presents and past participles as well. The number of verbs like these grew as new intensives, frequentatives, iteratives, and desideratives were coined and as verbs moved into the 4th conjugation by metaplasm. Meanwhile, stem changing verbs in *-tus* were replaced by these new coinages (Sect. 2.3.3). Once the lexicon changed enough in this direction, learners could have eventually received enough evidence to learn a broadly productive Present to *t*-deverbal

4.4 Summary

It is clear from the productivity analysis that irregularity is rampant in the Latin verbal system and that it follows a distribution that cannot be determined by qualitatively reasoning through examples. At best, over a third of PPtc stem forms, more than half of verbs outside the 1st conjugation, must have been memorized by Latin speakers. Their grammars must have contained hundreds of listed items. Most notably, the *-tus* and *-itus* past participle endings, which are among the most common outside of the 1st conjugation (Tables 2 and 5), are not broadly productive despite their frequencies. As revealed through the Tolerance Principle, these two frequent patterns just provide too many exceptions to one another for either to achieve productivity. Such a convoluted system rife with narrowly applicable productive patterns and high frequency unproductive patterns is not all that atypical and is certainly learnable—it is reminiscent of the conditioned productivity and non-productivity of frequent patterns in German noun plurals (Clahsen 1996), for example, but on a larger scale.

If no generalization is tolerable, then the speaker resorts to listing, and the lack of a default can yield apparent paradigmatic gaps (Gorman and Yang 2019). This analysis predicts the distribution of gaps described in Sect. 2.1.2. Defective past participles with no semantic motivation are rare, but those that exist, such as *bibō*, *-ere*, *bibī*—fall outside the scope of the productive generalizations uncovered here. Also notable is the lack of a broadly productive PPtc form for verbs with *-uī*-Perfects. The relatively rare *-ūtus* form is the only productive PPtc pattern for some subset of 3rd conjugation surface *-uī*-Perfect verbs. These results are predictive of the rise of **-utu* and decline in *-itus* and *-tus* (Sect. 2.3.3). The next section introduces the accounts of Aronoff (1994), Embick (2000) and Embick and Halle (2005), Calabrese (2020), Steriade (2016), and evaluates them in light of the acquisition and diachronic evidence.

5 Survey of theoretical accounts

The Latin past participles and their form correspondence with the *t*-deverbals have generated a significant amount of theoretical discussion. Not only are their forms often unpredictable from the other forms of a verb (Table 1), but so are their semantics (Table 3). If a past, perfective, usually passive, participle shares a stem with something as different as an active, imperfective, agent noun, then what do its components mean? How many *-t-* are there, and what semantics do they contribute?[23] The answers to these questions have served as motivating arguments for fundamentally different theoretical formalisms.

To summarize, early explanations for these patterns were essentially implementations of the traditional Priscianic analysis: there are three stems, the Present, Perfect, and past participle, and the *t*-deverbals are literally built on the past participle

correspondence. This hypothesis would be consistent with Maiden's suggestion that a reanalysis of the *t*-deverbals occurred on the basis of the 1st and 4th conjugations. Though this hypothesis has not been worked out quantitatively for Late Latin, the rise of regular iteratives and others at the expense of 2nd and 3rd conjugation verbs is exactly the change that could quantitatively precipitate this.

[23] I use *-t-* in prose to refer both to *-t-* and its *-s-* allomorph except when the distinction is relevant.

by adding the *t*-deverbal ending after *-t-* and changing the semantics accordingly. Aronoff (1994) continues the three-stem analysis but argues that the stems are *morphomes* which consist only of forms without associated meanings. The *t*-deverbal is not derived directly from the past participle, but rather both are derived independently from a meaning-free third stem (here called PPtc). Embick (2000) and Embick and Halle (2005), on the other hand, reject the notion of stems as representational objects and instead argue that the forms previously ascribed to stems emerge during syntactic derivation. They agree with Aronoff in arguing that there is no particular meaning associated with the form of the PPtc but argue that the correspondence between the past participle and *t*-deverbals is derived from shared syntactic structure rather than stored explicitly. Next, Steriade (2016) revives early assumptions as a challenge to Aronoff and Embick and Halle in introducing a violable constraint analysis in which the past participle's form does carry a meaning after all and the *t*-deverbals are based on the form of the past participle. Most recently, Calabrese (2020) proposes an analysis most similar to Embick and Halle's, but agrees with Steriade (2016) in assigning semantics to the PPtc.

Table 11 summarizes how well each account accommodates the empirical results from Sect. 4. Note that even though each account can achieve the correct synchronic forms, they vary in how well they can capture productivity, and none predicts the diachronic facts regarding the loss of the once frequent *-itus* and *-tus* past participles and rise of **-utu*. The rest of this section reviews the Aronoff (1994), Embick (2000) and Embick and Halle (2005), Calabrese (2020), and Steriade (2016) treatments of the past participles and *t*-deverbals with special attention paid to themes of arbitrariness and the description of Latin laid out in Sects. 2 and 4.

5.1 Aronoff (1994): Lexeme-based morphology

Aronoff (1994) presents a lexeme-based treatment of Latin verbal morphology which motivates a notion of stems as representational objects: forms without associated meanings on which the various inflections of a word are built. The forms of stems are derived by *realizational rules*, either from other stems or the lexical representation of the root itself. Aronoff argues that the Latin stems are actually largely predictable since each conjugation is associated with a most common pattern (cf. Table 2), contrasting with an earlier account in Lieber (1980) which proposes that the stem forms are effectively all memorized in the face of their numerous complexities. The evidence for this comes from 1st and 4th conjugation verbs whose theme vowels manifest in the Perfect and PPtc (*third stem*, to disambiguate from the past participle in his terminology) (Sect. 2.1.1), and from 2nd and 3rd conjugation verbs with nasal infix spreading.

The *t*-deverbals in this system share their forms with the past participle because both are instances of the same PPtc stem. Aronoff breaks with previous treatments as far back as Priscian that argue that the *t*-deverbals are derived from the past participle itself by parasitic (Matthews 1972) or replacive (Mel'čuk 1982) rules and instead maintains a non-directional derivation: the past participle and *t*-deverbals are on equal footing, both derived independently from the PPtc stem.

Table 11 Comparing the predictions of several treatments to desiderata for an adequate theory determined from the productivity analysis and diachronic evidence. Green/Bold predictions are judged to be adequate according to the desiderata described in this paper. Yellow/Italicized predictions are judged neutrally or with uncertainty, and Red predictions are judged to be inadequate

	Pres/Root/ ThV → PPtc	Perfect → PPtc	Listed PPtc	PPtc/*t*-Deverbal Correspondence	productive **-utu*?	loss of *-itus*/*-tus*?
Desiderata	1st, 3rd-*iō*, *faveō*-types	long ThV, *s*-perfs, *solvō*-types	exceptions + most of 2nd, 3rd	No necessary direction, but usually PPtc → *t*-deverbal	productive *-ūtus* for *solvō*-types is the only prod. PPtc for surface *uī*-Perfects	corresponds to limited productivity of *-tus*, non-productivity of *-itus*
Lexeme-Based	**through realizational rules, but argued for on majority-based metric**	**possible through realizational rules**	*most common for 3rd, relies on majority-based metric*	**shared stem, no implied direction**	not predicted	*maybe through listing in the 3rd*
DM E.&H.	**VIs, and Readjustments conditioned on TH or Root**	not possible	*possible, but not worked out*	**shared structure, no implied direction**	not predicted since Perfect cannot influence PPtc	not predicted since Perfect cannot influence PPtc
DM Calabrese	*indirectly when Perfect is predictable from Present*	*predicts thematicity correspondence, too narrow s correspondence*	2nd, 3rd largely predictable by thematicity	**shared structure and semantics, no implied direction**	not predicted	predicts productivity with corresponding thematicity
SBS	*indirectly when Perfect is predictable from Present*	**default, implemented through SBS**	*unclear how exceptions are accounted for*	implied direction by SBS, incorrect predictions when PPtc not available	not predicted	predicts productivity for *-itus* and *-tus*

One can conceive of these mappings between stems and morphological categories as in Table 12. Categories (rows in the table) are formed from any of the stems (columns). The *t*-deverbals and past participle share their form because they are in the same column. The assignment to columns is synchronically arbitrary (though diachronically motivated; Sect. 2.3.1), and none of the rows in particular is privileged. In this case, the form of each stem has to be listed, but stems in general may be realized on the basis of other stem forms or the forms of the root.

Reviewing Tables 1 and 12, we can see that the theme vowel from the Present often do not appear in the Perfect or PPtc, and sometimes some other theme vowel does

Table 12 Stems (columns) and example categories (rows) for the verb *serō*, *-ere*, *sēvī*, *satus* 'sow, plant' and derivatives illustrating stem-to-category mapping

	Category	Present	Perfect	PPtc	Meaning
Inflectional	Present Active	***ser****ō*			'I sow'
	Pres. Perfect		***sēv****ī*		'I sowed'
	Future Passive	***ser****ar*			'I will be sown'
	Pluperfect		***sēv****eram*		'I had sown'
	Past Participle			***sat****us*	'sown'
	...				...
Derivational	Agent Noun			***sat****or*	'sower'
	Event Noun			***sati****ō*	'act of sowing'
	...				...

(e.g., *pet**e**re* but *pet**ī**vī*, *ser**e**re* but *s**ē**vī* and *s**a**tus*). Aronoff (1994) interprets these apparently conjugation-changing verbs as supportive of his model. For him, their presence is unsurprising because there is nothing intrinsic to the stems that would force their theme vowels to conform synchronically. One diachronic advantage of this approach then is that nothing special needs to be done to account for the reanalysis of *solūtus*-type past participles to contain unique *ū* theme vowels. There is not much additional to say about Aronoff (1994) in light of acquisition results, since we are free to configure the realizational rules to line up with empirical productivity. It does not predict the diachronic patterns, but it is consistent with them if the realizational rules are adjusted correctly. This treatment achieves its goal of descriptive adequacy at a high level, but does not provide us with an implementation for the realizational rules or stem mappings.

5.2 Embick (2000) and Embick and Halle (2005): Distributed Morphology

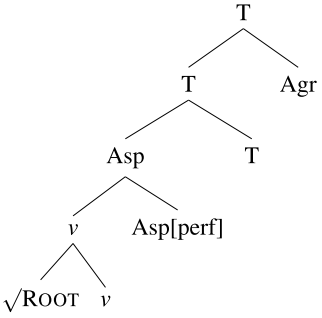
Embick (2000) sets out to build a DM account of an interesting pattern among Latin perfects: while most perfects are synthetic (*amāvī* 'I (have) loved'), passive perfects and deponent perfects are analytic, built on the copula and past participle (*amātus sum* 'I was/have been loved,' *locūtus sum* 'I spoke/have spoken'). He proposes an analysis in which the two share an underlying syntactic structure. In the process, he provides an account for the past participle and *t*-deverbal form correspondence in which the two simply share an underlying syntactic structure which spells out as the PPtc. The DM analysis of the Latin perfects is presented in Embick (2000) as well as in a follow-up by Embick and Halle (2005) as evidence against Aronoff's notion of stems as representational objects. Rather than storing stem forms associated with a root, the actual forms of the perfects, past participle, and *t*-deverbals in this account are the product of a complex interaction between the proposed syntactic structures, *Vocabulary Items*, mappings between semantic features and spelled out exponents which may be conditioned by local structures, and *Impoverishment* and *Readjustment rules*, which further alter the syntactic structure and forms of the exponents.

A Root in DM is category-less in the lexicon and must be associated with a node that assigns its syntactic category. In each case discussed here, some particular √ROOT combines with *v*, which assigns its category as a verb. This √ROOT-*v* complex then incorporates with an aspect-carrying Asp head during derivation. The resulting structure after movement is shared across (2) and is common to all of the forms discussed here. The synthetic perfect further raises to T (2a), while the analytic perfect cannot because it is blocked by a [pass] feature in the structure (see below). This results in a past participle (2b). At their core, the *t*-deverbals, share their structure with the past participle but include additional modifiers, for example the *-ūr-* of the future participle (2c). The forms traditionally described as the Perfect and PPtc stems are emergent from structures (2a) and (2b) respectively.

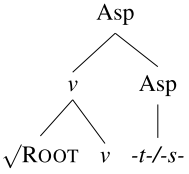
Embick finds common ground with Aronoff (1994) in arguing that there is no coherent semantic context associated with the form of the past participle, but rather than explaining it with semantics-free stems, *-t-/-s-* is taken to be the default realization of Asp. As the elsewhere condition, it can accommodate the heterogeneous semantically diffuse *t*-deverbals if no more specific Vocabulary Item is selected. This is a demonstration that the correct forms can be generated by DM despite the diverse semantics of the *t*-deverbals, but presenting a particular form as default does not constitute an explanation of the correspondence *per se*, as Maiden (2013) notes. One could argue that this is no less arbitrary than Aronoff (1994)'s stems.

(2) Structure after movement shared between all relevant forms (Embick and Halle 2005: 19, 30–31)

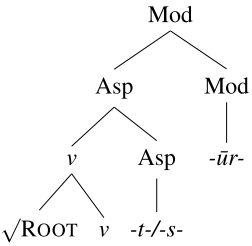
a. Perfect: √ROOT-*v*-Asp[perf] raised to T



b. Past Participle / PPtc: √ROOT-*v*-Asp not raised to T, *-t-/-s-* as default realization of Asp



c. Future Active Participle (an example *t*-deverbal): Past participle structure with additional material



The distinction between the synthetic and analytic perfect is accounted for by a [pass] feature which blocks √ROOT-*v*-Asp[perf] from raising to T. Embick (2000: Sect. 5) weighs multiple variations of this process, but they share common takeaways. First, [pass] is present in passive derivations, which handles the active (usually synthetic) / passive (analytic) alternation for perfect verbs. Second, deponent verbs exhibit passive morphology with active semantics, so [pass] must also be associated with deponent Roots as a kind of diacritic. Third, not all past participles are passive (Sect. 2.1.2), so [pass] must also find its way into the structures with active PPtcs. Taken altogether, [pass] is semantically disjoint. It can either indicate passive voice or serve as a kind of diacritic that triggers analytic perfects. There is one other necessary restriction, namely, [pass] must block the raising of Asp[perf] but not of other aspects, as passive and deponent non-perfects are actually synthetic (e.g., passive *amor* 'I am (being) loved,' *amābar* 'I used to love / was loving,' deponent *aggrediar* 'I will advance,' *aggrediminī* 'advance! (pl)').

Embick (2000: Sect. 8.2) does acknowledge that the split semantic and diacritical treatment of [pass] poses a challenge for his account, but argues that this move is "isolated and constrained" rather than an overarching lapse of theoretical restrictiveness. But that is an underestimation of its effect. Even the ability to split a feature like this into something that is sometimes semantically meaningful and sometimes just a diacritic is extremely powerful since it can be used to permit a wide range of arbitrary disjoint patterns. The entire synthetic/analytic analysis is only constrained if we ignore this split [pass]. I am willing to accept it for the sake of the analysis, but I have to reject Embick's argument that a framework that permits this is more parsimonious than one with Aronoff's stipulated form-meaning mappings. It is a more circuitous path to the same destination.

5.2.1 Form of the perfect

With the structural account established, we can move on to a discussion of forms. To derive the synthetic perfect, the verb's theme vowel is represented by a Theme Vowel node (TH) which is incorporated with *v* and is assigned its correct phonological form by the locally adjacent Root. In perfects which lack a TH, it is deleted by an Impoverishment rule in the context of Asp[perf] and listed Roots. Embick and Halle (2005) take Impoverishment as the default generalization for 2nd and 3rd conjugation verbs by including the conjugation diacritics in the list along with additional Roots (3).

(3) TH Impoverishment (Embick and Halle 2005: 23)
TH ⟶ Ø/LIST *v*____Asp[perf]

LIST = {[II],[III],[III(i)], √CREP, √CUB, √SEC}

The Vocabulary Item for Asp[perf] specifies the contexts which select the correct exponent of the perfective aspect (4). *-v-*/*-u-* is taken to be the default since it is by far the most common, and the *s*-perfect and bare perfect are said to appear in the context of T and listed Roots.

(4) Vocabulary Item for Asp[perf] (Embick and Halle 2005: 24)[24]

Asp[perf] ⟷ -s- in env. List1____T
List1 = {√AUG, √FULG, √DĪC, √SCRĪB}

Ø in env. List2____T
List1 = {√PRAD, √STRĪD, √TOND, √MORD}

-v- elsewhere

Any alterations to the form of the Root (Sect. 2.1.1) are accounted for by Readjustment rules which change the form of the Root within the structure of the perfect. Lists of Roots are associated with the appropriate Readjustment rules, though there is once again an opportunity to postulate phonological generalizations. The lists in (3–4) are not meant to be exhaustive and do not preclude an analysis that includes further generalizations over phonological forms. Both papers leave the reader to work out what system of Readjustment rules would yield all the observed outcomes.

5.2.2 Form of the past participle and *t*-deverbals

The forms of the past participle and *t*-deverbals are accounted for by similar means as the perfect. Most importantly for the analysis, *-t-* is the default realization of Asp, and *-s-* is an allomorph (again at least partially) associated with a list of Roots but not with a particular aspect (5). The Vocabulary Items are completely under-specified for aspect so that they can accommodate *t*-deverbals regardless of their semantics. Since the exponent of Asp is determined by the Root, not aspect, it is shared by the past participle and *t*-deverbals. Further, it can appear on nominal derivations as well, as in Table 4, which never appear as tensed verbs with T.

(5) Realization of Asp (not raised to T) (Embick 2000: 44; present participle VI given for exposition)
-nt- ⟷ [pres]
-s- ⟷ [ ] / ____ (List)
-t- ⟷ [ ]

[24] Vocabulary Items (3–4) listed in the two papers use a slightly different notation from one another. They are presented here in their original formats.

Any additional changes to the form of the Root or TH are accomplished by Readjustment rules which are triggered by the *-t-* and *-s-* exponents rather than by abstract features. This way, the Readjustments can target both the past participle and the *t*-deverbals without necessarily applying to any other forms. Here the formalism delivers on its goal of accommodating the form correspondence. It further does so in a unified framework that also captures the forms of tensed verbs without resorting to stored stems and an alternation between synthetic and analytic constructions in a shared morphological and syntactic system. The authors use this to build an argument against stored stems.

Under this analysis, conjugation-changing verbs are not the default case because the conjugation is decided by the diacritic on the Root which selects the appropriate TH. The authors take this to reflect favorably on the DM account and negatively on Aronoff since conjugation-changing verbs are restricted to "a handful of 'special' cases" (Embick and Halle 2005: fn. 17). This is not a strong argument against stored stems. Both analyses can support such verbs by well-placed realizational rules or Readjustment rules. The latter are every bit as powerful as the former in yielding the appropriate surface forms, despite the constraints that strict structural locality impose elsewhere in the framework (Bermúdez-Otero 2013; Merchant 2015). Embick and Halle's argument comes down to a claim about whether there are "a lot" or "a few" conjugation-changing verbs, but neither they nor Aronoff makes a real quantitative prediction.

5.2.3 Contending with the acquisition model and diachronic evidence

The DM account laid out here can produce the correct forms, but a problem arises when we try to account for the relationship between the Perfect and PPtc excluding the Present: taking regular 3rd-*iō* verbs as an example, TH is impoverished in the Perfect and PPtc but not the Present. Taking *s*-Perfects as a second example, there is no way to write a rule that impoverishes TH for these PPtcs without just listing them because the Asp[perf] exponent *s* is part of a Vocabulary Item that is not accessible in the PPtc structure. There is no way to write a Readjustment rule which targets both the Perfect and the PPtc without also targeting the Present since the two do not form a "natural class." The Perfect does not share a structure or features with the PPtc that it does not also share with the Present, so this has to be written with two coincidentally identical Impoverishment rules or one that applies in arbitrarily disjoint contexts.

Readjustment rules are not only very powerful (Bermúdez-Otero 2013; Merchant 2015) but also *not powerful enough* since they can yield the correct forms but cannot achieve motivated relationships between those forms. As such, this account incorrectly dozens of productively derived past participle forms to be listed, thus rendering it incompatible with the evidence from acquisition and diachrony. Even though it contains theoretical mechanisms as powerful as Aronoff's and can generate the correct surface forms, it is consistent with less of the evidence.

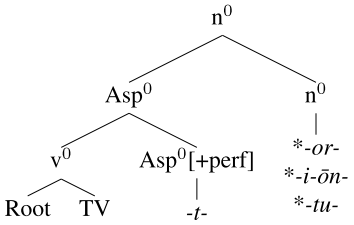
This shortcoming that the productivity analysis and diachronic evidence uncover for this DM account is more subtle and perhaps more interesting that the shortcomings of the other treatments discussed here. The new treatment introduced in Sect. 6 further explores the problem by asking what kind of changes would have to be made

to a DM-like model for it to account for the rest of the evidence. It effectively requires the reintroduction of stems to the formalism.

5.3 Calabrese (2020): Distributed Morphology

Calabrese (2020) presents a new DM treatment of the synthetic Perfect, PPtc, and *t*-deverbals in Italian, Latin, and Pre-Latin. Like Embick and Halle (2005), Calabrese joins Embick and Halle in criticizing Aronoff (1994), but he is also critical of the treatment of *-t-* as the default realization of Asp in Embick (2000) and Embick and Halle (2005) on account of it being "stipulative and opportunistic" (Calabrese 2020: 218). He instead argues that *-t-* has an associated perfective meaning. Since this is another DM treatment, I will not focus on the minutiae of the theory as it differs from Embick and Halle (2005) but instead will discuss the differing predictions as relevant for cross-framework comparison. The relevant structure (6) is overall quite similar to the one presented earlier in (4).

(6) Structure for the *t*-deverbals is extended from the past participle with additional category changing heads (adapted from Calabrese 2020: 130a)



5.3.1 The meaningful PPtc

The most important difference between this account and the treatments of Embick and Halle (2005) is the assignment of *-t-* as the exponent of Asp^0[+perf] rather than the default exponent of Asp. However, [+perf] is itself inserted as the unmarked default specification of Asp^0 for all roots expressing eventuality (Calabrese 2020: 56, 78). Since Asp^0[+perf] is also present in the structure for the Perfect, this allows the PPtc *-s-* and Perfect *-s-* to be analyzed as the same VI (7). Other than this, the VIs are quiet similar. Note that the diacritics employed by Calabrese to handle irregulars can be seen as a notational alternative to the lists of Embick and Halle.

(7) Vocabulary Items for Asp^0[+perf] (Calabrese 2020: 121, 122)

-s- ⟷ $[+perfect]_{Asp}$ / $Root^S$ ____ $Root^S$ = *scrib*, *curr*, *sparg*, etc
-t- ⟷ $[+perfect]_{Asp}$

-Ø- ⟷ $[+perfect]_{Asp}$ / ____ T, $Root^{Ø}$ ____, $Root^{Ø}$ = *leg*, etc
-v- ⟷ $[+perfect]_{Asp}$ / ____ T

As Calabrese (2020) notes in fn. 41, this makes the strong prediction that "all roots with /-s-/ in the perfect should also have it in the perfect participle," but there

are exceptions. This is handled, both in the Latin and Italian analyses, by an Impoverishment rule which deletes the diacritic specifying *-s-* for the PPtc. That way, the *s*-Perfects need not always correspond with an *s*-PPtc.

Another argument in favor of a shared feature between the Perfect and PPtc is that it is generally the case that the presence of the theme vowel in the form of the Perfect is matched with a theme vowel in the PPtc. In order to account for theme vowels in Italian stative adjectival participles and Latin supines, a constraint is proposed (Calabrese 2020: 69, 113) in which *v* and the Asp head entail one another. The presence of Asp forces the insertion of *v*, into which the theme vowel is inserted "ornamentally." Athematics are accounted for by a Root diacritic which blocks the ornamental insertion of the theme vowel. Exceptions to the thematicity correspondence are handled with impoverishment of the athematic diacritic, which allows the theme vowel to be inserted like normal. These are effectively exceptions to exceptions.

On the face of it, the *t*-deverbals render the analysis dubious, since they exhibit a variety of semantics (Maiden 2018: Chap. 7). Calabrese accounts for this by proposing that the deverbal suffixes introduce diacritics which alter the semantic "flavor" of the eventuality (Calabrese 2020: 81). A similar problem is found in the iteratives, intensives, frequentatives verbal derivatives built on the PPtc (Sect. 2.3.3). These classes are all canonically imperfective (Comrie 1976), and yet the analysis requires *-t-* to be the realization of Asp^0[+perf]. Either the actual meaning of [+perf] is so bleached as a generic eventuality marker that I would contend it is a "stipulative and opportunistic" way to capture the general trends between the Perfect and PPtc, or the /t/ in the iteratives, intensives, and frequentatives is achieved by different means. In either case, the proposal loses much explanatory force.

There are also cases where the *-t-* does not even express eventuality, as noted in (Calabrese 2020: fn. 40). To account for these denominal adjectives which share the affixal /t/ with the PPtc (Sect. 2.2.2; e.g., *barbātus* 'bearded,' *onustus* 'burdened'), an analysis is suggested in which the mutual entailment constraint between *v* and Asp^0 just does not apply. However, this misses the more significant problem: many of these have a stative meaning. They do not refer to an eventuality. If *-t-* is the exponent of Asp[+perf], where [+perf] is inserted by default as the prototypical eventuality, then there is no reason for it to be in the structure at all.

Calabrese (2020) makes another innovative claim, namely that there also exists a null exponent for Asp^0[+perf] in addition to *-t-/-s-*. This is meant to subsume *-men(tum)* deverbals under the same structure as the PPtc. It also captures the observation that the form of the verb in *-men(tum)* deverbals is often in line with the PPtc rather than the Present. For example, *mōmentum* 'movement' shares its form with the PPtc *mōtus* 'moved' rather than the Present **movimentum* or **movementum*.[25]

5.3.2 Evaluating the synchronic predictions

Calabrese's account makes several strong predictions: a tight relationship between *s*-Perfects and *s*-PPtcs, a tight thematicity correspondence between the Perfect and the

[25] Note that the Present-like form with the theme vowel eventually took hold similarly the death of the *t*-deverbal correspondence (Sect. 2.3.4). This results, for example, in the English doublet *moment(um)* < Classical Latin vs. *movement* < Old French.

PPtc, and *-t-* as a marker for eventuality and perfectivity. Each of these predictions bears out somewhat but is very exception-prone. In the first case, the *-s-* correspondence is not even the majority pattern in Latin and was unlikely to be productive in the Classical period. This is a minor issue though and can be solved by proposing two separate *-s-* VIs as in Embick and Halle (2005).

The exception-prone thematicity correspondence is more of a challenge, since this correspondence is taken as evidence for basic operations of the account, enforcing the presence of Asp^0 when *v* in the structure and vice-versa. Stem-specific athematicity is most directly explained with stems. Since those are not an option in Calabrese, the author must indicate athematicity on the Root itself. If it is indicated on the Root, then it should be consistent across emergent stem forms, but since this is not the case (worse than previously assumed, according to Sect. 4.1.2), one must propose repairs that serve as exceptions to exceptions, which themselves remove much of the explanatory force from the initial proposal.

The presence of stative adjectives in *-tus*, semantically diverse *t*-deverbals, and canonically imperfective verbal derivatives in *-t-*, are serious challenges since they undermine the assignment of eventuality and perfectivity to *-t-*. This semantically meaningful *-t-* is, in my view, the critical difference between Calabrese (2020) and the accounts of Aronoff (1994) and Embick and Halle (2005), and much of the account is built upon this.

Because the Calabrese (2020) structural analysis makes excessively strong predictions, much of the legwork of actual form derivation is offloaded onto repairs. Adding new repairs, new parameters for the grammar to utilize is the theoretical equivalent of overfitting, and it is employed (at least explicity) more so than Embick (2000) and Embick and Halle (2005). In practice, it can fit anything at all—in some cases, such as the relationship between *s*-Perfects and s-PPtcs, more than half of roots must rely on diacritic impoverishment rather than the VIs themselves. There is no question that (Calabrese 2020) can describe the Latin and Italian data, but it is worth asking how much of the data it is explaining.

This point about over-parameterization is illustrated again by the treatment of *-men(tum)* deverbals. Admitting a null exponent for Asp^0[+perf] to subsume them under the PPtc structure is another strong categorical proposal for a general trend full of exceptions. One such exception is the existence of *-mentum* derivatives with overt theme vowels corresponding to athematic past participles, such as *reg-i-mentum* contra *rēctum* (Calabrese 2020: fn. 46). This is handled with another repair, this time an Impoverishment of the athematicity diacritic precisely in this context. In fact, there are several more of these including *sent-ī-mentum* contra *sensum*, and *fer-mentum* contra *fervītum* showing the thematicity mismatch in the opposite direction. Together, these necessitate a pair of diacritic Impoverishment rules which allow in principle for any thematicity/athematicity pattern. On top of this, the form *īn-strū-mentum* like the Present *-stru-ō* contra the PPtc *-strūc-t-us* cannot be handled by just these Impoverishment rules. There is no phonological constraint preventing the velar-labial nasal cluster (cf. *augmentum*, *fragmentum*), so another repair is needed would be needed to derive this form instead of **īnstrūgmentum* if it is actually a PPtc form.[26]

[26]Even the examples highlighted in favor of the null exponent Asp^0[+perf] analysis are of mixed quality under further inspection. It is noted that the *-mentum* derivatives of verbs with nasal infixed Presents

The partial relationship between the PPtc and *-mentum* deverbals certainly does not entail a tight synchronic relationship as proposed. It may well better be explained outside the grammar as a diachronic accident. As Calabrese (2020) discusses, both the PPtc and *-mentum* deverbals descend from the old athematic stem. The same starting point, combined with a similar but not identical phonological environment (a consonant-initial ending adjacent to the root) is expected to yield similar but not identical forms in the absence of morphological intervention. Of course, the relationship could be handled by Calabrese's proposal and an elaborate series of repairs, but this comes at the cost of explanatory adequacy.

5.3.3 Contending with the acquisition and diachronic evidence

The Calabrese (2020) account has an advantage in accounting for diachronic trends over Embick and Halle (2005) in that it avoids the latter's "natural class" problem between the Perfect and PPtc. Though the treatment was criticized in this section on other grounds, we can see that it predicts a tight diachronic relationship betwen the Perfect, PPtc, and *t*-deverbals (and the null exponent Asp^0[+perf] *-men(tum)* derivatives).

Instead, the account runs into trouble trying to account for the details. The diachronic observation that *-itus* PPtcs, athematic PPtcs, and *s*-PPtcs suffer attrition across Romance to various degrees suggests a lack of productivity. This is consistent with the TP analysis to the exclusion of the DM treatment which does not naturally model unproductive PPtc forms. That said, since the framework is explicitly overparameterized, one could in principle model unproductive PPtc forms by contravening the structural relationship and abusing diacritic Impoverishment rules to enumerate the athematic PPtcs. The resulting lexicalized list would not be in the spirit of DM and would add nothing beyond what Aronoff (1994) already does. The same applies to the relationship between *s*-Perfects and *s*-PPtcs and between the PPtcs and *-mentum* deverbals as well.

lack the nasal infix, as in *frag-men(tum)* contra Present *fra<n>gō*. This is good evidence that *-mentum* deverbals are not built directly on the Present stem. However, Calabrese's further claim that they are instead based on the PPtc does not hold up. Note that the PPtc for this verb is *frāctus* with a long stem vowel yet the *-mentum* derivative *frag-men(tum)* has a short vowel. This is not apparently the PPtc. Rather, it is something "in between" with the Present's short vowel and PPtc's lack of nasal infix. A researcher operating in a framework which allowed derivatives to be built directly on the bare root might be tempted to propose that *-mentum* is suffixed directly to the root rather than to any of the stems in cases like this. The vowel-length problem recurs in forms including *agmen* contra *āctus* and *stāmen* contra *status*.

Calabrese (2020: fn. 45) addresses forms with an unexpected short /u/ such as *doc-u-mentum* and *mon-u-mentum*. These have *-uī* perfects, so Calabrese argues that this vowel is the exponent of Asp marshalled from the Perfect. This is taken as further support for the analysis. Note, however, the existence of forms like *teg-u-mentum* with an *s*-Perfect *tēxī*. Weiss (2020: Chap. 13) notes that a short *u* is the expected outcome of a short high vowel before a labial from Old Latin and that there are many examples which have persevered into the classical language. If that is accepted, then these should be treated as an additional class of exceptions more like *regimentum*, so they are not supportive of the account.

Some of the remaining example provided in (Calabrese 2020: 136) are similarly inconclusive: *acūmentum*, *argūmentum*, and *assūmentum* (and *īnstrūmentum*) show a long *ū* as in the PPtc contra the Present, but the Present short vowel could easily be the output of the prevocalic shortening rule and thus needs not be projected into any underlying form.

The account also appears to make an incorrect prediction regarding the fate of the PPtc-*t*-deverbal correspondence. The general trend in Romance has been for the the *t*-deverbals to realign with the present rather than the past participle in situations where the two differ. Calabrese handles Italian in the same way as Latin with diacritic Impoverishment, however, such an analysis applied to Spanish would require a repair to account for every regular *-edor* agent of an *-er* verb, for example (Sect. 2.3.4). The diachronic development in Calabrese's framework has to be conceived of a gradual increase in the amount of listing as more and more items have to be listed for repair. This is over-*ir*regularization, which is both diachronically and developmentally unusual. A more satisfactory account would model this as the long-term consequence of over-regularization, delisting of exceptions over time. That is common in acquisition and is the typical direction of analogical change.

5.4 Steriade (2016): Similarity-based syncretism

Steriade (2016) presents a phonology-centric model which challenges several of the basic assumptions integral to previous approaches. Implemented in terms of violable constraints, this Similarity-Based Syncretism (SBS) account argues that most past participle forms actually are predictable given the form of the Perfect. The correspondence between the perfect and PPtc is motivated by the argument that the *-t-* of the PPtc does in fact carry a semantic value as a perfective morpheme, triggering a comparison between the two in the phonology. This is similar to the Calabrese (2020) proposal, revives the view of Mel'čuk (1982) that the past participle stem contains meaning, and is a major departure from Embick (2000), Embick and Halle (2005), and Aronoff (1994),which hold that *-t-* is semantically empty.

However, past asserting a meaning for *-t-*, the account is very different from Calabrese (2020). Steriade argues that the underlying structure of *t*-deverbals is different from past participles. These are built directly on the root and consist underlyingly of the root, a buffer vowel short *-i-*, a synchronically coincidentally homophonous *t-extension* morpheme, and the meaning-bearing derivational suffix. The *t*-deverbal structure is brought into correspondence with the past participle through an Output-Output constraint on its phonological form because they share a phonological /t/ following the root.

This analysis is further taken to explain an apparent directionality in the correspondence, namely that the *t*-deverbals borrow their form from the PPtc rather than vice-versa. As a result, when the correspondence happens to fail (Sect. 2.2.2), the *t*-deverbal is more "regular" than the PPtc (e.g., *mortuus* but *moritūrus*), not vice-versa (e.g., *t*-form *victus* but *s*-form **vixor* instead of *victor*, to borrow Steriade's own example). Calabrese (2020) instead has to assert this directionality since there exist diacritic Impoverishment rules could could alter either form.

5.4.1 Form of the past participle

Steriade observes a pattern of rhythmic correspondence between the Perfect and PPtc: if the stem (left of person number agreement) is monosyllabic, then the PPtc tends to lack a theme vowel, and if it is polysyllabic, it tends to express a theme vowel. In

the 1st and 4th conjugations (*ā*- and *ī*-stem verbs), this observation is quite robust. A large majority of 1st and 4th conjugation verbs retain their long theme vowels in both forms (e.g., [*am-ā*]-*v-ī* ∼ [*am-ā*]-*t-us*; Table 2) and thus obey the correspondence generalization.

The situation in the 2nd and 3rd conjugations is more complex because their Perfect and PPtc forms vary significantly (Sect. 2.1.1). Steriade carries out a quantitative study of the rhythmic correspondence using 325 2nd and 3rd conjugation verbs drawn from searches of the online Perseus corpus (Smith et al. 2000) to determine its reliability. Of 202 verbs with monosyllabic PPtc stems analyzed, 86% are in rhythmic correspondence with their Perfects, while 93% of 86 polysyllabic stem PPtc verbs are in correspondence with their perfects (Steriade 2016: 14). Descriptively, there is clearly a pattern here, however it is not sufficiently reliable to admit it into the grammar, as we will see below.

To achieve rhythmic correspondence, the Perfect stem (called the *base*), which is selected according to several constraints of its own (Steriade 2016: 15), enters into another constraint analysis summarized in the tableaux in (8). It is not clear how verbs which violate the correspondence in any of the conjugations are meant to be handled, but it seems to me that they could be subject to listing via lexically specified constraints. The author's aside that "archaisms and further paradigmatic factors" are involved would be consistent with this assumption (Steriade 2016: Sect. 6.2.6).

(8) Deriving the perfect participles corresponding to monosyllabic and disyllabic verbal perfects (Steriade 2016: 16)

a. Monosyllabic (*scribō*, *-ere*, *scripsī*, *scriptus*)

Base [*scrip-s*]- Suffix: *-t*, *-it*	DEP V (PERFECT)
☞ a. [*scrip-t*]-*us*	
b. [*scrib-it*]-*us*	*!

b. Disyllabic (*molō*, *-ere*, *moluī*, *molitus*)

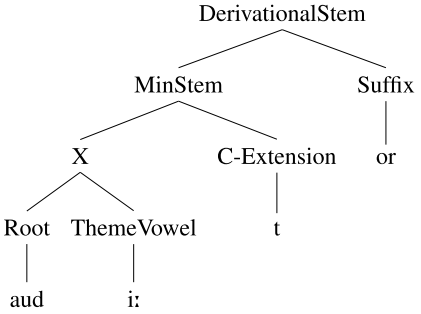
Base [*mol-u*]- Suffix: *-t*, *-it*	MAX V (PERFECT)
☞ a. [*mol-it*]-*us*	
b. [*mol-t*]-*us*	*!

MAX/DEP V (PERFECT): If two verb forms have the same lexical head and the same aspectual value, then each nucleus in the stem of one has a correspondent nucleus in the stem of the other.

5.4.2 Forms of the *t*-deverbals

The SBS account for the *t*-deverbals begins with an argument for their underlying structure. Steriade (2016) proposes that they share the following: a "buffer" *-i-*, followed by a *t*-extension, followed by the item-specific ending. The *t*-extension is argued to be part of a larger class of extensions (Steriade 2016: Sect. 6), but the details are out of scope for the this summary. Steriade proposes an underlying structure for the *t*-deverbals (9) which is quite similar to the DM structures (see (2c) and (6)).

(9) Structure of a 4th conjugation agent *t*-deverbal *audītor* (Steriade 2016: 33)[27]



Buffer *-i-* is assumed to be the global default in the construction of the *t*-deverbals. A central motivation for this comes from the claim that it is always present for *t*-denominals with no associated verb form, for example, *fund-a* 'sling' *fund-i-t-or* 'slinger' with no verb built on that root (Steriade 2016: Sect. 6.2.8).[28]

Additionally, it is claimed that when the *t*-deverbals do not correspond to the PPtc, then they always contain *-i-t-*, at least in the 2nd and 3rd conjugations. Treating buffer *-i-* as default here is crucial to the directionality argument, because it allows the non-corresponding *-i-t-* form to be treated as the more regular of the two.[29]

[27] See Maiden (2018: Chap. 7.1) for discussion on the C-Extension.

[28] 1st conjugation verbs with *-it-* PPtcs and *t*-deverbals or *-uī* Perfects in Classical Latin are archaisms which do not reflect productivity either of *-itus* or *-uī*. They were formed from roots ending in an inherited Proto-Italic short **-a-* (Sihler 1995: 528–530).

[29] Steriade (2016: Sect. 6.2.8.2) uses "always" to describe the reliability of these generalizations. In fact, both generalizations are far from exceptionless:

- Buffer *-i-* is indeed common in denominals, but it is far from ubiquitous. Table 4 lists several denominals with different vowels. Taking *senātor* (and *Senātus* 'the Senate') as an illustrative example, the adjective *senex*, *-is* is a 3rd declension *i*/consonant-stem adjective and is thus a prime target for a short-*i* in derivations. There is no derived verb **senāre*, and the stative *seneō* and inchoative *senescō* are unremarkable 2nd and 3rd conjugation verbs with no *ā* in any form, so influence from the verbal system is not possible. Nevertheless, Old Latin speakers chose the long *ā* for these forms rather than the buffer *-i-*. This is not an isolated case. More are given in Embick (2000: Sect. 6.5).
- There are some verbs with *t*-deverbals that are more "regular" than their past participles and yet do not contain buffer *-i-*. The 1st conjugation verb *sonō* lacks the *ā* theme vowel in the PPtc, but it returns in the future participle *sonatūrus*, so some mechanism needs to both override the global default and the short *-i-* of the verb's Perfect.
- Deponent past participles cannot be subject to rhythmic correspondence because deponent verbs do not have synthetic perfects, so 2nd and 3rd conjugation deponent PPtcs should have buffer *-i-*. They sometimes do, but often do not. Contrast 2nd conjugation *fateor* ∼ *fassus* 'acknowledge,' *liceor* ∼ *licitus* 'bid for, value,' *reor* ∼ *ratus* 'reckon,' *tueor* ∼ *tuitus* 'protect,' and 3rd conjugation *fruor*, *-ī* ∼ *frūctus* 'enjoy,' *gradior*, *-ī* ∼ *-gressus* 'step, advance.'
- Several of Steriade's examples (Steriade 2016: ex. (22)–(23)) turn out to be post-Classical or even Medieval (e.g., *fīcitor* cf. *fīca* Nonius Marcellus fl. late 3rd c., *Imporcitor* contra *imporcātus* Servius Honoratus fl. late 4th c., *bibitor* (no PPtc) Apollinarius Sidonius ob. 488, and *infenditor* contra *-fensus* in a 16th c. glossary attributed to a 'Vulcanius'), meaning that the attested writers were at best native speakers of Late Latin. Since Late Latin lost contrastive vowel length, we cannot be sure whether they are faithfully relaying the Classical language. Given this and the diachronic factors described in Sect. 2.3, it possible that any Classical example from the post-Classical period reflects interference from productive Late Latin **-itu* (< *-ītus*, not *-itus*) or its Romance reflexes rather than the Classical short buffer *-i-*. They may turn out to be valid, but it would take more research to determine that.

As the effective global default, buffer *-i-* is always present in the derivation of the *t*-deverbals, and it is brought into form correspondence with the PPtc if present and different through the help of a constraint $\textsc{Corr}_{\textsc{sim}}$ defined in (10) along with some agent examples.

(10) Similarity-based Syncretism (Steriade 2016: (27), (31–32))

a. $\textsc{Corr}_{\textsc{sim}}$: For any pair of surface MinStems S_1, S_2, if S_1, S_2 are lexically identical and (b) S_1, S_2 end in homorganic, [α sonorant] segments, then S_1, S_2 stand in correspondence.

b. Derivational suffixes attach to the root or the *infectum* (i.e., present) stem. A buffer *-i-* separates any stem-final C from a suffix-initial C.

Root *aud-*; PPtc: [*aud-ī-t*]$^{\text{i}}$*-us*	$\textsc{Corr}_{\textsc{sim}}$	Max/DepV, Ident OO	(10b)
a. [[*aud-i-t*]$^{\text{i}}$*-or*]	*!		
b. [[*aud-i-t*]$^{\text{j}}$*-or*]		*! (ī-i)	
☞ c. [[*aud-ī-t*]$^{\text{i}}$*-or*]		*	

Root *caed-*; PPtc: [*caes*]$^{\text{i}}$*-us*	$\textsc{Corr}_{\textsc{sim}}$	Max/DepV, Ident OO	(10b)
a. [[*caed-i-t*]$^{\text{i}}$*-or*]	*!		
b. [[*caed-i-t*]$^{\text{j}}$*-or*]		*! (s-d, i-Ø, t-Ø)	
☞ c. [[*caes*]$^{\text{i}}$*-or*]		*	

Root *fer-*, *lā-*; PPtc: [*lā-t*]$^{\text{i}}$*-us*	$\textsc{Corr}_{\textsc{sim}}$	Max/DepV, Ident OO	(10b)
a. [[*fer-i-t*]$^{\text{i}}$*-or*]	*!		
b. [[*fer-i-t*]$^{\text{j}}$*-or*]		*! (f-l, e-ā, r-Ø)	
☞ c. [[*lā-t*]$^{\text{i}}$*-or*]		*	

If a verb without a past participle or a noun has a *t*-derivative, then that derivative should default to *-i-t-* because there is no base for $\textsc{Corr}_{\textsc{sim}}$ to apply to. This also accounts for the observed directionality of regularity, since the *t*-deverbal should fall back on the underlying *-i-t-* when the correspondence fails. Additionally, establishing a relationship between the form of the perfect and the form of the past participle which is actively enforced in the grammar does provide a pathway for attested analogical reworking of the past participle on the basis of the Perfect (Sect. 2.3.2–2.3.3).

5.4.3 Contending with the acquisition and diachronic evidence

The SBS analysis provides a reason why the form of the PPtc would frequently depend on the form of the Perfect in arguing that the *-t-* of the PPtc carries perfective semantics. This claim is not uncontroversial (Maiden 2018: Chap. 7) and suffers from the same drawbacks as the Calabrese (2020) analysis as a result, but even if we accept it, there are some quantitative issues that render the basic assumptions of SBS unworkable. First, the analysis assumes that 1st and 4th conjugation verbs reliably form PPtcs with their theme vowels. This does not bear out for the 4th (Sect. 4.1.1).

Second, the analysis assumes a predictable and default buffer *-i-*, which is not actually reliable in the data (fn. 29), and is not remotely borne out by the productivity analysis (Sect. 4.1.1–4.1.3). Most importantly, it runs counter to diachronic developments, where the *-i-* fared worse than any other high-frequency form (Sect. 2.3.3).

The productivity analysis has implications for the apparent directionality in the past participle to *t*-deverbal correspondence as well (Sect. 5.4). First, if buffer *-i-* *t*-deverbals are not productive, then forms like *moritūrus* are not so much "more regular" as they are "differently irregular." Second, even if we grant the generalization, there is a perfectly reasonable and empirically motivated account for this pattern (Sect. 4.2). Namely, the overwhelming majority of *t*-deverbal forms must be inferred from their verbs' past participles, and most of the rest will be attested. If a *t*-deverbal is brought out of correspondence, it will be due to over-regularization of some productive pattern, as in *sonitus* ∼ *sonātūrus*. This is no diachronic or learning-based reason why a speaker would ever be motivated to innovate a more irregular *t*-deverbal like **vixor* for *victus* ∼ *victor*. Thus, a theory that explicitly excludes *t*-deverbals which violate this descriptive directionality does not gain anything over one which does not.

6 Bringing stems back

Patterns of morphological productivity can be complex and is not always reliably determined qualitatively from reading a data set (Sect. 3). Without a reliable metric for productivity, prior theoretical work on the Latin PPtc has made divergent assumptions regarding productivity and listedness. In motivating an analysis of productivity and "holding this variable constant" across accounts, several issues have come to light for the prior treatments discussed here.

Perhaps the most interesting challenge is posed to the DM treatments. While prior criticisms have noted that the framework is actually quite powerful despite the various restrictions it employs—the semantically disjoint [pass] of Embick and Halle (2005) or the bleached [+perf] and diacritic Impoverishment rules of Calabrese (2020)—the results presented here show that DM can also be quite weak. It cannot capture the productive relationships between forms independently suggested by the acquisition analysis and diachronic evidence because it cannot refer to stems. The DM analyses of the PPtc and *t*-deverbals make incorrect predictions regarding the diachronic trajectories even though they succeed at deriving the correct forms.

In the Embick and Halle (2005) treatment, one cannot define Readjustment rules which apply to the PPtc and Perfect but exclude the Present as doing so would require the rule to refer to a structure not present during the derivation. In this section, I work through a proposal to show what would be added to allow for a rule that references that structure. Doing so would be tantamount to referencing stems, in this case, represented as stored subtrees. This could be thought of as an implementation for Aronoff's realizational rules, for example, but done in a way that preserves some of the tenants of DM. Of course, this does undermine one of the framework's core tenants, that only categoryless roots, not stems, are stored, so it is emphatically not a version of DM. It does, however, yield the correct forms and the correct productive relationships. This section walks through such a system further facilitated by a

concept of *spans*, linearly adjacent but not necessarily structurally local sequences of morphemes (Svenonius 2012; Merchant 2015; Svenonius 2016).

I now introduce the mechanics of enriched rules and enumerate a system of rules that achieves Latin's empirical productivity. Crucially, one rule is stated for each productive pattern in order to correspond directly to the output of the model learner's hypothesis evaluation. Forms not covered by the productive patterns are listed. It would be incorrect to propose a more compact analysis that combines rules just because the machinery of the formalism allows for it. Recall that standard Readjustment rules are already quite powerful and can generate whatever surface forms are necessary despite DM's constraining premises (Bermúdez-Otero 2013; Merchant 2015). This extension is not more powerful in its weak generative capacity, in its ability to achieve the correct surface forms, but is better equipped to yield cognitively motivated underlying relationships between forms. Its power is limited on a case-by-case basis by factors outside the grammar itself; namely, a treatment should only encode the relationships that are learned from a speaker's input.

In Table 13, rules are presented according to the template in (11). As in a traditional Readjustment rule, the left side contains the components to be adjusted and the context in which the adjustment takes place, though here the adjusted component is a span. The right side of the rule contains the adjustment and the condition under which it applies. The difference here is that the adjusted form may be conditioned on a stored context, which need not have been accessed during this particular derivation. Stored contexts are subtrees which could conceivably be re-computed and stored. This is tantamount to storing stems with hierarchical structure behind them, allowing derivational constraints to limit meaning. These rules are elevated in status relative to DM and are used more like the Aronoff (1994) realizational rules rather than just as Readjustments.[30]

(11) SPAN / (CONTEXT)___(CONTEXT) ⟶ EXPONENT/
(STORED CONTEXT)___(STORED CONTEXT) if CONDITION

The basic structure is assumed to be similar to those proposed in Embick (2000). Each of the productive patterns uncovered in Sect. 4 receives a rule. Beginning with the 1st conjugation theme vowel pattern (Sect. 4.1.1) and 1st, 2rd, 4th conjugation Perfect -*V̄vī* ∼ -*V̄tus* pattern (Sect. 4.1.2), we can write rules as in (12). In these, the PPtc v (for simplicity, instead of a separate incorporated theme vowel node) in the context of Root and Asp[perf] is adjusted if it matches the appropriate pattern. In (12a), the specific √ROOT is sufficient context because this selects for the appropriate theme vowel following Embick and Halle (2005). In (12b), provided both in-line and in tree form following notation from previous work on spans to the extent possible, v is readjusted to match v in the context that defines the Perfect. It should be read as "the v_i-Asp span following the Root takes on the form of v in the context of the Root and the span Asp[perf]-T followed by *t* if v_i is a long vowel." The context

[30]The context tree here is the Perfect stem. Following the general learning-centric approach of this paper, the speaker is referencing the Perfect stem to infer the form of the PPtc as they must have done to produce any form not present in their input. As such, the context tree only has to be generated once when it is learned (or again if the grammar is updated), and then it can be stored. The effect is a lexicon that contains many small morphological tree structures.

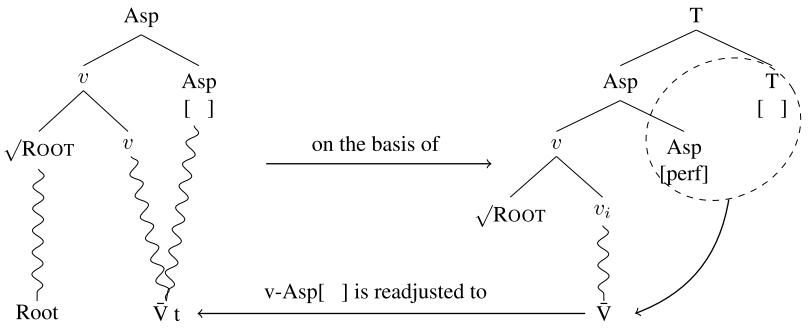
Table 13 Desiderata for an adequate theory determined from acquisition and diachronic evidence along with the predictions of the present theory. Compare with Table 11

	Pres/Root/ThV → PPtc	Perfect → PPtc	Listed PPtc	PPtc/*t*-Deverbal Correspondence	productive **-utu*?	loss of *-itus*/*-tus*?
Desiderata	1st, 3rd-*iō*, *faveō*-types	long ThV, *s*-perfs, *solvō*-types	exceptions + most of 2nd, 3rd	No necessary direction, but usually PPtc → *t*-deverbal	productive *-ūtus* for *solvō*-types is the only prod. PPtc for surface *uī*-Perfects	corresponds to limited productivity of *-tus*, non-productivity of *-itus*
Analysis	VIs, and Readjustments conditioned on derived and stored subtrees (12a)	VIs, and Readjustments conditioned on stored subtrees (12b)-(17)	listing (19)	shared structure, no implied direction	Productivity of *-ūtus* (16, 17)	Non-productivity of most *-itus* and *-tus*

containing Asp[perf] and T meet the string locality requirements for a span, but do not meet classic DM's stricter structural locality requirement. Specifying this extra context uniquely captures the Perfect and excludes those PPtcs which happen to have perfective semantics (e.g., most past participles).

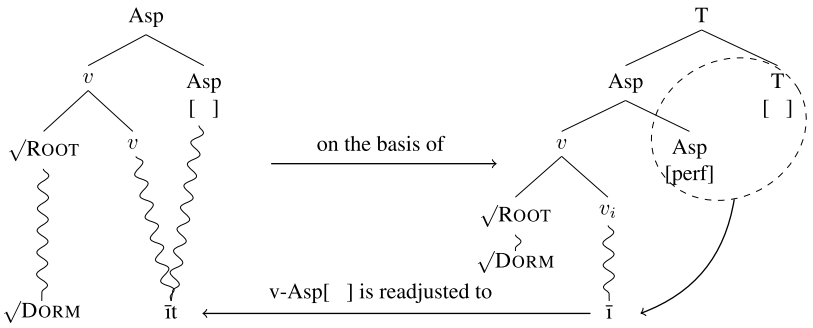
(12) a. v-Asp[ ] / $\sqrt{\text{ROOT}}$___ ⟶ v *t* if v = *ā*

b. v-Asp[ ] / $\sqrt{\text{ROOT}}$___ ⟶ v_i/($\sqrt{\text{ROOT}}$___Asp[perf]-T) *t* if v = $\bar{V}$



As a concrete example using (12), (13) gives the PPtc *dormīt-* for the verb *dormiō*, *-īre*, *-īvī*, *-ītus* as an example of a derivation. Recall that membership in the 4th conjugation is not sufficient to imply an *-ītus* past participle. The long *ī* productively appears in the PPtc only if it appears in the Perfect.

(13)

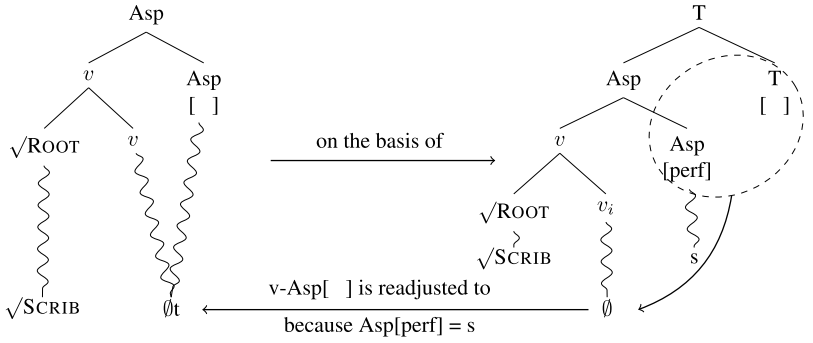


Recall that paradigmatic gaps can be attributed to situations where Spell-Out crashes because there is no default exponent to insert, and that in Latin, verbs with gaps appear where none of the generalizations uncovered by the Tolerance Principle apply. As such, if we assume that there is no default exponent for Asp, past participles and *t*-deverbals are rendered ineffable unless they are repaired by one of these rules or by listing. This is readily expressed with a v-Asp span on the left side of the rules and *t* on the right side. This also has the effect of treating the *t* as part of the stem. Though a full analysis will not be carried out in this work, treating the whole form as a stem this way also provides an avenue for handling verbs with defective Presents and Perfects.[31]

For 3rd-*iō*, the theme vowel just has to be impoverished when the default realization of Asp is selected as in Embick (2000) and Embick and Halle (2005). The *s*-Perfect generalization requires Impoverishment of the theme vowel but needs to reference the exponent of Asp[perf]. Since the theme vowel is also impoverished in the Perfect, it can be referenced as in (14). Further phonology then yields the regular *s*-PPtc and other predictable stem changes if the Root ends in an coronal obstruent (Sect. 2.1.1). (15) provides an example derivation according to this rule.

(14) v-Asp[ ] / √ROOT___ ⟶ v/(√ROOT___Asp[perf]-T) *t* if Asp[perf] = *s*

(15)



[31] Another advantage of simultaneously conditioning the theme vowel and *-t-/-s-* is that unpredictable *s*-PPtcs are managed by the same rules as the theme vowels. Otherwise a second parallel set of Readjustments would be needed to account for them. Contra Calabrese (2020), all non-phonological *-s-* PPtcs handled by one rule rather than splitting them between VIs and Readjustment rules.

Solvō-type verbs with PPtcs in *-ūtus* have multiple possible analyses, and the discussion of diachrony in Sect. 4.1.2 would suggest that there was variation in the population. One, described as the conservative grammar, takes these verbs to have underlyingly bare Perfects (*solu-ī*) and bare PPtcs (*solū-t-us*). These can be handled by (16) where the rule is conditioned on the form of Asp[perf] and the Root.

(16) v-Asp[ ] / $\sqrt{}$ROOT___ ⟶ v/($\sqrt{}$ROOT___Asp[perf]-T) *t* if Asp[perf] = Ø and $\sqrt{}$ROOT ends in /u/

The alternative innovative grammar analyzes the Perfect as containing *-u-ī* and the PPtc as containing *-ū-tus*. In this case, the conditioning context is an *-u-ī-*Perfect for a Root ending in *-u* as in 17.

(17) v-Asp[ ] / $\sqrt{}$ROOT___ ⟶ *ū t* if Asp[perf] = *-u-* and $\sqrt{}$ROOT ends in /u/

The last productive pattern described here is the *t*-deverbal correspondence. Without taking a position on the synchronic internal structure of the *t*-deverbal endings, whether they are whole (e.g., *-tor*) or the result of prior morphological operations incorporating something like the Steriade (2016) C-extension with the suffix *-t-or*, the presence of this *-t-* triggers a rule on the basis of the past participle stem (18). The *-t-* of the *t*-deverbals need not carry perfective meaning except in cases where it makes sense for it to. Thus the form correspondence is truly just form-based as it is in Aronoff's Third Stem.

(18) v-Asp[ ] / ___Mod ⟶ v Asp /($\sqrt{}$ROOT___Asp[perf]) if Mod begins with /t/.

Finally, exceptions are handled by listing. Since spans are already part of this formalism, this can be done most succinctly if the entire span corresponding to the PPtc is readjusted in one go (19a), which allows suppletives to be handled in the same way as other irregulars. Deponent PPtc that are not covered by Present or theme vowel generalizations need to be listed because they do not have synthetic Perfects to reference. *t*-Deverbals which do not correspond with past participles can be handled by a more specified Readjustment rule. For example, those with non-corresponding future participles (19b), assuming the structure in (2c).

(19) a. $\sqrt{}$ROOT-v-Asp[ ] ⟶ LIST, LIST={$\sqrt{}$FER:*lāt*, $\sqrt{}$PELL:*puls*, $\sqrt{}$SON:*sonit*, $\sqrt{}$MOR:*mortu*, etc.}

b. $\sqrt{}$ROOT-v-Asp[ ] / ___Mod ⟶ LIST, LIST={$\sqrt{}$SON:*sonāt*, $\sqrt{}$MOR:*morit*, etc.}

6.1 Contending with the acquisition and diachronic evidence

The account of the Latin past participles and *t*-deverbals outlined here aimed to explicitly encode the productive relationships uncovered by the decision procedure. As such, it is consistent with the calculations of the acquisition model. In contrast to previous accounts, it takes advantage of the relationship between productivity and analogical change described in Sects. 2.3.2–2.3.3 and 4.3. In a productivity-based approach to analogical change, actuation is largely due to over-regularized productions which gain a foothold in the speech community. In the terms of the present

Table 14 Analogical change of *cernō*, *-ēre*, *crēvī*, *certus*→*crētus* as over-regularization

Before Change	After Change
√CR:*cert* is listed in (19a) → Rule (12b) is not applied	√CR:*cert* is no longer listed in (19a) → Rule (12b) is applied
Irregular *certus* is produced	*crētus* is produced as an over-regularization

Table 15 Analogical extension of the *-ūtus* PPtc to *-uī*-Perfects

Conservative Grammar	Innovative Grammar	Analogical Extension
Bare Perfect and Root ending in *-u* → Rule (16) is applied	*-uī*-Perfect and Root ending in *-u* → Rule (17) is applied	*-uī*-Perfect and [*relaxed condition*] → Rule (17) is over-applied
Classical *-ūtus* produced	Classical *-ūtus* produced	Over-generalized *-ūtus* produced

framework, over-regularization happens when a learner fails to notice that a Root should be added to the list of exceptional stem forms and instead allows that verb to be subject to one of the productive Readjustment rules. For example, this accounts for the Pre-Latin reworking of PPtc *certus* → *crētus* by analogy with *crēvī* (Sect. 2.3.2). In Pre-Latin, √CR should have been listed with its PPtc *cert-* in (19a). If it were not for its presence in that list, it would be subject to the productive rule affecting verbs with *-V̄vī* Perfects (12b) because of its Perfect *-ēvī* ending. Any learner who acquired (12b) and witnessed *crēvī* before *certus* would be expected to over-regularize and produce *crētus* at least transiently. Table 14 schematizes this change.

Analogical extension occurs when the conditioning factors of a rule are relaxed, as in the rise of *-ūtus*. The rules governing these forms in Classical Latin (see (16), (17)) come with a synchronically arbitrary condition "Root must end with *-u*." With nothing about the structure necessarily motivating it, this condition simply had to be learned faithfully from the input. Any perturbation that relaxed this condition would result in an analogical extension. The innovative grammar which analyzes these as containing a *ū* theme vowel as in Romance also assumes that the Perfects contain *-uī*, so any relaxing its conditions would trigger extension first among *-uī*-Perfect verbs in particular. Keeping in mind that the actuation event for such a change is caused by perturbations outside of the grammar, Table 15 summarizes the grammatical implementation of the change. There are two extensionally equivalent grammars for Classical Latin. A learner who settles on the innovative one is primed for actuation.

Finally, the split between the perfective *-t-* and *t*-deverbal *-t-* provides a natural pathway for the collapse of the past participle-*t*-deverbal correspondence. The correspondence was ultimately transitory in the history of the language. It emerged as an accident, and it fell away as an accident. With no shared [+perf] feature, the only thing holding the two forms together is the observation during acquisition that the two tend to correspond, and that the correspondence with the past participle is more reliable than the correspondence with the Present. This compelled the learner to add rule (18) to the grammar. However, this coincidental productive correspondence was primed to be lost as soon as more regular 1st and 4th conjugation verbs were coined and the irregular PPtcs began to erode. Rule (18) could be replaced by a similar one

which references the Present instead of the past participle as soon as the learner's productivity calculations rendered it productive.

7 Conclusions

This paper addressed the complex forms of the Classical Latin past participles and their correspondence with the semantically diverse *t*-deverbals in light of both acquisition and change. The Tolerance Principle (Yang 2016), a quantitative model of productivity learning derived from work in language acquisition, was applied to a large set of forms extracted from the Classical texts of the Perseus Catalogue (Smith et al. 2000). Only handful of productive patterns were uncovered, far fewer than have been descriptively recognized. In Classical Latin, there was no generally productive past participle pattern for large verb classes including 2nd or 3rd conjugation verbs and verbs with *-uī* perfects. The relative lack of productivity may be surprising, but it closely aligns with observed diachronic trends in Latin and its Romance descendants.

Four theoretical analyses were reassessed according to their ability to achieve the productive relationships calculated with the acquisition model and observed in the historical data. Applying a consistent view of productivity across each of the accounts revealed that existing theories are inconsistent with the facts of productivity and diachrony. I present a stem-based model for the Latin system which explicitly encodes the relationships uncovered by the productivity analysis. Worked out for the Latin past participle stem, it contains rules which exactly cover the productive generalizations, and all other forms are listed. In capturing the necessarily productive relationships between stems, it also accounts for observed diachronic trends in the system. Analogical change occurs when an irregular verb is inappropriately not listed, and one of the productive generalizations over-applies.

The results of this analysis have general implications for morphological theory. First, they demonstrate that a grammar may contain a significant amount of listing or irregularity even when a linguist analyzing the data can draw out further patterns. Over a third of Latin verb types should be listed. The mere presence of a descriptive pattern does not in itself indicate whether it should be committed to the grammar. The pattern may be spurious and memorized as is the case for most apparent past participle generalization, it may be coincidental and emergent as in the directionality of the past participle to *t*-deverbal correspondence, or it may be emergent from the machinery of the grammar. A model motivated by advances in language acquisition research can be employed to uncover and justify patterns of productivity.

Second, it emphasizes the importance of diachronic evidence. When productivity exists synchronically, it has measurable consequences over the long term. This is well known for Latin and Romance in particular (Maiden 2013). In the absence of negative evidence from acceptability judgments, diachronic developments play a critical role in assessing the adequacy of a theoretical proposal for a pre-modern language or variety, they serve as an additional source of evidence for the internal organization of the grammar that is not available from a handful of synchronic examples alone, and they provide a mechanism for change. A theory of grammar, by itself, can only show consistency with a change, not provide a cause. An attempt at a grammar-only cause for a chance is left without an explanation for why a grammar that was

apparently well-formed and learnable for speakers at one point in time was no longer so at the next point. However, armed with a theory of learning that can push learners in a population from one instantiation of the grammar to the next as constrained by the grammatical framework, theory forms part of an explanatory system for change. The Tolerance Principle was applied as the core of an acquisition analysis here, and it successfully predicted major diachronic trends in the Latin and Romance verbal system, but any quantitative learning model could be employed instead if it could be shown to make more accurate predictions.

Third, it is recognized that all of the theories discussed in this paper including the new proposal are formally quite powerful. A researcher could fit any of them to the data with a clever combination of realizational rules or Readjustment rules. This applies equally to the Distributed Morphology accounts (Embick 2000; Embick and Halle 2005; Calabrese 2020) which present themselves as more constrained than prior work. Rather than presenting a framework that is more structurally limited, this paper presents a powerful framework that is limited by extra-grammatical constraints. The treatment was limited to only include structural relationships between the stems that were motivated by the productivity analysis, and as a result, it conforms with diachrony as well. Such external learning constraints could also serve as guides to other frameworks described as over-expressive, but each framework would have to be analyzed separately.

Acquisition did most of the legwork in this study. In general, in an integrated view of the language faculty, theory should not only inform but also be informed by the input and the learner. This is not a one way street. This project advocates for an approach to linguistic data which evaluates second and third factors in conjunction with first factors. Acquisition and change are two powerful tools for motivating and evaluating linguistic theory. More generally quantitative evidence should feature much more prominently in theoretical discussion. Questions of language processing and production, sociolinguistic variation, and the classic intuitions of acceptability all play complementary roles. Not all lines of evidence are available for all languages, as anyone who works on dead or under-documented languages knows well. The hope is that these will continue to be increasingly brought to bear on theoretical problems to build up a fuller understanding of the language faculty.

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Declarations

Competing Interests The author has no competing interests to declare.

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