Epenthesis Goes Beyond Phonology: A Unified Formal Account

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1. Introduction

What determines the sound of a linguistic sign? Since at least de Saussure (1916/1959), linguists have believed that a sign consists of the arbitrary association of sound and meaning and that the arbitrary signs of a language are listed in its lexicon. In the century since de Saussure, our understanding of the complexity of this association has become more nuanced.

The discovery of the phoneme (Sapir 1933, van der Hulst 2013) taught us that the lexical sound representation is quite abstract and that the relation between this abstract representation and the physical signal can be quite complex, albeit regular and predictable. This predictability led classical generative phonologists to adopt as a working hypothesis the idea that *all* surface phonological properties of *all* forms of a lexeme could be encoded in the underlying phonological representation, provided that it was abstract enough.[1]

The renewed study of morphology (Chomsky 1965, Matthews 1972) has shown that the realization of the phonological form of a word may depend on much besides its underlying form. Most importantly for our purposes, an individual lexeme or morpheme may have lexically listed arbitrary properties besides morphosyntactic features, properties that are in no way phonological in themselves but that determine its phonological form(s). For example, in all Semitic languages, verb roots may be inflected in one or more inflectional classes. An inflectional class may be assigned 'semantically', but just as often a verb's class membership(s) must be lexically listed as an arbitrary abstract property of that lexeme (Aronoff 1994). Consider the Hebrew verb class *hif'il*. This class is termed 'causative' because it is used to derive causative verbs: *qatal* 'kill' becomes *hiqtil* 'cause to kill'; *matar* 'rain' becomes *himtir* 'make it rain' (Genesis 2.5). But a good number of verbs must simply bear the label *hif'il*, although they have no causative meaning. This label determines how such a verb is conjugated, and that's all. For example, the verb root *r-g-ʃ* 'feel' occurs only in the "causative" *hif'il* inflectional class in Modern Hebrew. It can be either intransitive (*ani lo margiʃ tov* 'I don't feel well') or transitive (*hi hirgiʃa et haruax* 'she felt the

[1] For a recent formal treatment of precisely how abstract the phonological representation must be, see Bakovic et al. (2022).

wind') but it can never be used in any causative sense. There is simply no way to say 'she made them feel the wind' or 'she made them feel good'. We must posit that the verb *r-g-ʃ* is listed in the lexicon with a purely abstract marker that 'tells' the morphology to inflect it in this class.[2]

The main descriptive and analytical goal of this article is to unify under the umbrella of epenthesis – the insertion of meaningless phonological material – a number of lexically and morphosyntactically conditioned phenomena that have been treated disparately in past research. Many previous analyses of what we call "non-canonical epenthesis" have resorted to extra devices such as listed allomorphs and abstract segments. We reanalyze the data as instances of epenthesis with morphosyntactic and lexical conditioning, without resorting to such devices. Overall, we work within an inferential-realizational framework, following Matthews (1965), Stump (2001), and much subsequent work. We crucially distinguish lexical from morphosyntactic properties. Within such a framework, the job of morphology is to realize the phonological forms of grammatical words and lexical items within a specific morphosyntactic context. Throughout, we separate the phonological fact of epenthesis from the lexical and morphosyntactic conditions that determine precisely what segment is epenthesized. Finally, we model the interactions between variously conditioned forms of epenthesis using Boolean Monadic Recursive Schemes (Bhaskar et al. 2020; Chandlee and Jardine 2021), a formalism that can capture both linguistically significant and computational generalizations without exceeding the restricted computational power of regular languages (Chomsky 1959).

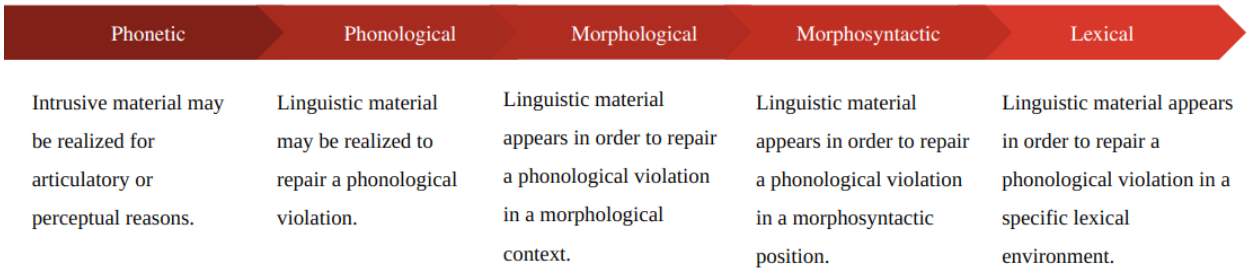
The term *epenthesis*[3] traditionally refers to the insertion of a segment whose appearance is motivated by phonology, and whose quality is also determined phonologically. The roots of epenthesis lie in articulation (§2), with recent results showing systematic instances of epenthesis that remain purely phonetic and may not rise to the level of phonology. But the factors determining the quality of the inserted material often go beyond phonetics to not only phonology (§3), but also

[2] This verb has lately been used in the passive/middle *nif'al* class (though not with a passive sense) and playfully in the reflexive *hitpa'el* (with no clear reflexive sense). See http://www.elephant.org.il/translate/translatable-but-debatable-hitragesh for a discussion of the latter. The relation between inflectional classes and semantics in Modern Hebrew is complex and nuanced, a fact that many choose to ignore.

[3] The rich range of terms used to refer to the insertion of unetymological material includes *epenthesis* (Ancient Greek *ἐπένθεσις* < *ἐπί* 'in addition' + *ἐν* 'in' + *θέσις* 'placing') referring to insertion in any context, *anaptyxis* (Ancient Greek, *ἀνάπτυξις* < *ἀνά* 'up' + *πτύξις* 'folding' 'unfolding') reserved for vowels inserted within a word and synonymous with *svarabhakti* (Sanskrit *svara* 'vowel' *bhakti* 'separation' 'vowel separation'), and its consonantal counterpart *vyanjanabhakti*, *pro(s)thesis* (Ancient Greek *πρόσθεσις* 'addition') for insertion at the beginning of a word, and *paragoge* (Ancient Greek *παραγωγή* 'additional') or *epithesis* (Ancient Greek *ἐπίθεσις* < *ἐπί* 'in addition' + *θέσις* 'placing') for insertion in final position.

morphology and morphosyntax (§4), and the lexicon (§5). In the latter cases, the language has a choice of segments to insert to repair a phonologically illicit structure, and the selection of one inserted segment over another is determined by factors outside phonology.

Figure 1. Conditioning factors in epenthesis



After briefly reviewing previous analyses of these non-canonical types of epenthesis (§6), we propose a new approach rooted in the observation that the non-canonical epenthetic segments are associated with either a specific entity or a morphosyntactic position to satisfy a markedness constraint within a restricted context (§7.1). In other words, the non-canonical epenthetic segments are triggered by an idiosyncratic feature of a lexeme, morphological entity, or morphosyntactic category, but the reason they take their specific quality is far from idiosyncratic. The formalism we use to represent the non-canonical epenthesis is not only sensitive to lexical, morphological, morphosyntactic and phonotactic conditions, it is highly restricted in its generative power and is limited to the class of regular languages, making it a good tool for morphophonological analysis (§7.2).

2. Phonetic Conditioning

We begin our analysis with an overview of various types of consonant and vowel insertion that have more of a phonetic than phonological motivation.

Intrusive segments may be realized between consonants for articulatory reasons.[4] For example, intrusive stops can be found in English between a nasal consonant and /s/, as in *prince* [pɹɪn̪ts] (for many speakers *prince* is homophonous with *prints*), and intrusive vowels can be found between certain heterorganic clusters (such as *arm* [ar̪əm] in some varieties of English) (Hall

[4] In the phonetic tradition, we find the terms *transitional segment*, especially *transitional vowel*, and more recently *excrescent vowel* (Levin 1987) and *intrusive vowel* (Hall 2006).

2006).[5] Monosyllables whose coda consists of a glide followed by a liquid may sometimes show an intrusive schwa, as in *owl* [awə̲], *oil* [ojə̲], *flour* [flawə̲ɹ], *fire* [fajə̲ɹ]. The schwa disappears when a vowel-initial suffix is added, because the offending liquid moves to the next syllable: *owlish*, *oiler*, *floury*, *fiery*. A new category of intrusive vowels has been identified by Miatto (2022) who shows that certain word-final vowels inserted after consonant-final loan words in Italian also qualify as intrusive: *jet* [d͡ʒɛttə̲]. Intrusive elements are described as optional and correlated with speech rate, and native speakers are often unaware of their presence. Intrusive vowels are usually realized as schwa or a copy of a neighboring vowel, and they do not quite have the status of segments, so that purely phonetic intrusive vowels do not count as syllable nuclei (Hall 2006, Levin 1987).

3. Canonical Epenthesis: Phonological Conditioning

We provide an overview of what we call "canonical epenthesis", the types of insertion that have received the most attention in the literature. We discuss types of consonant and vowel insertion that can best be described as phonological repair strategies, including those which use different segments in different phonological contexts.

Phonological epenthesis similarly involves the insertion of meaningless segmental material; its appearance is motivated by phonology (to repair an illicit phonological structure), the segment plays a role in phonology, and the quality of the segment is usually unmarked or predictable from the phonology of the language (Kitto and de Lacy 1999). Spanish illicit clusters are repaired by inserting the vowel [e], which is maximally underspecified (Archangeli 1988) and the most frequent vowel in Spanish (Guirao and García Jurado 1990). For example, word-initial *s-stop* clusters are realized with a prothetic [e]: *stop* [e̲stop].

In addition to the unmarked or default segment, we find other epenthetic segments whose quality is phonologically predictable. For example, in English, vowel hiatus is resolved through glide epenthesis, with the quality of the glide determined by the preceding vowel: *saying* with [j], *fluid* with [w] (Lombardi 1997, Staroverov 2014, Uffman 2007). "Copy epenthesis" involves the copying of a neighboring vowel. Consider English borrowings in American varieties of Italian (Repetti 2012) where a vowel is inserted after an illicit coda, and its quality is identical to the

[5] Throughout this article, the inserted segments are underlined.

preceding vowel: *cocktail* [kokkot̲élla], *washtub* [veʃʃet̲úbbo], *popcorn* [pappak̲ɔ́rno], *picnic* [pik̲iníkko]. Some varieties of Sardinian insert a paragogic vowel after a word-final consonant, and its quality is identical to the preceding vowel: /kantat/ > [kántat̲a] 's/he sings', /kompora-m-idas/ [komporamídaz̲a] 'buy them (fem.) for me', /kompora-m-idus/ [komporamíduz̲u] 'buy them (mas.) for me', /letámen/ > [letamen̲e] 'manure' (Bolognesi 1998, Kim and Repetti 2013). Finally, the quality of the inserted vowel may be "colored" by the surrounding phonetic environment: in initial clusters in Afrikaans loanwords in Sotho, labial and coronal consonants contribute place features to the following epenthesized vowel (Rose and Demuth 2006): /blɪk/ > [bɷleke] 'tin can', /truwn/ > [tʊroni] 'throne'. (See also Kim and Kochetov 2011 for vowel coloring of epenthetic vowels caused by adjacent consonants and non-adjacent vowels in loanwords in Korean.)

There are cases of epenthesis where the motivation for the insertion is phonological, a variety of epenthetic segments is attested in the language, and the choice of inserted segment is determined by phonological and prosodic considerations such as the type of illegal cluster or the phonological position of the inserted element. Bangla (Bengali) does not permit word-initial clusters, so English loanwords are adapted with prothetic [i] to repair an initial /s/ + stop cluster, but an anaptyctic [e] repairs an initial stop + /l/ cluster (Broselow 2015): *school* > [i̲skul], *glass* > [ge̲láʃ]. The Romance variety spoken in San Marino uses [ɪ] (which occurs in free variation with [i]) as the default epenthetic vowel (Michelotti 2008:332): /krsu:/ > [krɪ̲sú:] 'grown' (cf. [ɐ krɛs] 'I grow'), but [ɐ] in initial position before a sonorant + consonant sequence: /lgɛ:/ > [ɐ̲lgɛ́:] 'to tie' (cf. [ɐ le:g] 'I tie'). Hijazi Arabic aso uses two different epenthetic segments to repair different types of violations: "syllable structure-driven epenthesis" uses epenthetic [a] (/katabtlu/ > [katabt̲alu] 'I wrote for him'), while "sonority-driven epenthesis" uses epenthetic [i] (/lakm/ > [lak̲im] 'punching') (Bokhari 2021). Three epenthetic segments in Mohawk are used to resolve phonologically illicit strings, each under distinct conditions (Michelson 1989; Rawlins 2006: 11): we discuss [e] and [i] here, and [a] in §3. The vowel [e] can be regarded as the default epenthetic segment since it appears in most places where an epenthetic segment is needed (/s-wa-nuhweʔ-s/ > [se̲wanú:weʔs] 'you.PL like it'); however, in order to enforce a minimal word condition, prothetic [i] is inserted at the beginning of verb forms that contain a single syllable (/k-yʌ-s/ > [íkyʌs] 'I put it').

In each of these cases, the motivation for epenthesis is phonological and the choice among various epenthetic segments is influenced by phonological considerations. We now turn to our

main concern: instances in which the quality of the inserted segment is determined instead by morphological, morphosyntactic, and lexical considerations.

4. Non-Canonical Epenthesis: Morphological and Morphosyntactic Conditioning

In this section we introduce cases of "non-canonical epenthesis", or phonological repair processes with morphosyntactic conditioning of the context in which it applies and the quality of the inserted segment.

In this section we present a range of cases in which a non-default epenthetic segment is deployed to repair a phonological violation in a specific morphological or morphosyntactic context. Those contexts include illicit phonological strings created through suffixation (Brazilian Portuguese), within a specific noun category (Serbo-Croatian, Catalan, Nara), within a specific verb category (San Marino, Classical Arabic, Moroccan Arabic, Hungarian), and in a specific morphosyntactic position (Mohawk, Paduan).

Aronoff and Repetti (2021) discuss a case in Brazilian Portuguese in which the choice between two epenthetic segments to repair a phonological violation is made on the basis of morphological structure: [j] is the default epenthetic segment used to repair hiatus (*Correa* [koréja] '(name)'). However, if the hiatus is formed between morphemes, [z] is used instead: /sofá + iɲu/ > [sofaz̠ĩɲu] 'sofa (dim.)', /kafé + al/ > [kafezál] 'coffee grove', kafé + ejɾu/ > [kafez̠éjɾu] 'coffee producer' (Garcia 2017; Bachrach and Wagner 2007).

Serbo-Croatian also resolves hiatus with [j], except in a specific morphological context: [j] is the default epenthetic segment, used when one of the hiatus vowels is [i] (1a), while [t] is used before a suffix with /e/-final neuter nouns (1b). In a subset of this context — neuter stems with an /m/ before the final /e/ — the epenthetic segment is /n/ (1c) (Petrovic 2018).[6]

(1) Serbo-Croatian: (a) /naivan/ > [naj̠ivan] 'naïve'
(b) /uʒe + a/ > [uʒet̠a] 'rope.GEN.SG'
(c) /seme + a/ > [semen̠a] 'seed.GEN.SG'

[6] In other instances hiatus is tolerated: /zaova/ > [zaova] 'sister-in-law', /beograd/ > [beograd] 'Belgrade'.

There are also cases where an illegal sequence of consonants is repaired through vowel insertion, but the vowel quality is dependent on morphological factors. Catalan uses epenthetic [ə, e, i], depending on the variety, to syllabify an illicit sequence of consonants, as in Pallarese Catalan [e̲]Spielberg 'Spielberg (film director)' (Artés 2016). However, within the nominal domain, another vowel may be used. Catalan masculine nouns are sometimes realized with no gender marker (2a), but masculine noun stems ending in a sibilant (2b) are realized with an [u] (or [o] depending on the variety) before the plural suffix /s/.

(2) Catalan: (a) [gat] / [gat_s] 'cat/cats'
(b) [gos] / [gosu̲s] 'dog/dogs'

In Nara (a language isolate of Eritrea (Savà 2021)), [i] is the default epenthetic vowel used to repair a phonotactic violation (3a), but [e] is used in *CVCCe* nouns followed by plural marker *-ka* (3b).

(3) Nara: (a) /haajk-te/ → [haajki̲te] 'I played'
/todn/ → [tod.ni̲] 'want (SG)!'
(b) [kerfe] / [kere̲fka] 'fox/foxes'
[hajme] / [haje̲mka] 'gazelle/gazelles'

Another language in which the choice between two epenthetic segments to repair a phonological violation is made on the basis of non-phonological considerations – namely the verb conjugation class – is the Romance variety spoken in the Republic of San Marino (Michelotti 2008). In this variety, one of two epenthetic vowels is used to satisfy restrictions on word-final clusters: [ɪ] or [ɐ]: [ɪ] is the default epenthetic vowel (/ojm/ > [ójmɪ̲] 'elm'), and [ɐ] occurs only in word-final position with certain verb forms ending in unacceptable clusters. Those verb forms belong to the 2nd, 3rd, and 4th conjugation classes, and are inflected for 3SG/PL present indicative: /dɔrm/ > [dɔ́:rmɐ̲] 'sleep.PRS.IND.3SG/PL'. Evidence that [ɐ] is not a morpheme comes from the fact that 3SG/PL present indicative verbs from the same verb class that end in a single consonant do not have a final vowel: /fnɪs/ > [fnɪs] 'finish PRS.IND.3SG/PL'. (See Aronoff and Repetti 2021 for more details.)

Classical Arabic does not allow syllable onset clusters. In order to avoid them, the default epenthetic vowel [i] is inserted: /smaʕ/ > [ʔi̲smaʕ] ‘listen!’, /wad͡ʒadat l-bajt/ > [wad͡ʒadati̲lbajt] ‘she found the house’, /ʕan l-kita:b/ > [ʕani̲lkita:b] ‘from the book’ (Robert Hoberman, personal communication). Consonantal prefixes in verbal paradigms produce another context for epenthesis, but in this environment we never find an epenthetic [i]. Instead, the vowel inserted between the consonantal prefix and the first consonant of a verb stem depends on the class of the verb: [a] or [u], but never [i]. If the stem belongs to classes 2, 3, and 4 (4a-c), we find [u]; otherwise, the inserted segment is [a] (4d). Note that these vowels do not appear in other contexts, where the general default epenthetic vowel [i] is inserted (/smaʕ/ > [ʔi̲smaʕ] ‘listen!’).

(4) Classical Arabic:

(a) /t-darris/ → [tu̲darris] ‘you teach’ (class 2)

(b) /t-sa:biq/ → [tu̲sa:biq] ‘you race’ (class 3)

(c) /t-rsil/ → [tu̲rsil] ‘you send’ (class 4)

(d) /t-smaʕ/ → [ta̲smaʕ] ‘you hear’ (class 1)[7]

Moroccan Arabic, a modern Arabic variety, has two epenthetic vowels — [ə] and [i] — whose distribution is morphosyntactically conditioned (Noamane 2018). Epenthetic [ə] can be considered the default used to syllabify impermissible sequences of consonants: /ktb/ > [kt̲əb] ‘to write’. Epenthetic [i] is inserted only with geminate-final verbs inflected for past tense: /sədd + ti/ > [sədd̲iti] ‘close’. Here again, insertion is triggered phonologically, but the quality of the inserted segment is determined by morphosyntactic considerations.

Hungarian employs two epenthetic vowels to repair illicit sequences.[8] In the verb system this is done in a particularly complex way: the distribution of epenthetic [o] and [a] depends on the properties of the preceding morpheme. The template for Hungarian verbs is STEM – TENSE/MOOD – PERSON/NUMBER, with the linear organization resulting in the environments in (5); TENSE/MOOD is empty in the present tense (5a).

[7] There are 15 classes, of which 10 are productive, and of these only classes 2, 3, 4 take [u], all the rest take [a]. Thanks to Robert Hoberman for pointing this out.

[8] The role of vowel harmony in the processes discussed are beyond the scope of this paper.

(5) Hungarian

	STEM	TENSE/MOOD	PERSON/NUMBER	
(a)	-C_{stem}	Ø	$C_{person/number}$ #	[o]-epenthesis
(b)	-C_{stem}	$C_{tense/mood}$	$C_{person/number}$ #	[a]-epenthesis

The examples in (6) show a partial paradigm for a verb stem with a final consonant cluster: *áld* 'bless' (Fowler 1986: 4).[9] For verbs ending in a consonant cluster and followed by a PERSON/NUMBER suffix starting with a consonant, the epenthetic vowel is [o], as in (6a) (see also (5a)). But if there is a TENSE/MOOD suffix after the verb stem, then the epenthetic vowel must be [a] (6b) (see also (5b)).[10]

(6) Hungarian

	1SG.DEF /m/	1SG.DEF /d/	2PL.INDEF /tok/
(a) PRESENT	áld-o-m	áld-o-d	áld-o-tok
(b) PAST	áld-ott-a-m	áld-ott-a-d	áld-ott-a-tok
SUBJUNCTIVE	áld-j-a-m	áld-j-a-d	áld-j-a-tok
CONDITIONAL	áld-an-á-m	áld-an-á-d	áld-an-á-tok

It is evident that the quality of the epenthetic vowel in Hungarian is not determined by phonology alone but also by morphosyntactic conditions. These morphosyntactic conditions are almost bewilderingly diverse, but the distribution is entirely regular once the morphosyntax is factored in.

It has already been noted (§3) that Mohawk uses three epenthetic segments to repair phonologically illicit strings (Michelson 1989; Rawlins 2006: 11): [i] and [e] are used in different phonological contexts, and [a] appears in a particular morphosyntactic position to repair a phonologically illegal sequence. We find [a] used between a consonant-initial verb stem and a

[9] Fowler (1986: 8) suggests that TENSE/MOOD suffixes are lowering, in the same way that certain lexical stem classes discussed in §5 are described as lowering.

[10] There is a great deal of variation, both intra- and inter-speaker: áldottam / áldtam; küldném / küldeném (küld 'send'). Thank you to Robert Vago for pointing this out.

preceding consonant-final noun stem that has been incorporated into the verb (C_N# #C_V) (Rawlins 2006: 11).

(7) Mohawk:

(a) /hr-atʌ-yen-rho-s/ → [ra.tʌ.ye.nə́h.rhos]

MA-SRF-oil-spread-HABITUAL

'he is greasing up (lit. oil-spreading)'

(b) /k-r-kw-as/ → [kerə́kwas]

1SG-fill in-UNDER-HABITUAL

'I take it out of something'

The epenthetic [a] is also called a joiner vowel and is glossed as JOIN in the Iroquoian literature. However, as Michelson (1989) and Rawlins (2006) show, underlyingly it is not part of the word, and its appearance is predictable by phonological and morphological factors.

Lastly, we consider the Romance variety spoken in the province of Padua in northern Italy, which provides another example of a language in which the choice of epenthetic segment is determined by its morphosyntactic position (Aronoff and Repetti 2021, Cardinaletti and Repetti 2007, 2008). Paduan uses epenthetic [e] as the default vowel. In (8) we see that its position is determined by constraints favoring adjacent host and clitic (Bonet and Lloret 2005) and constraints on permissible coda consonants: /l/ is an acceptable coda (8a), but /t/ is not (8b).

(8) Paduan: (a) /l maɲa/ > [el máɲa] 'he eats'

he eats

(b) /t maɲi/ > [te máɲi] 'you eat'

you eat

However, if and only if an epenthetic vowel is needed at the right edge of a Phonological Phrase consisting of a verb + pronoun, epenthetic [o] is used instead (9a-b). Its position does not vary

because neither /l/ nor /t/ are permissible in final position; the only word-final consonant Paduan allows is /n/ (Zamboni 1974: 40, 1981: 34).[11]

(9) Paduan: (a) /maɲa l/ > [máɲe lo] ‘does he eat?’
eats he
(b) /maɲi t/ > [máɲi to] ‘do you eat?’
eat you

We have seen how an epenthetic vowel's quality might be determined by its morphosyntactic position. In the next section we present cases where the choice among epenthetic segments is lexically determined.

5. Non-Canonical Epenthesis: Lexical Conditioning

We now introduce cases of “non-canonical epenthesis”, or phonological repair processes with lexical conditioning, where the choice among epenthetic segments is lexically determined. When a non-canonical epenthetic segment is linked to a specific sign (affix, function word, lexeme), and deployed in restricted contexts, that segment has been referred to as a “ghost segment” (Archangeli 1991) or “latent segment” (Zoll 1996). The presence of a ‘ghost’ “is largely predictable from prosodic and cluster conditions in a language, but ghosts are distinct from canonical epenthetic segments in that the quality and/or underlying distribution are idiosyncratic” (Zoll 1996:25, see also Zimmermann 2019).[12] While the literature on ghosts is extensive, we limit our discussion to a small number of representative cases.

The wide range of epenthetic consonants in Persian has been the topic of many investigations (Kalbasi 1992; Kambuziya 2007; Naderi and van Oostendorp 2011; Sadeghi 2002). It is generally accepted that the phonologically default epenthetic consonant in Persian is [ʔ], which

[11] See a similar analysis of the Italian masculine singular definite article in Repetti (2020).

[12] Lindsey (2019: 1) describes ghosts as “phonological elements, whether consonants, vowels, features, or moras, that surface or delete in phonologically predictable contexts… [T]he quality or underlying distribution of these elements is idiosyncratic or unpredictable, which differentiates these elements from canonical epenthetic or syncopic elements.”

fills the onset position word-initially (10a), word-medially (10b) and before certain suffixes (10c) (Kambuziya 2007; Naderi and van Oostendorp 2011).

(10) Persian: (a) /asr/ → [ʔ̲asr] ‘era’
(b) /video/ → [videʔ̲o] ‘video’ (also allows epenthetic [j])
(c) /seke-i/ → [sekeʔ̲i] ‘a coin’ (also allows epenthetic [j])

Here we focus on [g] and [j], which are the most frequent epenthetic segments besides the default glottal stop. The insertion of [j] is conditioned by the presence of the Ezafé marker (EZ).[13] If hiatus results from the addition of the Ezafé suffix, the glide [j] is inserted, as in the first word in (11a). If hiatus is not formed, as in the second word in (11a) and in (11b), or if the suffix is not the Ezafé marker (see (10c) above), the glide is not present.

(11) Persian: (a) mɑhi-j̲-e sijɑh-e kučulu
fish-j-EZ black-EZ little
‘the little black fish’

(b) medɑd-e sijɑh
pencil-EZ black
‘black pencil’

In (12) there are two instances of [j], both of them intervocalic. In (12a) the [j] is before an Ezafé marker, and the [j] in (12b) is before an adjective-forming suffix. Note that the [j] in (12b) can be substituted with the default glottal stop, but not the [j] in (12a) (cf. Kambuziya 2007; Sadeghi 2002; Naderi and van Oostendorp 2011; Moradi 2017).

[13] Ezafé (EZ) literally means ‘addition’. Traditional grammarians use the word Ezafé or ‘Horuf-e Ezafé’ for case assigning pre/adpositions including *az, dar, be, ba, -ra*, and Ezafé *-e*. Note that other prepositions like *kenar, zir*,… take Ezafé before the nominal complement that follows them. The marker is an unstressed *–e* which joins elements within and across phrases, as in (a) and (b).

(a) ketab-e Sina
book-EZ Sina
‘Sina’s book’

(b) sib-e sorx-e Hava
apple-EZ red-EZ Eve
‘Eve’s red apple’

(12) Persian: (a) pɑrt͡ʃe-j/*ʔ-e (b) pɑlto-j/ʔ-i
fabric-j-EZ overcoat-j/ʔ-ADJ
'the fabric suitable/used for making an overcoat' (Rahbar 2012: 120)

Another commonly inserted segment in Persian is [g], appearing between words ending in [e] and one of the suffixes in (13).

(13) Persian:	(a) noun-forming /-i/	/suxte i/ → [suxtegi]	'scald'
	(b) adverb/adjective marker /-ɑne/	/bat͡ʃe ɑne/ → [bat͡ʃegɑne]	'childish/ly'
	(c) plural marker /-ɑn/	/bande ɑn/ → [bandegɑn]	'servants'

Persian has different kinds of /i/ suffixes: noun-forming /i/ ((13a) and (14a)), indefinite marker /i/ (14b), and 2nd person singular /i/ in verbs (14c). The /i/ with which [g] appears is the first one, although there are rare instances where the adjective-forming suffix also takes epenthetic [g]: /hafte i/ → [haftegi] 'weekly' or [xanegi] 'homemade' (Rahbar 2012: 312).

(14) Persian: /ɑmɑde i/ 'ready' + suffix →
(a) noun-forming /i/: [ɑmɑdegi] 'readiness'
(b) indefinite /i/: [ɑmɑdeʔ/ji] 'ready.INDF'
(c) 2nd singular /i/: [ɑmɑdeʔ/ji] 'are you ready?'

Hungarian also has non-canonical epenthetic segments associated with specific suffixes and lexemes. We saw above (§3.1) that Hungarian syllabifies illicit consonant sequences using one of two epenthetic vowels: [a] and [o]. Within the verb system, the choice of vowel depends on the morphosyntactic context and nature of the adjacent morphemes. Within the nominal system, it depends on the specific noun lexeme or individual suffix.

According to Grimes (2003), [o] is the default epenthetic vowel in Hungarian, but [a] is epenthesized in a large, closed class of noun stems, which Kornai (1991) calls "lowering stems". In (15a) we see that the vowel-final noun stem *hajó* does not condition epenthesis when a consonantal suffix is added. In (15b) and (15c), consonant-final stems followed by consonantal suffixes require epenthesis:sometimes default epenthetic [o] is used (15b), and sometimes non-

canonical epenthetic [a] is used (15c). Both stems in (15b)-(15c) have a low vowel [a], but the stem in (17b) uses epenthetic [o], while the stem in (15c) inserts epenthetic [a]. (Examples in (15) are taken from Grimes (2003).)

(15) Hungarian

	NOM.PL	ACC.SG	POSS.1SG	POSS.2SG
(a) *hajó* 'ship'	*hajó-k*	*hajó-t*	*hajó-m*	*hajó-d*
(b) *család* 'family'	*család-ok*	*család-ot*	*család-om*	*család-od*
(c) *kád* 'tub'	*kád-ak*	*kád-at*	*kád-am*	*kád-ad*

Specific suffixes can also select the non-canonical epenthetic segment. For example, the superessive case marker always triggers [o]-epenthesis (16), even when it follows another suffix, a context in which the insertion of epenthetic [a] is usual (17).[14] (Examples are taken from Grimes (2003) and Fowler (1986).)

(16) Hungarian

	SUPERESSIVE	PL + SUPERESSIVE	POSS.1SG + SUPERESSIVE
(a) *kád* 'tub'	*kád-on*	*kád-ak-on*	*kád-am-on*
(b) *kód* 'code'	*kód-on*	*kód-ok-on*	*kód-om-on*

(17) Hungarian

	ACC	PL + ACC	POSS.1SG + ACC
(a) *kád* 'tub'	*kad-at*	*kád-ak-at*	*kád-am-at*
(b) *kód* 'code'	*kód-ot*	*kód-ok-at*	*kód-om-at*

[14] Fowler (1986) claims that [o] in the superessive suffix is part of the suffix, but Vago (1980) takes [o] to be epenthetic, given the generalization that underlyingly all case suffixes are consonant-initial. Note that with a vowel-final noun, no epenthesis is necessary: *hajó-n* 'ship.SUPERESSIVE'.

As expected, if the noun ends in a vowel, no epenthesis is needed before the first suffix: *hajó-n* 'ship.SUPERESSIVE', *hajó-k-on* 'ship.PL.SUPERESSIVE', *hajó-m-on* 'ship, POSS.1SG.SUPERESSIVE', *hajó-t* 'ship.ACC', *hajó-k-at* 'ship.PL.ACC', *hajó-m-at* 'ship.POSS.1SG.ACC'.

Perhaps the most-discussed case of ghosts is French liaison, where certain words exhibit the alternation of a lexically specific consonant in pre-vocalic position and zero in pre-consonantal position (18a-b) (Tranel 1996).

(18) French:
(a) [le z̲ ami] 'the friends' [le _ tami] 'the sieves'
(b) [tʁo p̲ eme] 'too loved' [tʁo _ detɛste] 'too hated'
(c) [kafé ameʁikɛ̃̀] 'American coffee'
(d) [ʃɛf kanadjɛ̃] 'Canadian boss'

The situations in which the liaison consonants appear or do not are extremely complex, and we will not go into the details. The points here to note are that: (i) the quality of the consonant is specific to the lexical item; (ii) French tolerates hiatus (20c), so consonant epenthesis in intervocalic position is not obligatory; (iii) the ghost cannot be present in the underlying form of the lexical item in the usual way because, if it were, there would be no reason for its non-realization before a consonant since French tolerates coda consonants (cf. (20d)).

In the Ligurian Romance variety spoken in Miogliola (Ghini 2001) certain vowel-final words exhibit a specific consonant ([t d l ɾ], depending on the lexical item) before a vowel-initial suffix; however, this only happens before derivational suffixes, but not before vowel-initial inflectional suffixes (19).[15]

(19) Miogliola:

	(i) isolation	(ii) derivation	(iii) inflection
(a)	[pé _] 'foot'	[pɛ d̲ ɔ] 'kick'	[pé: _ ɪ] 'foot.PL'
(b)	[kat͡sý _] 'ladle'	[kat͡sy ɾ̲ éŋ] 'ladle.DIM'	[kat͡sý: _ ɪ] 'ladle.PL

[15] Miogliola tolerates word-final consonants, as in [maró:t] 'sick' (which Ghini represents as *maɾó:tᵘ*), [maɾɔtéŋ] 'sick.DIM'

The presence of the non-canonical epenthetic segment is clearly associated with a phonological context, hiatus, but its quality is lexically specified: [d] with 'foot', [ɾ] with 'ladle', etc. It is not realized in all hiatus contexts (21iii), but is limited to derivation (21ii).

6. Previous Analyses of Non-Canonical Epenthesis

In §4 we saw how non-canonical epenthetic segments are deployed in various morphosyntactic environments to repair a phonological violation, and in §5 we saw how they can be linked to specific items. In this section we review briefly previous analyses of these segments within a framework of rules and representations, as cases of allomorphy, of "weakly active segments", and as non-canonical epenthetic segments.

6.1 Rules and Representations

A rule-based approach has been applied to many of the cases presented above. For example, the Brazilian Portuguese facts have been formalized within a rule-based framework by Bachrach and Wagner (2007: 8) as: $\emptyset \rightarrow [z] / V[_{affix}\_\_$. Similarly, the French liaison data have been analyzed from the earliest days of generative phonology either as an example of consonant deletion (Dell 1980, Schane 1968) (20a) or consonant insertion (Klausenburger 1974) (20b). The glaring problem is that each rule must be lexically restricted.

(20) French liaison: (a) C → Ø / __ # C

(b) Ø → C / __ # V

Tranel (1996) makes the intriguing proposal that French liaison segments are "connective elements between words rather than parts of words", and they are deployed to satisfy a markedness constraint.

Ghosts, such as French liaison, have also been represented as cases of extrametricality (Clements and Keyser 1983) (21a) or features without a root node (Zoll 1996, Lindsey 2019) (21b).

(21) French liaison:

(a) extrametricality

(b) *full segment* *ghost segment*

We saw that in Miogliola, the consonants [t d l ɾ] are associated with particular roots, and they surface before derivational (but not inflectional) suffixes. A fully fleshed out derivational account of Miogliola non-canonical epenthetic consonants is provided by Ghini (2001), who analyzes the consonant as part of the root (for example, /ped/ 'foot') which can have a derivational suffix added (/ped + ɔ́/ > [pɛdɔ́] 'kick'). Otherwise, the root undergoes consonant deletion and compensatory lengthening (/ped/ > /pe:/) followed by the addition of an inflectional suffix (/pe: + ɪ/ > [pe:ɪ] 'feet'). If no suffixes are added, final shortening applies (/pe:/ > [pe] 'foot').

6.2 Allomorphy

Linguists are trained from an early age to analyze irregular morphophonological phenomena by means of listed allomorphs. In large part, this is because we seek to confine as much irregularity as we can to the lexicon and lexical representations, so that the rules that we value above all else can remain pristine. Listing allomorphs sometimes does make sense, as when the allomorphic alternation is arbitrary or one-off. The English definite article is such a case. In most varieties, <the> shows a special form in hiatus context: [ðə] *dog*, but [ði] *apple*. Here, the hiatus form is restricted to this single element, so the listing makes sense. Other examples include the two forms of the French prenominal adjective 'beautiful' (*beau* + C vs. *bel* + V) (Mascaró 1996), the Korean nominative suffixes (C-*i* vs. V-*ka*) (Sung 2005), and Moroccan Arabic 3rd singular possessive suffixes (C-*u*, V-*h*) (Mascaró 1996). But every lexically listed allomorph is, by definition, an arbitrary singularity in the most basic Saussurean sense. Once a phenomenon recurs, the listing of allomorphs gets in the way of detecting a pattern behind the recurrence. When a number of items share the same allomorphic alternation, each listed allomorph is a lost generalization, and the numbers can mount quickly. Allomorphy does exist, and when there is no pattern to the alternating forms we must list the contextually limited allomorph. But we must take great care.

Consonantal prefixes in verbal paradigms in Classical Arabic can be considered as a case of allomorphy: either verb allomorphy where every verb stem has two allomorphs (22a), or prefix allomorphy where person-prefixes have two allomorphs each (22b) (Fischer 2002: 116-117).[16]

(22) Classical Arabic:

(a) verb allomorphs: C-initial and V-initial

/smaʕ/, /asmaʕ/	(class 1, 5-15)
/darris/, /udarris/	(class 2)
/xa:bir/, /uxa:bir/	(class 3)
/ʔarsil/, /ursil/	(class 4)[17]

(b) prefix allomorphs: Ca and Cu

1.SG	/ʔa/ (class 1, 5-15)	/ʔu/ (class 2-4)
1.PL	/na/ (class 1, 5-15)	/nu/ (class 2-4)
2.SG, 2.DU, 2.PL, 3.FEM.SG, 3.FEM.DU	/ta/ (class 1, 5-15)	/tu/ (class 2-4)
3.MAS.SG, 3.MAS.DU, 3.PL	/ja/ (class 1, 5-15)	/ju/ (class 2-4)

But all sets of allomorphs would have the same conditions on their distribution, so listing the allomorphs hides the pattern, resulting in unnecessary redundancy.

Another possible case of allomorphy involves Catalan (Bonet et al. 2007, Artés 2016) where masculine nouns are realized with an [u] (or [o]) to avoid a sequence of sibilants that would be created after adding the plural suffix /s/ to a sibilant-final noun or adjective. In Catalan, the default epenthetic vowel is [ə, e, i] (depending on the variety) (23c), and [u]/[o] is used only in contexts to resolve "the OCP problem posed by sequences of sibilants" (23b) (Bonet et al. 2007: 916).

[16] McCarthy (1979, 1981) adopts an allomorphic treatment of the prefixes, whereby the subject marker is consonantal (1979: 296) and the systematic variation in vowel quality is associated with the binyanim (1979: 285).
[17] The imperative has its own form in class 4 (Robert Hoberman, personal communication).

(23) Catalan: (a) [gat] / [gat_s] ‘cat (MAS.)/cats’
(b) [gos] / [gosus] ‘dog (MAS.)/dogs’
(c) [templə] / [templəs] ‘temple (mas.)/temples’

Bonet et al. (2007: 918) propose that “an additional property of the lexical representation of allomorphs… [is] the lexical ordering of allomorphs,” or ranked allomorphs. In this example, that would mean {Ø>u>ə} for masculine nouns and adjectives, with the choice of gender allomorph selected from the constraint ranking.

The patterns in the San Marino verb paradigms have been described as examples of allomorphy: [ɪ] as the 1SG and 2SG phonologically conditioned allomorph of Ø, and [ɐ] and Ø are allomorphs of 3SG and 3PL (Michelotti 2008). Many linguists (Benincà 1983, Benincà and Vanelli 1982, Munaro 1999, Poletto 2000, Zamboni 1974) argue that the Paduan data also constitute an example of allomorphy: there is a proclitic paradigm and an enclitic paradigm of clitic pronouns. For Hungarian, Törkenczy (2004) and Rebrus and Törkenczy (2011) suggest that allomorphy is responsible for the alternations described above, although they observe that the selection of the allomorphs is morphological rather than phonological.

Similarly, for ghosts, many accounts take the alternant forms to be allomorphic. Tranel (1996) proposes an allomorphy analysis of French liaison, for example, with [le] and [lez] as masculine plural definite article options from which the surface form is selected in the appropriate phonological environment before a consonant- or vowel-initial word, respectively. Törkenczy (2004) and Rebrus and Törkenczy (2011) propose an allomorphic analysis of the Hungarian lowering stems and suffixes. A fairly large number of nominal stems and suffixes take the “wrong” epenthetic vowel, [a] instead of the expected [o], and we must list this fact in the lexical entry for each one of these items; however, since the ‘extra’ form always contains in [a], the following generalization is masked in an allomorphic approach: this same [a] is the default epenthetic vowel in this specific context.

Listing allomorphs is a powerful tool, one that should be used only as a last resort.

6.3 Other Proposals

The phonological principles that account for realization of the non-canonical epenthetic segment have been cast within numerous frameworks, including models using lexically-indexed

constraints (Fukuzawa 1999, Pater 2010), co-phonologies (Orgun 1996, Inkelas and Zoll 2007), syntax-derived prosodic structure (De Jong 1990), and models in which segment weight and constraint weight can vary. Naderi and van Oostendorp (2011) account for the Persian suffixes described above as cases of "latent segments" within an Optimality Theoretic (OT) framework using morpheme-specific constraints.[18] Using a model of Gradient Symbolic Representation within Harmonic Grammar, elements such as French liaison segments are analyzed as "weakly active", so that "they are only partially present in underlying forms" (Smolensky and Goldrick 2016: 2; see also Zimmermann 2019). Zimmermann (2019) proposes French liaison as an example of an "appearing ghost" that only surfaces when its presence results in an optimal structure.[19] She similarly treats the Catalan [u] "as a ghost segment /u/ that only surfaces if it avoids a marked structure or receives lexical support from certain nouns".

The Catalan data are analyzed by others as a morphologically conditioned epenthesis (Loporcaro 1997, Artés 2016, Moradi 2017, Aronoff and Repetti 2021). Aronoff and Repetti (2021) extend this analysis to the San Marino and Paduan data, and Petrovic (2018) proposes this for Serbo-Croatian. We pursue this last approach in the next section.

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[18] Non-canonical epenthetic consonants in Persian cannot be considered as part of the stem because their realization is not uniform in identical phonological contexts. For example, [g] is realized after /ɑmɑde/ 'ready' and before the noun-forming /i/ suffix (a), but not before the indefinite or 2SG /i/ suffixes (b)-(c). If [g] were part of the stem, how could we account for its deletion before other suffixes (Rahbar 2012: 341)?

(a) /ɑmɑde i/→ [ɑmɑdegi] 'readiness'
ready-N

(b) /ɑmɑde i/ → [ɑmɑdeʔ/ji] 'ready.INDF'
ready-INDEF

(c) /ɑmɑde i/ → [ɑmɑdeʔi/ 'are you ready?'
ready.2.SG

[19] "Disappearing ghosts" (Zimmermann 2019: 2) can be found in Yawelmani. These are suffix consonants which may appear with biconsonantal roots, but not with triconsonantal roots. While the ghost segment [h] in *-(h)nel* 'consequent passive adjunctive' is realized on the surface by default (a), it is not the case after a consonant (b) since its appearance would create a cluster (Archangeli 1991: 271, Zimmermann 2019: 2).

(a) surfacing: *doso-hnel* 'report-conseq.pass.adjunctive'

(b) disappearing: *hogon-nel, *hogon-hnel* 'float-conseq.pass.adjunctive'

7. A New Analysis of Non-canonical Epenthesis

Epenthetic processes that are conditioned by factors external to phonology proper have been observed in many languages. Steriade (1995) reports on languages with more than one epenthetic vowel, and notes that in many instances these vowels are conditioned morphologically or lexically. Kager (1999: 130) has a similar observation on vowel epenthesis in Mohawk (Michelson 1989; Piggott 1995). Cardinaletti and Repetti (2008) and Repetti (2012, 2020) show [o]-epenthesis in final position in Italian and other Romance varieties spoken in Italy is a kind of "morphological epenthesis" that appears at morphologically salient positions. Aronoff and Repetti (2021) report similar patterns in other Romance languages. Żygis (2010) classifies consonantal insertion into three main categories, i. e., grammatical, prosodic, and phonetic insertions, and notes that grammatical insertions "are conditioned morphologically, syntactically and morpho-syntactically" (p. 112). Despite these observations, most analyses of epenthetic segments have focused on phonological factors to the exclusion of any morphological influences that are, at best, considered as dross that hides the shining gem that is phonological epenthesis.[20]

These cases are mostly brought up as possible counterexamples to the unmarked quality of the epenthetic segment, or the naturalness of phonology (Vaux 2002). While the quality of most lexically- or morphosyntactically-conditioned non-canonical epenthetic segments appear to be arbitrary, in some cases an explanation for their particular quality can be found: in Paduan, [o] is the "morphological free and neutral vowel" in that position (Zamboni 1988: 254); in San Marino, [ɐ] is the most frequent vowel in final position with all 3SG/3PL verbs in all conjugation classes and tenses, aspects, and moods; in Persian (Naderi and van Oostendorp 2011) and Catalan (Loporcaro 1997), the quality can be accounted for historically.[21] Even when such generalizations

[20] This is in line with Zwicky's observation that in analyzing morphology-phonology boundary phenomena, "virtually all analysts have accepted some version of a principle favoring phonological determination of alternants over morphological determination" (Zwicky 1975: 137).

[21] Loporcaro (1997) suggests that the Catalan alternations like [pas]/[pasus] constitute an example of a suffix (/u/) that was reanalyzed as epenthetic. Joseph and Ralli (2021) discuss a case of epenthetic material that was reanalyzed as grammatical. Their example comes from the change in personal endings in the so-called contract verbs that led to cases of vowel hiatus in Modern Greek: e.g., 3sg *e-tímā* > *e-tíma-e*. The palatal glide, that originally was used to repair the situation, developed to a palatal fricative [ʝ], and since the palatal fricative was in complementary distribution with the velar fricative [ɣ], the epenthetic [ʝ] was reinterpreted phonemically as /ɣ/. This phoneme then

hold, we consider them peripheral to the mechanisms that underlie the process of non-canonical epenthesis. In this section, we propose a unified way to account for all cases of non-canonical epenthesis, regardless of the type of conditioning (§7.1), and introduce a formal analysis of such processes as logical transductions on strings (§7.2).

7.1 Proposal

All of the approaches to non-canonical epenthesis that we have considered in §6 share the premise that such inserted material is idiosyncratically associated with particular items, and that the choice of segment for any morpheme (or context) is largely unpredictable. Under any of those approaches, whether a rule inserts or deletes the segment linked to a specific lexical item, or two allomorphs are listed, or the segment is (partially) present in the input, these segments must be linked to a specific lexical item in its lexical entry.

We have observed that a non-canonical epenthetic segment can indeed be associated with a specific item (cf. §4-5), and it is deployed to satisfy a markedness constraint within a restricted context. We illustrate our observation in Table 1, where certain items, whether a specific affix, function word, or lexical word, have a non-canonical epenthetic segment associated with them. That segment is available to satisfy a markedness constraint: to avoid hiatus (*VV), or to avoid a complex syllable margin (*CCC), etc. In some cases, the non-canonical epenthetic segment is unrestricted in its use. For example, in Persian, the non-canonical epenthetic segment [j] is used any time the Ezafé suffix appears in a hiatus context. In other cases, the non-canonical epenthetic segment is restricted. That restriction can be phonological (in Persian, the non-canonical epenthetic segment [g] is used when the noun-forming /i/ suffix follows an [e]-final word) or morphosyntactic (Classical Arabic preposition /min/ uses non-canonical epenthetic [a] only if followed by a definite article).

spread analogically to all cells of the imperfective past, being treated as a morpheme marking imperfective aspect. We see that the grammaticalization cline can interact with the epenthesis cline.

Table 1. Non-canonical epenthesis and lexical items (affix, function word, lexical item)

	Specific item	**Restricted context**	**Non-canonical epenthetic segment**	**Usual epenthetic segment**	**Markedness constraint**
Persian	-e (Ezafé suffix)	n/a	[j]	[ʔ]	*VV
	-i (noun-forming suffix)	with [e]-final words	[g]		
French	le (definite article)	(various conditions)	[z]		*VV
	tro ‘too’		[p]		
Miogliola	pe ‘foot’	with derivational suffixes	[d]		*VV
	kat͡sy ‘ladle’		[ɾ]		

Crucially, however, we extend the proposal, observing that non-canonical epenthetic segments can be associated not only with specific items, but often with specific morphosyntactic categories, such as all suffixes, particular classes of nouns or verbs, or morphosyntactic positions. Once again, the non-canonical epenthetic segment is available to satisfy a phonological markedness constraint. For example, in Brazilian Portuguese, a non-canonical epenthetic segment [z] is deployed with all suffixes that create a hiatus context; in Catalan, the non-canonical epenthetic segment [o]/[u] is associated with masculine nouns and used to avoid adjacent sibilants. We illustrate our analysis in Table 2.

Table 2. Non-canonical epenthesis and morphological or morphosyntactic categories or positions

	Specific morphosyntactic category	**Non-canonical epenthetic segment**	**Usual epenthetic segment**	**Markedness constraint**
Brazilian Port.	suffixes	[z]	[j]	*VV
Serbo-Croatian	/e/-final neuter nouns	[t]	[j]	*VV
Catalan	MAS. nouns	[o]/[u]	[ə]/[e]/[i]	*ss
San Marino	3SG and 3PL verbs	[ɐ]	[ɪ]	*CC#
Classical Arabic	class 1, 5-15 verbs	[a]	[i]	*CC#
	class 2-4 verbs	[u]		
Paduan	enclitic pronouns	[o]	[e]	*C#

What exactly are these non-canonical epenthetic segments? A good parallel is the system of theme vowels found in many Indo-European languages and best-known to school-goers from Latin and its descendant Romance family members. While some, notably Bermúdez-Otero (2013), see theme vowels as part of the stem of a noun or verb, most treat them as conjugation-class markers. So, Latin verbs fall into four conjugation classes, each characterized by a theme vowel (a:, e:, e, or i:), which follows the stem, as in (24):

(24) am-a:-v-i:
love-THEME-PERF-1.SG.ACT.IND

The problem is that not all forms of all verbs show the theme vowel. Most second (e:) conjugation verb forms have no theme vowel, and it is not at all clear that the third conjugation

has any theme vowel at all (since its quality varies among e, i, and u). Most modern analysts follow Matthews (1972) in treating the conjugation classes as abstract attributes of the verbs. The theme vowels are then inserted as needed into the three verb stems by the realizational morphology. Nominal inflection works similarly, with each declension selecting a theme vowel or not (a, o, none, e, or u). Greek has three declensions (a, o, and no vowel). The relation between declension class and gender in these languages is complex, one of many reasons for also treating nominal gender as an abstract property (Aronoff 1994).

We propose to treat non-canonical epenthetic segments as triggered by abstract properties of lexical items and morphosyntactic categories in a similar fashion. In our framework a non-canonical epenthetic segment is not part of the underlying representation of the lexical item, but triggered by an idiosyncratic feature of a lexeme, morphological entity, or morphosyntactic category. This captures the intuition that the non-canonical epenthetic segment is "only partially present in underlying forms" (Smolensky & Goldrick 2016: 2). Under our analysis, the segment itself is not present; rather, its trigger is. Also, the fact that some of the triggering elements are not lexical items but rather more abstract entities, makes it impossible to resort to allomorphy in many cases. No allomorphic solution can express the fact that Brazilian Portuguese epenthesizes /z/ rather than /j/ only between morphemes.

Most importantly, the analysis allows us to tease apart the fact of epenthesis, which is phonologically driven, and the specific identity of the epenthetic segment, which is morphologically or morphosyntactically or lexically specified. We can now have our cake and eat it too. To our knowledge, no other analysis succeeds in this. While our approach is reminiscent of the rule features of early generative phonology (Chomsky and Halle 1968), which appeared to be overly powerful, recent developments in formal linguistics have shown that these fears were unwarranted, as we will now show.

7.2 Formalization

Given the nature of the processes that this paper focuses on, any formalization must allow the system to be sensitive to lexical, morphological, morphosyntactic and phonotactic conditions. Allowing for rules to be conditioned by non-phonological factors rules out a single-level, strictly modular, purely phonological framework that forbids interaction with lexical, morphological, and syntactic information. Rule features and their companion readjustment rules have been much

criticized for their excessive ability to turn any string into any other (Aronoff 2012). In this section, we show that rule features can be implemented within a highly restricted formal framework with limited mathematical power.

We conceptualize processes like non-canonical epenthesis as transductions on strings. This captures the observation that, in terms of their strong generative capacity, morphology and phonology are at most regular on the Chomsky hierarchy (requiring constant memory for computation, regardless of the size of the input), i. e., that morphological and phonological processes can be modeled with regular languages (Karttunen et al., 1992).

To that end, we use Boolean Monadic Recursive Schemes (BMRS), a framework introduced by Bhaskar et al. (2020) and Chandlee and Jardine (2021) as a formalism that can capture both linguistically significant and computational generalizations. BMRSs implement predicates that identify particular structures in either the input or output; such predicates are ranked hierarchically, and this ranking is captured by a simple "if–then–else" syntax. This is a way to capture the linguistic intuition that output forms are produced via a set of ordered, embedded, violable conditions (similar to OT constraints). All logical relations/operations are expressible via that syntax.

The primitives of BMRSs are the boolean values ⊤ and ⊥ (true and false, respectively), and a finite set of monadic predicates *P(x)* – predicates that take a single argument *x* and return ⊤ or ⊥. The alphabet Σ is a finite set of symbols; it represents the union of all necessary symbols, which for us are the set of (phonological) segments (like a or z), morphosyntactic and lexical features (like {m} for the masculine gender, or {pl} for the plural number), and the morpheme boundary symbol +. For all symbols in Σ, there is a set $\mathcal{I}$ of input predicates, and a set $\mathcal{O}$ of output predicates (25):

(25) $\mathcal{I} = \{a_i(x), ..., z_i(x), \{m\}_i(x), ..., \{pl\}_i(x), ..., +_i(x)\}$
$\mathcal{O} = \{a_o(x), ..., z_o(x), \{m\}_o(x), ..., \{pl\}_o(x), ..., +_o(x)\}$

The variable *x* is a term; *p(x)* is a term referring to the predecessor of *x*, and *s(x)* is a term referring to the successor of *x*. Strings in Σ are identified with structures of the form in (26), where the domain *D* is a finite set of indices, and each character $\sigma \in \Sigma$ has σ_n as the unary relation $\sigma_n \subseteq D$ selecting the indices that that segment occupies.

(26) $\mathbf{S} = \langle D; \sigma_1, \sigma_2, \ldots, \sigma_n, p, s \rangle$

$D = \{1, 2, \ldots, n\}$

Consider some examples drawn from previous sections. We have shown in (2) that Catalan masculine noun stems ending in /s/ cannot directly take the plural suffix /s/; disallowed */ss/ sequences are repaired via [u]-insertion between the two sibilants. To take a concrete example, we represent the input and output strings of [gosus] 'dogs' in Table 3:

Table 3. Input and output strings of Catalan [gosus] 'dogs'

	1	2	3	4	5
input	{m}	{m}	{m}		{pl}
	g	o	s	+	s
output					
	g	o	s	u	s

The insertion of [u] in Catalan /gos + s/ → [gosus] 'dogs' can be formalized by specifying the conditions under which the morpheme boundary symbol + can be rewritten as u.[22] Assuming that every segment of /gos/ is associated with the masculine gender feature {m}, in the definition of $u_o(x)$ in (27) we provide the conditions under which u appears in the output structure.

(27) $u_o(x) =$ if $+_i(x)$ then

if $\{m\}_i(p(x))$ then

if $\{pl\}_i(s(x))$ then

if $s_i(p(x))$ then $s_i(s(x))$

else $u_i(x)$

[22] Any input symbol in the alphabet Σ can be rewritten as any output symbol. Naturalness conditions are not overarching principles that constrain how transformations can be defined – such constraints are introduced in predicate definitions (i.e., *ss = "if $s_i(p(x))$ then $s_i(s(x))$" in (29)). In examples like the one in Table 3, the morpheme boundary symbol is there to define the locus of "if $s_i(p(x))$ then $s_i(s(x))$", and is not present in the (phonological word) output.

These conditions are ordered in such a way that the evaluation of one condition (⊤ or ⊥) can determine whether or not another one will be considered at all. Consider the first line of (27), repeated as (28) below.

(28) $u_o(x)$ = if $+_i(x)$ then

The evaluation of anything that comes after this condition is directly dependent on the evaluation of $+_i(x)$, that is to say, whether the position under consideration is occupied by a morpheme boundary + . Only if this is true do we consider the following line, repeated below as (29).

(29) if $\{m\}_i(p(x))$ then

The evaluation of $\{m\}_i(p(x))$ will return ⊤ only if the position directly preceding *x* (which we have determined is occupied by +) contains a segment that is marked for masculine gender. In Table 3 we have shown that we assume that all segments belonging to the realization of a masculine stem will bear a corresponding gender diacritic. If $\{m\}_i(p(x))$ evaluates to ⊤, the evaluation of the following line – repeated below as (30) – is considered.

(30) if $\{pl\}_i(s(x))$ then

This statement captures the generalization that only suffixes bearing the plural number diacritic {pl}, when added onto masculine stems, can trigger [u]-insertion. If this condition is also met, the following line (repeated below as (31)) is evaluated.

(31) if $s_i(p(x))$ then $s_i(s(x))$

The statement in (32) is a formalization of the */ss/ constraint: if (28), (29) and (30) evaluate to ⊤, there must also be an s in the input structure directly preceding the morpheme boundary + , and an input s directly following it.

Finally, if the predicate $+_i(x)$ in (28) (i. e., the first line of (27)) evaluates to ⊥, we skip directly to the last line of (27), repeated below as (32). In other words, if the position *x* under consideration is not occupied by a morpheme boundary + in the input, the only condition that could trigger an occurrence of an output u is the evaluation of $u_i(x)$ – i. e., the presence of an input u in the same position. The faithful output of any input u is thus ensured, and this is the most general, default condition on any such output symbol – parallel to low-ranked IDENT constraints in OT, for instance.

(32) else $u_i(x)$

Let us now consider an example of morphologically conditioned epenthesis in a different language. In Serbo-Croatian, a [t] is inserted between an [e]-final neuter stem and a vowel-initial case suffix. In Table 4, the genitive singular form of *tele* 'calf' is represented as the string tele+a in the input, which is output as teleta.

Table 4. Input and output strings of the genitive singular form of Serbo-Croatian *tele* 'calf'

	1	2	3	4	5	6
input	{n}	{n}	{n}	{n}		
	t	e	l	e	+	a
output						
	t	e	l	e	t	a

In a more specific context than that illustrated in Table 4 – after [me]-final stems – the morpheme boundary + is rewritten as n, not t. We provide the genitive singular form of *breme* 'burden' as an example in Table 5.

Table 5. Input and output strings of the genitive singular form of Serbo-Croatian *breme* 'burden'

	1	2	3	4	5	6	7
input	{n}	{n}	{n}	{n}	{n}		
	b	r	e	m	e	+	a
output							
	b	r	e	m	e	n	a

Similarly to what we did for Catalan above, we rewrite the morpheme boundary symbol + as either t (in the more general context, for any [e]-final stem), or n (in a more specific context, for [me]-final stems). As there are two possible epenthetic consonants here, the definitions of both $t_o(x)$ and $n_o(x)$ will start in the same way – by identifying the context that calls for consonant insertion (vowel hiatus across a morpheme boundary, with a neuter stem). Specifically, a morpheme boundary + in Serbo-Croatian is "rewritable" if the preceding segment is associated with the neuter gender feature {n}, provided that that segment is e, and that the following segment is a vowel. [n]-insertion is modeled as in (33), and [t]-insertion as in (34). The hierarchically ordered statements in the definitions of $n_o(x)$ and $t_o(x)$ lay out the conditions under which n or t can surface in the output. We first define [n]-insertion as the more specific case of insertion – for all "rewritable" morpheme boundaries, it must also be true that they are directly preceded by m in order to be output as n.

(33) $n_o(x) =$ if $+_i(x)$ then
if $\{n\}_i(p(x))$ then
if $e_i(p(x))$ then
if $vow_i(s(x))$ then $m_i(p(p(x)))$
else $n_i(x)$

[t]-insertion is then defined as the more general insertion pattern – it applies for any "rewritable" morpheme boundary that does not end up being rewritten as n:

(34) $\texttt{t}_o(x)$ = if $+_i(x)$ then
if $\{\texttt{n}\}_i(p(x))$ then
if $\texttt{e}_i(p(x))$ then
if $\text{vow}_i(s(x))$ then
if $\texttt{n}_o(x)$ then $\bot$ else $\top$
else $\texttt{t}_i(x)$

This reflects the idea that [n]-insertion in Serbo-Croatian occurs in a subset of contexts normally resolved by [t]-insertion. In other words, [t] is the default choice for morphological epenthesis after [e]-final stems, and that choice is overridden only by a subset of [e]-final stems – those that are [me]-final, which prefer [n]-insertion.

The predicate $\text{vow}_i(x)$, invoked in (33) and (34) above, is a user-defined predicate; its definition can be found in (35) below. $\text{vow}_i(x)$ returns $\top$ only for the members of the Serbo-Croatian vowel inventory.

(35) $\text{vow}_i(x)$ = if $\texttt{a}_i(x)$ then $\top$ else
if $\texttt{e}_i(x)$ then $\top$ else
if $\texttt{i}_i(x)$ then $\top$ else
if $\texttt{o}_i(x)$ then $\top$ else $\texttt{u}_i(x)$

Note that the terms in (35) can be reordered in any way. Standard logical disjunction could also be used (i. e., $\texttt{a}_i(x) \vee \texttt{e}_i(x) \vee \texttt{i}_i(x) \vee \texttt{o}_i(x) \vee \texttt{u}_i(x)$) as it is equally expressive (Chandlee and Jardine 2021, Moschovakis 2018); here we choose to use the 'if–then–else' syntax consistently.

Finally, we also need to be able to handle phonological epenthesis of [j] in vowel hiatus resolution, where one of the vowels is [i]. This is a purely phonological process, which does not depend on morphosyntactic or lexical conditions. At this point we abstract away from further constraints specific to phonology (e.g., at which point syllable structure is introduced, or whether glide epenthesis is motivated by a missing onset consonant), and only show how glide insertion between two vowels can be modeled with BMRS.

As is often the case with phonological epenthesis, no input position can be defined for the epenthetic segment; we therefore need a larger *copy set* of output positions, so that the inserted glide can occupy one of them. A copy set of size 2 (36) suffices here; Serbo-Croatian *na*[j]*ivan* 'naïve' is illustrated as an example in Table 6.

(36) $C = \{1, 2\}$

Table 6. Input and output strings of Serbo-Croatian [najivan] 'naïve'

input

	1	2	3	4	5	6
	n	a	i	v	a	n

output

Copy 1:	n	a	i	v	a	n
Copy 2:		j				

We follow Bhaskar et al. (2020) in that we maintain that the order of the output copies is fixed – derived from the order on C (36) and the order on the indices in **S** (26). In more straightforward terms, this means that, looking at Table 6, the order of the output copies follows left-to-right, and top-to-bottom. This is done so as to retain the desired computational complexity of the system; for a more formal definition, refer to Bhaskar et al. (2020). For more about the relation between order-preserving logical transductions and one-tape finite-state transducers, see Filiot (2015).

As can be deduced from Table 6, the definitions of all Copy 1 output predicates will simply allow for a faithful output of input segments. $\mathtt{n}_o(x)$, as defined in (33), already allows that (because it ends in "else $\mathtt{n}_i(x)$"); we repeat it as $\mathtt{n}_o^1(x)$ in (37), and define $\mathtt{a}_o^1(x)$, $\mathtt{i}_o^1(x)$ and $\mathtt{v}_o^1(x)$ in (38-40). Assuming that [j] is the only segment inserted via phonological epenthesis, we will only need one Copy 2 output predicate, and its definition is given in (41).

(37) $\texttt{n}_o^1(x)$ = if $+_i(x)$ then
if $\{\texttt{n}\}_i(p(x))$ then
if $\texttt{e}_i(p(x))$ then
if $\text{vow}_i(s(x))$ then $\texttt{m}_i(p(p(x)))$
else $\texttt{n}_i(x)$

(38) $\texttt{a}_o^1(x) = \texttt{a}_i(x)$

(39) $\texttt{i}_o^1(x) = \texttt{i}_i(x)$

(40) $\texttt{v}_o^1(x) = \texttt{v}_i(x)$

(41) $\texttt{j}_o^2(x)$ = if $\text{vow}_i(x)$ then
if $\text{vow}_i(s(x))$ then
if $\texttt{i}_i(x)$ then $\texttt{T}$ else $\texttt{i}_i(s(x))$

Unlike that of segments inserted via conditioned epenthesis, the identity of phonologically epenthesized segments is not arbitrary, or a result of rule inversion (Vennemann 1972): Serbo-Croatian [j]-epenthesis is a case of homorganic glide epenthesis, which is the most faithful epenthesis possible in vowel hiatus where one of the vowels is [i] (Staroverov 2014). We abstract away from further details when it comes to formalizing this, but see Chandlee and Jardine (2021) for how phonological features can be used instead of segments in a BMRS system.

In addition to phonological and morphological conditions, this kind of segment insertion can also be lexically conditioned – the process would apply only in certain lexical items. Let us once again take the example of Miogliola. As already shown in §5, this system has specific consonants for vowel hiatus resolution in specific words. The input and output strings of Miogliola [pɛdɔ́] ‘kick’ (simplified to `pedo` below), derived by adding a derivational morpheme to the stem /pe/ ‘foot’, are shown in Table 7.

Table 7. Input and output strings of Miogliola [pɛdɔ́] ‘kick’

input

1	2	3	4
L	L		der
p	e	+	o

output

p	e	d	o

We assume that both segments that make up the stem /pe/ are lexically specified as L; this diacritic will trigger [d]-insertion only after stems specified as such (and no others), if all conditions are met. Furthermore, for the purposes of this paper, we assume that derivational morphemes differ from inflectional ones in the diacritics they bear – der and infl, respectively. With those representations in place, we can define $d_o(x)$ as in (42) below: lexically conditioned [d]-insertion in Miogliola will happen as a rewriting of an input morpheme boundary + only if a segment lexically specified as L directly precedes, a derivational morpheme directly follows, and both segments on each side of the morpheme boundary are vowels.

(42) $d_o(x) =$ if $+_i(x)$ then
if $L_i(p(x))$ then
if $der_i(s(x))$ then
if $vow_i(p(x))$ then $vow_i(s(x))$
else $d_i(x)$

The rule applies only if all conditions are met. Table 8 exemplifies this with [pe:ɪ] ‘feet’ (simplified to pei below), where an inflectional morpheme is added to the stem /pe/ ‘foot’.

Table 8. Input and output strings of Miogliola [pe:ɪ] ‘feet’

	1	2	3	4
input	L	L		infl
	p	e	+	i
output				
	p	e		i

Finally, we observe that segment insertion can also be syntactically conditioned, in addition to the aforementioned phonological and morphological constraints. As outlined in §4, Paduan [o]-epenthesis is restricted to repairing consonant-final enclitic pronouns at the right edge of a Phonological Phrase consisting of a verb and a pronoun. To formalize this generalization as a process operating over strings, we need to expand our alphabet Σ to contain the right Phonological Phrase boundary]φ. Additionally, we can assume that pronouns come lexically marked with a D diacritic,[23] and verbs are marked with a V diacritic. Abstracting away from stem-internal phonological processes and stress placement, we illustrate the input and output strings of [máɲe lo] ‘does he eat?’ in Table 9, and those of [máɲi to] ‘do you eat?’ in Table 10.

Table 9. Input and output strings of Paduan [máɲe lo] ‘does he eat?’

	1	2	3	4	5	6
input	V	V	V	V	D	
	m	a	ɲ	e	l	]φ
output						
	m	a	ɲ	e	l	o

[23] We assume pronouns are D-heads, hence the choice of diacritic symbol.

Table 10. Input and output strings of Paduan [máɲi to] ‘do you eat?’

input

1	2	3	4	5	6
V	V	V	V	D	
m	a	ɲ	i	t	]φ

output

m	a	ɲ	i	t	o

The conditions on the output of o are then defined in (43). The predicate $\circ_o(x)$ evaluates to ⊤ if the right Phonological Phrase boundary]φ is directly preceded by any consonant other than n, and only if that consonant is also associated with the diacritic D. Otherwise, o can be output only if there is an input o in the position *x* under consideration.

(43) $\circ_o(x)$ = if]$\varphi_i(x)$ then
if $V_i(p(p(x)))$ then
if $D_i(p(x))$ then
if $cons_i(p(x))$ then
if $n_i(p(x))$ then ⊥ else ⊤
else $\circ_i(x)$

In order to define the class of consonants in Paduan, we used a user-defined predicate $cons_i(x)$ in (43) above. Its definition is provided in (44): $cons_i(x)$ returns ⊤ for any consonant that belongs to the Paduan consonant inventory.

(44) $cons_i(x)$ = if $p_i(x)$ then ⊤ else
if $t_i(x)$ then ⊤ else
if $k_i(x)$ then ⊤ else
(…)
if $n_i(x)$ then ⊤ else

(…)
if $w_i(x)$ then ⊤ else $j_i(x)$

All of the different flavors of non-canonical epenthesis can therefore be formalized as logical transductions on strings, which are understood to be augmented with additional lexical, morphological, and syntactic information.

In summary, BMRS can be readily used to model non-canonically conditioned insertion, effectively capturing its formal properties as well as its linguistic substance. Adopting such an approach allows us to directly consider what representations are necessary and sufficient. A system formalized in this way is not directly dependent on naturalness or phonological substance – its purpose is rather to define the necessary conditions on the realization of processes, restricted by their computational complexity. The motivations behind such processes can be varied, but are crucially external to the system that generates them, not central to formalizing them. BMRS makes it possible to precisely and formally separate the purely phonological fact of epenthesis from the conditions under which a particular segment is epenthesized. This separation is our central claim. BMRS is the only formal system in the literature to date that allows for the precise expression of this claim.

8. Conclusions

Our main empirical goal in this work is to show that epenthesis, which is commonly thought of as phonological, can be conditioned by individual lexical items, morphosyntactic features and even construction types. Our aim was to bring together a wide range of cases from many languages of the insertion of meaningless segments that do not follow the traditional purely phonological definition of epenthesis. We go on to show that this separation can be expressed elegantly within a well-defined and highly constrained formal system (BMRS). What epenthesis retains throughout the examples is its dependence on pure form. If what characterizes human language above all else is its double articulation (Martinet 1949), then epenthesis provides a striking demonstration of the persistence, power, and beauty of this property.

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