RESEARCH

What's wrong with being a rhotic?

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The class of rhotics is subject to extensive variation, and a reliable phonetic correlate has not been found. This variation is also why identifying a segment as a rhotic in an unknown language is not a trivial matter. In contrast to other phonological classes whose membership is attributed based on principled criteria, the set of rhotics is arbitrary. This article identifies two properties independent of phonetics which characterize rhotics cross-linguistically PROCEDURAL STABILITY—rhotics that are implicated in phonological processes can vary in a phonetically arbitrary manner without perturbing the process itself—and DIACHRONIC STABILITY: the phonetics of rhotics can vary in diachronic evolution without impact on their phonotactics. On the empirical side the article establishes a cross-linguistic survey of the phonetic variability of rhotics. It is also argued that the phonetic realization of a rhotic may be unpredictable and divorced from its phonological identity and this shows that languages are happy to instantiate an arbitrary phonetics-phonology relationship. Finally, it is argued that rhotics show that the interface which maps phonological objects to their phonetic instantiations is capable of handling an arbitrary relationship. Further, there is no reason to assume that this property of the interface is specific to rhotics; in principle, all phonetic and phonological categories could enter into an arbitrary relationship. This has important implications for theories which seek to impose phonetic or naturalness based constraints on phonology: it is difficult to see how the relationship between a phonetic object which has no obvious articulatory connection to its phonological representation could be considered phonetically natural. Rhotics thus provide support for the view of substance-free phonology whereby phonological objects are devoid of any reference to phonetic categories.

Keywords: rhotics; phonetics; phonology; arbitrariness; phonetics-phonology interface

1 Introduction

The goal of this paper is two-fold: the first is to contribute to the long-standing discussion concerning the status of rhotics. It is argued that membership in the set of rhotics, as presented in previous treatments, is arbitrary (Lindau 1985; Ladefoged & Maddieson 1996; Hall 1997; Walsh Dickey 1997; Scobbie 2006; Wiese 2011; Sebregts 2014). The paper aims to show that in the class of rhotics the phonetic object cannot be predicted from the phonological one, meaning that the *realization* of rhotics is arbitrary, but that phonological theory should assign class membership based on principled criteria. To that end, it provides a definition of rhotics that is not based on phonological representations, but instead on the behavior of members of the set. In particular, the tendency of rhotics to exhibit PROCEDURAL STABILITY—rhotics that are implicated in phonological processes can vary in a phonetically arbitrary manner without perturbing the process itself, and DIACHRONIC STABILITY—rhotics can vary on the diachronic axis without provoking a realignment in a phonological system.

The second goal is to make a novel contribution to phonological theory by exploring the implications of rhotic realizations for phonological theory; notably an argument that for

rhotics the interface between phonetics and phonology is capable of handling an arbitrary relationship between phonological primes and phonetic realizations. It is argued that if phonology is capable of handling such a relationship for one class of sounds, then it is worth asking if such is the case for all phonological objects. Arbitrariness is especially evident in the class of rhotics due to their variable phonetic nature. In this paper rhotics are viewed as an instrument which allows us to shed light on the working of phonology and its interface with phonetics. As such, it is suggested that the need to derive phonetic variability from the phonological representation of rhotics disappears if that variability is the result of the interface between phonetics and phonology.

In contemporary phonology there is a notable division between theories which explicitly incorporate the notion of melodic naturalness—articulatory, distributional, or procedural processes which are notationally straightforward or typologically well attested—into the theory (Chomsky & Halle 1968; Stampe 1973; Hooper 1976; Hayes & Steriade 2004), and those which exclude melodic naturalness from formal theory (Blevins 2004; Hale & Reiss 2008; Reiss 2018), instead relegating apparent generalizations based on naturalness to extra-linguistic domains such as diachronic evolution and the conditions imposed by our biology on what kinds of sounds we can make and perceive.

Any linguist who wishes to subject phonology to the yoke of phonetics[1] is faced with a puzzle: the extraordinary phonetic variability exhibited by rhotics, encompassing a wide range of phonetically diverse sounds; including variation in manner, place of articulation, and voicing across the entire class (see Barry 1997 for a detailed phonetic description of several rhotics). This variation is present not only across languages but often within a single language as well.

The structure of this article is as follows. The first section is a review of the major themes in the literature related to rhotics: their articulatory and acoustic properties, as well as possible phonological representations. It is argued in this section that phonological theory has misrepresented rhotics—a phonological class that is consistently assembled before any kind of primitive definition of a rhotic is given. While it is agreed that rhotic unity must be phonological, how to derive that unity is still not agreed upon, as shown for example in the volume edited by Spreafico & Vietti (2013). The present article argues that there may be no way of deriving rhotic unity via representational models; instead rhotics can be identified by recognizing the way they behave and the role they play within phonological systems. To this end rhotic data from several languages is presented.

The data in this article are well-known, and are assembled with the intention of illustrating a few particular patterns exhibited by rhotics in natural human languages; further, they are used to shed light on workings of phonology and its interface. The rhotic pattern in Brazilian Portuguese (BP) shows a particularly intricate pattern of phonetically disparate allophonic variation. The phonetic variation in BP shows that learners must be able to unite a class constituted of phones with no obvious phonetic relationship; that is, one with arbitrary realizations. A process of retroflexion in two dialects of Norwegian shows that surface forms are meaningless as a predictive tool. In the Frogner dialect of Norwegian there is no source of retroflexion on the surface but retroflexion is transmitted by a phonological process, suggesting that it is only the phonological quality—not the phonetic qualities—of the rhotic that is important. Data from Polish show that phonetic fricatives can be secondary elements in branching onsets. We know from their diachronic identity and from synchronic alternations that they were rhotics in the

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[1] See Bermúdez-Otero (2006) for an overview of various arguments for and against functional principles in phonology.

past. Today, their rhoticness is not recoverable from their surface identity, but their phonotactic behavior reveals it.

The last section explores the implications of the data from the preceding section. It is argued that the relationship between rhotic phonetics and rhotic phonology is best understood in a modular framework where phonology is not bounded by constraints imposed by phonetics, consistent with a substance-free phonology approach. An argument is made that since the interface between phonetics and phonology can handle an arbitrary phonetics-phonology relationship—as it must in the case of rhotics—it makes sense to ask if such is the case for all of phonology, since to imagine otherwise would be to stipulate two sorts of phonological classes: those which are phonetically natural and those which are not. Instead, it is suggested that the locus of apparent phonetic naturalness outside of the phonology, as has been argued elsewhere (for example Blevins 2004; Hale & Reiss 2008).

In this view it is in the interface—phonological spell-out (Scheer 2014)—where phonetic variation is found. Whatever their phonological representation (which likely varies across languages), the only thing phonology sees is that representation: their phonetic realization is invisible to phonology. Introducing spell-out into the phonological architecture means there is no need for establishing a specific rhotic identity in the phonology.

2 The problem with being a rhotic

Wiese (2011: 712) makes an insightful observation regarding sets of rhotics of the sort presented in Lindau (1985) and Ladefoged & Maddieson (1996), to wit that "classification in terms of articulatory categories does not lead to any uniform definition of the class of rhotics. As a result, there is no principled way of excluding other potential sounds." At the root of the problem seems to be the tendency of phonologists to assemble the set of rhotics without any principled criteria for doing so. Instead, it is often non-phonological notions which motivate the inclusion of a segment in the set of rhotics: IPA symbols representing R, orthographic conventions, or diachronic relationships. The result is a set of rhotics which is merely conventional. However, it is clear that the set of rhotics should not be restricted to those segments represented by an <r> in IPA, since at the very least it is easy to see that segments such as the uvular fricative [χ] in French acts like a rhotic, in terms of its phonotactic role.

This leads to the obvious question of just what is a rhotic, and on what grounds can a segment be included or excluded from the set of rhotics? While the analyst may be able to make appeals to notions such as orthography or diachronic relationships in order to constitute the set of rhotics, such diagnostics are unavailable to language learners, who nevertheless must be able to identify a phonological class constituted by a frequently phonetically disparate set of phones. For the language learner, there are no clear phonetic cues that might be exploited for the identification of rhotics. Instead, rhotics can be understood as a phonological class united by their behavior within a phonological system, and their phonological stability despite their phonetic variability: no matter their phonetic instantiation, a rhotic's phonological role remains stable. The consequence of establishing a class of rhotics in accordance with this definition is that there is no correlation between the phonetic object and the phonological object which it instantiates.

This section is a review of different solutions to the problem of being a rhotic. Ultimately I will argue that there may be no way of uniting rhotics via representational models; that is they cannot be understood outside of the role they play within a system. Phonology is conceived here as a system that functions independently from phonetics, in which syllable structure plays a crucial role. A speech sound may have a phonetic identity that does not correspond to its phonological identity, as we will see with rhotics. This conception

of phonology as a symbolic language harkens back to Saussure (1967 [1916]: 168), for whom "[l]a langue est pour ainsi dire une algèbre.[2]"

2.1 The phonetic status of rhotics—a variable identity

Generally speaking, in phonological theory the prototypical natural class is defined by shared properties, typically features with phonetic correlates. Those correlates may be acoustic or articulatory. For rhotics, however, no such classification can be made since rhotics constitute a phonetically diverse class, with no clear phonetic correlate (Lindau 1985; Ladefoged & Maddieson 1996; Walsh Dickey 1997).

In terms of articulation, Ladefoged & Maddieson (1996: 215) describe prototypical rhotics as "trills made with the tip or blade of the tongue (IPA r)." Barry (1997) also argues for the primacy of the trill among rhotics. Boyce et al. (2016) argue that in French, Persian, Malayalam, English, and Spanish, rhotics show consistent pharyngeal constriction in addition to the varying apical articulation. They suggest that this complex articulation, while variable for the anterior articulators, may be a feature of rhotics in general. However, Ladefoged & Maddieson (1996) conclude that neither manner nor place of articulation serve as useful criteria for identifying rhotics. Wiese (2011) is explicit in his agreement, concluding that there are no articulatory features common to rhotics.

Concerning acoustics, Lindau (1985) and Ladefoged & Maddieson (1996) suggest that rhotics share a lowered third resonance formant (F3). This is an adequate description for at least some rhotics, including the /r/ of American English. However, Ladefoged & Maddieson (1996) cite Hausa, Czech, Swedish, French and German as all having relatively high F3 formants for their disparate rhotic phones. Ultimately, Lindau (1985) and Ladefoged & Maddieson (1996: 244) abandon this tack, concluding that a lowered F3 "is thus not a good candidate for a property that unites the rhotic class."

The best phonetic approach seems to be that suggested by Lindau (1985): there is a "family resemblance" between members of the class of rhotics, where each member shares some property with other members of the class, but no single property is shared by them all. Magnuson (2007) expands Lindau's class by including laryngeal and pharyngeal segments. However, phonologically speaking, the family resemblance model is not very satisfying, suffering both from empirical and theoretical problems. For example, in the family resemblance model there is no direct connection between [ɾ] and [x] and yet speakers of Brazilian Portuguese must be able to relate both segments back to a single phonological object, as will be shown. Theoretically, the model is epistemologically problematic: the set of rhotics is assembled first, and then the phonetic resemblances are defined. The family resemblance model has no way of defining what is a rhotic except for relative to each other. This is clear when Magnuson discusses the Beijing Mandarin /r/ (realized as [ʐ])—there is no reason to assume this segment is a rhotic, other than (European) orthography and an underlying IPA transcription which is an r. In other words, the set of rhotics is arbitrary in this framework.

2.2 The phonological status of rhotics—a unified identity

Given the preceding, a perceptual or articulatory account of rhotics as a class based on phonetic properties seems doomed. However there are good reasons to suppose that rhotics do represent a phonologically real object (Lindau 1985; Walsh Dickey 1997; Proctor 2009; Wiese 2011). It follows that it is only phonologically that they can be described as a cohesive class: as Ladefoged & Maddieson (1996) point out, all rhotics behave in a similar fashion phonologically.

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[2] "Language is thus an algebra."

Wiese (2001: 340) summarizes a series of generalizations that describe the phonological class of rhotics. The first property is phonotactic: all rhotics are vowel adjacent and distributed according to a CrVrC pattern. In many languages that allow complex onsets it is common for only rhotics and laterals to be permitted as the second member in onset clusters; and in complex codas as the first member of the cluster. However, there is a crucial exception to this generalization since /r/ is permitted by some languages in syllabic positions, as in English, or as trapped consonants, as in Polish. Rather, what is shared by rhotics is their role as phonotactic sonorants.

Phonetic variability is also a particularly salient characteristic of rhotics. Rhotics frequently alternate synchronically—or in some cases diachronically—with each other. Ladefoged & Maddieson (1996), along with Wiese (2011) cite Persian as an example: this language has trilled phonemic /r/, but has three to four additional rhotic allophones in complementary distribution. A similar argument is put forth by Hall (1997), citing evidence from Assamese, Mundari, Tene, Tukang Besi, and Swedish—all of which have a rhotic phoneme with approximant, trill, and/or flap allophones. Ladefoged & Maddieson (1996: 216) also cite the alternating realizations of rhotics as the most important evidence pertaining to the phonological unity of the class:

> Most important as evidence that they belong in a single class, at least from a phonological point of view, is the fact that rhotics of one type often alternate with other rhotics. In Farsi, /r/, which is a trill in initial position, has a tap allophone in intervocalic position and a voiceless trill variant in word-final position. In Fula, /r/ is realized as an approximant ɹ before a consonant, as a trill elsewhere. In Palauan /ɾ/ is generally a tap in intervocalic and post-vocalic environments but an approximant in initial position; the contrasting orthographic 'rr' is most commonly an approximant with some frication, but its range of variation encompasses trills…

This article will take the position that it is the trill which has been phonologized as the "ur-rhotic", and from which rhotic variation stems.

How can the phonological unity of rhotics be formalized, then? Hall (1997) makes an explicit phonological categorization by assigning the feature [+rhotic] to potential candidates which display allophony, since they pattern together phonotactically, often to the exclusion of other consonants including laterals. Alternatively, for Wiese (2001) the phonological unity of rhotics is a prosodic one: in terms of sonority sequencing, rhotics form a unitary class between laterals and glides. Finally, Walsh Dickey (1997) proposes that the various rhotics cannot be categorized according to features, and it is rather their structure which unites them. In her model, a feature geometric model, rhotics are characterized by having a branching place node, meaning they can be specified both for coronal and dorsal gestures.

These formal representational models of rhotics have been criticized before, notably in Sebregts (2014), who suggests that Walsh Dickey's approach is likely inadequate in terms of the wide variety of rhotic candidates, unable to capture the full extent of rhotic variation. Like wise, Sebregts notes that Weise's sonority based model may not be an empirically valid observation, given that there are languages with glide-rhotic onset clusters. Finally, Sebregts points out that Hall's feature based solution is *ad hoc*, used only for rhotic phones. Furthermore, the feature [+rhotic] says nothing about the phonetic nature of rhotics, though it does accord them a particular status. Yet, phonologically there is nothing particularly special about rhotics which would warrant enlarging the inventory of phonological features; rhotics are sonorant phonemes like any other, their only particularity being their great phonetic variability—their phonological nature is absolutely

conventional. Ultimately, none of the formal, representational based models has been successful in categorizing the class of rhotics.

Sebregts adopts a partially diachronic model for the modeling of rhotics in Dutch, arguing that the class of rhotics may be united by appeals to their shared history. Sebregts builds on the family resemblance model of Lindau and Magnuson by adding a historical dimension in order to unite rhotic candidates, as well as exclude phones which may share articulatory traits with rhotics but are not included in the phonological class. Rennicke (2015) adopts a similar model for rhotic variation in Brazilian Portuguese; in these models the class of rhotics is defined by their phonotactic properties, as well as the historical connections between the sounds that constitute the class.

However, such models lack explanatory power in a synchronic model of phonology. While diachronic explanations are essential in understanding how synchronic patterns came to be, they are irrelevant in understanding synchronic phonology qua computation: speakers do not have access to the historical patterns which gave rise to their languages. In fact, this is the main thrust of the argument in Blevins (2004)—many patterns in language should be excluded from synchronic theory precisely because the locus for their explanation may be found in diachrony. While the analyst can use diachronic relationships and orthographic conventions to muster evidence for the analyses of a phonological class of rhotics, a child learning a language with extensive rhotic variation must be able to reach the same conclusions as the analyst without those tools. As such, there must be more to being a rhotic than just diachronic or orthographic conventions.

Critically, all of these models suffer from a fundamental flaw in that membership in the class of rhotics is assumed before the class is defined: there is no extra-theoretical method of identifying rhotics. For example, Sebregts (2014: 232) faults the feature based model because the feature [+rhotic] could in principle be assigned to any segment, and as such does not constrain the class of potential rhotics: "while the variation is wide, there is no reason to assume that anything, including [f] and [ʔ], could function as /r/." In fact, this criticism misses an important point: since there is no way of identifying what a rhotic is, there is no reason to assume that [f] or [ʔ] could not be rhotics in some language.

The problem we are left with, then, is that we have no way of knowing if a given phone is a rhotic or not, beyond the conventions of the IPA, orthography, or the intuitions of the linguist founded on diachrony—we have no principled criteria for membership in the class of rhotics. This may be because phonological theory is unable to model rhotics in representational terms: there is no one feature or set of features associated with rhotics. This is not a problem for theories which do not require phonological classes to be represented by a universal set of features with phonetic correlates, such as in Boersma (1998), emergent feature theory (Mielke 2008), or some schools of substance-free phonology (Odden 2006; Blaho 2008; Samuels 2011; Iosad 2012).

Indeed, since rhotics show such enormous variation and there are no phonetic clues or representational structure that can be used to identify them, the only way rhotics can be understood is by what Kaye (2005) calls the *epistemological principle*: phonological identity is only recoverable via observation of a segment's phonological behavior, both within the system and in phonological processing. The notion of an identity that hinges on its interaction within the system is part of an essentially structuralist point of view, one that was more or less sidelined by Chomsky & Halle (1968). However, Dresher (2009) for example has convincingly argued that generativism needs to be reconciled with notions of the system in structuralism; what Scheer (2010) calls the interaction of static (the system, inventories, contrast) and dynamic (phonological computation) properties of phonology.

In line with Mielke (2008), rhotics are a *phonologically active class* because they share a phonological identity but this identity is not derived from any shared representational

properties; a phonologically active class is in many cases synonymous with the traditional term natural class but does not imply any shared phonological feature or phonetic trait. This was anticipated by Scobbie & Sebregts (2010) who explicitly argued for an abstract representation of rhotics, not wedded to phonetic substance. Still, there must be a way to identify the segments which belong to this class; the next section will define rhotic class membership.

3 Towards a definition of rhotics

This article has set as one of its goals the establishment of a non-arbitrary basis for constituting membership in the set of rhotics, and has argued that the only way rhotics can be understood is via their phonological behavior, rather than phonetic correlates or phonological representations. This section will explore three aspects of rhotic behavior which form the basis for its coherence as a phonological class (1):

(1) i.   Rhotics behave as sonorants in syllable structure, in a fashion
           that is less restricted than laterals.
     ii. Rhotics tend to be stable in phonological processes.
     iii. Rhotics tend to be stable diachronically.

Each of the characteristics in (1) will be examined in the remainder of this section. In each case, it will be shown that the precise phonetic identity of the rhotic in question is irrelevant.

3.1 On the status of rhotics as sonorants

Wiese (2011) points out that in languages with extensive rhotic variation, variability in rhotics is stable cross-dialectically. In English and German for example, phonetic variability among rhotics is extensive depending on the variety in question but the phonotactic patterning is stable. That is to say that although the phonetic instantiation may be subject to variation, a rhotic always functions phonotactically as a sonorant. French is an illustrative case: in words such as *frelon* [fχəlɔ̃] 'hornet,' despite being a voiceless fricative, [χ] functions as a sonorant and is a permitted segment in complex consonant clusters.[3] Thus, the phonetic identity of the segment does not correspond to its phonological identity.

That the [χ] in French onsets is best analyzed as a sonorant is supported by evidence from French loanwords into Moroccan Arabic (MA) and Berber. Both MA and Berber contain an uvular or velar fricative like in French, as well as a tap. When French words with branching onsets and the fricative are borrowed into MA and Berber, it is systematically the tap that is realized in place of the uvular fricative, instead of the homologous phoneme in MA and Berber (Lahrouchi 2018). Why should speakers choose to replace a sound that is in their phonemic inventory with another?

This choice, far from being arbitrary, is a phonologically motivated one: Arabic and Berber speakers replace the French rhotic not with its *phonetic* twin, but rather with its *phonological* counterpart—a sonorant rhotic whose identity they divine thanks to its phonotactic role, not by its articulatory cues. In MA and Berber, the uvular or velar fricative is phonemically distinct from the anterior tap. Also true is that in both languages, the tap behaves like a phonological sonorant (Dell & Elmedlaoui 2002), while the same is not true of the uvular fricative. Thus a word such as the French *train* [tχɛ̃] 'train' is adapted into MA as [træn] (Lahrouchi 2018). While the phonetic identity of the rhotic changes, its phonological identity does not.

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[3] See for example Carvalho (2017) for an argument supporting the view that sonority is derived from structure.

Crucially to this point, it seems to be true that when there is allophonic variation within a language the phonotactics of the phoneme do not change—the phonological object still plays the same role no matter its actual phonetic realization. As Gussmann (2001: 242) puts it, "the phonological properties of segments are determined not only by an inspection of their phonetic characteristics but also by considering the way they behave in the system of a language. If there is a conflict between the phonetic and phonological clues, it is the latter that get the upper hand." Rhotics can always appear in positions reserved for sonorants,[4] even if it is a non-sonorant realization of the rhotic phoneme.

3.2 Procedural and diachronic stability of rhotics

In this section I will argue that one of the crucial defining characteristics of rhotics is their procedural stability on both the synchronic and diachronic axes. That is to say, in phonetic terms rhotics vary extensively synchronically without altering any phonological processes they may be implicated in. An example of the procedural stability of rhotics is provided by Hall & Hamann (2010), who argue that cross-linguistically, sequences of /rj/ and /ri/ are avoided. Although not all languages are subject to this restriction, where it is active the exact phonetic identity of the rhotic does not matter. The restriction begins life as an articulatory injunction against [rj], but the actual /r/ in question can mutate. Once the restriction is in phonology, the phonetic identity of the /r/ becomes invisible, and the restriction against the forbidden sequence still holds. On the diachronic axis, Scobbie (2006) noted that language change can affect the phonetic identity of rhotics without altering their role as contrastive elements in a system.

The following sections will explore data from a number of languages in order to illustrate the notion of procedural stability. Brazilian Portuguese provides an example of the extent to which a rhotic phone may exhibit allophonic variation while being best analyzed as a singular phonological object. A series of alternations in Norwegian dialects is presented as evidence for the synchronic stability of rhotics in phonological processes. Data from Polish are used to show that diachronic variation in rhotics is also stable, and is further used to show the arbitrary nature of phonetic variation in rhotics.

3.2.1 Rhotics in Brazilian Portuguese

Brazilian Portuguese (BP) is a good illustration of phonetic variability in rhotics since in BP rhotics are subject to a wide variety of social and geographic variation (see Rennicke 2015 for a very thorough overview). Though their exact realization varies widely, in broad terms rhotics behave similarly throughout Brazil (Noll 2008). For example, in the variety spoken in the state of São Paulo, a retroflex approximant [ɻ] appears in place of the final [x] of the variety spoken in Rio de Janeiro, but the phonological system is otherwise unchanged.

BP rhotic realization is characterized by a wide variety of phonetic alternation that is not easily generalized, but that can be phonologically described in a succinct and meaningful fashion. Cristófaro Silva (1998: 51) catalogs the following possible realization of rhotic phones and their contexts in varieties of BP: [ɾ] in intervocalic positions or element of a branching onset, [h], [x], or [ɻ] in intervocalic or syllable initial position, and [h], [x], or [ɻ] syllable finally. In this last context, the two voiceless phones are subject to contextual voicing when preceding a voiced consonant, resulting in [ɦ], [ɣ] respectively.

It is widely accepted among phonologists who work on BP that all rhotic segments are surface realizations of /ɾ/ that vary allophonically depending on their context (Câmara

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[4] Not all sequences of consonants have the same syllabic structure; see Ulfsbjorninn (2017) or Carvalho (2017), for example, for a discussion of the difference between true and bogus consonant clusters.

Jr. 1972; Nevins 2008). Following Cristófaro Silva (1998), the complete distribution of rhotics in one variety, that of Rio de Janeiro, known as *carioca*, is as follows (2):

(2)   a.   [ɾ] following a C in any branching onset or in the intervocalic position:
              praga   [pɾa.ga] 'curse'
              viração [vi.ɾasãu] 'sea breeze'

         b.   [ɣ] preceding a C[+voice] or in the intervocalic position:
              tarde [taɣ.dʒi] 'afternoon'
              barra [ba.ɣa] 'bar'

         c.   [x] word-initially or after a heterosyllabic consonant:
              rio   [xiu] 'river'
              honra [õ.xa] 'honor'

         d.   [x] preceding a C[-voice] or absolute final position:
              porta [pox.ta] 'door'
              mar   [max]   'sea'

Note that the phones in (2a, c) both appear in intervocalic positions: there is a contrast between [ɾ] and [x] here in a handful of lexical items, as in (3):

(3)   a.   carro [ka.xu] 'car'
              mirra [mi.xa] 'myrrh'

         b.   caro   [ka.ɾu] 'expensive'
              mira   [mi.ɾa] 'he or she looks'

As such, the distribution of the rhotic phones is not fully complementary, and an allophonic analysis runs into an obstacle. Câmara Jr. (1972) suggests that [x] in (3a) is the result of an underlying geminate /ɾ.ɾ/ which is subject to two rules in feeding order: a rule of coda velarization which yields […x.ɾ…] and one of debuccalization which yields […x.ɦ…]. The resulting sequence of homorganic fricatives then undergoes assimilation and surfaces as [x]. Subsequent works, including Abaurre & Sandalo (2003); Nevins (2008) and De Souza (2019) agree that whatever the exact mechanism, the pattern in (3) is allophonic with a single underlying phoneme. Given the fact that these words are reflexes of words with historical geminates, this analysis will not be contested here. A similar account for parallel phenomena in Spanish can be found in Harris (1983) and in Mascaró (1976) for Catalan. While the arguments in Harris (1983) based on distributional evidence are quite convincing, all opacity-based objections to such an analysis can of course be raised, but ultimately as far as the particular problem of rhotic variability is concerned are not germane to this paper.

  While the data in (3) show a static distribution of rhotics, [x] and [ɾ] are allophonic variants of a single underlying phoneme—the result of a synchronic process. This is made apparent by a series of sandhi-based alternations in which the rhotic segment is realized as [x] when word final, and as [ɾ] when between vowels (Collischonn 1996) (4):

(4)   a.   amor [amox] 'love'
              cor   [kox]   'color'

         b.   amor antigo [amo.ɾã.tʃigu] 'former love'
              cor escura   [ko.ɾiʃ.kuɾa] 'dark color'

In BP, complex onsets composed of two segments are permitted so long as the second segment is a liquid or a rhotic, as in *praga* [pɾaga] 'curse', *frango* [fɾãgu] 'chicken (food)', or *bloco* [bloku] 'street band.' The segménts in (2), while phonetically disparate, are all

identifiable as rhotics according to the criteria described by Wiese (2001): they pattern phonotactically together as vowel adjacent segments and are permitted as the rightmost element in complex syllabic onsets. It is worth noting however that this is true of the larger class of liquids and glides, and not just a quality unique to rhotics. Instead, their phonological unity as a class is derived from their allophonic relationships—they occupy the same place in the system of contrasts in BP, but vary contextually with each other without causing perturbations in the phonological system.

Furthermore, the phonology of BP is insensitive to the phonetics of rhotic realization. Several conclusions can be drawn from this data. The first is learners must be able to determine that [ɾ] and [x] are related to a single phonological object, and that notions of phonetic naturalness are not useful. They must also be able to do this without the diachronic or orthographic clues that the analyst can employ as means to the same end. Second, BP provides ample evidence that rhotic phonetics are not predictable from the phonological object—what is *phonetically* an obstruent and alternates in voicing according to the environment is in fact a *phonological* sonorant.

3.2.2 Rhotics in Norwegian

Kristoffersen (2000) describes standard Norwegian as having two phonemes, /ɾ/ and /ɽ/. The retroflex flap can also alternate allophonically in some cases with the tap where it is the reflex of Old Norse [rð], but the two are otherwise contrastive.[5] Norwegian is an example of a language in which rhotics play a role in synchronic processes, and the exact surface realization of the rhotic does not seem to be pertinent.

In Norwegian there exists a synchronically active phonological rule[6] which causes the coronal segments /t d n s/ to be realized as retroflex [ʈ ɖ ɳ ʂ] when following /r/, which is then deleted (5) (Stausland Johnsen 2012):

(5)   a.   /nyː/   'new'   + /-t/   NEUT →[nyt]
             /tɑː/   'take (INF)'   + /-də/   'it'   →[tɑːdə]
             /tɑː/   'take (INF)'   + /-n/   'him'   →[tɑːn]
             /tɑː/   'take (INF)'   + /-sæ/   REFL   →[tɑːsæ]

        b.   /bɑːɾ/   'bare'   + /-t/   NEUT →[bɑːʈ]
             /tɑːɾ/   'take (PRES)'   + /-də/   'it'   →[tɑːɖə]
             /tɑːɾ/   'take (PRES)'   + /-n/   'him'   →[tɑːɳ]
             /tɑːɾ/   'take (PRES)'   + /-sæ/   REFL   →[tɑːʂæ]

Stausland Johnsen (2012: 513) notes that in the Frogner, Tvedstrand, and Arendal dialects of Norwegian, the tap is replaced by dorsal uvular [ʁ]. In all of these dialects, the coronal retroflexion rule is synchronically active even after the uvular variant of the rhotic (6):

(6)   /høːʁ/   'hear'   + /-tə/   PRET →[høʈə]
        /tɑːʁ/   '(nonce)'   + /-tə/   PRET →[tɑːʈə]
        /stuːʁ/ 'big'   + /-t/   NEUT →[stuːʈ]
        /fɑːʁ/   'father'   + /-s/   POSS →[fɑːʂ]

The data from the Norwegian dialects presented by Stausland Johnsen (2012) show that the exact phonetic instantiation of the rhotic is totally irrelevant as regards the synchronically active coronal retroflex rule. This is what is referred to in this article as procedural stability: its surface identity is entirely irrelevant to the process—there must be a source

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[5] It is worth noting that /ʂ/ is also contrastive with /s/, though otherwise retroflexivity is not a fully exploited contrastive trait in Norwegian.

[6] Stausland Johnsen (personal communication) confirms that these processes are productive.

of retroflexion to which all of the dental segments assimilate, since there is retroflexion on the surface in all of the derived forms. That source of retroflexion is the rhotic phoneme, which is only *phonologically* retroflex.

3.2.3 Rhotics in Polish

In Polish, there is one traditional rhotic phoneme, /r/. Polish is an interesting case study for rhotics because of a series of palatalizations, the nature of which is contentious and still an open debate Gussmann (2007). What is clear, however, is that rhotics are implicated in the pattern of palatalization based alternations (7):

(7)　　a.　　por-a　　[pɔra]　　'time'
　　　　　　　　bior-ę　　[bʲɔrɛ]　　'take.1SG'
　　　　　　　　rower　　[rɔvɛr]　　'bicycle'
　　　　　　　　srebr-o　　[srɛbrɔ]　　'silver'
　　　　　　　　wiatr　　[vʲatr̥]　　'wind'
　　　　　　　　Piotr　　[pʲɔtr̥]　　given name

　　　　　　b.　　porz-e　　　　[pɔʒɛ]　　　　'time DAT LOC'
　　　　　　　　bierz-e-sz　　[bʲɛʒɛʃ]　　　'take.2SG'
　　　　　　　　rowerz-yst-a　[rɔvɛʒista]　'bicycle rider'
　　　　　　　　srebrz-yst-y　[srɛbʒistɨ]　'silvery'
　　　　　　　　wietrz-n-y　　[vʲɛtʃnɨ]　　'windy'
　　　　　　　　Piotrz-e　　　[pʲɔtʃɛ]　　　LOC

In (7a) the rhotic phoneme surfaces as a typical coronal trill while in (7b) that same underlying item is realized as a post-alveolar fricative [ʒ]/[ʃ] (agreeing in voicing with preceding obstruents) when preceding some morphemes. While their is no agreement on whether or not the exhibited patterns in (7a, b) are in fact the result of synchronic processing (Szpyra-Kozłowska 2003; Gussmann 2007; Zdziebko 2015), it is clear that there is at least a diachronic relationship between the rhotic phoneme and [ʒ]/[ʃ]. This is what is referred to in this article as diachronic stability: whatever the synchronic status of these phones, the (diachronically) palatalized, i.e. post-alveolars, are synchronically involved in a branching onset (Gussmann 2007: 189) and their diachronic evolution has not changed their phonotactic status—[ʒ]/[ʃ] are rhotics in this context.

3.3 The definition of a rhotic

The observations concerning rhotic behavior in the preceding sections provide a basis for making a formal definition of a phonological rhotic:[7]

(8)　　**Definition of a rhotic**
　　　　1.　A rhotic is a segment which may occupy specific syllabic positions—that of the secondary element in branching onsets or codas—and functions as a sonorant regardless of its phonetic instantiation.
　　　　2.　A rhotic demonstrates PROCEDURAL and DIACHRONIC STABILITY: its phonotactic status as a sonorant does not change even when the rhotic is subject to variation due to either diachronic evolution or synchronic processing—for example even if the rhotic is realized as an obstruent.

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[7] Since there is no way of predicting the phonetic form of a rhotic based on its phonology, the definition of a rhotic must be a substance-free one. We could just as well call them blood oranges: a rhotic is a purely phonological object with no fixed phonetic instantiation which contrasts with other objects in phonology—it may be realized as just about anything. This is a difference between the substance-free representation and Hall's [+rhotic] feature: the realization of [+rhotic] is limited to a subset of possible phonetic objects.

The definition in (8) finally provides phonological theory with a means of constituting a set of rhotics that is not arbitrary. Instead the set of rhotics derived from (8) is a principled one based on characteristics shared by a class of segments.

This has interesting implications for membership in the class of rhotics, throwing the door wide open and allowing potentially any phone to be considered as a rhotic. An obvious "outsider" candidate is the lateral /l/; if a definition of rhotics cannot maintain a principled distinction between laterals and rhotics then it just becomes a definition of liquids with no particular relevance to rhotics. Indeed, in languages where there is no phonemic contrast between rhotics and laterals, there is no reason to exclude lateral phones from the class of rhotics unless some other criterion can be brought to bear on the question. However, in some languages it can be shown that laterals and rhotics do not play identical phonological roles; for example, the phonotactic role of laterals tends to be restricted relative to rhotics. Laterals are also less subject to variation than rhotics.[8]

In fact, there is no principled reason to exclude any phone[9] *a priori* from the class of rhotics: only their behavior within a system can be used as an argument for their inclusion, or their exclusion. To use the example from Sebregts, if it can be shown that [f] or [ʔ] are members of true branching onsets and are in complementary distribution with other liquids and glides, then there is a strong reason to consider them as phonological rhotic candidates; although it seems unlikely for there to be occlusive secondary constituents in complex onsets, in substance-free phonology this is an observation about phonetics and not about phonology.

In (8) only the first part of the definition is available to learner/speakers; the second part is only available to the analyst but constitutes a relevant fact about the diachronic evolution of rhotics. The learner does not need to have access to the diachronic evolution of the segment in order to determine that such a thing as rhotic exists, they just need to be able to rely on their ability to categorize linguistic sounds and determine that an object which fits the criteria in (8) is a phonological object.

3.4 On membership in the set of rhotics

With the definition in (8), a brief cross-linguistic survey provides evidence for an expanded set of rhotics. In a wide variety of languages we can find objects in branching onsets which are subject to variation.

In British English (Foulkes & Docherty 2001; Scobbie 2006), the rhotic phoneme is usually realized as the alveolar approximant [ɹ], but can also be realized as [ɾ], [ʀ] and [r]. In addition, [ʋ] is a possible realization of the rhotic for some speakers of British English.

Dutch is subject to wide variation among its rhotics, including [r], [ʀ], [ɹ], [ʁ], and a glottal fricative [h] (Verstraeten & Van de Velde 2001).

We saw in the discussion of Polish and the data from Gussmann (2007) that [ʃ] and [ʒ] are possible rhotic variants.

In Icelandic, sonorants come in phonemic voice/voiceless pairs. Árnason (2011) points out that the voiceless sonorants have a historical contact with aspiration or a following voiceless consonant. In Icelandic, the dental trill [r] is voiceless when in contact with an unvoiced segment, or the historical reflex of /hɹ/ sequences (Árnason 2011) (9):

(9)   raða   [raːða] 'to arrange' hraða [r̥aːða]   'to speed up'
         marga [marka] 'many.ACC' marka [mar̥ka] 'to mark'

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[8] See Proctor (2009) for an extended discussion of asymmetric behavior in liquids.
[9] Though I will argue later that a rhotic can not be a vowel. See §3.5.2.

In Faroese (Árnason 2011), the rhotic is typically a postalveolar or retroflex approximant, /ɹ/, as in *feara* [fɛaːɹa], though an alveolar trill [r] is realized in the speech of some older people. The approximant [ɹ/ is realized as a retroflex when in contact with other consonants (which are also retroflexed) (10):

(10)   koyrlar [kʰɔɻʂaɻ] 'whips.PL'
         koyril   [kɔiɹɭ]   'whip'

Faorese sonorants, including /ɹ/ are devoiced preceding voiceless stops, as in kirkja [tʃɨɻ̥tʃa] 'church'.

In the Sino-Tibetan language Nusu, /ɹ/ may be realized as [ɻ�] when following [pʰ] (Ikeda & Lew 2017).

In Saigon Vietnamese (Thompson 1959), /r/ is realized as a tap or flap, or as retroflex [ʐ].

Demolin (2001) notes that in Belgian French, there is variation among rhotic phones, including [ʀ]; [ʀ̥] when following a voiceless consonant or word finally, [χ] in the same environment; [ʁ], [ɹ], [r], and a velar approximant, [ɰ] which can be realized in intervocalic position.

We saw that in the Portuguese spoken in Rio de Janeiro, [x], [ɣ], and [ɾ] are all possible rhotic phones (Cristófaro Silva 1998; Barbosa & Albano 2004). In other varieties of Portuguese spoken in Brazil, such as that of Belo Horizonte and São Paulo, [χ], [ɦ] as well as [ʂ] and [ʐ] are possible realizations of rhotics (Azvedo 1981). In European Portuguese, a voiceless rhotic, [ɾ̥], is reported by Jesus & Shadle (2005) in final position.

A principled set of rhotic phones looks something like the one in Table 1. Empty cells are either segments that are impossible to articulate (Barry (1997), for instance, says that retroflex trills do not exist), or a potential candidate that the present article did not identify. A nototable absent, for example, are the alveolar fricatives [s] and [z], which are elements of well attested rhotic alternations in historical processes: notably in Latin and Sanskrit (Catford 2001). As such, although I am unaware of any instances cited in the literature, [s] and [z] are predicted to be possible synchronic rhotic allophones.

3.4.1 A few questions raised by the definition of a rhotic
There are two obvious questions raised by (8):

i. Why are rhotics in particular so subject to phonetic variation?
ii. Why are there no stops in the class of rhotics?

The answer to both of these questions lies in phonetics, rather than in phonology.

Regarding the question of variation, Scobbie (2006) argues that rhotics are articulatory complex segments, involving an apical as well as a pharyngeal element, and this complexity is a possible cause of their tendency toward variation and change. Boyce et al. (2016:

Table 1: An inventory of rhotic segments.

	Labio-dental	Dental Alveolar Postalveolar	Retro-flex	Velar	Uvular	Glottal
Trill		r̥ r			ʀ̥ ʀ	
Tap or Flap		ɾ̥ ɾ	ɽ			
Fricative		ʃ ʒ	ʂ ʐ	x ɣ	χ ʁ	h ɦ
Approximant	ʋ	ɹ̥ ɹ	ɻ̥ ɻ	ɰ		

175) are in agreement, noting that rhotics are "known to involve complex articulations", in addition to being subject to an array of pathological conditions, being "later-developing sounds, … subject to clinically significant misarticulations, …[and] resistant to remediation." For Polish, Jaworski & Gillian (2011) suggest that rhotics are complex from an articulatory point of view, and this complexity makes rhotics especially susceptible to phonetic change. Lindau (1985: 161) also agrees, saying that "[a]n actual trill realization of an /r/ is not as common as might be expected from descriptions of languages, where an /r/ is often labeled as a 'trill.' Even in languages where a possible realization is a trill, not all speakers use a trill, and the speakers that do, have tap and approximant allophones as well as the trill." Widdison (1997) notes that the Spanish apical vibrant is as difficult for native speakers to master as it is for nonnatives.

The suggestion by Ladefoged & Maddieson (1996: 215) that the trill is the prototypical rhotic is worth taking seriously. If we consider the trill to be the ur-member of the phonological class of rhotics, then it follows that variation in rhotics starts with a phonetic trill. This seems to be an empirical fact: Kostakis (2007: 2–3) outlines a number of languages including French, German, Old Norse, varieties of Spanish, Portuguese, Armenian, and Hebrew where a historical trill has become dorsalized and is now realized as an uvular fricative or trill. In fact, Kostakis notes that there are no clear cases of uvular rhotics being coronalized as a result of diachronic evolution or synchronic alternations. While his conclusion is that markedness is responsible for this one-way course of diachronic evolution, there is no need to make recourse to cognitive constraints when a phonetic explanation exists.

Trills are phonetically difficult segments to articulate, and the variation they are subject to is the manifestation of speaker strategies to overcome the difficulty they pose. This difficulty is not phonological, it is strictly phonetic and speakers readily adopt variations of rhotic phones in order to cope with the impediments imposed by phonetics. Thus, the locus for rhotic variation is both diachronic and synchronic. Speakers are faced with a segment with complex articulation, particularly subject to variation, and the various phones which are realized as phonological proxies are passed down to the next generation of language learners, who simply incorporate the variation into their synchronic phonological systems. As a result, the *phonetic* identity of rhotics is subject to variation, while the *phonological* identity is stable. Stops such as /b/ or /t/ do not pose the same kinds of challenge to articulation, and therefore are not subject to the same obvious phonetic variation as rhotics—but phonology is blind to this fact of physiology.

Regarding the question of the manner of articulation in the class of rhotics, while rhotic variation is extensive, the data cited seems to indicated that variation is limited to non-stops: trills, fricatives, and approximants. Again, the reason for this empirical gap can be found in phonetics and not in phonology. According to Ladefoged & Maddieson (1996: 219) the trill is "very sensitive to small variations in the articulatory and aerodynamic conditions obtaining during [its] production." Catford (2001: 171) notes that "with too little airflow a trill may degenerate into a fricative, and with a further decrease in airflow and/or slight increase in the cross-sectional area of the articulatory channel the fricative may become an approximant."

Thus, variation between trills, fricatives, and approximants depends on a single phonetic variable—that of airflow and the Bernoulli effect; this physical fact accounts for the phonetic variation between the segments in Table 1. The reason there are no stop realizations of rhotics is that they are phonetically unlikely to arise as a consequence of the variation resulting from altered airflow, other factors would have to come into play for a stop to be realized. Further, nothing in (8) prevents rhotic phones from eventual reanalysis as something else; what was once a rhotic is not fated to always be so, given sufficient reason

a learner may analyze a rhotic as something else. Phonology is indeed capable of realizing a rhotic as a non-sonorant stop, but the phonetic changes and diachronic processes which would give rise to such a system are exceedingly rare.

3.4.2 What is not a rhotic

Notably lacking from the preceding discussion is any discussion of so called rhotic vowels, such as [ɚ]. The reason such segments are said to exist is because they are the historical reflex of vowel/rhotic sequences. However, there are several good reasons to exclude them from the set of rhotics.

    i. The initial impetus for their inclusion in the IPA focused on their retroflexive articulations, not on their rhoticness (A Petition 1939).
   ii. Their realization is restricted compared to other vowel/consonant reflexes, such as nasal vowels. Only central vowels seem to be capable of carrying retroflexion.
  iii. The term rhotic when applied to consonants is a phonological term; there is no phonetic correlate. When applied to vowels, however, it is a phonetic one and indicates a lowered F3 (Ladefoged & Maddieson 1996) (an acoustic property shared by the approximants which trigger r vocalisation).
  iv. Finally, and most importantly, only a small subset of rhotic phones seems to result in so-called rhotic vowels: those with approximant or retroflex realizations.

The conclusion is that rhotic vowels are, as was initially intended, more aptly referred to as retroflex vowels, since it seems to be a retroflex articulation that they are carrying, not a rhotic one. As such, vowels are not rhotics, being unable to fill the syllabic position reserved for branching onsets.

In sum, rhotics may be identified via observation of their behavior in a) phonological processing and b) distributional patterns.

In this light, the connection between phonetics and phonology is an arbitrary one. The unity of the class of rhotics is found in phonology—in their procedural stability and status as sonorants—and its phonetic diversity is found outside of phonology: in spell-out.

4 Rhotics in spell-out

The previous sections have elaborated an argument that the set of phonological rhotics is not an arbitrary set, but that the phonetic realization of rhotics is. This has implications of for a theory of phonology, which is the subject of this final section.

In a theory of phonology where phonological primes have a direct correlate with phonetic realizations, the primes themselves can serve as an interface between phonetics and phonology. However, as shown, evidence from rhotics suggests that phonetic realizations cannot be predicted from phonological objects. In turn, phonetic qualities are not sufficient grounds for the identification of the phonological nature of a segment, see Gussmann (2004) for palatalization in Polish, and Ploch (2003) for nasality, among other cases of phonological/phonetic "mismatches" (Hamann 2014).

This is what Ohala (1992: 9) calls many-to-one mappings: although any given vocal tract configuration will produce a specific acoustic object, the reverse mapping is not determinate—acoustic profiles can be the result of more than one articulatory configuration. The result is that listener/speakers may articulate a phonetic object with a different articulatory profile than the one used by the speaker the object was learned from. Melodic primes are not instructions that dictate the phonetic interpretation of segments, but rather are used to categorize segments in terms of contrastiveness.

In a theory of phonology that allows for such arbitrary realizations, there must be an interface between the phonetics and the phonology that transforms phonological primes into phonetic objects,[10] and that is capable of handling an arbitrary relationship between the two. A logical next step would be investigating whether or not the relationship between phonetics and all phonological classes is an arbitrary one. In order to avoid stipulating that the interface treats some classes in an arbitrary fashion and others in a phonetically natural fashion, the position adopted here is that the phonetics-phonology interface is capable of arbitrary realizations of all phonological objects. In the case of rhotics, articulatory complexity, discussed above, makes this arbitrariness especially obvious.

That phonological categories are interpreted arbitrarily and have no universal correlate which can be defined in terms of articulation or acoustics has been argued before, see for example Hamann (2011) for a general overview, Hamann (2004) for retroflexivity, Kingston & Diehl (1994) and Honeybone (2005) for voicing, and Clements (1990) for sonority. The conclusion is that cross-linguistic phonetic generalizations or universal articulatory correlates for phonological objects are elusive (Keating 1988).

The notion that phonetic realizations of phonological objects function in an arbitrary fashion is counterintuitive at best, confounding at worst. However, order is restored to both phonology and phonetics if a modular theory of mind (Fodor 1983) is considered. In a modular framework, cognition is viewed as work carried out by a series of modules, each of which uses its own vocabulary and transmits inputs and outputs to other modules via interfaces known as transducers (Pylyshyn 1984; Reiss 2007), and the relationship between phonetics and phonology *must* be arbitrary. This formalizes the intuition that phonology deals in the discrete while phonetics deals in the continuous. A phonological object is an abstract cognitive unit composed of features or elements, with a phonetic realization that is a physical manifestation of that object located in time and space, which is composed of articulatory and perceptual cues.

This is coherent with a view of phonology as a treatment of abstract categories which is strictly delimited from phonetics—the physical properties of speech sounds encoded in articulatory and/or acoustic terms. In a modular approach to phonology all phonological computation is completed with no input or output to or from phonetics; the representation of a rhotic carries no phonetic information on its own, and yet must be interpreted somewhere in the grammar in order to yield a phonetically real sound. The interpretation of rhotics and any other segment happens at the phonetics-phonology interface: the learned, language specific mechanism that assigns phonetic traits to phonological items.

The phonetic realization of phonological primes is a language-specific function found in a transducer, an interface between phonetics and phonology. In this paper the interface adopted is the one known as post-phonological *spell-out* (Scheer 2014), which was offered as a partial account of the mismatch between phonetic and phonological representatives of segments, for example English heterosyllabic /ng/ being realized as [ŋ].

Spell-out is an operation coherent with any action performed by a transducer, it converts a signal from one set of vocabulary to another; it is the operation which takes phonological material and shunts it to the phonetic module, assigning phonetic reality to the purely abstract phonological material. It functions as a dictionary which looks up phonological representations and converts them to phonetic signals. Since it functions as a dictionary, it is crucially *arbitrary* by its very nature. Spell-out is not beholden to any universal rules, it simply performs a translation operation, taking one phonological unit and rendering it intelligible for phonetic articulation.

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[10] See Scobbie (2007) and Hamann (2011) for an overview.

In the account developed here it is spell-out that determines how rhotics are realized for any given language. Thus, in the Frogner dialect of Norwegian, a rhotic is realized as [ʁ] through the operation of spell-out. This arbitrariness is also a defining feature of morphological spell-out, which translates notions such as past tense or plural into objects such as *-ed* and *-s*: there is no fundamental reason outside of historical developments that *-ed* should mark the past tense.

Assigning responsibility for surface alternations in spell-out is related to the larger problem in phonology of clearly delineating between phonetic and phonological processes (see for example the discussion in Scobbie 2007). This is because spell-out is being assigned work to be performed that could, depending on point of view of the linguist, instead be assigned to phonology. While this particular problem is of crucial theoretical importance, it is somewhat outside the scope of this article. What I will do, instead, is clarify the role of spell-out so that a general picture regarding what kind of work it does can be formulated.

Scheer (2014) elaborates four essential qualities of spell-out (11):

(11) i.   The match between phonetic realizations and phonological objects is done via *lexical access*.
      ii. There is no computation in spell-out: the conversion is not based on instructions that work on one object to produce the other.
      iii. The match between phonetic realizations and phonological objects is arbitrary.
      iv. Conversion is exceptionless: only alternations that are exceptionless can be the result of post-phonological spell-out.

Spell-out can only function once all phonological work has been completed. It is clear that spell-out offloads some of the work that was assigned to phonology in the generative tradition. However, it is by no means an *ad hoc* operation that the phonologist can rely upon to cherry-pick which alternations are a part of phonology and which are not. Spell-out is a post-phonological operation that handles exceptionless alternations, it cannot manipulate or modify phonological objects on their way to phonetic output, it can only translate them. It would be impossible for spell-out to de-link an object from the skeleton, for example; as such spell-out can never be responsible for operations such as liaison in French, compensatory lengthening, etc.[11]

Spell-out shoulders some of the work done by "low-level" phonetic rules in rule based frameworks, or some of the work done by post-lexical rules in derivational frameworks where the dichotomy of phonological rules already exists, notably Lexical Phonology (Kiparsky 1985) and Stratal-OT (Bermúdez-Otero 2003; 2018). In Lexical Phonology, for example, post-lexical rules are said to be rules that are exceptionless and capable of transforming phonemes into allophones. In these frameworks, there are two sets of processes that are active in different morpho-syntactic environments, both operating within their own overlapping domains, with their own constraints, and to varying degrees of exceptionality. Spell-out merely makes explicit the long standing observation that not all phonological rules are equal: phonetic rules are relegated to the interface, and are not a part of the computational module of phonology.

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[11] Spell-out also provides us with another solution to the specter of opacity mentioned above in regards to the rhotic-based contrast found in intervocalic position in Portuguese, Spanish, and Catalan. Instead of suggesting that a series of transformational rules is responsible for the surface realization of /rr/ as [x] in Portuguese, since the realization of the putative geminate as [x] is exceptionless, the work done by rules in traditional analysis can be delegated to spell-out: /rr/↔[x]. The pattern is still opaque and handled in serial fashion, but spell-out removes the later operation from phonology and thus without serial ordering of operations in the phonology. The serial character of derivation then lies in the ordering of spell-out after phonology.

Spell-out also takes over the work traditionally assigned to the redundancy rules present in theories of under-specification. Redundantly assigned features have no life of their own in the phonology since they are phonologically inert and do not participate in phonological processes, as noted by Hall (2011: 14): "phonological processes are often demonstrably insensitive to redundant feature values." Given this argument, it is somewhat awkward to force phonology to create features to which it is insensitive. In spell-out, the redundancy rules do not need to be explicitly stated in the phonology itself; similar to the recent elaboration of Modified Contrastive Specification (Hall 2011), in which phonetic implementation is language specific, the filling in of missing features is already baked into spell-out—which for example in English when given an input such as /u/ will automatically realize a round vocalic phone on the surface. Spell-out then is in line with Dresher (2009) and Hall (2011), for whom only contrastive features participate in phonological operations—non-contrastive features are relegated to extra-phonological processes.

From the perspective that phonology is a module that does all of its work in blithe ignorance of other linguistic modules, this an entirely plausible accounting of the reality of the mind. The phonetically arbitrary nature of features is in line with the program of substance-free phonology (Hale et al. 2007; Hale & Reiss 2008; Iosad 2012; Hall 2014). In this framework, phonetic correspondences with phonological features are "a specific property of individual phonologies, not phonology in UG" (Blaho 2008: 23).

5 Conclusion

To conclude, I have argued that previous treatments of rhotic have all suffered from a critical flaw in that the set of rhotics is an arbitrary one. I have argued that a principled set of rhotics can be identified not by using phonetic clues or phonological representations, but giving a definition of rhotics that is based on their phonological behavior: their status as sonorants, their procedural stability, and their diachronic stability.

Rhotic data from three different languages was assembled in order to demonstrate that behavior. The data show that rhotics constitute an arbitrary phonetics-phonology pattern; in this case a phonological class that cannot be usefully described by making appeals to phonetic qualities, since it is a diverse class of phonetically disparate segments. The result is that the phonetic instantiation of a phonological rhotic can not be predicted cross-linguistically.

Finally, it was argued that an interface which mediates between phonetics and phonology is required to make sense of arbitrarily realized phonological objects. This is especially clear for rhotics because they are segments which require complex articulatory gestures making them particularly prone to phonetic variation. It is argued that is not because of any phonological property of rhotics, but rather a simple phonetic fact about the ur-member of the set of rhotics, the apical trill. The conclusion is that rhotics thus provide a useful piece of evidence about all of phonology: if rhotics are in an arbitrary phonetics/phonology relationship, such a relationship must in principle be possible for all phonology. The interface adopted here is known as phonological spell-out, a language specific operation that tells phonetics what to do with the information it receives from phonology—spell-out is the locus of phonetic variation.

Phonology and phonetics are certainly tied one to the other, but in line with the program of substance-free phonology, the elucidation of phonology is best undertaken by first removing phonetic substance from the domain of inquiry. While "natural" (i.e. typological, anatomical and physiological, etc.) concerns may be useful in phonetics, they should not be included in theories of phonology, as shown by rhotic evidence.

Abbreviations

ACC = accusative, BP = Brazilian Portuguese, DAT = dative, LOC = locative, MA = Moroccan Arabic, NEUT = neuter, PL = plural, POSS = possessive, PRES = present, PRET = preterite, REFL = reflexive, SG = singular

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Competing Interests

The author has no competing interests to declare.

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