Substance-free approaches to phonology

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Abstract

This chapter provides an overview of substance-free approaches to phonology. Substance-free approaches assume that phonetic substance plays no role in the composition of representations or the way phonological computations operate over those representations. As a consequence, they assume that formal grammars which claim to model phonological knowledge are insensitive to phonetic substance. The chapter proposes an overview of phonetic substance in the history of phonology, in particular as a way of limiting overgeneration and providing explanation for typologically recurrent patterns. It then discusses some of the basic principles of substance-free approaches, demonstrating how reasoning without recourse to phonetic patterns can yield insight into the fundamental properties of the human faculty of phonology. It concludes with a brief overview of specific proposals and some of the major questions and sources of debate within the substance-free program.

1 Introduction

Of the conceptual requirements of any theory of phonology, one of the most basic is determining what kinds of facts are within the theory's remit and thus its explananda. The purpose of a theory of phonology is to explain what the phonological knowledge instantiated in the brains and minds of human beings is like, but a critical challenge facing any phonologist is the fact that what is directly available to speakers and to linguists is not the knowledge itself but rather *the interaction* between knowledge and the physical world. Not everything that is true about the physical dimensions of language production is necessarily recapitulated or represented in internal knowledge. Indeed, the physical world of speech includes a great many facts about things such as the gross timing of articulators, muscle movements in dynamic speech, laryngeal anatomy and its effects on frequency spectra, and other gradient physical phenomena which are boundless in their potential to yield measurable data points; many of these may be empirically verifiable events but linguistically insignificant, and not a reflexion of phonological knowledge.

"Substance-Free Phonology" (SFP) does not by itself designate a theory of phonology; rather it is a research program in the sense of Lakatos (1978). The core assumption is that phonological patterns in human languages are the reflection of specialized knowledge in the minds of human beings. This knowledge is of phonological structure and of the computational operations which build and operate over that structure, rather than language-specific phonetic details of speech production. SFP assumes that many language-specific phonetic cues such as median duration or gradient gestural overlap are artifacts of the contingencies imposed on speech by the mechanics of the vocal apparatus, shape of the inner ear, or facts related to attention, human perception, and auditory acuity rather than linguistically significant knowledge. As a consequence, substance-free approaches are not concerned with the incidental aspects of speech, emphasizing instead inquiry into the cognitive realm. They make no primitive assumptions about the relationship between phonological structure and phonetic exponence of that structure.

Though it has historical antecedents (Foley 1977; Fudge 1967), the foundation for the substance-free approach was laid out in Hale & Reiss (2000b) and Hale & Reiss (2000a). There is a common thread that runs between these two works: phonological theory is inquiry into systems which emerge from a core of formal properties strictly cognitive in nature (c.f. Sapir 1925). That is, phonology is an aspect of human cognition, and the nature of this formal core is the empirical object of phonological theory, which must cleave between the fine details of speech and the form of internal phonological knowledge. Any approach to phonology can be said to be "substance free" if it does not assume that phonological representations and structures encode facts about acoustic or articulatory cues. As a corollary, substance-free approaches eschew the notion that direct inspection of acoustic or articulatory cues in acts of speech reveals phonological structure—there are no invariant phonetic correlates which can be used to reliably discover the nature of phonological structure.

It seems, then, that theories which are surface-oriented and assume a direct relationship between the two have an epistemological advantage in that the form and structure of knowledge can be discovered through adequate observation of the phonetic signal. Indeed, in substance-free approaches phonological investigation is less obviously amenable to instrumental measuring, since the object of study is not of sounds or their properties in the physical world. Careful observation and empirical data are obviously essential, but the data cannot be understood in "raw" terms and must be interpreted in the light of a rationalist theory. Explanation for phonological patterns comes explanation comes about through reasoned interpretation of sound patterns and generalizations over those patterns which reveal the formal core of phonology (Chabot in press).

This chapter provides an overview of the current state of the field as it is viewed in substance-free phonology. §2 opens the chapter with a discussion of the notion of explanation in phonology, and the role of measurable phonetic substance as explanans in phonological theory. In §3 I provide a summary of the basic principles of substance-free approaches to explanation and the empirical object of phonology—an algebraic system of abstract knowledge which encodes contrastive representations and those computations which are responsible for patterns that emerge in phonological systems. This section further provides an outline of reasoning in approaches where raw phonetic measurements are seen as unreliable correlates for phonological structure. §4 is a survey of work within Substance-Free Phonology that treats three critical components of any phonological grammar: representations, computations, and the interface of phonology with phonetics.

2 Explanation in phonology: A brief history of substance

2.1 Phonological significance

The Neogrammarian era of descriptive, taxonomic classification of languages gave way to a conception of linguistic practice with a more ambitious program of providing explanation for those properties of language which can be generalized to causal claims concerning the nature of linguistic knowledge in human minds and the relationship between this knowledge and directly-observable facts in speech (Baudouin de Courtenay 1870 [1972]: 55). Linguistics moved away from a purely historical science to one that included the study of an innate property of human beings, Faculty of Language, which emerges from properties of brains and minds (Saussure 1916 [1967]). Linguistic theory, in turn, became a rationalist evaluation of that significant linguistic data which allows for the discovery of the mechanisms by which human beings acquire and use Language—it provides explanation for the form and content of linguistic knowledge.

In phonological terms, significant data does not come in the form of raw *sound*, but comes instead in the form of generalizations of *sound patterns*—alternations, distributional regularities, and other categorical effects in speech production which are not reducible to purely mechanical facts about human audition or articulation (Chomsky & Halle 1968; Hurford 1971). Phonological theories are claims about human minds, they are an "ontological commitment" to a model of the human capacity for organizing speech sounds, through which sound patterns emerge (Odden 2013: 250). Accounting for observed sound patterns requires only faithfully reproducing those patterns in all their possible detail (see Chomsky 1965; Hurford 1977; Prideaux 1971), but providing an *explanation* for those sound patterns requires establishing a causal relationship between generalizations and the knowledge from which those patterns emerge. Put another way, an explanatory theory is a characterization of the fundamental properties of human cognition from which language—and thus phonology—emerges in the species (see Chomsky 1964: 29 and Dinnsen 1980: 172).

There is a critical conceptual issue in phonological epistemology, however: phonologists are not in agreement concerning the nature of phonological knowledge, since they do not have a reliable way of distinguishing between the conceptual requirements of an explanatory theory and the impact of the many non-phonological facts inherent in physical speech acts Odden (2011). This issue is long standing, and it is clear that phonetic cues vary quantitatively and qualitatively across languages (see Cohn 1990, 1998,Cohn 2007: 6; Keating 1984, 1985; Solé 1992 *inter alia*). For example, some aspect of the speech signal might correlate to a purely phonetic gradient effect emerging from the mechanics of speech production in one language (e.g. leaking of air into the nasal cavity during co-articulation of a vowel followed by a nasal consonant), but to a phonologically-significant categorical property of grammar in another (e.g. phonemic nasalization after assimilation in the same context).

As a result of this variable linguistic significance inherent in phonetic cues, the phonetic signal is not isomorphic with the form and content of phonological knowledge. However, it is obvious from the cross-linguistic record that phonological patterns often seem to be in a tight relationship with phonetic cues—nasality is a cue that seems to be relevant at both the phonetic and phonological levels of description in many, if not most, languages. This is one reason that many theories of phonology have incorporated phonetic substance into their formalisms: there seems to be a reliable correlation between phonetic description and phonological structure. Since formal theories are claims about the form of knowledge, theories which tightly link phonetic substance to phonological structure are implicit claims that phonological knowledge itself contains the set of phonetic facts taken to be significant.

2.2 Phonetic substance as phonological assay

Since phonology is, ultimately, an organizational system for linguistic sound[1], it is not unreasonable to consider the possibility that the essence of phonological knowledge is sound itself. In this view, measurements of physical sound are adequate assays of phonological knowledge, since that sound reliably contains the content of phonological structure. In the history of phonology, approaches to phonological epistemology have varied in terms of the extent to which substance is used as an assay for determining the nature of phonological knowledge (see Chabot in press).

In structuralism, the content of basic phonological representations, the phoneme, was its subjective role as distinctive symbols embedded into a language-specific system rather than the objectively real acoustic signals (Saussure 1916 [1967]; Sapir 1925). Saussure (1916 [1967]: 155f.) argued that linguistic sounds are not fixed or rigid, they do not have linguistic identities which can be established based on their physical properties. While there was undeniably a "certain amount of contact" between phonetics and phonology, their ontological status as independent empirical domains was a basic assumption of structuralist inquiry (Trubetzkoy 1969: 4). At the heart of this conception of phonological knowledge is the contrastive relationship each phoneme enters into with every other phoneme in a given, language-specific system—it is from this network of contrasts and predictable variation that sound patterns emerge. Structuralist phonology was investigation into the language-specific systematic properties which determined how phonological systems were organized (Trubetzkoy 1969: 71f.), rather than the fine details of the physical properties of sound (Sapir 1933).

When the structuralist phoneme was atomized into phonological features (Jakobson 1939), they inherited the contrastive function of phonemes. Features contained an "essence" conditioned by the human vocal apparatus and the acoustic effects it can produce (Jakobson 1939: 321). In Jakobson's view, features were inherently linked to "gross sound matter", though this substance had no meaning in terms of the semiotic function of features, since they classified that matter according to a restricted number of relevant phonological dimensions (e.g. place of articulation), thereby reducing the variation inherent in physical

[1]Though the use of the word "sound" here is infelicitous given the phonological systems which organize sign language (Brentari 2011, 2019; Marshal 2011; Sandler 1993, 2012, 2014; Stokoe 1960 [2005]).

sound to mental categories.

In generativism, the contrastive role of features was conserved, but the notion of substance was exploited more fully in an effort to provide a way of accounting for patterns of morpho-phonological variation (Halle 1959). Explanation of this kind comes in several forms. First, natural classes are organized around features, and thus are typically based on some configuration of the articulators tied to those features. Second, the content of features has consequences for computational rule formalisms, since (in principle) phonetically natural patterns are more parsimoniously accounted for relative to phonetically unnatural ones. In this way, phonetic content was one solution to the problem of overgeneration: it could be used to limit the set of possible rules through the way markedness impacted them (Chomsky & Halle 1968: 480ffs.). Explanation for the range of possible phonological patterns was thus derived from the intrinsic content of representations: what was phonetically unnatural was not phonologically possible.

Indeed, following Chomsky & Halle (1968), the potential of substantive representations for providing explanation and restricting the power of the formal theory sparked a great deal of research in phonology (see Kiparsky 1968 [1973]). Outside of generativism, as in Natural Phonology (Stampe 1973; Donegan & Stampe 1979), phonological patterns were essentially reduced to phonetic knowledge. Within generativism, this mostly took the form of making phonological systems sensitive to phonetic content and thus limiting their purview—examples can be found in Natural Generative Phonology (Hooper 1976; Vennemann 1971), Articulatory Phonology (Brownman & Goldstein 1986), and Grounded Phonology (Archangeli & Pulleyblank 1994). In Optimality Theory, this sensitivity comes through markedness constraints that are phonetically grounded (Hayes & Steriade 2004). Though the boundary between phonology and phonetics was most often preserved, the use of phonetic substance as explanatory device opened up the possibility of dissolving any ontological distinction between phonology and phonetics (Blevins 2004; Flemming 2001; Kirchner 2000)—in this view, all phonological patterns are essentially reducible to phonetic explanation.

Research into substantive phonetic effects within phonology often assumes that phonological representations have phonetic content, and that phonological processes and structures are sensitive to that content. This has a distinct advantage in that it provides substantive theories with an explanation for a number of typological observations about what kinds of phonological processes characterize human language on a broad-based, typological scale. Such theories also have the virtue of making strong predictions about what kinds of phonological grammars are impossible, since the substantive character of the formalism will not produce phonetically unnatural patterns. The empirical record shows, however, that not all phonologically patterns are phonetically natural.

2.3 Functional effects in phonology

Functional pressures are undeniably operational in the emergence of phonological patterns, a fact reflected in very robust typological generalizations. Yet, it does not seem possible to provide complete explanation for the nature of human phonology through recourse to functional effects (Anderson 1981). For example, Bach & Harms (1972) coined the term "crazy rules" to refer to phonological patterns which seem to defy our understanding of what is phonologically natural (see Chabot 2021 for an detailed overview of crazy rules reported in the literature). Hale & Reiss (2000b) argue that phonological grammars are arbitrary in terms of how phonetic substances impacts the computational system; phonological computation is not sensitive to articulatory or perceptual difficulties, naturalness, or other properties of the physical world.

For example, Wichita (described by Rood 1971, 1975) is a polysynthetic language with a number of active rules of internal sandhi, one of which in particular does not seem explainable on a purely phonetic basis. When /k/ precedes /r/ or /j/, it is realized as [h], as in (1). If the conditioning segment is /r/ (1a), it metathesizes to the position preceding [h], such that any underlying sequence /kr/ will be realized [rh].

(1) a. ti+a+ʔak+raʔa+s → taʔarhaʔas 'he brought them'

b. ra+t+a+a+raːk+jaː+iki+h → ratáraːhéːkih 'you, my children'

The triggering segments, the coronal flap /r/ and the palatal glide /j/, constitute a typologically unusual natural class. There is also no clear phonetic explanation for why /r/ should nasalize when word-initial preceding a vowel, as reported by Rood (1971).

If phonology can generate phonetically unnatural patterns, then the apparent effect of substance in phonology may not be the reflection of phonological competence, and the explanatory value of functional explanations for the nature of phonological knowledge is seriously compromised. Instead, functional effects must be recast as extra-grammatical, outside the remit of the formal theory (§2.4).

To understand the tension between the apparent phonetic character of many phonological patterns and those which defy phonetic explanation, consider the common cross-linguistic pattern of vowel reduction in unstressed syllables. European Portuguese (EP) is a typical example (Carvalho 1994), characterized by a centralizing reduction of vowels in unstressed syllables, resulting in the neutralization of some tonic contrasts when stress moves in morphophonological derivation (2):

(2)

vowel quality	stressed/unstressed	gloss
[i]—[ɪ]	*tiro/tirar*	'I take off'/'to take off'
[e]—[ə]	*meto/meter*	'I put'/'to put'
[ɛ]—[ə]	*levo/levar*	'I take away/'to take away'
[a]—[ɜ]	*bato/bater*	'I strike'/'to strike'
[ɔ]—[ʊ]	*voto/votar*	'I vote'/ 'to vote'
[o]—[ʊ]	*cozo/cozer*	'I cook'/'to cook'
[u]—[ʊ]	*futo/furar*	'drill'/'to drill'

This pattern illustrates the relationship between stress and vowel quality in EP (Miguel 2003; Vigàrio 2003)—stressed syllables host the full set of vocalic contrasts in EP, while unstressed syllables host only lax, ecntralized allophones (3):

(3) **stressed** **unstressed**

[a]	[ɐ]
[i]	[ɪ]
[e ɛ]	[ə]
[u o ɔ]	[ʊ]

This pattern of vowel reduction has a ready functional explanation. Stress is a kind of relative prominence between syllables in a domain, a marker of rhythmic structure (Liberman 1975; Liberman & Prince 1977). While its phonetic correlate varies from language to language (Fry 1955, 1958), stressed vowels are often longer in duration relative to unstressed vowels cross linguistically. As the duration of vowels is reduced in atonal syllables, so is the time for the articulators to reach their intended targets, resulting in a less expansive vowel space relative to stressed syllables (cf. Harris 2005).

This functional effect drives the cross-linguistic tendency to reduce vowels outside of stressed positions (Barnes 2006; Lindblom 1963). Further, it may be possible to encode this relationship between stress, length, and vowel quality in the grammar by making the articulatory correlates for tense vowels antagonistic with unstressed positions. If phonological grammars recapitulate functional effects, then they can be used to provide another sort of explanation for the centralizing effect of unstressed syllables.

However, while the functional relationship between stress, duration, and vowel quality is no doubt reflected in the typological record, this does not entail that the pattern is the way it is because the grammar itself is structurally bound by functional pressure. Indeed, the aforementioned crazy rules and other unnatural patterns suggest that phonological grammars are insensitive to functional pressures in the physical world (see Beguš 2018; Blevins 2008; Buckley 2000; Chabot 2021; Hellberg 1978; Stausland Johnsen 2012). In fact, it seems that languages vary extensively in the sorts of patterns they exhibit, and grammars in turn are operating according to principles which are not strictly functional. While atonal positions have a functional effect on vowel qualities in many languages, this is not a property of grammars, and theories which recapitulate the functional story make false predictions.

Consider, for example, Kaqchikel Mayan, spoken in Guatemala (Chacach Cutzal 1990). The basic contrastive system of Kaqchikel is a tense/lax one (Patal Majzul et al. 2000), where both classes of vowels can be realized in stressed position. Interestingly, the distribution of tense and lax vowels in unstressed syllables is exactly the opposite of EP—in Kaqchikel, all unstressed syllables have tense vowels, and only stressed syllables can host lax vowels (Hendrick Krueger 1986: 12), as seen in (4).

(4) a. [k'iʃ] 'chayote squash'
[rɪʃ] 'you.PL'

b. [ox] 'avocado'
[ɔk] 'little'

Stress in Kaqchikel is fixed on the final syllable of words, and changes position accordingly in morphophonological derivations, as shown the data in (5) from Comolapa Kaqchikel (Chacach Cutzal 1990):

(5) a. [ɜ] and [a]
ninb'än [n-in-ˈɓɜn] 'I make it'
b'anöl [ɓan-ˈɔl̥] 'maker of...'

b. [ɪ] and [i]
nintik [n-in-ˈtɪkʰ] 'I sow it'
tiköy [tik-ˈɔj̥] 'sower of. . .'

c. [ʊ] and [u]
ninchüp [n-in-ˈʧʊpʰ] 'I turn it off'
chupüy [ʧup-ˈʊj̥] 'power switch for'

The pattern of vowel reduction in Kaqchikel is typologically unusual. It is especially interesting because the functionalist account which ties phonetic centralizing to stress does not hold. While there is a good functional explanation for the recurrent observation that unstressed vowels tend to be lax, there is not an equivalent explanation for why lax vowels should be realized as tense when unstressed. Accounting for Kaqchikel vowel reduction, then, seems to require an account in which phonetic functionalism is inert or exists; as the functional explanation is not adequate, a formal, phonological explanation in which computational processes are not hobbled by phonetic notions may be more useful.

The functionalist conception of grammar as enforcer of phonetic pressure also sits uneasy in the company of modalities other than the vocal/oral (see Samuels et al. 2022). Sign languages are organized according to phonological principles and categorical contrasts (Brentari 2011, 2019; Marshal 2011; Sandler 1993, 2012, 2014; Stokoe 1960 [2005]), but these dimensions obviously have nothing to do with sound. Thus, theories based on substance make phonetic explanation the unique property of the vocal/oral modality, since articulatory and acoustic substance cannot provide any sort of explanation for the structure of sign language.

This brief discussion of phonetically "agnostic" phonological patterns suggests that functionalist pressure does not come from within the grammar itself. It may be, then, conceptually and empirically advantageous for theories to jettison phonetic substance in their formalisms, and move towards entirely abstract accounts of phonological knowledge (cf. Fudge 1967: 26).

2.4 Minimalism and third factors

The explanatory use of substance in phonology was of cross-theoretical relevance exactly because the assumption that features contain phonetic substance was so widespread in generative practice. However, each theory which exploits substance has its own bespoke formal mechanism sensitive to that substance, and the empirical record has shown that the kinds of functional pressures one language seems to be sensitive to may be entirely inert in another. This has led to the proliferation of markedness and naturalness effects in phonology, along with a host of mechanisms that are sensitive at different levels of the grammar to different effects. The more varied and intricate a theory is, the more it becomes difficult to understand why that theory is the way it is (Chomsky 2005). A phonological analysis may draw from both categorical phonological effects and gradient phonetic effects indiscriminately, leading to a kind of ontological scrambling where the analysis is reduced to a mere description of the narrow set of facts it aims to explain. More seriously, reliance on phonetic substance as explanation leads phonologists away from inquiry into linguistically-significant knowledge in human brains and minds, and towards theories of surface-level properties of particular languages and taxonomic classification of incidental phonetic effects which are essentially mechanical, rather than cognitive.

In Minimalism (Chomsky 1995, 2002), linguistic theories are more than just theories of particular languages: they are theories of those principles common to the minds of all human beings from which the form and structure of language emerges. At the heart of Minimalism is the idea that computational systems underlying human languages are in some way optimal (Freidin & Lasnik 2011), an approach which assumes that the variety of human language should be accounted for by the most parsimonious language-general formalism possible (Hale & Reiss 2000a: 176). This is an application of Occam's razor, which requires the avoidance of duplicating explanation (Cohn 2007; Sampson 1975). For example, a phonological theory which explains patterns of vowel reduction by recapitulating the functionalist explanation in the form of substantive or markedness effects in the grammar has provided the same explanation twice—once at the phonetic level of description and a second time at the phonological rather—rather than greater explanatory power. Minimalist theories seek to produce claims about language-general properties with as few language-specific stipulations or mechanisms as possible.

One way of doing this is by excluding from the remit of the formal theory of knowledge so-called "third factors" Chomsky (2005: 8)—aspects of language which do not emerge from the human capacity for language but that are still relevant to the form linguistic patterns as they emerge during speech production. These are effects which are not domain-specific properties of grammars, or related to the idiosyncratic linguistic experience of individual humans; for example properties of physical sound, the anatomy of the vocal tract and ear canal, other cognitive capacities which could be marshaled for language use such as categorization, or principles of efficient computation in the mapping between the mind and the physical world are all third factors.

One of the goals of Minimalism is to go "beyond explanatory adequacy" by understanding the individual contribution of each of the three factors to the form of languages Rizzi (2016), in part by teasing them apart to cut to the essential stuff of grammatical competence. Functional factors have an undeniable impact on the form of languages (see Haspelmath 2004: 565), but these can be fruitfully understood as third-factor impacts rather than properties of knowledge. Considering phonology in this way, it is possible to both exclude substance from the theory of knowledge while still providing an extra-grammatical explanation for typological tendencies. What is left of a theory of phonology once third factor explanations have been exhausted are the fundamental aspects of grammars from which emerge the persistent and otherwise unexplainable facts of phonological patterns which cannot be reduced to functional effects.

The apparent influence of phonetic naturalness in typology is the result of what Moreton (2008) calls *channel bias*; a set of third-factor phonetic effects inherent to the physical nature of sound which are the result of interactions between articulatory anatomy and perception in the sense organs of humans. Present in the speech signal are a variety of mechanical, non-grammatical cues which are contingencies of the structure of the human vocal tract or perceptual system—for example gradient co-articulatory effects which emerge from the transition from one articulatory gesture to another—without as such being the reflection of phonological knowledge (Cohn 1990, 1998; Hammarberg 1976; Solé 1992). That is, phonological effects are categorical, but the speech signal is full of gradient cues that are not phonological (Anderson 1975; Chitoran & Cohn 2009; Cohn 2007; Janda 1987; Keating 1988, 1996; Pierrehumbert 1990; Scobbie 2007) (see Hamann 2011; Myers 2000, and Kingston 2019 for informed overviews). Gradient phonetic effects, being artifacts of human anatomy and perception, are common to all human beings and independent of language-specific knowledge. Over diachronic time scales, these gradient phonetic precursors can be reinterpreted during the course of normal language acquisition as properties of phonological grammars (Anderson 1981; Blevins 2004, 2009; Hellberg 1978; Hyman 1976, 2001; Stausland Johnsen 2012; Vaux 2008), resulting in typological tendencies which nonetheless are not the explicandum of phonological theory.

In this view, language-specific facts emerge from the grammar, but they are not necessarily the content of that grammar. For example, while most theories of phonology assume some kind of symbolic representation (see §3.1.2), there is no *a priori* reason to assume that those representations should contain the qualities of the physical objects they represent (Pylyshyn 2004: 2). In the substance-free view, phonetic naturalness effects and typologically recurrent patterns are epiphenomena of how production, perception, and transmission interact with knowledge, but they are not knowledge or part of the formal grammar (Blaho 2008: 2); indeed imputing them to the grammar bloats the theory of phonology and leads to epistemological confusion.

This means that—rather than deriving formal explanation through phonetic content—explanation comes from the structure of phonological representations, their relationship with each other, and how phonological processes operate over them. A substance-free theory of phonology seeks to elucidate this knowledge of phonology at a conceptual and predictive level (Odden 2011). The conceptual level is concerned with providing an account of the content of phonological representations, the kinds of processes which interact with those representations, and what the relationship between phonology, phonetics, and morphosyntax is like. It is at this level that the scope of a theory is determined in terms of the kinds of generalizations it treats as being phonologically significant. The predictive power of a theory, in turn, comes from its success in generating novel discoveries about phonological structure, which in turn lead to explanation for why sound patterns are they way they are, instead of being some other way.

3 Principles of Substance-Free Phonology

3.1 Phonology without phonetics

The basic assumption in substance-free approaches is that phonetic phenomena do not directly impinge the form or structure of phonological knowledge. Phonological theory is not, as such, a model of human anatomy or perceptual properties; it does not encode facts about the acoustics of speech, the structure of the human vocal tract, facts about the timing of muscular movements, notions such as ease of articulation, markedness, or other functional properties impacting speech production from outside of human minds. Phonological patterns are meaningful generalizations of observations over variable data in the physical world; the more those observations are stated in terms of fine-grained phonetic terms, the more generalizations are reduced to simple recapitulation of that raw variation, and the less a theory explains (Chabot in press). A substance-free theory does not seek to provide an account of every detail of observable speech—rather it seeks to provide an explanatory account of the fundamental nature of phonological knowledge. In this view, there are language-specific facts concerning sound patterns, but only a subset of those facts emerge from the grammar. The task of phonological theory is to cleave between the myriad statable facts to claims concerning the essential properties of all grammars from which phonologically significant facts emerge (Odden 2013).

The substance-free mode of investigation is an application of Minimalism (§2.4), in that it's goal is to account for significant generalizations with the fewest assumptions concerning the structure of the grammar (Samuels 2011a). This leads to a productive, progressive research program in the sense of Lakatos (1978), where new questions can be asked concerning the basic nature of phonology (Hale & Reiss 2000b). For example, what is the simplest representational system available? What are the minimal computations required? What is the nature of the interface between phonetics and phonology? Above all, this approach seeks to build a unified set of claims concerning the nature of phonological knowledge, without assuming that substantive facts concerning speech production are required for explanation of those claims (Chabot in press); it assumes that a phonological explanation for sound patterns comes about through an elucidation of the fundamental representations and computations that characterize phonology, and nothing else.

Since the substance-free approach does not make any primitive assumptions about the phonetic content of those essential properties, it must derive generalizations through abstract structure. The existence of abstract structure of this kind is not confirmed through empirical measurement, but by the value it provides in uniting seemingly disparate phenomena and providing an explanation for why we find the patterns we do.

Phonology, in this view, is a theory of knowledge which is not directly observable in empiricist terms, but that has an observable effect in the form of generalizations in sound patterns. This basic assumption of the substance-free program has been adopted in formal work seeking to establish a set of hypotheses concerning the causal principles of phonological knowledge, rather than the phonetic content of utterances (Blaho 2008; Chabot in press.; Cyran 2023; Dresher 2014; Enguehard 2018; Hale & Reiss 2008; Iosad 2012, 2017; Leduc et al. 2024; Odden 2013, 2022; Reiss 2017; Samuels 2011b; Scheer 2022; Volenec & Reiss 2020, 2022). Phonology is by nature abstract in the substance-free approach, in that it does not reproduce the host of real-world factors outside of cognition which impact it. The relative tension of jaw muscles or the way timing of speech articulators line up may have a measurable effect on experimental results, but they are not directly relevant to understanding the basic structure of knowledge.

In this way, the substance-free approach is like the frictionless plane described by Galileo, a conceptual model of the forces acting on objects moving down inclined planes. Galileo's model explains the relationship between motion and the plane through an account of the core operational forces—vectors, slopes, and gravity—while discounting other measurable forces such as surface friction or air drag, which would impact the movement of the object in any real-world observation. Indeed, this kind of hypothesis-driven approach is what Weinberg (1976), borrowing from Edmund Husserl, refers to as the *Galilean* style of scientific methodology, or the idea that abstract systems can provide insight the natural world. For example, Helmholtz, Hering, Hurvich, and Jameson provided an explanatory account of color perception *before* the underlying physiology was understood (Palmer 1999: 111). This was done by starting from an abstraction and working towards the physical implementation of an algorithmic theory.

Any phonological analysis naturally depends on careful observation of the facts of sound; the substance-free approach seeks to provide a reasoned evaluation of those facts within the constellation of extra-grammatical effects that impact those sounds. A substance-free theory moves beyond the fine-grained, language-specific facts in raw empirical observations by establishing a conceptual framework which accounts only for those facts which are domain-specific to phonology—those which are the unique reflection of phonological knowledge.

3.1.1 Modular Phonology

More generally, substance-free approaches are meant to be situated within the larger context of cognitive science (Hale & Reiss 2000a). That is, such approaches are investigation into the relationship between form and substance, where phonological form includes the set of symbolic representations and their interactions, modeled as a formal theory of a cognitive process (see also Kaye 1989: 42ff.). This basic premise means that it fits well into modular models of cognition (Carruthers 2006; Fodor 1983; Gerrans 2002). Phonology is a specialized functional aspect of human minds, operating in a specific way with a specific symbolic vocabulary—the modular approach is useful in investigating the nature of this operation.

In the modular view, phonological computation is quick and efficient since it is sensitive only to phonological information and insensitive to all of the other information that might be in the minds and brains of human beings (Coltheart 1999: 117). Phonology's modular character means that it is *domain specific* and *informationally encapsulated*. This has several consequences for any hypothesis concerning the nature of phonological representations and the kinds of information available to domain-specific phonological computations. In short, the modularity hypothesis makes phonology "watertight" and impervious to information from other levels of description, thereby limiting its scope and interactions with non-phonological effects. As such the substance-free view holds that phonology is isolated from phonetics and morphosyntactic computation (Chabot 2021); it operates only over phonological vocabulary and is in this sense a model of a *localist* computational system, rather than a *globalist* system in which morphology, phonetics, and phonology are all operating within the same grammatical system (Embick 2010: 4f.).

If phonology is domain specific and informationally encapsulated, then it operates according to proprietary principles and a particular symbolic vocabulary (Coltheart 1999: 118). That is, non-phonological vocabulary has to be translated into phonological vocabulary before it can be interpreted by the phonological module. This means that any phonetic information is not directly available to phonology, since such information is a property of the infinite physical world, not the symbolic domain of phonology. In the same way, phonology cannot directly interpret the vocabulary of other linguistic domains such as FOCP or "3SG" (Iosad 2017; Newell & Sailor in press; Scheer 2011). Information from the physical world or from morphosyntax can be encoded into phonological vocabulary through a translational interface, but there is no reason to assume that the entire informational content of one representational level is fully carried into another.

The architecture of modular phonology makes restrictive hypotheses concerning the nature of computations and representations, limiting overgeneration in a principled way. For example, a rule that palatalizes coronals when they precede a nominative case marker would not be possible, since it would mix phonological and morphosyntactic vocabulary. In the same way, a rule that lengthens vowels when they are followed by an F1 transition would also be invalid, since it mixes up a phonological representation with a phonetic fact. This is not the same as saying such patterns are impossible *descriptively*, just that they would not be appropriate phonological generalizations, and so would offer nothing in terms of phonological explanation.

A modular approach contextualizes phonology as a cognitive process (Scheer 2011), and provides an avenue for explanation by providing a means of distinguishing what is phonological knowledge and what is extra-phonological (Cairns & Raimy 2009; Reiss 2009). It also allows for the possibility of making new discoveries concerning phonological representations and computations when what seem like recalcitrant exceptions to generalizations can be made sense of through abstract analysis (see Faust et al. 2018; Lowenstamm 1999; Passino 2013; Raimy 2009; Scheer 2009 for examples). This approach places much of the explanatory emphasis on the form of representations and what computations can do to those representations, providing parsimonious generalizations and unifying seemingly disparate phenomena.

3.1.2 Algebraic knowledge in phonology

Substance-free approaches are by nature internalist, committed to a view of phonology as being an innate property of human minds, and as such a natural object that may be described in terms of the basic architecture of phonology common to human beings. This internalist perspective views phonological form something which emerges from knowledge of phonological structure. This is not knowledge of how to *do* things with language (Chomsky 1986: 10), it is not knowledge of behavior (see Chomsky 1959); rather it is knowledge of an internal, highly specialized formal structure (see Chabot in press). A theory of phonology is not, then, a model of production or of perception *sensu stricto*, but rather a model of knowledge (Chomsky 1965: 9), one meant to explain the relationship between the linguistically significant cognitive properties in human minds and their correlates in the physical world.

One way of conceptualizing these fundamental properties is to view them as part of a computational system which maps between states of information (Embick & Poeppel 2015; Gallistel & King 2009; Poeppel & Embick 2005; Pylyshyn 1984; Thagard 2005)—for example between knowledge and instructions to the sensory-motor system for the production of speech. Computational/representational theories of mind are claims about the computations and basic representations used by brains to make sense of sensory information (Gallistel & King 2009: 59). Whether explicitly stated or not, much of the generative program is an implementation of a computational/representational theory of mind; substance-free approaches simply assume that, whatever the nature of computations and representations, their content and operation is isolated from phonetic substance. Explanation for the form of possible phonological grammars comes about through an adequate understanding of the representations and computations which build those grammars.

As discussed in §2.2, structuralism was a foundational approach to phonology in which the content of the basic phonemic representations was not substantive (Saussure 1916 [1967]). Rather, the content of a phoneme was understood as the contrastive role it played within a specific linguistic system. Though phonemes were "two-fold entities" with articulatory and acoustic dimensions, the mental correlate of those dimensions was about categories and classifications imposed over them (Saussure 1916 [1967]: 99). Indeed, in this view a physical description of "sound images" does not provide adequate understanding of their *function* in a language.

Representations are "symbolically utilizable counters" (Sapir 1925: 39); they have a paradigmatic function as mental representations for sets of internally varying linguistic sounds, marking linguistically significant distinctions. Critically, understanding sound patterns comes through explanation of their role in a system of oppositions (see also Dresher 2009), rather than the external phonetic properties of these categorical variables. In addition to contrastive content which encoded "differentess", inherent in the structuralist view of representations was their symbolic encoding of "sameness" through phonological equivalence classes. A set of segments [m n ŋ] were the same in that they all are characterized as nasal, and where one nasal segment might be part of a larger pattern, so were all other nasals. In this sense, phonology was a kind of algebra (Saussure 1916 [1967]: 168), operating not over sounds themselves, but over variables in a linguistic system.

Conceptualizing representations as variables rather than high-fidelity reproductions of physical phenomena is in line with computational/representational theories, which hold that representational symbols must be efficiently stored and easily accessed (Gallistel 2008). Although physical sound is a waveform with a potentially infinite number of measurable points, in substance-free approaches representations are entirely symbolic and categorical Chabot (in press). In this view, knowledge of representations is encoded as algebraic variables (see Berent 2018), from which generalizations—including over novel forms a speaker has never been exposed to—emerge.

This works by assuming the grammar builds identity functions in the form of natural classes, through which class members share some structural property, such as [+voice][2] or being a coda. Identity functions are category types, and link all members of that category (Berent 2018). For generalizations to emerge, the identity function unites class members, while irrelevant differences between class members are ignored. For example, any voiceless fricative is a good exemplar of the class of voiceless fricatives, regardless of their frequency in the language, typological status or statistical facts about their distribution, or difficulty in articulation or perception: this is because the computational system views the members of a natural class, say the relatively common /f/ and /s/ and the marked /ɸ/, as being

[2]Here the use of [voice] is a familiar and useful shorthand, it is not meant to be a claim about anything in the larynx of acoustic signal and could be recase as [+α] or something similar.

equivalent where phonological computation is concerned. In turn, if some generalized operation targets /f s ɸ/ but not /x/ then /x/ does not contain the unifying feature and is not a part of the natural class, despite its phonetic identity as a voiceless fricative.

The algebraic approach provides a way to reason about phonological knowledge that is independent of the physical world. It is internal, eschewing ontological statements made purely on the basis of external facts. Instead, it views phonology as an interaction between representations and computational processes in which knowledge takes the form of abstract properties which build phonological structure. Phonological theory, in turn, is an elucidation of that structure in formalized terms.

3.2 Reasoning in substance-free phonology

3.2.1 Phonetic correlates of phonological identity

Thus far, the discussion has suggested that phonology is a symbolic system of knowledge which emerges from a formal core in the minds of human beings, and that this knowledge is in the form of an algebraic grammar which is not itself sensitive to the physical properties of externalized speech. It follows that strict adherence to the details of physical phenomena does not provide reliable cues for discovering the nature of the representations and computations which characterize this formal core.

The substance-based position, on the other hand, assumes that phonological identity can be read off phonetic properties in a reliable manner, where for example a phonological vowel is trivially recoverable from the phonetic signal (see wbctp0129 for discussion, this volume). In part, this is because the descriptive vocabulary used for phonetic and phonological categories is often shared across both domains (see Vennemann & Ladefoged 1973). More importantly, it is based on the assumption that representations contain some of the substance of their phonetic correlates.

While this seems to be a reasonable assumption for many patterns which can be straightforwardly described in the same terms at the phonetic and the phonological levels of description, this relationship does not seem to hold everywhere. As Sapir (1925: 47f.) put it, "it is most important to emphasize the fact, strange but indubitable, that a pattern alignment does not need to correspond exactly to the more obvious phonetic one." This is made clear in cases of phonetics/phonology mismatches where phonological identity cannot be trivially recovered from inspection of the phonetic signal since a phonetic cue does not seem to match the expected behavior of a segment in a phonological system(Hamann 2014). For example, Gallagher (2019) describes a phonetic sonorant [ʁ] in South Bolivian Quechua which, though realized as a voiced fricative, patterns with the stops and is analyzed as voiceless /q/. In Hiw, an Austronesian language spoken on Vanuatu, a complex segment /g͡ʟ/ is best understood through its patterning as a liquid rather than a voiced stop (François 2010).

These are not isolated cases, and what the empirical record suggests is that phonological representations are not realized physically in an invariant way—yet another manifestation of the lack of invariance between phonological representations and phonetic expression of those representations. Naive inspection of phonetic cues does not provide reliable insight into a segment's significance as part of a phonological pattern, rather it must be considered in the light of its function within a phonological system.

3.2.2 Sound patterns and phonological structure

The fundamental role played by phonological behavior in the discovery procedure is embodied by the *the phonological epistemological principle* in Kaye (2005: 283) (6):

(6) *Kaye's Phonological Epistemological Principle*:
The only source of phonological knowledge is phonological behavior.

The discovery of phonological identity comes about through the way segments behave in a phonological system (see also Chabot 2019; Gussmann 2001, 2004; Ploch 2003; Purnell 2009). Distributional regularities, allophonic conditioning contexts, natural class behavior, and segment interactions are among the kinds of systematic regularities that phonologists can exploit in the discovery procedure.

As an example, consider the case of Campidanese Sardinian[3], which exhibits an interesting pattern of alternation between obstruents realized as singletons, spirants, and geminates. The pattern is difficult to make sense of: in the intervocalic context the voiceless series [p t ʧ k] sometimes spirantize (7a) and sometimes lengthen (7b), while the voiced series [β ð ʒ ɣ] sometimes spirantize (7c) and sometimes surface faithfully (7d).

(7)	a.	[puɖːa]	'hen'	[sa βuɖːa]	'the hen'
		[tɛrːa]	'earth, soil'	[sa ðɛrːa]	'the earth, the soil'
		[ʧivraʒu]	'durum bread'	[su ʒivraʒu]	'the durum bread'
		[kwatːru]	'four'	[dɛ ɣwatːru]	'of four'
	b.	[piʃːi]	'fish'	[bendia pːiʃːi]	'sell-3SG.PST fish'
		[tɛmpuzu]	'time'	[kustu tːɛmpuzu]	'in those days'
		[kojai]	'to marry'	[oʁia kːojai]	'want-3SG.PST to marry'
	c.	[biɖːa]	'village'	[a βiɖːa]	'to the village'
		[dɔmu]	'house'	[kusːa ðɔmuzu]	'those houses'
		[gatːu]	'cat'	[trɛ ɣatːuzu]	'three cats'
	d.	[barːĩã]	'drill'	[sa barːĩã]	'the drill'
		[dɔtːɔri]	'doctor'	[su dɔtːɔri]	'the doctor'
		[ʤovunu]	'young man'	[su ʤovunu]	'the young man'

Campidanese makes an interesting case study for substance-free phonology because the data has received some attention in the literature (Bolognesi 1998; Molinu 1999), but it has posed particularly acute difficulties for surface-oriented theories (Hayes & White 2015; White 2013). The difficulty stems in part from the fact that all of these alternations are conditioned by what is phonetically a singular intervocalic context, making the pattern resist phonological analysis. Two recent papers, Katz (2021) and Chabot (in press.) provide

[3]For descriptions of Campidanese, see Wagner (1950 [1997]); Virdis (1978); Contini (1986); Jones (1988); Bolognesi (1998); Lai (2021).

analyses of Campidanese lenition and fortition, and provide very different kinds of explanation for the patterns in (7), where each explanation is a consequence of the analytical approach adopted. Katz (2021) adopts a substantive approach based on fine-grained measurements of speech tokens where instrumental evidence is the primary analytical tool, arguing that the pattern is unrelated to any positional effects of phonological lenition or fortition and ejecting the pattern from the remit of phonology.

In contrast, Chabot (in press.) adopts a substance-free approach, arguing that the pattern in (7) is perfectly regular, and phonologically predictable. The key to understanding the pattern, in Chabot's view, is identifying two distinct intervocalic contexts through an account of abstract phonological structure and behavior, rather than raw phonetic cues. The ontological status of these two phonologically distinct contexts is not revealed through direct measurement, but through their effects on phonological patterning.

In the analysis of Katz (2021), lenition and fortition effects in Campidanese are not structural or positional effect, because there is no generalizable effect that the intervocalic position produces; the pattern is reduced to phonetic effects originating in phrasal prosody. Katz identifies two phonological contexts, the initial position and the intervocalic position; consonants in the latter position are subject to a probabilistic phonetic increase in baseline duration in larger prosodic domains, and this is true of both the voiceless and the voiced series. This means that there is no reliable way to predict what the output of a consonant realized in intervocalic contexts will be—a probabilistic property of phonetics (Katz 2021: 657). In turn, the variable output of voiceless and voiced consonants is not the product of a feature-changing phonological operation, but an extra-phonological effect, unrelated to any change in phonological representation. This analysis is based on the observation that all of the alternations in (7) are conditioned by what is phonetically an intervocalic context, where the inspection of surface facts is used to determine phonological identity.

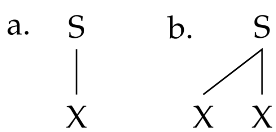
However, this account misses a critical generalization concerning the pattern in (7). Chabot (in press.) argues that the intervocalic context is not a coherent context in Campidanese. To wit, the contexts in (7a) and (7d) are the same, while also being distinct from (7b) and (7c). This is critical generalization that is not captured in the analysis provided by Katz (2021): it is an empirical fact that the morphosyntactic context which spirantizes voiceless stops is not the same as that which lengthens them. In fact, the scope of lengthening of voiceless stops as in (7b) and of voiced stops as in (7c) is complementary, and distinct from the context which conditions (7a).

That is, it is not an accident that voiceless stops lengthen and voiced stops spirantize in the same context, since this context conditions phonological fortition in both sets (see Chabot in press. for the full analysis). Supposing there is a contextual difference between (7a) and (7b), and that this difference is representational, reveals that voiced stops are realized faithfully in the first context (7d), and spirantize in the latter (7c). This provides a means of establishing a direct link between lengthening in the voiceless series and spirantization in the voiced. That is, both series are geminated in one intervocalic context, but not the other.

This generalization argued for by Chabot (in press.) is not equivalent to forcing the pattern in (7) into phonology through the use of some morphological diacritic. The contexts in (7a) and (7d) are said to be the true intervocalic context, in both phonetic and in phonological terms, while the contexts in (7b) and (7c) can all be unified through the use of phonological representations: Chabot (in press.) shows that every context which lengthens a voiceless stop or spirantizes a voiced stop can be represented by an empty position on the phonological timing tier. That is, the contexts in (7b) and (7c) cause lengthening as an underlying segment spreads into an empty position to its left.

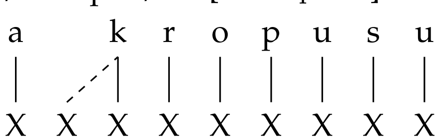
Empty positions are abstract structures with a long history in phonology, beginning with Anderson (1982) and continuing for example in Clements & Keyser (1983); Kaye (1990); Kaye et al. (1985, 1990); Lowenstamm (1996); Schane (1984); Scheer (2004). The existence of abstract structures cannot be confirmed by instrumental observation, but they are assumed to be ontologically real things in human minds revealed through their unifying effect and the explanatory power they provide (see Hyman 1970). Abstract structures of this kind are acquired by learners in the same way they acquire any other phonological representation with no invariant phonetic correlate: by accounting for the generalization with the most appropriate representational configuration provided by their innate faculty of phonological cognition.

Any autosegmental theory (Clements 1986; Clements & Keyser 1983; Goldsmith 1976, 1990; Lowenstamm & Kaye 1985) with a timing tier can account for this representational difference through the distribution of timing positions (8):

(8)


In these representations, singletons are associated to a single timing position (8a), making them distinct from geminates, which are single segments associated to two timing positions (8b).

This means that the phonological process which produces post-lexical geminates can be understood as a process which associates segments to two timing positions. Like some other languages of Italy, Campidanese exhibits a pattern of Raddoppiamento Fonosintattico (RF)[4] (Chabot in press.). That is, an initial consonant is realized as geminate if immediately preceded by an item specified in the lexicon to trigger RF (Fanciullo 1986: 67). In RF contexts, there is an empty position on the timing tier, into which a following stop spreads, as indicated by the dashed association line (9):

(9) /a krɔpus/ → [a kːroβuzu] 'to crows'


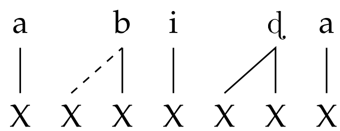
This analysis assumes that phonological length will correlate to an increase in phonetic duration *ceteris paribus*, but that things are often not equal and there are many non-phonological aspects of speech production which may impact the duration of cues

[4]See Loporcaro 1997; Passino 2013, and Russo 2013 for an overview of RF, and Fanciullo 1997 for RF in central and southern Italian languages.

(Clements 1986: 39). In this view, phonological timing a matter of phonological representations (see Davis 2011 for discussion), and Campidanese does not have a reliable durational correlate for geminate structure, as geminates may be realized with approximately the same durations as singletons (Bolognesi 1998; De Iacovo & Romano 2015). The consequence of this lack of an invariant phonetic correlate for geminate structure in the analysis of Katz, where lenition is identified by measuring the phonetic correlates of segments, it that it cannot reveal the geminate identity of spirants derived from voiced stops. In fact, the principal diagnostic for geminates in Campidanese is phonological: they never lenite (see Jones 1988: 321 and Bolognesi 1998: 33). Phonological geminates realized with no increase in phonetic duration are analytic tools known as *virtual geminates* (Ségéral & Scheer 2001: 311ff.), the existence of which is demonstrated through the useful generalizations they allow.

Instrumental data collected by Katz & Pitzanti (2019) suggests that the lenited output of voiced stops (7c) is longer than the lenited output of voiceless stops, but their status as spirants takes empirical priority. Importantly, this phonetic durational effect is in line with the arguments made by Chabot but it is not necessary for establishing their status as phonological geminates. From the perspective of an approach that places the epistemological priority on phonological behavior and structure, it does not seem reasonable to deny that voiced stops also spread into empty timing positions in the same way as voiceless stops, as in (10):

(10) /a biɖɖa/ → [a βiɖːa] ‘to the village’



Most views of fortition do not include spirantization of stops in the set of possible fortitions (Bybee & Easterday 2019; Fougeron & Keating 1997; Lavoie 2001), since fortition is typically considered as a set of phonetic correlates that decrease sonority or increase durational cues. Indeed, where fortition and lenition are identified through inspection of phonetic correlates, spirantization of voiced stops looks like lenition (Bauer 1988; Bybee & Easterday 2019; Kirchner 1998, 2000; Kaplan 2010; Lavoie 2001). Based on the phonetic status of spirantizing voiced stops, Katz (2021: 666) assumes that all spirants are the result of lenition, and forbids the phonological grammar from geminating voiced stops through the most-highly ranked constraint which blocks gemination of voiced stops (see also Bolognesi 1998: 165 and Molinu 1999: 169 who propose equivalent constraints). Chabot (in press.) argues that this is an example of “substance abuse” (Hale & Reiss 2000b, 2008)—misusing phonetic facts in the building of a phonological analysis.

Where explanation for the pattern in Campidanese is concerned, this has two deleterious consequences. First, in entails a loss of generalization since it does not recognize the two distinct intervocalic structures or the scope of fortition over both voiceless and voiced obstruents. Second, such constraints bloat the synchronic grammar by imposing a language-specific device on it, over fitting the formal theory to the data, restricting it the narrow set of facts it describes rather than revealing a more general property of grammars.

In an approach which assigns epistemological priority to phonetic substance, it is impossible to distinguish between the two kinds of intervocalic context in Campidanese, though their existence is an empirical fact: in morphosyntax they are also distinct contexts. More critically, there is no reliable way to distinguish between the two different kinds of voiced spirants: [β ð ʒ ɣ] might be the output of an underlying voiceless stop or an underlying voiced stop, but there is no way to tell for sure which is which.

In contrast, the substance-free approach provides additional generalizations, revealing the distinct intervocalic contexts as well as demonstrating that one of those contexts is a fortition context with scope over both voiceless and voiced stops. In the view of Chabot (in press.), the correct analysis identifies a phonological process which builds geminate structure—an analytic strategy which is only available if the phonetic cues are disregarded in favor of phonological behavior. The analysis in Chabot (in press.) is modular, in that it does not assume that the phonological system is sensitive to substantive content. Further, it does not rely on morphological diacritics to make critical generalizations: it uses well-known representational tools. These two consequences of modularity generate hypotheses concerning phonological representations and computations. To wit, they require the translation of morphological distinctions into phonological vocabulary, thereby revealing the existence of empty timing positions; and they reveal that the lengthening of voiceless stops and the spirantization of voiced stops is a unified process of fortition, a surprising and novel fact about the relationship between phonological computations and their phonetic expression.

4 Strategies of Substance-Free approaches

Substance-free approaches have been adapted to a variety of theoretical frameworks, including rule-based formalisms (Bale & Reiss 2018; Reiss 2018; Hale & Reiss 2008; Volenec & Reiss 2020, 2022), Strict CV Phonology (Chabot in press.), Optimality Theory (Iosad 2017), and Autosegmental Phonology (Odden 2022; Scheer 2022). A substance-free approach is possible in all of these theories because nothing inherent in their basic mechanism requires that representations have phonetic content. As in any adequate theory of phonology (c.f. Anderson 1985: 350), substance-free theories require models of a computational system and of a representational system. In substance-based theories, a phonological feature such as [+nasal] can be directly interpreted as phonetic nasality. However, in a substance-free approach, this is not possible since features contain no directly interpretable phonetic material; a model of the phonetics/phonology interface is thus an additional conceptual necessity.

Beyond this assumption about the three basic parts of the grammar's architecture, there is debate concerning the fundamental nature of all three components of the phonological architecture. These debates have lead to new questions, new discoveries, and new avenues for inquiry.

Representational strategies (§4.1) in substance-free approaches make no primitive assumption about how phonological structure is realized in phonetic terms. Instead, arguments about representational structure are based on how completely the posited structure explains the facts at hand. Representations must be in the form of phonological vocabulary, should be independently motivated, and the success of any proposal can be measured both in terms of how many novel facts it reveals and in terms of how they unify what had previously been seen as unrelated phenomena. Within substance-free phonology the debated facts concern the set of features available to learners, and whether these features are innate or emerge during the course of acquisition.

Computational strategies (§4.2) attempt to account for the behavior of dynamic patterns in phonology, including aspects of natural class behavior and how allophones are realized. Claims about what computations can do are not based on notions of naturalness or markedness, but are limited by notions of parsimony and explanatory power. Questions raised in the literature concern how allophonic computations operate over natural classes and other representational vocabulary, whether computation is parallel or serial, and what kinds of possible phonological operations exist.

Finally, treatments of the interface between phonetics and phonology §4.3 are concerned with the relationship between features and other representations and their phonetic exponents. Work exploring the interface has centered around two opposing positions. The first views the interface as being essentially deterministic and universal, while the second views the interface as working according to an acquired, language-specific program. Each analytic decision across these three components entails consequences for one another.

4.1 Features and high-order representations

There is a consensual view in substance-free approaches that features are the basic representational unit in phonology, and that these features do not contain any phonetic substance; features have thus been the topic of much of the substance free literature treating representational questions (see the discussion in Chabot 2022). Less attention has been paid to higher-order structures such as syllables and other suprasegmental representations (though see Chabot in press. and Idsardi (2022)), perhaps because abstractness above the level of the segment has been a general assumption since Kahn (1976). Beyond the absence of substantive content, there is disagreement as to whether or not feature values are binary (Volenec & Reiss 2020, 2022), or if it is more appropriate to think of them as being unary (Blaho 2008; Chabot 2021; Dresher 2014; Odden 2013, 2022; Samuels 2011b; Samuels et al. 2022). At the level of the segment itself, work by Odden (2022) and Scheer (2022) has explored different ways that features may be organized into hierarchical structures to express sub-segmental dominance relations.

Beyond the content of features, much of the work in the substance-free approach has focused on whether there is a fixed set of innate, universal features (Volenec & Reiss 2020, 2022), or if they emerge over the course of acquisition (Blaho 2008; Boersma 1998; Boersma et al. 2022; Chabot 2021; Dresher 2014; Iosad 2017; Odden 2022; Samuels 2011b). Each of these hypotheses raises further related questions, which continue to spur work within the substance-free program.

4.1.1 Innate, universal feature sets

In early work done within substance-free phonology (Hale et al. 2007), features were argued to be innate and universal. Models that adopted this conception of innate features represent some of the most extensive models with substance-free phonology (Volenec & Reiss 2017, 2020, 2022). In this view, features are devoid of substantive content, but there is a biologically determined set of features from which all phonological systems are built. This means that features are substance-free in the most restrictive sense—they have traditional labels like [nasal] and [high] with fixed phonetic correlates, even though these labels are do not have any particular meaning within the computational system itself beyond serving as the basis for natural-class membership. Feature labels are essentially interchangeable in the computational system since [nasal] is functionally identical to [labial], but they have a consequence in the phonetic expression of representations since [nasal], for example, is deterministically and universally interpreted as phonetic nasality (see §4.3).

The innate, universalist hypothesis is based on an argument that there are no true blank slates in human cognition (Volenec & Reiss 2022: 594); learning can only happen if there are basal primes which themselves are not learned but can be put together in novel ways to allow for learning to happen. While there is no definitive claim concerning the exact number of features in the universally determined set, Volenec & Reiss (2020, 2022) argue that whatever the set of features, since they are combinable, a relatively small number could account for a great many segments—more than any one language uses and probably more than humans could actually articulate.

A set of binary features can be used to build a natural class defining a single segment, say /t/ or /d/, but natural classes can be in a sense incomplete and thereby build larger sets of segments, including abstract, underspecified segments such as /D/. This allows for analytic strategies that provide explanatory accounts for the behavior of segments which seem to have some phonetic cue, but that cue seems to be inert in the phonology. A classic example is the behavior of [v] in several Slavic languages including Polish and Russian, which like the class of sonorants does not trigger voicing assimilation, but does, like the obstruents, undergo devoicing. This ambiguity in patterning has caused a great deal of ink to be spilled, and the solution proposed by Reiss (2017) is to view [v] as a segment underspecified for voice, /V/. In other words, /V/ does not trigger voicing assimilation because it has no [+voice] specification to spread, but it can be devoiced like any other obstruents when [-voice] spreads to it.

4.1.2 Emergent features

There is an alternative view which holds that features emerge over the course of acquisition (this view is not just held by practitioners of substance-free phonology, see Mielke 2008 and the volume edited by Clements & Ridouane (eds.)). This is a minimalist assumption concerning the nature of representations, in which no feature is predetermined in human cognition, though the capacity to extract features from the ambient linguistic data in order to build phonological systems (perhaps stemming from a general capacity for category building, see Ashby & Maddox 2011; Harnad 2005; Skelton et al. 2017). In this view, there is no conceptual need for natural classes to be phonetically heterogeneous—features serve as indices of natural class-hood, but have no deterministic exponent.

There are two basic strategies for the acquisition of feature systems in the emergent views. In the first, the basis for feature acquisition is activity: learners posit features to account for the patterns of alternations in the ambient linguistic data (Blaho 2008; Danesi

2022; Iosad 2017; Odden 2021, 2022; Samuels 2011b). That is, it is possible that feature are learned on the basis of pertinent evidence in sound patterns, as demonstrated by Odden (2022) for the Bantu language Kerewe; what allows for patterns to be acquired is the innate knowledge that phonological computations exist.

The details of the computational formalism depend on the specific theory (§4.2), but in any theory the form of computations is limited by the possible operations in the phonological component. For example, the computational system may spread features, but there is no operation which can switch all feature values across alternating segments. This view holds that what is innate to humans is their capacity for defining segment classes for rule application and their sensitivity to distinct representations, but not any kind of knowledge about labiality or voicing in phonology.

The use of phonological activity in the construction of feature sets depends critically patterns of alternation—distributional facts and other static patterns are not thought to play a role. This means that some languages, such as Hawaiian or Vietnamese, which have relatively fewer dynamic patterns, pose an analytic challenge for learners. In such cases, Odden (2022) suggests that contrast can step into the breach and serve as the basis upon which learners posit features to arrive at a system of distinct representations.

Given the role contrast plays in this discovery procedure, it may be that contrast is in fact all that is required, a position defended by Dresher (2014). In the contrastivist view, the only features which are phonologically relevant are those which are contrastive (Dresher 2009; Hall 2007; Iosad 2017). During acquisition, learners organize contrastive features into feature hierarchies (see Dresher 2009 for details); the structure of these hierarchies is language specific and their organization reflects phonological activity. In this view, feature hierarchies provide explanation for the phonological patterns in languages. While sensitivity to contrast and the capacity for hierarchical organization of features is universal, the features themselves, and their content, are not.

4.2 Substance-free computation

The computational wing of substance-free theories—as in any generative theory—operate over representations as they are mapped from underlying forms to surface representations. Specific proposals for computational mechanisms have been framed in a variety of theories, including serial and parallel approaches. In all of these models, features are indices of natural classes; since they contain no phonetic content, the computational operations are insensitive to any information about the physical world. This means that the computational system could potentially effect phonetically unnatural operations, such as changing [dorsal] into [labial] in the context of [nasal].

In serial approaches computations are ordered, feature-changing operations with formally defined contexts and domain-specific scope. In a Minimalist approach, the basic desideratum of rule formation is simplicity: given multiple analytical possibilities for accounting for a pattern of alternation, the formalism which involves the fewest features and the most parsimonious operations is to be preferred. Odden (2021) argues that the notion "change" as a primitive operation is a conceptual anomaly, since any kind of change effected on the way from underlying representation to surface form may be understood as either deletion or insertion—or a sequential process of insertion followed by deletion.

Bale & Reiss (2018); Volenec & Reiss (2020, 2022) propose a model which dispenses with change, in which computations may insert features or delete them, but not change them. A change from [dorsal] to [labial] then would first delete [dorsal] and then insert [labial]. Serial models have been proposed by Samuels (2011b) using precedence based models (see Raimy 2009 and Idsardi 2022), and Chabot (2021, in press.) using an autosegmental model.

Parallel approaches assume that computations are mediated by constraints on output forms (Iosad 2018; Kager 1999; Prince & Smolensky 1993 [2002]). These models are framed in Optimality Theory (Prince & Smolensky 1993 [2002]), where features interact through constraint templates. Where serial theories are typically stated as rules that are explicitly-defined operations over strings, constraints are well-formedness conditions imposed on possible computational outputs (see Odden 2011 and Uffmann 2011 for discussion). The constraint templates serve as a filter, insuring that an unbounded set of inputs can be compared such that the one which satisfies the greatest number of constraints will be selected as the output form (Paradis 1988).

Classical OT is a surface-oriented theory in that markedness constraints are assumed to be instantiations of universal conditions imposed on representations by the physical world—notions of ease of articulation, perception, and phonetic naturalness. Thus, most versions of OT are not substance-free (see discussion in Reiss 2018: 427ff.), as the grammar has substantive-content built directly into it. This is not a property of the overall architecture of OT however, it comes about through the content of markedness constraints. Blaho (2008); Iosad (2017) use the architecture of OT but excise it of universal markedness by recasting markedness constraints as emergent patterns which arise on a language-specific basis, in a sense as grammaticalized epiphenomena following from the interactions of representations within the grammar itself. In these models, constraints are learned and impact the selection of optimal forms, but the constraints are neither fixed nor universal. Critically, they are also informationally encapsulated, and do not contain information from the physical world; they are sensitive only to phonological vocabulary.

4.3 The interface of phonetics with phonology

Whether or not a given phonological theory traffics in substantive representations or not, there is an ontological distinction between the gradient, continuous domain of phonetics and the discrete, categorical domain of phonology (see Cohn 2007; Keating 1984 *inter alia*). There is thus a conceptual necessity for an interface which maps between the two domains, translating between the categories of phonological representations and the gradience of durational means and articulatory ballistics of phonetic implementation (Cohn 1998; Keating 1988, 1996; Hamann 2011; Kingston 2007, 2019; Scobbie 2007). In Chomsky & Halle (1968), this interface is trivial since labels like [nasal] and [voice] refer to qualities of both domains: the phonological category [+nasal] only needs to be translated into a scalar analogue, e.g. [3.2nasal].

In substance-free approaches, this conceptual necessity requires a more elaborate model which can map between the abstract, substance-free representations and their concrete physical exponents. Since phonological representations contain no phonetic substance, there must be a mechanism through which representations are imbued with phonetic content before they can be realized as their phonetic exponents.

It is worth noting, however, that this requirement is not the unique property of substance-free approaches. Significant work on the phonetic realization of cross-linguistically comparable patterns described a variety of language-specific phonetic effects (Keating 1985, 1990), suggesting that at least some properties of phonetic exponence must be learned (Kingston 2019; Kingston & Diehl 1994). The existence of these effects demonstrated the inadequacy of direct mapping of the kind modeled in Chomsky & Halle (1968)—features are not in the interface, but rather are interpreted by the interface according to speaker knowledge acquired in language-specific contexts.

Indeed, the model developed in Chomsky & Halle (1968) posited a universal mechanism by which phonological features were interpreted; this predicted that [+nasal] would be phonetically realized in one language essentially the same way as in another. However, it became clear that, although features could be fruitfully compared in terms of their contrastive function across languages (c.f. Trubetzkoy 1969), those contrastive features did not reliably display comparable phonetic targets or the same pattern of phonetic variation (Fudge 1967; Ladefoged 1971; Pierrehumbert 2001). For example, what might be transcribed as [i], a symbol for a specific position within a vowel system, is only approximately the same across different languages in phonetic terms (Cohn 2011). This is yet another indication that the phonetic expression of representations of equivalent phonological relationships varies in its physical details.

Put another way, it seems that acquisition of a phonological system entails a language-specific means of phonetically implementing phonological features (Boersma 1998; Cowper & Hall 2015; Cyran 2014; Keating 1985, 1988; Kingston & Diehl 1994; Pierrehumbert 2003). If features correlate to acoustic cues, the expression of a feature can be effected in multiple ways since those cues can come about through multiple articulatory configurations (Halle 1983; Hamann 2004; Ladefoged 1980). One interpretation of this is that the expression of a phonological feature is not fixed—the only constant is the role a feature plays in as a contrastive unit in a system (Dresher 2009), or as a natural-class index.

This variable correlation between phonetic expression and phonological identity is apparent in how laryngeal contrasts are realized. That is, [±voice] may mark a contrast between [p t k] and [b d g], or unite the natural class [b d g v z], but there are multiple laryngeal configurations that can satisfy these functions (Avery & Idsardi 2001; Boersma 1998; Honeybone 2005; Iverson & Salmons 1995). One interpretation of these facts is that phonological [voice] contrasts are not in a fixed relationship with an invariant articulatory configuration (Ohala 1992).

In substance-free phonology, this lack of invariance between phonological features and their exponence is interpreted in one of two ways. In the view of those who hold that phonological features are universal and form a fixed set (Hale et al. 2007; Volenec & Reiss 2017, 2020, 2022), it is hypothesized that the relationship between features and phonetic correlates is also universal and thus fixed: individual features are realized the same way in every language. The apparent language-specific phonetic effects discussed above are due to the combinatorial nature of features, meaning that subsets of a relatively small super set of features can result in a great many possible surface segments through combinatorial explosion—possibly more segments than human vocal anatomy could produce.

In models with innate features, computations are not sensitive to the content of features like [nasal], but in the interface their expression is deterministic: [nasal] must be expressed with phonetic nasality. However, for models in which features emerge during acquisition, the universal, fixed-interpretation interface cannot hold. Since the features emerge based on language-specific patterns, it follows that the mapping between those features and their phonetic interpretation also emerges during acquisition. In this view, the expression of phonological features works essentially like a look-up table (Boersma 1998; Boersma & Hamann 2008; Chabot 2021; Scheer 2014), where a given feature [F] is expressed through an acquired, rather than an innate mapping.

This means that a feature [F] has no innate interpretation, it could be interpreted phonetically as nasality, or as labiality, or any other phonetic exponent, depending on its mapping in the interface. This means that the interface can take on a certain amount of labor that has been imputed to phonological computations in other models. For example, Iosad (2012) provides a substance-free analysis of vowel reduction in Russian, arguing that realization of schwa allophones of full vowels is not the output of phonological computation, but rather of how phonological structure is interpreted at the interface. While this kind of look-up table model predicts an arbitrary spell-out of phonological representations, the model is not unconstrained in what it does. For example, the interface is only interpretative, it cannot effect any computations—it cannot change feature values, add or remove association lines, or resyllabify. While phonetic exponence of phonological representations is unconstrained, the range of possible phonological structures and possible computational operations is not.

It is apparent from this discussion that there is still a great deal that we do not understand about how phonological representations are realized as physical objects. As pointed out by Hamann (2011), it is unlikely that experimental work alone will provide full explanation, since determining what the interface even does depends a great deal on a host of theoretical assumptions. The interface thus represents one of the areas with the most potential for fruitful work—including collaboration between phonologists and phoneticians—as there is still much about it to be learned.

5 Conclusion

This chapter opened with one of the hardest challenges facing phonologists: determining to what extent phonetic substance is reproduced in phonological knowledge. The substance-free answer to this challenge is to assume that there is no phonetic substance at all in phonological knowledge. When phonetic substance is evacuated from phonology, phonology can not be understood as the study of sound; rather it must be understood as the study of sound patterns—the principals by which human minds organize the infinitely gradient world of physical sound. While speech sounds are not linguistically significant by themselves, their structure and use as linguistic symbols is.

Phonetic substance has a long-standing role in phonological inquiry. While assuming that phonology is yoked tightly to the physical world served as a useful tool in limiting overgeneration, the variable correlation between sound and structure is an unreliable assay in phonological epistemology and makes false predictions about what is possible and impossible in sound patterns. Substance-free phonology places the theoretical priority on explanation for sound patterns and loosens the reins on the computational system, predicting that many more languages are possible than are actually attested (see Hale & Reiss 2008: 3 for discussion). For example, there is no reason to assume, in a substance-free approach, that a language could not nasalize /æ/ in closed syllables, but such a phenomena may be unattested for purely mechanical reasons which lay outside of phonology.

However, this does not mean that substance-free phonology assumes that languages can vary "without limit and in unpredictable ways" (Joos 1958: 96), or that it has no predictive ambitions. For example, Hale & Reiss (2008: 3) predict that there are no languages which stress prime-numbered syllables. Chabot (2021: 188) predicts that length harmony is impossible, arguing that the computational system can not harmonize timing positions in the same way it can harmonize features. Scheer (2022: 465) predicts that there can be no voice/place interactions between consonants because of the way voice and place are organized within segments. While any of these predictions may be falsified, they are all based on claims about the structure and organization of phonological representations and their interaction with the computational component, rather than conceptions of markedness, phonetic naturalness, or other ways in which the physical world might impact sound systems.

The substance-free view holds that, as theories recapitulate surface-level variation, the formal structures become as varied as the surface patterns they are meant to generalize over, sapping the theories of explanatory value as they become increasingly faithful reproductions of the physical signal. This is not to say that phonology does not depend on detailed observations of sound patterns, only that those observations are considered within a reasoned framework which leads to classificatory schemes, a systematic classification of those abstract structures and processes that are available to all human beings. Substance-free theories continue a long tradition in phonology and in science more generally in that they *increase* regularities (Goldsmith & Laks 2019: 72) across languages as they abstract away from language-specific variation. The ultimate goal of this enterprise is to move beyond the narrow scope of measuring physical sound, increasing our understanding of the fundamental nature of the human capacity for organizing sound patterns.

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