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3xPhonology

Abstract
What does it take to run a full substance-free phonology (SFP)? Because in classical approaches only items below the skeleton have phonetic properties that according to SFP need to be expunged, to date work in SFP only ever concerns segmental aspects. If substance is removed from segmental representation and primes and computation are therefore arbitrary, the non-trivial question arises how such a system can communicate with a system where primes and computation are not arbitrary (at and above the skeleton). The two phonologies below and at / above the skeleton that exist in production are complemented with a third phonology that occurs upon lexicalization, i.e. when L1 learners or adults transform the acoustic signal into a stored representation. Finally, the core of the article argues that this broad architecture is inhabited by three distinct computational systems along the classical feature geometric divisions: Son(ority) is located at and above the skeleton, while Place and Lar(yngeal) live below the skeleton. A non-trivial question is then how a multiple-module spell-out works, i.e. how ingredients from three distinct vocabularies can be mapped onto a single phonetic item. It is argued that the skeleton plays a central role in this conversion.

1. Introduction[1]

The goal of this article is to make explicit what it takes to run a substance-free phonology (SFP). The very idea of phonology being substance-free entails i) that in current approaches there is substance in phonology which needs to be removed and ii) that there is a place where substance can and should exist, which is not phonology. Substance being another word for phonetic properties, ii) means that SFP is necessarily modular in kind: there is a phonological system that is different from a phonetic system. Both communicate but do not overlap: there is no phonology in phonetics and no phonetics in phonology. This describes exactly the Fodorian idea of modularity where distinct computational systems work on distinct sets of vocabulary and communicate through a translational device (spell-out).

The consequence of i) is the starting point of the article: to date work on SFP only ever concerns melody, i.e. items which in a regular autosegmental representation occur below the skeleton. The reason is that this is where phonetic properties are located and need to be removed: there is nothing to be removed from items at and above the skeleton because they have no phonetic properties. That is, the feature [±labial] has phonetic content, but an onset, a grid mark or a prosodic word do not. This is why work in SFP never talks about syllable structure or other items that occur at and above the skeleton (section 2.1).

Therefore what it takes to make SFP a viable perspective is not only to remove substance from phonology, to show how phonology relates to phonetics and to explain how acquisition works: it is also necessary to answer a number of non-trivial questions that arise when the area from which substance was removed and where primes and computation are therefore arbitrary (below the skeleton) communicates with a system where primes and

[1] The paper is a result, among other things, of the discussion with local phonologists in Nice: Diana Passino, Alex Chabot and Paolo Danesi.

computation are not arbitrary (at and above the skeleton). This distinction is the heart of the article (section 2).

The two phonologies at hand occur in speech production, i.e. when a multi-morphemic string submitted to phonological interpretation (a phase, or cycle) is pieced together from morphemes that are stored in long term memory. Phonological activity also occurs prior to this situation, though: in order for a lexical item to be stored in long term memory, the gradient and non-cognitive acoustic signal needs to be converted into a discrete cognitive representation. Lexicalization phonology (as opposed to production phonology) is introduced in section 3. This amounts to three phonologies altogether (two in production, one upon lexicalization), which is one motivation for the title of the article.

Sections 4 and 5 take a closer look at the content of the two areas that are distinguished in production. It is argued in section 4 that the traditional division of phonology into sonority, place and laryngeal primes (as embodied in Feature Geometry) in fact defines three distinct computational systems (modules): Son, Place and Lar. In section 5 these are shown to either live at and above (Son) or below the skeleton (Place, Lar). A lexical entry of a segment has thus three compartments hosting items of three distinct vocabulary sets (just like the lexical entry of a morpheme is made of three distinct vocabulary sets: morpho-syntax, phonology, semantics). The challenge then is to explain how the three modules communicate in general, and what guarantees segment integrity in particular (how does the system "know" which Son primes, Place primes and Lar primes belong to the same segment?). The question is thus how a multiple-module spell-out works, i.e. how ingredients from three distinct vocabularies can be mapped onto a single phonetic item. It is argued that the skeleton plays a central role in this conversion.

The division into three content-defined modules Son, Place, Lar also motivates the title of the article.

Section 6 considers a pervasive question raised by the presence of a spell-out in addition to regular phonological computation: is a given alternation due to the former (interpretational) or to the latter (phonological)? Finally, the conclusion in section 7 addresses questions that are raised by the distinction between phonologically meaningful (non-arbitrary: Son) and phonologically meaningless (arbitrary: Place, Lar) primes. It is argued that the former match Hale & Reiss' version of SFP where primes and their association to phonetic categories are given at birth, while the latter instantiate the take of all other SFP approaches where both primes and their association to phonetic categories are emergent (i.e. acquired by the infant). In a biolinguistic perspective, the concluding section also speculates on the question why Son primes are non-arbitrary and Place primes arbitrary, rather than the reverse.

2. What exactly is substance-free?

2.1. Phonological objects with and without a phonetic correlate

The idea of substance-free phonology (SFP) concerns the melodic (or segmental) side of phonology, i.e. items that are found below the skeleton in a regular autosegmental representation. The area at and above the skeleton is not within the purview of this approach.[2] The reason is that only items can be substance-free which are (wrongly according to SFP) taken to have a substance. Substance is another word for phonetic properties, but onsets, rhymes, stress, prosodic words, metrical grids, skeletal slots or whatever other item occurs at

[2] As far as I can see this holds for all versions of SFP or approaches that are akin (see the overview in Scheer 2019), including Hale & Reiss (2000, 2008), Volenec & Reiss (2018), Boersma & Hamann (2008), Hamann (2011, 2014), Mielke (2008), Carvalho (2002), Odden (2006, 2019), Blaho (2008), Samuels (2012), Iosad (2017), Dresher (2014, 2018), Chabot (2019).

and above the skeleton do not have any: only items below the skeleton (segments) have a phonetic correlate that SFP argues needs to be removed.[3]

The exclusive focus of SFP on items below the skeleton highlights a fundamental property of cross-theoretically consensual autosegmental representations: phonetic properties are only present below the skeleton. In a substance-free perspective, this division translates into the following statement: items at and above the skeleton have no phonetic correlate, while items below the skeleton do.

Note that this is not just an analytical choice that phonologists happen to have made when autosegmental representations were developed. Rather, it transcribes the true workings of phonology independently of the question whether phonological representations ought to be substance-free or substance-laden. Even if SFP standards are met and phonetic correlates are entirely expunged from phonology, the difference remains: items below the skeleton (now in substance-free guise: α, β, γ etc.) will be specified for a phonetic correlate post-phonologically at the interface with phonetics (there are a number of ways of how this is done in the SFP literature, see the overview in Scheer 2019a): just like at the upper interface (of morpho-syntax with phonology, for example past tense ↔ -ed in English), spell-out is based on a list that infants need to acquire. This list (spell-out instructions) defines which phonological objects are associated to which phonetic categories, e.g. α ↔ labiality, β ↔ backness etc. Certain phonological objects are part of this list, while others are absent, and the division is the one mentioned above: items below the skeleton (alphas, betas etc.) do entertain a spell-out relationship with a phonetic category, but items at and above the skeleton do not and hence are absent from that list. As was mentioned in note 3, they may influence the phonetic properties of segments (through phonological computation: ɫ → w in coda position), but are not themselves associated to any phonetic correlate (there is nothing like coda ↔ palatality etc., more on this in section 6).

As far as I can see this crucial distinction plays no role in the literature and is not made explicit. Considered from the phonetic viewpoint, it is about the presence or absence of a phonetic correlate. Looked at from the phonological perspective, it distinguishes items without phonological identity that are interchangeable and whose only raison d'être is the expression of contrast (alphas, betas, gammas etc.) and objects whose phonological identity matters and which are not interchangeable (onsets, nuclei, feet, prosodic words etc.). That is, the phonological prime to which phonetic labiality is associated may be anything and its reverse as long as it is distinct from other primes (an alpha is not any more appropriate than a beta or a gamma), but an onset could not be replaced by a nucleus. In short, items below the

[3] Items at and above the skeleton bear on the phonetic realization of segments (e.g. a lateral is pronounced w in a coda, but ɫ in an onset), but do not have any phonetic properties themselves. This is obvious for onsets, nuclei, prosodic words, the metrical grid etc., but also true for prominence: the supra-skeletal item is lexically defined or distributed according to an algorithm (ictus), and then represented above the skeleton (as foot structure, metrical grids, extra syllabic space etc.) with no reference to its phonetic value. The phonetic correlates of prominence are not present in the phonological representation (unlike labiality in [±labial] etc.): they are only introduced in regular phonetic interpretation thereof. That is, prominent segments bear three phonetic properties (in all languages, Ladefoged & Ferrari-Disner 2012: 24): loudness (measured in decibels), length (measured in milliseconds) and pitch (measured in Hertz), the two latter being able to be phonologized (Hyman 2006). Therefore there is no substance to be removed from the phonological representation of prominence that only marks the ictus (foot structure or the metrical grid have no phonetic content) and SFP is not concerned with it.

In principle the same goes for tone that occurs above the skeleton in an autosegmental representation: L and H distinguish two phonologically relevant tonal items, but do not bear any intrinsic phonetic value (in pre-autosegmental days tone was considered a segmental property, though: see Hyman 2011: 206ff).

Finally, in Government Phonology, empty nuclei are said to have a specific pronunciation, ɨ (or ə) – but this is the pronunciation of an *empty* nucleus, not of a nucleus. That is, the absence of melody is a melodic item, and it is this melodic item, zero, which has a phonetic correlate.

skeleton are phonologically meaningless, while items at and above the skeleton are phonologically meaningful.

Table (1) sums up the discussion thus far, showing that SFP in fact operates a fundamental segregation between two types of phonology, below and (at and) above the skeleton.

(1) phonologically meaningful and meaningless items

	phonologically	interchangeable	phonetic correlate
items below the skeleton	meaningless	yes	yes
items at and above the skeleton	meaningful	no	no

2.2. Consequences of being phonologically meaningless or meaningful

Removing phonetic substance from (melodic) primes turns them into naked placeholders of phonological contrast that lack any phonological identity, are interchangeable and hence arbitrary.[4] They are arbitrary in three ways:[5]

(2) arbitrariness

a. the prime itself is arbitrary
Calling primes alphas, betas etc. expresses their lack of phonological or phonetic identity: they are arbitrary items without intrinsic phonological value whose only raison d'être is to exist and to be different from others. They become non-arbitrary only post-phonologically through an association with a phonetic correlate.

b. the computation of primes is arbitrary
Any substance-free prime (or value thereof) may be turned into any other substance-free prime (or value thereof) in any context and its reverse.

c. the association of a prime with a phonetic category is arbitrary
Any phonetic category may in principle be associated to a phonological prime: the symbol "↔" materializes the arbitrary character of the association just like at the upper interface where, say, the association past tense ↔ -ed (in English) is arbitrary. The choice made in a given language is arbitrary, but of course once this choice is made (past tense ↔ -ed in English, α ↔ labiality) the association is settled, lexically stored (as a spell-out instruction) and cannot be modified (except in diachronic evolution).

The computation of substance-free and phonologically meaningless primes is necessarily arbitrary: in presence of colourless alphas, betas etc., it is not even possible to talk about "natural" or "unnatural" processes, or to distinguish any type of licit vs. illicit event for that matter. Substance-free primes do not "know" how they will eventually be pronounced and hence all logically possible processes based on them are equally probable, possible,

[4] The structuralist heritage in this setup is obvious: the only function of phonological primes is to assure contrast. Also, the elimination of phonetics from phonology makes good on the saussurian distinction between Langue and Parole: there is no Parole in Langue and Langue is a kind of algebra of abstract units ("la langue est pour ainsi dire une algèbre" Saussure 1916: 168).

[5] (2)c is not shared by all versions of SFP: Hale & Reiss' approach is innatist in the sense that both (substance-free) primes and their association to phonetic categories are genetically coded and present at birth (Hale *et al.* 2007: 647f, Volenec & Reiss 2018). By contrast all other versions of SFP quoted in note 2 hold that primes are emergent, i.e. absent at birth, and that their association to phonetic categories is learned during first language acquisition. See the survey of this issue in Scheer (2019a: 111-113).

legal.[6] Substance-laden n → ŋ / __k is "natural" and ŋ → m / __r is not, but the same processes expressed with alphas and betas cannot even be judged for naturalness: $\alpha \rightarrow \beta$ is not any more or less "natural" than $\alpha \rightarrow \gamma$ since naturalness is not defined for alphas, betas and gammas. Only objects with phonetic properties can be more or less natural, but the very essence of alphas and betas is to not bear any phonetic properties (in the phonology where phonological computation occurs).

By contrast phonologically meaningful items that occur at and above the skeleton do have an intrinsic phonological value and therefore are not interchangeable. As a consequence, their computation is not arbitrary: a vowel cannot be placed in a coda during syllabification, stress cannot fall on onsets etc. The following section shows that this segregation between the arbitrary workings of phonologically meaningless and the non-arbitrary workings of phonologically meaningful items is supported by an interesting empirical pattern.

2.3. Crazy rules are only ever melodically crazy

A crazy rule is one that does not make sense phonetically speaking, i.e. which is not "natural". Since Bach & Harms (1972) there is a small literature on crazy rules that documents particular cases such as i → u / d__ (Southern Pomoan, Buckley 2000, 2003) (Hyman 2001, Vennemann 1972). Chabot (to appear) has drawn an inventory of cases mentioned in the literature. A relevant generalization is that crazy rules are only ever melodically crazy (see also Scheer 2015: 333f). That is, in a crazy rule A → B / C, A and B are only ever items that occur below the skeleton. There do not appear to be crazy rules that manipulate items at and above the skeleton: compensatory shortening, closed syllable lengthening, tonic shortening etc. (syllable structure) or anti-Latin stress (stress falls on the antipenultimate syllable except when the penultimate syllable is short, in which case this syllable is stressed) are not on record.

But crazy rules not only appear to spare items at and above the skeleton: they also seem to make no reference to them in the conditioning context: i → u / d__ is reported for Southern Pomoan, but rules like i → u in closed syllables, p → r in coda position, or p → r after tonic vowels do not appear to occur.

Of course Chabot's sample of crazy rules is incomplete and there is no guarantee that there are no syllabically or stress-wise crazy rules out there. But given the arbitrary and incomplete sample, there is no reason for all documented cases to accidentally concern only melodic properties.

Therefore the absence of crazy rules concerning syllable and stress properties is likely to be significant. This absence is exactly what is predicted by SFP: the computation of phonologically meaningless items (alphas and betas that occur below the skeleton) is arbitrary (2)b, but the computation of phonologically meaningful items (at and above the skeleton) is not.

2.4. An arbitrary and a non-arbitrary phonology

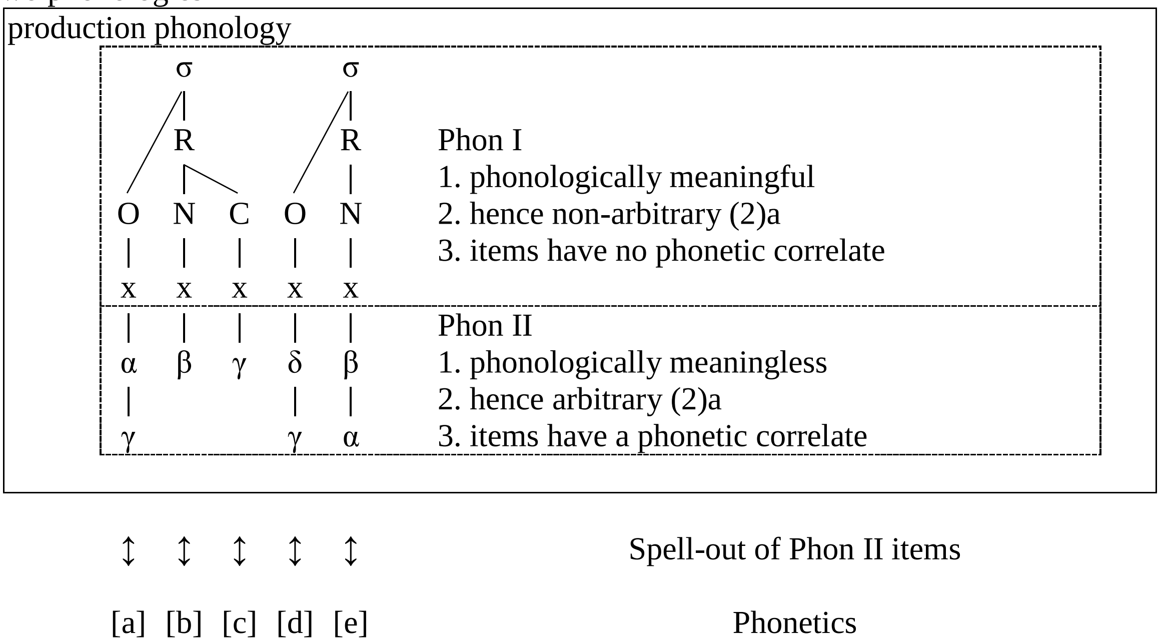
[6] But there may be formal restrictions on what a possible process is: Reiss (2003: 230) argues that for example the computational system must not be able to produce a situation where two segments must have opposite feature values for all of a given subset of features. This is still expressible when features are alphas, betas etc. But it is not if they turn out to be monovalent, as Odden (2019) argues for. Hence some decisions need to be made even with substance-free primes, which may be monovalent or binary, of the size of SPE features or bigger, holistic items such as Elements in Government Phonology (or primes in Dependency Phonology and Particle Phonology). These issues are orthogonal to the purpose of the present article.

A direct and necessary consequence of SFP is thus the coexistence of an arbitrary and a non-arbitrary phonology in the sense of (2)a (objects) and (2)b (the computation of these objects). Arbitrary phonology occurs below, non-arbitrary phonology at and above the skeleton. This is shown under (3). The representation also shows a plausible consequence of the fact that only items below the skeleton have a phonetic correlate: only these items are spelt out. Since spelling out an item is the process of assigning it a phonetic value, items at and above the skeleton cannot be spelt out: as was shown they precisely lack any phonetic correlate.

For the time being the two phonologies are i) taken to be static (i.e. areas in the autosegmental representation) and ii) are called Phonology I and II. They occur in a box termed production phonology under (3), referring to the computation that turns an underlying (lexical) into a surface representation (which is then subject to spell-out). It is opposed to lexicalization phonology, to be introduced in section 3, which includes those phonological operations that occur upon lexicalization of morphemes, i.e. when the phonetic signal is transformed into a lexically stored item.

This setup will be refined as the discussion unfolds.

(3) two phonologies[7]



The coexistence of an arbitrary and a non-arbitrary phonology has an obvious consequence: we are dealing with two distinct computational systems, i.e. two distinct modules. Computation within a single module could not possibly be arbitrary and non-arbitrary at the same time, or process two distinct kinds of vocabularies (phonologically meaningless alphas / betas and phonologically meaningful onsets, feet etc.). Indeed, Fodorian modularity expresses the insight that the mind/brain is made of a number of distinct computational systems that operate over individual and mutually unintelligible input vocabularies (domain specificity, Segal 1996, Gerrans 2002, Carruthers 2006: 3ff ajouter les réfs et un peu de discussion de la section 3 du papier pour Radical).

This setup raises non-trivial questions regarding the communication of Phon I and Phon II:

[7] Here and below representations are used that are as theory-neutral as possible. The onset-rhyme structure is meant to represent a common denominator for autosegmental syllable structure. Nothing hinges on its properties and alternative incarnations of syllable structure would be just as well suited to illustrate the purpose.

(4) questions raised by the existence of two phonologies in production
  a. bottom-up communication
     Syllable structure is a function of items below the skeleton, i.e. of the sonority of segments as well as of their linear order. How could arbitrary units whose computation is also arbitrary produce non-arbitrary syllable structure?
  b. top-down communication
     Lenition and fortition that are visible on segments are a function of syllable structure. How could non-arbitrary syllable structure be transmitted to the arbitrary part of phonology, i.e. influence arbitrary alphas and betas?

In both cases under (4) the communication between the two phonologies is non-arbitrary: syllable structure is not just anything and its reverse given (segmental) sonority, and the lenition / fortition that is visible on segments is not random (lenition occurs in weak, not in strong positions).[8]

3. What happens upon lexicalization

Children (upon first language acquisition) and adults (when they learn new words such as acronyms, loans etc.) create new lexical entries.[9] The input of this process is the (acoustic) gradient phonetic signal, and its output is a discrete symbolic (phonological) representation. This much is true for sure and undisputed.[10]

The lexicalization process filters out linguistically irrelevant properties contained in the phonetic signal such as pitch variations caused by male / female speakers, the emotional state of speakers or the influence of drugs such as alcohol on their production.

Linguistically relevant information is transformed by the lexicalization process: the gradient non-symbolic input is stored as a sequence of discrete phonological units (segments) that decompose into melodic primes (traditionally substance-laden [±lab] etc., substance-free alphas and betas in SFP). This includes temporal order: the temporal continuum is transformed into a linear sequence of discrete phonological units (segments). Linear structure in phonology is represented as a sequence of timing units (the skeleton).

Traditionally, syllable structure is absent from the lexicon: rather than being constructed upon lexicalization and stored, it is built during production phonology, i.e. when the multi-morphemic string created by morpho-syntactic computation is interpreted by the phonology (underlying-to-surface). There is good reason to believe that the syllabification algorithm runs already upon lexicalization, though, and that the lexicon is hence fully syllabified (rather than containing an ordered sequence of unsyllabified segments).[11]

In Slavic languages for example, phonetically identical vowels may or may not alternate with zero: whether or not they alternate is a lexical property of each morpheme. Thus the

[8] Of course lenition may also occur in strong positions: this is the case in spontaneous sound change, i.e. when a given segment is modified in all of its occurrences regardless of position. But there is a non-arbitrary impact of position on lenition and fortition: lenition may occur in strong position, but only when it also occurs in weaker position. Cases where, say, lenition is observed word-initially (strong) but not intervocalically (weak) do not appear to be on record. That is, positional strength is relative, rather than absolute (Ségéral & Scheer 2008: 140-143).

[9] Much of this section owes to Faust *et al.* (2018).

[10] For those who believe that there are symbolic representations at all. It should also be consensual in exemplar theory quarters (Bybee 2001 and related work) where lexical items are still symbolic and discrete, but enjoy multiple versions for each lexical entry.

[11] This is the position taken by Government Phonology since its inception (Kaye *et al.* 1990, Scheer & Kula 2018). Vaux & Samuels (2018) provide a documented overview of the question whether syllable structure should be present or absent in the lexicon.

vowel of a Czech CeC root may (*pes* - *psa* "dog NSG, Gsg") or may not (*les* - *les-a* "forest NSG, Gsg") alternate with zero. When a child comes across the unsuffixed CeC form without having heard its inflected version that bears the vowel-initial suffix, they need to decide whether the vowel will be marked as alternating or non-alternating in the lexicon (and may be wrong: taking stable for alternating vowels or the reverse is a typical error made by children, Łukaszewicz 2006). This information is thus stored in the lexicon for sure. In autosegmental times, it is consensual that the difference between alternating and non-alternating vowels is syllabic in kind: the latter is endowed with an x-slot, while the former is floating according to Rubach (1986) (see Scheer 2011 for an overview, also of other syllabic means to represent the difference).

Another convincing argument comes from syllabic minimal pairs. Kaye & Lowenstamm (1984: 139) mention the case of French *ouate* "cotton wool" and *watt* "watt (electric unit)" which are homophonous: both are pronounced [wat]. The former provokes elision (/lə wat/ is realized *l'ouate* [lwat][12]), though, while the latter does not (/lə wat/ is pronounced *le watt* [lə wat]). Since elision occurs when the following word is vowel-initial and does not when it is consonant-initial, it must be concluded that the initial w- is a consonant in *watt*, but part of a diphthong in *ouate*. This difference in syllable structure is thus lexically recorded.

Beyond the creation of a symbolic and discrete representation that includes syllable structure, there is good reason to believe that lexicalization also imposes well-formedness conditions on items that are stored. This insight is formalized as Morpheme Structure Constraints (MSC) in SPE (Chomsky & Halle 1968: 171, 382): for example, in a language like English where only clusters of rising sonority can begin a morpheme, lexical items with initial #RT clusters are prohibited, i.e. will never be lexicalized. Relevant literature includes Rasin & Katzir (2015), Rasin (Ms.) and Becker & Gouskova (2016), the latter authors talking about a Gatekeeper Grammar.

So-called Lexicon Optimization embodies the same idea. Bermúdez-Otero (2003: 29) provides the following formulation (after Hale 1973: 420): prefer inputs that are well-formed outputs. Relevant literature includes Prince & Smolensky (1993: §9.3), Yip (1996), Bermúdez-Otero (1999: 124) and Inkelas (1995).

The action that is taken upon lexicalization falls into two distinct computational systems according to the input. The phonetic signal is a non-cognitive, gradient (real world) item that is converted into cognitive, discrete and symbolic units: the segments. These segments are then the input to further computation which builds phonological structure (syllable structure) and imposes well-formedness conditions on them. The former may be called lexicalization conversion and the latter lexicalization phonology.[13]

The two systems are different in kind because they work on dramatically different input vocabulary: lexicalization conversion is one of the human perception devices that transform real-world items into cognitive categories: light waves into colours, chemical substances into odours etc. (more on that in section 5.2.2). By contrast lexicalization phonology is just like production phonology (3) that occurs when the multi-morphemic string created by morpho-syntactic computation is interpreted (underlying-to-surface): it takes as input cognitive, discrete and symbolic units that belong to the phonological vocabulary; it produces phonological structure and assesses well-formedness.[14]

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[12] But there is variation: some speakers produce *la ouate*.

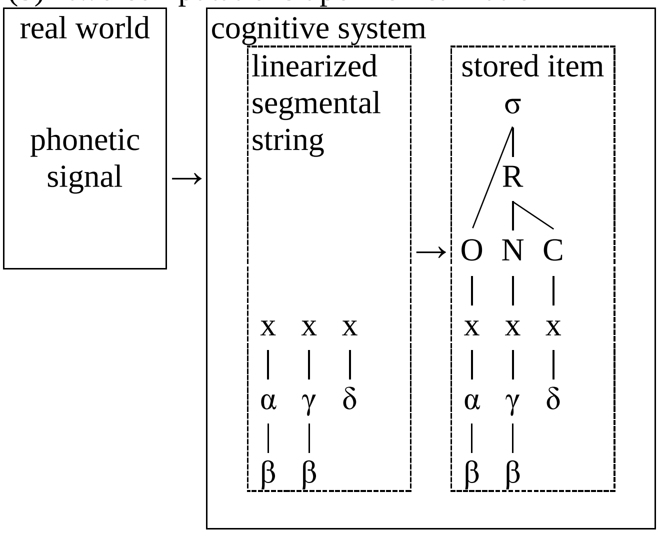
[13] There is a massive literature on the question how exactly the phonetic signal is converted into lexical representations that are stored in long term memory. Boersma *et al.* (2003) is a relevant contribution in this context.

[14] The overall architecture pieced together from lexicalization (this section) and production (sections 2.4, 5) is akin to the BiPhon model (Boersma 1998, Boersma & Hamann 2008) in a number of ways (including substance-

Obviously there is some overlap between the phonological operations that are carried out in production and upon lexicalization: syllabification for example is running on both occasions. There is reason to believe that both are not identical, though. This issue is discussed in the conclusion (section 7).

Summing up the discussion, table (5) below depicts what happens upon lexicalization.

(5) two computations upon lexicalization



computations involved

1. lexicalization conversion
   input: real world items;
   output: cognitive categories

2. lexicalization phonology
   input: linearized segmental string;
   output: syllabified and well-formed string

4. Sonority is different

Section 3 describes how the items that are used in production come into being, i.e. enter the lexicon. They have the structure described in section 2, i.e. what was called Phon I and Phon II under (3). For the time being this difference is only grossly depicted as two areas in an autosegmental representation. The present and the following section takes a closer look at how Phon I (at and above the skeleton) comes into being, what kind of items do and do not occur in this area, as well as how Phon I and Phon II communicate.

Below the traditional partition of segmental properties (as embodied in Feature Geometry, Clements & Hume 1995) is referred to as Son (sonority defining primes) Place (place defining primes) and Lar (primes defining laryngeal properties).[15]

4.1. Isolation of Son in regular segmental representation

In SPE, major class features such as [±son], [±cons] or [±voc] were scrambled in a single feature matrix together with features defining melodic properties such as place of articulation and laryngeal properties. OT implements sonority along the same lines, except that scrambling concerns constraints, rather than features (e.g. Smith & Moreton 2012).

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freeness). The heart of BiPhon is to assume that the same computational system is responsible for the operations in perception and production (hence the name of the approach). That is, gradience and discreteness are converted into one another by the same computational device in both directions.

Lexicalization is perception, but not necessarily identical with the perception that occurs when speakers work on the acoustic signal in order to access its meaning in a verbal exchange: nothing is lexicalized here. Therefore lexicalization is the word used in this article for the process that leads to storage in long-term memory. Perception is more general and its devices likely overlap with lexicalization. Also, linearization upon lexicalization (of segments within a morpheme) and in production (of morphemes) appears to be quite different in kind.

[15] The section is a digest version of Scheer (2019b).

Departing from an amorphous and unstructured set of primes, Feature Geometry made a first step towards the structural representation of sonority. The theory introduced by Clements (1985) autosegmentalized the amorphous bundle of SPE features, aiming at grouping them into natural classes (class nodes) in a feature geometric tree (more on this in section 5.4). In this approach sonority is still represented in terms of the SPE features (or some version thereof), but following the class node logic features are grouped together and isolated from other classes of features. In Clements & Hume's (1995) final model of Feature Geometry, the Son primes [±son], [±approximant] and [±vocoid] are borne directly by the root node, as opposed to other features which are represented in the feature geometric tree below the root node.

Standard Government Phonology (SGP) further promotes the structural idea: there are no primes that encode sonority. Rather, sonority may be read off segmental structure: the more complex a segment (i.e. the more primes it is made of), the less sonorous it is (Harris 1990, Backley 2011: 114ff). In GP2.0 (Pöchtrager & Kaye 2013), the idea is still the same (the less sonorous the more structure), but structure now embodies as projections in a hierarchy-expressing tree. This is also the case in Onset Prominence (Schwartz 2017). Finally, a similar approach is taken by Carvalho (2017): in his model, Place is encoded by primes, while Son and Lar identify as structure.

This panorama shows that the isolation of Son among segmental properties is a conclusion that a number of authors have drawn from the empirical record.

4.2. The Son module
4.2.1. Sonority is different

It is a trivial, though rarely explicitly stated fact that Son is projected above the skeleton, while Place and Lar are not. Syllable structure is a function of two and only two factors: the linear order of segments and their relative sonority. That syllable structure depends on these two factors (plus parametric settings[16]) and on no other is an undisputed and theory-independent fact which is transcribed in all syllabification algorithms (e.g. Steriade 1982: 72ff, Blevins 1995: 221ff, Hayes 2009: 251ff).

That Son but not Place and Lar are present above the skeleton is also shown by reverse engineering. Sonority values may to a certain extent be predicted given syllable structure (onsets and codas contain low sonority, nuclei high sonority items, the sonority of the members of a branching onset is rising, it is non-rising in a coda-onset sequence), but nothing can be deduced about Place or Lar properties of segments: the fact of being a nucleus, onset or coda tells you nothing about whether the segments associated are labial, palatal, velar etc.; onset- and codahood provide no clue either whether segments are voiced or voiceless (except of course in case a relevant process is active in the language, such as final devoicing).

There is thus reason to believe that Phon I under (3), i.e. the items that occur at and above the skeleton, are the result of a structure-building computation that is based on (phonologically meaningful) sonority primes. That is, the domain-specific vocabulary of the Son module are Son primes, and modular computation based on them returns structSon, the items familiar from above the skeleton.

4.2.2. Diagnostics

As was mentioned, syllable structure is built without reference to Place or Lar. This indicates that the vocabulary of Son on the one hand and Place / Lar on the other hand is distinct: if

[16] Relevant parametric settings for a given language determine whether or not specific syllabic configurations such as codas, branching onsets etc. are provided for.

Place / Lar primes were present and available when structSon is built, they would be expected to be taken into account. The fact that they are not suggests that they occur in a different module.

This conclusion is supported by a solid empirical generalization: processes which occur at and above the skeleton may be conditioned by Son, but are blind to Place and Lar.[17] This is the case for linearization as evidenced by the definition of infix landing sites (6)a, for phonologically conditioned allomorph selection (6)b, for stress placement (6)c, for contour tone placement (6)d and for positional strength (6)e. If the processes at hand occur in the Son module that is different from the Place / Lar module(s), it follows that they cannot see Place / Lar properties (just as syllabification is blind to them).

(6) selective visibility from above

a. Linearization (infixation)

The list of anchor points that infixes look at in order to determine their landing site falls into two categories: edge-oriented and prominence-oriented. For the left edge for example, documented situations are "after the first consonant (or consonant cluster)", "after the first vowel", "after the first syllable" and "after the second consonant". Prominence-based attractors are stressed vowels, stressed syllables or stressed feet.

In no case are Place or Lar reported to be relevant for the definition of the landing site. Hence cases where infixes are inserted after, say, the first labial or voiceless consonant of the word (and in their absence are prefixed) do not appear to be on record.

This is a typological generalization based on Moravcsik (2000) and Yu (2007). The latter studied 154 infixation patterns in 111 languages belonging to 26 different phyla and isolates. See also Samuels (2009: 147ff).

b. Phonologically conditioned allomorphy

The selection of allomorphs, i.e. independently stored variants of the same morpheme, may be conditioned by purely morpho-syntactic factors (like in the case of *go* and *went*, selected according to tense), but phonological properties may also play a role (as in Moroccan Arabic where the 3sg masculine object/possessor clitic is *-h* after V-final, but *-u* after C-final stems). Phonological factors boil down to Son, though: conditioning factors regarding Place and Lar are not on record.

This is a typological generalization established in Scheer (2016) based on the empirical record of Paster (2006), who has surveyed about 600 languages and described 137 patterns in 67 languages. Seven cases that may appear problematic are analyzed in Scheer (2016).

[17] This generalization is a piece of a broader project, melody-free syntax (and morphology), whose goal is to show that morpho-syntactic computation and items below the skeleton are incommunicado in both directions. Sonority stands aside since, like items at and above the skeleton, it may influence morpho-syntactic computation. The conclusion therefore is that sonority is not present below the skeleton. Melody-free syntax is developed in Scheer (2011a: §§412, 660, 2019b) as well as in a number of conference presentations since Scheer (2012b), as well as in Scheer (2016) regarding phonologically conditioned allomorphy.

c. Stress
   Stress placement is known to be conditioned by syllable structure: so-called Weight-by-Position regulates whether or not closed syllables count as heavy. In some languages a more fine-grained distinction is found, though, appealing to Son: sonorant, but not obstruent codas contribute to the weight of their syllable (e.g. Wilson 1986, Zec 1995: 103ff, Szigetvári & Scheer 2005: 44f, see the typological survey in Gordon 2006). But there is no case on record where Place or Lar has this effect ("a coda is heavy only if it is labial / voiceless").
   On the vocalic side, de Lacy (2002) and Gordon (2006: 52) have established the same generalisation: in many languages stress placement is sensitive to the sonority of vowels (low, mid, high), but Place and Lar never play a role (de Lacy 2002: 93).
d. Tone
   The situation for tone is much the same as for stress. In many languages contour tones may only appear on heavy syllables, and what counts as heavy may be determined by the presence or absence of a long vowel and a coda, as well as by coda sonority. Place and Lar are never involved in the definition of what counts as light or heavy, though.
   This generalization is based on the typological work by Gordon (2006: 34, 85), who has studied some 400 languages.
e. Positional strength of post-coda consonants
   Positional strength, i.e. lenition and fortition, is a function of syllable structure (initial and post-coda position is strong, intervocalic and coda position is weak), except for a cross-linguistic parameter that controls the behaviour of consonants in post-coda position. In this context, consonants may either be strong no matter what, or only after obstruents (while following a weak pattern after sonorants). The reverse distribution (i.e. strength after sonorants, weakness after obstruents) does not seem to exist. Also, Place and Lar have no bearing on post-coda strength (there is nothing like "post-coda weak if the coda hosts a labial / voiceless consonant").
   This pattern is discussed by Ségéral & Scheer (2008a: 156-161).

Note that the diagnostic for tone provided by contour tone placement (6)d is consistent with the fact that tone may also influence allomorph selection (6)b: Paster (2006: 126-130) discusses a case from the Yucunany dialect of Mixtepec Mixtec (Otomanguean, Mexico) where the first person sg is marked by a floating low tone, except when the final tone of the verb stem is low, in which case -yù is suffixed. This suggests that the traditional location of tone above the skeleton is correct: tone lives in the Son module.

4.3. The Place and Lar modules

Place and Lar computation appears to be mutually waterproof. While of course Place can impact Place (e.g. velar palatalization) and Lar bears on Lar (e.g. voicing assimilation), Place modifications triggered by Lar (a velar is turned into a palatal before a voiceless consonant) or the reverse (a voiceless consonant becomes voiced when followed by a labial) appear entirely outlandish and stand a good chance to be absent from the record.

This situation suggests that Place and Lar are two distinct modules, each working on a specific vocabulary.[18]

[18] Lombardi (2001) concludes that Place and Voice are different because the cross-linguistic reaction against coda consonants are in complementary distribution according to whether the coda offense is du to place or voice. While illegal laryngeal configurations in codas are resolved by neutralization (i.e. the shift to a legal laryngeal value), illegal place patterns in codas provoke epenthesis of a vowel or deletion. This reaction is never found for laryngeal coda offenses, and neutralization (e.g. velar becoming dental) is absent from the record for place-based

4.4. Impact of structSon on Son, Place and Lar

Section 4.2 has shown that there is no bottom-up conditioning: Son (at and above the skeleton) is not influenced by Place or Lar (which live below the skeleton). Top-down conditioning exists, tough.

(7) top-down conditioning
  a. structSon bears on Lar
    1. devoicing (or more generally delaryngealization) in coda position.
    2. lenition
       typical syllable-conditioned trajectories along the sonority scale involve laryngeal stages, e.g. $p^h > p > b > v$ in intervocalic position.
  b. structSon bears on Place
    1. lenition: debuccalization f > h, s > h in coda position.
    2. unstressed vowels centralize (become schwa)

These patterns are unexpected if Son and Place / Lar are different modules. But consider the fact that regular Place and regular Lar computation appears to be unimpacted by structSon: there is nothing like "velars palatalize before front vowels, but only if they belong to a coda" or "obstruents undergo progressive voice assimilation, but only if they are engaged in a branching onset".

This suggests that Place- and Lar-internal computation is indeed insensitive to structSon, as predicted. The patterns under (7) are different: rather than bearing on regular Place- and Lar-computation that exists anyway, they describe a situation where a Place or Lar modification occurs that is *triggered* by structSon. How could that be possible in a modular environment?

In order to approach this question, let us take a closer look at lenition and fortition. These processes modify Son primes given structSon: for example, a segment whose Son primes define a stop is turned into a fricative with corresponding Son primes because it occurs in intervocalic position. The input, conditioning context and output of this process are all located in Son and that complies with modular standards.

However, as was mentioned, typical lenition trajectories move along the sonority scale but also involve steps that are defined by Lar ($p^h > p > b > v$ etc.) (7)a2. This is reflected in sonority scales that scramble Son and Lar properties (Szigetvári 2008, Parker 2011: 1177 counts 17 steps).

But there is also another type of lenition that may not be described as a rearrangement of Son primes, but rather involves the loss of Place primes: debuccalization (7)b1. Szigetvári (2008) shows that these two types of lenition exhaust the empirical record: one makes segments more sonorous (thus involving Son primes: t > θ, b > β, t > ɾ etc.), the other makes them lose all Place primes, as in t > ʔ, s > h, f > h.

In Government Phonology, lenition (of both types) is interpreted as a loss of (privative) primes (Harris 1990). Although structSon cannot see or bear on Place primes across a module boundary, it may influence the properties of timing units. Following the GP logic, timing units that are weak because their associated syllabic constituent is, are unable to sustain other primes in other modules.

This mechanism may be generalized: structSon bears on timing units and makes them more or less apt at sustaining (licensing) primes that are associated to them. A strong position

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coda offenders.

is a position that allows for a large number of primes to be associated, while a weak position can only sustain a few, or indeed no prime. Timing units do not belong to any particular module but rather instantiate the temporal and linear sequence. The primes of all three modules that co-define a segment are attached to the timing unit that defines this segment. Hence restrictions that weigh on a timing unit will be visible in all tree modules.

All cases under (7) share the fact that under the spell of structSon some prime is lost: a Lar prime under (7)a1 (devoicing), Son primes (b > v) or Lar primes (p > b) under (7)a2 (sonority-lenition), Place primes under (7)b1 (debuccalization-lenition) and (7)b2 (centralization of unstressed vowels). Hence the analysis whereby structSon weighs on timing units whose weakness (or strength) then has consequences on Place and Lar is workable throughout.

A structSon conditioning on timing units may lead to the loss of a segment in diachronic lenition (s > h > ø, loss of coda consonants), but also in synchronic computation: vowel-zero alternations are governed by a (cross-linguistically stable, Scheer 2004: §16) syllabic context where lexically specified vowels (schwas, short vowels, high vowels etc.) are absent in open, but present in closed syllables. In Czech for example, the root vowel of *pes* "dog Nsg" alternates with zero in presence of the case marker *-a* in *ps-a* "dog Gsg" (while the phonetically identical root vowel in *les* - *les-a* "forest Nsg, Gsg" is stable: alternating e is marked as such lexically).

In Strict CV, alternating vowels are underlyingly present but floating: the vowel under (8)a fails to be associated when its nucleus is governed. This is the case in Gsg where the following nucleus hosts *-a* (8)c. In Nsg under (8)b, though, the following nucleus is empty and hence cannot govern. Therefore the nucleus containing the alternating vowel remains ungoverned, which allows the floating melody to associate.

(8) Czech *pes* - *ps-a* "dog Nsg, Gsg"

a. lexical entry	b. Nsg pes	c. Gsg ps-a
	gvt	gvt
C V C V	C V C V	C V C V
| |	| ↑ |	| | |
p e s	p e s	p e s a

Note that in Strict CV government (and licensing) represent syllable structure, i.e. structSon. But whatever the framework used, the presence or absence of the alternating vowel is controlled by syllable structure. In Strict CV, its absence is due to the pressure that structSon puts on the nucleus (government). This is parallel to what we know from lenition: the ability of constituents to sustain primes is curtailed under positional pressure. In the case of vowel-zero alternations its ability to host primes is zero.

In sum, structSon may indirectly cause the loss of primes in all three modules by defining strong and weak timing units, which then may not be able to tolerate the association of certain primes. But there is no bearing of structSon on regular computation that occurs in the Place or the Lar module.[19]

[19] The cross-linguistically pervasive intimacy and interaction between voicing and nasality (Nasukawa 2005) has a phonetic basis (Solé *et al.* 2008). The typical phonological process is post-nasal voicing, but post-nasal devoicing also exists (Solé *et al.* 2010). This situation suggests that nasality is located in Lar, rather than in Son.

5. Workings of phonology with three modules
5.1. Lexical entries

If Son vs. Place vs. Lar are three distinct computational systems, according to modular standards each one carries out a specific computation based on a proprietary vocabulary. A segment thus combines items from three distinct module-specific vocabularies. The situation where a single lexical entry is defined by items that belong to different vocabularies is known from the morpho-syntax - phonology interface where idiosyncratic properties of single lexical entries (morphemes) are used by multiple computational systems. The lexical entry of a morpheme stores three types of information written in three distinct vocabularies that are accessed by three different computational systems: morpho-syntax (using vocabulary items such as number, person, gender etc.), semantics (LF-relevant properties) and phonology (vocabulary items such as occlusion, labiality, voicing etc.). The lexical entry for *cat* for example may look as under (9)a.[20]

(9) lexical entries
  a. of a morpheme: *cat*
     M307
     [<Morph-synt = animate, count etc.>, <Sem = "idea of cat">, <Phon = /kæt/>]$_{\text{morph}}$.
  b. of segments:
     P12 [<Son = stop>, <Place = velar>, <Lar = voiceless>]$_{\text{segment}}$ (= k)
     P16 [<Son = stop>, <Place = dental>, <Lar = voiceless>]$_{\text{segment}}$ (= t)
     P19 [<Son = vowel>, <Place = front low>, <Lar = – >]$_{\text{segment}}$ (= æ)

In the same way, the lexical identity of a segment contains several compartments that host items from three distinct vocabularies, as shown under (9)b for the constituent segments of *cat*. Each vocabulary is then accessed by the relevant computational system. For instance, the computation that builds syllable structure is specific to Son and can only parse this vocabulary. Hence only Son primes are projected and the result of the computation, structSon, contains no information pertaining to Place or Lar. This is why other computations which occur above the skeleton and take into account items in that area are unable to access anything else than Son primes and structSon (section 4.2.2). In the same way, Place computation (e.g. palatalization) accesses only Place primes (and outputs structPlace), while Lar computation (e.g. voice assimilation) only reads Lar primes (and produces structLar).

5.2. Computation upon lexicalization
5.2.1. Real world conversion and structure building

Given this situation, an obvious question is how primes that belong to different computational systems can concur in the pronunciation of a single segment: what is the glue that holds the three sets of primes together? The answer can only be the skeleton: a segment is an item that is made of three distinct vocabulary sets which belong to the same timing unit. As will be discussed in section 5.3.4, these timing units must be specified for consonant- and vowelhood: they therefore appear as "C" and "V" under (10) below.

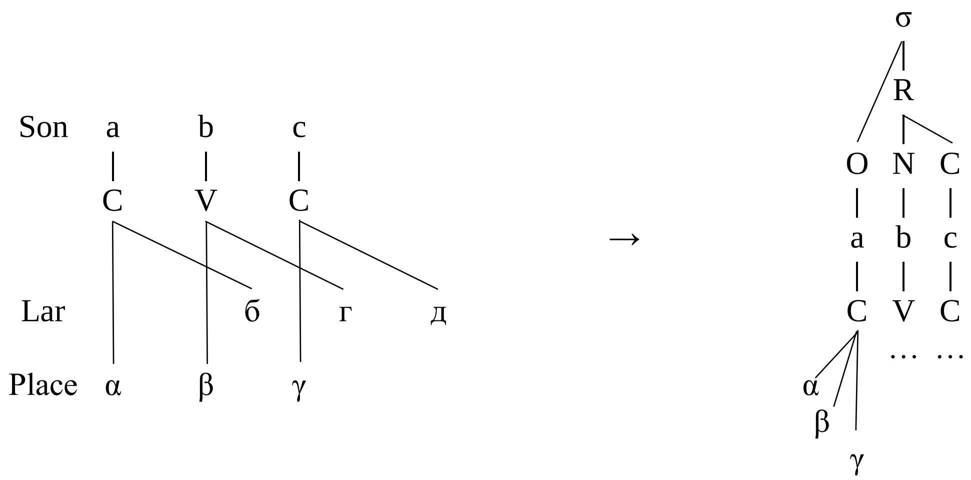
The linearized string of segments thus defined is the output of the process that converts real world items (the phonetic signal) into cognitive categories (segments) upon lexicalization. The first version of this situation under (5) in section 3 is completed under (10)a with the presence of three distinct vocabulary sets: Son, Place and Lar.

[20] The content of Phon under (9)a is simplified: in addition to the three segments shown, linearity (the skeleton) and syllable structure are represented (see section 3).

(10) lexicalization

a. linearized string of segments

b. stored item



In the structure under (10)a, bundles of primes are assigned to C- and V-slots and each slot together with its primes represents a segment. But the primes are unordered for the time being since they have not yet undergone any computation in their respective module. This computation takes (10)a as an input and produces (10)b, the object that will be stored in the lexicon (long term memory). The computation in each system is based on relevant primes and projects structure: Son primes a, b, c project structSon, i.e. syllable structure, Lar primes б, г, д project structLar for each segment, and Place primes α, β, γ project structPlace for each segment. What exactly the structure projected in each module looks like varies across theories, but as far as I can see all theories do warrant some organization of primes into structure (rather than unordered sets of primes). For example, Feature Geometry organizes primes into a feature geometric structure according to natural classes, while Dependency and Government Phonology assign head or dependent status to primes.[21]

An interesting property of structSon is that it spans segments (a rhyme accommodates two or three segments, a branching onset is made of two segments, government and licensing relate different segments). By contrast, structPlace and structLar are bound by the segment.

5.2.2. Extraction of Son primes from the phonetic signal

Section 2 has concluded that Son primes are phonologically meaningful, i.e. not interchangeable. This is the origin of the fact that the Son module as a whole is not arbitrary: the computation of Son primes is not, the resulting structSon (syllable structure) is not and the computation of structSon upon production (see section 5.3.2) is not either.

If Son primes are non-arbitrary, their genesis must follow a lawful procedure. This means that Son primes are extracted from the phonetic signal in a predictable way that is at least partly the same in all languages. For instance, there are no flip-flop systems where all items that are vowels phonetically speaking are interpreted as consonants in the cognitive system upon lexicalization (i.e. are associated to a C position), and all items that are phonetic consonants become phonological vowels (i.e. are associated to a V position).

There must thus be a way for humans to recognize the difference between consonants and vowels in the acoustic signal, and this capacity is put to use in such a way that there is a hard wired relationship between a phonetic vowel and its lexicalization as a cognitive /

[21] In SFP, "natural" classes are not natural (i.e. phonetically defined) but rather group together primes that share phonological properties in a given language (phonologically active classes in Mielke's 2008 terms).

phonological vowel, as well as between a phonetic consonant and its lexicalization as a cognitive / phonological consonant.[22]

The question which property of the phonetic signal exactly correlates with sonority or is used by speakers in order to attribute a sonority value to sounds is studied, among others, by Bloch & Trager (1942: XXX), Wright (2004: 39f), Parker (2008, 2011), Gordon *et al.* (2012) and Bakst & Katz (2014). Authors conclude that loudness (or energy, intensity) is a cross-linguistically robust correlate of sonority.

This is not to say that there is no slack, of course. It is not the case that all languages build the same sonority hierarchy based on the phonetic signal: in some languages nasals count as (pattern with) sonorants, while in others they go along with stops. Only liquids may be second members of branching onsets in some languages, while in others nasals and / or glides also qualify for this position. In some languages only vowels may be sonority peaks, while in others sonorants (or a subset thereof, typically liquids) may also occur in this position and act like vowels (syllabic consonants). The slack that is observed cross-linguistically in the specific location of a given phonetic item on the sonority hierarchy is called relative sonority. This variation has produced a massive body of literature (Clements 1990, Parker 2011, 2017).

This suggests that the conversion of the phonetic signal into Son primes is partly shared by all humans but allows for some slack that is conventionalized by each language. The mechanism driving the conversion is thus somehow genetically coded and present at birth, although not necessarily linguistic in kind (more on that in section 7).

These workings are known from other cases where a real world continuum is converted into discrete cognitive categories. In colour perception, some distinctions like black and white have a physiological basis (magna vs. parvo layer cells of the lateral geniculate nucleus located in the thalamus, Kay *et al.* 2009: 26) and may be selectively impacted by dysfunction: there are humans with no chromatic vision (achromatipsia, i.e. seeing only black and white). Beyond physiological grounding, the World Color Survey based on colour naming in 110 languages (Kay et al. 2009: 25) has found that there are six universal sensations (four chromatic: red, yellow, green, blue and two achromatic: black and white) related to colour along which humans partition the colour space. But given this basic structure there are zones of overlap and indistinction where an identical (distal and proximal) stimulus may be interpreted in a number of different ways in different communities, languages or individuals (Grieve 1991, Choudhury 2014: 144-184, Whittle 2003, Webster 2003).

5.3. Computation upon production
5.3.1. Computational domains

In production, a computation is carried out in each module, based on the content of the lexical items (10)b that are retrieved from long term memory, i.e. the linearized string of morphemes that co-occur in a given computational domain (cycle, phase).

Computation that occurs in production thus takes structure (created upon lexicalization for each morpheme) as an input and returns (modified) structure. The difference between computation creating structure based on primes (lexicalization) and computation modifying existing structure (production) is parallel to the distinction that is made in syntax between internal Merge (creation of hierarchy based on primes) and external Merge (movement, i.e. the modification of existing structure).

In all cases, the domain of phonological computation is defined by the spell-out of morpho-syntactic structure which delineates specific chunks of the linear string that are called

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[22] Parker (2008, 2011) has studied the non-trivial question what the phonetic correlate(s) of sonority is or are. He concludes on loudness.

cycles or phases. It is obvious and consensual that these chunks are not defined in the phonology.[23]

5.3.2. StructSon

Computation modifying structSon includes all regular syllable-based processes, as well as the communication with morpho-syntax: structSon (but not structPlace or structLar) and morpho-syntax do communicate, in both directions. Before proper phonological computation can run, though, the string of morphemes over which it operates must be pieced together and linearized.

Computation of structSon caused by linearization is shown under (11)a. Morphemes need to be linearized and this process may be conditioned by phonological information pertaining to Son (infixation (6)a). But items other than morphemes also need to be linearized: there is reason to believe that the exponent of stress may be syllabic space: an x-slot, an empty CV unit, a mora etc. (Chierchia 1986, Ségéral & Scheer 2008, Bucci 2013). This extra space thus needs to be inserted to the left or right of the tonic vowel once the location of stress is determined. That is, the linear order present in the lexicon is modified.

The same goes for approaches where the carrier of morpho-syntactic information in phonology is syllabic space: in Strict CV the beginning of the word incarnates as a CV unit (the initial CV, Lowenstamm 1999, Scheer 2012, 2014). Note that there are no cases on record where the exponent of morpho-syntactic information is reported to be a Place or a Lar item inserted into structPlace or structLar (such as a labial or a voicing prime at the beginning of the word) (Scheer 2012: §126, see note 17).

In the reverse direction, bearing of structSon on morpho-syntactic computation is documented for the items mentioned under (11)b. Again, there are no cases on record where Place, Lar, structPlace or structLar would influence morpho-syntax. That is, morpho-syntax communicates with structSon in both directions, but is completely incommunicado with Place or structPlace (see note 17).

Finally, cases of regular phonological computation involving structSon are shown under (11)c.

(11) computation of structSon upon production
- a. linearization
  the linear sequence that undergoes phonological computation is pieced together from various sources:
  1. the lexical entries of morphemes that occur in the computational domain: affix placement, including infixation (definition of the landing site, see (6)a)
  2. insertion of the exponent of stress which may be syllabic space (an x-slot, an empty CV unit, a mora etc.).
  3. exponents of morpho-syntactic information such as the initial CV representing the beginning of the word.
- b. structSon information that is used by morpho-syntactic computation
  1. phonologically conditioned allomorphy, see (6)b
  2. intonation and stress
     Szendrői (2003, 2004), Hargus (1993)

[23] The Prosodic Hierarchy (Selkirk 1981 [1978], Nespor & Vogel 1986) is a representational way of defining phonologically relevant chunks. The traditional assumption is that phonologically relevant chunks are derivationally defined below the word level (cycles), but have a representational definition at and above the word level (prosodic constituency). This peaceful coexistence (Scheer 2011: §§435-440) is called into question by phase theory (D'Alessandro & Scheer 2015), but the debate is orthogonal to the discussion below.

3. tone
   Rose & Jenks (2011)
4. size of lexical items, e.g. minimal word constraints: number of syllables or moras
   Inkelas & Zec (1990: 372ff), Hargus (1993)
5. rhythm
   Guasti & Nespor (1999)

c. phonological computation
   (that may or may not use morpho-syntactic information)
   1. stress placement (in languages where stress is not lexical)
   2. calculation of syllable structure
      across the syllabic material that is pieced together from different sources (11)a
   3. calculation of positional strength
      the (relative) strength of positions depends on syllable structure.
   4. lenition and fortition
      modification of primes due to structSon: for example, lenition in coda position such as ł → w modifies relevant Son primes, turning a lateral into a glide in the specific structSon configuration "coda". This pattern is discussed in section 4.4.

5.3.3. structPlace and structLar

There is also a computation concerning Place primes and structPlace, such as palatalization, vowel harmony etc.: the prime associated to palatality is absent in velar but present in palatal segments, and a palatal source may add it to velars (front vowel harmony in V-to-V interaction, palatalization in V-to-C interaction). There is no need for going into more detail regarding Place and Lar: relevant phenomena are well known and not any different in the present environment from what they are in a regular autosegmental structure: spreading, linking and delinking of primes.

5.3.4. Timing units are specified for consonant- and vowelhood

As is obvious in general and from the preceding, Place computation is informed of whether the items computed belong to a consonant or a vowel: vowel harmony is only among vowels, and in regular palatalization the trigger is a vowel and the target, a consonant. Information about vowel- and consonanthood is absent from the Place system, though. It must therefore be present in the only other structure that Place has access to: the timing units that represent linearity.

That Place has access to consonant- and vowelhood is also shown by a fundamental insight of autosegmentalism: the same primes may produce different segments depending on whether they are associated to consonantal or vocalic slots. High vowels and corresponding glides i-j, u-w, y-ɥ are the same segmental items and distinct only through their affiliation to a consonantal or a vocalic slot (Kaye & Lowenstamm 1984). For instance, when an i spreads its segmental content to a vacant consonantal position, it is interpreted as j: French *li-er* "to link" is pronounced [li-j-e], but the j is absent from both the root (*il lie* [li] "he links") and the infinitive suffix (*parl-er* [paʁl-e] "to eat"). The same goes for *lou-er* [lu-w-e] and *tu-er* [tu-ɥ-e]: in all cases the glide is a copy of the preceding vowel into a C-position. This is shown under (12) where the Element I represents the Place specification of i/j (in substance-laden guise).

(12) high vowels and corresponding glides are segmentally identical
French *li-er* [li-j-e] "to link"

a. lexical ingredients
```
C  V  -  C  V
|  |        |
l  I        e
```

b. spreading
```
C  V  C  V
|  |↗     |
l  I      e      [lije]
```

The idea that timing units are specified for consonant- and vowelhood goes back to Clements & Keyser (1983).

5.4. Spell-out

5.4.1. How to spell out three modules simultaneously

The existence of several computational systems (Son, Place and Lar) that concur to the pronunciation of a single segment raises a non-trivial challenge for the spell-out mechanism at the phonology-phonetics interface. Note that the situation is quite different from what we know from the morpho-syntax - phonology interface where the input to spell-out comes from one single system (morpho-syntax) and hence conveys one single vocabulary.

At the phonology-phonetics interface, Son, Place and Lar do not see each other and cannot communicate, but are segment-bound, i.e. must co-define the same segment. Therefore segment integrity can only exist if the items of the three computational systems are related through a third player that defines the segment: the skeleton. Timing units that embody the linear structure of the string do precisely the job that is needed, i.e. the definition of what does and does not belong to a segment. The difference between the upper spell-out that receives information from one single module and the lower spell-out which needs to combine inputs from three different modules is thus reflected by the presence of linearity in the latter, against its absence in the former. It is only the existence of linearity and hence the skeleton that affords the existence of a multiple-module spell-out.

It follows that the lower interface does not spell out individual primes or the set of primes defined by each one of the three computational systems, but entire segments as defined by timing units. How exactly timing units relate to segments is discussed in the following section.

5.4.2. Segment-defining root nodes are spelt out

Regular autosegmental representations allow for the association of a set of primes to multiple timing units as under (13)a where a geminate is shown. It is obvious that the primes must "know" whether they are associated to one or two timing units: it makes a difference whether a given prime is associated to one or two skeletal slots.

Spell-out cannot proceed timing unit by timing unit, though, since this would create two identical phonetic items under (13)a: the association of α,β to a C would be spelt out two times, for the two Cs of the geminate. What is realized, though, is not two times the consonant in question, but the consonant with a longer duration.[24]

Spell-out cannot proceed prime by prime either since in this case α of the geminate under (13)a will be converted into a phonetic item, followed by the conversion of β, effecting on the phonetic side a sequence of items. In this case the phonetics would not "know" that the representatives of α and β need to be pronounced simultaneously, rather than in sequence.

[24] This is the case of true geminates (or long vowels). There are also fake geminates, i.e. the consecution of two identical consonants (Hayes 1986).

(13) regular autosegmental representations

a. without root nodes

C V C V

α, β α,γ

b. with root nodes

C V C V

x x

α, β α,γ

c. spell-out

C V C

x ↔ xx ERB

α, β

It thus appears that the representation under (13)a does not allow to identify the geminate segment at hand, i.e. "α and β associated to two consonantal timing units": there is no single item that encompasses this set. In traditional Feature Geometry (Clements & Hume 1995), the segmental unit is defined by the root node. This option is shown under (13)b where "x" is the root node. If the segment is defined by this item, spell-out may proceed root node by root node: for every root node present on the phonological side, a spell-out instruction is searched that contains all items affiliated. That is, the geminate under (13)b will be able to be spelt out by the spell-out instruction under (13)c (phonetic categories appear as ERB values, see section 5.5.2).

This means that languages possess exactly as many spell-out instructions as there are phonemes (segments), i.e. objects that are phonologically distinct. Unlike at the upper interface of morpho-syntax and phonology, the number of lexical entries whose content is inserted into the receiving module is very small: thousands of morphemes against 15 or 20, in very large inventories maybe 40 phonemes (segments).

5.4.3. Workings

When phonological computation (in all three modules) is completed, the result is spelt out root node by root node (i.e. segment by segment): root nodes are associated to Son, Place and Lar primes, which in turn are associated to their respective structure (see (10)). Spell-out considers only timing units and associated primes. The structure projected by these primes is not taken into account. The restriction of spell-out to timing units and primes is motivated in section 6 below.

Spell-out matches the result of phonological computation with the phonological side of spell-out instructions, a lexicon where (language-specific and hence acquired) correspondences between phonological and phonetic categories are defined. For example, the spell-out lexicon entry under (14)a associates the Place prime α and the Son prime b, both belonging to a root node "x" and linked to a V slot, with the phonetic value "high front unrounded vowel". This assures the spell-out of the leftmost V of French *li-er* [lije] "to link" under (12)b. By contrast, the second C under (12)b will match the spell-out entry (14)b where the same primes α (Place) and b (Son) are associated to a C position, a configuration whose phonetic correspondence is a high front unrounded glide.

(14) spell-out lexicon

a. V-x-α,b ↔ high front unrounded vowel
b. C-x-α-b ↔ high front unrounded glide

5.4.4. Spell-out mismatches

Spell-out is a list-based mapping of one vocabulary set onto another. Therefore the relationship between the two items matched is necessarily arbitrary (2)c. The overwhelming majority of mappings appears to be "natural", i.e. phonetically reasonable, though: an item that shows the phonological behaviour of a labial is also realized as a phonetic labial. The overwhelming naturalness of mappings is due to the fact that phonological categories come into being when a phonetic item or event is phonologized. At birth, phonology is thus phonetically transparent and natural, and the mapping is faithful. It takes some accident in the further life of phonological processes to become crazy, or of phonological items to develop a non-faithful mapping (Bach & Harms 1972, Scheer 2014: 268ff, Chabot 2019). That is, processes are not born crazy and mappings are not born unfaithful – they may become crazy and unfaithful through aging.

This being said, the existence of a spell-out that converts phonological into phonetic categories through a list-based mapping predicts that at least some mismatches exist. Table (15) shows that this is indeed the case for all components discussed (Son, Place, Lar, timing units).

(15) spell-out mismatches

a. Son
   1. the phonological sonorant r appears as ʃ/ʒ in Polish, as ʁ/χ in French (Chabot 2019).
   2. the phonological sonorant w has an obstruent realization v in a number of Slavic languages (Cyran & Nilsson 1998).

b. Place
   uu-fronting in South-East British English where *boot* is pronounced [biit] (Henton 1983, Harrington *et al.* 2008), but [ii] continues to trigger w-insertion in *do it* [dii w it], thereby attesting its phonological identity /uu/.

c. Lar
   cross-linguistically, preaspiration continues former geminates (Clayton 2010). In Icelandic (Hansson 2001, Helgason 2002: 216ff), voiceless geminates are realized preaspirated but without extra duration (i.e. as non-geminates). Old Norse p, t, k are represented as such, Old Norse voiced geminates bb, dd, gg appear as voiceless geminates pp, tt, kk, but Old Norse voiceless geminates are preaspirated ^{h}p, ^{h}t, ^{h}k. Beyond the diachronic patterning, the geminacy of ^{h}p, ^{h}t, ^{h}k is evidenced by their synchronic behaviour (long vowels cannot appear to their left).

d. timing units (length)
   In the case of timing units, the length of phonologically long vowels and phonological geminates may be marked in the phonetic signal by duration (no mismatch), but also by other means (mismatch). In case their long identity is flagged by some other property, their own realization or the context allows the speaker (and learner) to recover underlying length.[25, 26]
   1. In English and German, agma [ŋ] is a singleton on the surface but represents the partial geminate /ŋg/: diagnostics are the fact that it occurs only after short vowels and is absent word-initially (Dressler 1981, Gussmann 1998).

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[25] Especially when the only cue to geminacy is found in the surrounding context, non-executed duration may be interpreted as a means of realizing economy: if geminacy is already marked for example on the preceding vowel, there is no need to realize it a second time on the consonant.

[26] An interesting question regarding timing mismatches is why phonological length may be pronounced without duration (/CC/ ↔ [C], /VV/ ↔ [V]), while the reverse pattern where a phonologically short item is phonetically realized with extra duration (/C/ ↔ [CC], /V/ ↔ [VV]) appears to be absent from the record.

2. Hammond (1997) argues that in English intervocalic (singleton) consonants as the t in *city* are phonological geminates when preceded by a short/lax vowel. This is because short/lax vowels occur in closed syllables: the i in *city* must thus be checked.[27]
3. Rather than by duration, the phonological contrast between long and short vowels was found to be phonetically expressed by
   – reduced (schwa, representing short vowels) vs. unreduced (non-central vowels, representing long vowels) vowels in Semitic (Lowenstamm 1991, 2011), Ge'ez (Old Ethiopian) (Ségéral 1996), Kabyle Berber (Bendjaballah 2001, Ben Si Saïd 2011) ;
   – ATRness (+ATR representing long, -ATR short mid vowels) in French, Rizzolo 2002).
4. Rather than by duration, phonological geminates have been found to be expressed by
   – the length of the preceding vowel in German (Caratini 2009), the Cologne dialect of German (Ségéral & Scheer 2001), English (Hammond 2007);
   – the inhibition of a preceding vowel-zero alternation in Somali (Barillot & Ségéral 2005);
   – preaspiration (15)c.

5.5. Phonetics
5.5.1. Language-specific phonetics

There is reason to believe that phonetics falls into two distinct computations: one that is language-specific, acquired during L1 acquisition and cognitive in kind (Language-Specific Phonetics, LSP), the other being universal and located outside of the cognitive system (Universal Phonetics). Unlike phonology which manipulates discrete objects, both phonetic systems are gradient in kind. LSP thus identifies as a cognitive system which is part of the grammar that speakers acquire, and like other grammatical systems (phonology, syntax) affords well-formedness: phonetic items may be well- or ill-formed (this is expressed by articulator constraints in BiPhon, Boersma & Hamann 2008: 227f). Kingston (2019: 389) therefore says that "speakers and listeners have learned a *phonetic* grammar along with their phonological grammar in the course of acquiring competence in their language" (emphasis in original).

Evidence for LSP comes from the fact that "speakers' phonetic behavior cannot be entirely predicted by the physical and physiological constraints on articulations and on the transduction of those articulations into the acoustic properties of the speech signal" (Kingston 2019: 389). A classical case is vowel duration, which is variable according to the voicing of the following consonant: voiced articulations (both sonorants and voiceless obstruents) provoke longer durations to their left than voiceless obstruents. This appears to be (near) universal (Chen 1970), but the ratios of long and short vowels are quite different across languages: Cohn (1998: 26) reports that while vowels before voiceless consonants are 79% of the length of vowels before voiced consonants in English, in Polish the ratio is 99%, with other languages coming in between these values. This suggests that some phonetic properties are under the control of the speaker and depend on the language they have acquired.

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[27] Geminates and so-called ambisyllabic consonants both belong to two syllables and are therefore heterosyllabic, but the difference is that the former are associated to two, the latter only to one timing unit. Ambisyllabicity is the representation developed in times when phonology-phonetics mismatches could not be conceived of, i.e. where a phonetically simplex consonant could not possibly belong to two timing units.

Relevant literature describing the properties and workings of LSP includes Keating (1985), Cohn (1998), Pierrehumbert & Beckman (1988); Kingston (2019) provides an overview.

5.5.2. Phonetic categories

If a spell-out hands over the output of phonology to another computational system that is cognitive (and grammatical) in kind, LSP, the question arises what the domain-specific vocabulary looks like in this system. In the BiPhon model the auditory continuum is expressed as an auditory spectral mean along the ERB scale (Equivalent Rectangular Bandwidth) (Boersma & Hamann 2008: 229).

That is, the spell-out from phonology to LSP associates a phonological and a phonetic category: s ↔ 20,1 ERB. This reads "s is realized with a spectral mean of 20,1 ERB" and in a substance-free environment the consonant is replaced by alphas and betas. The goal of LSP (Auditory Form in BiPhon) in production is to determine an acoustic target in form of an ERB value that is transmitted to Universal Phonetics (Articulatory Form in BiPhon). Since LSP is gradual but a simple spell-out instruction such as s ↔ 20,1 ERB produces a discrete ERB value, the computation carried out in the LSP module creates relevant variation: given an invariable and discrete phonological s, LSP computation produces ERB values with slight variation around the input from the spell-out instruction. This is responsible for some of the phonetically variable realizations of s. Variation / gradience is thus introduced by both the variable acoustic target that LSP produces and transmits to Universal Phonetics and the undershoot / overshoot that this target is subject to in physical implementation carried out by Universal Phonetics.

Note that the red line between the discrete and the gradual is crossed in LSP: the input to LSP is a discrete ERB value contained in each spell-out instruction (s ↔ 20,1 ERB etc.). The modular computation operates over this ERB value and produces a gradient output. In the BiPhon model, the generation of the gradient output is achieved by adding noise to the computation either in the guise of multiple, slightly varying ERB values for a given spell-out that undergo an OT computation (constraints such as *s ↔ 20,1 ERB, *s ↔ 20,2 ERB, *s ↔ 20,3 ERB etc., Boersma & Escudero 2004, Boersma & Hamann 2008: 233f) or by having the computation done by an artificial neural network (Seinhorst *et al.* 2019).

5.5.3. Visibility of morpho-syntactic divisions

Since LSP is a grammar-internal computational system, like all other modules it computes specific stretches of the linear string that are defined in terms of morpho-syntactic divisions, i.e. cycles or phases (see section 5.3.1).

The visibility of morpho-syntactic divisions for phonetic processes is a disputed issue: in a feed-forward implementation of modularity as argued for by Bermúdez-Otero & Trousdale (2012), modules can only take into account information of the immediately preceding module. Since phonology intervenes between phonetics and morpho-syntax, this take predicts that morpho-syntactic information will never be taken into account by phonetic processes. In a diachronic perspective, it is only when phonetic processes have been phonologized that a morpho-syntactic conditioning may kick in.

In the modular architecture exposed above, there is no reason to restrict the availability of morpho-syntactic divisions, though. Like all other modules LSP necessarily applies to a given computational domain. It is unclear how a cognitive computational system could work in absence of a specified stretch of the linear string over which it operates: there is no computation in absence of a computational domain. Hence the chunks defined in the morpho-syntax are handed down to all subsequent computational systems until the realm of the cognitive system is reached: universal phonetics is not cognitive in kind and hence unbound by computational domains.[28]

Starting with Lehiste (1960), there is a substantial literature documenting cases where morpho-syntactic divisions are taken into account by phonetic processes. A well-studied item is l-darkening in English (Giles & Moll 1975, Lee-Kim 2013, Strycharczuk & Scobbie 2016, Mackenzie *et al.* 2018), but there is debate whether the gradient darkening overlaps with a categorical phonological process (Bermúdez-Otero & Trousdale 2012, Turton 2017). If this is the case, Bermúdez-Otero & Trousdale (2012) who reject the visibility of morpho-syntactic information in phonetics can argue that l-darkening is influenced by morpho-syntactic divisions not in the phonetics, but in its phonological incarnation.

In order to get around this caveat, Strycharczuk & Scobbie (2016) have tested whether phonetic processes may be sensitive to morpho-syntactic divisions. They study fronting of the *goose* vowel [uu], an ongoing sound change in Southern British English that is reported to be inhibited by a following coda l as in *fool*. The authors have experimentally contrasted *fool* with intervocalic l that is (*fool-ing*) or is not (*hula*) morpheme-final. Their results show that fronting is more inhibited in the former than in the latter case, thus documenting the impact of the morphological boundary. They carefully argue that the process at hand is gradient rather than categorical and hence not a case of phonologically controlled allomorphy. They conclude that "morphological boundaries may affect phenomena that are phonetically continuous and gradient, and not only clear cases of allophony" (Strycharczuk & Scobbie 2016: 90).

6. Is a given alternation computational or interpretational in kind?

Approaches that provide for a spell-out operation in addition to regular phonological computation are confronted to the question whether a given modification of the lexical representation is computational (caused by phonological computational) or interpretational (due to spell-out) in kind.

Consider the trivial process of l-vocalization whereby lexical l (or ł) appears as w in coda position (like in Brazilian Portuguese for example, Collischonn & Costa 2003). This could be due to phonological computation (Son primes are rearranged under positional pressure), or to a spell-out instruction "l (coda) ↔ w". On the latter count, the phonological side of the spell-out instruction not only mentions Son primes (the definition of a lateral), but also structSon, i.e. the fact for the lateral to belong to a coda position.

In the latter interpretational perspective, lenition and fortition would be subjected to the arbitrariness of spell-out (2)c. That is, one would expect the existence of mismatches (or crazy matches) that are typical for spell-out relations: laterals could appear as θ in coda position (l (coda) ↔ θ), or they could appear as w word-initially (anti-l vocalization: l (word-initial) ↔ w). Such mismatches do not appear to exist, and significantly Chabot's inventory of crazy rules (section 2.3) features no case of a syllabic conditioning: i → u / d__ is reported for Southern Pomoan, but there is no case of, say, i → u in open syllables. This suggests that structSon is not used in spell-out instructions.

It thus appears that, at least for Son, only primes are spelt out: structure is absent from spell-out. In our example, l-vocalization in coda position is thus effected by regular

[28] The literature on production planning (Wagner 2012, Tanner *et al.* 2017, Tamminga 2018, Kilbourn-Ceron & Sonderegger 2018) works with a production planning window (or production scope) that defines the stretch of the linear string for which production is prepared in one go. This window is variable (across speakers, individual speech acts etc.) and defined by a number of factors that include morpho-syntactic information. That is, a production planning window may not be identical to a phase (or a cycle), but will in part have been defined by it.

phonological computation of Son. Like all other segments, the result of this computation w undergoes spell-out and may be subject to a mismatch, say, w ↔ θ. But this will then concern *all* w's of the language, not just those that occur in a coda. By contrast if spell-out were able to feature syllable-sensitive instructions, lexical laterals could appear as θ only in codas through a spell-out instruction "l (coda) ↔ θ". It was mentioned that this kind of syllable-sensitive crazy rules appear to be absent from the record.

This result is supported by the discussion in section 2.4: structSon is not subject to spell-out because spelling out an item is assigning it a phonetic correlate, but structSon has no such correlate. Its absence from spell-out instructions is also more generally consistent with the fact that processes at and above the skeleton are not arbitrary in the empirical record (section 2.3): their computation is not arbitrary (2)b because they are based on meaningful vocabulary. In sum, Son primes may experience arbitrary distortion (through spell-out), but structSon may not: it always reaches (language-specific) phonetics faithfully.

Finally, Son primes (section 5.2.2) and structSon (section 2.1) being phonologically meaningful, their computation is not arbitrary. An illusion of arbitrary Son computation may be created, though. Suppose an underlying b is turned into β by Son computation and this β is then be spelt out as, say, θ. This creates the impression of an arbitrary computation b > θ, but in fact involves regular computation followed by a spell-out mismatch.

7. Conclusion

The architecture discussed prompts some more general questions that are discussed below.

It is redundant in the sense that phonological computation occurs twice, upon lexicalization and upon production. Syllabification for example is running on both occasions, the difference being the portion of the linear string that is concerned: first within the to-be-lexicalized morpheme, then over the plurimorphemic domain defined by morpho-syntax (cycle, phase).

This relates to Morpheme Structure Constraints (MSC) mentioned in section 3, which have motivated the principle of Richness of the Base in OT (Prince & Smolensky 2004 [1993]: 191, McCarthy 1998): as McCarthy (2003: 29) puts it, "OT solves the Duplication Problem by denying the existence of morpheme structure constraints or other language-particular restrictions on underlying forms. OT derives all linguistically significant patterns from constraints on outputs interacting with faithfulness constraints ('Richness of the Base' in Prince and Smolensky 1993)". Vaux (Ms: 5) believes that "the duplication argument, […] is the heart of the attack on MSCs and in general perhaps the most invoked OT argument against DP [Derivational Phonology]". Morpheme Structure Constrains (MSCs) are restrictions on lexical representations, such as the prohibition of morpheme-initial sonorant-obstruent clusters in English, which will also be an impossible output of phonological computation upon production (the restriction is stated twice, in the lexicon and in computation). Rasin (2018: 93-152), Rasin & Katzir (2015) and Vaux (2005) argue that there is nothing wrong with this kind of redundancy because MSCs are conceptually and empirically necessary. The architecture exposed in this article is in line with this position.

Another question is why Son is related to morpho-syntax (in both directions, section 5.3.2), while Place and Lar are not (they are incommunicado with morpho-syntax in both directions). There is no answer to this question other than the observation that the wiring among modules is more generally unpredictable. The McGurk effect (McGurk & MacDonald 1976) for example documents that vision influences Place: in so-called McGurk fusion, subjects who are presented with synchronized visual g (the video recording of somebody pronouncing g) and audio b (the audio recording of somebody pronouncing [b]) perceive d.

Hence g_{video} and b_{auido} have combined into d, even though d is absent from the sensory input to the subject. The impact of vision is thus on Place. There is no McGurk effect reported on Son, i.e. a situation where, say, visual p (an obstruent) combined with audio [a] produces the perception of r, i.e. a sonorant that occurs half way on the sonority hierarchy. In the same way, synesthesia relates colours with objects or concepts in an unpredictable way: synesthetic subjects (about 4% of the population) associate this or that colour to this or that number, letter, person, concept, sound etc. (Sagiv & Ward 2006).

Finally, the question arises why Son is phonologically meaningful but Place and Lar are not. Consequences of this distinction based on their behaviour are that the Son vocabulary is meaningful, i.e. not substance-free, while Place and Lar vocabulary is meaningless, hence interchangeable and therefore arbitrary. In other words, SFP is not about Ssubstance-Free Phonology but rather merely about Substance-Free Place and Lar. This is reflected by the fact that work in SFP is only ever concerned with segmental phonology (section 2.1). In turn, the consequence of the fact that Son vocabulary is meaningful is its non-arbitrary relationship with the phonetic signal: there must be a way for humans to extract Son-relevant properties from the phonetic signal. While allowing for some slack that produces language-specific arrangements in the sonority hierarchy and relative sonority settings, the core of this mechanism appears to be universal (section 5.2.2).

It was mentioned in section 2.2 that the majority of SFP approaches considers i) primes and ii) their association to phonetic categories to be emergent, i.e. absent from the genetic endowment and absent at birth. Both are then constructed during L1 acquisition upon exposure to a specific language, based on contrast and phonological processing. The group working in the line of thought established by Hale & Reiss (2000) has a different take, though (note 5): both primes and their association to phonetic categories are universal, genetically coded and hence present at birth.

The former option is shown under (16)a, the latter under (16)b.

(16) substance-free melodic primes:

	phonology	mapping	phonetics
	α	⟷	[x]
	β	⟷	[y]
	γ	⟷	[z]
	melodic primes present at birth?	associations present at birth?	
a. SFP except H&R	no	no	
b. Hale & Reiss	yes	yes	

The properties of Place and Lar appear to match (16)a, while the workings of Son corresponds to (16)b. The next question is why the distribution is this way and not the other way round: why are Place and Lar emergent while Son is hard-wired, rather than the reverse? A possible answer is that the correlate of Son, loudness according to Parker (2008) (section 5.2.2), is used for other purposes by humans, while Place and Lar appear to do labour only in phonology. That is, loudness is used to evaluate emotions, danger, relevance of noise etc., while Place and Lar distinctions do not play any role for humans outside of phonology: what would a distinction between, say, labial and velar, or voiced and voiceless, be used for outside of speech?

In an evolutionary / biolinguistic perspective, this means that humans have developed a stable means to convert loudness into cognitive categories and Son is an exaptation thereof that occurred when language emerged in the species. In evolution, an exaptation is an opportunistic adaptation of an existing device for a function that it was not designed for. That is, Son primes and their association to phonetic categories predate language in the species and is likely present in animal cognition, while this is not the case for Place and Lar. These are rather a creation ex nihilo for the needs created by language, i.e. the expression of contrast with the anatomic devices offered by the speech organs. Hence new cognitive categories representing Place and Lar needed to be created by each language individually and ex nihilo: this may be the reason why they are arbitrary (phonologically meaningless), and why their association to phonetic categories is not hard wired but rather language-specific.

If all this makes sense, there are two types of primes that cognitive computational systems work on: meaningful (non-arbitrary) and meaningless (arbitrary). Modularity holds that the input to modular computation is domain-specific (section 2.4) and this is a chief criterion for detecting modules and telling them apart from others. The phonetic correlates of Son, Place and Lar, as well as their behaviour in computation, certainly allow the observer to discriminate three distinct items – this is what the pages above mean to show. But looked at from the cognitive side (i.e. without knowing about phonetic correlates), in which way are different vocabularies really different? That is, in which way does a given computational system know which vocabulary is relevant for its computation? The answer is obvious for meaningful vocabulary: it is domain-specific precisely because it is meaningful. But what about meaningless vocabulary? How could alphas and betas be specific to any particular module? Suppose there are a number of computational systems, maybe colour, shape, odor etc., which like Place and Lar work on meaningless vocabulary. How are these different sets of meaningless alphas, betas and gammas then distinguished and ascribed to the computational system they belong to? This seems to require some diacritic or attribute that each set bears: colour alphas against Place alphas against odour alphas etc.

This taps into the next question, which is about the status of non-linguistic modules: are odour, shape, colour, number sense etc. based on meaningful or meaningless vocabulary? The line of division suggested above is that those systems which are present in the human for a longer period of time, e.g. before the emergence of language, and which are likely to be also present in animals, work with meaningful vocabulary. This suggests that the cognitive system is able to create new cognitive categories and associate them to real-world items whenever this is needed (case of Place and Lar when language emerged in the species), but that in the initial stage these young systems have arbitrary, meaningless vocabulary. It is only over time that meaningless vocabulary may be knighted meaningful.

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