Emergent minimalism: /R/ in a stratal grammar

Eric RUSSELL WEBB
University of California, Davis
erussell@ucdavis.edu
http://philo.ucdavis.edu/home/~erussell

1. Introduction

Optimality Theory (OT, Prince & Smolensky 1993) provides that the source of language specificity is a ranking of violable constraints and, according to the Richness of the Base (ROTB), denies that linguistic idiosyncrasies may be attributed to the lexicon. Segments like the French dorsal /R/ are particularly interesting, given apparent featural minimalism and sensitivity to phonetically based constraints (Tranel 1987: 141-143, Russell Webb 2004 & in press). The present work reexamines this segment, questioning base richness, the nature of input and the learning of phonological representations. A stratal grammatical model is proposed, incorporating a restrictive interpretation of ROTB.

The paper proceeds as follows. Preliminary sections survey French /R/ data, ROTB and the status of input in OT. A third section reviews featural emergence, the nature of phonological inputs and the learning of underlying representations (UR) and licensing implications. A fourth section articulates the proposed model, accounting for French /R/ in learning, declarative and productive sub-modules. A final section provides synthesis and draws preliminary conclusions.

2. Background

Rhotics or "r-like sounds" present particular challenges to phonological theory, due in part to their surface variability. The back or dorsal /R/ of convergent varieties of French constitutes a particular case involving voice and aperture, described using traditional rules in (1).[1]

(1) French /R/ (Tranel 1987: 141-143, Russell Webb 2002)

/R/ → [ʁ̝] (voiced fricative)	/ D __ V (*brosse* [bʁ̝ɔs] 'brush')
/R/ → [x̝] (voiceless fricative)	/ T __ V (*pro* [px̝o] 'pro')
/R/ → [ʁ̞] (voiced approximant)	/ V__ V (*morose* [moʁ̞ɔz] 'morose')
	/ V __ D (*orgue* [ɔʁ̞g] 'organ')
/R/ → [x̞] (voiceless approximant)	/ V __ T (*orque* [ɔx̞k] 'orca')
	/ V T __ (*autre* [ɔtx̞] 'other')
/R/ → [ʁ̞] or [x̞]	/ V __ (*or* [ɔʁ̞] or [ɔx̞] 'gold')
	/ V D __ (*coudre* [kudʁ̞] or [kudx̞] 'sew')

Following (1), the surface form of /R/ is predictable from its phonological environment. Output of this nature has been accounted for with constraints referring to aperture licensing and passive voicing (see Russell Webb 2004, in press & forthcoming). Fundamental to most analyses is the assumption of a richly specified input segment, i.e. one which contains featural specification for both voice and aperture. Russell Webb (forthcoming) begins with the assumption that /R/ is fundamentally fricative, based on widely held assumptions noted in phonetic and phonological literature (see inter alia Delattre 1971, Dell 1980, Walker 2001).

[1] D = voiced obstruent, T = voiceless obstruent. Variation in place of articulation (e.g. velar, uvular and uvulo-velar /R/) is ignored throughout this work. Note that the plain capital R is used in general reference, absent of other considerations.

In contrast, Russell Webb (in press) follows Kirchner (1998), allowing the input to remain undetermined, where output form is predicted entirely from markedness rankings.

Both analyses are framed in OT, which relies solely on constraint ranking to account for cross-linguistic particularity and distributions noted in the output. OT avoids the problematic duality of lexicon and grammar (see Kisseberth 1970 & 1972) and the idiosyncrasy of certain phonological rules common to antecedent grammatical models. Per ROTB, the input may not be constrained in any meaningful way, e.g. it cannot provide that coda /R/ is fundamentally approximant and onset /R/ is fundamentally fricative. Instead, the grammar must contend with all theoretically possible input and predict attested output for post-vocalic fricative /R/ and prevocalic approximant /R/ inputs, among others.

2.1. Base and Richness

In an OT grammar, all possible adaptations or exaptations of the input (satisfying markedness) or limitations thereupon (satisfying faithfulness) are attributed to violable constraints; grammatical knowledge embodied in CON (the set of constraints) is considered part of Universal Grammar and idiosyncratic rules are dispensed with altogether.[2]

Much of OT's explanatory potential lies in the concentration of knowledge in the grammar, rather than the lexicon. This follows from ROTB, defined as

> [a principle] which holds that *all* inputs are possible in all languages, [and that] distributional regularities follow from the way the universal input set is mapped onto an output set by a grammar… (Prince & Smolensky 1993: 209, italics of the original).

A slightly different interpretation of ROTB is provided by Kager, providing that "no constraints hold at the level of underlying forms" (1999: 19). The two iterations of this principle are not incompatible, as both provide that the repository of grammatical specificity cannot be the input, eliminating formalisms such as morpheme structure rules (Smolensky 1996: 3).[3] This is not to say that the lexicon and language-specific vocabulary are dispensed with altogether; rather, it is a denial that "any significant regularities have their source in the lexicon" (McCarthy 2002: 76).

ROTB is supported by evidence from loanwords and inter-grammatical borrowings, among other data. With varying exceptionality, and typically due to the type of borrowing and language contact situation, as well as to particularities of the language in question (e.g. Itô & Mester 1999), loanwords adapt to the grammar of the borrowing language and not the reverse. Following from this, a straightforward account may be made of loanword adaptation (see inter alia Kenstowicz 1995 & 2003). Absent ROTB, OT would either place a blanket restriction on non-native inputs or posit multiple grammars, e.g. one for native and one for non-native inputs.

2.2. Learning in OT

Lexicon optimization (LexO) accounts for the assignment of input structure, based upon evidence induced of output forms during language learning. In the case of French /R/, for example, LexO provides that speakers posit phonemic UR corresponding to outputs [ʁ̞], [ʁ̝], [x̞] and [x̝] when these are in paradigmatic relation, e.g. *réel* [ʁ̝e.ɛl] 'real' and *irréel* [i.ʁ̞e.ɛl] 'unreal.' Learning of this type is predicated upon prior discrimination of significant speech noise in the target language, a process which appears to be well underway by the time a child's motor skills are developed enough to begin producing these sounds with any

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[2] For criticism of OT's blanket refusal of rules, see McMahon (2000a, notably 62-90).

[3] Archangeli (1997) provides that the only limitation on the input is that this must not contain non-linguistic objects. Recent refinements have narrowed the original scope of ROTB, as seen in e.g. McCarthy, where this is essentially an obligation that "the analyst [make] sure that the grammar gives phonetically permitted results even when presented with unpronounceable inputs" (MS: 3).

regularity (Clements 2003, 2004, Dehaene-Lambertz & Pena 2001, Boersma 1998: 347-378). It should be noted that LexO does not imply that, because a language learner never encounters a form, her grammar needn't deal with it (i.e. "pseudo-lexicon optimization," McCarthy 2002: 78-79).

Following LexO, the input assigned to a given output should correspond to the most harmonic output-input mapping; a learner re-arranges her grammar in order to match the experienced output onto input (Prince & Smolensky 1993: 209-210). Grammatical restructuring involves the re-ranking of constraints based upon evidence from ambient linguistic data, i.e. the output available to a learner. As the child interprets her output to match (or not) that of the adult language surrounding her, pertinent constraints are either promoted or demoted. Phoneme inventory learning may be correlated to the learning of language-specific constraint ranking, following either constraint demotion (e.g. Tesar & Smolensky 2000) or a gradual learning algorithm (e.g. Boersma & Hayes 2001, Boersma & Levelt 2003, Escuerdo & Boersma 2004).[4]

Phoneme or segment learning poses a distinct problem, as learners are often faced with output forms which could logically provide for multiple input correspondents. Stated complementarily, two or more experiential inputs might infelicitously lead to distinct UR as output, as in (2) below, which considers the learning of /R/ based on data in (1) and focuses solely on aperture (i.e. fricative versus approximant). This simple example employs the hypothetical constraints *R-fric ('R should not be fricative') and *R-approx ('R should not be approximant'), as well as a blanket faithfulness constraint; a more elaborate grammar and constraints are employed to fully account for /R/ learning and surface forms in subsequent discussion.

(2) Example of two inputs leading to the same output

a. /R/ in onset: *rat* 'rat' [ʁ̝a], *réel* 'real' [ʁ̝e.ɛl], etc.

ʁ̝	FAITHFULNESS	*R-fric	*R-approx
☞ /ʁ̝/ (fricative)		*	
/ʁ̞/ (approximant)	*!		*
/R/ (unspecified)	*!		

b. /R/ in coda: *par* 'by' [paʁ̞], *irréel* 'unreal' [i.ʁ̞e.ɛl], etc.

ʁ̞	FAITHFULNESS	*R-fric	*R-approx
☞ /ʁ̞/			*
/ʁ̝/	*!	*	
/R/	*!		

Logically, neither *R-fric nor *R-approx can be ranked above faithfulness in (2), as either ranking would result in unattested surface forms, e.g. *[ʁ̞a] or *[kuʁ̝]. However, the ranking as provided leads to the selection of two underlying forms, a seeming contradiction to the paradigmatic associability of these. A possible solution to the grammar involves additional constraints, e.g. IDENT(onset) ('onsets should be identical'). This approach leads to the choice of one or the other variant as underlying, an ad hoc solution for which motivation is lacking. The ranking IDENT(onset) above IDENT(coda), or the converse, must also be motivated in order to obtain an output /ʁ̝/ or /ʁ̞/, respectively.

[4] The reader will note that I do not enter into debate regarding the particularities of one or another mechanism of learning, as either is compatible with the proposal made here.

2.3. Questions of base richness

The issue of UR learning and access is discussed at length in Hale & Reiss (1998). Here, the dilemma of needing a grammar to provide for UR, but needing UR to provide a grammar is termed a *Teufelkreuz* or vicious circle (see also McMahon 2000a regarding implications for historical linguistics). The vicious circle evoked by Hale & Reiss alludes to a particularly troubling point, namely the lack of attention paid to the input itself, specifically its form (what can and cannot be an input), its source (how a speaker accesses inputs), and its inevitable—and importantly indirect—constraint. While theory-specific input may be infinite, the data to which a learner is exposed during acquisition is, on the contrary, relatively limited.

Reiss (2000) approaches these questions from a cognitive science orientation and considers OT anti-mentalist, as it implies little psychological reality save for the learning of constraint hierarchies. He also questions ROTB as a linguistic principle and the ban on input constraints, noting that, according to a rigorous interpretation of grammar learning, input is inherently constrained.[5] He argues that LexO is incompatible with ROTB, as it provides that the underlying form of an item will be stored as matching its surface form (although it is unclear the extent to which UR should be equated with grammatical input). LexO can only operate given invariant output, i.e. those items which do not fluctuate along some paradigmatic or syntagmatic dimension.

Van Oostendorp (MS) evokes different concerns raised by examples in two German and two Dutch dialects, each having variant UR which cannot be accounted for by LexO. He argues against an orthodox interpretation of ROTB, noting that there must be a place for learned UR in phonological grammars, i.e. a way to learn and discriminate among possible inputs not having a logically occurring output correspondent without a large amount of specifically targeted faithfulness violations. As a solution to this, Van Oostendorp introduces declaratively-oriented constraints, e.g. "a dorsal stop can only surface if it belongs to a stop underlyingly" (10), essentially providing the indirect constraint of (at least some) input forms at (at least some) levels of the grammar.

A final problematic issue for ROTB is underspecification and the status of redundant phonological features in the input (see Archangeli 1988, Cohn 1995, Hall 2001). Itô, Mester and Padgett (1995) demonstrate that the non-derivational framework of the theory denies any serial ordering or minimalism, providing that underspecification is an output property (see discussion in §4.2). This approach to indeterminate UR is distinct from that taken by Kirchner (1998) and Russell Webb (in press), which provide that UR can be un-specified as a means of avoiding circuitousness (see also Boersma 1998).

It is worth noting that ROTB has been very widely accepted, although a casual glance at contemporary linguistic publications reveals little interest its fuller implications. Few analyses treat a broad range of logically possible inputs pertinent to a given question; most are, rather, reliant on implicitly delimited—not to say explicitly constrained—input sets, since what is most important for the majority of OT practitioners is not the theory itself, but the potential it affords for greater understanding of particular linguistic problems.

3. Input and Phonological Building Blocks

Echoing many of the objections noted above, the assumption that human grammars function without relation to learned representations begs the question as to whether ROTB is merely a

[5] Reiss further addresses the confusion of three linguistically-oriented pursuits, which he terms problems: the AI (intelligence) problem, the linguist's problem and the human problem. As a strongly output-oriented theory of language production, OT is seen as a response to the first pursuit, i.e. as a means by which to reproduce the same output as human language, though the means by which this output is attained in human language may not be the same as that which is posited for the theoretical grammar.

good idea for an output-oriented theory or whether this is truly a principle of linguistic production. This section reconsiders the source of input to a phonological grammar, the nature of the input itself (an issue noted by Archangeli 1997: 200 and McMahon 2000a: 55-56), and the possibility of limitations of such input. Reflecting many of the concerns in Reiss (2000), Hale & Reiss (1998) and McMahon (2000a), it is argued that a place must be made for learned representations in OT.

3.1. The source of input

Traditionally, an OT grammatical input is situated outside of linguistic competence, constituting a type of mechanistic control. For natural language, however, linguistically meaningful input has an observable source—the language learner's uptake of adult grammatical output during acquisition. This corresponds to perceived surface forms (see Dupoux et al 2001 regarding the distinction between perception and hearing), i.e. the product of constraint interaction in other speakers' grammars. Such output-as-input serves as the catalyst for both grammar and UR learning. Crucially, this input is constrained; not all possible outputs will be present and made available to learners in a given speech situation. While it is imperative that a grammar contend with any possible input at some level of analysis, it is doubtful at best whether this occurs in natural language; more importantly, any conceptualization of fully unconstrained input in learning ignores the experiential means by which human speakers acquire grammars.

Input to lexical borrowing also involves a constrained output, albeit of a nature distinct from that of language learning. For Boersma (2004), borrowing has as its source linguistic production. This output serves as input to a perception grammar, i.e. a grammar in which the candidates are potential UR corresponding to perceived input. Not unimportantly, input leading to this output is constrained and tied to a physical reality. Perception itself is influenced by several factors, such that the raw physical manifestation of an utterance does not uniformly correspond to what is perceived by the listener (see e.g. Flege 1995 & 2003, Kuhl & Iverson 1995). For the present purpose, it is sufficient to note that such input constitutes an apparent contradiction to a strong interpretation of ROTB. Furthermore, a theoretically infinite, universal set of linguistic inputs is difficult, if not impossible to quantify, engendering formal and categorical complexities for production grammars.

Without proposing a blanket denial of ROTB as theorem, the case can be made for a limitation of its scope. In this paper, this is accomplished by distinguishing between grammatical strata or modules in which complementary types of grammatical knowledge are formalized. Prior to focusing more closely on this issue, it is important to reconsider the content of inputs, focusing on phonological building blocks.

3.2. Featural emergence and the nature of input

Phonological inputs are understood as feature bundles, although the content and form of these is theory dependent, such that /t/ might be considered [- voice] or [spread glottis] depending upon the feature theory chosen for application (see e.g. Jessen & Ringen 2002). While there is disagreement about how to best capture certain featural distinctions, traditional views hold that featural specification is innate and/or universal (Chomsky & Halle 1968: 43, 164; Mielke 2004: 39-43).

Boersma (1998) provides that feature values are not universal, but are learned and language-specific, such that

> [the] continuous articulatory and perceptual phonetic spaces are universal, and so are the constraints that are defined on them; the discrete phonological feature values, however, are language-specific, and follow from the selective constraint lowering that is characteristic of the acquisition of coordination and categorization (172).

Mielke (2004) arrives at a similar conclusion regarding features, arguing these to be "abstract categories based on generalizations that emerge from phonological patterns" (7, see also 92-140). According to his Emergent Feature Theory (EFT), features are born of generalizations made by language learners from experienced phonological patterns. These phonological patterns may be indirectly grounded in phonetically motivated diachronic changes or in phonetic form, but such factors do not directly motivate features themselves (2004: 118-121, 126-127).[6] While it is not the purpose of the present work to discuss EFT and featural emergence in great detail, it should be understood that the grammatical model proposed here assumes that phonological primitives are not innately specified.

If features emerge from language learning and use, subscription to orthodox ROTB as a grammatical principle becomes far more difficult. In addition to constraint rankings, language learners must also acquire the discrete elements cast upon that grammar, i.e. the meaningful oppositions which are present in the ambient language. It is this output-as-input which feeds GEN, from which candidate output UR are made available to be judged according the constraint ranking as it is posited at a particular moment in time. It bears reiteration that this input (a reflection of adult output) is constrained. Of course, a theoretically large number of inputs could be made available to a grammar and, as suggested by McCarthy, a grammar which assumes to model human linguistic competence should be able to successfully predict attested outcomes for all potential or possible inputs, including those which do not have an underlying correspondent and are not present in the learner input (2002: 78). What is at issue is not the theory-internal need for ROTB, but the scope of ROTB and the nature of the base or input itself.

Several important questions emerge from reconsideration of features and phonological input. Firstly, given the useful theoretical premise that all grammars should be able to deal with all inputs, regardless of the status of these, what can be said of the dual functional needs cast upon the grammar, that of both filter to eventual production and implementer of production? Secondly, if it assumed that UR learning is fed by perceived output and that features are emergent, what is the role and formal structure of the grammar with regard to the selection of optimal grammatical output, i.e. of surface forms? Finally, how is this grammar learned while, at the same time, the UR which feed it and serve as the catalysts of learning must also be acquired? The proposed solution consists of a formal distinction between unique knowledge types (categorical parsing, declarative and procedural), expressed in different constraint families.

4. The Proposal

The proposal made here is inspired by antecedent models (e.g. Rubach 2000, Hale, Kissock & Reiss 1998 and Kenstowicz 1995) and by Boersma (2004), who distinguishes between the grammatical functions of filter and implementer.[7] Gess' (2003) model of sound change serves as a framework for formalizations advanced in the following sections. His lexical and post-lexical strata are reflected in the proposed declarative and procedural strata, respectively; the former refers to knowledge of UR structure and form, while the latter refers to knowledge about the production of surface forms (see also Walenski & Ullman 2005). A number of modifications to Gess' model are made. Foremost among these is the explicit concentration of phonetically oriented constraints at the productive (his post-lexical) stratum. An additional stratum involving the learning of phonemic UR and licensing implications (perceptually-

[6] Neither Boersma nor Mielke deny that certain features are quasi-universal (e.g. place features such as [coronal]). Both the functional (Boersma) and emergent (Mielke) featural positions propose that such apparent universality is not due to innateness, but to language use and learning.

[7] Also of note are criticisms of serial approaches to OT, e.g. Itô & Mester (2002 & 1999).

orientated tasks) is added, although the learning of constraint rankings is not discussed in any detail.

4.1. The Learning Stratum

Due to the present approach's dependence upon systemically emergent features, a brief overview of assumptions made of French is warranted. For more complete treatment of this and motivation for specific emergent featural specifications, see Russell Webb (MS). Subsequently discussed is the organization of constraints relevant for the learning stratum and the establishment of featural licensing relations.

Following §3.2, features employed below are assumed to emerge early in language acquisition. Without yet referring to the specific UR of different sounds, and assuming that the learner has already distinguished between those sound segments which are and are not part of the language in her surrounding environment (e.g. that |ʁ̞| and |ʃ| are, while |ß| and |h| are not linguistically significant in French), categorizations and their idealized descriptions are formalized as in (3).

(3) Featural Emergence in (convergent) French

a. obstruent

Some sounds are always low-sonority, have widely dispersed acoustic characteristics and will never occur in a syllable nucleus (constitute a sonority peak)

b. sonorant

Some sounds may co-occur with other sounds in complex syllabic clusters (i.e. onsets and codas), provided that these are closest to the sonority peak (i.e. rightmost member of a branching onset or leftmost of a branching coda)

c. continuant

Some sounds involve no mid-saggital closure and may co-occur with other sounds in complex syllabic clusters (i.e. onsets and codas) having the same place of articulation

d. voice

Some sounds are contrastive by virtue of source voicing; other sounds are not (i.e. some sounds are inherently voiced or voiceless, whereas others are not contrastive in this regard).

Note that since the focus of discussion is on features pertinent to /R/, several irrelevant categorizations are not presented and place distinctions are assumed to be straightforwardly categorized.

If a child acquiring French is exposed to data along the lines of (1), grammatical input consists of her perception of the corresponding adult output forms. Given the relation of forms such as *réel* and *irréel* ([ʁ̝]and [ʁ̞] respectively) and countless others, LexO holds for the learning of UR across paradigms (Tesar & Smolensky 2000: 77-78).[8] This is captured by the interaction of PARSE, here promoting input-output correspondence, and *CATEG(ORIZE), penalizing the categorization of indistinctive input information, as in (4.a). Note that the original definition of PARSE has been reformulated, referring here to features of surface representations and those of the underlying form. The constraint series in (4.b) and (c) are targeted to specific input features of (3). It is worth noting that /R/ and its surface variants are assumed to be distinguished as [+sonorant], based on its ability to freely group with obstruents in complex syllabic structures, as well as its acoustic characteristics.

(4) Learning Constraints (Boersma 1998: 189, 164; cf. also Kager 1999: 100)

a. General Faithfulness and Markedness

PARSE(*f*): a surface feature appears in the underlying form

[8] Hale, Kissock and Reiss (1998) also consider full paradigms, although LexO is not called upon as such.

*CATEG(*f:v/S*): the value *v* is not a category of feature *f*, i.e. a perceptual feature *f* cannot be recognized as the value *v* for segments *S*[9]
b. Targeted Faithfulness
PARSE(manner): manner features should appear in the underlying form; output manner features should have an input correspondent
c. Targeted Markedness
*CATEG(FO, voice/son): the perceptual feature of source voicing (F0) should not be categorized as [voice] for segments recognized as [sonorant] (abbreviated *CATEG(voice-son))
*CATEG(fric, continuant ∧ obstruent/son): the perceptual features of frication should not be categorized as [continuant ∧ obstruent] for segments recognized as [+sonorant] (abbreviated * CATEG(fric-son))

As a logical extension of the formalizations in (4.b), PARSE can be targeted to different features, including PARSE(voice), PARSE(obstruent), etc. *CATEG constraints in (4.c) include only factors relevant for discussion and are specified such that they target only segments which are both continuant and sonorant, i.e. /R/; all related constraints should be assumed as crucially ranked and not pertinent to the present analysis.

Both UR and featural licensing are grammatical outputs of the learning stratum (Itô, Mester & Padgett 1995; see also Kiparksy 1985, Hermans & Van Oostendorp 2000). Licensing refers to the implication of one feature by another, as in (5), and may be considered a byproduct of UR learning, i.e. that the learning stratum leads not only to a UR output, but to implications concerning featural associations which hold across categorizations.

(5) Licensing (Itô, Mester & Padgett 1995: 579-580, their 11)
$F \supset G, \neg(F \lambda G)$
"If the specification [F] implies the specification G, then it is not the case that [F] licenses [G]"

Given an assumption of high ranking of PARSE constraints pertinent to place, continuance and sonorance (not included in following tableaux), the ranking of *CATEG(voice-son) and *CATEG(fric-son) above complementary PARSE constraints predicts the selection of output UR lacking voicing and aperture-specific manner features, though these constraints have no effect on other segments in the language (e.g. [±voice] and [+obstruent] for /b:p, d:t, g:k, v:f, z:s, ʒ:ʃ/). A demonstration of this is provided in (6), using the examples *réel* and *irréel*. All output notations should be read as specified for [dorsal], [+continuant] and [+sonorant], with /ʁ̞/ being specified as [+obstruent, +voice], /ʁ/ as [+voice] only, /X/ as [+obstruent] only and /R/ as absent of both voice and obstruent specifications. Perceptual input is presented between vertical bars. Among the possible output candidates presented in the tableau, only that which contains a minimally specified /R/ (i.e. [dorsal, +sonorant, + continuant]) is selected. Stated in terms of licensing and licensing cancellation, a parallel output which serves to establish static knowledge holding at the declarative stratum (see §4.2), the most optimal output is one which provides that neither [voice] nor [obstruent] are licensed for continuant sonorants.

[9] *CATEG is distinct in both formalization and scope to *SPEC (Prince & Smolensky 1993: 213, their example 303), which provides that "underlying material must be absent (in the output)."

(6) Learning feature licensing and UR

|ʁ̞e.ɛl| |iʁ̞e.ɛl| etc…	*CATEG(voice-son)	*CATEG(fric-son)	PARSE(±voice)	PARSE(±obstr)
cont + sonλobstr ∧ cont + sonλvoice (e.g. /ʁ̞eɛl/)	*!	*		
cont + sonλvoice ¬cont + sonλobstr (e.g. /Xeɛl/)		*!	*	
¬cont + sonλvoice cont + sonλobstr (e.g. /ʁeɛl/)	*!			*
☞ ¬cont + sonλvoice ∧ ¬cont + sonλobstr (e.g. /Reɛl/)			*	*

Beyond related input paradigms, licensing- and UR-learning can be conceived of as global tasks, involving multiple input and output correspondents, in this case for different experiential manifestations of /R/. The tableau in (7), using the abbreviations of (1), demonstrates the selection of a singular /R/ and related licensing conditions across those contexts where /R/ appears. For presentational economy, only the fully faithful and minimally specified output candidates are considered.

(7) Learning UR and feature licensing: the case of /R/

	*CATEG(voice-son)	*CATEG(fric-son)	PARSE(±voice)	PARSE(±obstr)
|Dʁ̞V| → /Dʁ̞V/	*!	*		
☞ |Dʁ̞V| → /DRV/			*	*
|Tχ̞V| → /Tχ̞V/	*!	*		
☞ |Tχ̞V| → /TRV/			*	*
|Vʁ̞V| → /Vʁ̞V/	*!			
☞|Vʁ̞V| → /VRV/			*	*
|Vʁ̞D| → /Vʁ̞D/	*!			
☞ |Vʁ̞D| → /VRD/			*	*
|Vχ̞T| → /Vχ̞T/	*!			
☞ |Vχ̞T| → /VRT/			*	*

Here again, only those UR which do not specify obstruence and voicing are selected, providing that positive specification for [sonorant] (accomplished by the ranking PARSE(sonorant) >> *CATEG(voice-son), *CATEG(fric-son)) cancels licensing for these features.

The learning stratum performs an evaluative function based on inherently constrained input. As discussed in § 4.2, this does not deny the mechanistic need for ROTB in the larger grammar. The proposed grammar predicts, however, that perceptual inputs not present in the acquisition environment will not lead to the learning of UR and corresponding licensing relations. This allows for greater explanation in declarative grammar, as it associates constraint rankings based on UR and licensing implications. By calling upon licensing relationships and implicationally minimal UR in the case of variant input, the grammar avoids the position of multiple UR for forms in paradigmatic relation (e.g. positing two or more underlying /R/) and, complementarily, the position of a single UR and subsequent need for high ranking markedness constraints targeted uniquely to this segment, as in (2).

4.2. Declarative Stratum

The declarative stratum includes phonological knowledge captured in constraints deriving from licensing principles, the most relevant of which are summarized in (8).[10] It is here that the grammar contends with theoretically infinite input, including those which do not have a UR correspondent (e.g. loanwords), as discussed in §4.2.1.

(8) Licensing Implications

-cont ⊃ +obstr, "non-continuants imply obstruence"
+son ⊃ ∅voice, "sonorants imply no voice specification
+cont ∧ +son ⊃ ∅obstr , "continuant sonorants imply no obstruent specification"

Much like the principle of categorization underlying featural emergence—providing that the featural categorization is universal, even if the content of these categorizations is not (see §3.1)—licensing is construed as a universal operating parameter, even though its adjudication is system specific. Based upon the featural specifications which emerge from the learning stratum, licensing imperatives are formalized in constraints of (9), which are limited to those applicable to /R/.

(9) Declarative Constraints

a. Voicing
LICENSE(voice): the phonological feature [voice] must be licensed;
*SON(voice), "sonorants are not licensed for [voice]"
b. Obstruence
LICENSE(obstruent): the phonological feature [obstruent] must be licensed;
*CONTSON(obstr), "continuant sonorants are not licensed for [obstr]"

Markedness in (9) targets input involving unlicensed featural combinations, such that an input /ʁ̞/ ([+obstruent, +voice]) violates *SON(voice) and *CONTSON(obstr). Faithfulness plays a crucial role at this stratum; not all output segments should be minimally specified, as is the case with /R/, hinting that certain input featural combinations are licensed and should be unaffected by declarative filtering. This is captured in a series of correspondence constraints built upon featural identity, as in (10).

(10) Faithfulness (Kager 1999: 205, his 16.c)

IDENT(f): $\forall f,\ f \in \mathrm{I} \wedge f \in \mathrm{O} \rightarrow \mathrm{I}f = \mathrm{O}f$; "input and output features should correspond"

In the present discussion and analysis, faithfulness is provided as IDENT(voice), IDENT(obstr), IDENT(place), IDENT(cont), IDENT(son). Faithfulness to input featural specifications for [continuant], [place] and [sonorant] outranks that for [voice] and [obstruent]; these are also higher ranked than *SON(voice) and *CONTSON(obstr). Were this not the case, the grammar would predict output varying along these featural dimensions. The tableaux in (11) successfully account for the determination of a minimally specified output form, exemplified by (fully specified) inputs /ʁ̞/ and /x̠/. For demonstrative purposes, output candidates have been limited to those involving input-output discordance vis-à-vis the featural variables in (3); /l/ should be understood as [+sonorant, -continuant, +obstruent], following discussion in Russell Webb (MS) and the definitions in (3).

[10] The reader will note that the conception of a lexical stratum, distinct from production, borrows heavily from traditions in Lexical Phonology (see inter alia Kiparsky 1982, McMahon 2000b).

(11) Output featural minimalism: /R/

	IDENT(cont)	IDENT(son)	IDENT(place)	*SON(voice)	*CONTSON(obstr)
/ʁ̟/ ʁ̟				*!	*
ʁ̝				*!	
x̟				*!	*
x̝				*!	
l	*!		*		
g	*!	*			
☞ R					
/x̝/ x̝				*!	
x̟				*!	*
ʁ̝				*!	
ʁ̟				*!	*
l	*!		*		
k	*!	*			
☞ R					

In (11), minimal specification is a grammatical outcome, agreeing with Itô, Mester & Padget (1995) and Hermans & van Oostendorp (2000). Declarative filtering at this stratum also accounts for representational minimalism in the case of /l/, which is unspecified for voicing. Absent output featural minimalism, a series of highly specific constraints targeting /R/ alone would be required at the productive stratum, where the primary task of the grammar is to account for regularity involving passive voicing and onset fortition.

While the declarative grammar effectively filters input in the case of /R/, it must also not over-predict output minimalism or predict surface variability not attested in French, engendering another unnecessarily complication of the productive grammar. Pertinent faithfulness in this instance involves specification for [voice] and [obstruent], providing that voice contrast is maintained for fricatives and plosives, and that obstruent specification is maintained for all segments which are not continuant sonorants. This is shown in (12), using example inputs /s/ and /l/. Note that [ɹ], [s̝] and [ɬ] are considered [+sonorant]; S should be read as unspecified for voicing and obstruence.

(12) Featural preservation in the output: /s/ and /l/

	Ident(cont)	Ident(son)	Ident(place)	*Son(voice)	*ContSon(obstr)	Ident(voice)	Ident(obstr)
/s/ ☞s							
z						*!	
ʃ			*!				
S						*!	*
s̝							*!
t͡s	*!						
/l/ ☞l							
ɬ			*!				
d		*!					
ɹ	*!						
l̬				*!		*	
l̥				*!		*	

In the case of /s/, the fully faithful output [s] is most optimal, as all others involve one or more IDENT violations. In the case of /l/, only the minimally specified [l] emerges the winner from constraint interaction, as both voiced [l̬] and voiceless [l̥] violate licensing cancellation for sonorants (*SONVOICE).

4.2.1. Loan phonology and declarative filtering

As ROTB holds at the declarative stratum, it is here that the grammar must logically contend with all input forms, including those which do not have UR correspondents, avoiding the pitfalls of pseudo-lexicon optimization while accounting for loanwords and input representations which are not categorized by the system.[11] To offer one example of declarative filtering of rich input at this stratum, consider the case of *gay pride* (/gɛʲpɹaʲd/), an English loan surfacing as [gepχ̟aʲd] in most convergent forms of French. Among the several allochthonous phonological elements in the input is the coronal approximant /ɹ/. As it stands (and regardless of [ɹ] voice specification), the declarative grammar does not accurately predict attested output, as in (13), where the most harmonious output should be R.

(13) Declarative filtering

/ɹ/	IDENT(cont)	IDENT(son)	IDENT(place)	*SON(voice)	*CONTSON(obstr)
☞ ɹ					
s		*!		*	*
z		*!			*
l	*!				
χ̟			*!		*
ʁ̟			*!		*
χ̞			*!	*	
ʁ̞			*!	*	
☹ R			*!		

The solution to (13) lies in the licensing implications which emerge from the learning stratum, specifically those which provide that the place feature [coronal] cannot be associated with both [continuant] and [sonorant], formalized in the constraint *ContSon(cor), "continuant sonorants are not licensed for [coronal]." This constraint may be assumed to emerge from the learning stratum and is ranked above {IDENT(cont), IDENT(son), IDENT(place)}, predicting R as the most optimal output, as in (14). Note that such considerations motivate a distinct ranking for IDENT(place), which is co-ranked with IDENT(son) and (cont) above. Parallel predictions can be made in a fully expanded grammar, including other rhotic inputs (e.g. Italian /ɾ/, *paparazzi* /papaɾatsi/ → [papaʁ̞adzi]), as well as non-sonorant obstruents (e.g. English *Thatcher* /θat͡ʃə/ → [sat͡ʃɛʁ̞] or [zat͡ʃɛʁ̞]).

[11] I do not exhaustively treat issues surrounding loanword adaptation in the grammar; the reader is referred to much more complete discussion of this in Itô & Mester 1999, Kenstowicz 1995 & 2003, among others.

(14) Declarative filtering revisited

/ɹ/	*SonCont(cor)	Ident(cont)	Ident(son)	Ident(place)	*Son(voice)	*ContSon(obstr)
ɹ	*!					
s			*!		*	*
z			*!			*
l		*!				
x̝				*		*!
ʁ̝				*		*!
x̞				*	*!	
ʁ̞				*	*!	
☞ R				*		

Within the grammar as a whole, declarative static knowledge serves as a base filter, responding to ROTB and the imperative that a grammar make valid predictions from all potential inputs or, at the very least, demonstrate that it is capable of doing so. The output of the declarative stratum is then made available to the productive stratum, i.e. to phonologically governed regularities of implementation. Distinction between declarative and productive strata allows the grammar to capture two crucial elements lacking in orthodox OT analyses: the status of UR (cf. Hammond 1997, van Oostendorp MS) and the role of lower-level, phonetically based knowledge in phonological grammars.

4.3. Productive Stratum

The productive stratum is framed around constraints grounded in phonetic knowledge. A growing body of literature within OT advocates the inclusion of phonetic factors in the grammar, including knowledge pertinent to the on-line processing of structural descriptions and other abstract representations (for a useful introduction, see Hayes, Kirchner & Steriade 2004). The proposed productive stratum incorporates phonetically based constraints, which are assumed to indirectly reflect learned phonetic goodness following discussion in Hayes (2004[1996]). Constraints pertinent to the productive stratum are formalized as IDENT(ITY) and PRES(ERVATION), as well as two families of markedness constraints. The constraints relevant to the productive stratum are provided in (15).

(15) Productive constraints

a. faithfulness

IDENT(I-O): Output is identical to input

PRES(*f*, I-O): Preserve input featural information in the output

b. markedness

-EFFORT(GLOT): do not actively control glottal gestures (“allow passive voicing and devoicing”)

-EFFORT(V_V): minimize articulatory effort in intervocalic position

ONSET(OBS): segments in the onset should be obstruents

Faithfulness in (15.a) is rather straightforward and requires little additional explanation. The first series of markedness constraints is oriented toward articulatory ease and targets effort reduction, provided here as –EFFORT, a general constraint which provides that positive effort expenditure should be minimized (Kirchner 1998: 38-44, 50-52, where effort minimization is formalized as LAZY). In (15.b), this is targeted to specific environments (i.e. intervocalic position) and specific gestures (i.e. glottal configurations for voicing), following discussion in Russell Webb (2004, in press & MS). The second markedness type derives from perceptual considerations, targeting autosegmental positions in output candidates (Wright 2001, 2004; Steriade 2001). Concern here is with onsets, where more robust acoustic cues allow for ease of perception.[12]

Constraint interaction in French, where PRES >> –EFFORT >> ONSET(OBS), highlights two important and complementary points: that the representational minimalism of /R/ emerging from the declarative stratum renders it particularly sensitive to phonetically based constraints, and that other, more richly specified segments are unaffected by these. The grammar provided in the tableaux in (16), below, successfully predicts the surface form of /R/ in different environments.

(16) SF /R/ aperture and voice output

a. Complex onset following voiced obstruent, *grue* ‘crane’

/gRy/	PRES	-EFFORT(V_V)	-EFFORT(GLOT)	ONSET(OBS)	IDENT
☞ gʁ̝y					*(obstr)
gx̝y			*!		*(obstr)
gʁ̞y				*!	
gx̞y			*!	*	
gɐy				*!	*(vowel)

b. Complex onset following voiceless obstruent, *cru* ‘raw’

/kRy/	PRES	-EFFORT(V_V)	-EFFORT(GLOT)	ONSET(OBS)	IDENT
kʁ̝y			*!		*(obstr)
☞ kx̝y					*(obstr)
kʁ̞y			*!	*	
kx̞y				*!	
kɐy				*!	*(vowel)

c. Intervocalic, *arabe* ‘arab’

/aRab/	PRES	-EFFORT(V_V)	-EFFORT(GLOT)	ONSET(OBS)	IDENT
aʁ̝ab		*!			*(obstr)
ax̝ab		*!			*(obstr)
☞ aʁ̞ab				*	
ax̞ab			*!	*	
aɐab				*	*!(vowel)

d. Word-final, *perte* ‘loss’

/pɛRt/	PRES	-EFFORT(V_V)	-EFFORT(GLOT)	ONSET(OBS)	IDENT
pɛʁ̝t					*!(obstr)
pɛx̝t					*!(obstr)
pɛʁ̞t			*!		
☞ pɛx̞t					
pɛɐt					*!(vowel)

In (16.a), only [gʁ̝y] satisfies –EFFORT(GLOT); approximant and vocalized candidates are evaluated as sub-optimal due to violation of ONSET(OBS). The converse is obtained in (16.b), where the optimal output is a voiceless fricative, this an effect of –EFFORT(GLOT) in the context of an voiceless obstruent. Interaction in (16.c) establishes the ranking -EFFORT(V_V), -EFFORT(GLOT) >> ONSET(OBS), as the means to predict the attested output [aʁ̞ab] for input

[12] ONSET(OBS) is closely related to Prince & Smolensky’s principle of the best onset (1993: 99-101)

/aRab/, i.e. excluding onset fortition in word-internal intervocalic environments, as in *[aʁ̞ab]. In syllabic codas, as in (16.d), the grammar predicts that the minimally specified /R/ will be interpolated as an approximant [ʁ̞], as all other relevant candidates are excluded by one (or potentially several) IDENT(I-O) violations. For presentational economy, only one candidate involving /R/ vocalization is provided, exemplified by /R/ → [ɐ]. Each of these violates IDENT(I-O) as vocalic output contain the feature [+vowel], which is lacking in the input. By extension, multiple faithfulness violations would obtain for candidates consisting of vocalization to a different output form, e.g. outputs where /R/ → homorganic [w] preceding a rounded vowel.

As input has been effectively filtered by the declarative stratum, PRES(I-O) has little effect on phonological output when it comes to /R/. Although not relevant to (16), PRES is included in these tableaux, noting that no input featural information was lost. This constraint proves crucial, however, in the case of other, more richly specified segments, exemplified by /l/, /j/ and /s/ in (17), below.

(17) SF /l/, /j/ and fricatives

a. Word-initial /l/, *blanche* 'white-FEM'

/blɑ̃ʃ/	PRES	-EFFORT(V_V)	-EFFORT(GLOT)	ONSET(OBS)	IDENT
☞ blɑ̃ʃ					
bl̥ɑ̃ʃ			*!		
bl̝ɑ̃ʃ	*!(obstr)			*	

b. Word-final /l/, *calte* 'flee-3S'

/kalt/	PRES	-EFFORT(V_V)	-EFFORT(GLOT)	ONSET(OBS)	IDENT
☞ kalt					
kal̬t			*!		
kal̝t	*!(obstr)				

c. /j/, *paye* 'pay-3S'

/pɛj/	PRES	-EFFORT(V_V)	-EFFORT(GLOT)	ONSET(OBS)	IDENT
☞ pɛj					
pɛi	*!(son)				
pɛʝ	*!(vowel)				

d. /s/, *peste* 'plague'

/pɛst/	PRES	-EFFORT(V_V)	-EFFORT(GLOT)	ONSET(OBS)	IDENT
☞ pɛst					
pɛzt	*!(voice)				*(voice)
pɛs̝t	*!(obstr)				

e. /s/, *plaça* 'place-3S/PAST'

/plasa/	PRES	-EFFORT(V_V)	-EFFORT(GLOT)	ONSET(OBS)	IDENT
☞ plasa		*	*		
plaza	*!(voice)	*			*(voice)
plas̝a	*! (obstr)		*	*	
plaz̝a	*!* (voice, obstr)			*	*(voice)

In the case of richly specified input, the productive stratum has little overt effect. It should be noted that, in the case of loanwords involving phonemes not part of the French inventory, the productive stratum plays a limited role, as such input are assumed to be effectively filtered by the declarative stratum.

4.4. Synthesis

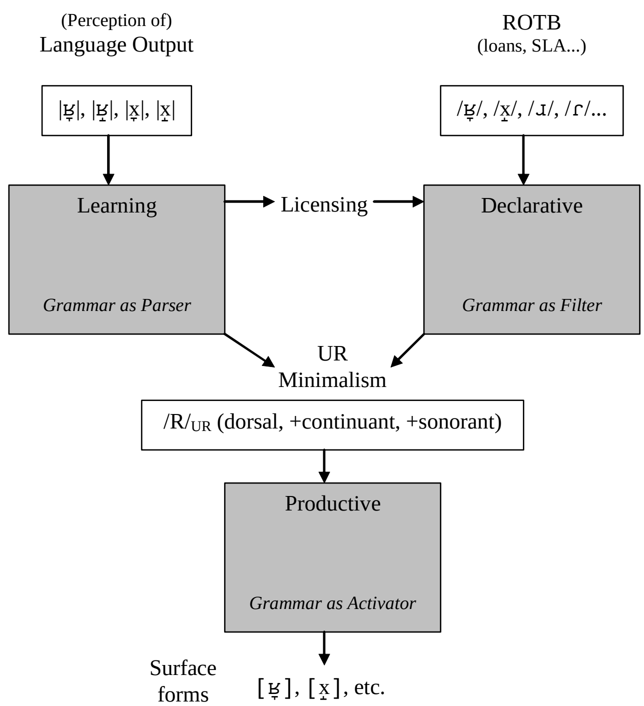
The proposal made here distinguishes between three grammatical levels: a learning stratum, for which grammatical input is the learner's perception of linguistic output; a declarative stratum, containing constraints which serve to filter a theoretically infinite input; and a productive stratum, where filtered input is evaluated by phonetically based constraints. The distinction between the three, as well as the nature of constraints and inputs, the scope of ROTB, and the role of each stratum in the larger grammar is summarized in (18).

(18) Strata, input and ROTB

Stratum	Input	Constraints	ROTB?	Grammatical Role
Learning (perception)	Learner's perception of output	Categorization of speech sounds and their features	No: constrained by output	Parsing; UR learning and feature licensing
Declarative (lexical)	Theoretically infinite	Declaratively-oriented; static knowledge	Yes	Filter; application of static knowledge
Productive (post-lexical)	Filtered representations	Productively-oriented; dynamic knowledge	No: input limited to phonological filtered input	Interpolation of intermediate representations

It should be stressed that the proposal here is modular and implies sequencing, although this is not circuitous. As illustrated in (19), the larger grammar proceeds sequentially and is externally fed at the declarative stratum, where ROTB applies, and at the learning stratum, where acquisition data constitutes input. Minimalism emerges as an output property of the learning and declarative strata, which provide for categorization of experiential data and filtering of a rich base, while variability manifest in surface forms is accounted for by the production grammar.

(19) Model of Emergent Minimalism: French /R/



5. Discussion and Conclusion

The present work proposes a stratal phonological grammar distinguishing between learning, declarative and procedural constraint rankings. This approach presents several advantages over previous analyses, as it makes more explicit statements about how language users come to posit underlying phonemic representations and how learning can account for the grammatical filtering of a theoretically infinite input set. Focusing on the example of French /R/, the stratal approach accounts for the learning of phonological representations built upon emergent features, the filtering of relatively richer and allochthonous input representations and the sensitivity of minimally specified phonemes to phonetically based constraints.

The handful of contemporary analyses which address variability of the type observed for French /R/ take for granted this segment's underlyingly specification for both voice and manner features (see e.g. Dell 1980, Brousseau & Nikiema 2001). This assumption necessitates a series of rules applicable to the generation of surface forms, establishing, for instance, that /R/ is lenited in post-vocalic environments or that it assimilates in voice quality to adjacent consonants. While straightforward and certainly appealing from the perspective of descriptive—if not explanatory—efficacy, these rules must target /R/ alone (or, in the case of voicing, only /R/ and /l/), as no other consonant demonstrates surface variability seen in (1). OT's principled refusal of rules further complicates such an approach. The difficulty with rules or constraints targeted to only one segment is their ad hoc nature, namely their position in response to a theoretical need, rather than to a principle having its basis outside the grammar (see Haspelmath 2004, Wunderlich 2004). Alternatively, constraints may target phonological classes, e.g. sonorants; this implies the ad hoc selection of input, however, as it supposes a highly-deterministic, innate input, whose motivation is attained via the proposed grammar. The position of fully-specified underlying forms (either voiced or voiceless, approximant or fricative) for /R/ further ignores the relation of different forms across the lexicon (and within the larger set of linguistic data which serves as the primary input to learning in all models) and provides for a restricted UR for this phoneme.

Of course, the present proposal can be critiqued from several perspectives, especially given its apparent complication of the phonological grammar when viewed as a whole. While several criticisms of stratal OT have been leveled (e.g. Itô & Mester 1999, McCarthy 2005), few completely dismiss the need for some distinction between lexical or word-level phonology and more general phonological constraints. The role of phonetics in phonology and the applicability of phonetically oriented constraints are also contested by many. Although these debates are crucial to the vitality of the discipline, they are far beyond the scope of the present work, especially given its stated assumptions. As such, these larger theoretical and/or procedural questions are not addressed.

Despite potentially complication of the larger phonological grammar, the stratal approach specifically avoids difficulties inherent to antecedent approaches to the questions raised in §2 and many others, while introducing a greater degree of representational knowledge into the grammar. Ad hoc input is avoided by making explicit reference to learning of both featural contrasts and of feature licensing; at the same time, the strategic, theory driven mechanism of ROTB is maintained, albeit in more restrictive scope, ensuring that the grammar can make attested predictions based upon all input, including those which have no UR correspondent. Finally, the proposal provides a crucial distinction between phonological knowledge types, formalized in specific constraints, themselves organized at different levels of the grammar. This affords greater inclusion and, perhaps, more appropriate situation of phonetically based constraints in the phonological grammar.

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