THE SYLLABLE AND OPTIMALITY THEORY

An insight into the viability of Optimality Theory
in Speech Synthesis and its effectiveness in modelling the French language.

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CONOR EVANS
16322861

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1. Introduction

This analysis seeks to shed light on how Optimality Theory can be used to explain phonological phenomena, with a focus on phenomena within the French language. Given that Optimality Theory (OT) originally sought out to explore the notion that phonological constraints belong to a Universal Grammar (Prince & Smolensky, 1993, p. 2) from which individual grammars are formed based on the hierarchy they attribute to these constraints, other languages, such as English and Spanish, may be used to enrich examples or to compare/contrast phenomena across languages.

This analysis aims to explore the idea that there exists a strict hierarchy of rules[1] or, rather, constraints, that determine the transformation of morphemes from their Underlying Representation (UR) to their Surface Representation (SR) – the way they are actually realized in speech, and that OT best provides the framework to determine this hierarchy. While traditionalist phonologists have "expressed doubts of 'fictitious' base forms [URs]" (M. Zwicky, 1972), the idea of an underlying representation has been fundamental in Generative Phonology, a family to which both OT and many rule-based phonologies belong. The idea of an underlying form will be pivotal in this analysis' exploration of the ways in which OT can provide the framework to examine how languages deal with hiatuses and, in particular, how underlying forms are pivotal to the liaison between the two vowels of a hiatus in French.

Given the relevance of computational linguistics as a Computer Science & Linguistics student, this analysis will also give particular attention to OT and its viability in the field of Text-to-Speech (TtS), also known as speech synthesis. This is a particularly vibrant sector in the modern age, with Google releasing a particularly revolutionary tool in January of (2019) based off the WaveNet software developed by (DeepMind).

Furthermore, the effectiveness of OT as a framework for modelling the French liaison is an area that interests me as a L2 French speaker. While increased exposure to the language has led to improved liaising, no software currently available can mark a consonant, i.e. embolden it, where the consonant acts as a liaising consonant. Encoding such a software requires a phonological framework and this analysis will seek to examine OT's potential to be said framework.

[1] To ensure consistency of terminology and to avoid overlap between Optimality Theory and other generative, rule-based, phonologies, constraints will henceforth be used to refer to OT, while rules will be used to refer to traditional generative phonologies.

2. Key Concepts

2.1 Syllable

Arguably one of the most accessible linguistic concepts, i.e. understandable to the general speaker of a language, syllables are in fact remarkably dense and complex. Present right from the earliest stages of linguistic development, the rules and constraints present in the background are easily absorbed by the youngest of speakers. In fact, Saffrin et al. (1996) found that 8 month old babies were able to learn where the word boundaries in an artificial language occurred after merely 2 minutes exposure to a stream of artificial speech.
That said, these constraints are much harder to formalize and particularly to automate, as machines are much more limited than humans in determining that a sequence[2] sounds *off*.
Syllables can be broken down into two components: onset and rhyme. This latter component then further breaks down into two components: nucleus and coda. As one would imagine, the nucleus is at the core of every syllable and the two are in a symmetric relation; there can be no syllable without a nucleus and no nucleus without a syllable. As a basic, but not strict, rule, the nucleus is filled by a vowel and by extension of the symmetric relation, a syllable cannot exist without a nucleus which cannot exist without a vowel, therefore a syllable cannot exist without a vowel. It is worth noting here that diphthongs and triphthongs are considered to be one vocalic unit and any of the up to three vowels would be present within the nucleus. The nucleus would merely take on a branching structure where more than one vocalic phoneme is present in the vocalic unit. Regardless, there are still exceptions as there exist syllabic consonants (Ridouane, 2008) which can create a syllable with no vowel present. An example of this in American-English would be the [ɫ] in *bottle* [bɑ.tɫ]. Vowel-filled nuclei will be the sole interest of this analysis, however, as they are at the base of hiatuses.
Although “generally recognized as an important phonological unit” (Hooper, 1972), the syllable had never truly defined in phonological theory until first proposed as a prosodic unit in generative phonological theory in the seventies by phonologists such as (Vennemann) and Hooper and “the relevance of the syllable for linguistic theory has increased ever since” (Féry & Van de Vijver, 2003).
Ultimately, it is syllabic structure that is at the base of most of the phenomena in this analysis. Hiatuses are found in sequences where the following occurs: *‘_V.V_’*. As noted by (Tranel, 2000), it is generally accepted that *CVCV* sequences are “ideal” in speech chains. These speech chains are favoured by French infants (Cissé, 2014) in the babbling stage of linguistic development. However, despite this preference, many exceptions exist to the CVCV pattern and, ultimately, the spectrum of combinations found in French is much broader than this ideal sequence.

[2] See glossary (5.1) for clarification on the usage of ‘sequence’ in this analysis henceforth.

2.2 Hiatus

A less accessible linguistic concept to the average speaker, a hiatus is defined by the Oxford English Dictionary (OED) (2019) as "a break between two vowels coming together but not in the same syllable" and derives from the Latin word for 'gap'. As aforementioned, hiatuses arise when two nuclear elements find themselves on either side of a syllabic break. In order for this to occur, the first syllable must have a null coda and the second syllable must have a null onset. In syllabic tree representations, only the null onset will form part of the structure, filled by a null element, while null codas will not. This is because of the idea that is no true null onset – sonority must come from somewhere before peaking (in the nucleus). OT's original authors (Prince & Smolensky, 1993) originally encoded an ONS constraint, the idea that an onset cannot be empty, which has been since been expanded upon by linguists such as (Smith, 2012).

Hiatuses[3] manifest in two primary manners: intra-word, as in *coopérer* 'cooperate' [k**o.ɔ**peʁe], or inter-word, as in *the ear* [ð**i.i**r]. We will explore what universal constraints exist to deal with hiatuses in speech and how individual languages hierarchize these constraint, with particular focus on how liaising consonants in French prevent inter-word hiatuses.

Dealing with hiatuses has been an issue in languages since the beginning of recorded languages. Isocrates, renowned philosopher who was one of the ten Attic orators (Oxford University Press, 2019), "laid down the rule that it [hiatus] should be avoided" almost two thousand five hundred years ago (Pearson, 1975).

2.3 Liaisons

Defining the liaison can prove tricky, particularly on an academic level. Historically, it comes from the French word *lier 'to bind'*. As such, it could be considered a consonant which *binds* the two vowels on either side of the syllabic boundary. It is not unreasonable, thus, to consider this consonant as being 'inserted' at the syllabic boundary to link the vowels and, by extension, see to the disappearance of the hiatus. Published academia has even employed such terminology (Côté, 2005, p. 76). This analysis, however, considers it more accurate to consider the liaising consonant as a latent element of the sequence, i.e. an element of its underlying representation (in keeping with Generative Phonology and OT principles), realized when necessary, i.e. when a hiatus occurs, but omitted for fluidity in the flow of speech when unnecessary.

Consider the following example (1) and the EVAL generated by the OT matrix in *Table 1,* and the following OT structure where CON will consist of any constraints defined in this analysis, thus far $1:

$INS-C: Insertion of consonant after any sequence whose final syllable has a null coda not at sequence-end.

$HIA-C: two vowels in a hiatus must be separated by a liaising consonant.

(1) *Les 'the' + amis 'friends'*
    ⇨ *Les amis 'the friends', SR: [le.za.mi]*

[3] Hiatus occurs at syllable break (see glossary for symbol used to denote syllabic break in phonetic transcriptions) between two vowels.

Table 1

Input->GEN	**GEN->CON**		**CON->EVAL**
	INS-C	**HIA-C**	
[le.a.mi]	**!**	**!**	
[le.za.mi]			**?**
[le.ma.mi]			**?**
[le.ʁa.mi]			**?**

See glossary for information on symbols/abbreviations and their meanings.

As seen above, if we consider the liaison to be realized through insertion of a consonant, our constraint component does not raise any issue with any of the three inputs generated and the evaluation would result in either a manual or automatic timeout error if this was encoded on a machine. Any French speaker will affirm that input two, [le.za.mi], is the actual concrete realization of this sequence, that is to say its Surface Representation. However, it is impossible for our constraint to reach this conclusion. If liaison is dealt with by insertion of a liaising consonant, it is unlikely that the CON could determine which consonant would assume this role of liaising consonant. In fact, inputs two and three, though not ranked lower than Input 1 using our current CON, produce two SRs with completely different meaning – *[lemami]* is *les mamies* 'the grannies', while *[leʁami]* is *les ramies* 'the ramies'[4].
The above example supports the notion of an underlying representation where *les* is |lez| which can then manifest in SR as |le| or |lez|. This idea of a latent consonant is defined particularly well by Delattre (1947), who describes the liaison as "the survival of certain final consonants from Old French", a language where "all final consonants were pronounced". Many of these sequence-final consonants underwent elision, while those whose "union with the succeeding vowel-initial word was strong enough" were preserved in oral speech. Insertion of a consonant is one of the potential realizations of a VV sequence, i.e. becoming VCV, according to (Tranel, 2000). That said, is it not correct to consider these UR-final consonants to be inserted. As outlined above and supported by Delattre, it is more accurate to consider the consonants to be latent elements that are realized in contexts where their realization leads to the avoidance of a hiatus.

2.4 Cacophony

Cacophony is defined as a "harsh discordant mixture of sounds" by the OED (2019), though in linguistics it is primarily when concurrent sounds clash and produce a bothersome sequence to the ear of a native speaker. As a linguistic concept, it is primarily a phonological concept, central to a rather niche area of phonology – phonoaesthetics, or the study of "expressive properties of sounds" (Crystal, 1995). However, it has also been studied within the scope of syntactic linguistics, such as in (Gross, 1967) where he outlined two rules to explain the elision of determinants in certain contexts.

[4] A type of plant (Larousse, 2019)

There has always been a strong co-incidence between hiatuses and cacophony, as cacophony often occurs when a vowel directly succeeds another vowel in the chain of speech, i.e. a hiatus. Dionysius of Halicarnassus noted that it requires “considerable skill on the speaker's part if disagreeable cacophony is to be avoided (Pearson, 1975). As noted by Pearson himself, some British-English speakers may insert an [r] into a sequence such as "no law r-against it” or, following in the footsteps of the Greek, English speakers may insert a semivowel, e.g. "totally y-absurd” or “no w-evidence”. This latter technique is often present in the inter-word hiatus example given in Section 2.1: *the ear* [ð**i.i**r] -> [ði.jir].

2.5 Prefix

The OED (Oxford English Dictionary, 2019) defines the prefix as ‘an element placed at the beginning of a word to adjust or qualify its meaning or (in some languages) as an inflection’. None of this analysis’ target languages, all of whom have significant Latin roots, use prefixes for inflection. Furthermore, prefixes are, in these languages, a rather fixed grammatical category with little propensity for change. As noted by (Rousseau, 1995), French has no prefixes ‘of its own invention’, rather all prefixes are ‘directly inherited’ from Latin, be it by historical evolution or by late borrowing. Finally, as a result of their roots, our target languages often share prefixes, e.g. *‘in-‘*. The effect this will have on OT’s CON component and the notion of universality of phonological constraints are two areas this analysis will seek to explore.

2.6 Text-to-Speech

Text-to-Speech (TtS) or Speech Synthesis is the artificial production of sound from a given input, i.e. a given text. Though sound is at its core, and thus phonology is important, there are other processes in TtS that are outside of the scope of a purely phonological framework such as OT. Such processes include text ‘normalization’, also known as *tokenization*, as well as several other processes (Rojc & Kačič, 2007). Once grapheme-phoneme conversion has taken place, the phonetic sequence of URs would be passed to OT’s generator component and the inputs would then be passed through the constraint component. The evaluated output would then be sent to the speech synthesizer, considered the ‘back-end’ (Donovan, Ittycheria, Franz, & Eide, 2001) of the TtS system.

Though it is involved in neither the text preparation nor the speech synthesizing, a phonological framework needs to be in place to model the transformation from the input generated at the grapheme-phoneme conversion step to the output passed to the speech synthesizer. This analysis will endeavour to determine the viability of OT as said phonological framework.

3. Optimality Theory as a Model for these Key Concepts

3.1 Liaison

Having introduced our key concepts in section two, this section will serve as the main section of this analysis, employing and expanding on OT tableaux such as *Table 1*. Consult the appended glossary for any clarification regarding OT constraints or general terminology. The primary intent of this section will be to explore OT as a phonological theory for the future, with an eye on automation of UR to SR transformations. Other theories such as rule-based phonology will be referenced for the purpose of comparison.
As we discovered in *Table 1, **$HIA-C*** was not a satisfactory constraint and did not generate the correct output. Take the following constraints:

$ELIDE-ART: A sequence-final consonant will undergo elision when followed by a sequence beginning with a consonant or at overall-sequence end.

$RET-ART: A sequence-final consonant will be realized when followed by a sequence beginning with a vowel.

(1) *les 'the', UR: [lez] + amis 'friends', UR: [a.miz]*
⇨ 'les amis', *UR: [le.za.miz], SR: [le.za.mi]*

<u>*Table 2*</u>

Input -> GEN	GEN -> CON		CON -> EVAL
	$ELIDE-ART	$RET-ART	
[le.za.mi]			W
[le.a.mi]		!	
[le.za.miz]	!		
[le.a.miz]	!	!	

As we can see in this phonetic transcription, the [z] originally present in the UR for *'les'* has 'brought forward' to the next syllable. This is due to the Maximal Onset Principle, explained well by (Deterding, 2001). In effect, our OT model would receive each sequence as a UR and note a syllabic break between each sequence. The application of the constraint(s) that would be present in the related to the Principle of Maximal Onset (PMO) would benefit from OT's constraint component's strict hierarchy. Though it would not cause a problem for these noun phrases, as [lez] ending in [z] means two things:

- It will always be realized when followed by a vowel.
- It will not be brought forward before a consonant because no permissible sequence in French starts with [z] + [other consonant]. This would violate one of the constraints in applying the PMO and therefore would violate the constraint.

That said, that does not mean that the order of application between a hiatus-based constraint and a PMO-based constraint. For example, [ts] is a valid, albeit rare, onset sequence, found in words such as *tsigane 'gypsy'* (Larousse, 2019) and in sequences ending in [t], the PMO-based constraint would bring it forward to the sequence beginning with [s]. Were the constraints correctly hierarchized, the hiatus constraint, not a constraint defined here, would elide the [t] from the sequence as it occurs before a sequence beginning with a consonant, such as in:

(2) *le [lə] + enfant, UR: [ã.fãt] + intelligent, UR: [ɛ̃.tɛ.li.ʒãt]*
" + " " " + sage, UR: [saʒ]

<u>$HIA -> $PMO</u>

l'enfant intelligent, SR: [lã.fãt ɛ̃.tɛ.li.ʒã]
l'enfant sage, SR: [lã.fã.saʒ]

<u>$PMO -> $HIA</u>

l'enfant intelligent, SR: [lã.fãt ɛ̃.tɛ.li.ʒã]
*l'enfant sage, SR: [lã.fã.tsaʒ]**

The above example re-enforces the importance of a strict hierarchy of violable constraints.
While Table 2 and its output are no less feasible via a rule-based phonological model, the benefits of OT's strict CON filter will be seen when its constraints are more plentiful. Moreover, it supports OT – and by extension, generative phonology – in its base concept of the existence of an underlying representation of morphemes and dispels the notion of an 'insertion' of a consonant. The breakdown of the sentence in example (2) further cements this concept as fundamental to phonological theory.

(3) *Mes 'my', UR: [mez] + amis 'friends', UR: [amiz] + ont amené 'brought' UR: [ɔnt] [am(e)ne] + un chien 'a dog', UR: [œn] [ʃje]*
⇨ *'Mes amis ont amené un chien',* SR: [me.za.mi.zɔ̃.tam.ne.œ̃.ʃjɛ̃]

To avoid prolonged and distraction phonetic transcriptions in the input column, the prospective inputs will be broken below and referred to by their corresponding number in the input column.

1 – [me.za.mi.zon.tam.ne^.œ̃.ʃjɛ̃]
2 – [me.za.mi.zon*.am.ne^. œ̃.ʃjɛ̃]
3 – [me.zami*.ont.am.ne^. œ̃.ʃjɛ̃]
4 – [me.zami*.on*.am.ne^. œ̃.ʃjɛ̃]
5 – [me*.amiz.on.tam.ne^. œ̃.ʃjɛ̃]
6 – [me*.ami*.on.tam.ne^.œ̃.ʃjɛ̃]
7 – [me*.ami*.on*.am.ne^.œ̃.ʃjɛ̃]
8 – [me.za.mi.zon.tam.ne.tœ̃.ʃjɛ̃]

Table 3:

GEN	CON			EVAL
	$ELIDE-ART	$RET-ART	$INS-C	
1			!^	W[5]
2		!*	!^	
3		!*	!^	
4		!*	!^	
5		!*	!^	
6		!*	!^	
7		!*	!^	
8				W

If **$INS-C** really were a valid constraint, then input eight would be evaluated to be the correct output. This, however, is not true and, thus, **$INS-C** and the concept behind the rule must be disregarded. If it were to be true and all of the 'inserted' consonants at syllabic boundaries were correctly chosen, there is no discernible pattern to the naked eye, much less a pattern that could be encoded, as to which consonant is inserted in any given distribution.

The concept is not without base, however, and there may be credence to the notion that URs are not intrinsic and the realization of an "incorrect [liaising] consonant" (Wauquier-Gravelines & Braud, 2005) is a "regular" occurrence for children at the period of "lexical explosion" in the acquisition of French. As aforementioned, these final consonants at word end are remains from Old French, so it is unsurprising that children must be exposed to realizations of the UR before they are aware of its existence.

In the above examples, it is evident that OT and its strictly ranked constraints can provide the framework needed to map the UR to SR transformation. However, the framework falls into uncertainty when extrapolated to the language as a whole. This is because not all liaising consonants were kept in the historical transition from Old French to Modern French. As aforementioned in quoting Delattre (1947), only those sequences whose "union with the succeeding vowel-initial word was strong enough" were preserved in oral speech.

This has led to a dichotomy between obligatory and facultative liaisons which is challenging to model as automation heavily favours binary choices. In fact, the ability to model such liaisons becomes even more difficult when factoring for a third scenario – forbidden liaisons. As noted by (Pernot, 1937, p. 337), some of these forbidden liaisons can even lose this forbidden status depending on the context. The aforementioned work by Delattre (1947) constituted a "detailed" table of contexts in which a potential liaison would be attributed to any particular category.

Moreover, OT's potential to model such a transformation appears to be further limited as the majority of the constraints which lead to the correct SR are syntactically constrained. In fact, by extension, this is a limiting factor for any phonological theory with regard to dealing with liaisons. That said, these forbidden liaisons are in fact not too onerous to model if we consider the notion of the underlying representation.

[5] This sequence is the 'winning' or outputted sequence as it satisfies the hierarchy of constraints better than any other inputs. The W in red represents the input that would be the winner were $INS-C a valid constraint.

Consider examples (3) and (4) as noted by Delattre, the below permutations[6], as well as the previously defined **$ELIDE-ART** and **$RET-ART**:

(4) Des 'some', UR: [dez] + (mots || mot + s, UR: [mo] + [z]) + abominables 'awful', UR: [a.bɔ.mi.nabl]

Des mots abominables 'some awful words'

1 – [de.mo.za.bo.mi.nabl]
2 – [de*z.mo.za.bo.mi.nabl]
3 – [de.mo*.a.bo.mi.nabl]

(5) Un 'a', UR: [œn] + mot 'word', UR: [mo] + abominable 'awful' [a.bɔ.mi.nabl]

Un mot abominable 'an awful word'

4 – [œ̃.mo.a.bo.mi.nabl]
5 – [œn.mo.a.bo.mi.nabl]

Table 4:

GEN	CON		EVAL
	$ELIDE-ART	$RET-ART	
1			W
2	!*		
3		!*	
4			W
5	!*		

As seen above, OT is capable of determining the correct output if the URs in our generated inputs are correctly passed to the constraint hierarchy.
The scenario which poses most difficult for OT as a model, and for its ability to serve as a model for automatic parsing and/or production of speech, is that of facultative liaisons. Though there exists a field in computer science called Fuzzy Logic, first proposed in (1965) by Lofti Zadeh, in which the truth of a statement is on a spectrum between 0 and 1, binary logic is a fundamental and virtually non-avoidable concept at the base of all automation. Thus, how can OT map when a facultative liaison is a 0, i.e. not to be realized, and when it is a 1, i.e. to be realized. Perhaps a weight can be given to each facultative liaison and this weight applied based on frequency of its realization in a sample corpus of speech. This, however, increases complexity and computing time. Furthermore, these weights would have to be further analysed to be context-appropriate.

[6] For the sake of brevity and readability, the list of permutations is not exhaustive.

Moreover, where liaisons occur between multiple successive sequences, OT may be faced with further challenges. As Delattre stated, sequence-final consonants remained where their “union with the succeeding vowel-initial word was strong enough” to be preserved. However, the strength of this union can be context-dependent and a previously strong union may be weakened when successive sequence-pairs, i.e. sequence one/two and sequence two/three and so forth, occur.
Take the following example (5), the title of a prize-winning book by Nicholas Mathieu (2018):

(6) *Leurs ‘Their’: UR* [lœʁz*] + *enfants ‘children’: UR [ɑ̃.fɑ̃t±]*
+ après ‘after’: UR [a.pʁɛz^] + *eux ‘them’: UR [ø]*

If these URs were passed to the CON component, all three sequence-final consonants of the first three sequences would be kept, per the **$RET-ART** constraint. However, it is highly unlikely that all three liaisons would be realized. Per Delattre’s table, liaison one* is obligatory, whereas liaison two± and liaison three^ are facultative. It is unlikely that all three liaisons would be realized. Although he never utters the title himself, the hosts of multiple interviews with Mathieu including a French national television broadcast with (La Grande Librairie, 2018) omit both facultative liaisons.
In theory, this makes the prospect of automating the evaluation much easier. As would entail its definition, facultative liaisons are not obligatory and a one-size-fits-all constraint of dropping any facultative liaison, such as **$FAC**, would not produce a theoretically incorrect output based on Delattre’s table.

$FAC – any sequence-final consonant in a facultative liaison will undergo elision.

This, however, is unsatisfactory in practice. In fact, if this were the approach taken, it would likely be ‘better’ for our GEN component to apply this constraint when generating input candidates. The CON component only applies a series of constraints; it could not take into account the addition information required to identify a facultative liaison based on its context. Furthermore, technically correct is not the only objective in computational linguistics, particularly in TtS. As outlined by (Juang & Rabiner, 2004), Speech Synthesis has advanced a long way since the first intelligible, but robotic, speech synthesis software of the 1970s. This advancement has only continued in the 15 years since that paper, with researchers striving for speech production as humanized as possible.
Thus, facultative liaisons would have to be given a contextual weight for OT to best apply its constraint component to the generated inputs in order to determine the best evaluation depending on the contextual weights of each facultative liaison. Delattre’s work goes no further in outlining a hierarchy within each category of liaison and this lack of hierarchy poses a problem for an automated transformation modelled by OT as there is no way to determine if one of these facultative liaisons has precedence over the other.
This weight, however, would have to be applied in the GEN component, with the UR passed in as SR1, where the UR remains as is, or as SR2, where the sequence-final consonant is elided. Although this allows the CON component to remain a series of ‘strictly violable’ constraints, it does mean that phonological analysis needs to be done before getting to the CON component, which, ultimately, is in fact where OT analyses and determines the correct output. No longer would the division between GEN and CON be as defined. If facultative

liaisons could be processed purely by the CON component, it would keep URs and SRs solely in their respective components, GEN and EVAL.
Furthermore, facultative liaisons pose an additional challenge. If there were a hierarchy, be it decided by a context-based grammar system or by a contextual weighting based on analyses of corpora, OT would need to take into account more information than what is present in just the current sequence in the transformation and its surrounding context.
It would need to take into account elements that may not be currently in the 'scope' of the parsing from GEN to EVAL via CON. This has been a "difficulty" that has arisen in syntactic formalisms (Nagao, 1992) which consider "only [a] two element relation at a time … ignoring that there exist many sophisticated relations [between] many elements in a sentence".
While such a consideration would undoubtedly improve evaluations, it would also complicate automation as it entails much more information being stored for longer periods of time.
Finally, whether OT were to apply weighting in the GEN or the CON component, there are more factors to be considered than just phonological context. As explored by (Nardy, Chevrot, & Barbu, 2011), facultative liaisons are not realized at the same rate by children from different socio-economic backgrounds. Though not present at all ages, by age 5 the difference had become significant and children from higher socio-economic backgrounds produced facultative liaisons at nearly double the rate of children from lower socio-economic backgrounds.
Thus, any TtS system modelled by OT would need to consider the implication of weighting facultative liaisons. Furthermore, although TtS systems generally offer a production considered to be general or the 'standard' dialect of a language, ideally many dialects would be modelled and, as previously explored (Milroy & Milroy, 1993), social class or socio-economic background is often a role in the formation of a dialect.

3.2 Cacophony

Another key area of this analysis, this section will discuss OT and its viability as a model with regard to cacophony. Whereas liaisons are only present in French among our target languages, per sé, this section will mainly look at cacophony in English and Spanish.
While many phonological features, nay many features across all linguistic fields, may vary between speakers, between dialects, etc., one constant in English is the avoidance of cacophony in noun phrases composed of the indefinite article 'a' and any noun beginning with a vowel. This can be defined rather easily by OT constraints in examples (5) and (6):

$DROP-AN: the sequence [an] will undergo elision to [a] when preceded by a syllabic break or silence and when before a sequence beginning with a vowel.

$RET-AN: the sequence [an] will not undergo elision when preceded by a syllabic break or silence and when followed by a sequence beginning with a consonant.

(7) *an, UR: [an] apple, UR: [æpl] : 'an apple'*

1 – [a.næpl]
2 – [a*.æpl]

(8) *a, UR: [an] + truck, UR: [trʌk] -> 'a truck'*

3 – [a*n.trʌk]
4 – [a.trʌk]

<u>*Table 5:*</u>

GEN	CON		EVAL
	$DROP-AN	**$RET-AN**	
1			**W**
2		!*	
3	!*		
4			**W**

Once more, the idea of an underlying representation is crucial to OT's success in correctly parsing the inputs. Furthermore, the notion of inserting a consonant would once more be incorrect. According to any etymological sources, such as (2019), '*an'* was the original form, a weakened derivation of Old English '*an'* meaning 'one'. The form was then further weakened by elision to *'a'* before consonants. Incidentally, these rules would also correctly parse any orthographical mistakes where the word begins with a letter-vowel, but not a phonetic vowel, for example '*an euro'* or '*an university'*.
The above pair of rules and the previously introduced pairing of **$ELIDE-ART** and **$RET-ART** are an important example when we consider the universality of constraints, an idea that was at the base of the original Optimality Theory explored by (Prince & Smolensky, 1993). As noted in the introduction, in seeking out to explore their theory, they postulated that phonological constraints belong to a Universal Grammar from which individual grammars are formed based on the hierarchy they attribute to these constraints. Evidently, English and French must have different hierarchical structures when it comes to the phonological constraints behind simple noun phrases - *Determinant + Noun* or *Article + Noun*, for example. Though the two pairs of constraints are defined in different *Key Concept* sections of this analysis, they are both examples of phonological rules that avoid a hiatus.

Spanish differs from both French and English in that virtually no words differ in their orthographic form from their phonological form. This means that everything that is said is transcribed and vice versa – with some exceptions, such as the silent word-initial [h], noted by (Rini, 2010) to be one of "the most challenging topics of Spanish historical phonology". As such, the notion of an UR differs between Spanish and French. Firstly, URs are much more accessible in Spanish. Few sequences can have different surface representations as a result of passing the sequence's underlying representation through the phonological constraints OT, or any model, could define. This means that OT is unlikely to be a better framework than any other phonological model for Spanish.
However, there are some aspects of Spanish for which OT can provide a framework. One such aspect is cacophony. Both *o 'or'* and *y 'and'* change form in cacophonous contexts:

(9) *¿Esos chicos 'These guys' + u 'or', UR: [o] + otros chicos? 'other guys?'*

1- [e.sos.tʃ[7]i.ko.su.o.tros.tʃi.kos]
2- [e.sos.tʃi.ko.so.o.tros.tʃi.kos]

(10) *Hablo francés 'I speak French' + e 'and', UR: [i] + inglés 'English'*

1- [a.blo.fran.se.se.iŋ.gles]
2- [a.blo.fran.se.si.iŋ.gles]

That said, while rule-based phonologies might not lead to the correct evaluation in cases such as (8) and (9) as they would simply look for [o] preceded by a syllabic break and followed by a vowel – which can occur in different cases where this phonological rule to avoid cacophony does not take place, there is no reason to believe that OT is preferable to any other generative phonology, or any phonology that supports the presence of an underlying representation.

Though certain French processes for avoiding cacophonous sequences, such as the *Règle de Cacophonie* 'Rule of Cacophony' investigated by (Gross, 1967) among others, are irrelevant to TtS as the syntactic context leads to omission of part of the sequence, therefore this omitted content is not present in the input passed to the CON component, OT can serve as a model for cacophonies who are not accounted for by syntactic constraints, such as nasal cacophonies.
Given that nasal cacophony only occurs between successive nasal vowels, i.e in a hiatus, the previously introduced **$RET-ART** and **$ELIDE-ART** can be mirrored by a new constraint pair, with a slight modification, or the constraints can simply be extended to cover cacophonous liaisons between nasal vowels. In fact, only **$RET-ART** needs to be redefined[8]:

$RET-ART: a sequence-final consonant will undergo will not undergo elision when followed by a sequence beginning with a vowel or nasal vowel.

Once more, we see that OT and its CON component can rather easily generate the correct output. That said, the example does not support OT as a model any more than it supports any other generative phonology.

As noted in section 2.4, ancient Greeks often inserted semi-vowels in hiatuses to avoid cacophony and, per the quoted examples, this is a phenomenon that has been imported and adopted by English. Further noted was the original example of an inter-word hiatus: *the ear* [ð**i.i**r] -> [ði.jir]. This is a rather sensible transition from [i], a high-front vowel, to [i] via [j], a palatal, i.e. rather front, approximant. This is supported by linguistic works such as (Pak, 2014) who presents data regarding the dichotomy between [ði] and [ðə] in an OT table

[7] The arc above tʃ in the IPA is not able to be displayed in word. Thus, this blue colouring will be used to portray the same idea in this analysis.
[8] This, once more, is due to the acceptance of an underlying representation to which constraints are applied until it is transformed into a context-dependent surface representation.

with constraints of **$ONSET** and **$NO-CODA**[9] and notes the presence of the [j] semi-vowel between the two cacophonous vowels.

However, caution must be undertaken when considering the application of a constraint which would see to the introduction of a semi-vowel to liaise between vowels of a hiatus. The above sequence, [ði.jir], at its base as a linguistic sign (de Saussure, 1916), refers to *the year* and not *the ear*. A cursory Google search will reveal many language forum posts seeking clarity on the matter, particularly in the idiom *play it by ear* which is often misinterpreted as *play it by year*. The [j] semi vowel once more acts as a liaison between the diphthong [aɪ], which finishes nearing [ɪ] - a high near-front vowel, and the high-front [i]. The malapropism even spawned an (RTÉ) television programme.

Thus, while native English speakers commonly employ the use of a liaising semi-vowel in hiatuses, even when it may create ambiguity such as above, it is something that would need to be formalized before defining what evaluation would be led to by modelling the phenomenon using OT. Furthermore, it poses an interesting question with regard to TtS. The objective of TtS is primarily to produce accurate speech, but, as noted in Section 3.1, it is also to provide speech that is more resemblant of a human than of a robot. If the employment of a liaising [j] is common among native speakers, should OT seek to re-produce this or should it model it in a different manner to avoid ambiguities such as above. Pearson (1975) proposes that “if he [an English speaker] is careful to observe a real hiatus in the middle of a sentence in formal declamation, he must make a break between the words”. Thus, it is perhaps better for OT to avoid the insertion of a semi-consonant to produce an ideal evaluation. It is worth noting, however, that this formality and the ‘choppy’ nature of consistent breaks between words is one classic aspect of TtS systems and a downfall in terms of their objective to resemble a typical human and not an automated robot. The choice between authenticity of the speech production and phonological correctness, which is essentially what OT’s constrain component covets, must be carefully considered.

[9] See glossary for definitions. As noted by Pak, these constraints would be lowly-ranked – many syllables exist without onsets and many syllables exist with a coda before a syllable with an onset.

3.3 Prefix

As noted in 2.4, this section will look into OT can model prefixes in our target languages, with a focus on the universality of constraints.
Take the following three words, all meaning innumerable:

(11) [EN] in, UR: [ɪn] + numerable, UR: [njuː.mə.rə.bəl]
innumerable, SR: [ɪ.njuː.mə.rə.bəl]

(12) [ES] in [in] + numerable, UR: [nu.me.ra.ble]
innumerable, SR: [in.nu.me.ra.ble]

(13) [FR][10] in [in] + nombrable, UR: [nɔ̃.bʁabl]
innombrable, SR: [i.nɔ̃.bʁabl][11]

Our three SRs evidently show that no one constraint can model the phonological processes at play in all three languages. As noted before, Spanish orthography is incredibly similar to its underlying phonological representations and as seen above, there is no difference between UR and SR, nor is there when *'in-'* is prefixed before a vowel. Given that no constraint needs to be applied to Spanish, OT must only model the transformation from SR to UR for English and French in the case of this specific prefix.
Seemingly, both prefix sequences undergo elision of the sequence-final consonant when the next element in the overall sequence chain is a nasal consonant. This rule holds true for alternate SRs of *'in-'* such as when it occurs before [m]:

(14) [EN] in, UR: [ɪn] + material, UR: [mə.tɪə.ri.əl]
immaterial, SR: [ɪ.mə.tɪə.ri.əl]

(15) [FR] in, UR: [in] + materiel, UR: [ma.te.ʁjel]
immatériel, SR: [i.ma.te.ʁjel]

However, the two languages diverge before non-nasal consonants and vowels. Whereas English SR is identical to its UR in both cases, French phonological rules regarding nasality come into effect and the sequence elides to a nasal vowel rather than a vowel plus nasal consonant. Incidentally, the vowel also moves forward to a nasal [ɛ] rather than becoming a nasal [i] – though this latter does not exist in French nor in any other language.
Thus, while the modelling of both transformations by OT could share some common constraints, it will be necessary to define other constraints specific to each language in order for the correct evaluation to be output.
The above example is a particularly interesting one with consideration to the universality of phonological constraints at the base of Prince and Smolensky's original OT publication (1993). Theoretically, there is no basis to dispute that these differing phonological processes exist within a universal grammar and that English and French simply hierarchize them

[10] See ISO 639.2 (2019)
[11] As noted by WordReference (WordReference, 2019), it is possible to realize the N of both 'in' and 'nombrable' but in most cases it would undergo elision.

differently. Furthermore, it might be preferable from a computational side of things as fewer space needs to be given to these constraints if there is an inter-grammar overlap.
Another pronoun inherited by all three of our target languages from Latin is that of '*re-*' (RE). Spanish is once more rather universally simple to model, thus our focus will return to English and French, with the latter being more interesting with regard to OT.
In French, RE is rather simple to model when in a pre-consonant context, its UR and SR are always [ʁə]. This constraint holds true for any such sequence to which RE is prefixed. That said, there can be minor variation with regard to the 'silent e' or the e caduc , a scenario where the schwa - such as in [ʁə] - is elided in certain contexts. This is more common in informal contexts (Geerts, 2011, p. 41) and is not obligatory, albeit very common. Much like facultative liaisons, this would probably have to be dealt with in the GEN component by assigning a contextual weight to each instance rather than applying a constraint proportionally in the CON component.
That said, this analysis is more interested with the transformation from UR to SR for sequences prefixed by RE where the prefixed sequence begins with a vowel. When in a pre-vowel context, RE can manifest in multiple surface forms: 'ré-' [ʁe] or 'r-' [ʁ]. In terms of semantics, this difference can be important and so determining which is the correct choice would be important. As the Académie Française, the governing body for official French language matters in France, note (2019), forms can often co-exist but may have different meanings in some or all contexts. However, from a phonological point of view and, thus, an OT perspective, notably with regard to TtS, the fact that there are different forms having potentially different meanings is not of great interest.
Furthermore, as the two surface representations have differing orthographies, parsing text and assigning URs in the GEN function would not pose a problem to a TtS software modelled within the OT framework.
It is worth noting that RE once more shows the importance of URs to OT and phonological models in general. As it only has SR sequences whose final element is a vowel, it will always create a hiatus when prefixed to a sequence beginning with a vowel. Were we to consider insertion of a consonant as the manner in which the hiatus in French were to be modelled, it would again lead to an incorrect output.

4. Conclusion

This analysis sought out to examine Optimality Theory's viability as a phonological framework, with particular focus on certain phenomena in the target language of French, as well as certain phenomena in other European languages. Moreover, it sought out to examine OT from a computational standpoint with particular reference to Text-to-Speech (TtS), also known as Speech Synthesis.

Although substantial progress has been made in TtS, albeit slower than that of other fields such as Machine Translation in syntax, it is difficult to see OT as a ground-breaking framework that can continue to advance the sector. As outlined in several sections, traditional rule-based phonologies can easily break down if rules are applied in the incorrect order. As such, OT's constraint component being a series of "strictly ranked" constraints seems rather appealing, and it does yield better results in many of the examples than rule-based phonologies.

Furthermore, OT's basic tenet that all constraints belong to a Universal Grammar from which all individual grammars derive is also appealing, but it is ultimately unsatisfactory. It is difficult to envisage the difference between OT's individual grammar constraints and applying tailored rule-based phonological rules to an individual grammar. Any constraint in the UG not present in an individual grammar, or of such low rank that it is not used or is superseded by a rule of higher rank, is ultimately irrelevant to its CON function.

As such, this set of individual grammars will be identical to a similar set of individual rule-based grammars. From a computational standpoint, any such 'irrelevant' constraint is a waste of resources and would only serve to increase time complexity.

One aspect of OT that has, in fact, repeatedly shown itself to be crucial is the notion of each sequence having an Underlying Representation. This applies particularly under the scope of TtS. The ability to put an UR behind each sequence and the application of the CON to the entire sequence of URs has continually shown to lead to the correct evaluation. These URs have been particularly important in outlining reliable constraints for words who have multiple forms, such as the definite article in English or many words in French who have lost sequence-final consonants in certain contexts. These multiple forms often have different orthographies, e.g. *a* vs. *an*, and so it is important to consider these forms to be variants of one underlying representation. This importance is particularly pertinent for liaisons in French, where identical orthographical forms can take on multiple surface representations depending on the context.

However, the fact that this analysis supports the importance of underlying representations in phonological theory, and consequently in speech synthesis, is not truly an endorsement of OT. Rather, they are a concept supported by all generative phonological theories (Kean, 1974), a family of phonologies to which OT belongs. An additional advantage of OT over generative rule-based phonologies is that the constraints are more detailed. As noted by (Tranel), rules tell us "what happens, but not why things are the way they are".

In setting out this analysis, I sought to examine OT as a viable framework to model TtS transformations, with particular interest in its potential to model the French liaison. OT has undoubtedly been an influential framework in phonology, with (McCarthy, 2007) claiming that it "would probably go on anyone's list of the top five developments in the history of generative grammar". Throughout this analysis, however, it has been unsatisfactory, or rather no more satisfactory than any given generative phonological model. Undoubtedly, (Prince & Smolensky, 1993)'s 493-page publication is extensive and its findings are compelling. With regard to the key concepts of this analysis, and in particular with respect to the field of TtS, it often resulted in more doubt than it did answers. This does not necessarily mean that OT is any less viable as a phonological model than others, as these doubts or problem areas would need to be covered by any phonological model. Furthermore, a strong argument could be made that several of these issues, such as the class-based division of facultative liaison realization noted in section 3.1 or the potential difference in meaning of different SRs of *RE + verb* noted in 3.3, are outside the scope of phonological theory. At the very least, a multi-model linguistic analysis, e.g. both phonological and semantic, would be needed. Thus, certain issues may not be critiques of OT as a whole, but rather limitations of phonological models in general for TtS. As noted in section 2.6, the phonological framework is not involved in a substantial portion of the processes carried out by a TtS system. As such, it is possible that OT could be an excellent phonological framework for TtS provided that other components of the TtS system are capable of resolving these issues before the transformation from possible inputs to determined output is carried out.

Certainly, however, this analysis does not support OT in its belief that all phonological constraints belong to a universal grammar, from which individual grammars stem, whose hierarchy of these constraints differ from one grammar to another. When applying this notion to an automated process, it is preferable to have the grammar at hand keep track of only the necessary information, and for it not to need to send information nor requests for information to a different source.

That said, the analysis of prefixes in Section 3.4 did find that, at times, universal constraints could actually use less memory than multiple individual grammar models where this is an inter-grammar overlap of constraints. Though this is true, generally inter-grammar overlaps are less substantial than inter-grammar differences. Thus, memory space saved by the universality of constraints would likely be less than memory space expended by the universality of constraints. The section also outlined, however, that multiple languages sharing a common prefix between them may have entirely different constraints. Given that each language will only apply a certain number of the constraints, it would be preferable to only include the constraints specific to each grammar in the OT modelling. Furthermore, if the rule of highest importance is not applied in a certain context, OT may apply one of the constraints of lower importance in the target language to the input and this could lead to an incorrect evaluation as a result of these 'universal' constraints that may not have any importance in the target language but may ultimately lead to the incorrect evaluation.

As noted in Section 3.2, there can be situations where OT's objective of perfectly grammatical outputs can clash with TtS software's aim to produce speech resembling that of a human speaker. Though this holds true for any phonological framework used to model the transition from input text to output speech, it is something that would need to be addressed in the implementation of the OT model.

Though the analysis did not ultimately champion OT as a model for TtS software, OT certainly provides a framework which could be employed by a TtS software. Its importance in generative phonology is widely accepted and I found it to be a significant improvement on rule-based phonologies, a family which I had had significantly more exposure to in linguistic courses than generative phonologies. Moreover, analyses such as (Tranel, 2000) have outlined that OT can, in fact, be a viable framework for modelling certain phenomena in this analysis, such as the hiatus and elision in simple noun phrases composed of *DEFINITE ARTICLE + NOUN.*

5. Optimality Theory as a Model for Further Research

Though OT was not a satisfactory framework for this analysis, it would be interesting to continue researching into OT. In particular, I found TtS and speech synthesis to be fascinating and it is certainly an area of computational linguistics that continues to grow in importance. Many of the world's technological powerhouses are producing cutting-edge 'Natural User Interfaces' (NUI), e.g. Alexa or Siri, of whom speech recognition and speech production are a key aspect. These NUIs have been the subject of linguistic analyses such as (López, Quesada, & Guerrero, 2017). Thus, it would be interesting to see if further research of OT could attest to its viability as the phonological model for such a TtS or NUI system.

A potential area of pursuit in a different field for which OT may be a viable framework would be identifying and highlighting word boundaries where liaisons occur. The transition from grapheme to phoneme could be considered as part of the generating component and our relevant hiatus constraints - available en masse in section 5.3 – would then be applied to these inputs and an evaluation would be output. This could certainly be a useful software for any L2 students who may not have high exposure to French and whose learning of the language is less based in immersion. As discussed in section 3.1, the acquisition of obligatory liaisons and facultative liaisons are both significantly linked to increased exposure to the language and these sequences that may have several SRs.

One potential complication would be highlighting the relevant text[12] of the input in the evaluated output. As noted above, there must be a transition from grapheme to phoneme. This is true for any phonological analysis of text. Though OT is perfectly capable of determining which liaising phonemes would be retained in the transition from input to output, its evaluation is a sequence of phonemes. In the above software, both the input and the output are text, i.e. graphemes. An additional process would then need to be implemented upon OT's evaluation. This process would need to re-transition phonemes to graphemes. It might be more efficient to create a referential relation between our graphemic input and the phonetic inputs generated in the GEN component.

Each phoneme would have a referenced grapheme and whenever the constraint component identifies a violation for the appropriate hiatus-based constraint, it could highlight the relevant grapheme in the graphemic input. Once the entire phonemic input has been parse by the constraint component, the original graphemic input will have had any relevant liaising graphemes highlighted and what was originally the input text is now the output text. Below is a brief example of what this process may resemble at a basic level:

Text input:

(16) *'Les amis ont averti…'*
The friends warned…

[12] Almost exclusively, the liaising consonant is represented by one letter/grapheme in the word. However, to avoid the misnomer of phonemes as letters, e.g. 'th' can represent [θ] or [ð], this analysis will avoid using the word 'letter'.

Grapheme-to-Phoneme Translation:

'{les} {amis} {ont} {averti}'

↓ ↓ ↓ ↓

[lez] [a.miz] [ɔ̃t] [a.vɛʁ.ti][13]

OT Modelling

GEN	CON	EVAL
	$RET-C	
[le.za.mi.zɔ̃.ta.vɛʁ.ti]		**W**

As defined in our glossary, eliding the sequence-final consonant of either sequence one or sequence two would result in a violation of constraint **$RET-C**. Each time this occurs in the constraint component, the model would refer back to the graphemic input and determine which grapheme is related to the sequence-final consonant. It would then highlight this consonant, and the constraint component would continue to be applied to the remainder of the input sequence.

As outlined above, the software seems feasible and OT could certainly be the phonological framework implemented therewithin. Furthermore, as few constraints are present - the one above may need to be modified or accompanied by others when applied to a wider range of sample inputs, there are relative few comparisons and the complexity of the model is reduced. That said, there is one assumption that underlines the entire process and that is rather complex to implement. This assumption is that we can map each word (i.e. series of graphemes) to an underlying representation. While these URs may be identifiable in speech or on sight, they must be encoded into a corpus of word-UR key-value pairs and this is not trivial. This corpus must either be built or incorporated from an external source.

This is particularly menacing given that even extensive dictionaries who provide word-phonetic key-value pairs rarely take into account URs. Rather, the phonetic transcription accompanying the word is the SR when the word is realized as a lone sequence, with no contextual variation taken into account. Incorporating a corpus from WordReference, a website that proposes 'more than 100,000 words and expressions in each language [French and English]' (2019) and which provides phonetic transcriptions for many of these words, would fail our model in the above example. *'Ont'*, the 3PP[14] of the verb avoir, an auxiliary verb in the above example, would be assigned a UR of [ɔ̃] (2019).

As repeated throughout this analysis, URs are key to analysing the hiatus in French and, as such, this problem would need to be addressed before such a software could be realized. It might be more reliable to ascertain a sequence's UR in the grapheme-to-phoneme (GP) translation stage of the process. For example, the above sequence, *ont*, would have its UR determined via the following process:

'on' would be identified as a grapheme, as it is a vowel and nasal consonant cluster. Its phoneme translation would be [ɔ̃]. 't' would also be identified as a grapheme and mapped to [t]. Thus, the output of the GP conversion would be [ɔ̃t]. This could then be mapped to [ɔn] were it to be followed directly by a vowel – this would be a constraint of our CON

[13] Once more, it is to their underlying phonetic representations that our model must map the input to.

[14] Third person plural.

component. Finally, [t] would undergo sequence-final consonant elision lest its “union with the succeeding vowel-initial word” be strong enough to be preserved (Delattre, 1947). Thus, if our GP translation function were well defined, the software could avoid relying on an external dictionary or corpus such as that of WordReference. Fortunately, the task of defining this GP function is less onerous than it would be were the target language English – a language whose orthography is notoriously “opaque” (Wimmer & Goswami, 1994). Although French’s orthography can initially appear to be daunting as it can have several graphemes represented by one phoneme, e.g. *eaux ‘waters’ [o]*, its GP translation is very consistent, significantly more so than in English in monosyllabic words (Peereman & Content, 1998). That said, many linguists consider French to also be an orthographically opaque language (Jaffré, 2005). However, while both languages can be considered rather opaque in their orthography, the consistency of French GP translations is what simplifies the challenge of GP translation.

6. Glossary

6.1 General

OT – Optimality Theory

UR – Underlying Representation

SR – Surface Representation

EN – English

FR – French

ES – Spanish

TtS – Text-to-Speech, a.k.a. Speech Synthesis.

GP – Grapheme-to-Phoneme

Sequence - sequence is a term that will be used abundantly throughout this analysis. At its base, a sequence can be considered a morpheme, a building block from which words are formed. This morpheme is a sequence of phonemes/phones. The words are then used to create chains of speech, i.e. sentences. Thus, sequence may refer to an individual sequence or to a sequence of individual sequences. Though the term may be used interchangeably, it is important to recognise each individual sequence in a sequence of sequences as being distinct from how it appears in the chain of sequences.

6.2 OT

GEN – component which generates inputs to be parsed by the constraint component.

CON – constraint component that applies a series of ordered constraints to the GEN inputs.

EVAL – evaluation component which chooses the correct output based on violations of the constraints and the importance or hierarchical position of the violated constraints from one potential output to another.

6.3 OT Constraints

$INS-C: Insertion of consonant after any sequence whose final syllable has a null coda not at sequence-end.

$HIA-C: two vowels in a hiatus must be separated by a liaising consonant.

$ELIDE-ART: A sequence-final consonant will undergo elision when followed by a sequence beginning with a consonant or at overall-sequence end.

$RET-ART: a sequence-final consonant will undergo will not undergo elision when followed by a sequence beginning with a vowel or nasal vowel.

$ONSET: a syllable must have an onset.

$NO-CODA: a syllable should have no coda before a syllable with an onset.

$DROP-AN: the sequence [an] will undergo elision to [a] when preceded by a syllabic break or silence and when before a sequence beginning with a vowel.

$RET-AN: the sequence [an] will not undergo elision when preceded by a syllabic break or silence and when followed by a sequence beginning with a consonant.

$RET-C: a sequence will retain its final consonant if its elision results in a hiatus.

6.4 Syllable

.[15] – use to mark syllabic boundaries in phonetic transcriptions

[15] Full stop or period

7. Bibliography

Académie Française. (2019). *r(e)-*. Retrieved 07 16, 2019, from https://www.dictionnaire-academie.fr/article/A9R0685

Cissé, I. (2014, 09 18). Développement phonético-phonologique en fulfulde et bambara d'enfants monolingues et bilingues : étude du babillage et des premiers mots. Leiden, Netherlands.

Côté, M.-H. (2005). Le statut lexical des consonnes de liaison. *Langages, 158*(2), 66-78.

Crystal, D. (1995). Phonaesthetically Speaking. *English Today 41, 11*(2), 8-12.

de Saussure, F. (1916). *Cours de linguistique générale.* Geneva.

DeepMind. (2019). *Deepmind*. Retrieved 07 09, 2019, from https://deepmind.com/

Delattre, P. (1947). La Liaison en Français, Tendances et Classification. *The French Review, 21*(2), 148.

Deterding, D. (2001). The measurement of rhythm: a comparison of Singapore and British English. *Journal of Phonetics (Volume 29)*, 1-14.

Donovan, R.-E., Ittycheria, A., Franz, M., & Eide, E. (2001). Current Status of the IMB Trainable Speech Synthesis System. *Proceedings of ISCA Tutorial and Research Workshop on Speechsynthesis,*, 1-4.

Etymonline. (2019). *A*. Retrieved 07 08, 2019, from https://www.etymonline.com/word/a

Féry, C., & Van de Vijver, R. (2003). *The Syllable in Optimlaity Theory.* Cambridge: Cambridge University Press. Retrieved from https://www-jstor-org.elib.tcd.ie/stable/412031?Search=yes&resultItemClick=true&searchText=the&searchText=syllable&searchText=in&searchText=phonological&searchText=theory&searchUri=%2Faction%2FdoBasicSearch%3FQuery%3Dthe%2Bsyllable%2Bin%2Bphonological%2Bt

Geerts, T. (2011). Ch(e) va : Schwa français en syllabe initiale. *Langue Francaise, 169*(1), 39-54 .

Google. (2019). *Cloud Text to Speech*. Retrieved 07 09, 2019, from https://cloud.google.com/text-to-speech/

Gross, M. (1967). Sur une règle de "cacophonie" . *Langages, 7*, 105-119.

Hooper, J. (1972). The Syllable in Phonological Theory. *Language, 48*(3), 525-540.

International Standards Organisation. (2019). *ISO 639.2*. Retrieved 07 15, 2019, from https://www.loc.gov/standards/iso639-2/php/code_list.php

Jaffré, J.-P. (2005). Introduction: The Orthography of French. *L1-Educational Studies in Language and Literature Volume 5 Issue 3*, 353-364.

Juang, B., & Rabiner, L. (2004). Automatic Speech Recognition – A Brief History of the Technology Development .

Kean, M.-L. (1974). The theory of markedness in Generative Grammar. MIT.

La Grande Librairie. (2018, 11 08). *Nicolas Mathieu, Prix Goncourt 2018 pour son roman « Leurs enfants après eux »*. Retrieved 07 10, 2019, from https://youtu.be/GEqpHh9yeJw?t=64

Larousse. (2019). *Ramie*. Retrieved 07 03, 2019, from https://larousse.fr/dictionnaires/francais/ramie/66380?q=ramie#65636

Larousse. (2019, 07 20). *Tsigane*. Retrieved from Larousse: https://larousse.fr/dictionnaires/francais/tsigane/80102?q=tsigane#79133

Léon, P. (1966). Apparition, maintien et chute du "E" caduc. *La Linguistique, 2*, 111-122.

López, G., Quesada, L., & Guerrero, A. (2017). Alexa vs. Siri vs. Cortana vs. Google Assistant: A Comparison of Speech-Based Natural User Interfaces. *Nunes I: Advances in Human Factors and Systems Interaction, 592*, 241-250.

M. Zwicky, A. (1972). The Strategy of Generative Phonology. *Phonologica*, 151-165.
Mathieu, N. (2018). *Leurs enfants après eux.* Actes Sud Littéraires.
McCarthy, J. (2007). What is Optimality Theory? *Language and Linguistic Compass, 93*.
Milroy, J., & Milroy, L. (1993). Mechanisms of change in urban dialects: the role of class, social network and gender. *International Journal of Applied Linguistics, 3*(1), 57-77.
Nagao, M. (1992). Are the grammars so far developed appropriate to recognize the real structure of a sentence? *Proceedings of 4th TMI*, 127-137.
Nardy, A., Chevrot, J.-P., & Barbu, S. (2011). Developmental dynamics of SES-related differences in children's production of obligatory and variable phonological alternations. *Language Sciences, Elsevier, 33*, 180-191.
Oxford English Dictionary. (2019). *Cacophony*. Retrieved 07 04, 2019, from https://www.lexico.com/en/definition/cacophony
Oxford English Dictionary. (2019). *Hiatus*. Retrieved 07 03, 2019, from https://www.lexico.com/en/definition/hiatus
Oxford English Dictionary. (2019). *Prefix*. Retrieved 07 15, 2019, from https://www.lexico.com/en/definition/prefix
Oxford University Press. (2019, 07 22). *Attic Orators* . Retrieved from Oxford Research Encyclopedias: https://oxfordre.com/classics/view/10.1093/acrefore/9780199381135.001.0001/acrefore-9780199381135-e-951
Pak, M. (2014). A/an and the: allomorphy or phonology. *Linguistics Society of America (presented at Annual Meeting)*.
Pearson, L. (1975). Hiatus and Its Purposes in Attic Oratory. *The American Journal of Philology Vol 96 Issue 2*, 138-159.
Peereman, R., & Content, A. (1998). *Quantitative analyses of orthography to phonology mapping in English and French.* Retrieved from Vrije Universiteit Brussel: http://homepages.vub.ac.be/~acontent/OPMapping.html
Pernot, N. (1937). Quelques Notes sur la liaison en français: Liaison et Enchaînement. *The Modern Language Journal, 21*(5), 333-338.
Prince, A., & Smolensky, P. (1993). *Optimality Theory: Constraint Interaction in Generative Grammar.* Retrieved 07 03, 2019, from https://doi.org/doi:10.7282/T34M92MV
Ridouane, R. (2008). Syllables without vowels: Phonetic and phonological evidence from Tashlhiyt Berber. *Phonology, Cambridge University Press*, 321-359.
Rini, J. (2010). When Spanish h- Went Silent. How Do We Know? *Bulletin of Spanish Studies, 87*(4), 431-446.
Rojc, M., & Kačič, Z. (2007). Time and Space-Efficient Architecture for a Corpus-based Text-to-Speech Synthesis System. *Speech Communication, Elsevier, 49*(3), 230.
Rousseau, A. (1995). *Les Préverbes dans les langues d'Europe: Introduction à l'étude de la préverbation* (1st ed.). Presses Univ. Septentrion.
RTÉ. (2015, 12 27). *Play it by Year*. Retrieved from RTÉ: https://presspack.rte.ie/2015/12/27/play-it-by-year-new-series/
Saffran, J., Aslin, R., & Newport, E. (1996). Statistical Learning by 8-Month-Old Infants. *Science , 274*(5294), 1926-1928.
Smith, J. L. (2012). The formal definition of the Onset constraint and implications for Korean syllable structure. *Advances in Optimality Theory*(Prosody Matters: Essays in Honor of Elisabeth Selkirk), 73–108.
Tranel, J. (2000). Aspects de la phonologie du français et la théorie de l'optimalité. *Langue Francaise - Vol 126*, 39-72.
Vennemann, T. (1978). UNIVERSAL SYLLABIC PHONOLOGY. *Theoretical Linguistics*, 175-216.

Wauquier-Gravelines, S., & Braud, V. (2005). PROTO-DÉTERMINANT ET ACQUISITION DE LA LIAISON OBLIGATOIRE EN FRANÇAIS. *Langages, 158*(2), 53-65.

Wimmer, H., & Goswami, U. (1994). The influence of orthographic consistency on reading development: word recognition in English and German children . *Cognition - Volume 51*, 93-103.

WordReference. (2019). *English-French dictionary*. Retrieved 07 17, 2019, from https://www.wordreference.com/enfr/

WordReference. (2019). *https://www.wordreference.com/fren/ont*. Retrieved 15 17, 07, from 2019

WordReference. (2019). *innombrable*. Retrieved 07 15, 2019, from https://www.wordreference.com/fren/innombrable

Zadeh, L. (1965). Fuzzy sets. *Information and Control, 8*, 338-353.