The XYZ effect in phonotactics

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Motivating example

Observation 1. Consider the fact that the English words *spill*, *sow* (the verb), and *pillow* can be matched against the template XY – XZ – YZ. Using phonological representations from General American English[1], we observe that we have effectively bound the template variables X, Y, and Z to values (X, Y, Z) = (s, pɪl, oʊ).

Observation 2. Next, consider the fact that XYZ = /spɪloʊ/ is, on the one hand, a pseudo-word, but on the other hand, a phonotactically well-formed one.

Could Observations 1 and 2 be related? We hypothesize that it is indeed so, and that a very general *XYZ effect* mediates this. We postulate that it is both universal in any given idiom (language variety), and cross-linguistically as well.

Hypothesis

Assume that X, Y, and Z are non-empty strings of phonemes. Then, if XY, XZ, and YZ are words (or phonotactically well-formed pseudowords) in some idiom *L*, then XYZ is phonotactically well-formed in *L*.

Challenges

Types of challenges

Phonotactics is commonly divided into local and long-distance varieties. We must, then, demonstrate, that both in local and long-distance phonotactics, the XYZ effect is maintained.

When one violates a constraint of *local* phonotactics, the violation can always be traced to its *locus* within a word. Typologically, the locus seems to always be a bigram or a trigram, that is, 2 or 3 adjacent phonemes. The very presence of such violating locus, even when deprived of its context, should unambiguously signal a violation.

For the bigram case, we advance a generic argument. The trigram case poses more difficulty, and has to be dealt with on a more detailed basis.

[1] And ignoring suprasegmentals. In its current version, the hypothesis concerns segmental phenomena only.

When it is a constraint of *long-distance* phonotactics that is violated, the evidence for this violation can be spread out through the entire word. Such are harmony phenomena, long-distance dissimilation rules, and, in their own peculiar way, quantifications, such as "at least 1 vowel per word" or "at least 1 unreduced vowel per word".

The typology of harmony has received much scholarly attention and was found to be quite diverse. We advance a schematic argument for "classical" harmony systems, such as the vowel harmony in Finnish, and extend it to handle harmonies with simple *blockers*, such as the rounding harmony in Buriat. We deal with some other salient long-distance explananda on a per-case basis.

Local bigram phonotactics

There can never be a bigram in XYZ that would not have already been there in XY, or YZ, or both. In fact, in this case, XZ is redundant. Therefore, bigram phonotactics alone cannot contradict the XYZ effect.

For example, let (XY, XZ, YZ) = (spɪl, soʊ, pɪloʊ) once again, so that (X, Y, Z) = (s, pɪl, oʊ). In the pseudo-word /spɪloʊ/, one might find the bigrams /sp/ and /loʊ/[2] suspect, but they are, in fact, found in XY = /spɪl/, and YZ = /pɪloʊ/, respectively.

Local trigram phonotactics

A priori, trigram phonotactics might, in fact, contradict the XYZ effect – unless one requires additionally that Y consist of at least 2 phonemes. It is, however, interesting to consider the implications of dispensing with this proviso.

Firstly, trigrams allow us to apply sonority sequencing rules for syllable structure. For example, Lithuanian is commonly described as having syllables of the shape $(S_1)(T_1)(R_1)V(R_2)(T_2)(S_2)$, where S, T, and R are distinct and disjoint classes of consonants (Girdenis, 2014:130). Notice here that TR and RT are both legal types of bigrams. That said, trigrams of the shape TRT are ill-formed.

To create TRT by recombination alone, one needs, however, to let Y = R, and XY = …TR. The latter is of itself a violation of the sonority sequencing rule operating in Lithuanian: sonority begins to rise – Son(T) < Son(R) – and then the word abruptly ends. As a consequence, such XY will be unavailable to begin with.

[2] As is customary in phonological treatments of General American, /oʊ/ is a single phoneme.

A rather analogous argument obtains for the distribution of Finnish /d/, which, as per (Suomi et al., 2008), consists of /VdV/ and /hdV/.

Lack of evidence for higher n-gram phonotactics

To the best of our knowledge, languages do not exhibit *n*-gram phonotactics for *n* = 4, 5, or higher, that would not be better treated as long-distance phonotactics, and that would not be properly subsumed by any of the known types of long-distance phenomena.

Word-final and word-initial phonotactics

Often subsumed under local phonotactics, neither word-final nor word-initial constraints pose any difficulties here. This is because the entire beginning of XYZ is nothing else than the beginning of XY, and the entire ending of XYZ is just the ending of XZ. Recall here that we have *required* XY and XZ to be well-formed in the statement of the hypothesis.

Classical harmony systems

Consider some numerals in Finnish, which exhibits a well-known case of vowel harmony:

kaksi	‘2’	*kahdeksan*	‘8’
yksi	‘1’	*yhdeksän*	‘9’

Now, mutate them slightly, in an attempt to violate the harmony rule:

*k**ä**ksi*	‘?’	**kahdeks**ä**n*	–
***u**ksi*	‘?’	**yhdeks**a**n*	–

The mutated ‘1’- and ‘2’-words are still well-formed (pseudo-)words. This is because *e* and *i* do not participate in the harmony, in the same way that none of the consonants do.

On the other hand, our changes turned the ‘8’- and ‘9’-words into phonotactic violations. This is because in this harmony system, *a*, *o*, *u* /a, o, u/ can never enter the same word with *ä*, *ö*, *y* /æ, ø, y/, unless they end up on different parts of a compound.

To demonstrate the compatibility of the XYZ effect with this type of harmonies, color the segments X, Y, and Z either **G**reen, **O**range, or **T**ransparent. 27 combinations obtain: (X, Y, Z) = (G, G, G), (G, G, O), (G, G, T), (G, O, G), and so on.

Finnish (Uralic)

Backness harmony:

- [+back] = /a, o, u/
- [–back] = /æ, ø, y/

Use **G**reen if the segment contains /a, o, u/, **O**range if it contains /æ, ø, y/, and **T**ransparent if it has none of these. Next, make an exhaustive list of these combinations – manually or automatically – to verify that an ill-formed output (that is, XYZ) can only result from ill-formed inputs (that is, XY, XZ, or YZ).

Of course, the domain where the effect holds cannot extend to full compounds. One must either introduce an unpronounced root boundary "segment" /+/, or apply the effect to both sides of the compound separately.

Harmony systems with simple blockers

In Buriat (Aksënova et al., 2020:8; Poppe, 1960), one finds a rounding[3] harmony with an apparent complication beyond the Finnish case: there is an actual, fully pronounced equivalent of the /+/ segment described above. In fact, there are four: /u, uː, ʊ, ʊː/ all subdivide the word into domains where the harmony holds separately. In the literature, such separator segments are called *blockers*.

Removing the /u, uː, ʊ, ʊː/ – the blocker – can fuse two domains into one and introduce a violation:

	ɔr-ʊːl-aːd	'enter-CAUS-PERF'
*	ɔr-l-aːd	–
*	ɔr-aːd	–
	ɔr-ɔːd	'enter-PERF'

Importantly, the "complication" of the blocking segment being phonologically real is in fact not a complication at all. It makes our treatment simpler and farther-reaching, as far as the XYZ effect is concerned.

In case X contains blockers, split X = X_1MX_2, so that X_1 and X_2 are now blocker-free, even if empty. Crucially, pick such X_1 and X_2 that they are maximal: in other words, that they span the

Buriat (Mongolic)

Rounding harmony, as per Aksënova et al. (2020):

- [+round] = /ɔ, ɔː, o, oː/
- [–round] = /a, aː, e, eː/

Blockers in rounding harmony:

- /u, uː, ʊ, ʊː/

[3] Wherein, for example, /a, ɔ/ are respectively [–round] and [+round].

longest possible blocker-free initial and final parts of X. Mark the colors of X_1 and X_2 separately. If X has no blockers, let color(X_1) = color(X_2) = color(X). Repeat for Y, and then for Z.

Now, the same "colored segment" procedure from the previous subsection ("Classical harmony systems") holds, except that there are now 6 segments: X_1, X_2, Y_1, Y_2, Z_1 and Z_2. To cut the procedure down to size, one might observe that X_1 and Z_2 are irrelevant.

Parasitic assimilation

In Yowlumne (Jurgec, 2013; Kuroda, 1967), one finds a vowel harmony system that involves *parasitic assimilation*. Therein, vowel rounding harmonizes "parasitically on" vowel height. This means that vowels which already match with respect to height, must also match with respect to rounding. Where there is **no** match in vowel height, rounding is also allowed to differ:

	muʈ-		**gop-**	
-hun / -hin	muʈ-hun	'swear.AORIST'	gop-hin	'take.care-AORIST'
-taw / -tow	muʈ-taw	'swear.NDIR.GER'	gop-tow	'take.care-NDIR.GER'

We have not dealt with anything of this kind in our "color procedure", so it might be unclear how it could be carried out here. Certainly, it would involve more colors than just two.

As a solution, we propose that the harmony be segregated into two subsystems: (1) a low vowel rounding harmony and (2) a high vowel rounding harmony. These two harmonies can be added one at a time and handled separately.

In a way, we find Yowlumne in the *intersection* of two "languages", for both of which the XYZ effect can be easily verified. Set intersection, in the mathematical sense, preserves the XYZ effect. For a proof idea, see "Remarks on intersection closure".

Yowlumne (Yokuts)

Rounding harmony on high vowels, as per Jurgec (2011):

- [+high, +round] = /u/
- [+high, –round] = /i/

Rounding harmony on low vowels (ibid.):

- [–high, +round] = /o/
- [–high, –round] = /a/

Local distributed blocking

Yaka (De Santo & Aksënova 2021; Hyman, 1995) presents us with a consonant harmony system, in which it takes two adjacent segments (nasal + stop) to block it. Just one – either of them – is not enough.

There is the obvious risk that the XYZ formalism – to anthropomorphize it slightly – might "attribute" the blocking effect to either of the segments (the nasal or the stop) separately and produce disharmonious inferences.

However, assume that half of the blocker ends up in X, and the rest in Y. Obviously, the XY part of XYZ is inherited from the XY input and thus harmonious. The rest of the situation is salvaged by XZ, which must continue the harmony as if there were no blocking – because in XZ, there is none[4]. Therefore, the XYZ formalism can only be excessively "cautious" here.

Yaka (Atlantic-Congo)

Nasal harmony, as per De Santo & Aksënova (2021):

- [+nasal] = /n, m, ŋ/
- [–nasal] = /d/

Blockers in ATR harmony:

- /nd, mb, ŋg/

[4] Unless Z begins with the same segment as Y, which is also a safe case.

Long-distance distributed blocking

The ATR harmony in Tutrugbu is a recent and fascinating explanandum in the typology of harmony (McCollum et al., 2020). As in Yaka (see “Local distributed blocking”), blockers here come in two halves, which are inactive on their own, but become active in combination. However, unlike Yaka, Tutrugbu allows the halves (B_1, and any number of B_2s) to lie as far apart as the morphology allows. This phenomenon in the blocking of harmony has been termed *circumambience*.

Consider the following examples[5] from (McCollum et al., 2020:5):

Transcription,
harmonizing feature (±ATR),
blockers (B_1, B_2) — **Gloss**

[	e	t	i	w	u	]	‘3S-NEG-climb’
	+		+		+		
	B_2						

[	i	t	i	w	u	]	‘1S-NEG-climb’
	+		+		+		
	B_1						

[	ɪ	b	a	w	u	]	‘1S-FUT-climb’
	–		–		+		
	B_1		B_2				

[	ɪ	t	ɪ	k	a	w	u	]	‘1S-NEG-PFV-climb’
	–		–		–		+		
	B_1				B_2				

[	ɪ	t	ɪ	k	a	a	w	u	]	‘1S-NEG-PFV-PROG-climb’
	–		–		–	–		+		
	B_1				B_2	B_2				

[	e	t	i	k	e	e	b	e	b	e	w	u	]	‘3S-NEG-PFV-PROG-VENT-VENT-climb’
	+		+		+	+		+		+		+		
	B_2				B_2	B_2		B_2		B_2				

Tutrugbu (Atlantic-Congo)

ATR harmony, as per McCollum et al. (2020):

- [+ATR] = /i, e, u/
- [–ATR] = /ɪ, ɛ, a, ɔ, ʊ/

Blockers in ATR harmony:

- First half: /ɪ/ in word-initial syllable, that is, /#(C)ɪ/
- Second half: /a/

[5] Tone marks elided for clarity of presentation. Wider spaces are morpheme boundaries. The language also has nasal vowels, which are behaved identically to their non-nasal counterparts with respect to the harmony.

The harmony system in question fully conforms with the XYZ effect. One way to demonstrate this is to state the harmony as the formal language generated by the following automaton:

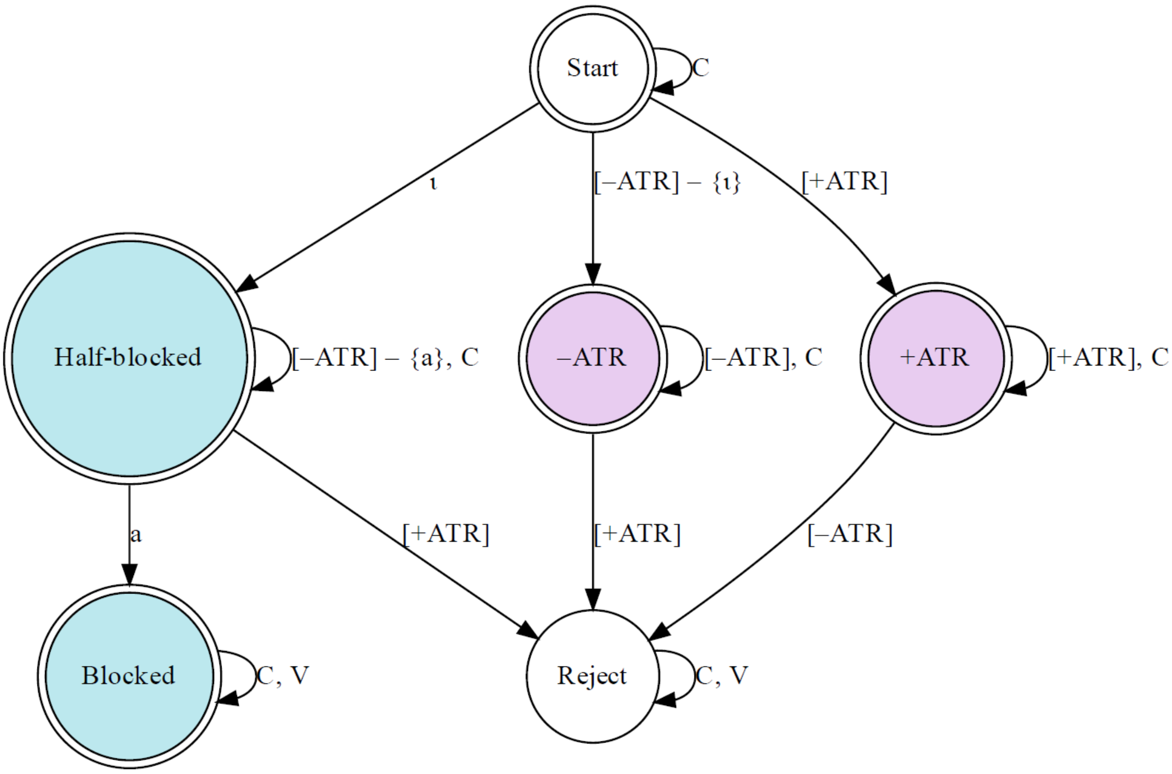

Figure 1. Simplified automaton for Tutrugbu ATR harmony

We begin scanning the word in the "Start" state. The purple states (–ATR and +ATR circles) are ones in which full harmony is expected within the word. The teal states ("Half-blocked" and "Blocked") are entered upon encountering the first half of the blocker, which is /ɪ/. All states are accepting, except the one labeled "Reject".

The teal portion of the automaton presented here has been simplified. After encountering the second half of the blocker, that is, /a/, it allows arbitrary disharmony. In reality, the rest of the word must be all [+ATR] or [–ATR]. We shall reverse the simplification later in "Relation to formal languages and automata", by intersecting the automata in Figures 1 and 3.

Now, we prove – by enumeration – that any automaton with the same topology as in Figure 1 (the topology itself can be represented as Figure 2) will display the XYZ effect.

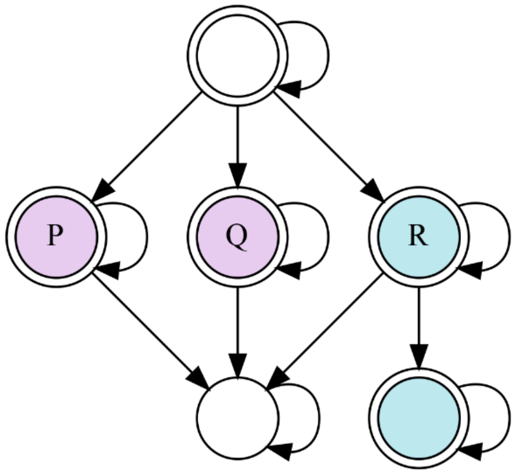

Figure 2. Topology of the simplified automaton for Tutrugbu ATR harmony

To do so, we assume, for example, that feeding the string X to state P will leave us in state P. Next, we list all such assumptions of the shape (String, Entry, Exit), starting with (X, P, P), which we have just discussed. Lastly, we *combine* the assumptions in all logically compatible ways. One possible combination would have the shape {(X, Start, Start), (X, P, P), (X, Q, Reject), (X, R, R), …, (Z, R, Reject)}.

A combination of this type is essentially a transition table for the automaton, except that instead of symbols triggering the transitions, we are interested in the strings X, Y, and Z. We use a computer to search the entire space of these transition tables to check for contradictions of the XYZ effect. For automata of this size, the search completes rather quickly.

Remarks on intersection closure

One might wonder if two sets of phonotactically well-formed strings – two artificially augmented "languages" derived from some idiom L – keep the XYZ effect, if we *intersect* them. This means that we take only the part common to both and discard the rest.

Assuming that this is true was part of the argument that we advanced for Yowlumne (see "Parasitic assimilation"). In fact, relatively many languages that possess harmony systems, actually possess two or more. The validity of this step is thus important.

Consider now *hypothetically* that the opposite has happened: the XYZ effect has ceased to hold in the intersection of L_1 and L_2, having held in both of them separately. We shall see that this would entail absurd consequences and is, therefore, impossible.

This would mean that there is a triple (XY, XZ, YZ) in the intersection, for which there is no XYZ. Perhaps there are more such triples.

Recall here, however, that what is in the intersection, was in L_1, and was in L_2, as well. Moreover, we began with the assumption that the effect did hold for L_1 and L_2. Therefore, the XYZ (pseudo-)word in question is both in L_1 and L_2.

By analogous reasoning, the triple (XY, XZ, YZ) could not have come to the intersection in two parts, such as (XY, XZ) & (YZ), from separate sides of the intersection, either.

Therefore, one cannot carry the triple to the intersection without carrying the XYZ. Our anticipation that the effect might cease to hold this way was, in fact, unwarranted.

Relation to formal languages and automata

It is curious to inquire if some kind of formal languages exhibit the XYZ effect in their entirety – especially, those formal languages that are relevant to phonotactics.

MTSL$_2$ languages

Preliminarily, we have observed by means of computational simulation (Rudaitis, 2021) that the MTSL$_2$ class of formal languages (multiple tier-based strictly 2-local), investigated by Aksënova et al. (2020 et passim) as a broad-coverage model of phonotactics, might inherently have the effect. A formal demonstration is still in the plans.

Automata and regular languages

The relation between XYZ effect-observing formal languages (henceforth, XYZ languages) and the regular languages is yet unclear.

Of particular interest would be those XYZ languages that have a finite characteristic sample *S*. In these, the entire language can be extrapolated by applying the effect's statement on the strings in *S*, then augmenting *S* with the results, and repeating indefinitely. It appears very preliminary that these “finitary” XYZ languages are subregular.

Additionally, one might want to prove the XYZ effect for particular automata. Whenever this is successful for two automata, it is notable that their intersection will also exhibit the XYZ effect, because both regularity and the XYZ effect are closed under intersection.

A remark on Tutrugbu ATR harmony

In “Long-distance distributed blocking”, where we discussed the ATR harmony in Tutrugbu, we demonstrated the XYZ effect using the automaton in Figure 1. We had remarked that this was a simplified automaton.

Now that we have seen that XYZ effect-observing automata can be intersected freely, let us intersect the automata in Figure 1 and Figure 3:

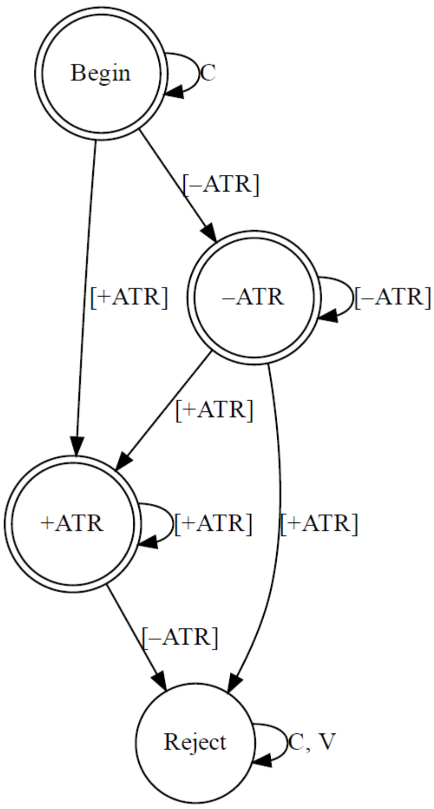

Figure 3. Automaton that corrects the simplification made in Figure 1

Observe that the automaton in Figure 3 only accepts one [+ATR] part after an optional preceding [–ATR] part. Additionally, it accepts purely [–ATR] strings.

By intersecting it with Figure 1, we accept only those strings that both automata would accept. This effectively reverses the simplification, where arbitrary disharmonies could follow blockers.

Concluding remarks

We have currently drawn a relatively representative cross-linguistic sample of phonotactic explananda and provided sketches of demonstrations of the XYZ effect operating throughout the entire sample.

The implications of the present work are yet to become clear, but for the following reasons we believe them to have the potential to be far-reaching.

Firstly, the effect is remarkably simple to state; it is, arguably, simpler to state than the rules for any particular harmony system.

Secondly, one can derive a phonotactic inference algorithm from the statement of the effect very straightforwardly. We have run preliminary simulations of this algorithm, whereby the effect's statement is enacted in an iterated manner. While the results are reassuring, it is also true that on real-life corpora, the algorithm is rather hesitant to generalize, given that triples of the form (XY, XZ, YZ) have a relatively low chance of co-occurring in a corpus of a cognitively realistic size.

Lastly, the effect seems to extend to morphotactics and syntax, albeit in an unusual way. There, one can mostly observe only a "silent" XYZ effect: the effect holds almost vacuously because (XY, XZ, YZ) only co-occur with extreme rarity. However, this is not to be ignored: morphosyntax might have an anti-(XY, XZ, YZ) tendency which would let us synthesize negative stimuli for learning.

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