

Strict Locality In Morphological Derivations

Alëna Aksënova and Aniello De Santo
Stony Brook University

ABSTRACT

In this paper, we argue that a computational perspective can help highlight differences between similar but distinct theoretical approaches. In particular, we compare two approaches to representing morphological sequences: derived and derivational. We introduce the reader to Russian patterns — nominalization and telicity conversion — requiring particular dependencies between prefixes and suffixes. Then, we use formal language theory (in the form of the subregular class of strictly local languages) to capture the relevant pattern. We show how the computational power needed to capture these apparently complex dependencies is significantly reduced, if we allow the grammars to judge the wellformedness of morphological operations over derivational representations instead than surface forms.

1 Introduction

The topic of representations in morphology has kept linguists on alert for decades. Should the wellformedness of morphological forms be evaluated over the surface forms (*derived* representations), or considering the sequence of morphological operations (*derivational* representations)? There are multiple arguments in both directions — for example, see Vikner & Vikner (2003) or McGregor (2003) — but no game-changer has been proposed so far. In this paper, we argue that mathematical characterizations of morphological patterns can contribute to this debate.

Formal language theory helps us abstract from narrow and theory-specific details, and *quantify* theoretical intuitions. One specific notion of interest to us is the classification of languages (viewed as sets of well-formed strings) based on the complexity of the grammars needed to generate them. The class of languages that is being used in this paper is *strictly local* (Heinz *et al.* 2011). The core idea behind this class is to capture generalizations by listing *disallowed strings*. The computational complexity of a pattern is then measured by the length of such strings, which shows how many items should be kept in memory simultaneously in order to encode the properties relevant to wellformedness. Leveraging these ideas, we provide an argument in favor of a derivational view of morphology that emerges from considerations of computational simplicity: less computational resources are required to capture a pattern if the representation of this pattern is derivational.

In order to guide the reader through this line of reasoning, we present an analysis of the complex interaction of aspectual metamorphosis and nominalization in Russian. There, a telic prefix can only be attached if the stem is atelic, an atelic suffix can only be attached if the telic prefix had been attached before, and so on. To complicate the patterns even further, there is a nominalization marker *-nie* that attaches only to atelic stems, i.e. if the last conversion of the stem made it atelic.

We show how a language-theoretical characterization of this pattern over the surface forms proves to be surprisingly complex: the required length of the prohibited strings is 5 — that is sequences of 5 morphemes must be memorized in order to reproduce the atelic nominalization pattern. However, if we build a grammar based on strings representing the derivational order of morpheme application, only the information about the last conversion is required to determine whether an affix can be added to the stem. This results in a grammar significantly simpler from a computational perspective: only a window of length 2 is needed to characterize banned substrings.

The paper is organized as follows. Section 2 is a brief discussion of derived and derivational representations in morphology. Section 3 presents the reader with the computational perspective adopted in this paper, informally introducing strictly local grammars, and the importance of subregular characterizations for natural languages. Section 4 and Section 5 are the core of the paper. They contain a discussion of telicity metamorphosis and atelic nominalization in Russian, and their formal analyses under both perspectives. The last section concludes the paper.

2 Derived vs. derivational representations

There are at least two ways of looking at morphological forms in order to evaluate their wellformedness.

One approach (henceforth the *derived* approach) is to look only at the surface representation of morphological strings, i.e. the linear order of the morphemes in the string. *Derived sequences* are the result of all operations applied to the root. According to McGregor (2003), under this perspective, morphology is not hierarchical, but a simple concatenation of smaller strings. A different approach (hereafter the *derivational* approach) is to look at the order of operations that were applied to the root in the process of building the current string¹. We assume that such order of morphological operations can be encoded in a derivational string. In this view morphology is intrinsically hierarchical (Vikner & Vikner 2003).

Both perspectives can be understood by considering the English word *unlockable*, that contains the prefix *un-* as well as the suffix *-able*. Importantly, there are two possible meanings for this word: ‘impossible to lock’ and ‘possible to unlock’. In the derived approach, *unlockable* is derived via putting together the tree substrings, i.e. *un+lock+able*. The semantics is extracted based on the form of the

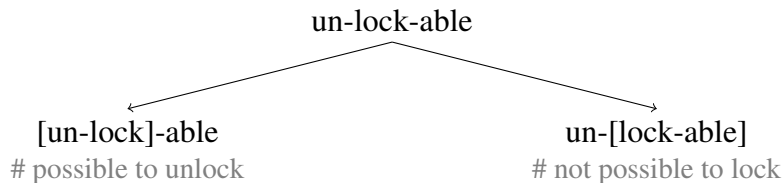


Figure 1: Unlockable: Ambiguity of the surface form

¹More complex structures would be required to account for movement, but it is never the case for morphology. We leave further discussion of this issue for future work.

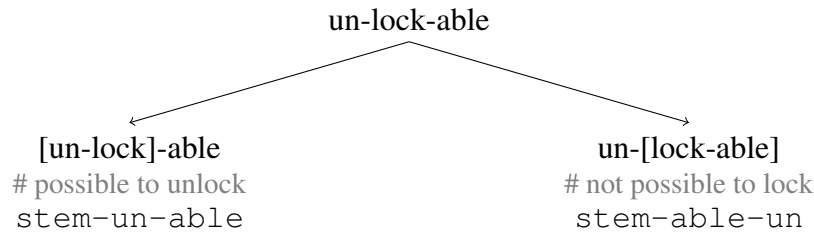


Figure 2: Unlockable: Derivational representations

string (cf. Figure 1).

In a derivational perspective however, there are two distinct *derivational sequences* associated to the word *unlockable*: *lock-able-un* and *lock-un-able* (cf. Figure 2). Each string now represents the different order in which morphemes were applied to the root. A derivational representation then captures the different semantic interpretations (‘impossible to lock’ and ‘possible to unlock’) underlying each order of affix application.

It could be argued that one obvious benefit of the derivational approach is the straightforward way in which scope effects of different morphemes are captured. However, we believe that the differences between the two approaches can be better appreciated by formalizing the analysis in a mathematical system that provides a well-defined (i.e. non arbitrary) notion of simplicity. In the next section we informally introduce general notions of formal language theory, focusing on the idea of classifying language patterns based on the simplicity of their grammars, with particular attention to strictly local languages and their importance for natural languages.

3 Strictly Local grammars

Formal language theory provides linguistics with ways to measure computational complexity of patterns or dependencies. The most well-know hierarchy of string complexity is the *Chomsky Hierarchy*, introduced by Chomsky (1956), see Jäger & Rogers (2012) i.a. for a more recent review. One of the most important classes in this hierarchy for the study of natural languages is the class of *regular languages*, the ones that can be accepted or generated by finite state automata. In particular, it has been argued that the computational complexity of dependencies in phonology and morphology fits in the class of regular languages (Kaplan & Kay 1994; Beesley & Kartunnen 2003).

However, while the Chomsky Hierarchy treats regular languages as a monolithic unit, it has been shown that this class can be decomposed in a finer-grained hierarchy of classes of decreasing complexity — the *subregular hierarchy* (Fig. 3, cf. McNaughton & Papert 1971; Rogers *et al.* 2010). Recently, it has been suggested that most of the phonological patterns occurring in natural language do not need the full power of regular languages, but can in fact be captured by classes in this hierarchy (Heinz 2011a; Heinz 2011b, i.a.).

Crucially the lower, simpler classes in the hierarchy widely match patterns found in phonotactics: strictly local (SL), tier-based strictly local (TSL), and strictly

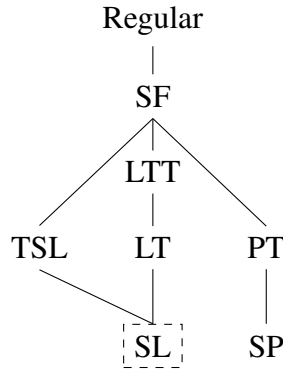


Figure 3: The hierarchy of subregular languages

piecewise (SP), see (Heinz 2011a; McMullin 2016; Graf 2017). Further in this paper, we only focus on strictly local languages.

SL grammars enforce local dependencies by adopting sets of *constraints* that only make distinctions on the basis of contiguous substrings of segments up to some length k . Essentially, a *strictly local grammar* consists of a set of strings that must not appear in a well-formed string of the language.

Example (SL Grammar). As an example of SL processes in English, consider the morphemes *un-* and *-able*. Since *un-* is always a prefix, a corresponding SL grammar would need to block its appearance after the stem: $*stem-un$. Moreover, *un-* is not a free morpheme, so it cannot occur as the last item in the string: we also need to block the word-final symbol following it, $*un-\times$. On the contrary, *-able* is a suffix, so its appearance before the stem is illicit: $*able-stem$. The simplified SL grammar capturing this pattern then is $G_{ing} = \{ *STEM-UN, UN-\times, *ABLE-STEM, * \times -ABLE \}$.

Start- and end-markers \times and \times are usually added in the alphabet over which the grammar operates and to the strings under consideration, in order to limit the evaluation of a wellformedness to word-boundaries. The locality domain of the grammar above is 2: we only need to keep track of two immediately adjacent items in order to evaluate wellformedness of a string. This grammar does not require the well-formed words to contain any prefix or suffix, so words consisting of a single stem such as *do* are allowed. Apart from permitting strings like *do-able* or *un-do*, such grammar also predicts co-occurrence of these affixes, and this is correct: *un-do-able*. Strings where the order is reversed, such as *able-do*, are banned by this grammar.

As another example, consider the German iterative prefix *-über* ‘after’:

- (1) a. morgen ‘tomorrow’
- b. über-morgen ‘the day after tomorrow’
- c. über-über-morgen ‘the day after the day after tomorrow’

The only constraint is that the prefix *über-* cannot follow the stem, therefore the only substring that needs to be banned is $*stem-über$. The grammar’s locality domain is again 2. Interestingly, a pattern where the amount of prefixes would

match the amount of suffixes is not strictly local (in fact, it is not even regular): this would correspond to a language of the type $a^n b^n$ where, at any given moment, the amount of a must match the amount of b . In order to capture this kind of pattern with a strictly local grammar, we would need to include all a and b into the locality domain. This is not possible when the number of a s and b s is unlimited: keeping track of this dependency would in fact require unbounded memory resources.

Now that the mathematical framework is in place, we can move on and use formal complexity to compare the derivational and derived analyses of two phenomena in Russian morphology.

4 Russian telicity metamorphosis

In Russian, the majority of verbal stems are intrinsically atelic (Laleko 2008). In order to convert such stems to telic one should add to it an atelic prefix such as *ot-* (cf. (2) vs. (3)). Crucially, it is impossible to add atelic suffix directly to the atelic stem (4).

- | | | |
|------------|---------------|----------------|
| (2) kry-t' | (3) ot-kry-t' | (4) *kry-va-t' |
| cover-INF | TEL-cover-INF | cover-ATEL-INF |
| ‘to cover’ | ‘to open’ | |

The verb *otkryt'* ‘to open’ is telic. Adding atelic suffix *-va* makes it atelic (5). Note that adding this suffix was not possible before the prefix *ot-* was added. Similarly to (4), which showed how it is impossible to add the atelic suffix to an atelic stem, (6) shows how the telic stem *otkryt'* rejects the telic prefix *na-*.

- | | |
|--------------------|-------------------|
| (5) ot-kry-va-t' | (6) *na-ot-kry-t' |
| TEL-cover-ATEL-INF | TEL-TEL-cover-INF |
| ‘to be opening’ | |

The verb *otkryvat'* is atelic. As expected, it is now possible to add to the atelic stem another telic prefix (7), but not an atelic suffix (8).

- | | |
|------------------------------|-------------------------|
| (7) na-ot-kry-va-t' | (8) *ot-kry-va-va-t' |
| TEL-TEL-cover-ATEL-INF | TEL-cover-ATEL-ATEL-INF |
| ‘to have been opening a lot’ | |

At this point, further conversions do not seem possible. However, it is not clear whether additional conversions are ungrammatical, or if wellformedness judgments become increasingly hard to get due to the number of telicity-changing affixes.

In brief, it seems that a stem can be converted to telic only if it is atelic, and the atelic conversion can be applied only if the stem is telic. Figure 4 presents a schematic summary of this pattern: solid arrows represent possible telicity changes, and dotted arrows stand for impossible conversions.

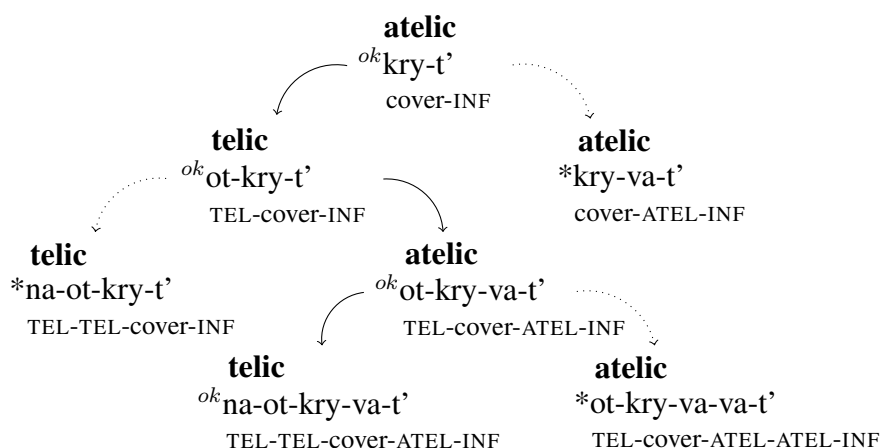


Figure 4: Russian aspectual conversions

4.1 A Computational Analysis over Derived Strings

Given the nature of the telic and atelic affixes — telic prefixes and atelic suffixes — iterative conversions create a pattern that might remind the reader of a context-free dependency. Crucially though, the boundedness of iterations keeps the dependency local. Thus, this pattern can be captured by a strictly local grammar over the derived string. There are three types of strings that are banned within the pattern described above. Examples in (9a) and (9c) are impossible because it is not allowed to add the atelic affix to an atelic stem, and (9b) is out because a telic stem cannot accept another telic affix.

- (9) a. **stem-ATEL-INF*
 b. **TEL-TEL-stem-INF*
 c. **TEL-stem-ATEL-ATEL-INF*

In order to ensure that forms of the type showed in (9a) cannot be generated, one cannot simply ban **stem-ATEL*: in general, this sequence of morphemes be an allowed substring, since for example it is contained in the verb *ot-kry-va-t'*. What the grammar needs to block is a bare stem (a stem not preceded by any other prefix), and followed by *-va*: **x-stem-ATEL*. The example in (9b) contains two telic prefixes and no atelic affixes, so the whole sequence **TEL-TEL-stem-INF* must be banned. Finally, the illicit substring contained in (9c) is **ATEL-ATEL*, since attaching an atelic suffix to a stem that is already atelic is impossible.

The following strictly local grammar captures the full Russian aspectual pattern as presented above: $G_{m_1} = \{*\times\text{-stem-ATEL}, *\text{TEL-TEL-stem-INF}, *\text{ATEL-ATEL}\}$. The longest banned sequence is **TEL-TEL-stem-INF*, therefore the size of such grammar is 4: up to four adjacent items need to be evaluated in order to decide the wellformedness of a string.

It is important to note that the 4 strictly local grammar we derived above corresponds in fact to memorizing every possible illicit substrings and any real linguistic generalization about the telicity alternation is lost. Thus, while a local analysis of

this pattern is indeed possible, this results in a fairly opaque characterization — hardly a desirable property in any good theory of linguistic constraints.

4.2 A Computational Analysis over Derivational Strings

As we mentioned before, in the derivational approach not the order of affixes, but the order in which they were applied to the stem is important for wellformedness considerations. Figure 5 depicts the conversion process discussed above, but highlights a derivational representation for the aspectual conversion.

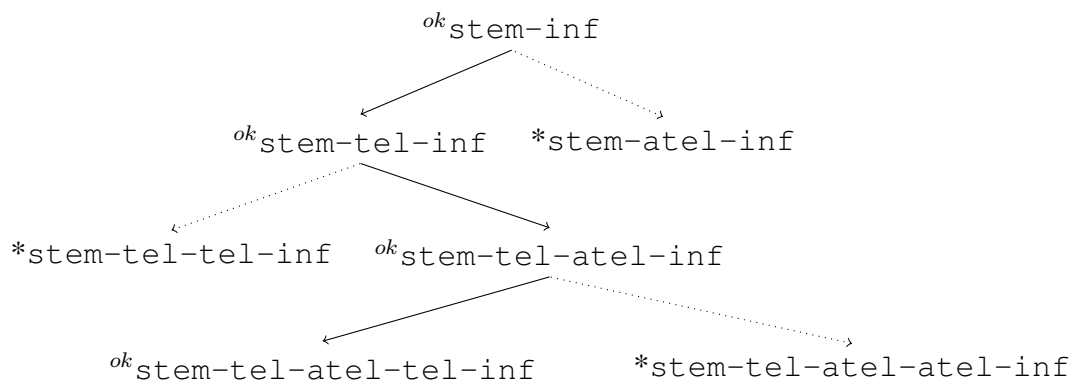


Figure 5: Russian aspectual conversions: derivational approach

Thus, all the strings that need to be banned are listed in (10).

- (10) a. **stem-ATEL-INF*
 b. **stem-TEL-TEL-INF*
 c. **stem-TEL-ATEL-ATEL-INF*

As (10a) shows, it is impossible to add atelic affix to the root, because verbal roots are atelic. In order to avoid such configuration, **stem-ATEL* must be blocked. Telic affixes cannot be added to a telic root (10b), and atelic affixes cannot be added to an atelic root (10c), respectively, therefore **TEL-TEL* and **ATEL-ATEL* conversions must be blocked as well.

The resulting strictly local grammar for the derivational representation of the morphological strings is $G_{m2} = \{*\text{stem-ATEL}, *\text{TEL-TEL}, *\text{ATEL-ATEL}\}$. This grammar is significantly more succinct in comparison to the previously discussed G_{m1} : all illicit sequences in this grammar are of the length 2, whereas the locality window for G_{m1} was 4. Moreover, instead of just listing the memorized ill-formed sequences, this grammar explicitly reflects the intuitive generalization behind the telicity conversion: do not attach (a)telic affixes to stems of the same telicity.

5 Russian atelic nominalization

In the previous section, we outlined a pattern of telicity conversion in Russian: telic stems can be converted to atelic, atelic stems can be converted to telic, and this is done by dint of adding telic or atelic affixes. In this section, we will complicate

the picture by discussing how the telicity pattern interacts with the nominalization marker *-nie* (see Tatevosov & Pazelskaya (2003)) and Pazelskaya (2012) for a detailed discussion). This affix cannot be attached to the bare verbal stem (11). It also cannot be added to telic verbs — for example, see (12) with the telic prefix *ot-*.²

(11) *kry-nie
cover-NMN

(12) *ot-kry-nie
TEL-cover-NMN

It is possible to apply the nominalization *-nie* to the stem that was converted to atelic (13). In most, although not all cases, this nominalization goes along the forms of secondary imperfective (Tatevosov 2011).

(13) ot-kry-va-nie
TEL-cover-ATEL-NMN
'the process of opening'

However, the mere presence of an atelic suffix is not enough to license *-nie* affixation: if the stem is converted to telic again by using one more telic prefix (e.g. *na-*), adding the *-nie* nominalization becomes impossible (14).

(14) *na-ot-kry-va-nie
TEL-TEL-cover-ATEL-NMN

Figure 6 schematically illustrates this pattern. As before, solid arrows indicate possible transitions, whereas dotted arrows stand for improper applications.

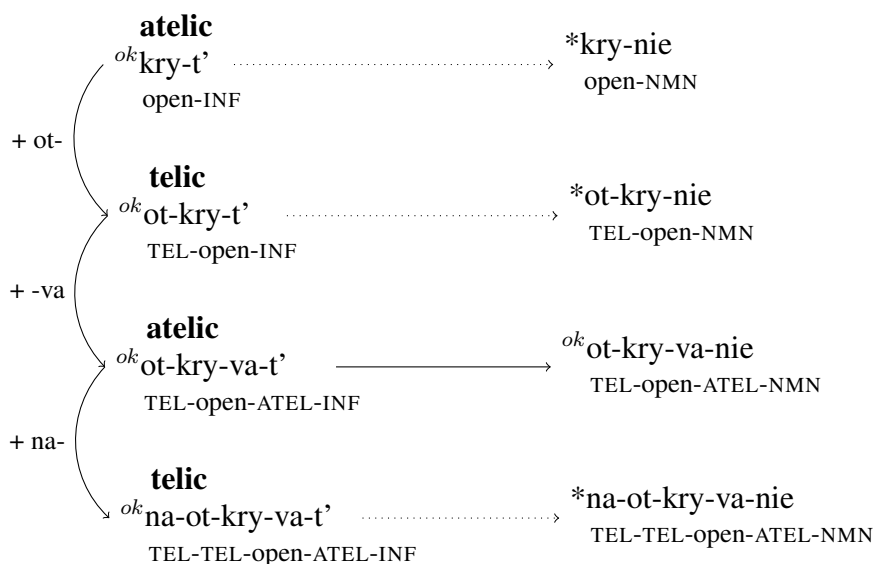


Figure 6: Russian *-nie* nominalization

²The nominalization marker that attaches to (most of) telic stems is *-tie* (Tatevosov & Pazelskaya 2003).

5.1 A Computational Analysis over derived strings

From the discussion above it should be clear that the application of the nominalization suffix *-nie* is allowed only for converted atelic stems. A summary of all banned configurations is given in (15).

- (15) a. **stem-NMN*
 b. **TEL-stem-NMN*
 c. **TEL-TEL-stem-ATEL-NMN*

The pattern in (15a) is impossible because *-nie* cannot be added directly to the stem, and (15b) and (15c) are out, because the stem is telic. In order to rule out the examples in (15a) and (15b), one can simply block strings that have the nominalization marker immediately following a stem: **stem-NMN*. This grammar would not help to rule out (15c), since it does not contain such substring. We could try to block the longer substring *stem-ATEL-NMN*, or even *TEL-stem-ATEL-NMN*. However, this would lead to under-generation, since both of them are part of the well-formed string in (13). The only solution is to increase the locality window of the grammar to 5, thus explicitly disallowing the full string in (15c): **TEL-TEL-stem-ATEL-NMN*.

The following strictly local grammar then captures the nominalization pattern depicted above: $G_{n_1} = \{*\text{stem-NMN}, *\text{TEL-TEL-stem-ATEL-NMN}\}$. As in the case of G_{m_1} for the derived representation of the telicity metamorphosis, G_{n_1} is simply a record of full strings that are disallowed by the grammar, and doesn't highlight any general property of the pattern.

5.2 A Computational Analysis over derivational strings

Let us now derive a strictly local grammar to capture the nominalization pattern from a derivational perspective. Under this approach, strings in (15) become the ones in (16).

- (16) a. **stem-NMN*
 b. **stem-TEL-NMN*
 c. **stem-TEL-ATEL-TEL-NMN*

Figure 7 is a schematic summary of possible and impossible applications for the nominalization affix.

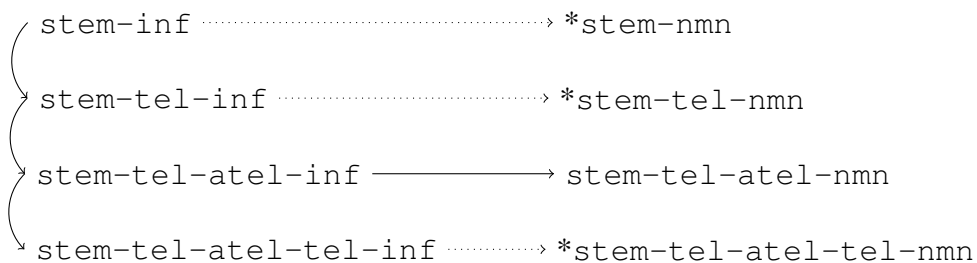


Figure 7: Russian *-nie* nominalization: derivational representations

As for the telicity conversion pattern, working over derivational representations leads to a computationally simpler grammar: **stem-NMN* shows that it is impossible to apply *-nie* directly to the stem, and banning **TEL-NMN* results in prohibiting the addition of suffix *-nie* to telic verbs. As a result, the grammar $G_{n2} = \{*\text{stem-NMN}, *\text{TEL-NMN}\}$ only requires a locality window of 2 — just as the grammar G_{m2} for the derivational representation of the telicity changes. Again, instead of memorizing the illicit string entirely, this grammar explicitly captures the linguistic intuition.

6 Conclusion

In this paper, we discussed two approaches to morphological representations. For the *derived* approach, the only relevant morphological strings are the surface forms. Instead, the *derivational* approach looks at the derivational history of the string and refers to representations that directly encode the order in which each of the affixes was applied to the initial stem.

We argued in favor of a derivational analysis of morphological operations, using Russian telicity and nominalization patterns in order to show how allowing our grammars to judge the wellformedness of morphological strings over derivations significantly reduces the computational power needed to capture apparently complex dependencies. Under both approaches these patterns can be captured by the subregular class of strictly local languages, but the size of their locality domain differs significantly: whereas the locality that is needed for the analysis under the derivational representation is 2, the one for the derived approach is 5.

Although the difference between 2 and 5 might not look impressive from an abstract point of view, these computational distinctions are particularly relevant if we look at subregular classes as highlighting cognitive requirements of the language faculty. In this perspective, the locality domain of a grammar corresponds to the amount of memory required to verify the wellformedness of a string (Rogers & Pullum 2011; Jäger & Rogers 2012). Moreover, it is once again interesting to observe how the grammars derived from the derivational strings naturally highlight the linguistic generalizations behind the patterns.

The results in this paper draw interesting parallels with many other works showing the subregular nature of phenomena in different domains of human language. For example, apart from the already cited works on phonology and phonotactics, Chandee (2014) claims that morphological mappings can be analyzed as subregular functions, and Aksënova *et al.* (2016) argue that morphotactics does not require more power than phonology. Recent work even suggests that subregularity might be a property of syntactic dependencies, if the representation is moved from strings to trees (Graf & Heinz 2015). Indeed, formal languages allow for cross-domain complexity generalizations, whereas it does not seem possible within purely linguistic-theoretical paradigms.

Finally, we would like to stress how our current results should not be taken as to completely discard the relevance of derived sequences for studies of morphological complexity — see for example Aksënova *et al.* (2016) for a discussion of the relation between complexity of surface forms and typological gaps in phonotactics. However, we believe that the significant computational advantage given by working over an encoding of the sequence of morphological operations should not be

ignored. Our results then open the path for future work on derivational representations in linguistic theory, and on the different roles of derivations and surface forms in particular.

Acknowledgments

We are grateful to Thomas Graf, Jeff Heinz, three anonymous reviewers, and the participants to the 53rd Meeting of the Chicago Linguistics Society for useful comments and suggestions. All mistakes, of course, are our own.

References

- Aksënova, A., T. Graf, & S. Moradi. 2016. Morphotactics as tier-based strictly local dependencies. In *Proceedings of the 14th SIGMORPHON Workshop on Computational Research in Phonetics, Phonology, and Morphology*, 121–130.
- Beesley, K., & L. Karttunen. 2003. *Finite state morphology*. Stanford, CA: CSLI Publications.
- Chandlee, J. *Strictly Local Phonological Processes*. University of Delaware dissertation.
- Chomsky, N. 1956. Three models for the description of language. *IRE Transactions on Information Theory* 2.113–124.
- Graf, T. 2017. The power of locality domains in phonology. *Phonology* 34.1–21.
- Graf, T., & J. Heinz. 2015. Commonality in disparity: The computational view of syntax and phonology. Slides of a talk given at GLOW 2015, April 18, Paris, France.
- Heinz, J. 2011a. Computational phonology part II: Grammars, learning, and the future. *Language and Linguistics Compass* 5.153–168.
- Heinz, J. 2011b. Computational phonology – part 1: Foundations. *Language and Linguistics Compass* 5.140–152.
- Heinz, J., C. Rawal, & H. Tanner. 2011. Tier-based strictly local constraints for phonology. In *Proceedings of the 49th Annual Meeting of the Association for Computational Linguistics*, 58–64, Portland, USA. Association for Computational Linguistics.
- Jäger, G., & J. Rogers. 2012. Formal language theory: Refining the chomsky hierarchy. *Philosophical Transactions of the Royal Society B: Biological Sciences* 367.1956–1970.
- Kaplan, R., & M. Kay. 1994. Regular models of phonological rule systems. *Computational Linguistics* 20.331–378.
- Laleko, O. 2008. Compositional telicity and heritage russian aspect. In *The Proceedings of the 38th Western Conference On Linguistics*, 150–160, California, Davis. UC Davis.
- McGregor, W. 2003. A fundamental misconception of modern linguistics. *Acta Linguistica Hafniensia* 35.39–64.
- McMullin, K. *Tier-based locality in long-distance phonotactics: learnability and typology*. University of British Columbia dissertation.
- McNaughton, R., & S. Papert. 1971. *Counter-Free Automata*. Cambridge: MIT Press.
- Pazelskaya, A. 2012. Verbal prefixes and suffixes in nominalization: grammatical restrictions and corpus data. In *The Russian Verb*, 245–261. Atle Grønn and Anna Pazelskaya.
- Rogers, J., J. Heinz, G. Bailey, M. Edlefsen, M. Visscher, D. Wellcome, & S. Wibel. 2010. On languages piecewise testable in the strict sense. In *The Mathematics of Language. Lecture Notes in Computer Science*, ed. by E. C., J. G., & M. J., volume 6149, 255–265. Berlin, Heidelberg: Springer.
- Rogers, J., & G. Pullum. 2011. Aural pattern recognition experiments and the subregular hierarchy. *Journal of Logic, Language and Information* 20.329–342.
- Tatevosov, S. 2011. Severing perfectivity from the verb. *Scando-Slavica* 57.216–244.

- Tatevosov, S., & A. Pazelskaya. 2003. Nominalization in russian: eventuality types and aspectual properties. In *Proceedings of the 14th Amsterdam Colloquium*, ed. by P. R. van Rooij Dekker, 169–174. Amsterdam: Amsterdam University.
- Vikner, C., & S. Vikner. 2003. Hierarchical morphological structure and ambiguity. In *L'énonciation dans tous ses états: Mélanges offerts à Henning Nølke*, ed. by M. Birkelund, M.-B. M. Hansen, & C. Norén, 541–560. Peter Lang.