Strictly Local Patterns are not Closed Under Optimization

Nate Koser
Rutgers University
NECPhon
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Introduction

- In Optimality Theory (Prince & Smolensky 1993), optimization over strictly local (McNaughton & Papert 1971) constraints can generate fully regular patterns
- Take SL to be the *Constraint Definition Language* (Eisner 1997b; Potts & Pullum 2002; de Lacy 2011) (CDL) for markedness constraints
- SL constraints bans on contiguous substructure: PARSE – $\neg\breve{\sigma}$

Introduction

- Set of markedness-only stress constraints produces novel "sour grapes"-like stress pattern, importantly not SL
- Tells us that establishing a CDL is no guarantee of a typology with matching complexity

Roadmap

- Introduce the constraint set
- Explore the sour grapes pattern in detail
- Prove that the pattern is properly regular
- Discuss implications and future work

Questions

- When formally evaluating OT, some questions we can ask:
  - What is the complexity level of the CON constraints? (Eisner 1997c; Potts & Pullum 2002; Jardine & Heinz 2016)
  - What is the nature of the functions that can be described by OT grammars? (Eisner 1997a; Frank & Satta 1998; Riggle 2004; Buccola 2013); and:
  - Examine the outputs of these functions as *phonotactic* patterns: as formal languages.

Gen

- Consider strings of syllables – unstressed σ, stressed $\acute{\sigma}$, unparsed $\breve{\sigma}$, and foot boundaries right), and left (
- $(\acute{\sigma}\sigma)\breve{\sigma}\breve{\sigma}\breve{\sigma}$ or $(\acute{\sigma}\sigma)(\acute{\sigma}\sigma)(\acute{\sigma}\sigma)$
- No superbinary feet (this requirement is SL)
- Allow stressless strings; obligatoriness (requiring at least one stress) Locally Testable; Rogers et al. (2013)

Constraints

- SL class definable with *conjunctions of negative literals* (CNLs), where literals are substructure: $\neg\ s_1 \wedge \neg\ s_2 \wedge \ldots\ s_n$
- Statements forbidding contiguous substructures, no requirement of structure
- Relevant to markedness constraints in OT, overwhelmingly negative i.e. ban certain structures
- Example: TROCH, bans iambs and unary feet $\neg\ (\sigma\acute{\sigma}) \wedge \neg(\acute{\sigma})$

Constraints

- Strong prediction that markedness constraints are local only
- Banishes more complex constraints from Con
- Align-type constraints (McCarthy & Prince 1993); more powerful, produce pathological patterns (Eisner 1997b; Hyde 2012)

Constraints

- Defined with CNL logic
- Count number of violations – number of ill-formed structures
- TROCH: $\neg\ (\sigma\acute{\sigma}) \wedge \neg\ (\acute{\sigma})$
  - Violated by strings $\breve{\sigma}(\sigma\acute{\sigma})$ and $(\acute{\sigma})(\sigma\acute{\sigma})$
  - Unviolated by strings $\breve{\sigma}\breve{\sigma}(\acute{\sigma}\sigma)$ and $(\acute{\sigma}\sigma)(\acute{\sigma}\sigma)$
- Defined over alphabet $\Sigma = \{(,), \sigma, \acute{\sigma}, \breve{\sigma}\}$

Constraints

Constraint set:

IAMB violated by trochees and unary feet; $\neg\ (\acute{\sigma}\sigma) \wedge \neg\ (\acute{\sigma})$
TROCHEE violated by iambs and unary feet; $\neg\ (\sigma\acute{\sigma}) \wedge \neg\ (\acute{\sigma})$
PARSE violated by an unparsed syllable; $\neg\ \breve{\sigma}$
$^*\breve{\sigma}F$; $\neg\breve{\sigma}(\sigma \wedge \neg\breve{\sigma}(\acute{\sigma}$
$^*F\breve{\sigma}$; $\neg\sigma)\breve{\sigma} \wedge \neg\acute{\sigma})\breve{\sigma}$

Constraints

- $^*\breve{\sigma}F$ and $^*F\breve{\sigma}$
  $\neg\breve{\sigma}(\sigma \wedge \neg\breve{\sigma}(\acute{\sigma}$ and $\neg\sigma)\breve{\sigma} \wedge \neg\acute{\sigma})\breve{\sigma}$

$^*\breve{\sigma}F$		$^*F\breve{\sigma}$	
$(\acute{\sigma}\sigma)\breve{\sigma}(\acute{\sigma}\sigma)$	$(\acute{\sigma}\sigma)(\acute{\sigma}\sigma)$	$(\acute{\sigma}\sigma)\breve{\sigma}(\acute{\sigma}\sigma)$	$\breve{\sigma}(\acute{\sigma}\sigma)$
$\breve{\sigma}(\acute{\sigma}\sigma)\breve{\sigma}(\acute{\sigma}\sigma)$	$(\acute{\sigma}\sigma)(\acute{\sigma}\sigma)\breve{\sigma}$	$(\acute{\sigma}\sigma)\breve{\sigma}$	$(\acute{\sigma}\sigma)(\acute{\sigma}\sigma)$

- Motivate placement of feet
- Similar to *$Ft/\_\sigma$* and *$Ft/\sigma\_$* discussed in McCarthy (2003); defined as CNLs

Constraints

- Troch and Iamb
  $\neg\ (\sigma\acute{\sigma}) \wedge \neg\ (\acute{\sigma})$ and $\neg\ (\acute{\sigma}\sigma) \wedge \neg\ (\acute{\sigma})$

Troch		Iamb	
$(\acute{\sigma}\sigma)(\sigma\acute{\sigma})$	$(\acute{\sigma}\sigma)(\acute{\sigma}\sigma)$	$(\acute{\sigma}\sigma)(\sigma\acute{\sigma})$	$\breve{\sigma}(\sigma\acute{\sigma})$
$(\sigma\acute{\sigma})(\acute{\sigma})$	$(\acute{\sigma}\sigma)$	$(\acute{\sigma}\sigma)(\acute{\sigma})$	$(\sigma\acute{\sigma})(\sigma\acute{\sigma})$

Constraints

- PARSE: constraint against unparsed syllables
  $\neg\ \breve{\sigma}$

PARSE	
$(\acute{\sigma}\sigma)\breve{\sigma}$	$(\acute{\sigma}\sigma)$
$(\acute{\sigma}\sigma)\breve{\sigma}\breve{\sigma}$	$(\acute{\sigma}\sigma)(\acute{\sigma}\sigma)$
$(\acute{\sigma}\sigma)\breve{\sigma}\breve{\sigma}\breve{\sigma}$	$(\acute{\sigma}\sigma)(\acute{\sigma}\sigma)(\acute{\sigma})$

Constraints

- All constraints from the literature with an explicit CNL definition
- Application of constraints consistent with use in literature

Typology

- Analysis in OTWorkplace (Prince et al. 2007-2017) reveals typology of 9 languages: 2 sour grapes languages, 1 stress-less language, 2 ambiguous languages (more than one optimal output), 4 near-misses of attested patterns (iterating binary feet)

Sour Grapes Stress

- Sour grapes phenomena in harmony, spreading, and tone (Padgett 1995; Wilson 2003, 2006; McCarthy 2010; Jardine 2016)
- If some feature cannot spread completely, candidate with no spreading wins instead
- Canonically involves markedness-faithfulness interaction (AGREE vs. IDENTIO(F))
- Here there are only CNL markedness constraints

Sour Grapes Stress

$\breve{\sigma}$

$(\acute{\sigma}\sigma)$

$\breve{\sigma}\breve{\sigma}\breve{\sigma}$

$(\acute{\sigma}\sigma)(\acute{\sigma}\sigma)$

$\breve{\sigma}\breve{\sigma}\breve{\sigma}\breve{\sigma}\breve{\sigma}$

$(\acute{\sigma}\sigma)(\acute{\sigma}\sigma)(\acute{\sigma}\sigma)$

$\breve{\sigma}\breve{\sigma}\breve{\sigma}\breve{\sigma}\breve{\sigma}\breve{\sigma}\breve{\sigma}$

…

- Want to build binary feet to the end; if this can't be done, build no feet instead. No "spread" of feet in odd-syllable forms

- Pathological – no such extreme sensitivity to word length in natural language stress patterns

Sour Grapes Stress

$\breve{\sigma}$
$(\acute{\sigma}\sigma)$
$\breve{\sigma}\breve{\sigma}\breve{\sigma}$
$(\acute{\sigma}\sigma)(\acute{\sigma}\sigma)$
$\breve{\sigma}\breve{\sigma}\breve{\sigma}\breve{\sigma}\breve{\sigma}$
$(\acute{\sigma}\sigma)(\acute{\sigma}\sigma)(\acute{\sigma}\sigma)$
$\breve{\sigma}\breve{\sigma}\breve{\sigma}\breve{\sigma}\breve{\sigma}\breve{\sigma}\breve{\sigma}$
...

input	winner	loser	$*\sigma F$	$*F\sigma$	TROCH	PARSE	IAMB
3syll	$\breve{\sigma}\breve{\sigma}\breve{\sigma}$	$\breve{\sigma}(\acute{\sigma}\sigma)$	W			L	W
3syll	$\breve{\sigma}\breve{\sigma}\breve{\sigma}$	$(\sigma\acute{\sigma})\breve{\sigma}$		W		L	W
1syll	$\breve{\sigma}$	$(\acute{\sigma})$			W	L	W
2syll	$(\acute{\sigma}\sigma)$	$\breve{\sigma}\breve{\sigma}$				W	L

Sour Grapes Stress

$\breve{\sigma}$
$(\acute{\sigma}\sigma)$
$\breve{\sigma}\breve{\sigma}\breve{\sigma}$
$(\acute{\sigma}\sigma)(\acute{\sigma}\sigma)$
$\breve{\sigma}\breve{\sigma}\breve{\sigma}\breve{\sigma}\breve{\sigma}$
$(\acute{\sigma}\sigma)(\acute{\sigma}\sigma)(\acute{\sigma}\sigma)$
$\breve{\sigma}\breve{\sigma}\breve{\sigma}\breve{\sigma}\breve{\sigma}\breve{\sigma}\breve{\sigma}$
...

input	winner	loser	$*\sigma F$	$*F\sigma$	TROCH	PARSE	IAMB
3syll	$\breve{\sigma}\breve{\sigma}\breve{\sigma}$	$\breve{\sigma}(\acute{\sigma}\sigma)$	W			L	W
3syll	$\breve{\sigma}\breve{\sigma}\breve{\sigma}$	$(\sigma\acute{\sigma})\breve{\sigma}$		W		L	W
1syll	$\breve{\sigma}$	$(\acute{\sigma})$			W	L	W
2syll	$(\acute{\sigma}\sigma)$	$\breve{\sigma}\breve{\sigma}$				W	L

- In odd-syllable forms, cannot satisfy $*\breve{\sigma}F$ or $*F\breve{\sigma}$ with binary feet
- Any unary feet violate TROCH
- In even syllable forms, full satisfaction of PARSE – anything less incurs violations of higher ranked constraints

Sour Grapes Stress

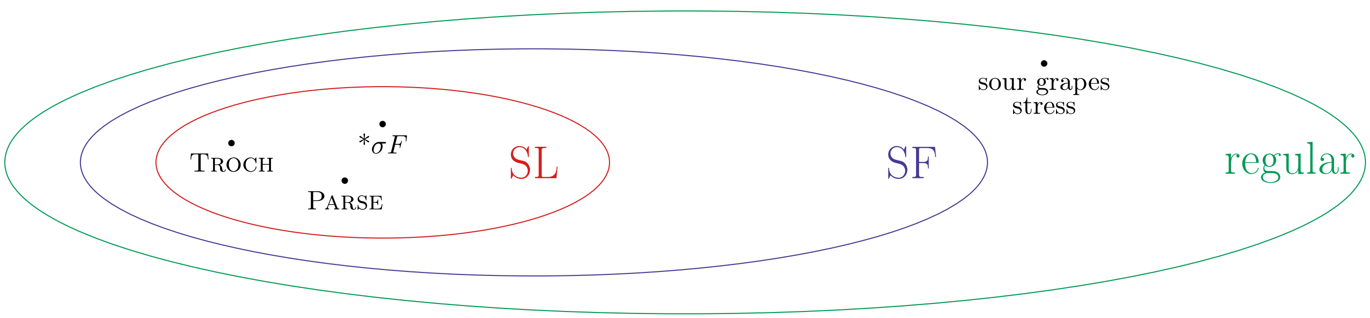
- Sour grapes-like stress pattern from markedness constraints only
- Generated by SL constraints, pattern is properly regular
- SL patterns are not closed under optimization

Star Free?

- Sour grapes pattern discussed here is regular (see Appendix); can also show is not Star Free (McNaughton & Papert 1971, (SF))

- Natural language stress patterns overwhelmingly SF (Heinz 2009; Rogers et al. 2013)

- SF higher-level complexity class than SL, supports claim of lack of closure under optimization



Not Star Free

- Alphabet change: $\Sigma = \{(,), \sigma\}$
- Before distinguished between stressed, unstressed, unparsed syllables – important in generating specific pattern, not necessary for studying its general properties

Not Star Free

- Sour grapes-like language as a stringset:
  $L = \{\sigma$
  $(\sigma\sigma)$
  $\sigma\sigma\sigma$
  $(\sigma\sigma)(\sigma\sigma)$
  $\sigma\sigma\sigma\sigma\sigma$
  $(\sigma\sigma)(\sigma\sigma)(\sigma\sigma)$
  $\sigma\sigma\sigma\sigma\sigma\sigma\sigma...\}$

- This L is not star free

Not Star Free

Theorem 1(McNaughton & Papert 1971) A language L is Star-Free iff it is non-counting, that is, iff there exists some n > 0 such that for all strings u,v,w over Σ, if uv^nw occurs in L then $uv^{n+i}w$, for all i ≥ 1, occurs in L as well.

- $\exists n\ \forall i$ such that $uv^nw \in L \rightarrow uv^{n+i}w \in L$
- Find two classes of counter-examples – one for odd n and one for even n and show that any even or odd number n (any integer) will fail the requirements of the theorem
- Prove that the sour grapes pattern is fully regular
- No string $\sigma\sigma\sigma^n$ for even n, can use as target for $uv^{n+i}w$

Not Star Free

Odd n, $i = 1$, $v = \sigma$

$$
\begin{array}{ccccc}
 & uv^n w \in L & \rightarrow & uv^{n+i} w \in L \\
n & & & \\
1 & \sigma\sigma\sigma\sigma\sigma & & \sigma\sigma\sigma\sigma\sigma\sigma \notin L \\
3 & \sigma\sigma\sigma\sigma\sigma\sigma\sigma & & \sigma\sigma\sigma\sigma\sigma\sigma\sigma\sigma \notin L \\
5 & \sigma\sigma\sigma\sigma\sigma\sigma\sigma\sigma\sigma & & \sigma\sigma\sigma\sigma\sigma\sigma\sigma\sigma\sigma\sigma \notin L \\
 & & \vdots &
\end{array}
$$

- Can construct same argument for even n (see Appendix)

Not Star Free

- It is not the case that for all $i \geq 1$, there is an odd n or even n such that if $uv^{\mathrm{n}}w$ is a string of L then $uv^{\mathrm{n+i}}w$ is a string of L for all $i \geq 1$
- Proves that Thm. 1 does not hold for the sour grapes-style pattern
- Proves that this pattern is not SF and so is properly regular

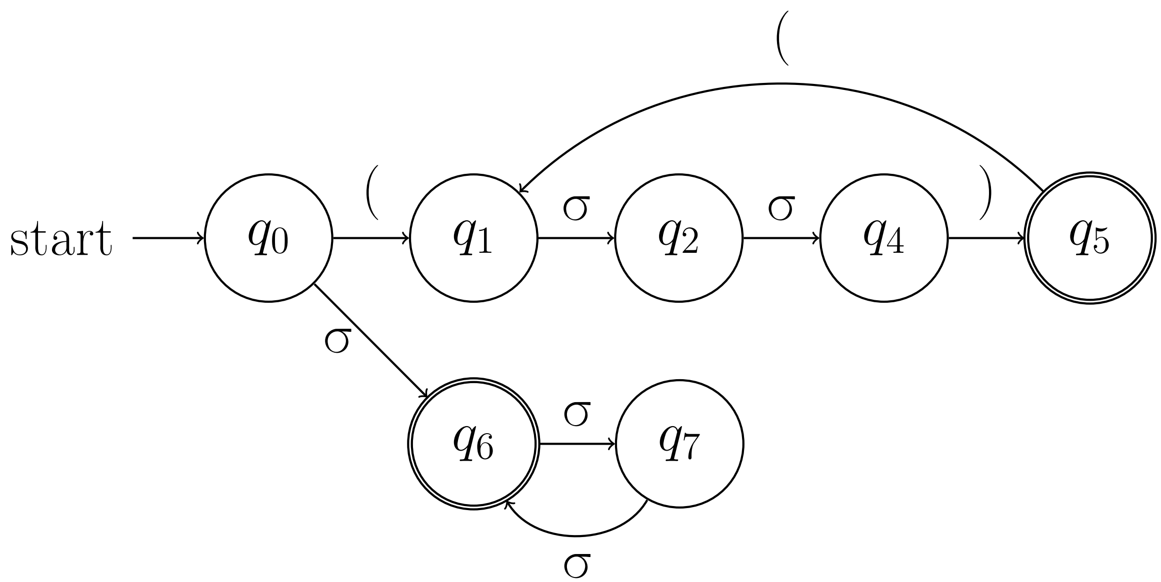
Discussion

- A system of SL constraints that produced a fully regular pattern
- Pattern was a novel sour grapes-type pattern in stress
- What happens with strictly piecewise constraints? Still CNL logic but adds precedence (non-local)
  - Align-type constraints? Is e.g. Align(F,R,Pwd,R,σ) writeable as SP constraint $\neg$)...σ...$]_\omega$ and does this produce things like the *Midpoint Pathology* (Eisner 1997b; Hyde 2012)
- What is the typology of CDLs with other levels of logic?

Thanks!

Thanks to all viewers and all involved in production, particularly Adam Jardine and Bruce Tesar.

Appendix: Regularity



- Top path – only accepting state after a binary foot has been read
- Bottom path – only accepting state after an odd number of syllables and no foot boundaries have been read

Appendix: Not Star Free, Even n

Even n, $i = 1$, $v = \sigma$

$$
\begin{array}{rcccc}
 & uv^{n}w \in L & \rightarrow & uv^{n+i}w \in L \\
n & & & \\
2 & \sigma\sigma\sigma\sigma\sigma & & \sigma\sigma\sigma\sigma\sigma\sigma \notin L \\
4 & \sigma\sigma\sigma\sigma\sigma\sigma\sigma & & \sigma\sigma\sigma\sigma\sigma\sigma\sigma\sigma \notin L \\
6 & \sigma\sigma\sigma\sigma\sigma\sigma\sigma\sigma\sigma & & \sigma\sigma\sigma\sigma\sigma\sigma\sigma\sigma\sigma\sigma \notin L \\
 & & \vdots &
\end{array}
$$

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