A Game of Tiers: Exploring the Formal Properties of TSL Languages

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Computational Phonology Workshop
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The Talk in a Nutshell

Subregular Hypothesis for Phonology

- Phonotactic patterns can be described by classes in the subregular hierarchy;
- Pin-pointing the right class will be useful for typology, learnability, cognitive predictions ...

Current Hypothesis

- Tier-based Strictly Local seems to be the right fit;
- But ... several problematic patterns have been reported!

Idea

We can explore (minimal) extensions to TSL

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Outline

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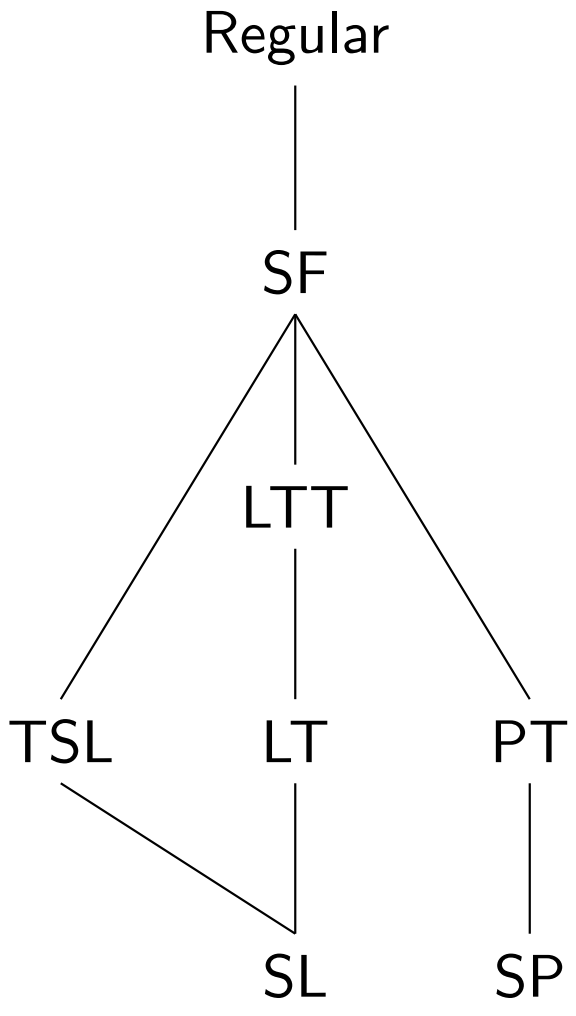

Subregular Hypothesis

- Phonology is **subregular**;
- Local phonotactic dependencies are Strictly Local.

SL: Example

Word-final devoicing: $^*[+voice]\ltimes$

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What about unbounded dependencies?

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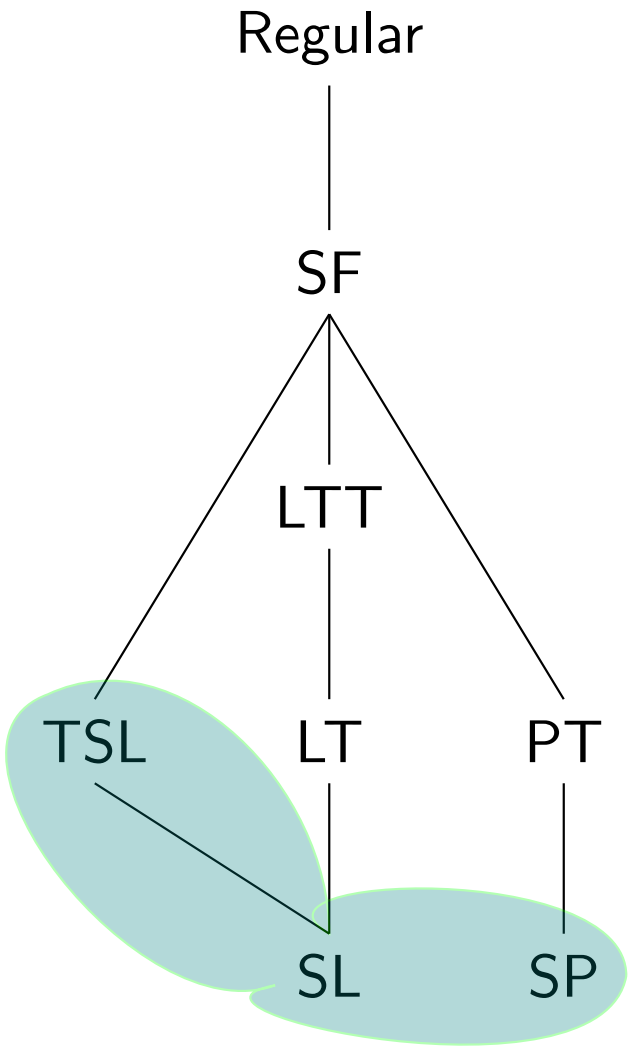

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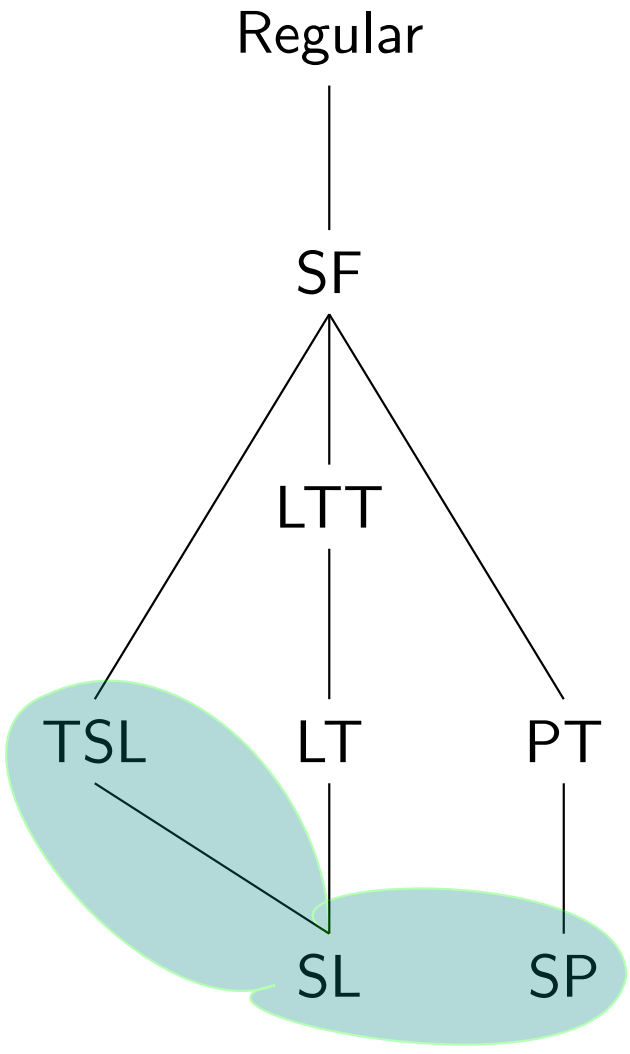

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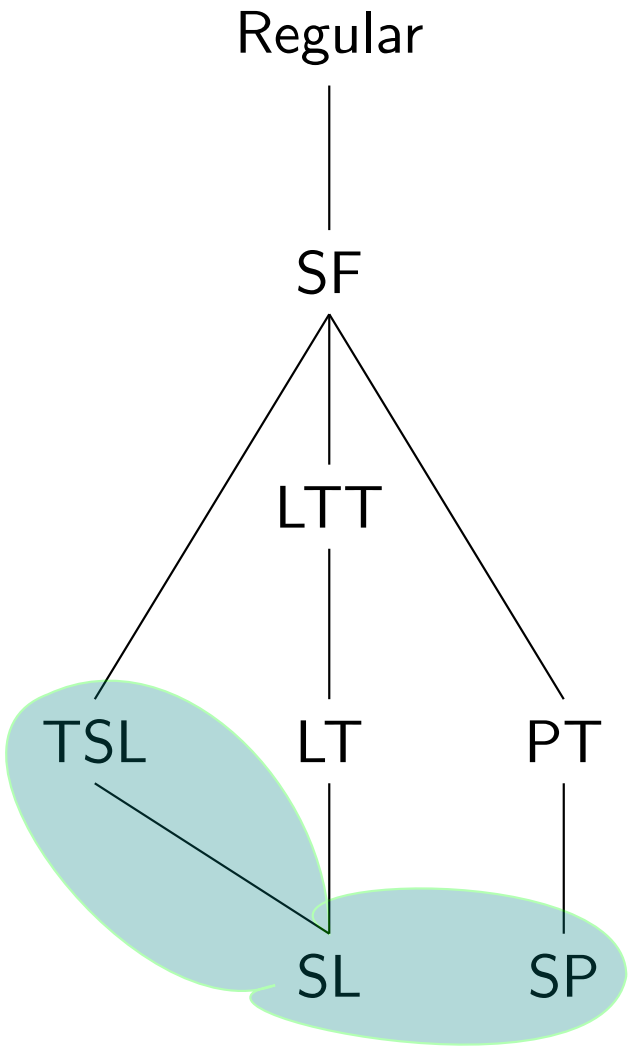

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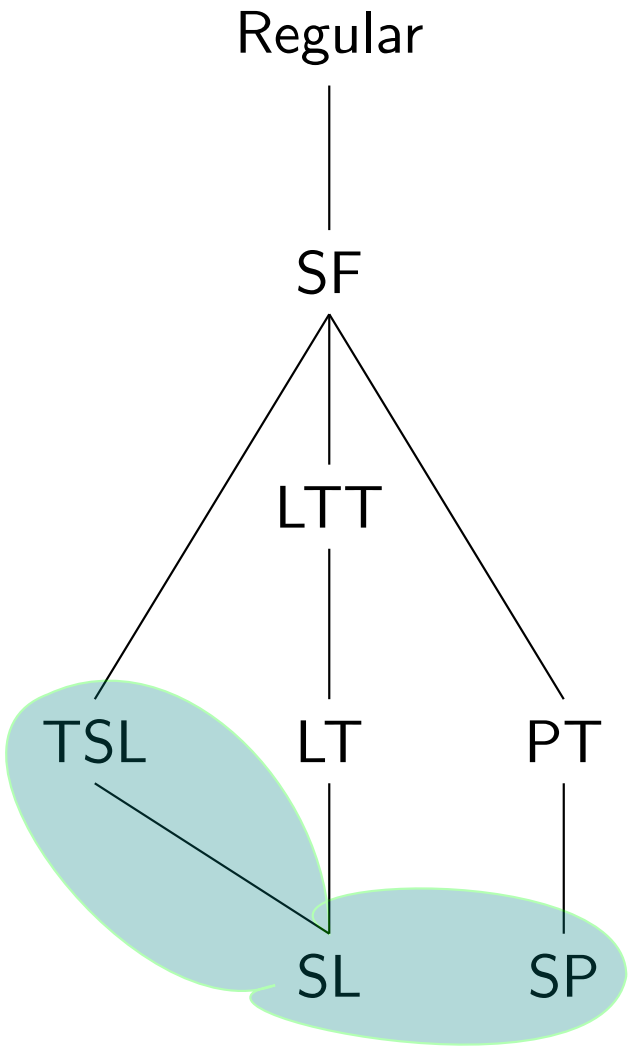

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Long Distance Dependencies as Tier-based Strictly Local

- Problem: Unbounded processes cannot be captured by Strictly Local Grammars
- Solution: Select a subset of segments and enforce constraints only over it.

Tier-based Strictly Local (TSL) Grammars

- a projection function $E : \Sigma \rightarrow T$ with $T \subseteq \Sigma$
  $\Rightarrow$ projection on a tier is determined just by the "shape" of the segment (no structural or "proximity" information);
- strictly local constraints over T;

TSL Example: Sibilant harmony in Aari

Grammar

$T = \{s, z, ʒ, ʃ\}$ $S = \{{}^{*}ʒs, {}^{*}sʒ, {}^{*}sʃ, {}^{*}ʃs\}$

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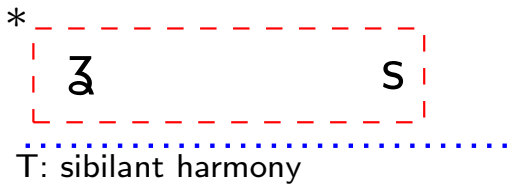

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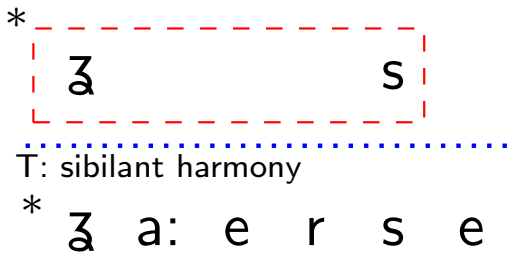

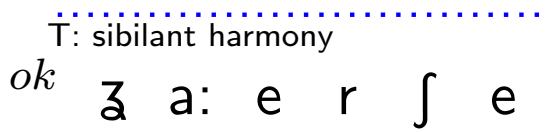

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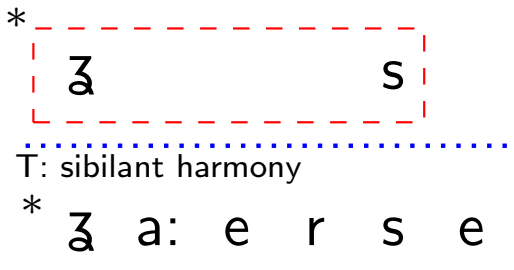

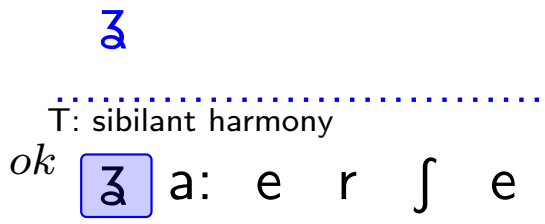

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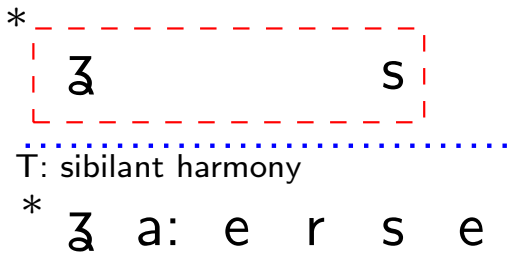

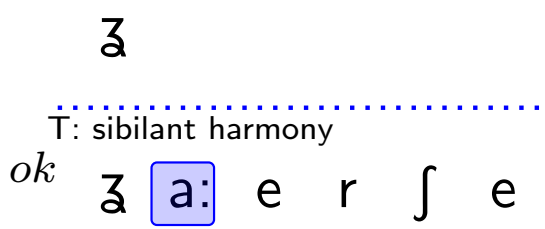

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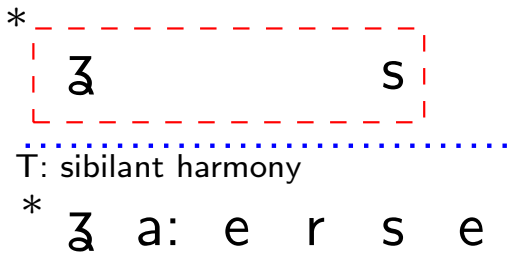

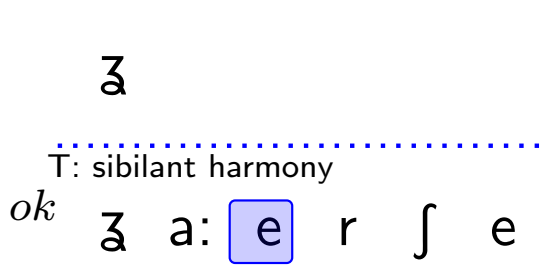

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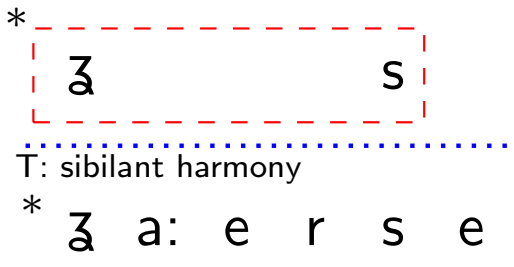

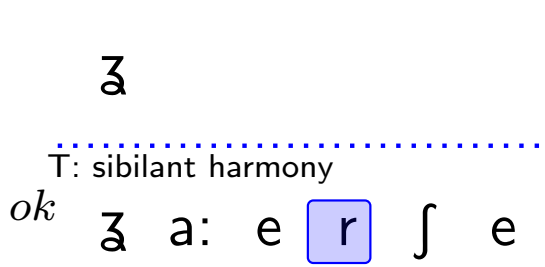

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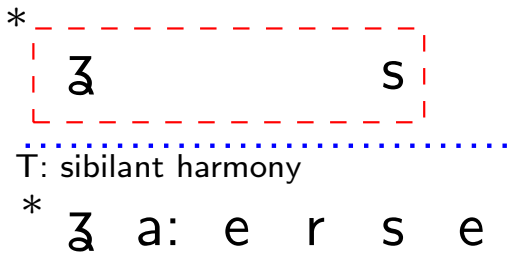

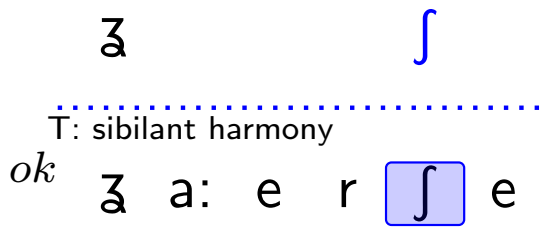

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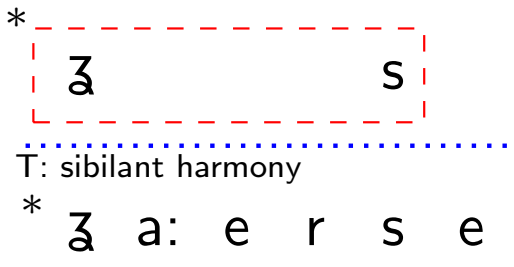

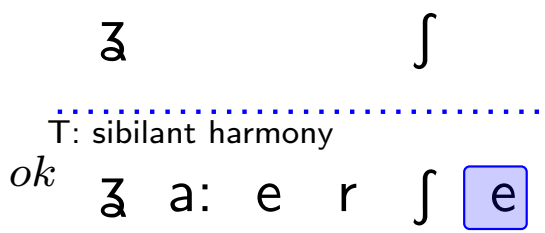

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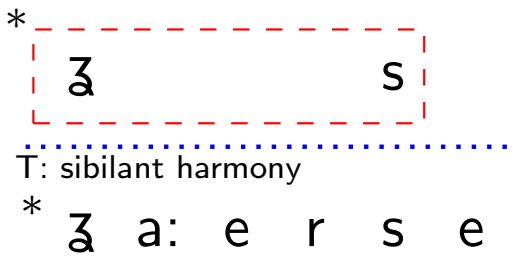

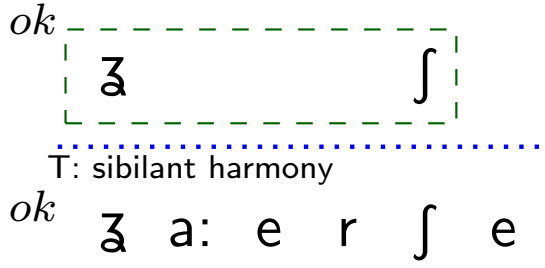

Problematic Patterns (1/2)

Sibilant Harmony in Imdlawn Tashlhiyt (McMullin2016)

1) Underlying causative prefix /s(ː)-/

	Base	*Causative*	
a.	uga	sː-uga	"be evacuated"
b.	asːtwa	s-asːtwa	"settle, be levelled"

2) Sibilant harmony

	Base	*Causative*	
a.	fiaʃr	ʃ- fiaʃr	"be full of straw, of discord"
b.	nza	zː-nza	"be sold"

3) Sibilant voicing harmony blocked

	Base	*Causative*	
a.	ukz	sː-ukz	"recognize"
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Can we write a TSL grammar to capture this pattern?

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Sibilants must agree in anteriority and voicing.

Grammar

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$S = \{$ *sʒ͡ʃ, *sz, *sʃ, *ʒ͡ʃs, *ʃs, *zs, *zʃ, *zʒ͡ʃ, *ʃz, *ʃʒ͡ʃ, *ʒ͡ʃʃ, *ʒ͡ʃz $\}$

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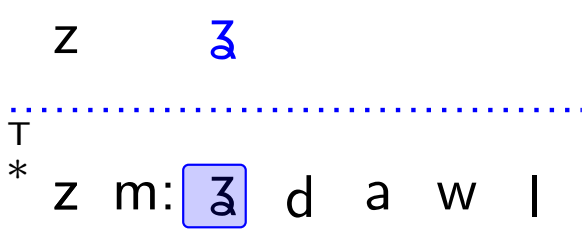

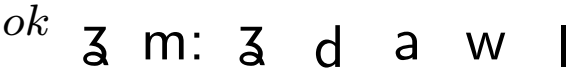

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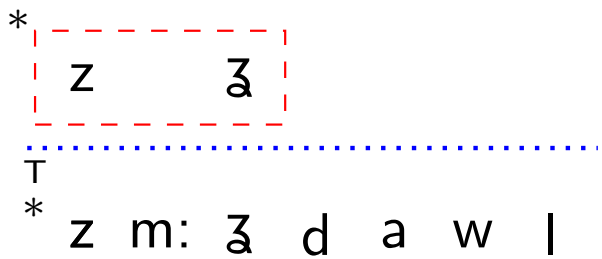

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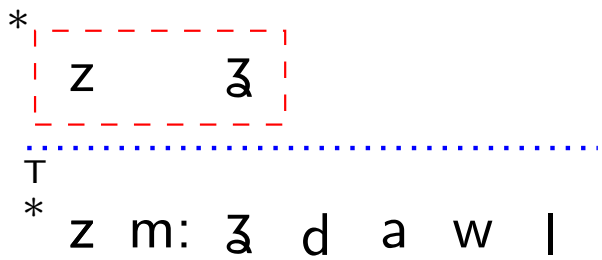

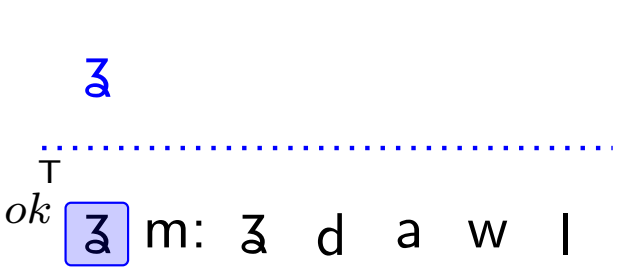

Sibilant Harmony in Imdlawn Tashlhiyt

Generalization (1/2)

Sibilants must agree in anteriority and voicing.

Grammar

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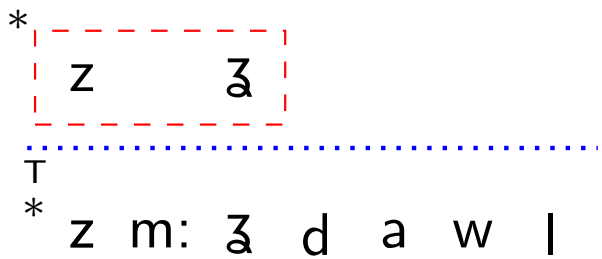

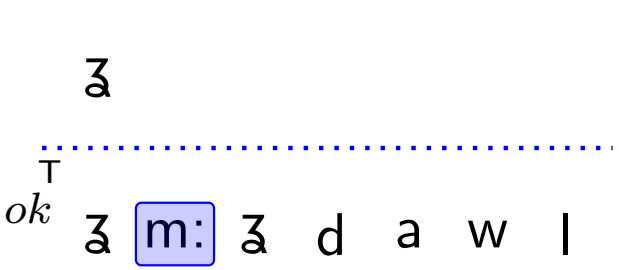

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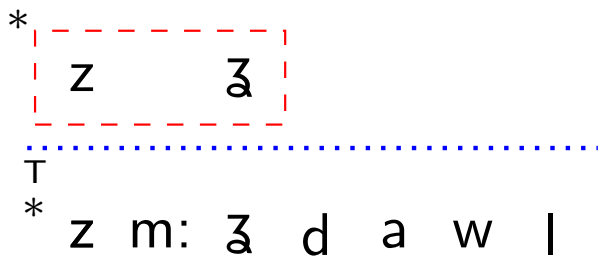

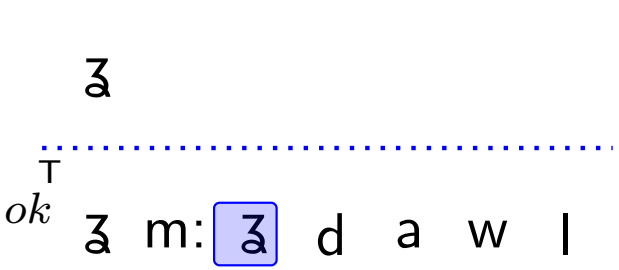

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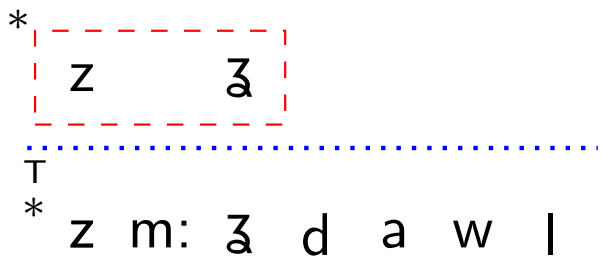

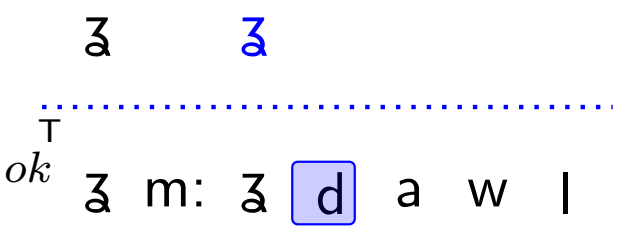

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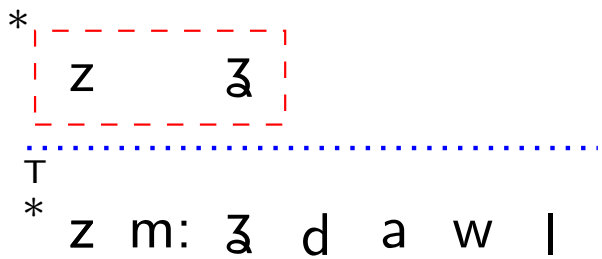

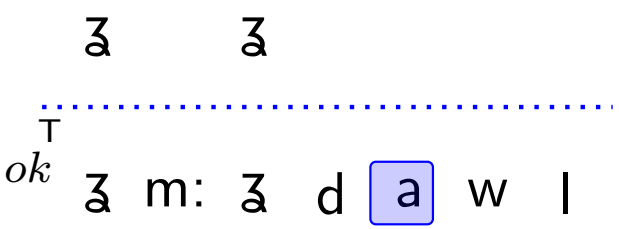

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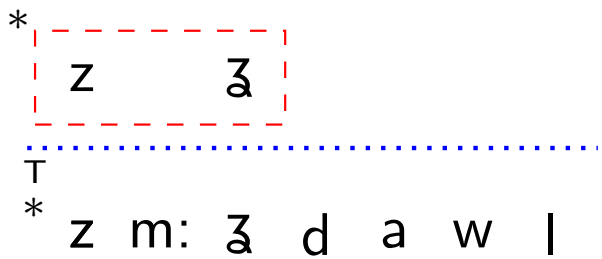

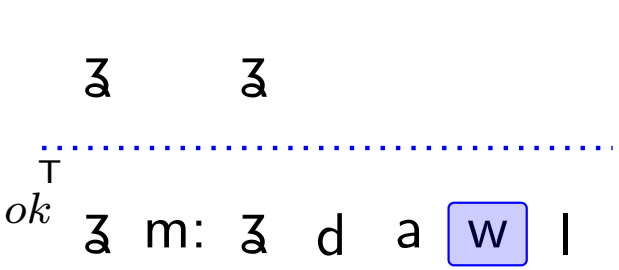

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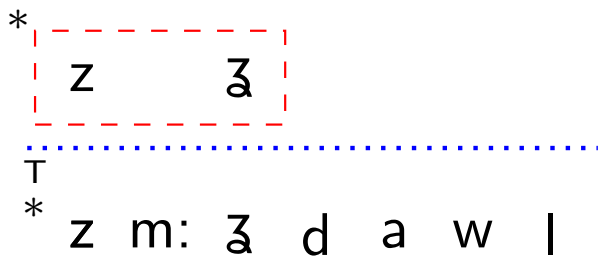

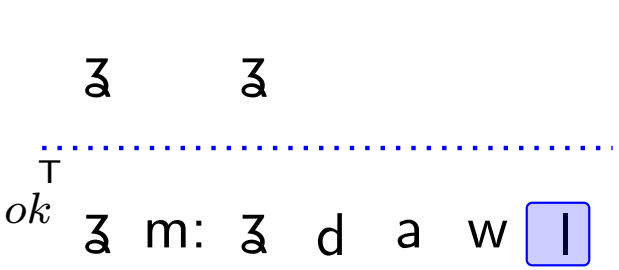

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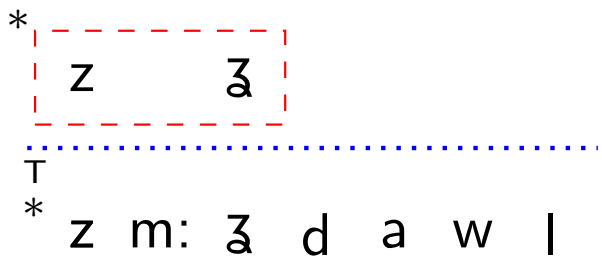

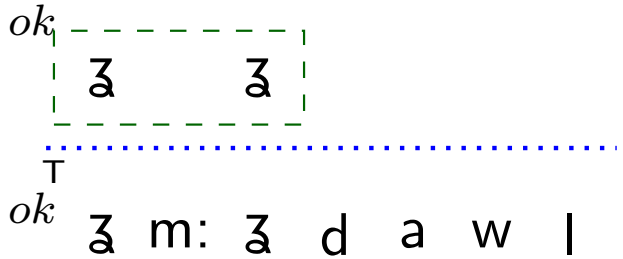

Sibilant Harmony in Imdlawn Tashlhiyt

Generalization (2/2)

Voiceless obstruents block agreement in voicing.

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^{ok} ʃ q u ʒː i

* s q u ʒː i

Sibilant Harmony in Imdlawn Tashlhiyt

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ʃ q

T

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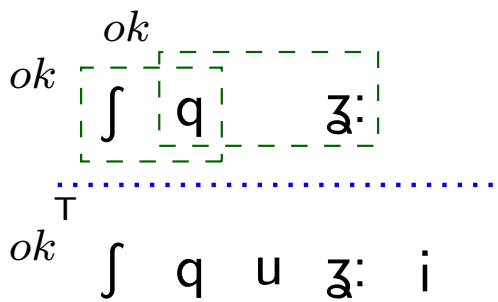

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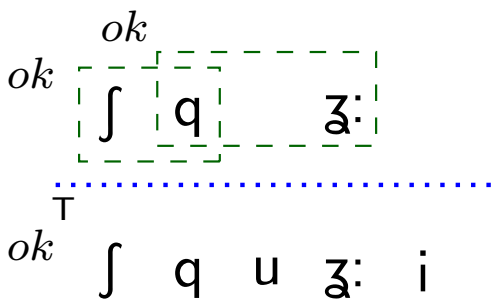

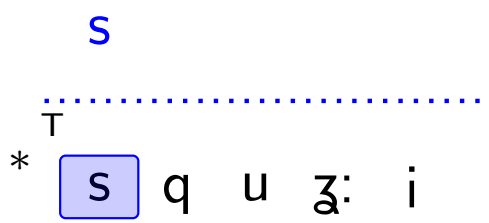

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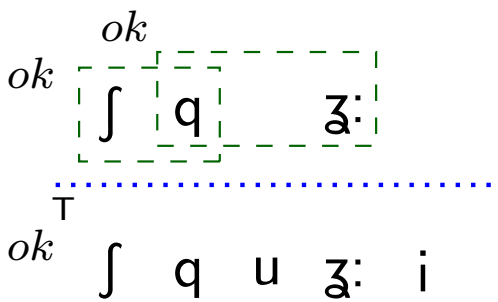

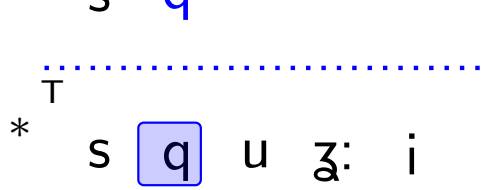

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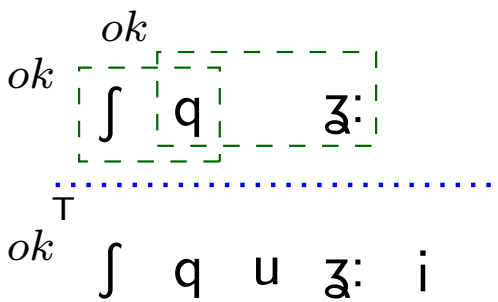

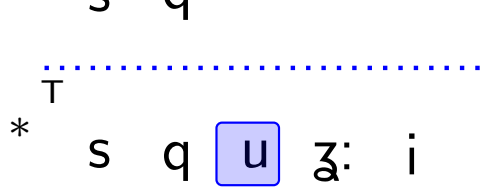

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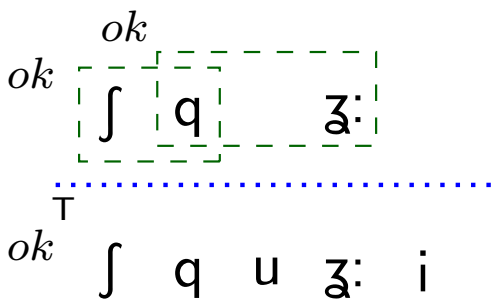

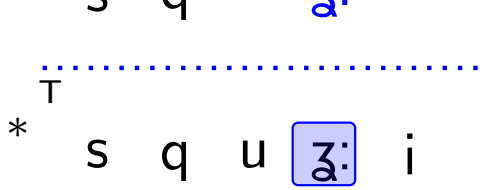

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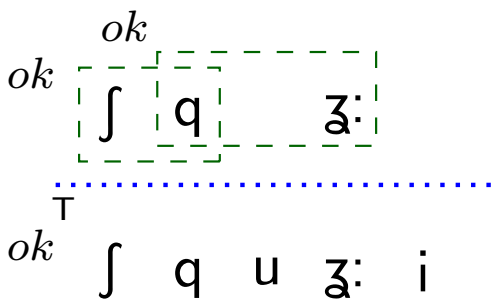

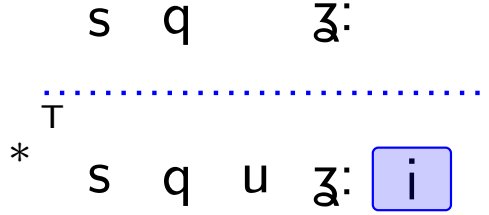

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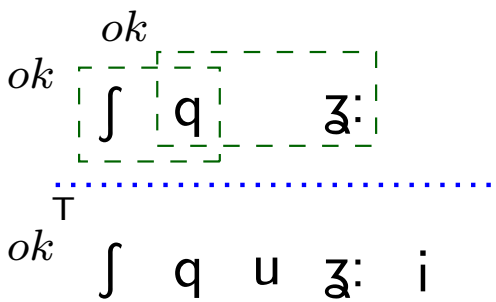

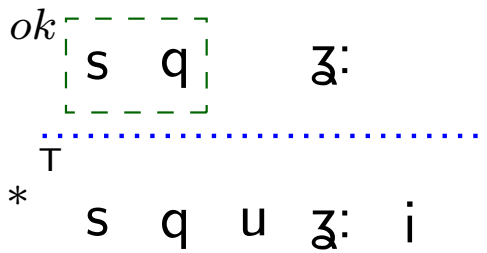

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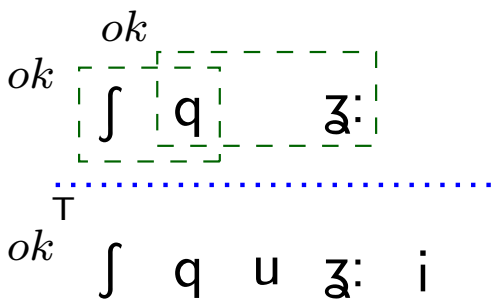

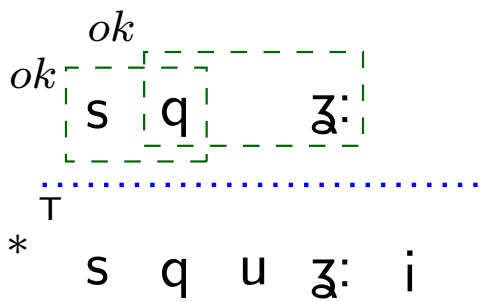

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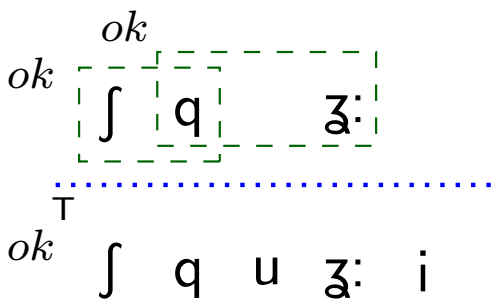

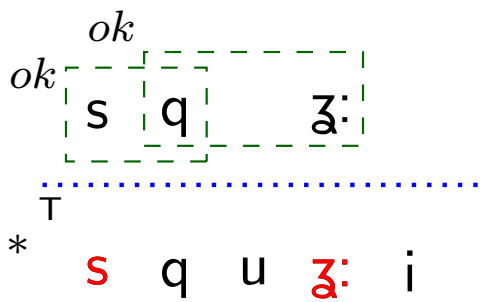

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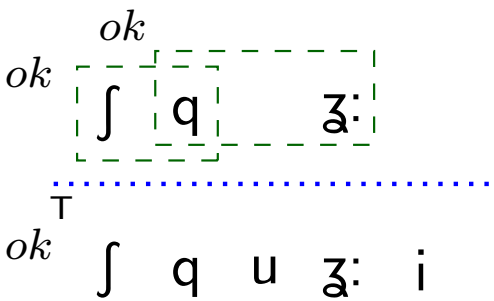

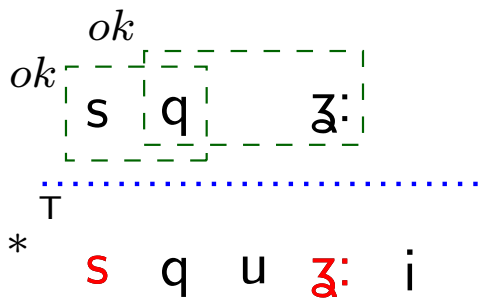

No TSL grammar can block voicing and enforce anteriority!

Problematic Patterns (2/2)

Sibilant Harmony in Samala (McMullin2016)

1) Unbounded sibilant harmony

a.	/k-su-ʃojin/	kʃuʃojin	"I darken it"
b.	/k-su-k'ili-mekeken-ʃ/	kʃuk'ilimekeketʃ	"I straighten up"

2) /s/→ [ʃ] when preceding (adjacent) [t, n, l]

a.	/s-lok'in/	ʃlok'in	he cuts it
b.	/s-tepu?/	ʃtepu?	"he gambles"

3) Long-distance agreement overrides local disagreement

a.	/s-iʃt-tiʃti-jep-us/	sististijepus	"they show him"
b.	/s-net-us/	snetus	"he does it to him"

Can we write a TSL grammar to capture this pattern?

Problematic Patterns (2/2)

Sibilant Harmony in Samala (McMullin2016)

1) Unbounded sibilant harmony

a.	/k-su-ʃojin/	kʃuʃojin	"I darken it"
b.	/k-su-k'ili-mekeken-ʃ/	kʃuk'ilimekeketʃ	"I straighten up"

2) /s/→ [ʃ] when preceding (adjacent) [t, n, l]

a.	/s-lok'in/	ʃlok'in	he cuts it
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Sibilant Harmony in Samala (1/2)

Generalization

- Anticipatory Sibilant harmony
- Local restriction agains [*sn, *st, *sl]

Grammar

T = {s, ʃ, n, t, l} S = {*sʃ, *ʃs, *sn, *st, *sl }

^{ok} k ʃ u ʃ o j i n ^{ok} ʃ l o k' i n

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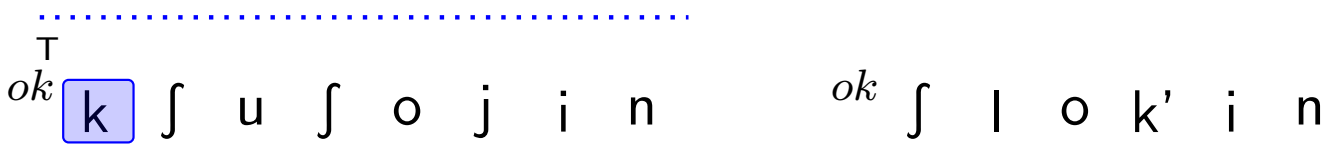

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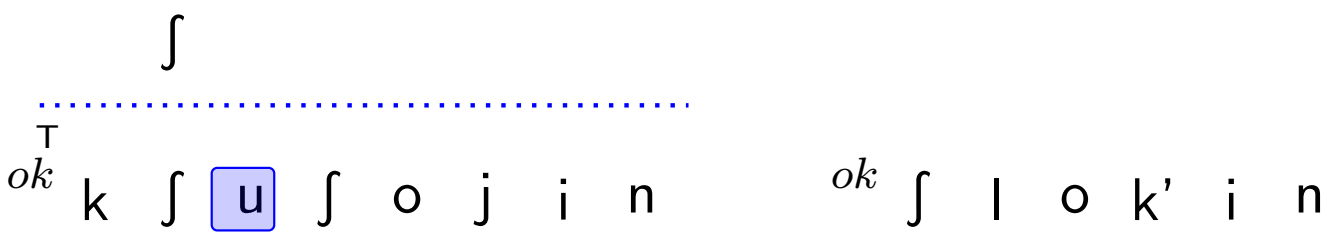

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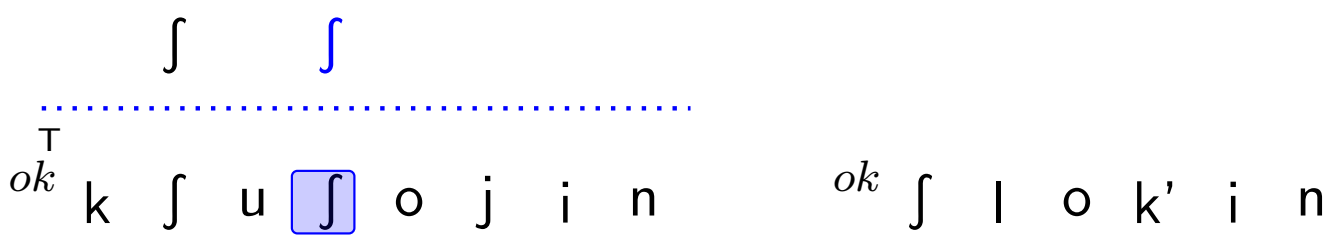

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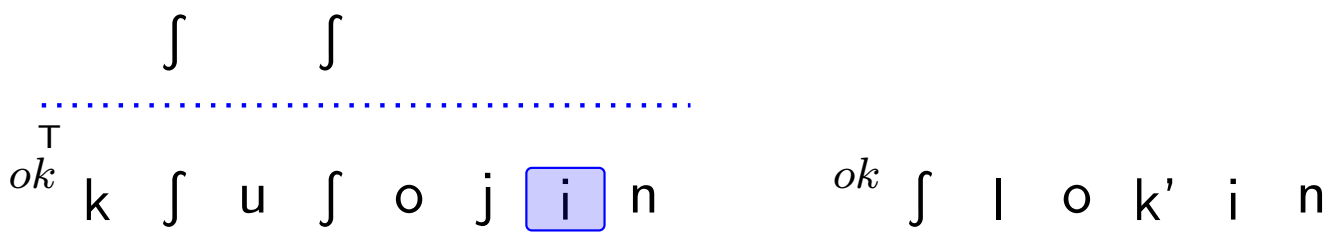

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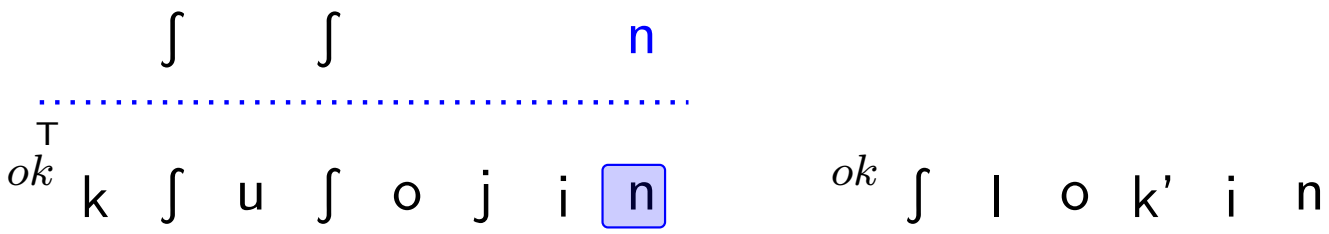

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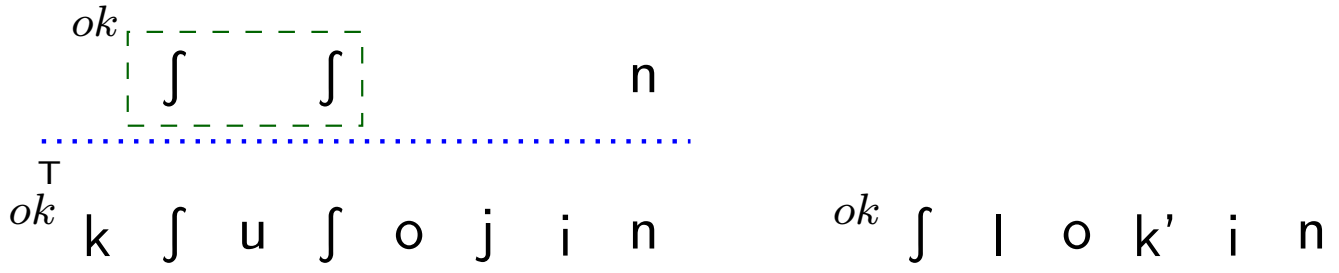

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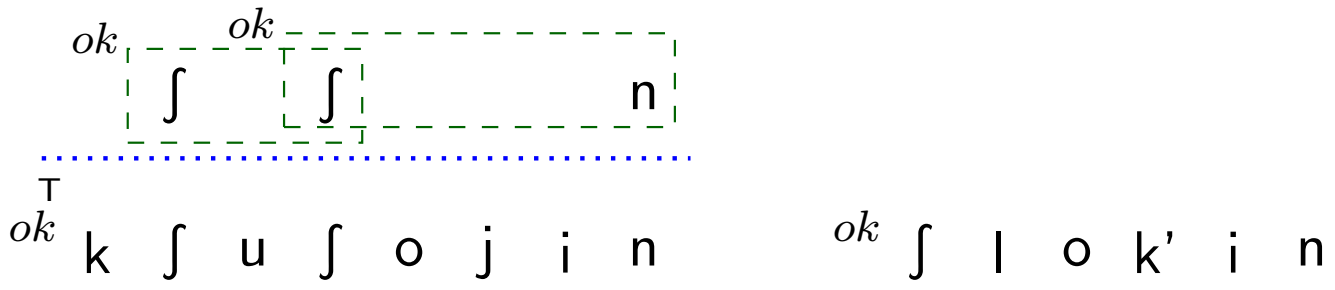

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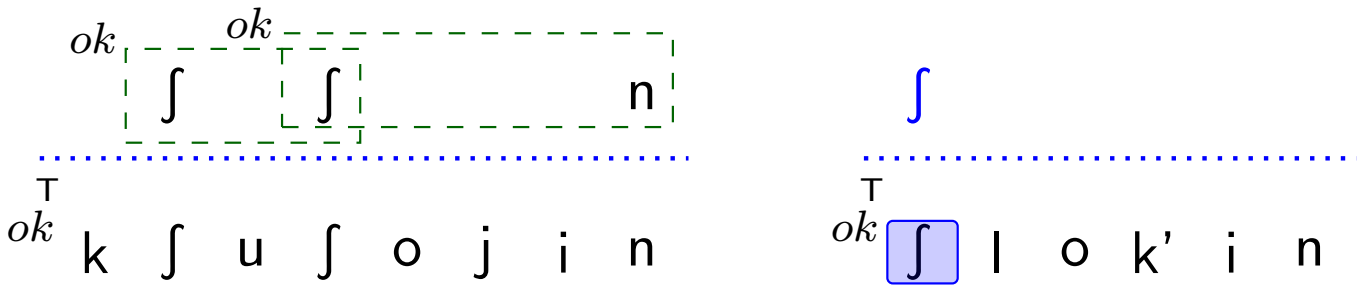

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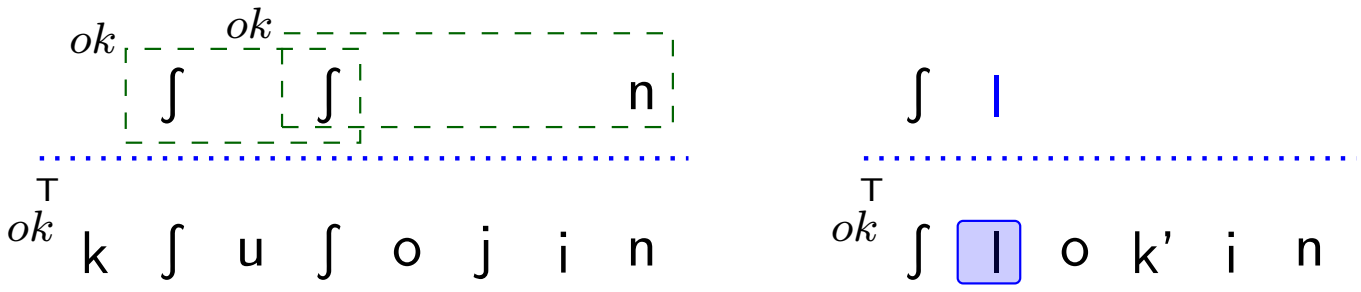

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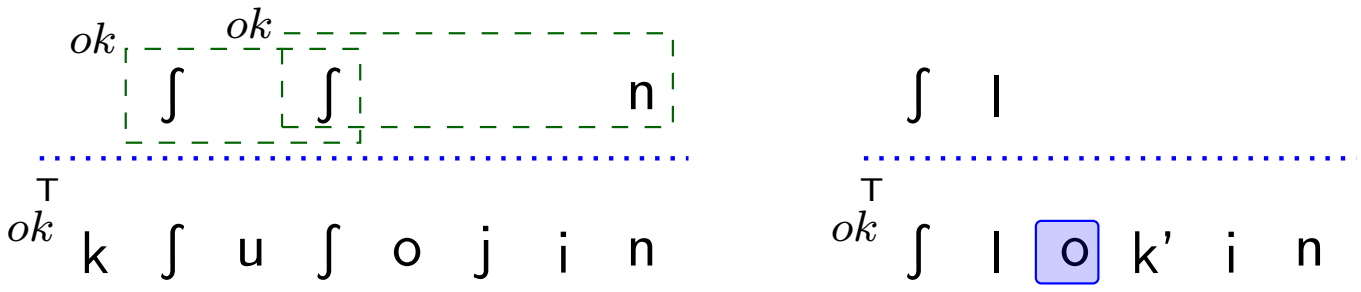

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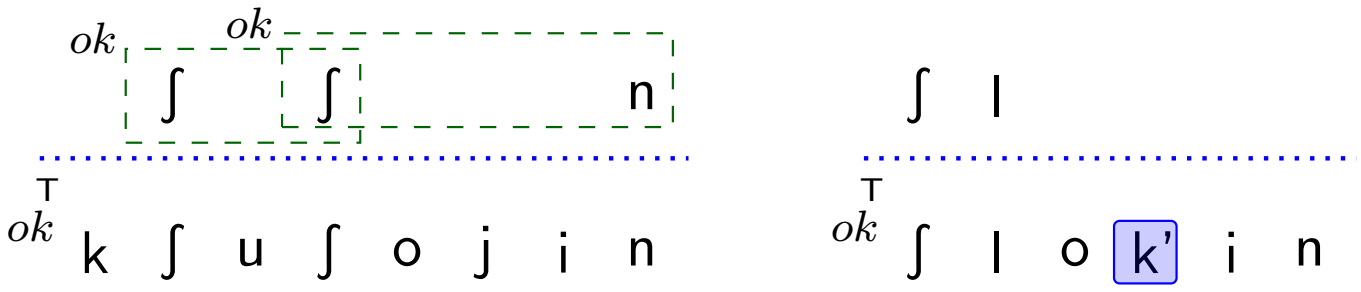

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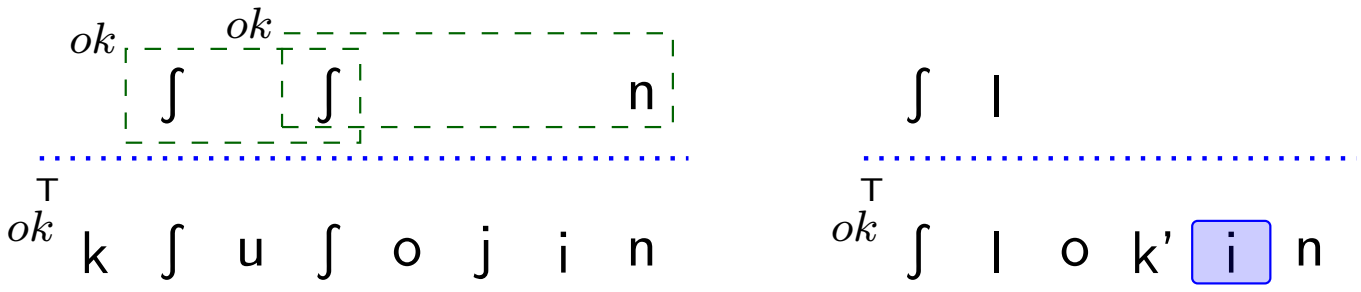

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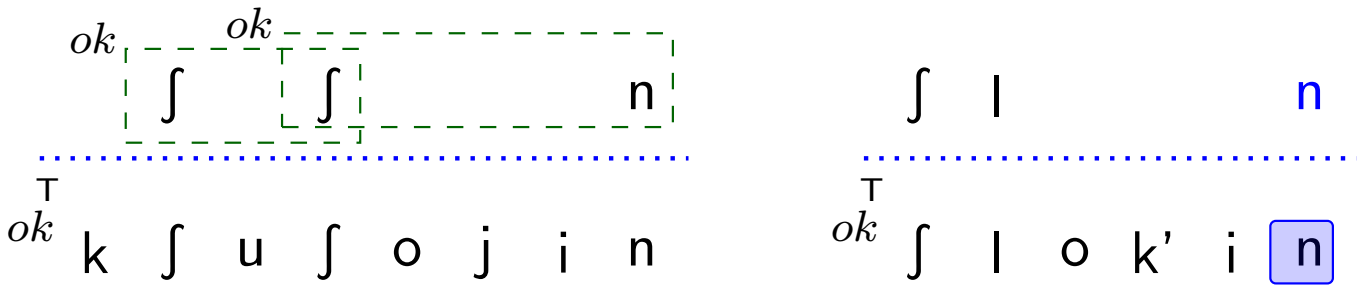

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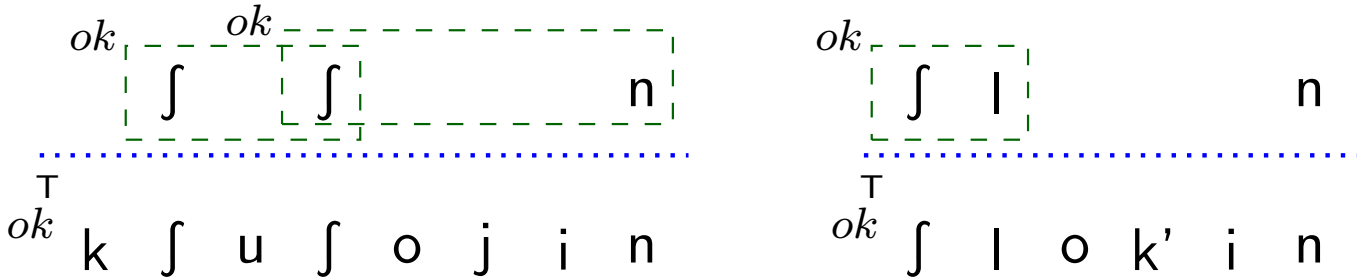

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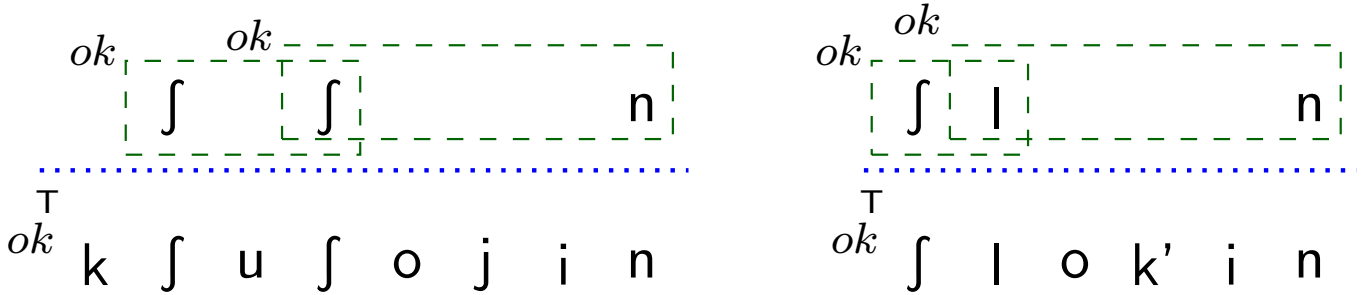

Sibilant Harmony in Samala (2/2)

Generalization (Extended)

- anticipatory sibilant harmony
- palatalization to avoid local restriction
- sibilant harmony overides palatalization

Grammar

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^{ok} s n e t u s

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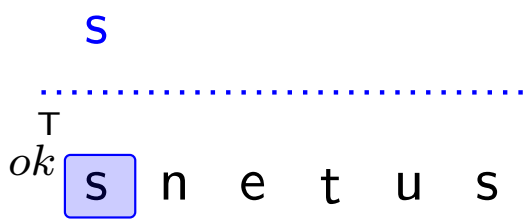

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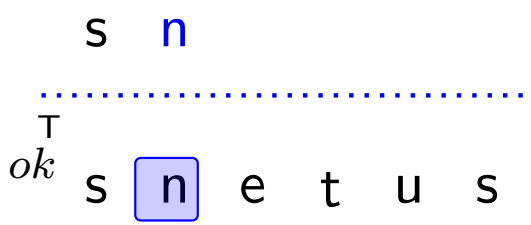

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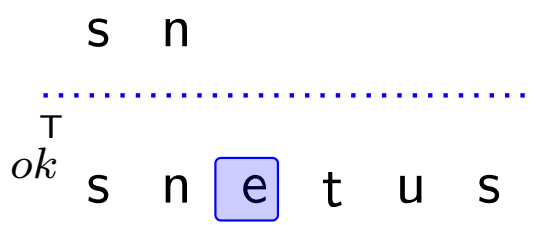

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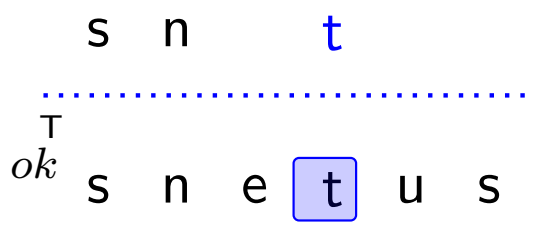

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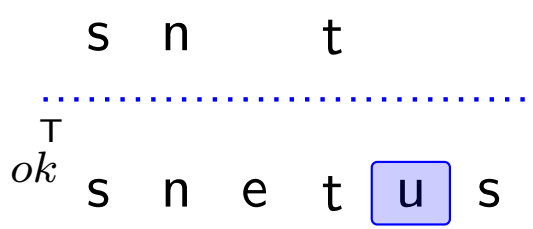

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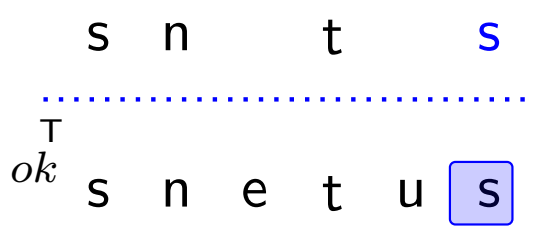

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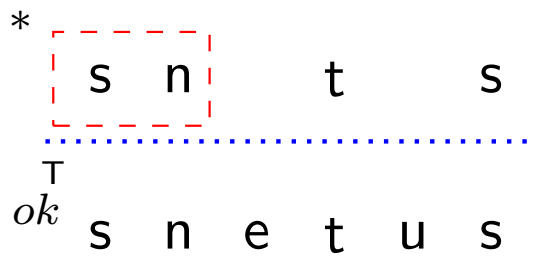

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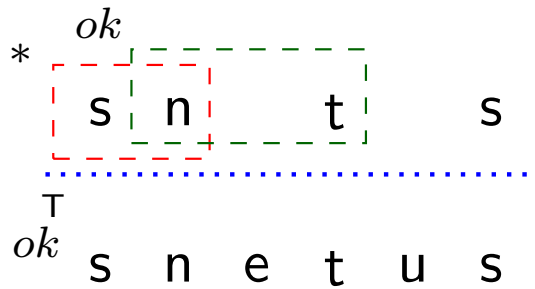

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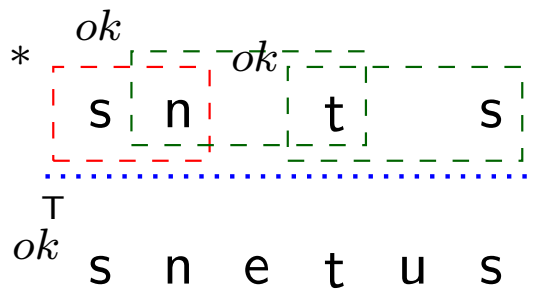

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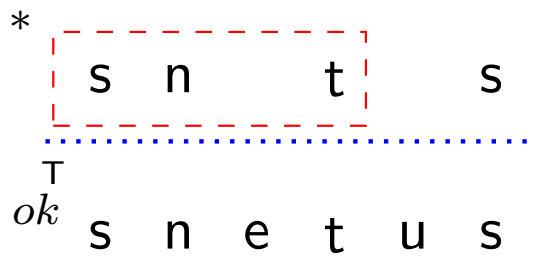

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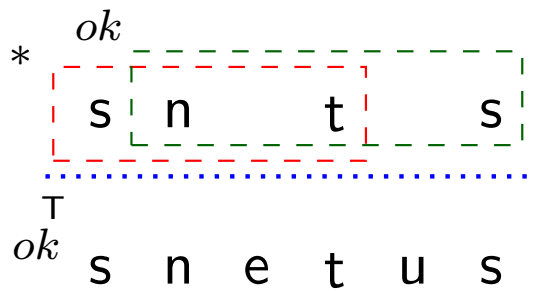

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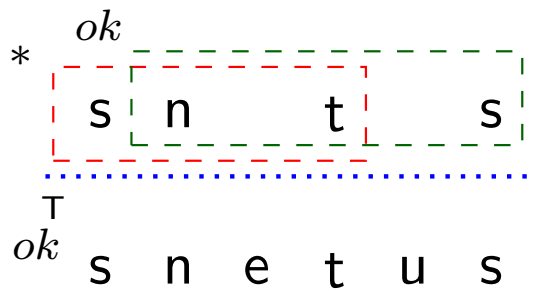

No TSL grammar can capture this patter...

Interim Summary

TSL is a good fit for long distance dependencies:

- projection of a subset of segments on a tier T;
- strictly local constraints enforced on T.

Not every attested pattern can be described this way:

- overlapping constraints cannot work on the same tier.
- not enough information is used when projecting elements.

Generalizing the TSL class

TSL languages are characterized by:

- a 1-local projection function that projects one tier T;
- strictly k-local constraints applied on T.

Idea

What if ...

1. we could apply different projection functions to project multiple tiers?
2. the locality of the projection function was higher than 1?

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Multiple-Tier Strictly Local (MTSL) Languages (1/2)

Sibilant Harmony in Imdlawn Tashlhiyt (Revisited)

Voiceless obstruents block agreement in voicing:

- $T_1 = \{$ʒ, s, z, ʃ, q$\}$ $S_1 = \{$*sʒ, *sz, *ʒs, *zs, *ʃz, *ʃʒ, *ʒʃ$\}$

ok ʃ q u ʒː i

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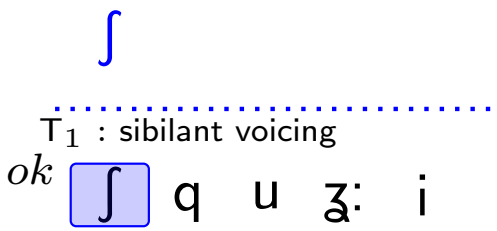

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ʃ q

T_1 : sibilant voicing

ok ʃ q u ʒː i

Multiple-Tier Strictly Local (MTSL) Languages (1/2)

Sibilant Harmony in Imdlawn Tashlhiyt (Revisited)

Voiceless obstruents block agreement in voicing:

- $T_1 = \{$ʒ, s, z, ʃ, q$\}$ $S_1 = \{$*sʒ, *sz, *ʒs, *zs, *ʃz, *ʃʒ, *ʒʃ$\}$

ʃ q

T_1 : sibilant voicing

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Multiple-Tier Strictly Local (MTSL) Languages (1/2)

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ʃ q ʒː

T_1 : sibilant voicing

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Multiple-Tier Strictly Local (MTSL) Languages (1/2)

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ʃ q ʒː

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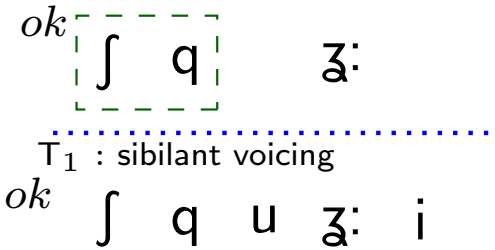

Multiple-Tier Strictly Local (MTSL) Languages (1/2)

Sibilant Harmony in Imdlawn Tashlhiyt (Revisited)

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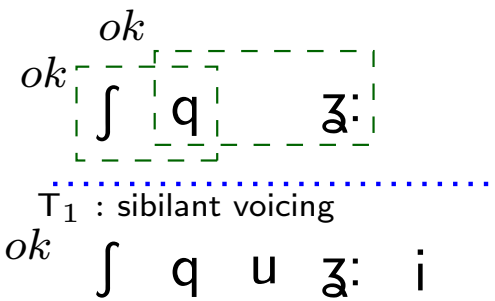

Multiple-Tier Strictly Local (MTSL) Languages (1/2)

Sibilant Harmony in Imdlawn Tashlhiyt (Revisited)

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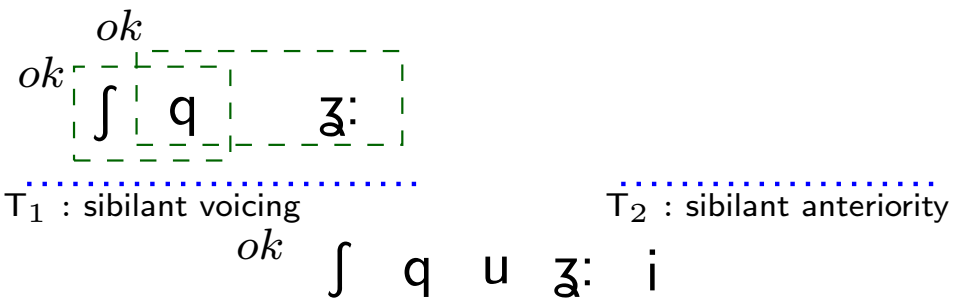
Unbounded agreement in anteriority:

- $T_2 = \{$ʒ, s, z, ʃ$\}$ $S_2 = \{$*sʒ, *sʃ, *ʒs, *ʃs, *zs, *zʃ, *zʒ, *ʃz, *ʒz $\}$



Multiple-Tier Strictly Local (MTSL) Languages (1/2)

Sibilant Harmony in Imdlawn Tashlhiyt (Revisited)

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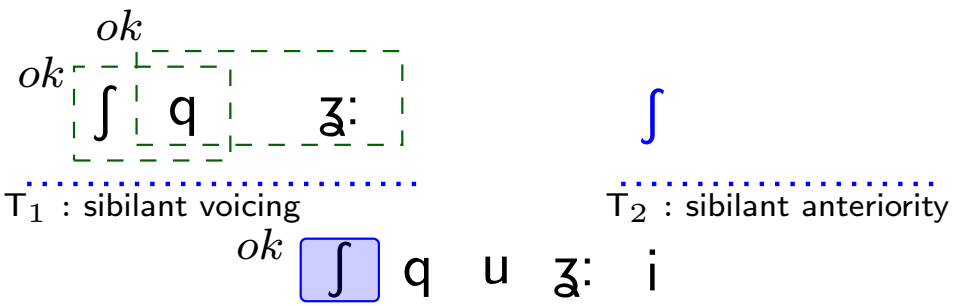

Multiple-Tier Strictly Local (MTSL) Languages (1/2)

Sibilant Harmony in Imdlawn Tashlhiyt (Revisited)

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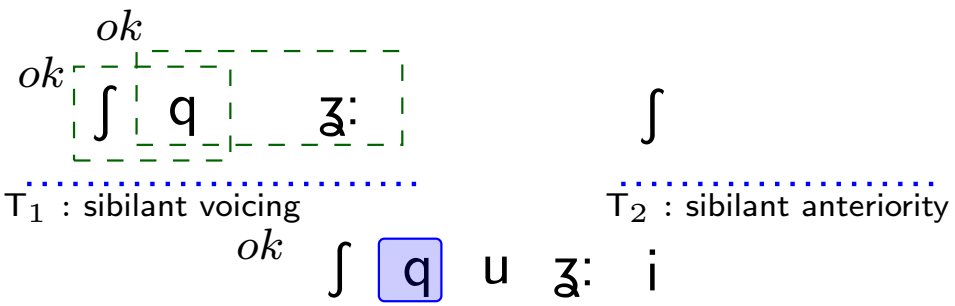
Unbounded agreement in anteriority:

- $T_2 = \{$ʒ, s, z, ʃ$\}$ $S_2 = \{$*sʒ, *sʃ, *ʒs, *ʃs, *zs, *zʃ, *zʒ, *ʃz, *ʒz $\}$



Multiple-Tier Strictly Local (MTSL) Languages (1/2)

Sibilant Harmony in Imdlawn Tashlhiyt (Revisited)

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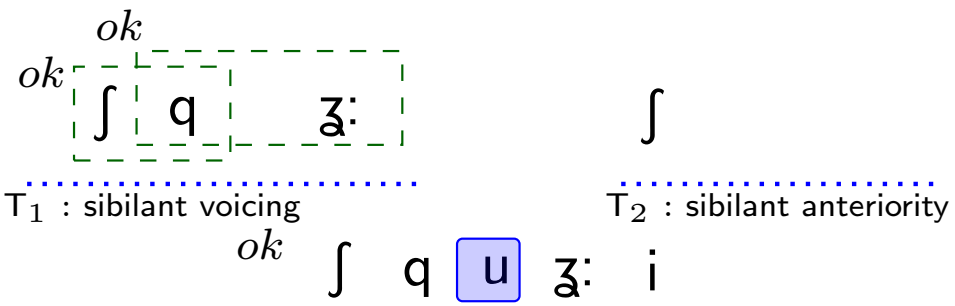
Unbounded agreement in anteriority:

- $T_2 = \{$ʒ, s, z, ʃ$\}$ $S_2 = \{$*sʒ, *sʃ, *ʒs, *ʃs, *zs, *zʃ, *zʒ, *ʃz, *ʒz $\}$



Multiple-Tier Strictly Local (MTSL) Languages (1/2)

Sibilant Harmony in Imdlawn Tashlhiyt (Revisited)

Voiceless obstruents block agreement in voicing:

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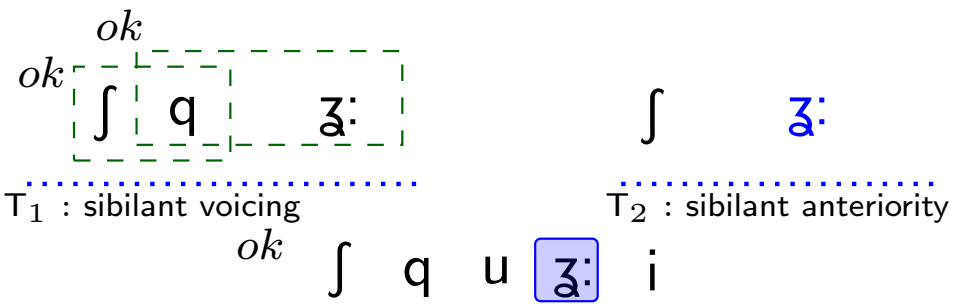
Unbounded agreement in anteriority:

- $T_2 = \{$ʒ, s, z, ʃ$\}$ $S_2 = \{$*sʒ, *sʃ, *ʒs, *ʃs, *zs, *zʃ, *zʒ, *ʃz, *ʒz $\}$



Multiple-Tier Strictly Local (MTSL) Languages (1/2)

Sibilant Harmony in Imdlawn Tashlhiyt (Revisited)

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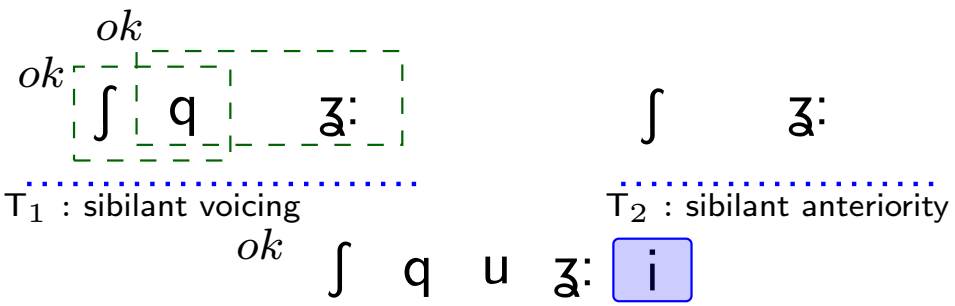
Unbounded agreement in anteriority:

- $T_2 = \{$ʒ, s, z, ʃ$\}$ $S_2 = \{$*sʒ, *sʃ, *ʒs, *ʃs, *zs, *zʃ, *zʒ, *ʃz, *ʒz $\}$



Multiple-Tier Strictly Local (MTSL) Languages (1/2)

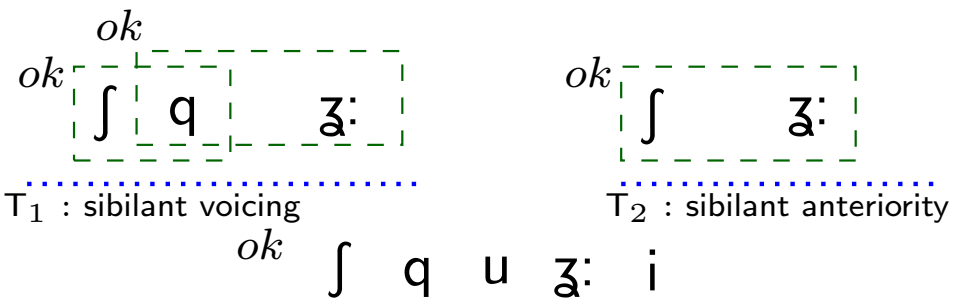
Sibilant Harmony in Imdlawn Tashlhiyt (Revisited)

Voiceless obstruents block agreement in voicing:

- $T_1 = \{$ʒ, s, z, ʃ, q$\}$ $S_1 = \{$*sʒ, *sz, *ʒs, *zs, *ʃz, *ʃʒ, *ʒʃ$\}$

Unbounded agreement in anteriority:

- $T_2 = \{$ʒ, s, z, ʃ$\}$ $S_2 = \{$*sʒ, *sʃ, *ʒs, *ʃs, *zs, *zʃ, *zʒ, *ʃz, *ʒz $\}$



Multiple-Tier Strictly Local (MTSL) Languages (2/2)

Sibilant Harmony in Imdlawn Tashlhiyt (Revisited)

Voiceless obstruents block agreement in voicing:

- $T_1 = \{$ʒ͡ʃ, s, z, ʃ, q$\}$ $S_1 = \{$*sʒ͡ʃ, *sz, *ʒ͡ʃs, *zs, *ʃz, *ʃʒ͡ʃ, *ʒ͡ʃʃ$\}$

Unbounded agreement in anteriority:

- $T_2 = \{$ʒ͡ʃ, s, z, ʃ$\}$ $S_2 = \{$*sʒ͡ʃ, *sʃ, *ʒ͡ʃs, *ʃs, *zs, *zʃ, *zʒ͡ʃ, *ʃz, *ʒ͡ʃz $\}$

* s q u ʒ͡ʃː i

Multiple-Tier Strictly Local (MTSL) Languages (2/2)

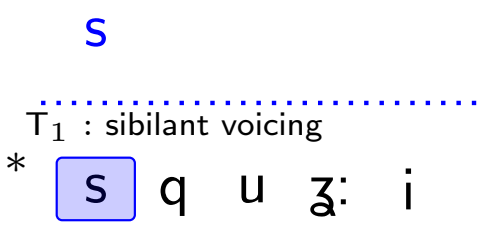
Sibilant Harmony in Imdlawn Tashlhiyt (Revisited)

Voiceless obstruents block agreement in voicing:

- $T_1 = \{$ʒ, s, z,ʃ, q$\}$ $S_1 = \{$*sʒ, *sz, *ʒs, *zs, *ʃz, *ʃʒ, *ʒʃ$\}$

Unbounded agreement in anteriority:

- $T_2 = \{$ʒ, s, z,ʃ$\}$ $S_2 = \{$*sʒ, *sʃ, *ʒs,*ʃs, *zs, *zʃ, *zʒ, *ʃz, *ʒz $\}$



Multiple-Tier Strictly Local (MTSL) Languages (2/2)

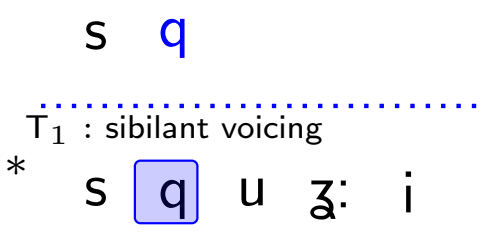
Sibilant Harmony in Imdlawn Tashlhiyt (Revisited)

Voiceless obstruents block agreement in voicing:

- $T_1 = \{$ʒ, s, z, ʃ, q$\}$ $S_1 = \{$*sʒ, *sz, *ʒs, *zs, *ʃz, *ʃʒ, *ʒʃ$\}$

Unbounded agreement in anteriority:

- $T_2 = \{$ʒ, s, z, ʃ$\}$ $S_2 = \{$*sʒ, *sʃ, *ʒs, *ʃs, *zs, *zʃ, *zʒ, *ʃz, *ʒz $\}$



Multiple-Tier Strictly Local (MTSL) Languages (2/2)

Sibilant Harmony in Imdlawn Tashlhiyt (Revisited)

Voiceless obstruents block agreement in voicing:

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Unbounded agreement in anteriority:

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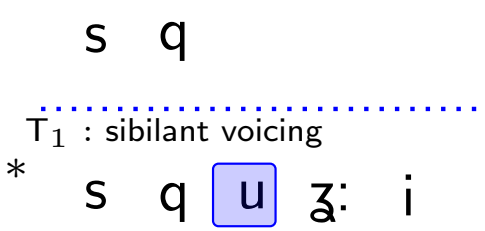

Multiple-Tier Strictly Local (MTSL) Languages (2/2)

Sibilant Harmony in Imdlawn Tashlhiyt (Revisited)

Voiceless obstruents block agreement in voicing:

- $T_1 = \{$ʒ͡ʕ, s, z, ʃ, q$\}$ $S_1 = \{$*sʒ͡ʕ, *sz, *ʒ͡ʕs, *zs, *ʃz, *ʃʒ͡ʕ, *ʒ͡ʕʃ$\}$

Unbounded agreement in anteriority:

- $T_2 = \{$ʒ͡ʕ, s, z, ʃ$\}$ $S_2 = \{$*sʒ͡ʕ, *sʃ, *ʒ͡ʕs, *ʃs, *zs, *zʃ, *zʒ͡ʕ, *ʃz, *ʒ͡ʕz $\}$

s q ʒ͡ʕː

T_1 : sibilant voicing

* s q u ʒ͡ʕː i

Multiple-Tier Strictly Local (MTSL) Languages (2/2)

Sibilant Harmony in Imdlawn Tashlhiyt (Revisited)

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Unbounded agreement in anteriority:

- $T_2 = \{$ʒ, s, z, ʃ$\}$ $S_2 = \{$*sʒ, *sʃ, *ʒs, *ʃs, *zs, *zʃ, *zʒ, *ʃz, *ʒz $\}$

s q ʒː

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Multiple-Tier Strictly Local (MTSL) Languages (2/2)

Sibilant Harmony in Imdlawn Tashlhiyt (Revisited)

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Unbounded agreement in anteriority:

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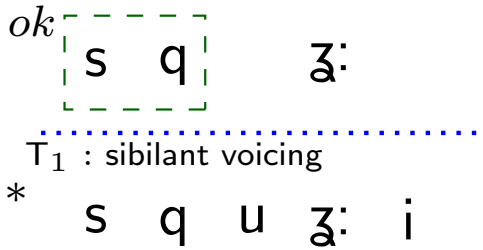

Multiple-Tier Strictly Local (MTSL) Languages (2/2)

Sibilant Harmony in Imdlawn Tashlhiyt (Revisited)

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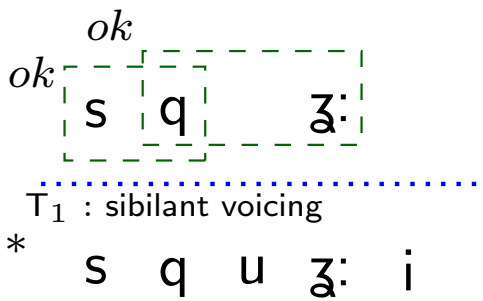

Multiple-Tier Strictly Local (MTSL) Languages (2/2)

Sibilant Harmony in Imdlawn Tashlhiyt (Revisited)

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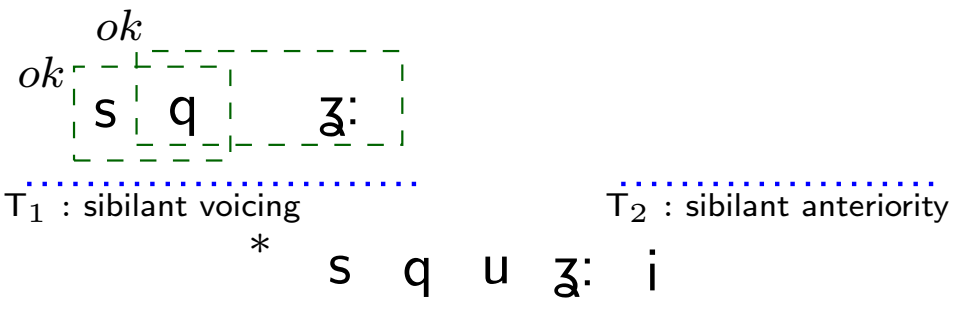

Multiple-Tier Strictly Local (MTSL) Languages (2/2)

Sibilant Harmony in Imdlawn Tashlhiyt (Revisited)

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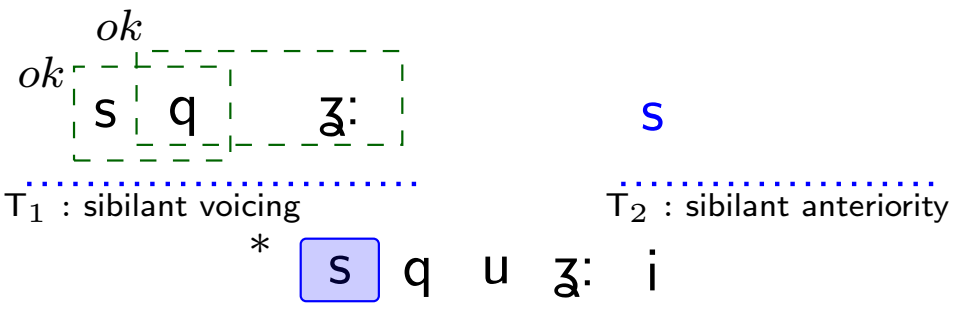

Multiple-Tier Strictly Local (MTSL) Languages (2/2)

Sibilant Harmony in Imdlawn Tashlhiyt (Revisited)

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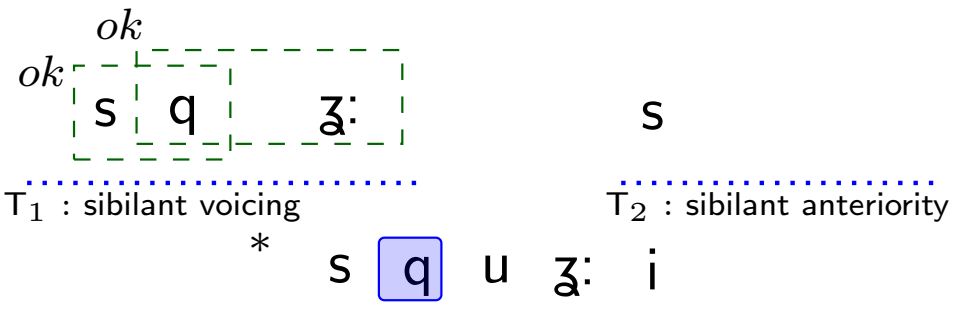

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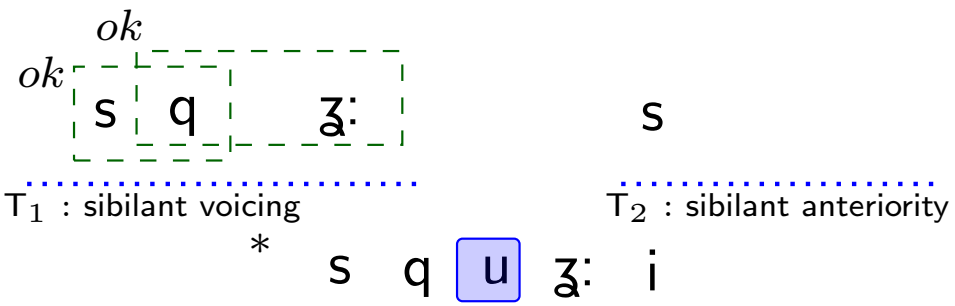

Multiple-Tier Strictly Local (MTSL) Languages (2/2)

Sibilant Harmony in Imdlawn Tashlhiyt (Revisited)

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Unbounded agreement in anteriority:

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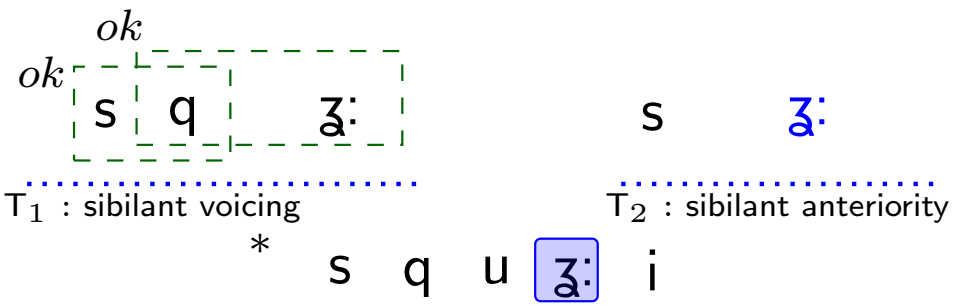

Multiple-Tier Strictly Local (MTSL) Languages (2/2)

Sibilant Harmony in Imdlawn Tashlhiyt (Revisited)

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Unbounded agreement in anteriority:

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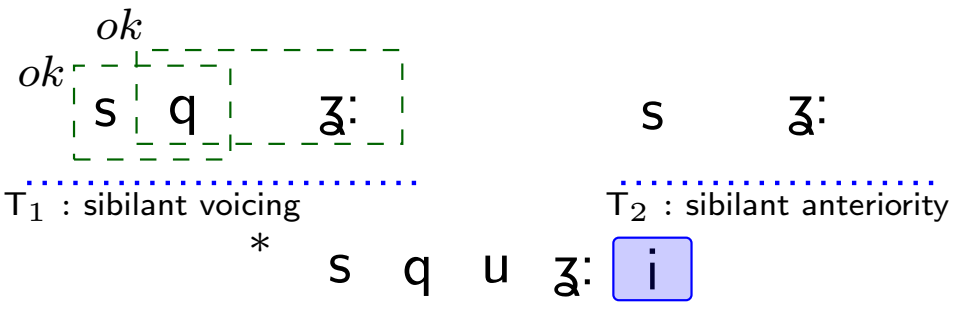

Multiple-Tier Strictly Local (MTSL) Languages (2/2)

Sibilant Harmony in Imdlawn Tashlhiyt (Revisited)

Voiceless obstruents block agreement in voicing:

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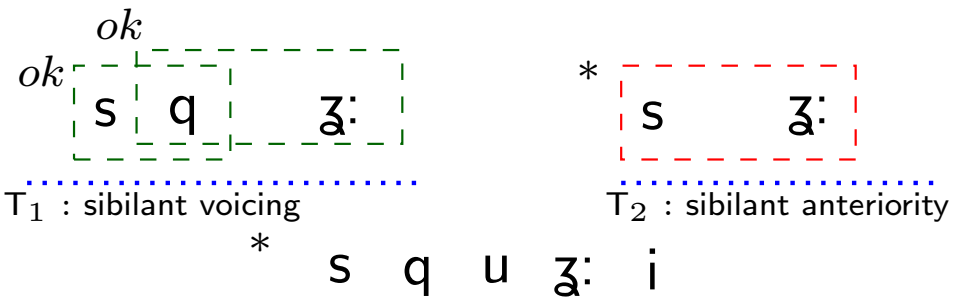
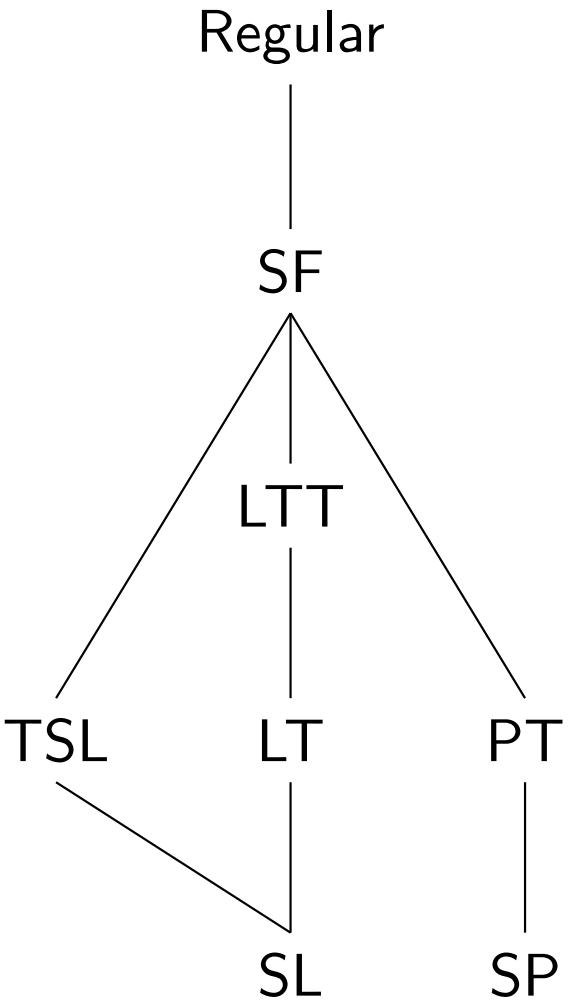
Unbounded agreement in anteriority:

- $T_2 = \{$ʒ, s, z, ʃ$\}$ $S_2 = \{$*sʒ, *sʃ, *ʒs, *ʃs, *zs, *zʃ, *zʒ, *ʃz, *ʒz $\}$



MTSL: Relations to other Classes



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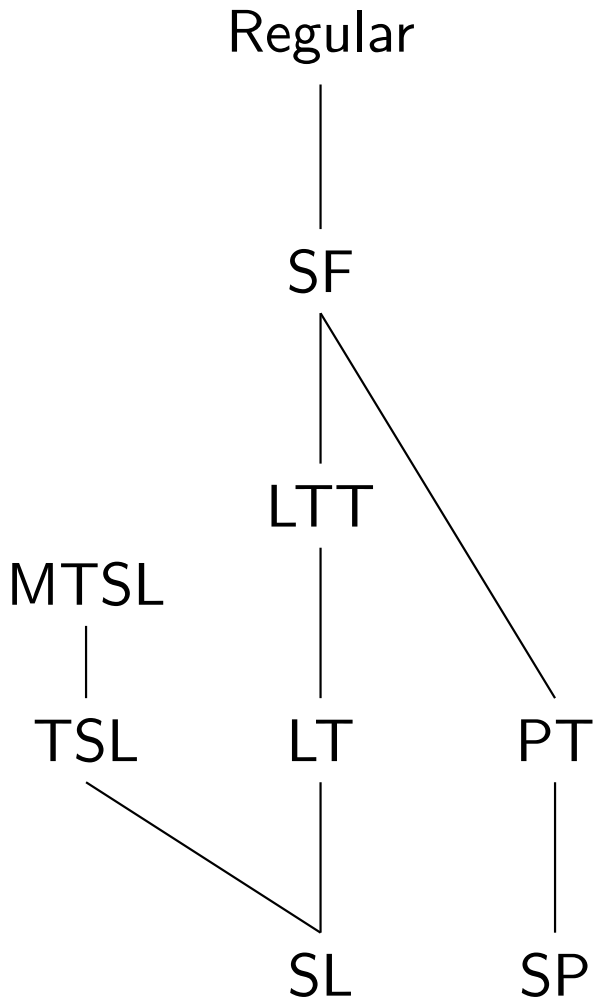

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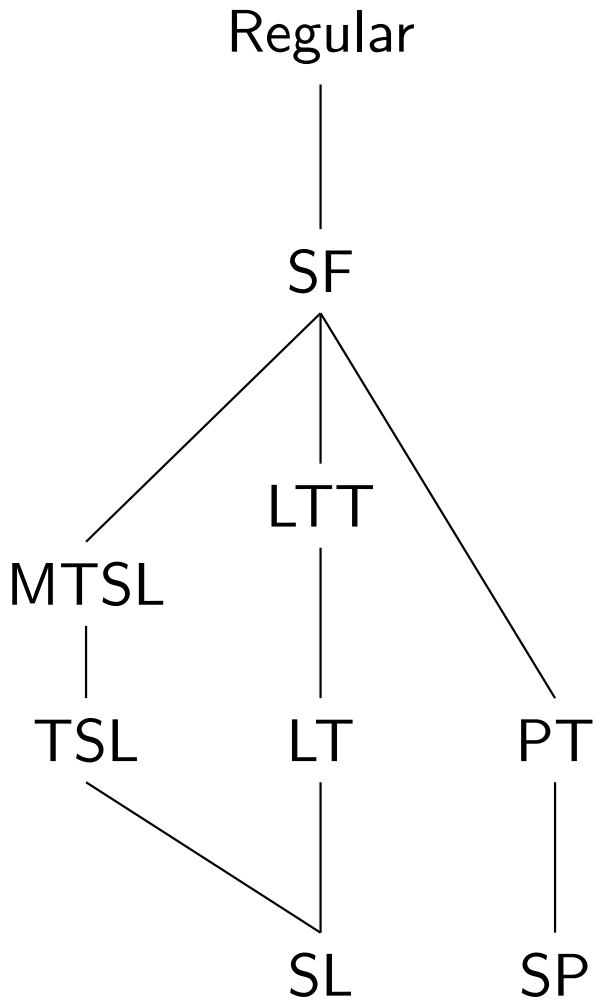

Generalizing the TSL class (Reprise)

TSL languages are characterized by:

- a 1-local projection function that projects one tier T;
- strictly k-local constraints applied on T.

Idea

What if ...

1. we could apply different projection functions to project multiple tiers?
2. the locality of the projection function was higher than 1?

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Structure-Sensitive TSL (SS-TSL)

Samala Sibilant Harmony (Revisited)

- anticipatory sibilant harmony
- palatalization to avoid local restrictions
- sibilant harmony overrides palatalization

s n e t u s

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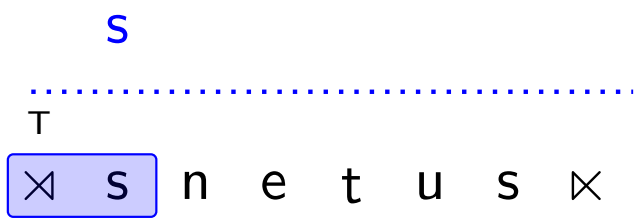

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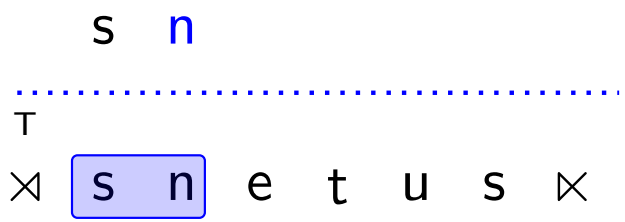

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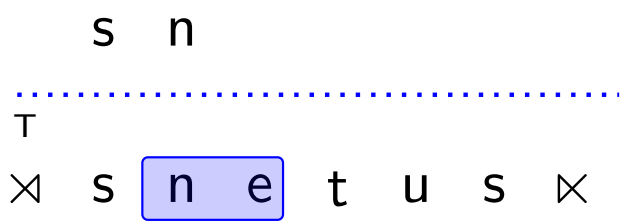

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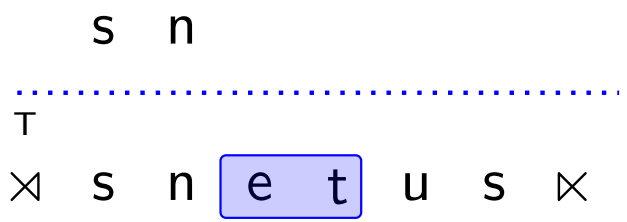

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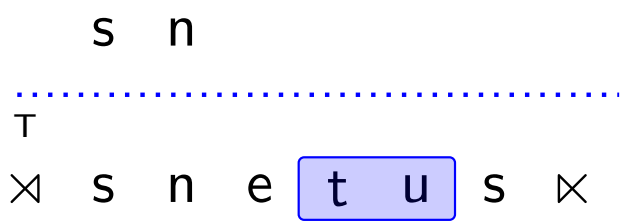

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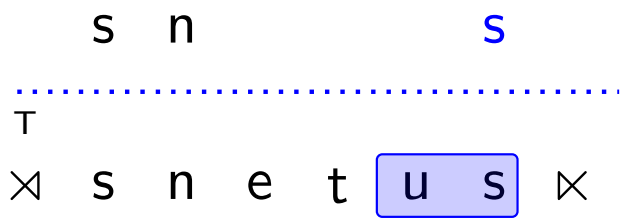

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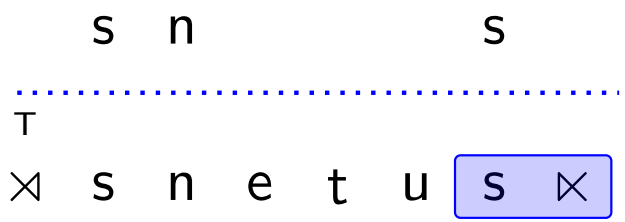

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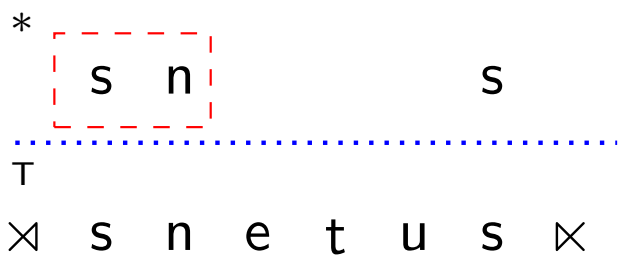

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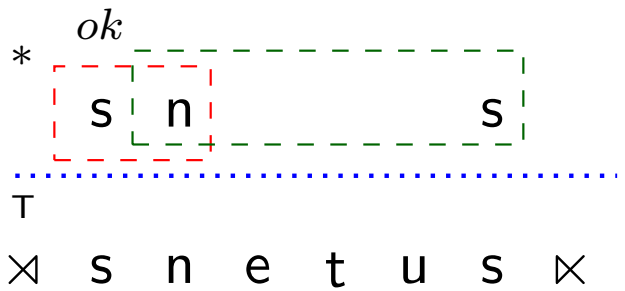

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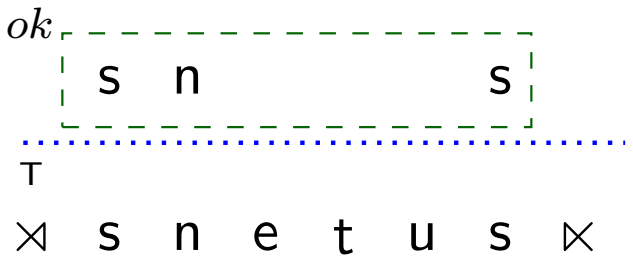

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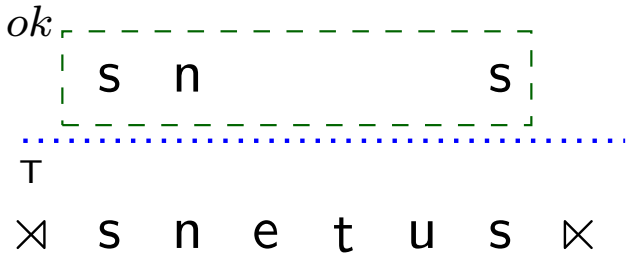
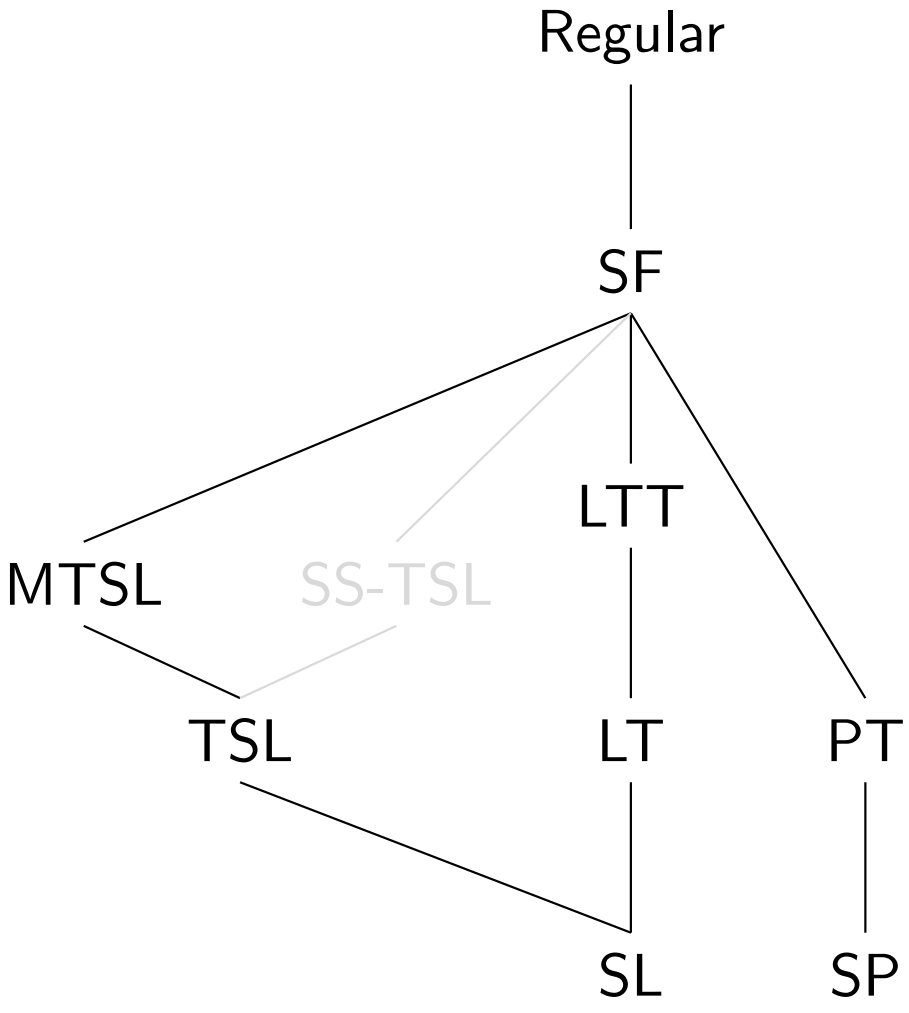


Grammar

$T = \{s, \int \wedge \{n, t, l\} \triangleright s\}$ $S = \{{}^*s\int, {}^*s\int, {}^*sn(\neg s), {}^*st(\neg s), {}^*sl(\neg s)\}$

SS -TSL: Relations to other Classes



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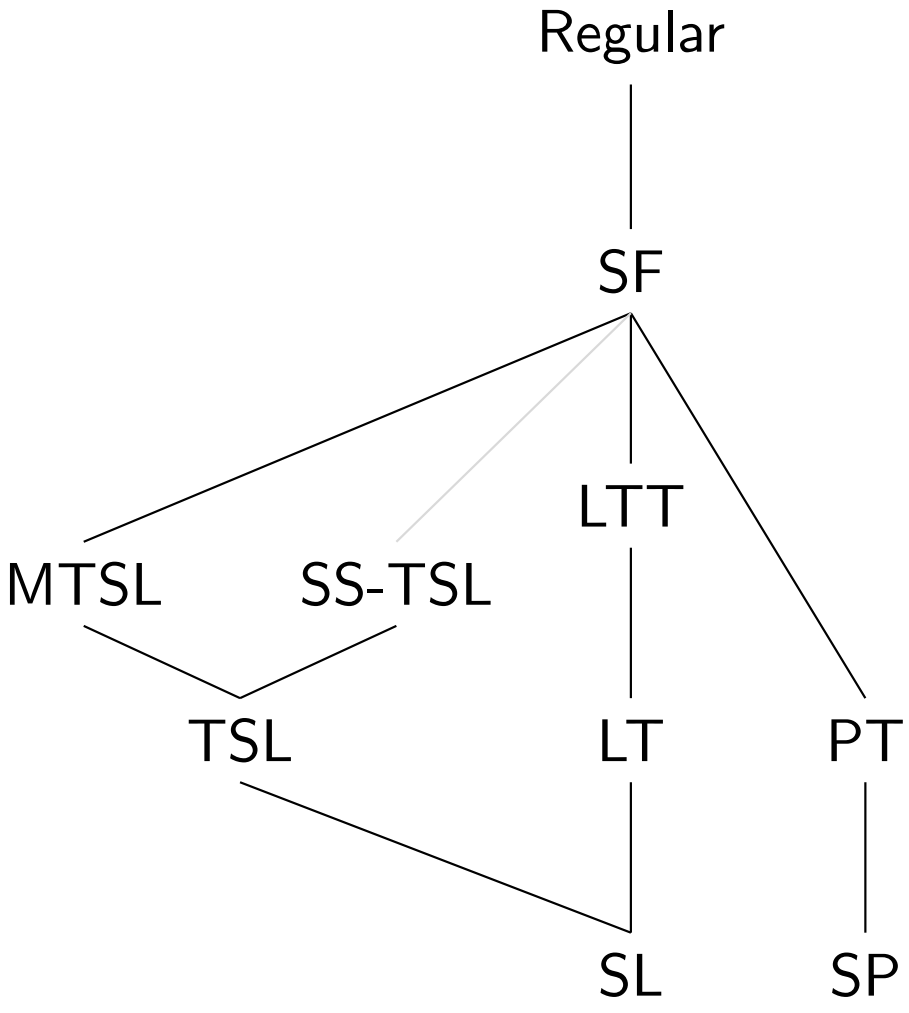

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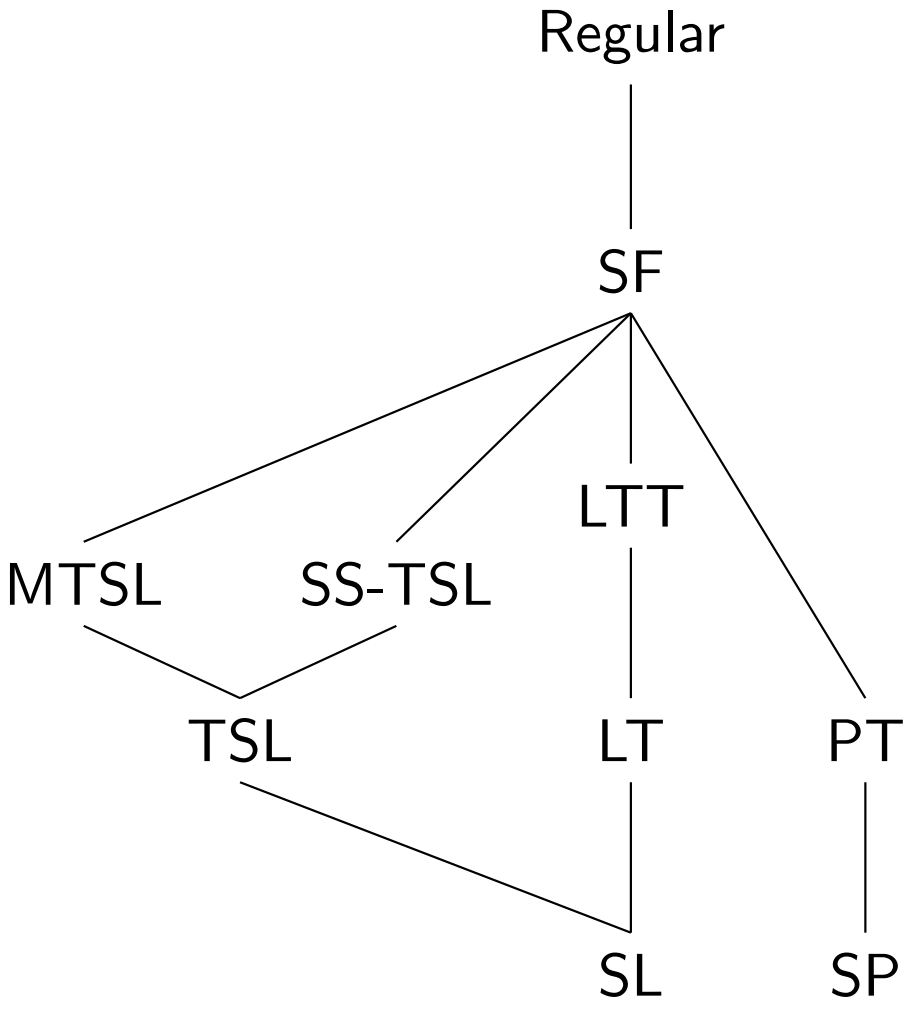
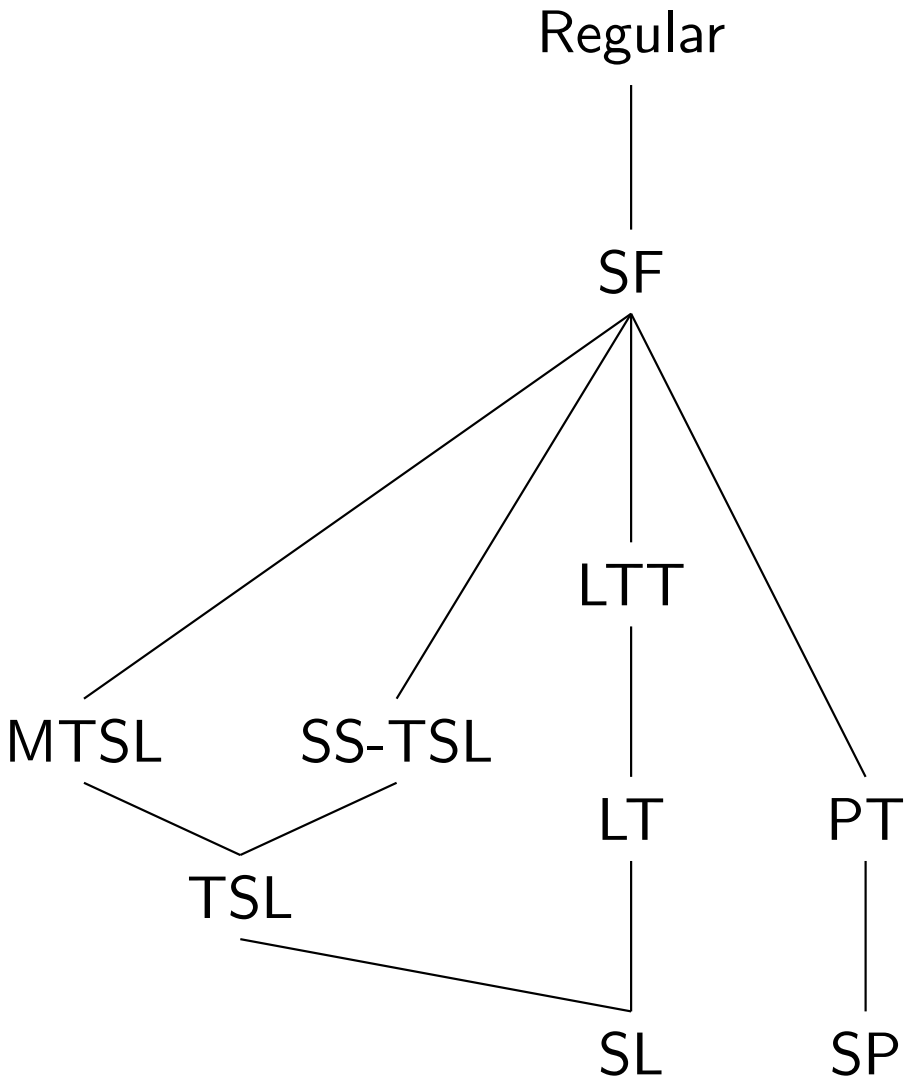


The TSL Neighborhood: a Plethora of Combinations



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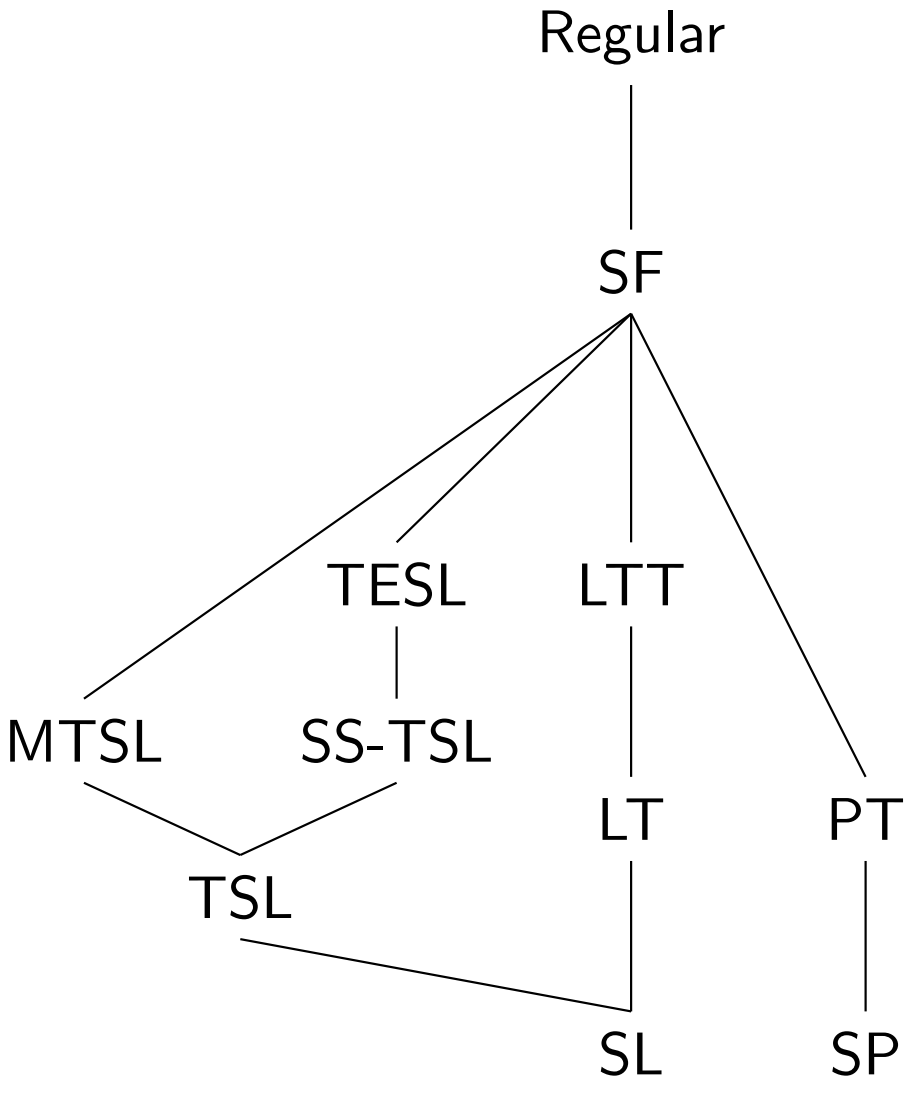

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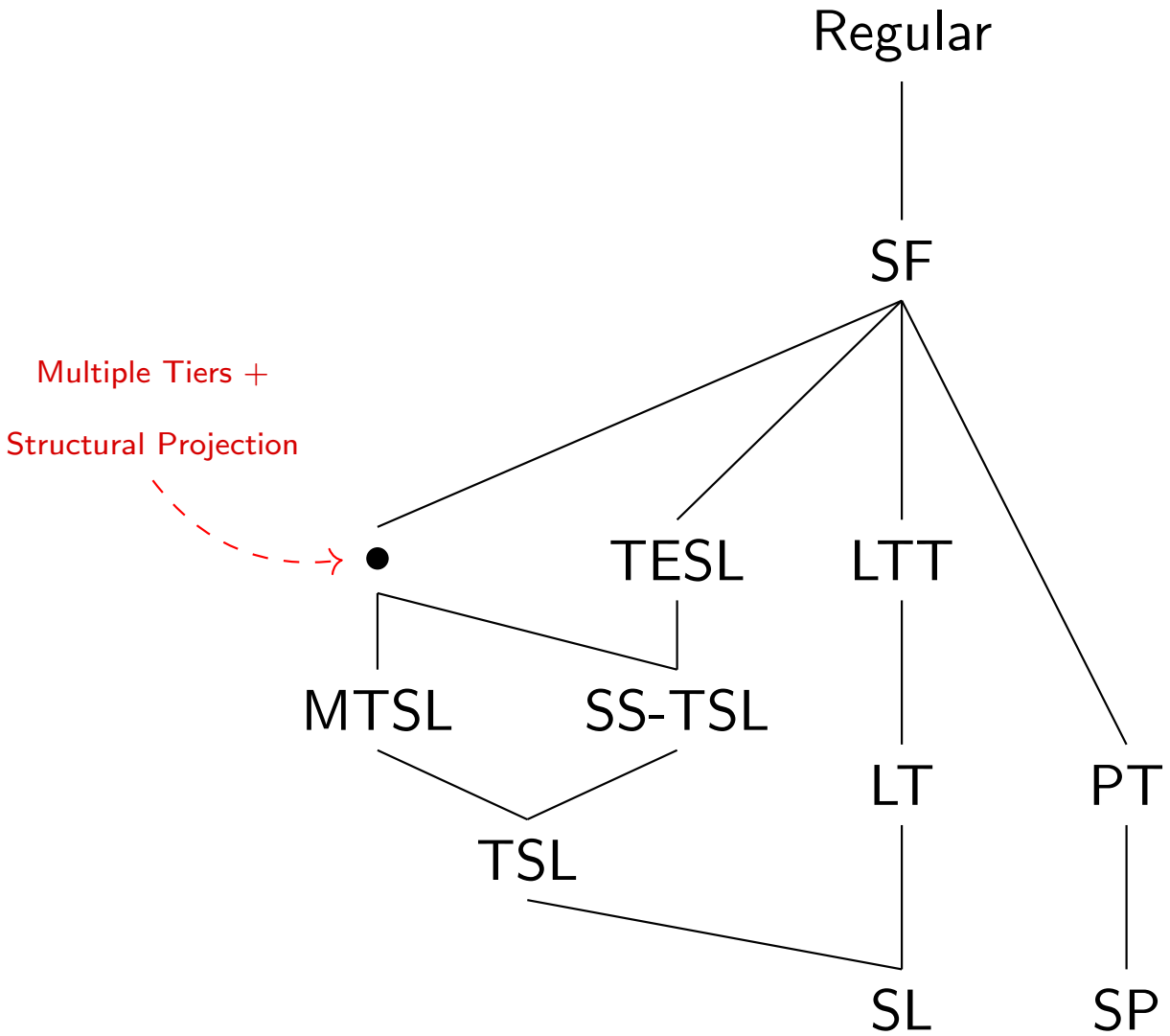

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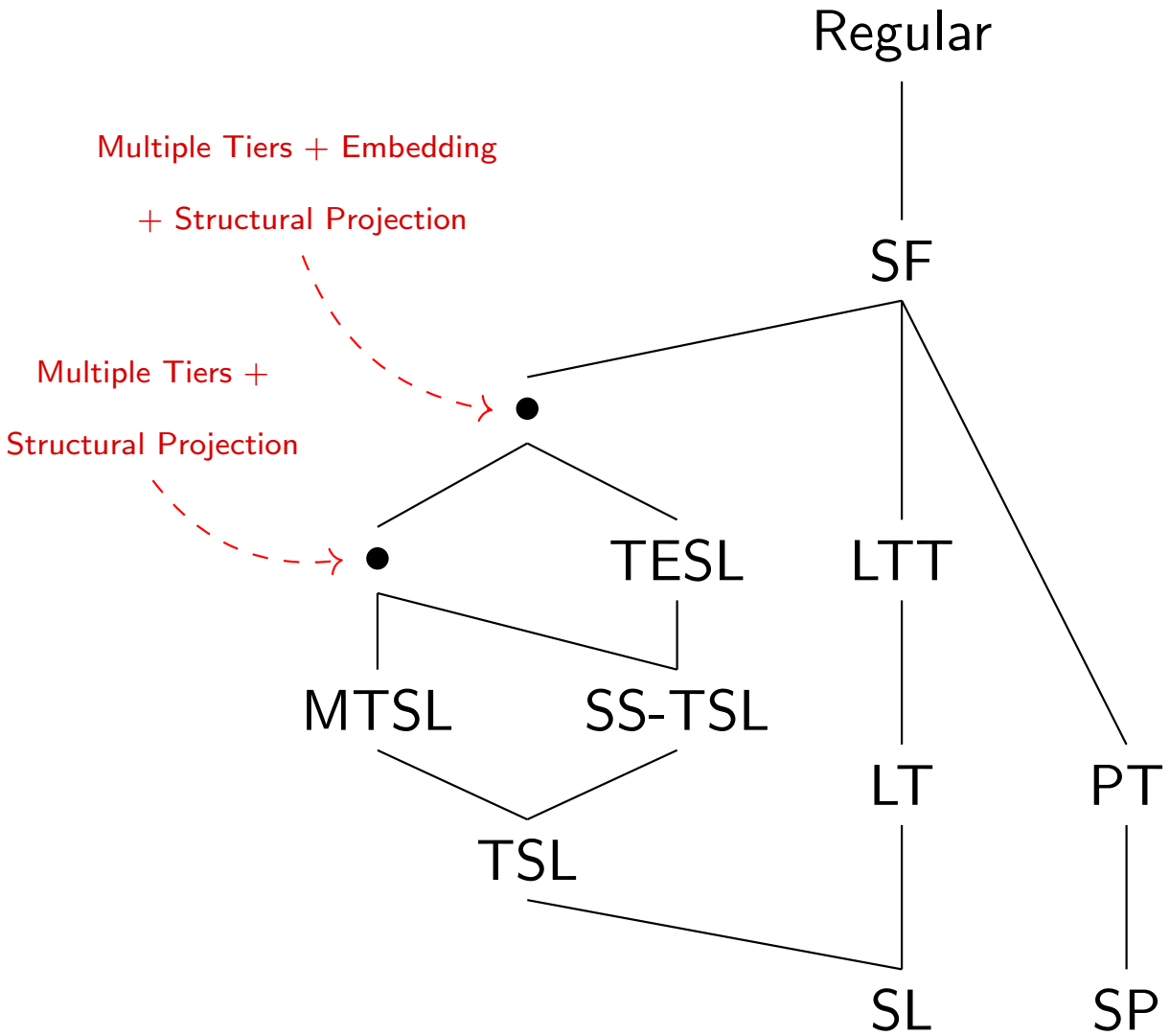

Conclusions and Future Work

Tracing Back our Steps

- subregular hypothesis as a strong computational theory of language complexity. Phonology is SL + SP + TSL
- but there are patterns that are unaccounted for!

In this Talk

- TSL is not the right fit, but it seems to be close!
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Selected References

1. **Chandlee, Jane**. 2014. *Strictly Local Phonological Processes*. Ph.D. thesis, University of Delaware.
2. **Heinz, Jeffrey**, Chetan Rawal, and Herbert G. Tanner. 2011.Tier-based strictly local constraints in phonology. In *Proceedings of ACL 49th*, 58–64.
3. **Heinz, Jeffrey**. 2014. Culminativity times harmony equals unbounded stress. In *Word Stress: Theoretical and Typological Issues*, Chap 8.
4. **McMullin, Kevin**. 2016. *Tier-based locality in long-distance phonotactics: learnability and typology*. Doctoral dissertation, University of British Columbia.

Appendix

Structure-Sensitive TSL: Over-generation

Anticipatory Harmony in Samala

T = { s, ʃ, tʃʰ}, S= {* sʃ, *ʃs, *stʃʰ, *tʃʰ}

ʃ a p i tʃʰ o l u ʃ w a ʃ

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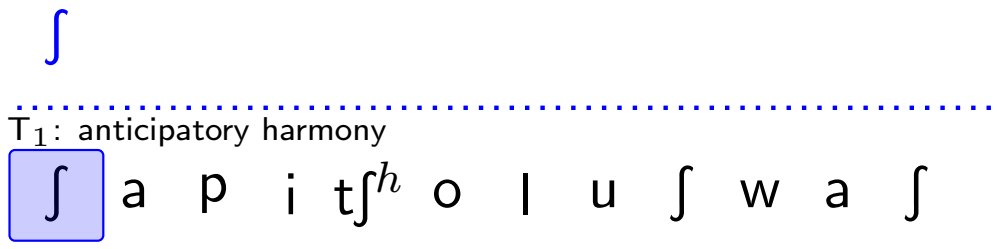

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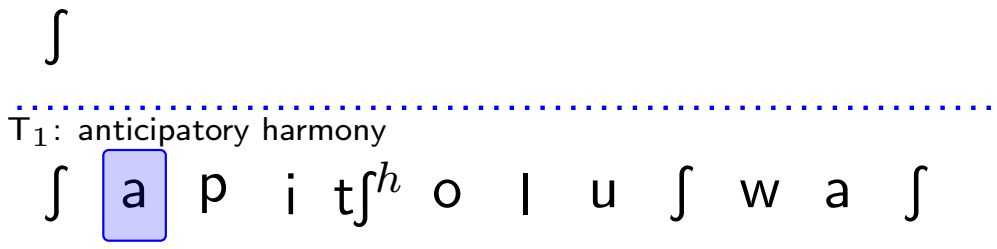

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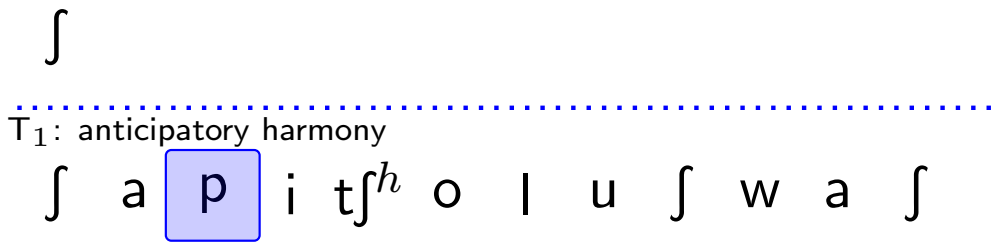

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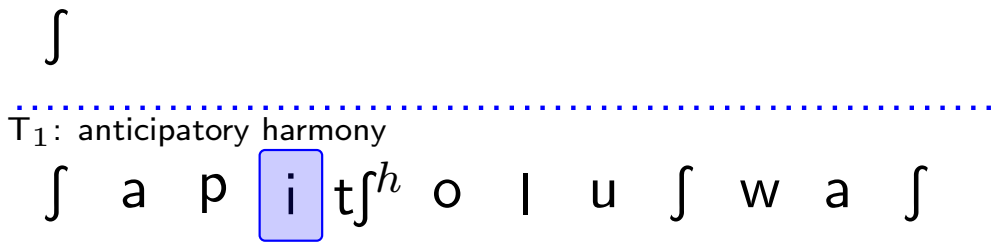

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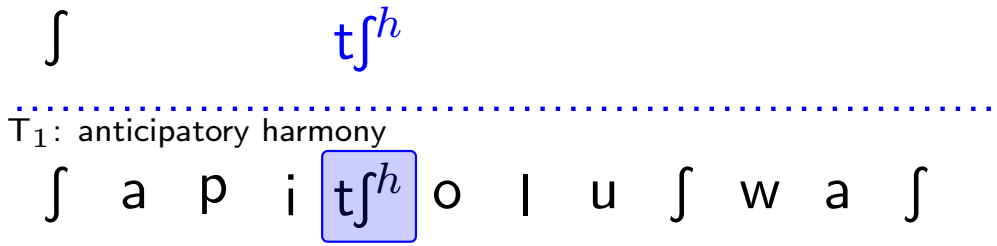

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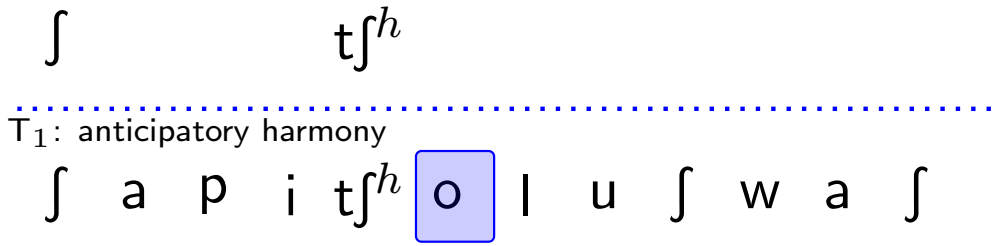

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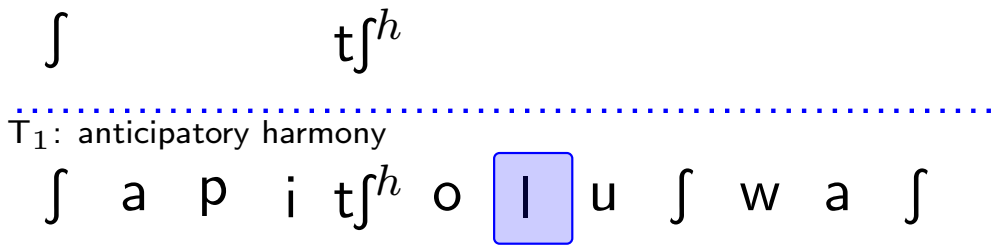

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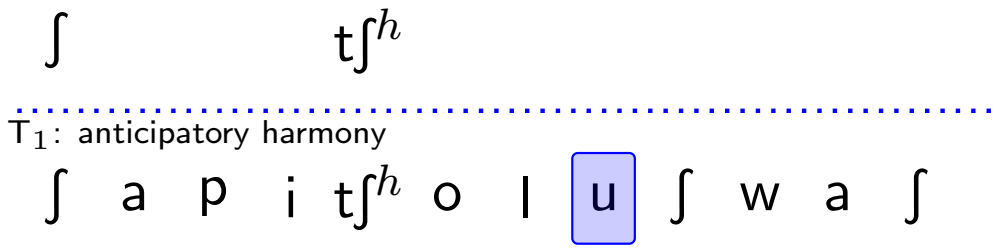

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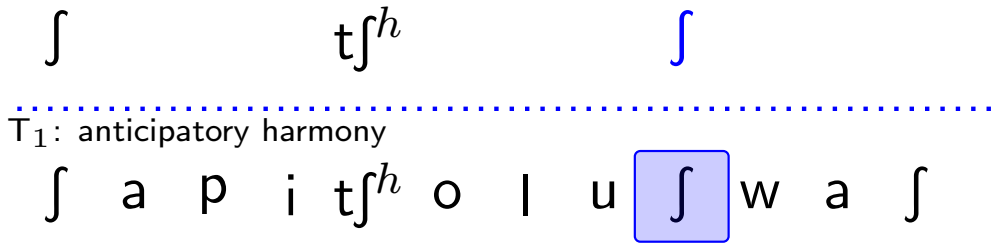

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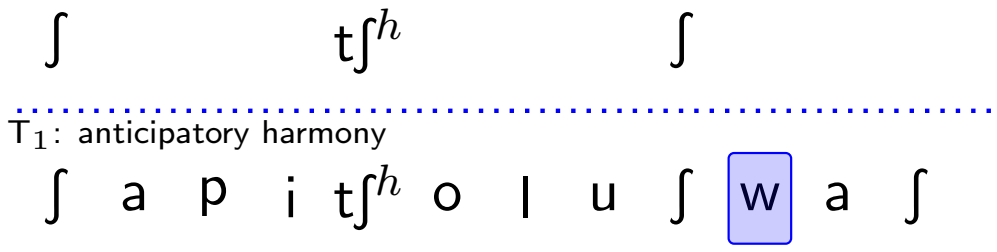

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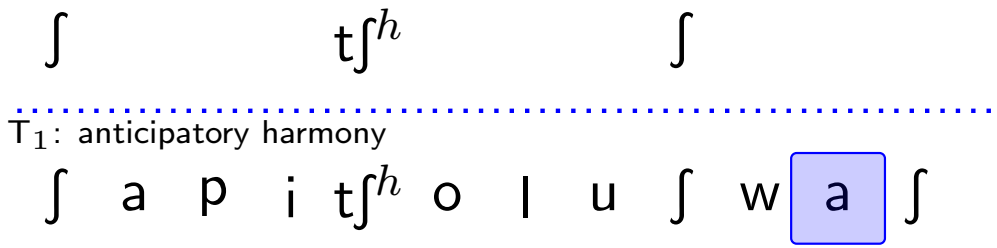

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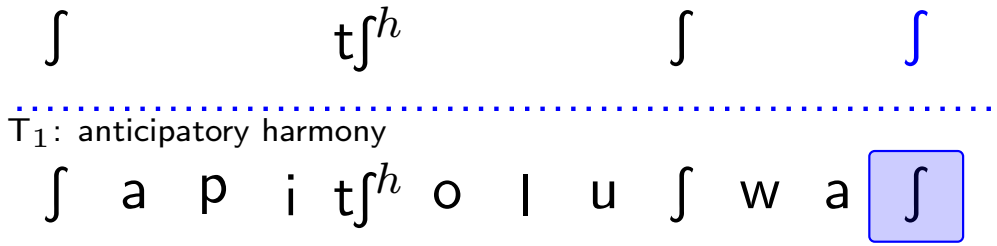

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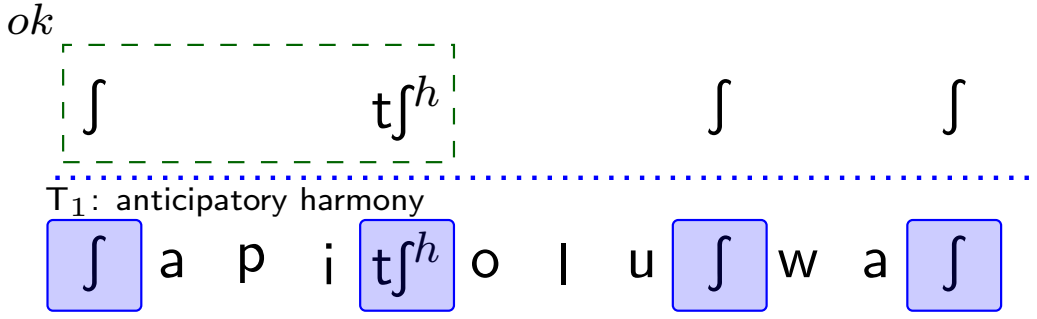

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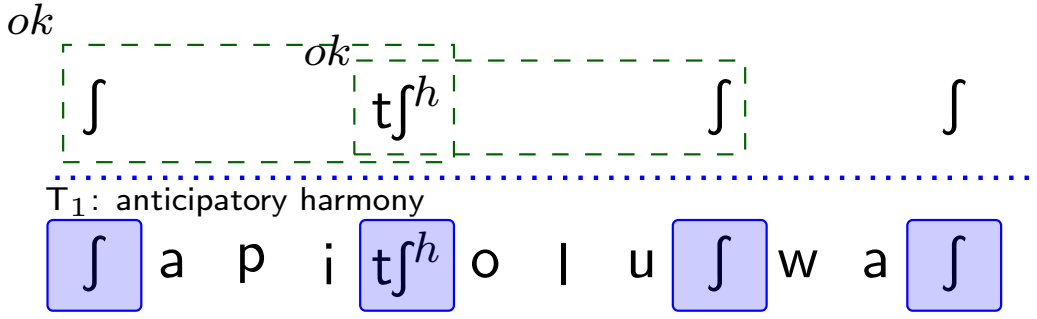

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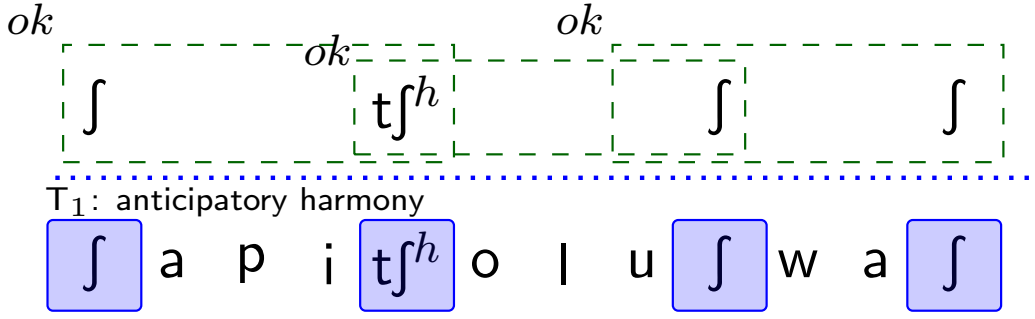

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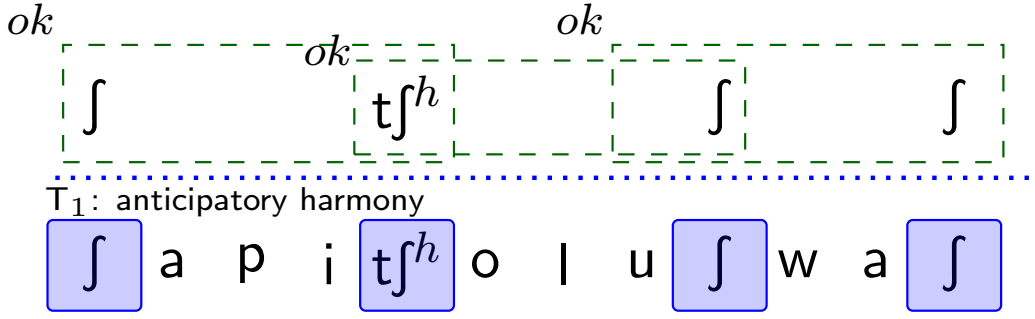

First/Last Harmony in Pseudo-Samala

T = {σ: σ ∈ {s, ʃ, tʃʰ} ∧(⋊σ ∨ σ⋉)} S= {*sʃ, *ʃs, *stʃʰ, *tʃʰ s}

ʃ a p i tʃʰ o l u s w a ʃ

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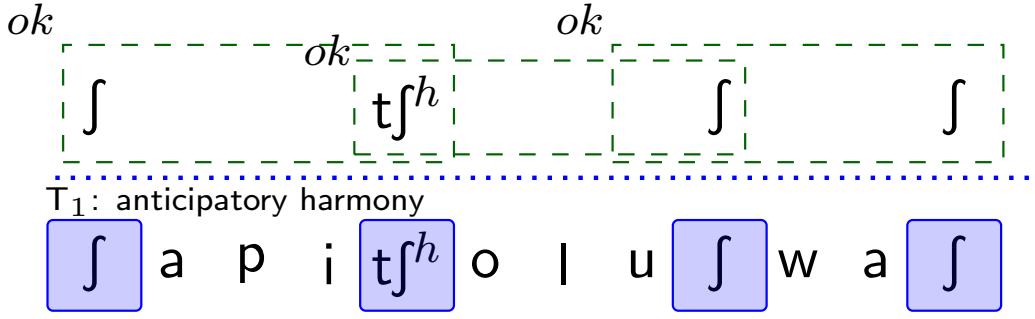

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Structure-Sensitive TSL: Over-generation

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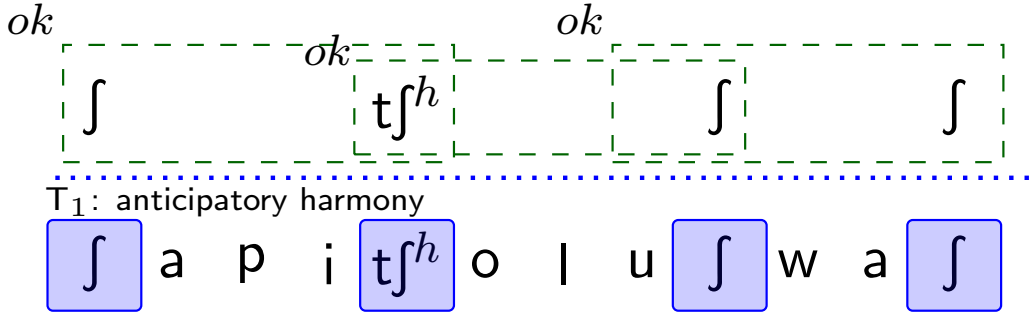

First/Last Harmony in PSEUDO-SAMALA

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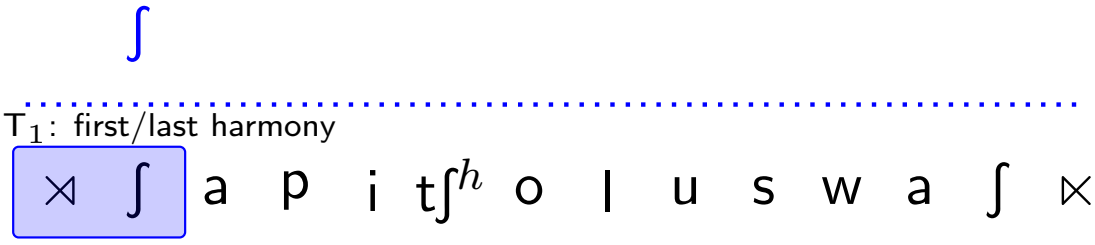

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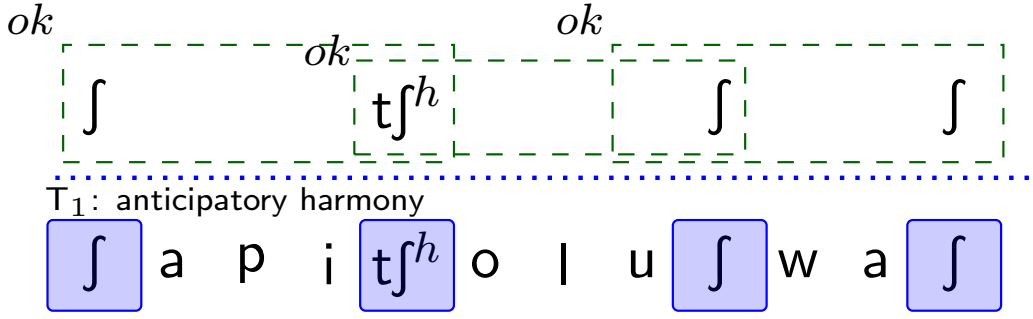

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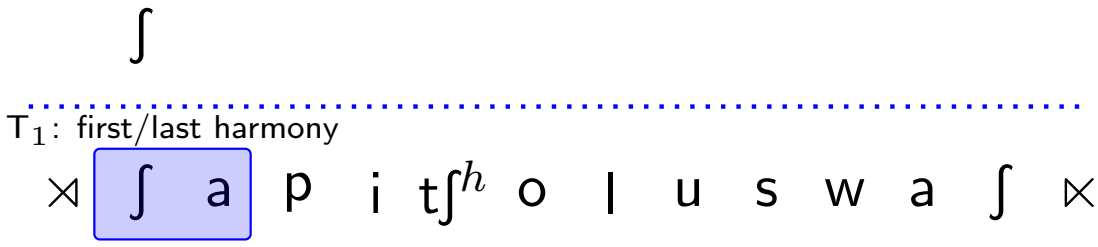

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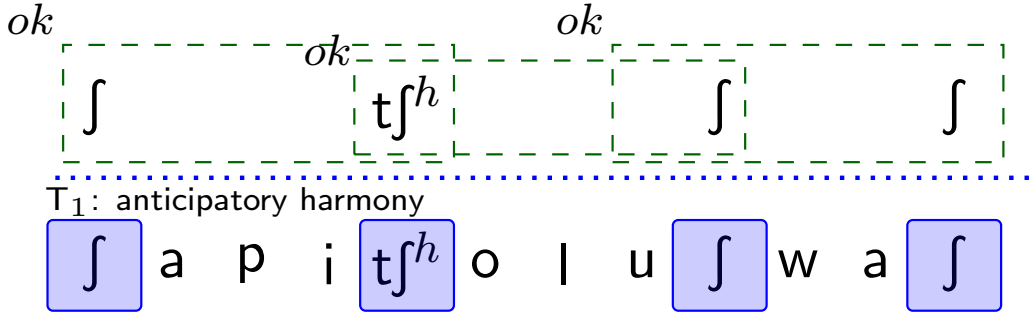

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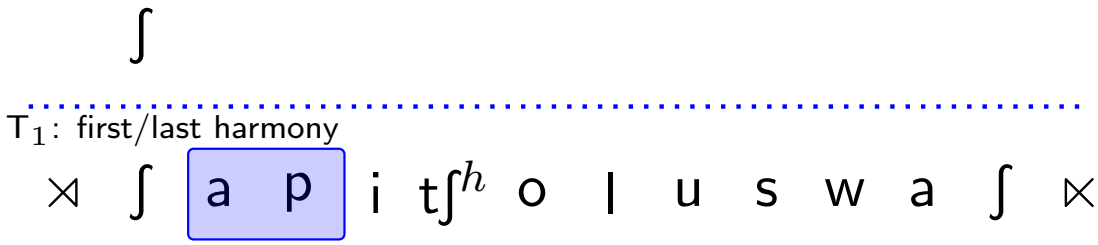

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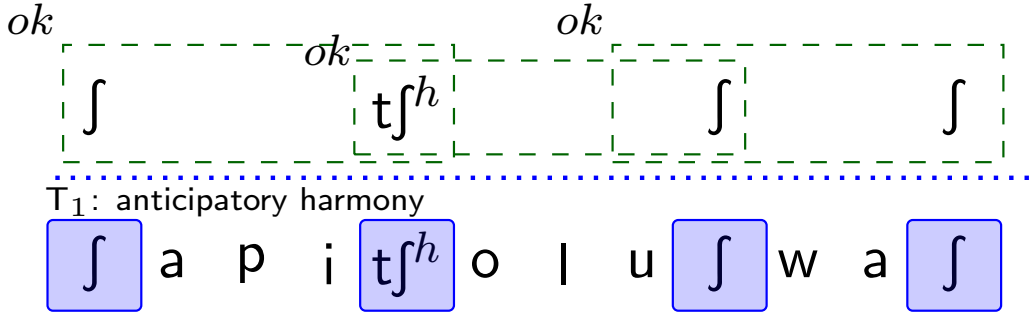

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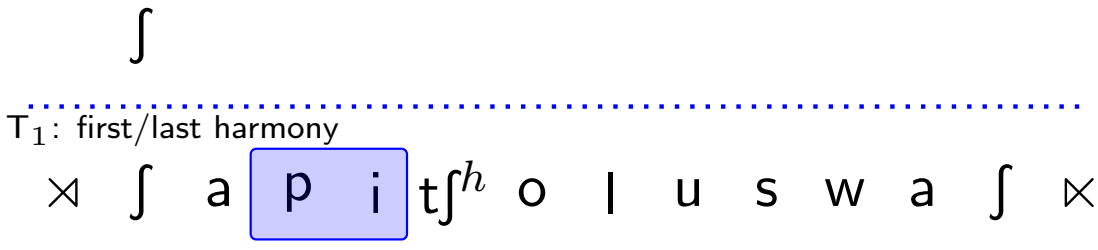

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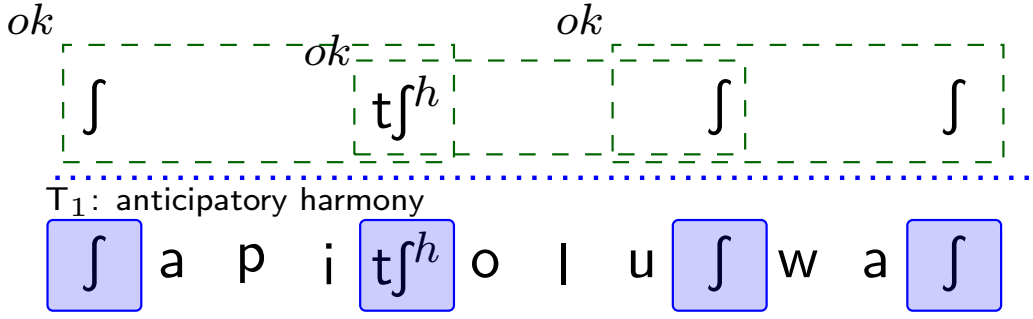

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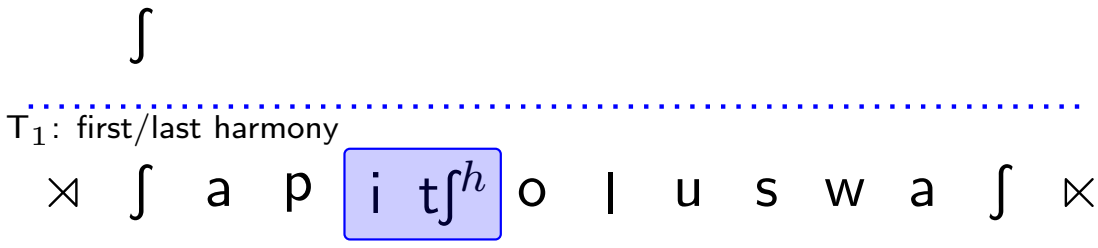

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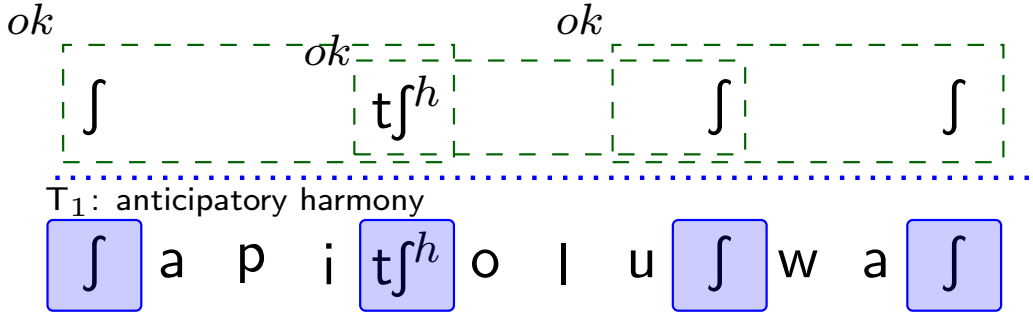

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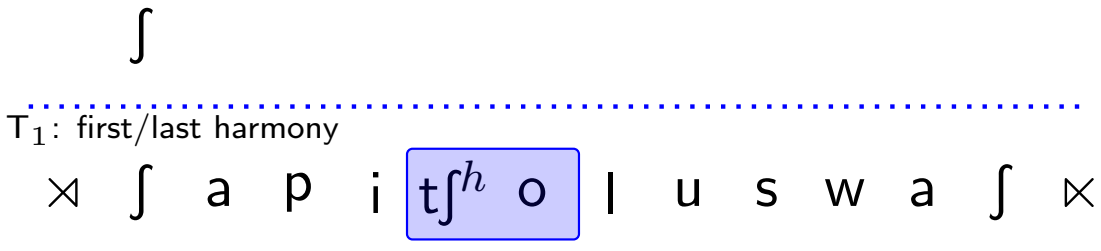

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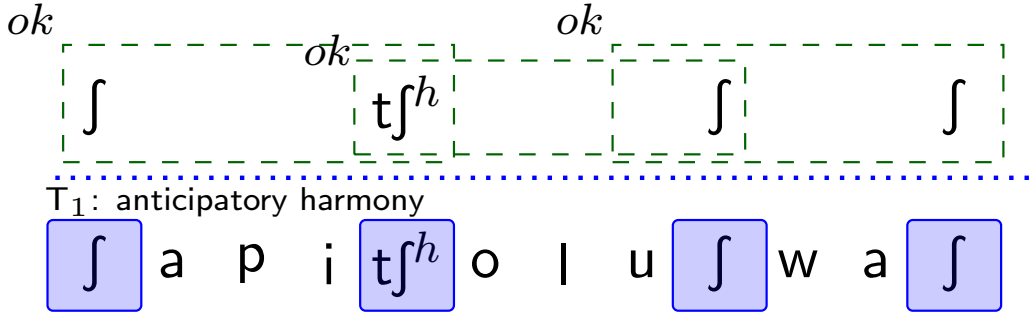

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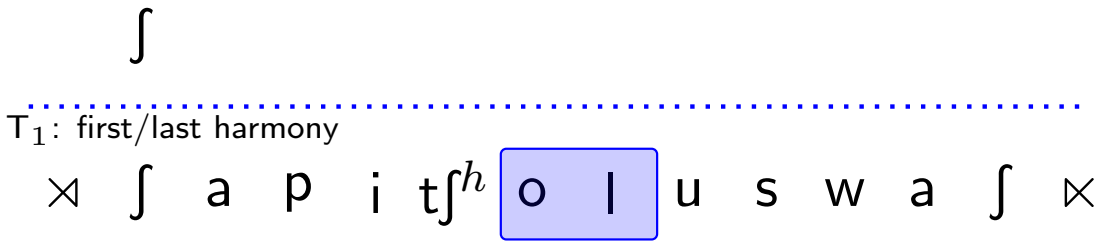

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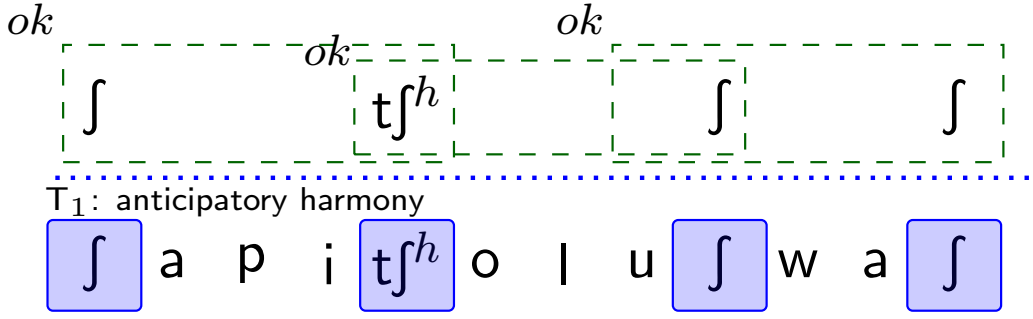

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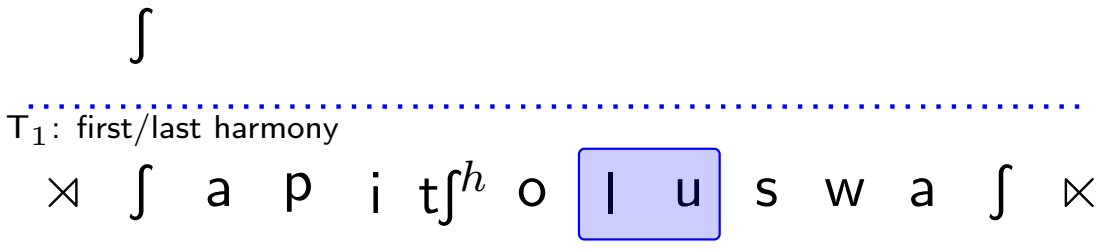

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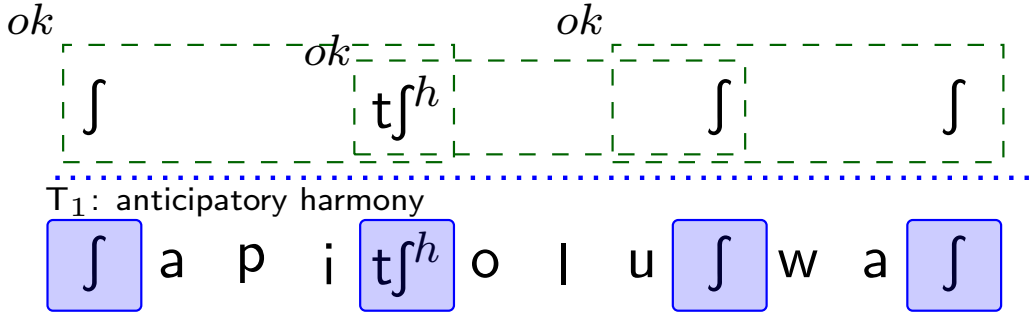

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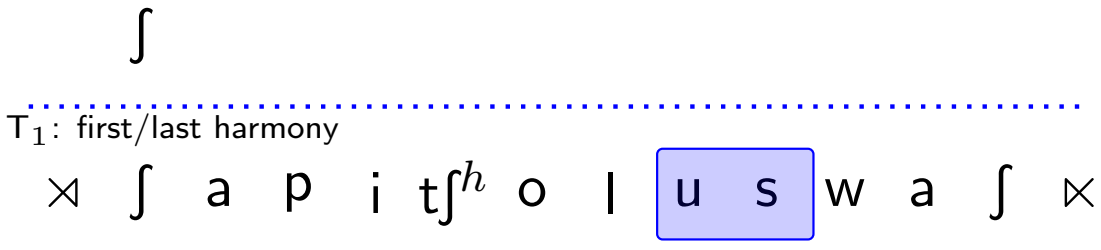

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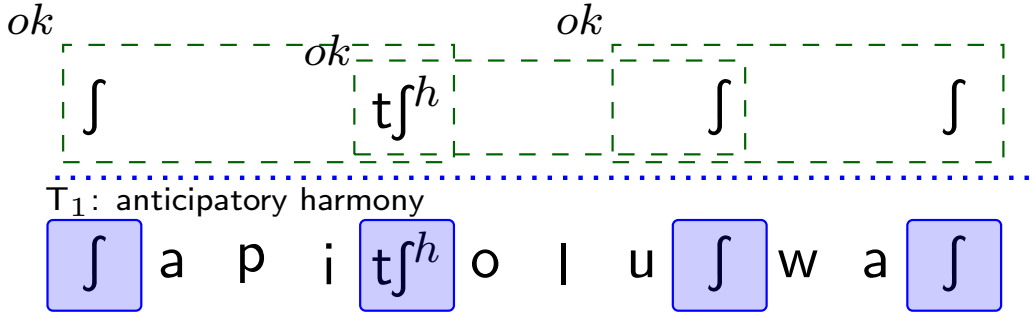

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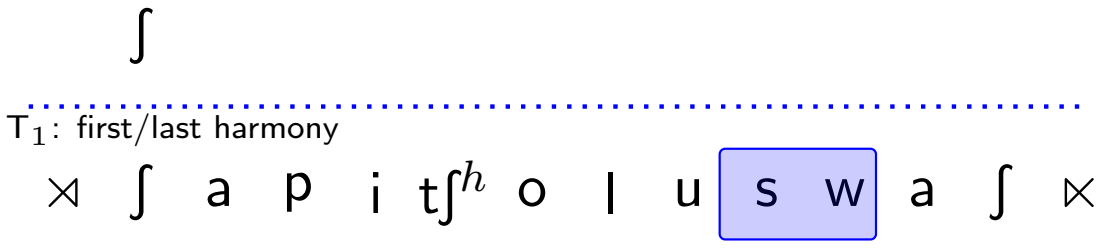

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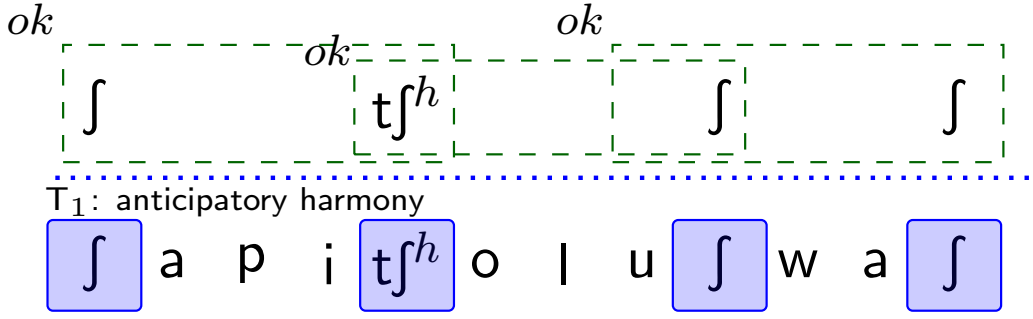

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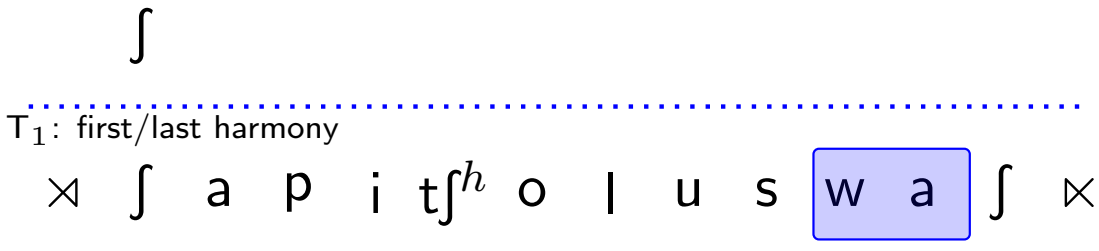

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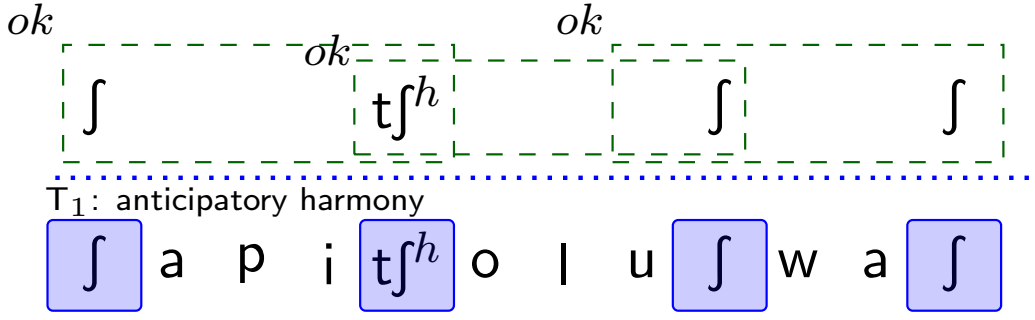

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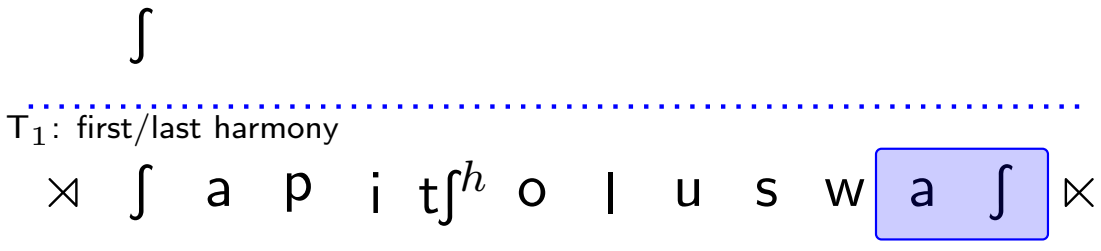

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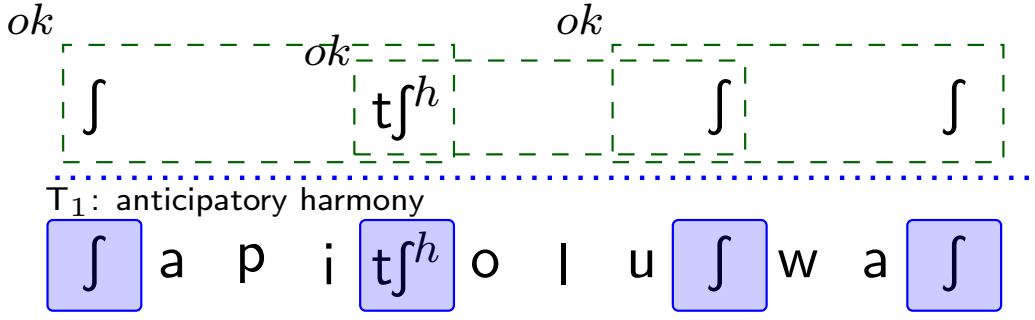

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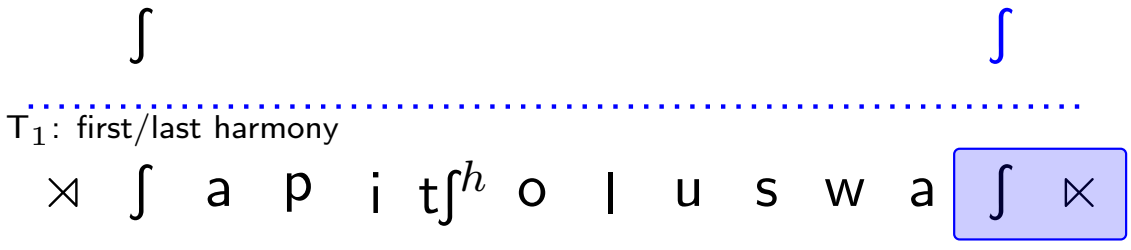

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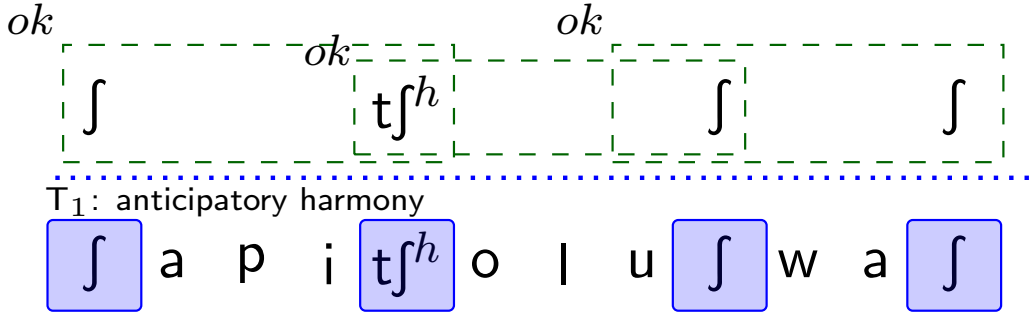

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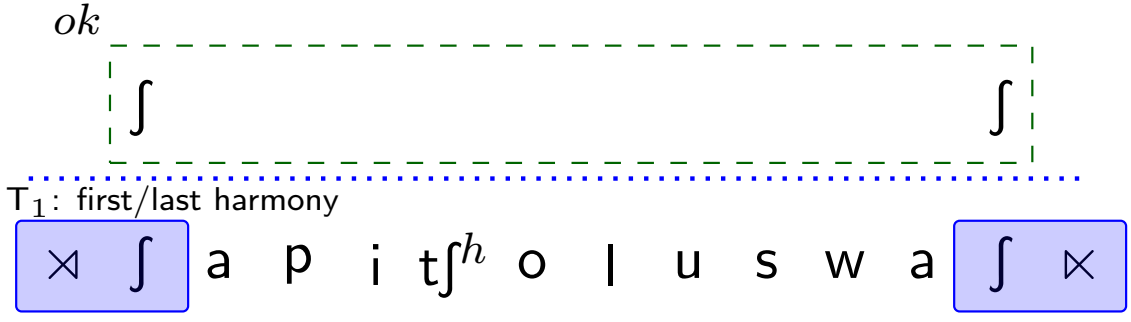

Closure Properties of Subregular Classes

	SL	TSL	MTSL	SS-TSL	SF	Reg
$\cup$	×	×	×	×	✓	✓
$\cap$	✓	×	✓	×	✓	✓
Relabeling	×	×	×	×	×	✓
Complement	×	×	×	×	✓	✓