An Alternate View on Strong Lexicalization in TAG

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TAG+12

The Talk in a Nutshell

A well-known fact

Lexicalized grammars are *good* for parsing algorithms

Problem

TAGs not closed under strong lexicalization

Idea

- generalize TAGs to multi-dimensional TAGs;
- lexicalization via increase in dimensionality:
  ⇒ every d-TAG is strongly lexicalized by some $(d+1)$-TAG

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Lexicalized Grammars

A grammar is lexicalized if the atoms from which compound structures are assembled each contain a pronounced lexical item.

Lexicalized grammars are *finitely ambiguous*:

- recognition is decidable;
- parsing is simplified [Schabes et al., 1988]

An Essential Distinction

weak lexicalization *vs* strong lexicalization

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TAGs and Lexicalization

Existing Results

- TAGs can be weakly lexicalized [Fujiyoshi, 2004]
- TAGs are not closed under strong lexicalization [Kuhlmann and Satta, 2012]
- TAGs are strongly lexicalized by context-free tree grammars of rank 2 [Maletti and Engelfriet, 2012]

Aim of this Paper

Derive lexicalization properties of TAGs by generalizing to multidimensional structures

- Every d-dimensional TAG is a $(d+1)$- dimensional TSG
- Every d-dimensional TSG is strongly lexicalized by some d-dimensional TAG
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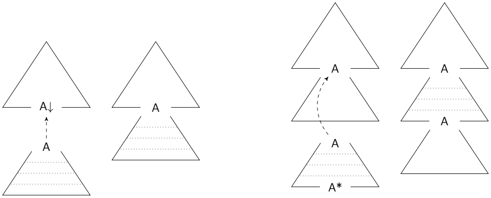

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Tree Substitution Grammar (TSG)

A restricted TAG where all licit instances of adjunction only rewrite leaf nodes

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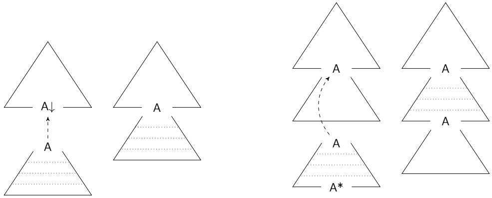

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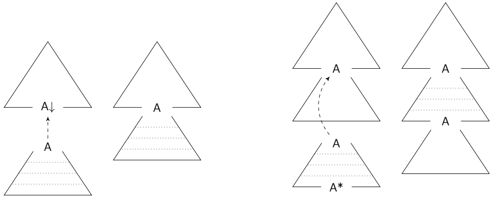

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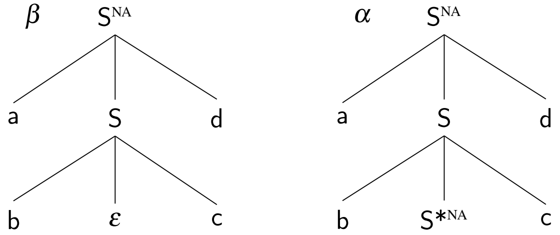

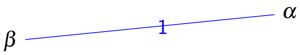

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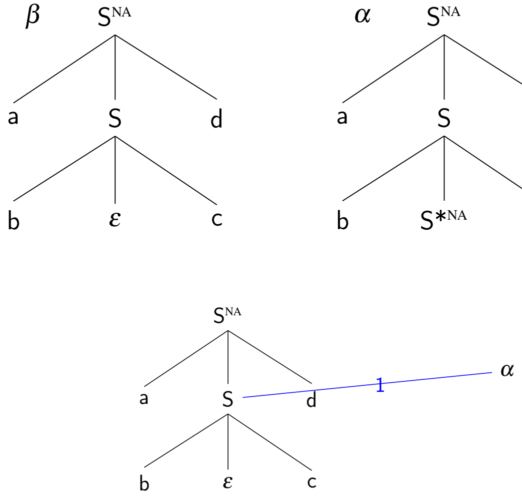

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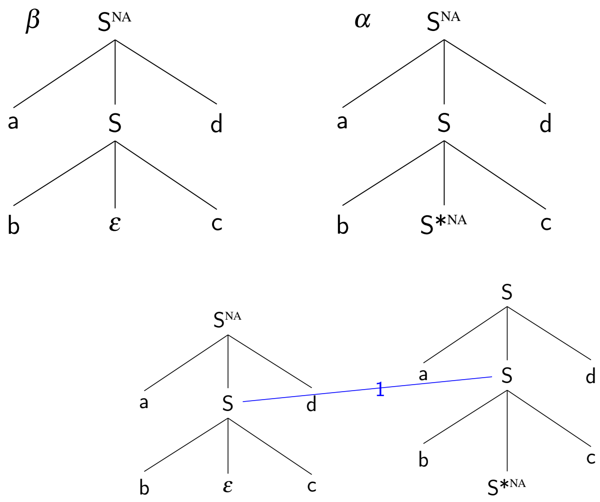

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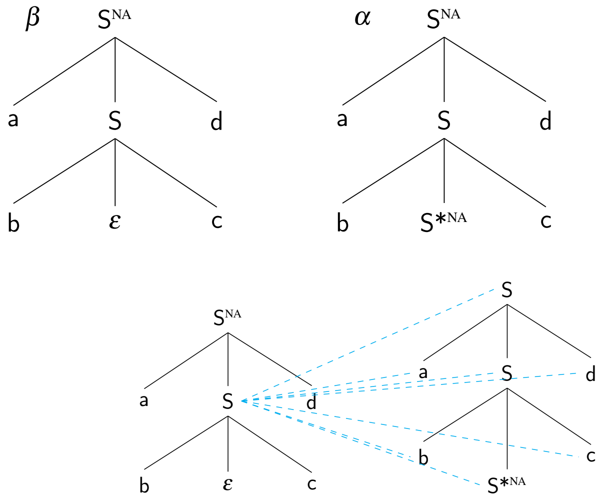

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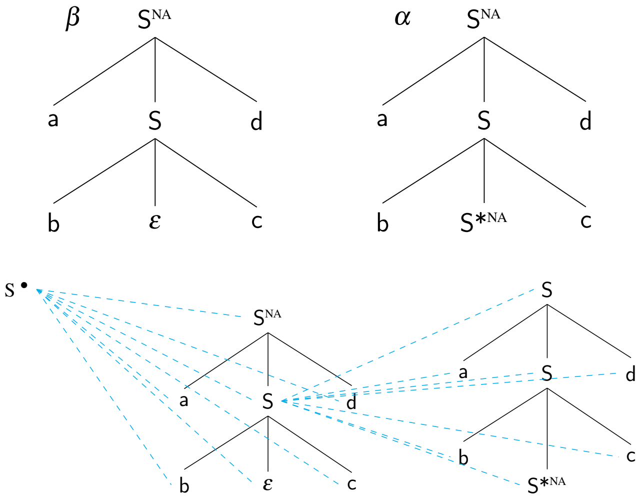
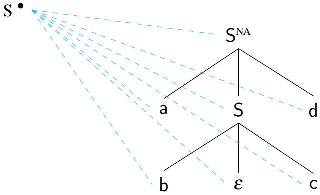


TAGs as multi-dimensional structures [Rogers, 2003]

We can increase the dimensionality of a grammar



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- d-dimensional mother
- yd^{d-1}: (d-1)-yield

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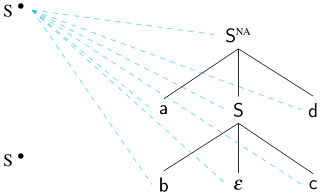

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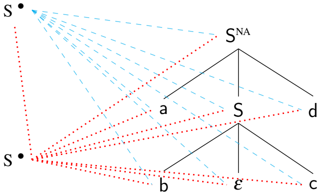

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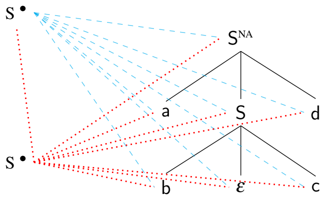

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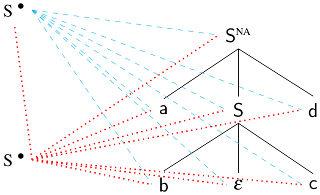

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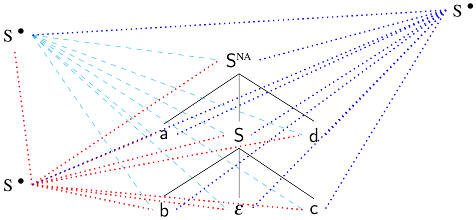

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A 4d Example

The 8-language

$$a^n b^n c^n d^n e^n f^n g^n h^n$$

(u) (w)

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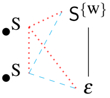

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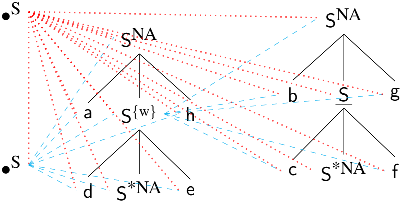

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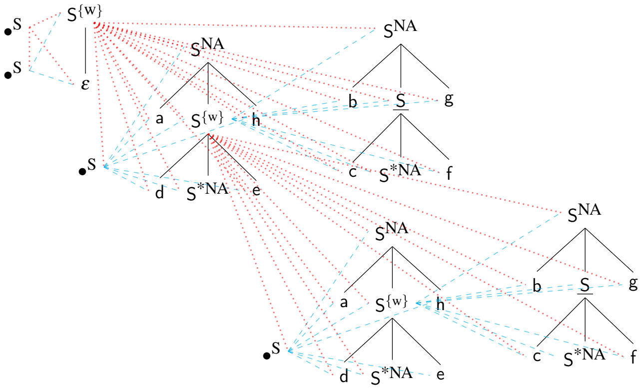
The 8-language: a derivation

The 4-d structure



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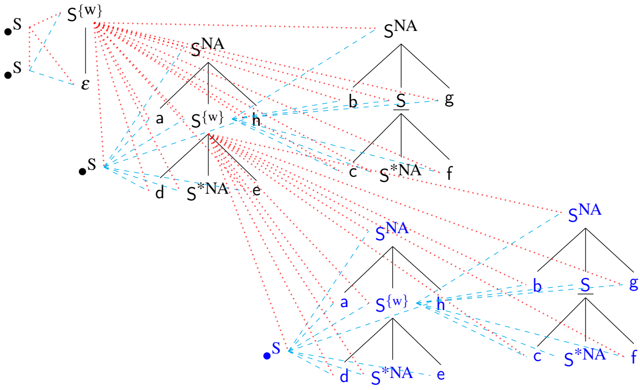

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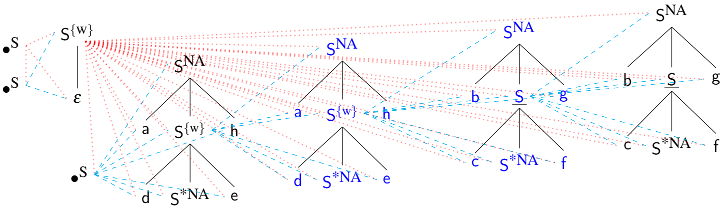
S
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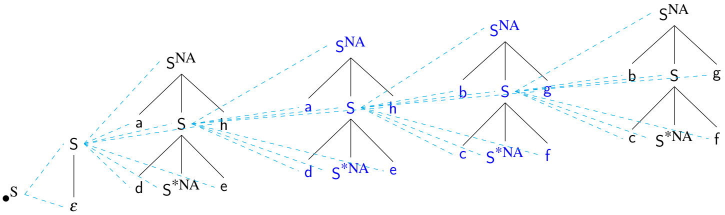

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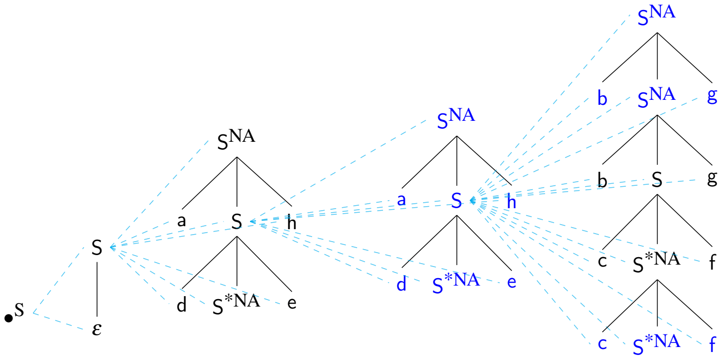

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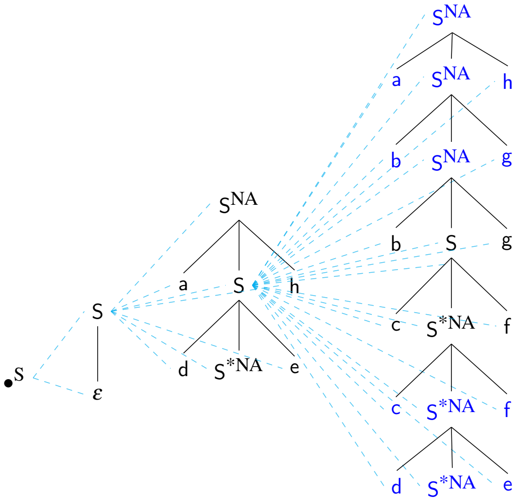

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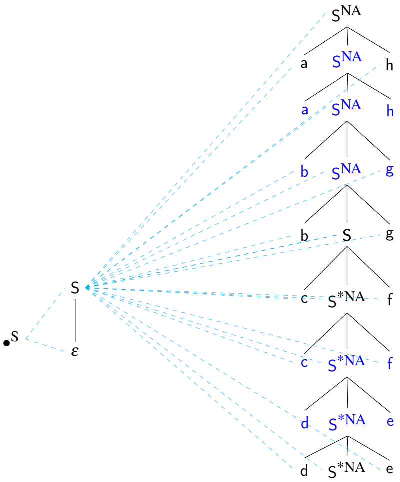

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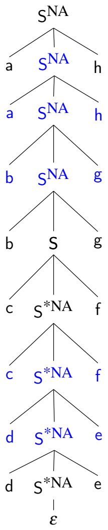

Interim Summary

The Road so far

- Substitution as Adjunction
- TAGs as natural 3-d structures
- the generalization to higher dimensions is easy

Next Steps

We can generalize existing proofs to multidimensional structures:

- d-TAGs are $(d+1)$-TSGs
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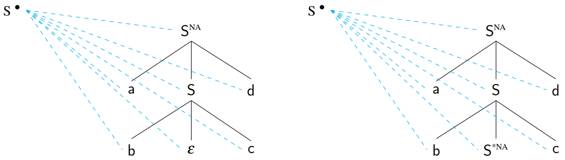

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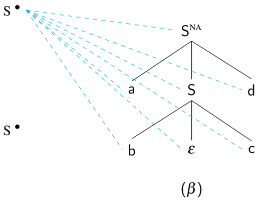

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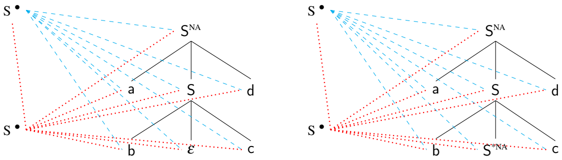

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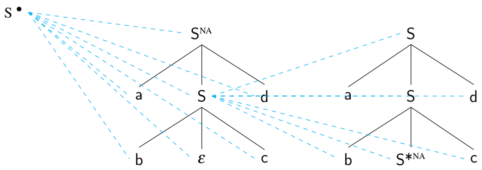

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2-dimensional mother ⇒ 3d adjunction

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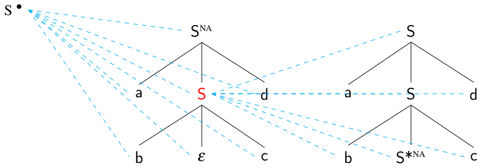

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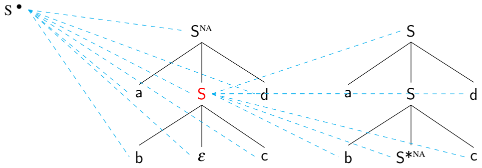

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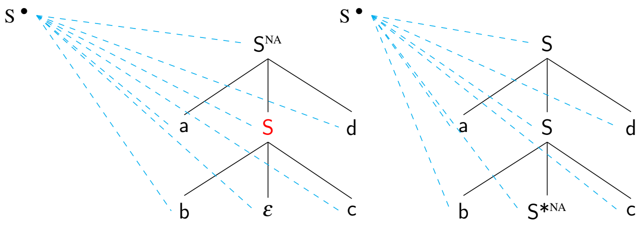

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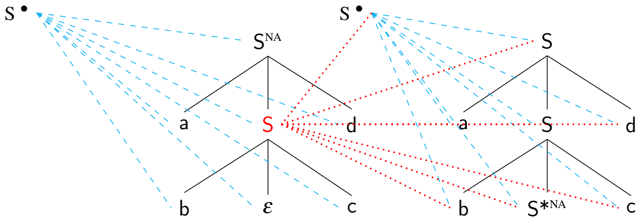

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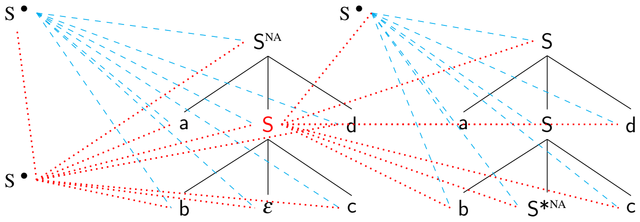

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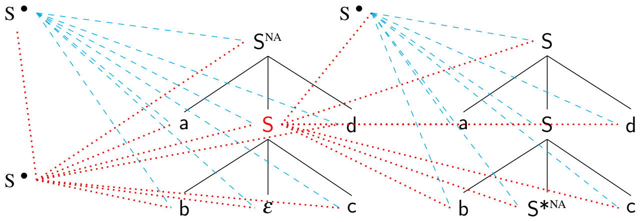

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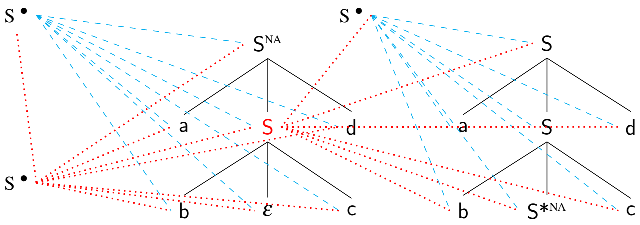

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Consider a TSG G:

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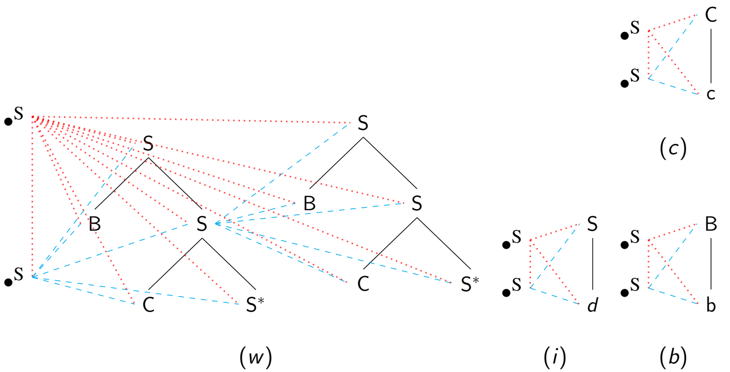

A non lexicalized 4d-TSG: a derivation

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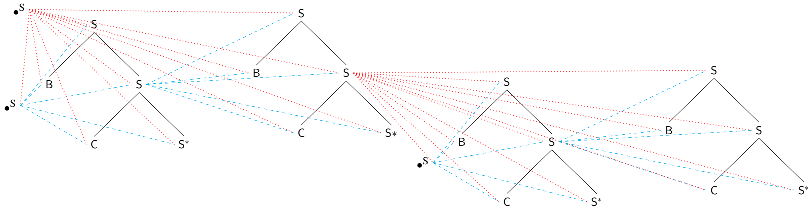

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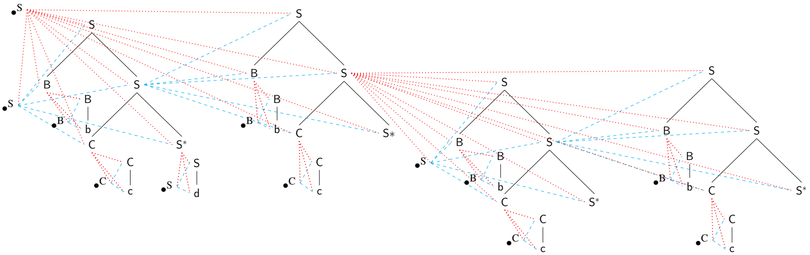

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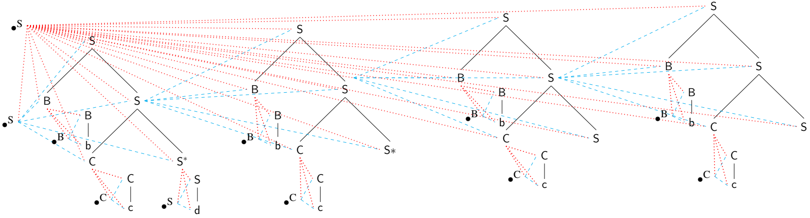

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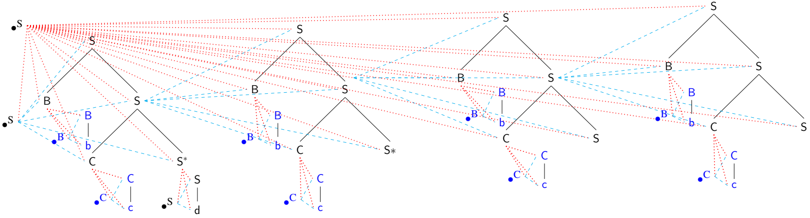

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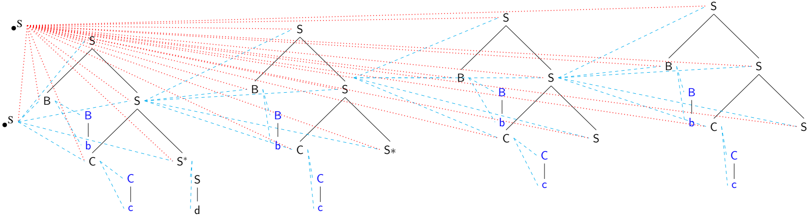

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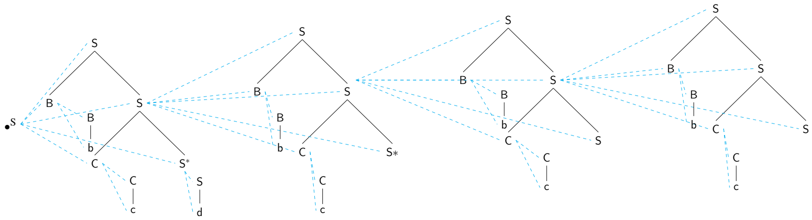

A non lexicalized 4d-TSG: a derivation

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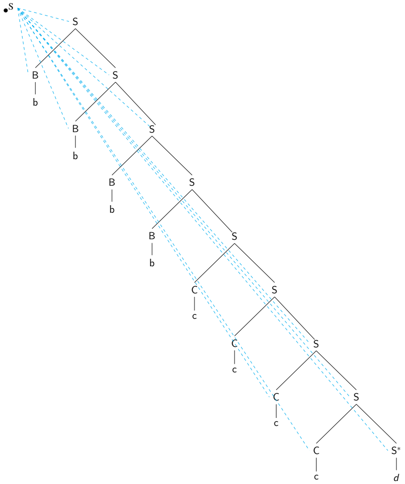

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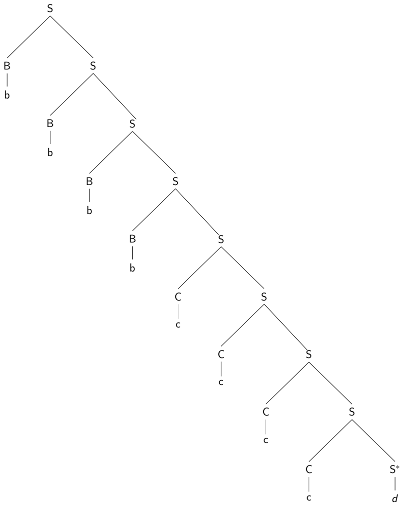

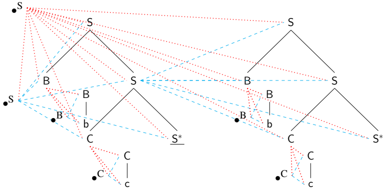

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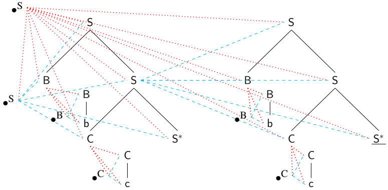
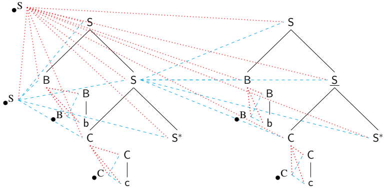
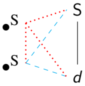


(w_3)

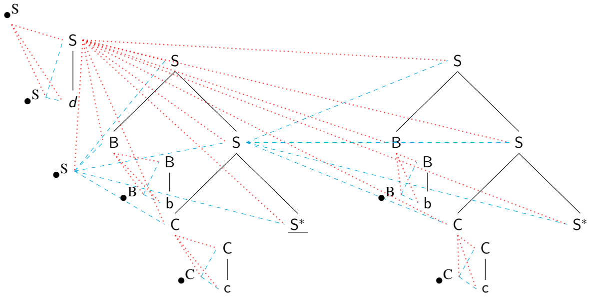


(w_1)

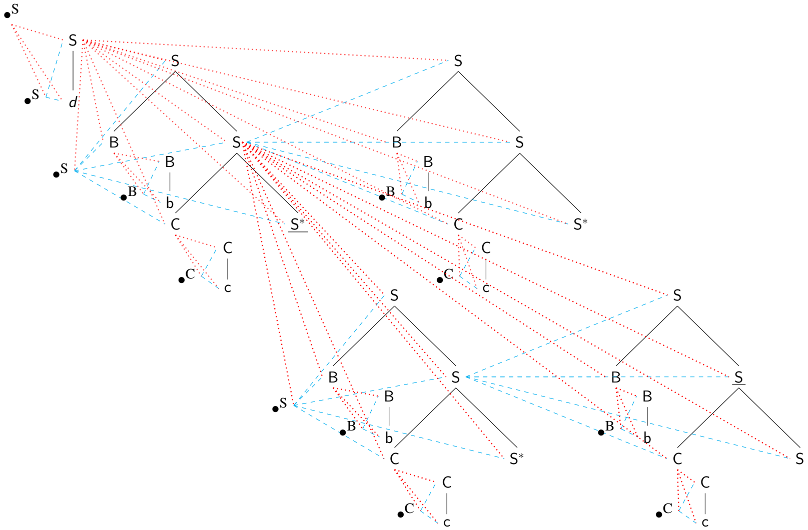


(i)

The lexicalized 4d-TAG: a derivation



The lexicalized 4d-TAG: a derivation



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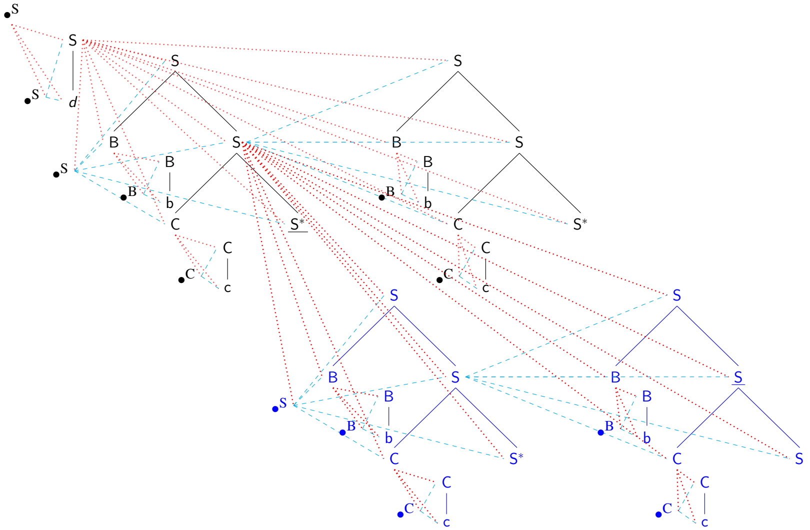
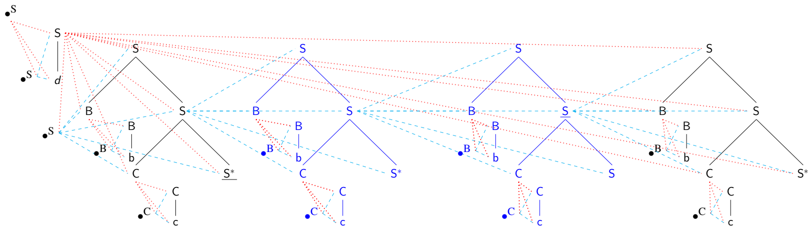
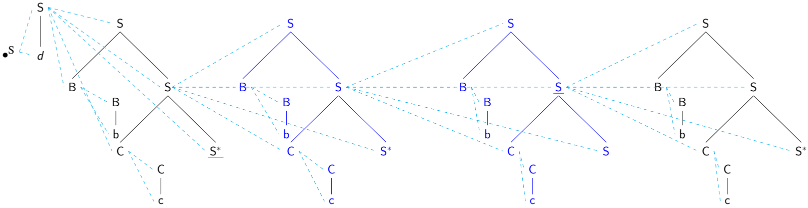


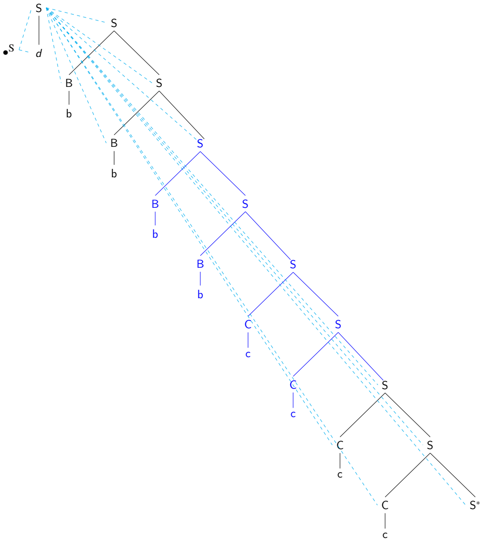
The 3d yield ...



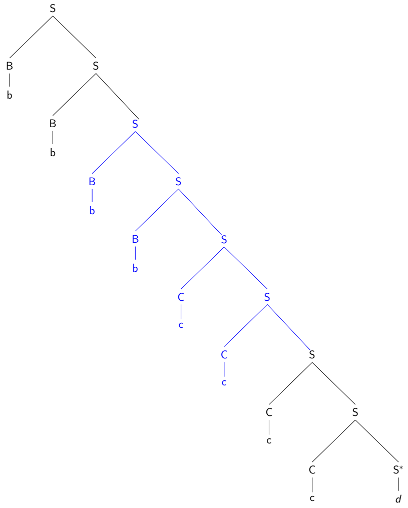
The 3d yield!



The 2d yield ...



The 2d yield!



Strong Lexicalization of d-TAGs

Proposition

For each finitely ambiguous d-dimensional TSG that does not generate the empty string and contains only useful trees, there is a strongly equivalent d-dimensional Lexicalized TAG.

but

d-TSGs are equivalent to (d - 1)-TAGs.

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Conclusion

- TAGs can be generalized to higher dimensional trees [Rogers, 2003]
- TAGs strongly lexicalize CFGs/TSGs [Schabes, 1990]

$\Rightarrow$ (d+1)-TAGs strongly lexicalize d-TAGs

TAGs as higher dimensional-trees

- lifting of existing results is straightforward
- increase in generative power
- what about parsing?

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Fujiyoshi, A. (2004).
Epsilon-free grammars and lexicalized grammars that generate the class of the mildly contextsensitive languages.
In *Proceedings of the 7th International Workshop on Tree Adjoining Grammar and Related Formalisms*, pages 16–23.

Kuhlmann, M. and Satta, G. (2012).
Tree-adjoining grammars are not closed under strong lexicalization.
Computational Linguistics, 38:617–629.

Maletti, A. and Engelfriet, J. (2012).
Strong lexicalization of tree adjoining grammars.
In *Proceedings of the 50th Annual Meeting of the Association for Computational Linguistics: Long Papers - Volume 1*, ACL '12, pages 506–515.

Selected References II

Rogers, J. (1998).
On defining TALs with logical constraints.
In Abeillé, A., Becker, T., Rambow, O., Satta, G., and Vijay-Shanker, K., editors, *Fourth International Workshop on Tree Adjoining Grammars and Related Frameworks (TAG+4)*, pages 151–154.

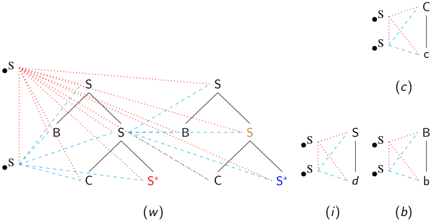
Rogers, J. (2003).
Syntactic structures as multi-dimensional trees.
Research on Language and Computation, 1:265–305.

Schabes, Y. (1990).
Mathematical and Computational Aspects of Lexicalized Grammars.
PhD thesis, Philadelphia, PA, USA.

Schabes, Y., Abeillé, A., and Joshi, A. K. (1988).
Parsing strategies with 'lexicalized' grammars: Application to tree adjoining grammars.
Technical Report MS-CIS-88-65, Department of Computer & Information Science, University of Pennsylvania, Philadelphia, PA.

Lexicalization of a d-TSG: Step 1

Step 1: Determine Recursion



The TSG is Partitioned in Two Sets

$NR = \{b, c, i\}$
$R = \{I - NR\} = \{w\}$

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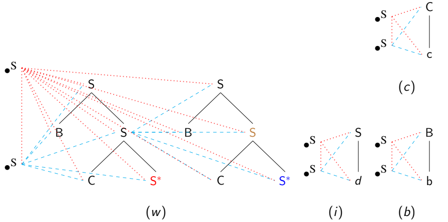

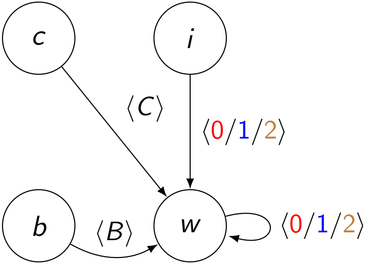

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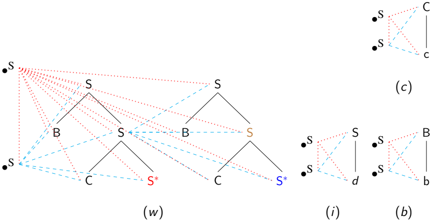

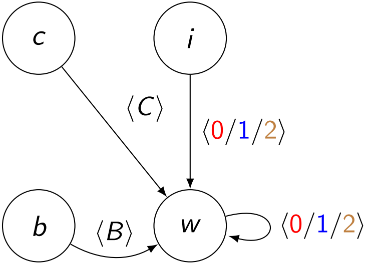

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Step 2: Determine the set I_{lex}.

- $T(NR)$: the closure of NR under adjunction

I_{lex}

is the maximal subset of $T(NR)$ that only contains d-trees whose root is labeled by the start category S.

$$I_{lex} = \{i\}$$

Lexicalization of a d-TSG: Step 2

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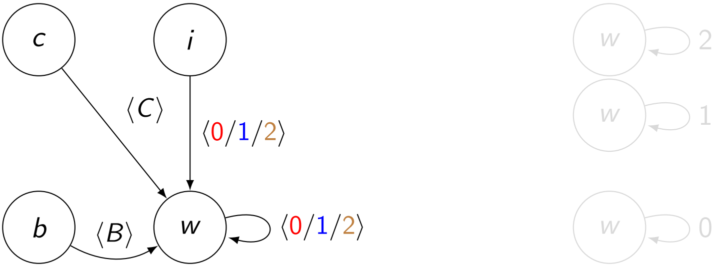
Step 3: Compute Base Cycles



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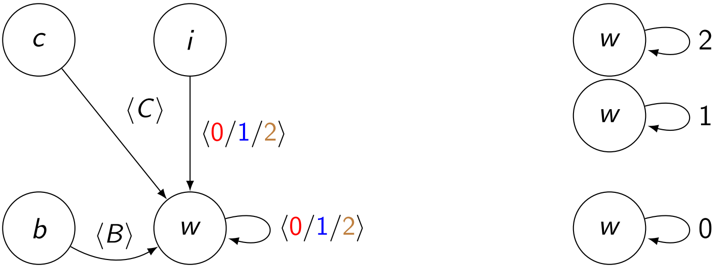
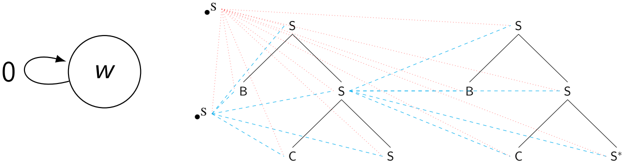
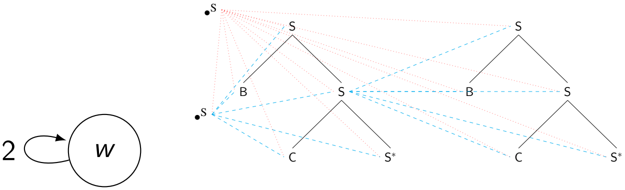


Lexicalization of a d-TSG: Step 4

Step 4: Determine A_{lex}

- expand base cycles;
- relabel $3d$ foot node;
- exhaustive substitution;





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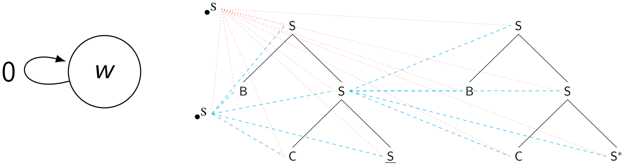

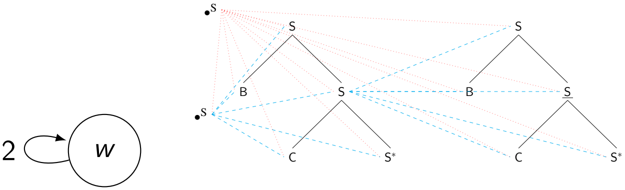

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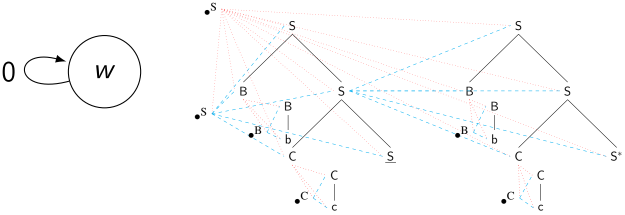
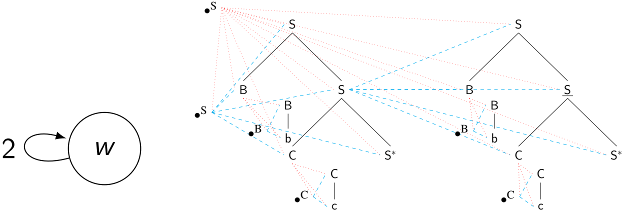


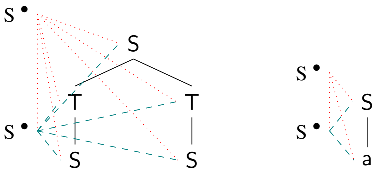


One final question

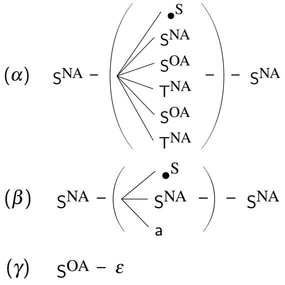
Are *d*-dimensional TAGs closed under strong lexicalization?

[Kuhlmann and Satta, 2012]

TAGs are not closed under strong lexicalization



(α) (β)



Excess

measures the distance between a root node and a terminal node

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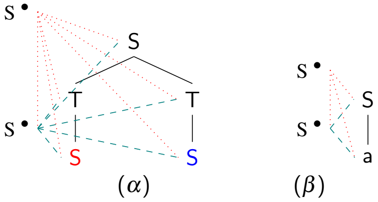

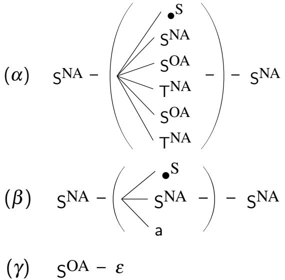

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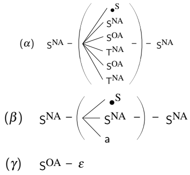
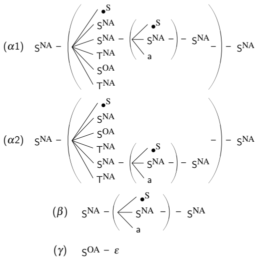
d-TAGs are not closed under strong lexicalization

Non Lexicalized



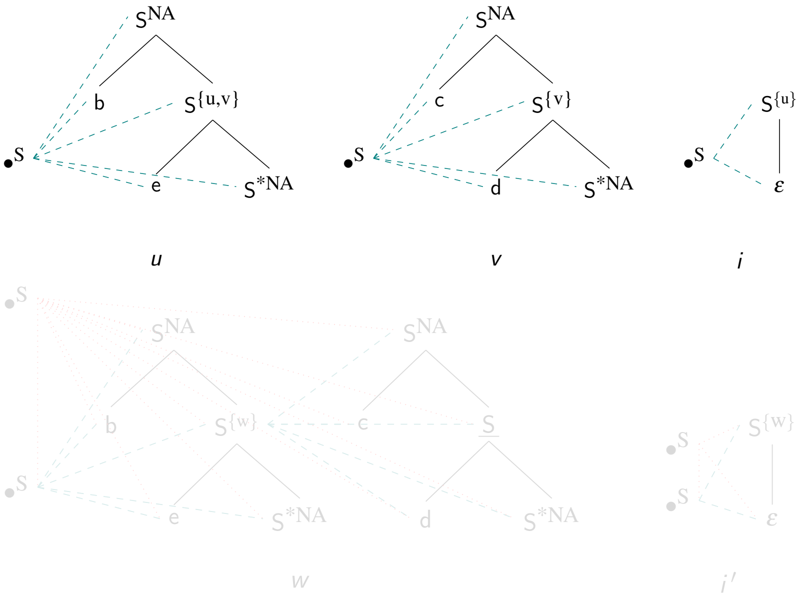
max. excess of node *a* is unbounded

Lexicalized



max excess of node *a* is 2

Increasing the power by increasing the dimensionality: Ex. 2



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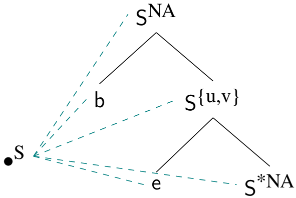
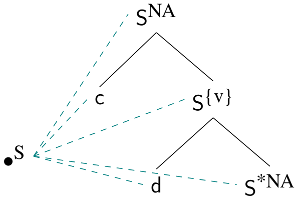
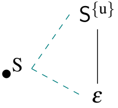


u



v



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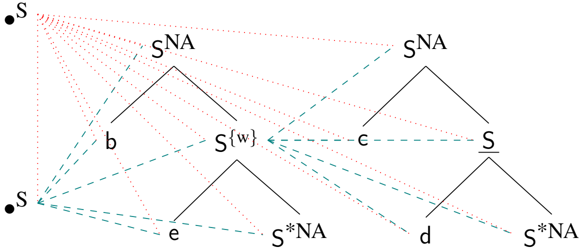

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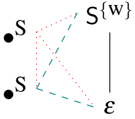

i′

Map of Existing Results