

An Introduction to
Mildly Context-Sensitive Grammar Formalisms
— *Cross-Serial Dependencies* —

Gerhard Jäger & Jens Michaelis
Universität Potsdam

`{jaeger,michael}@ling.uni-potsdam.de`

example: 'that Charles lets Mary help Peter to teach John to swim'

example: 'that Charles lets Mary help Peter to teach John to swim'

daß der Karl die Maria dem Peter den Hans schwimmen

that Charles Mary₁ Peter₂-DAT John₃-ACC swim₃-inf

lehren helfen läßt

teach₂-inf help₁-inf lets

example: 'that Charles lets Mary help Peter to teach John to swim'

daß der Karl die Maria dem Peter den Hans schwimmen

that Charles Mary₁ Peter₂-DAT John₃-ACC swim₃-inf

lehren helfen läßt

teach₂-inf help₁-inf lets

dat Karel Marie Piet Jan laat helpen leren zwemmen

that Charles Mary₁ Peter₂ John₃ lets help₁-inf teach₂-inf swim₃-inf

example: 'that Charles lets Mary help Peter to teach John to swim'

daß der Karl die Maria dem Peter den Hans schwimmen

that Charles Mary₁ Peter₂-DAT John₃-ACC swim₃-inf

lehren helfen läßt

teach₂-inf help₁-inf lets

dat Karel Marie Piet Jan laat helpen leren zwemmen

that Charles Mary₁ Peter₂ John₃ lets help₁-inf teach₂-inf swim₃-inf

example: 'that Charles lets Mary help Peter to teach John to swim'

daß der Karl die Maria dem Peter den Hans schwimmen

that Charles Mary₁ Peter₂-DAT John₃-ACC swim₃-inf

lehren helfen läßt

teach₂-inf help₁-inf lets

dat Karel Marie Piet Jan laat helpen leren zwemmen

that Charles Mary₁ Peter₂ John₃ lets help₁-inf teach₂-inf swim₃-inf

example: 'that Charles lets Mary help Peter to teach John to swim'

daß der Karl die Maria dem Peter^m den Hans schwimmen

that Charles Mary₁ Peter₂-DAT John₃-ACC swim₃-inf

lehren^m helfen^m läßt

teach₂-inf help₁-inf lets

dat Karel Marie Piet^m Jan laat helpen^m leren zwemmen

that Charles Mary₁ Peter₂ John₃ lets help₁-inf teach₂-inf swim₃-inf

example: 'that Charles lets Mary help Peter to teach John to swim'

daß der Karl die Maria dem Peter^m den Hansⁿ schwimmen

that Charles Mary₁ Peter₂-DAT John₃-ACC swim₃-inf

lehrenⁿ helfen^m läßt

teach₂-inf help₁-inf lets

dat Karel Marie Piet^m Janⁿ laat helpen^m lerenⁿ zwemmen

that Charles Mary₁ Peter₂ John₃ lets help₁-inf teach₂-inf swim₃-inf

example: 'that Charles lets Mary help Peter to teach John to swim'

daß der Karl die Maria dem Peter^m den Hansⁿ schwimmen

that Charles Mary₁ Peter₂-DAT John₃-ACC swim₃-inf

lehrenⁿ helfen^m läßt

teach₂-inf help₁-inf lets

■ *German fragment as string language: $a^m b^n d^n c^m$ — CFL*

dat Karel Marie Piet^m Janⁿ laat helpen^m lerenⁿ zwemmen

that Charles Mary₁ Peter₂ John₃ lets help₁-inf teach₂-inf swim₃-inf

■ *Dutch fragment as string language: $a^m b^n c^m d^n$ — Non-CFL*

example: 'that Charles lets Mary help Peter to teach John to swim'

dass de Karl d'Maria em Peter de Hans laat helfe lerne

that Charles Mary₁ Peter₂-DAT John₃-ACC lets help₁-inf teach₃-inf

schwüme

swim₃-inf

example: 'that Charles lets Mary help Peter to teach John to swim'

dass de Karl d'Maria em Peter de Hans laat helfe lerne

that Charles Mary₁ Peter₂-DAT John₃-ACC lets help₁-inf teach₃-inf

schwüme

swim₃-inf

example: 'that Charles lets Mary help Peter to teach John to swim'

dass de Karl d'Maria em Peter^m de Hansⁿ laat hülfe^m lärneⁿ

that Charles Mary₁ Peter₂-DAT John₃-ACC lets help₁-inf teach₃-inf

schwüme

swim₃-inf

example: 'that Charles lets Mary help Peter to teach John to swim'

dass de Karl d'Maria em Peter^m de Hansⁿ laat hülfe^m lärneⁿ

that Charles Mary₁ Peter₂-DAT John₃-ACC lets help₁-inf teach₃-inf

schwüme

swim₃-inf

■ *Züritüütsch fragment as string language: $a^m b^n c^m d^n$ — Non-CFL*

Swiss German example: '...' the homomorphism h

$$h(\text{em Peter}) = a$$

$$h(\text{de Hans}) = b$$

$$h(\text{h\u00e4lfe}) = c$$

$$h(\text{l\u00e4rne}) = d$$

$$h(s) = \varepsilon \quad \text{otherwise}$$

Swiss German example: '...' the homomorphism h

$$h(\text{em Peter}) = a$$

$$h(\text{de Hans}) = b$$

$$h(\text{halfe}) = c$$

$$h(\text{larne}) = d$$

$$h(s) = \varepsilon \text{ otherwise}$$

L the Swiss German language/Zuritutsch

Swiss German example: '...' the homomorphism h

$$h(\text{em Peter}) = a$$

$$h(\text{de Hans}) = b$$

$$h(\text{halfe}) = c$$

$$h(\text{larne}) = d$$

$$h(s) = \varepsilon \quad \text{otherwise}$$

L the Swiss German language/Zuritutsch

$$h(L) \cap \{a^k b^l c^m d^n \mid k, l, m, n \geq 0\} = \{a^m b^n c^m d^n \mid m, n \geq 0\}$$

Swiss German example: ‘...’ the homomorphism h

$$h(\text{em Peter}) = a$$

$$h(\text{de Hans}) = b$$

$$h(\text{halfe}) = c$$

$$h(\text{larne}) = d$$

$$h(s) = \varepsilon \quad \text{otherwise}$$

L the Swiss German language/Zuritutsch

$$h(L) \cap \{a^k b^l c^m d^n \mid k, l, m, n \geq 0\} = \{a^m b^n c^m d^n \mid m, n \geq 0\}$$

Assuming Swiss German to be context-free, therefore, would yield a contradiction to the fact that the class of CFLs is closed under intersection with regular sets.

Dutch example: '...' the homomorphism h

$$h(\text{Piet}) = a$$

$$h(\text{Hans}) = b$$

$$h(\text{helpen}) = c$$

$$h(\text{leren}) = d$$

$$h(s) = \varepsilon \quad \text{otherwise}$$

Dutch example: '...' the homomorphism h

$$h(\text{Piet}) = a$$

$$h(\text{Hans}) = b$$

$$h(\text{helpen}) = c$$

$$h(\text{leren}) = d$$

$$h(s) = \varepsilon \quad \text{otherwise}$$

L the Dutch language

Dutch example: '...' the homomorphism h

$$h(\text{Piet}) = a$$

$$h(\text{Hans}) = b$$

$$h(\text{helpen}) = c$$

$$h(\text{leren}) = d$$

$$h(s) = \varepsilon \quad \text{otherwise}$$

L the Dutch language

$$h(L) \cap \{a^k b^l c^m d^n \mid k, l, m, n \geq 0\} = \{a^k b^l c^m d^n \mid k + l = m + n\}$$

Dutch example: '...' the homomorphism h

$$h(\text{Piet}) = a$$

$$h(\text{Hans}) = b$$

$$h(\text{helpen}) = c$$

$$h(\text{leren}) = d$$

$$h(s) = \varepsilon \text{ otherwise}$$

L the Dutch language

$$h(L) \cap \{a^k b^l c^m d^n \mid k, l, m, n \geq 0\} = \{a^k b^l c^m d^n \mid k + l = m + n\}$$

■ $\{a^k b^l c^m d^n \mid k + l = m + n\}$ is context-free

Dutch example: ‘...’ the homomorphism h

$$h(\text{Piet}) = a$$

$$h(\text{Hans}) = b$$

$$h(\text{helpen}) = c$$

$$h(\text{leren}) = d$$

$$h(s) = \varepsilon \quad \text{otherwise}$$

L the Dutch language

$$h(L) \cap \{a^k b^l c^m d^n \mid k, l, m, n \geq 0\} = \{a^k b^l c^m d^n \mid k + l = m + n\}$$

- The CFG $G = \langle \{S, T, U, V\}, \{a, b, c, d\}, R, S \rangle$ “does the job,” where $R = \{S \rightarrow a S d \mid a T c \mid b U d \mid b V c \mid \varepsilon, T \rightarrow a T c \mid b U d \mid b V c \mid \varepsilon, U \rightarrow b U d \mid b V c \mid \varepsilon, V \rightarrow b V c \mid \varepsilon\}$

... 'that we have wanted to let the children help Hans paint the house'

dass mer de chind em Hans es hus händ weele laa

that we the children₁-ACC Hans₂-DAT the house₃ have wanted let₁-inf

hälfe aastriiche

help₂-inf paint₃-inf

... 'that we have wanted to let the children help Hans paint the house'

dass mer **de chind** **em Hans** es hus händ weele **laa**

that we the children₁-ACC Hans₂-DAT the house₃ have wanted let₁-inf

hölfe aastriiche

help₂-inf paint₃-inf

... 'that we have wanted to let the children help Hans paint the house'

dass mer **de chind^m** **em Hansⁿ** es hus händ weele **laa^m**

that we the children₁-ACC Hans₂-DAT the house₃ have wanted let₁-inf

hälfeⁿ aastriiche

help₂-inf paint₃-inf

... 'that we have wanted to let the children help Hans paint the house'

dass mer **de chind**^m **em Hans**ⁿ es hus händ weele **laa**^m

that we the children₁-ACC Hans₂-DAT the house₃ have wanted let₁-inf

hälfeⁿ aastriche

help₂-inf paint₃-inf

■ *Züritüütsch fragment as string language: $a^m b^n c^m d^n$ — Non-CFL*

dat Karel Marie Piet Jan laat helpen leren zwemmen

that Charles Mary₁ Peter₂ John₃ lets help₁-inf teach₂-inf swim₃-inf

dat Karel Marie Piet Jan laat helpen leren zwemmen

that Charles Mary₁ Peter₂ John₃ lets help₁-inf teach₂-inf swim₃-inf

dat velen iets iemand alles zagen helpen laten

that many something₁ someone₂ everything₃ saw help₁-inf let₂-inf

ontploffen

explode₃-inf

dat Karel Marie Piet Jan laat helpen leren zwemmen

that Charles Mary₁ Peter₂ John₃ lets help₁-inf teach₂-inf swim₃-inf

dat velen iets iemand alles zagen helpen laten

that many something₁ someone₂ everything₃ saw help₁-inf let₂-inf

ontploffen

explode₃-inf

dat Karel Marie Piet Jan laat helpen leren zwemmen

that Charles Mary₁ Peter₂ John₃ lets help₁-inf teach₂-inf swim₃-inf

dat velen iets iemand alles zagen helpen laten

that many something₁ someone₂ everything₃ saw help₁-inf let₂-inf

ontploffen

explode₃-inf

dat Karel Marie Piet^m Janⁿ laat helpen^m lerenⁿ zwemmen

that Charles Mary₁ Peter₂ John₃ lets help₁-inf teach₂-inf swim₃-inf

dat velen iets iemand^m allesⁿ zagen helpen^m latenⁿ

that many something₁ someone₂ everything₃ saw help₁-inf let₂-inf

ontploffen

explode₃-inf

dat Karel Marie Piet^m Janⁿ laat helpen^m lerenⁿ zwemmen

that Charles Mary₁ Peter₂ John₃ lets help₁-inf teach₂-inf swim₃-inf

dat velen iets iemand^m allesⁿ zagen helpen^m latenⁿ

that many something₁ someone₂ everything₃ saw help₁-inf let₂-inf

ontploffen

explode₃-inf

■ *Dutch fragment as string language: $a^m b^n c^m d^n$ — Non-CFL*