Statistical Machine Translation of Natural Languages

Heiko Vogler
Technische Universität Dresden
Germany

Graduiertenkolleg "Quantitative Logics and Automata"
Dresden, November, 2012

Weighted Tree Automata and Weighted Tree Transducers

can help in

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outline of the talk:

- Statistical machine translation

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given:

- source language SL
- target language TL

find:

translation $h : \mathrm{SL} \to \mathrm{TL}$

e.g.

SL = English
TL = German

s = I saw the man with the telescope
h(s) = Ich sah den Mann durch das Tel.

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assumptions $\longrightarrow$ [modeling] $\longrightarrow$ $\mathcal{H}$ hypothesis space

assumptions: mental work, experience, no data

hypothesis space: $\mathcal{H} \subseteq \{h \mid h : \mathrm{SL} \to \mathrm{TL}\}$

log-linear modeling:

$\overline{\hspace{3em}}_{s \in SL}$ $\overline{\hspace{3em}}_{t \in TL}$

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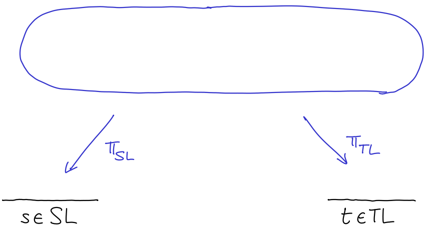

set Y of correspondence structures [Liang et al. 06]

$\pi_{SL} : Y \to \mathrm{SL}$
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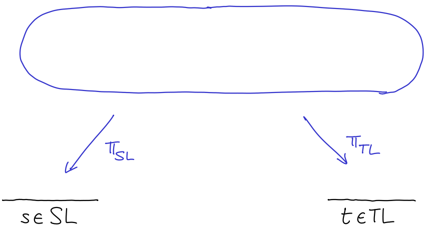

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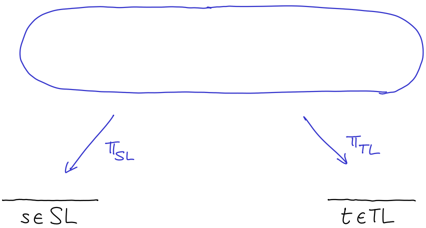

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here:

$$m = 2$$
$$\Phi(y) = (h_{\mathrm{TM}}(y), h_{\mathrm{LM}}(y))$$

h_{TM}: translation model
h_{LM}: language model

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first assumption:

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weighted tree language: $L : T_{\Sigma} \to \mathbb{R}$

L is recognizable:

if there is a wta $\mathcal{A}$
which "recognizes" (computes) L

weighted tree automaton (wta) $\mathcal{A} = (Q, \Sigma, \delta, F)$

- Q finite set (states)
- Σ ranked alphabet (input symbols)
- $\delta = (\delta_\sigma \mid \sigma \in \Sigma)$ $\quad \delta_\sigma : Q^k \times Q \to \mathbb{R}$
  $\delta_\sigma(q_1 \cdots q_k, q) \in \mathbb{R}$
- $F \subseteq Q$ (final states)

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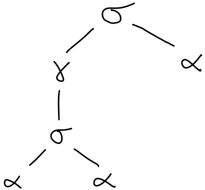

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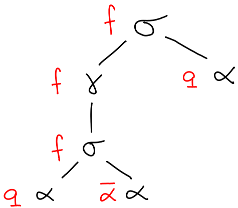

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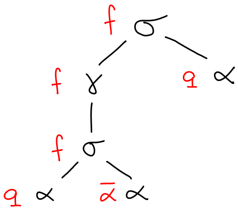

σ: label of ξ at w

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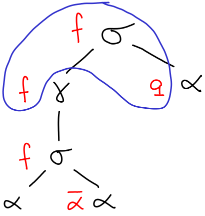
$w = \varepsilon$

$\delta_\sigma(fq, f)$



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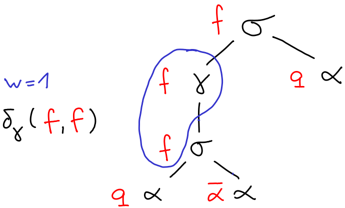

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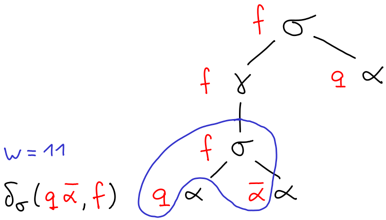

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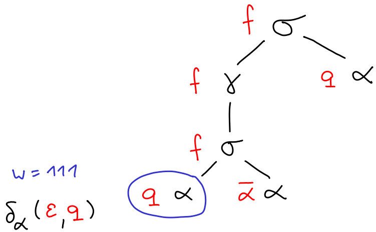

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weighted tree language recognized by $\mathcal{A}$:

$$L_{\mathcal{A}} : T_\Sigma \to \mathbb{R}, \quad L_{\mathcal{A}}(\xi) = \max_{r \in R_{\mathcal{A}}(\xi)} \mathrm{wt}(r)$$

second assumption:

translation from SL and TL is specified by a weighted tree transducer

[Yamada, Knight 01] translation from English to Japanese

weighted tree transducer (wtt) $\mathcal{M} = (Q, \Sigma, q_0, R)$

- Q, Σ as for wta

  Σ: input <u>and</u> output symbols
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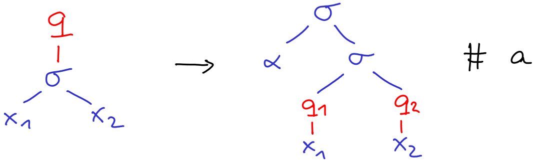

linear, nondeleting in $x_1, \ldots, x_k$

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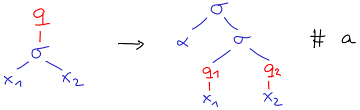

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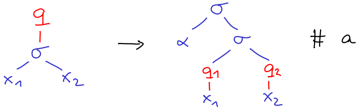

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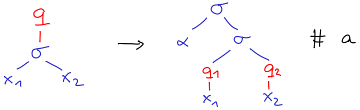

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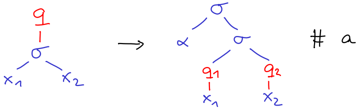

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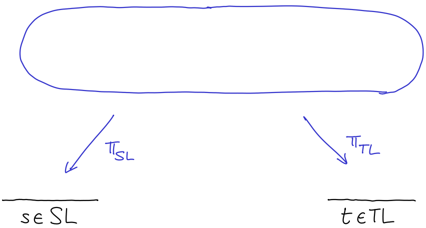
weighted tree transformation computed by $\mathcal{M}$:

$$\tau_{\mathcal{M}} : T_\Sigma \times T_\Sigma \to \mathbb{R}, \quad \tau_{\mathcal{M}}(\xi_1, \xi_2) = \max_{\substack{d \in D_{\mathcal{M}}: \\ \pi(d) = (\xi_1, \xi_2)}} \mathrm{wt}(d)$$

$D_{\mathcal{M}}$: set of all derivations

log-linear modeling with wtt and wta:



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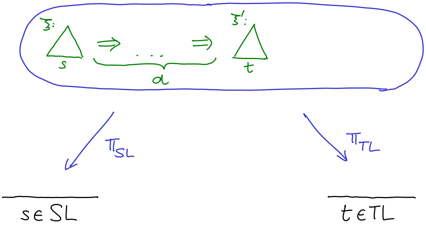

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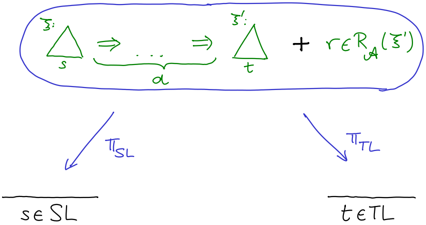

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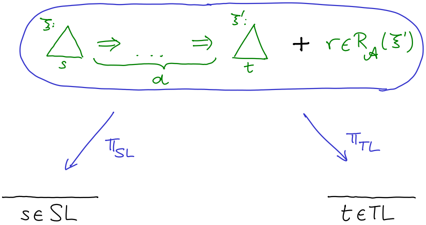

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$$Y = \{(d, r) \in D_{\mathcal{M}} \times R_{\mathcal{A}} \mid r \in R_{\mathcal{A}}(\mathrm{last}(d))\}$$

$$\pi_{SL}(d, r) = \mathrm{yield}(\mathrm{first}(d))$$
$$\pi_{TL}(d, r) = \mathrm{yield}(\mathrm{last}(d))$$

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here:

$$\begin{aligned} m &= 2 \\ \Phi(d, r) &= \Big(\log \mathrm{wt}_{\mathcal{M}}(d),\ \log \mathrm{wt}_{\mathcal{A}}(r)\Big) \end{aligned}$$

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$$\mathcal{H} = \{h_{\lambda,\mathcal{M},\mathcal{A}} \mid \lambda \in \mathbb{R}^2_{\geq 0}, \quad \text{wtt } \mathcal{M}, \quad \text{wta } \mathcal{A}\}$$

$$\begin{aligned} h_{\lambda,\mathcal{M},\mathcal{A}} : \quad & \mathrm{SL} \to \mathrm{TL} \\ & s \mapsto \pi_{\mathrm{TL}}\left(\operatorname*{argmax}_{\substack{(d,r)\in Y: \\ \pi_{\mathrm{SL}}(d,r)=s}} \mathrm{wt}_{\mathcal{M}}(d)^{\lambda_1} \cdot \mathrm{wt}_{\mathcal{A}}(r)^{\lambda_2}\right) \end{aligned}$$

outline of the talk:

- Statistical machine translation
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  - Weight exponentiation
  - Output product
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outline of the talk:

- Statistical machine translation
- Modeling with wta and wtt
- Using automata theoretic results to “improve” modeling
  - Weight exponentiation
  - Output product
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Let $\tau : T_\Sigma \times T_\Sigma \to \mathbb{R}$ and $L : T_\Sigma \to \mathbb{R}$

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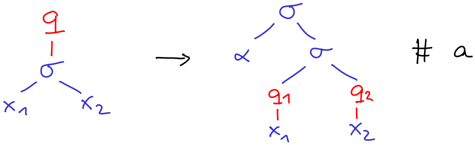
rule of $\mathcal{M}$:



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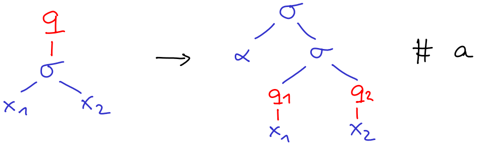

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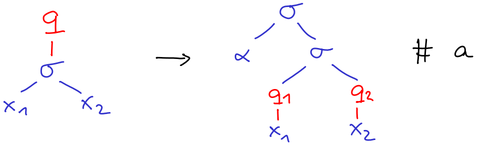

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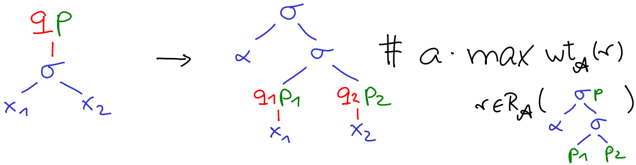
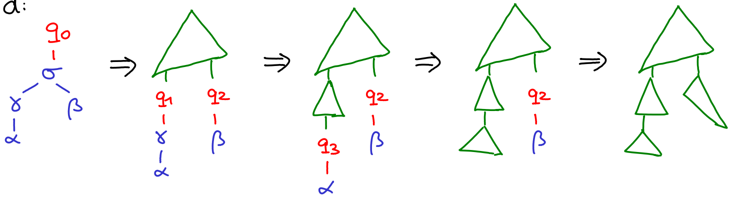
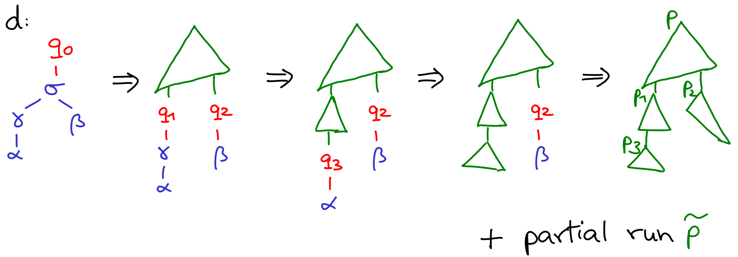


d:




d:
q0
σ
γ
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α
q1
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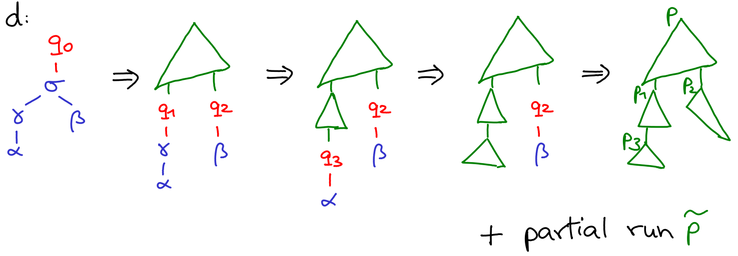
p
p1
p2
p3
+ partial run p̃


d:
q0
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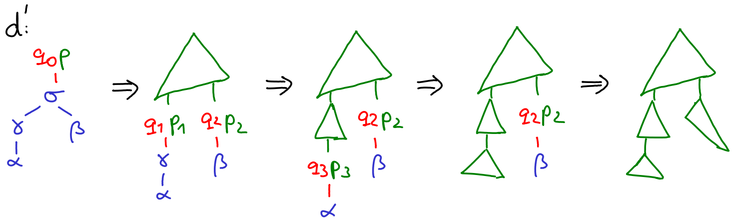
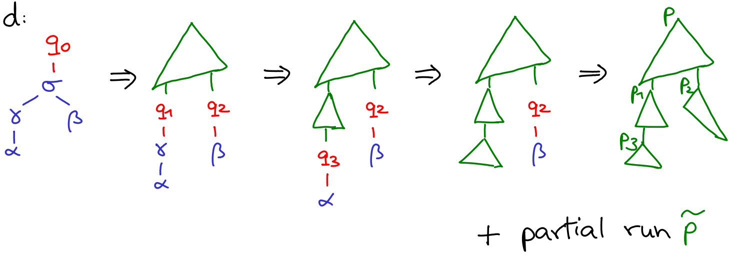
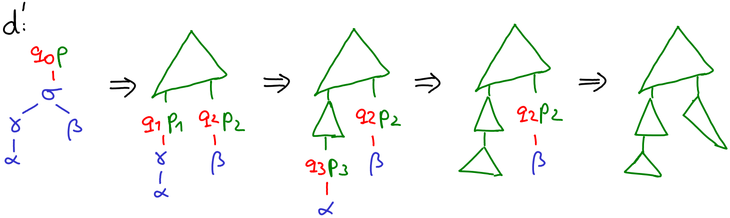

d':
q0 p
σ
γ
β
α
⇒
q1 p1
q2 p2
q3 p3





$\varphi : D_{\mathcal{M}'} \rightarrow \{(d, \tilde{p}) \mid d \in D_{\mathcal{M}}, \tilde{p} \in R_{\mathcal{A}}^{\text{partial}}(d)\}$ bijection

$\mathrm{wt}(d') = \mathrm{wt}(d) \cdot \max_{r \in \mathrm{completion}(\tilde{p})} \mathrm{wt}(r)$

recall:

$$h_{\lambda,\mathcal{M},\mathcal{A}} : \mathrm{SL} \to \mathrm{TL}$$

$$s \quad \mapsto \quad \pi_{\mathrm{TL}}\left(\operatorname{argmax}_{\substack{(d,r)\in Y': \\ \pi_{\mathrm{SL}}(d,r)=s}} \mathrm{wt}_{\mathcal{M}}(d) \cdot \mathrm{wt}_{\mathcal{A}'}(r)\right)$$

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generalization to mildly context-sensitive languages

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Let $\mathcal{M}$ synchronized tree-adjoining grammar (STAG)
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outline of the talk:

- Statistical machine translation
- Modeling with wta and wtt
- Using automata theoretic results to “improve” modeling
- Summary

- model for translation from SL to TL: wtt $\mathcal{M}$
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- sentence s of SL

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\text{(output product)} &= \pi_{\mathrm{TL}}\left(\operatorname{argmax}_{\substack{d\in D_{\mathcal{M}\triangleright\mathcal{A}'}:\\ \pi_{\mathrm{SL}}(d)=s}} \mathrm{wt}_{\mathcal{M}\triangleright\mathcal{A}'}(d)\right)
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$$= \pi_{\mathrm{TL}}\big(\,\mathrm{Knuth}(\mathcal{A}_s\triangleleft(\mathcal{M}\triangleright\mathcal{A}'))\,\big)$$

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but: SMT is an engineering task!

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weighted tree automata and weighted tree transducers

can help in **modeling**

statistical machine translation of natural languages

References:

- [Baker 79] Composition of top-down and bottom-up tree transductions
- [Bar-Hillel, Shamir, Perles 61] On formal properties of simple phrase structure grammars
- [Büchse, Nederhof, V. 11] Tree Parsing with Synchronous Tree-Adjoining Grammars
- [Engelfriet, Fülöp, V. 02] Bottom-up and Top-down Tree Series Transformations
- [Fülöp, V. 09] Weighted tree automata and tree transducers
- [Knight et al. 03-...] ...
- [Knuth 77] A generalization of Dijkstra's algorithm
- [Lopez 08] Statistical Machine Translation
- [Liang, Bouchard-Côté, Klein, Taskar 06] An End-to-End Discriminative Approach to Machine Translation
- [Maletti 06] Compositions of Tree Series Transformations
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- [Thatcher 67] Characterizing derivation trees of context-free grammars through a generalization of finite automata theory
- [Yamada, Knight 01] A syntax-based statistical translation model

[Knight et al. 03-...]

- [Charniak, Knight, Yamada 03] Syntax-based language models for statistical machine translation
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Survey: Weighted Extended Top-down Tree Transducers –
Part III: Applications in Machine Translation

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Part III: Applications in Machine Translation

Thank you!