Tree Transducers in Machine Translation

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Machine Translation

**Schema**

Input Text (e.g., Arabic) $\xrightarrow{}$ Black Box (e.g., computer) $\xrightarrow{}$ Output Text (e.g., English)

**Applications**

- Automatic news wire translations
- Automatic translation of proceedings
- ...
- Powerful in conjunction with speech recognition and synthesis
See for yourself:

http://www.nist.gov/speech/tests/mt/mt06eval_official_results.html

Disclaimer
These results are not to be construed, or represented as endorsements of any participant’s system or commercial product, or as official findings on the part of NIST or the U.S. Government. ⟨...⟩
Conditions:

- Large Data Track (limited training data; publicly available)
- Arabic-to-English and Chinese-to-English
- 1 week processing time
- ≈ 40 competitors (industrial and academic)

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Phrase-based Machine Translation

Features

- Process input and output string
- String-based transformations
- $\Rightarrow$ (Weighted) finite-state automata and transducers

Example
Translation with FSA and FST

Mary did not slap the green witch.
Phrase-based Machine Translation

Features

▶ Process input and output string
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Mary did not slap the green witch.

Mary $\varepsilon$ not slap slap slap the green witch.
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Example

Translation with FSA and FST

Mary $\varepsilon$ not slap slap slap the green witch.

Mary not slap slap slap NULL the green witch.
Phrase-based Machine Translation

Features

- Process input and output string
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Example

Translation with FSA and FST

Mary not slap slap slap NULL the green witch.

Mary no dió una bofetada a la verde bruja.
Phrase-based Machine Translation

Features

- Process input and output string
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- \(\Rightarrow\) (Weighted) finite-state automata and transducers

Example

Translation with FSA and FST

Mary no dió una bofetada a la verde bruja.

Mary no dió una bofetada a la bruja verde.
Syntax-based Machine Translation

Features

- Process parse trees of sentence instead of sentence
- Tree-based transformations
- \( \Rightarrow \) (Weighted) tree automata and tree transducers

Schema
Syntax-based Machine Translation (cont’d)

Example

```
He adores listening to music
kare ha ongaku wo kiku no ga daisuki desu
```

```
He TO NN to music
```

```
He ha TO listening no
```

```
kare ha ongaku wo kiku no ga daisuki desu
```
Extended Top-down Tree Transducer

Definition
An extended top-down tree transducer is a tuple \((Q, \Sigma, \Delta, I, R)\) where

- \(Q\) is a finite set of states;
- \(\Sigma\) and \(\Delta\) are input and output ranked alphabet;
- \(I \subseteq Q\) is a set of initial states; and
- \(R\) is a finite set of rewrite rules of the form

\[ q(t) \rightarrow r \]

with \(q \in Q\), \(t \in T_\Sigma(X)\) linear, and \(r \in T_\Delta(Q(\text{var}(t)))\).
Semantics of Extended Top-down Tree Transducers

\[ M = (Q, \Sigma, \Delta, I, R) \] an extended tdtt

**Definition**

Define \( \Rightarrow_M \subseteq T_\Delta(Q(T_\Sigma))^2 \) by \( \xi \Rightarrow_M \xi' \) iff

1. there exists a position \( w \in \text{pos}(\xi) \);
2. there exists a rule \((l \rightarrow r) \in R\); and
3. there exists a substitution \( \theta: X \rightarrow T_\Sigma \)

such that

\[ l\theta = \xi|_w \quad \text{and} \quad \xi' = \xi[r\theta]_w . \]

**Definition**

The tree transformation computed by \( M \) is defined by

\[ \| M \| = \{(t, u) \in T_\Sigma \times T_\Delta \mid \exists q \in I : q(t) \Rightarrow^*_M u\} . \]
A Hierarchy
Open Problems (according to [Knight, Graehl 2005])

- What is the most efficient algorithm for selecting the $k$-best trees from a probabilistic regular tree grammar?

- How can efficient integrated search be carried out, so that all tree acceptors and transducers in a cascade can simultaneously participate in the best-tree search?
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  Bottom-up and Top-down Tree Series Transformations by J. Engelfriet, Z. Fülöp, and H. Vogler

  complexity not analysed; not specific for $\mathbb{R}$
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- For large tree transducers, what data structures, indexing strategies, and caching techniques will support efficient algorithms?

- What is the linguistically most appropriate tree transducer class for machine translation? For text summarization? Which classes best handle the most common linguistic constructions, and which classes best handle the most difficult ones?
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  nondeleting and linear extended top-down for machine translation; open for summarization
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  class of nondeleting and linear extended top-down tree transformations not closed under composition
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- Where do synchronous grammars and tree cloning fit into the tree transducer hierarchy?

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  - efficiently train on large amounts of data,
  - accurately model that data by assigning it higher probability than other models, and
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