RELATIONAL-REALIZATIONAL SYNTAX
An Architecture for Learning and Specifying Morphosyntactic Descriptions

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Statistical Parsing
Statistical Parsing

“John likes Mary”
Statistical Parsing

“John likes Mary”
Statistical Parsing

S
  NP-SBJ  VP-PRD
    PRP    likes    NP-OBJ
      "John"  "likes"    PRP
           "Mary"
Analysis By Generation

S
   NP-SBJ
      NP-SBJ
         PRP
            PRP
               "John"
   VP-PRD
      NP-OBJ
         PRP
            PRP
               "Mary"
   VP-PRD
      VB
         VB
            NP-OBJ
               "likes"
Constituency-Based Statistical Parsing for English

```
S
  | NP-SBJ  VP-PRD
  |   |   
  PRP VB ADJP
  | “This” | “is” ADJ
  |        | “easy”

Model Study F-Score

Treebank Charniak 1996 75
Grammar

Head-Driven Collins 1997 88.6

Discriminative Reranking Collins 2000 89.7

Discriminative Reranking Johnson & Charniak 2005 91.0

Self-Training McClosky 2006 92.1

CRF-CFG Finkel et al 2008 90.7

State-Splits Petrov et al 2007 90.1

Forest Reranking Liang Huang 2008 91.7
```
Statistical Parsing from a Typological Perspective

And what about this?

And this?

And? ...

<table>
<thead>
<tr>
<th>Language</th>
<th>Parser</th>
<th>F-Score</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>German</strong></td>
<td>Rafferty &amp; Manning 2008</td>
<td>79.2</td>
</tr>
<tr>
<td><strong>Czech</strong></td>
<td>Collins et al. 1999</td>
<td>79.3</td>
</tr>
<tr>
<td><strong>Arabic</strong></td>
<td>Maamouri, Bies &amp; Kulick 2008</td>
<td>78.1</td>
</tr>
<tr>
<td><strong>Hebrew</strong></td>
<td>Tsarfaty &amp; Sima’an 2007</td>
<td>74.4</td>
</tr>
</tbody>
</table>
The Data

Typological Dimensions of Variation

Morphological Synthesis/Fusion
(Sapir 1921, Greenberg 1954)

Basic Word-Order Typology
(Greenberg 1966, Mithun 1992)

Nonconfigurationality
(Hale 1983, Austin and Bresnan 1996)
Modern Hebrew

A Semitic Language

SVO

Highly Synthetic

‘Less-Configurational’
Modern Hebrew

Word-Order

(1)  a. dani natan et hamatana ledina
    Dani gave ACC the-present to-Dina
    “Dani gave the present to Dina” (SVO)

    b. et hamatana natan dani ledina
       ACC the-present gave Dani to-Dina
       “Dani gave the present to Dina” (OVS)

    c. natan dani et hamatana ledina
       gave Dani ACC the-present to-Dina
       “Dani gave the present to Dina” (VSO)

    d. ledina natan dani et hamatana
       to-dina gave Dani ACC the-present
       “Dani gave the present to Dina” (VSO)
Argument Marking in Modern Hebrew

Case-Assigning Prepositions

(2)  a. dani natan et hamatana ledina
    Dani gave ACC DEF-present DAT-Dina

       b. et hamatana natan dani ledina
           ACC DEF-present gave Dani DAT-Dina

       c. natan dani et hamatana ledina
           gave Dani ACC DEF-present DAT-Dina

       d. ledina natan dani et hamatana
           DAT-dina gave Dani ACC DEF-present
Argument Marking in Modern Hebrew

Differential Object-Marking

(3)  a. dani natan et hamatana ledina
     Dani gave ACC DEF-present to-Dina

     b. et hamatana natan dani ledina
        ACC DEF-present gave Dani to-Dina

     c. natan dani et hamatana ledina
        gave Dani ACC DEF-present to-Dina

     d. ledina natan dani et hamatana
        to-dina gave Dani ACC DEF-present
Argument Marking in Modern Hebrew

Feature Spreading (Danon, 2007)

(4)  a. dani natan [et matnat yom hahuledet] ledina
     Dani gave [ACC present day DEF-birth] to-Dina

     b. [et matnat yom hahuledet] natan dani ledina
        [ACC present day DEF-birth] gave Dani to-Dina

     c. natan dani [et matnat yom hahuledet] ledina
        gave Dani [ACC present day DEF-birth] to-Dina

     d. ledina natan dani [et matnat yom hahuledet]
        to-dina gave Dani [ACC present day DEF-birth]
Argument Marking in Modern Hebrew

Agreement

(5)  
  a. dani natan et hamatana ledina
      Dani.MS gave.3MS ACC DEF-present DAT-Dina
  b. et hamatana natan dani ledina
      ACC DEF-present gave.3MS Dani.MS DAT-Dina
  c. natan dani et hamatana ledina
gave.MS Dani.3MS ACC DEF-present DAT-Dina
  d. ledina natan dani et hamatana
      DAT-dina gave.3MS Dani.MS ACC DEF-present
Pro-Drop and Clitics

(6) a. ani natati et hamatanot ledina
   I.1S gave.1S ACC DEF-presents.3FP DAT-Dina
   “I gave the presents to Dina”

   b. natati et hamatana ledina
      gave.1S ACC DEF-presents.3FP DAT-Dina
      “I gave the presents to Dina”

   c. natatihen ledina
      gave.1S ACC.3FP DAT-Dina
      “I gave them to Dina”
The Data

Recap:

CONFIGURATIONAL ———— NONCONFIGURATIONAL
1:1 ————————————————— many : many
Vietnamese > English > Hebrew > Warlpiri

Require:

An architecture to model many-to-many correspondence
The Hypothesis
The Hypothesis

Morphological Exponence

- Simple (1:1)
- Cumulative (many:1)
- Distributed/Extended (1:many)
The Hypothesis

Morphological Exponence: Properties $\leadsto$ Words

- Simple (1:1)
- Cumulative (many:1)
- Distributed/Extended (1:many)

Morphosyntactic Exponence: Relations $\leadsto$ Configurations

- Simple (e.g., SBJ $\leadsto$ nominative)
- Cumulative (e.g., SBJ, PRD, OBJ $\leadsto$ clitics)
- Distributed/Extended (e.g., OBJ $\leadsto$ feature-spreading)
Reminder: Modeling Principles for Morphology

LEXICAL vs. INFERENTIAL Approaches

- **LEXICAL**: morphemes are primary, properties stored in the lexicon
- **INFERENTIAL**: properties are primary, forms are computed

INCREMENTAL vs. REALIZATIONAL Approaches

- **INCREMENTAL**: morphemes/properties are accumulated incrementally ("monotonic" rules)
- **REALIZATIONAL**: property-bundles are pre-condition for rule application ("spell-out" rules)
Inferential-Realizational Morphology

Paradigmatic Organization

<table>
<thead>
<tr>
<th>/EAT/</th>
<th>1Sing</th>
<th>2Sing</th>
<th>3Sing</th>
<th>1Pl</th>
<th>2Pl</th>
<th>3Pl</th>
</tr>
</thead>
<tbody>
<tr>
<td>Past</td>
<td>1SingPast</td>
<td>2SingPast</td>
<td>3SingPast</td>
<td>1PlPast</td>
<td>2PlPast</td>
<td>3PlPast</td>
</tr>
<tr>
<td>Present</td>
<td>1SingPres</td>
<td>2SingPres</td>
<td>3SingPres</td>
<td>1PlPres</td>
<td>2PlPres</td>
<td>3PlPres</td>
</tr>
<tr>
<td>Perfect</td>
<td>1SingPerf</td>
<td>2SingPerf</td>
<td>3SingPerf</td>
<td>1PlPerf</td>
<td>2PlPerf</td>
<td>3PlPerf</td>
</tr>
</tbody>
</table>

Realization Rules

/EAT/ +1SingPast → ‘ate’
/EAT/ +3SingPast → ‘ate’
/EAT/ +1SingPres → ‘eats’
/EAT/ +3SingPres → ‘eat’
The Proposal: Relational-Realizational Syntax

Paradigmatic Organization

<table>
<thead>
<tr>
<th>ARG-ST</th>
<th>S(PRED) FEATS</th>
<th>Affirmative</th>
<th>Interrogative</th>
<th>Imperative</th>
</tr>
</thead>
<tbody>
<tr>
<td>intransitive</td>
<td>S_{affirm}+{SBJ,PRD}</td>
<td>S_{inter}+{SBJ,PRD}</td>
<td>S_{imper}+{SBJ,PRD}</td>
<td></td>
</tr>
<tr>
<td>transitive</td>
<td>S_{affirm}+{SBJ,PRD,OBJ}</td>
<td>S_{inter}+{SBJ,PRD,OBJ}</td>
<td>S_{imper}+{SBJ,PRD,OBJ}</td>
<td></td>
</tr>
<tr>
<td>ditransitive</td>
<td>S_{affirm}+{SBJ,PRD,OBJ,COM}</td>
<td>S_{inter}+{SBJ,PRD,OBJ,COM}</td>
<td>S_{imper}+{SBJ,PRD,OBJ,COM}</td>
<td></td>
</tr>
</tbody>
</table>

Realization Rules

\[
\begin{align*}
S_{\text{affirm}}+\{\text{SBJ,PRD,OBJ,COM}\} & \quad \langle \text{NP}_{\text{nom}} \text{, } \text{NP}_{\text{def,acc}} \text{, } \text{NP}_{\text{dat}} \rangle \\
\langle \text{Dani, natan, et hamatana, ledina} \rangle & \quad \text{Dani gave ACC-the-present to-Dina} \\
\end{align*}
\]

\[
\begin{align*}
S_{\text{affirm}}+\{\text{SBJ,PRD,OBJ,COM}\} & \quad \langle \text{NP}_{\text{def,acc}} \text{, } \text{NP}_{\text{nom}} \text{, } \text{NP}_{\text{dat}} \rangle \\
\langle \text{et hamatana, natan, Dani, ledina} \rangle & \quad \text{ACC-the-present gave Dani to-Dina} \\
\end{align*}
\]
The Realization Rules

Relational-Realizational (RR) Parsing

S

NP-SBJ

NP+Def+Acc-OBJ

PP-COM

dani

natan
gave

etmol

et hamatana

Acc Def-present

ledina
to Dina

yesterday

Acc Def-present
The Realization Rules

Relational-Realizational (RR) Parsing

S

{SBJ, PRD, OBJ, COM}@S

NP

dani
Dani

VB

natan
gave

ADVP

etmol
yesterday

NP_{Def+Acc}

et hamatana
Acc Def-present

PP

ledina
to Dina
The Realization Rules

Relational-Realizational (RR) Parsing

S

{SBJ,PRD,OBJ,COM}@S

SBJ@S

NP
dani
Danni

PRD@S

VB
natan
gave

PRD:OBJ@S

ADVP
etmol
yesterday

OBJ@S

NP+Def+Acc
et hamatana
Acc Def-present

COM@S

PP
ledina
to Dina
The Realization Rules

Relational-Realizational (RR) Parsing

Diagram showing the syntactic structure of a sentence in a specific language, with nodes labeled with parts of speech and other linguistic information.
The Model Parameters

Projection:

\[ P \]

\[ \{ gr_i \}_{i=1}^n @ P \]

Configuration:

\[ \{ gr_i \}_{i=1}^n @ P \]

\[ gr_1 @ P \quad gr_1 : gr_2 @ P \quad ... \quad gr_n @ P \]

Realization:

\[ gr_1 @ P \quad gr_1 : gr_2 @ P \quad ... \quad gr_n @ P \]

\[ C_1 \quad ..C_{1:2}.. \quad C_n \]
The Probabilistic Model

The RR Probabilities:

\[ P_{RR}(r) = \]

**Projection** \[ P_p(\{ gr_i \}_{i=1}^n | P) \times \]

**Configuration** \[ P_c(\langle gr_0 : gr_1, g_1, \ldots \rangle | \{ gr_i \}_{i=1}^n, P) \times \]

**Realization** \[ \prod_{i=1}^n P_{r1}(C_i | gr_i, P) \times \]

\[ P_{r2}(\langle C_{0_1}, \ldots, C_{0_{m_0}} \rangle | gr_0 : gr_1, P) \times \]

\[ \prod_{i=1}^n P_{r2}(\langle C_{i_1}, \ldots, C_{i_{m_i}} \rangle | gr_i : gr_{i+1}, P) \]

The RR Parser:

\[ \pi^* = \arg\max_{\pi} P(\pi) = \arg\max_{\pi} \prod_{r \in \pi} P_{RR}(r) \]
Experiments
Experiments

<table>
<thead>
<tr>
<th></th>
<th>CONFIGURATIONAL</th>
<th>RELATIONAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>INCREMENTAL</td>
<td>Head-Driven Parsing</td>
<td>Dependency Parsing</td>
</tr>
<tr>
<td>REALIZATIONAL</td>
<td>Tree Adjoining Grammars</td>
<td>Relational-Realizational</td>
</tr>
</tbody>
</table>

Table: A Taxonomy of Generative Statistical Parsing Frameworks
Application I: Parsing Modern Hebrew

Data
The Modern Hebrew Treebank v2, head annotated. 6500 sentences, 500/5500/500 dev/train/test split

Models
▶ Grammatical Functions: PRD, SBJ, OBJ, COM, CNJ
▶ Morphological Splits: PoS/Def/Acc
▶ Conditioning Context: Horizontal/Vertical

Estimation
Relative Frequency + Simple Unknown Words Smoothing

Parsing
Exhaustive Viterbi Parsing (using BitPar, Schmid 2004)

Evaluation
PARSEVAL (i) Overall, and (ii) Per Category Evaluation
### Overall Results

| Precision/Recall (#parameters) | 74.66/74.35 (7385) | 73.52/74.84 (21399) | 76.32/76.51 (13618) |
Overall Results

| Precision/Recall (#parameters) | 74.66/74.35 (7385) | 73.52/74.84 (21399) | 76.32/76.51 (13618) |
## Results Per Category

<table>
<thead>
<tr>
<th>Category</th>
<th>First Score</th>
<th>Second Score</th>
<th>Third Score</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>NP</strong></td>
<td>77.39 / 74.32</td>
<td>77.94 / 73.75</td>
<td>78.96 / 76.11</td>
</tr>
<tr>
<td><strong>PP</strong></td>
<td>71.78 / 71.14</td>
<td>71.83 / 69.24</td>
<td>74.4 / 72.02</td>
</tr>
<tr>
<td><strong>SBAR</strong></td>
<td>55.73 / 59.71</td>
<td>53.79 / 57.49</td>
<td>57.97 / 61.67</td>
</tr>
<tr>
<td><strong>ADVP</strong></td>
<td>71.37 / 77.01</td>
<td>72.52 / 73.56</td>
<td>73.57 / 77.59</td>
</tr>
<tr>
<td><strong>ADJP</strong></td>
<td>79.37 / 78.96</td>
<td>78.47 / 77.14</td>
<td>78.69 / 78.18</td>
</tr>
<tr>
<td><strong>S</strong></td>
<td>73.25 / 79.07</td>
<td>71.07 / 76.49</td>
<td>72.37 / 78.33</td>
</tr>
<tr>
<td><strong>SQ</strong></td>
<td>36.00 / 32.14</td>
<td>30.77 / 14.29</td>
<td>55.56 / 17.86</td>
</tr>
<tr>
<td><strong>PREDP</strong></td>
<td>36.31 / 39.63</td>
<td>44.74 / 39.63</td>
<td>44.51 / 46.95</td>
</tr>
</tbody>
</table>
Towards Probabilistic Universal Grammar

Basic Word-Order Parameter:
\[ P(< \text{configuration} > | \{ \text{SBJ, PRD, OBJ} \}@S) \]

<table>
<thead>
<tr>
<th>Probability</th>
<th>Configuration</th>
<th>tri-</th>
<th>bi-</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2%</td>
<td>OBJ [ SUBJ PRD ]</td>
<td>OSV</td>
<td>OV</td>
</tr>
<tr>
<td>0.2%</td>
<td>PRD OBJ SBJ [</td>
<td>VOS</td>
<td>VO</td>
</tr>
<tr>
<td>0.2%</td>
<td>[ PRD OBJ [ SBJ ]</td>
<td>VOS</td>
<td>VO</td>
</tr>
<tr>
<td>0.2%</td>
<td>PRD SBJ [ OBJ ]</td>
<td>VOS</td>
<td>VO</td>
</tr>
<tr>
<td>0.4%</td>
<td>[ PRD [ SBJ [ OBJ ]</td>
<td>VOS</td>
<td>VO</td>
</tr>
<tr>
<td>0.6%</td>
<td>OBJ [ PRD SBJ ]</td>
<td>OVS</td>
<td>OV</td>
</tr>
<tr>
<td>0.8%</td>
<td>OBJ PRD [ SBJ ]</td>
<td>OVS</td>
<td>OV</td>
</tr>
<tr>
<td>1%</td>
<td>[ PRD [ SBJ OBJ ]</td>
<td>VSO</td>
<td>VO</td>
</tr>
<tr>
<td>1.3%</td>
<td>SBJ [ PRD OBJ ]</td>
<td>SVO</td>
<td>VO</td>
</tr>
<tr>
<td>1.7%</td>
<td>[ PRD OBJ SBJ ]</td>
<td>VOS</td>
<td>VO</td>
</tr>
<tr>
<td>1.7%</td>
<td>[ SBJ PRD [ OBJ ]</td>
<td>SVO</td>
<td>VO</td>
</tr>
<tr>
<td>3%</td>
<td>OBJ PRD SBJ [</td>
<td>OVS</td>
<td>OV</td>
</tr>
<tr>
<td>3.7%</td>
<td>[ PRD SBJ [ OBJ ]</td>
<td>VSO</td>
<td>VO</td>
</tr>
<tr>
<td>4.1%</td>
<td>SBJ [ PRD [ OBJ ]</td>
<td>SVO</td>
<td>VO</td>
</tr>
<tr>
<td>6.5%</td>
<td>[ SBJ PRD OBJ ]</td>
<td>SVO</td>
<td>VO</td>
</tr>
<tr>
<td>10.3%</td>
<td>SBJ [ PDR OBJ ]</td>
<td>SVO</td>
<td>VO</td>
</tr>
<tr>
<td>12.3%</td>
<td>[ PRD SBJ OBJ ]</td>
<td>VSO</td>
<td>VO</td>
</tr>
<tr>
<td>15.6%</td>
<td>SBJ PRD [ OBJ ]</td>
<td>SVO</td>
<td>VO</td>
</tr>
<tr>
<td>35.3%</td>
<td>SBJ PRD OBJ [</td>
<td>SVO</td>
<td>VO</td>
</tr>
</tbody>
</table>
Towards Probabilistic Universal Grammar

Differential Object-Marking Parameter:
\[ P(< \text{morphosyntactic representation} > | \text{OBJ}@S) \]

<table>
<thead>
<tr>
<th>Probability</th>
<th>Realization</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.8%</td>
<td>NP.DEF.ACC\langle PRP\rangle@S</td>
</tr>
<tr>
<td>6.5%</td>
<td>NP.DEF.ACC\langle NNT\rangle@S</td>
</tr>
<tr>
<td>6.7%</td>
<td>NP.DEF.ACC\langle NN.DEF\rangle@S</td>
</tr>
<tr>
<td>7.4%</td>
<td>NP.DEF.ACC\langle NNP\rangle@S</td>
</tr>
<tr>
<td>8.8%</td>
<td>NP\langle NNT\rangle@S</td>
</tr>
<tr>
<td>14.7%</td>
<td>NP.DEF.ACC\langle NN\rangle@S</td>
</tr>
<tr>
<td>43.5%</td>
<td>NP.\langle NN\rangle@S</td>
</tr>
</tbody>
</table>
Application II: Towards Computational Typology?

Can we Use the RR parameters to...

- Quantify Intra-Language Variation?
- Quantify Cross-Linguistic Variation?
- Learn Parameters Settings from Data?
- Quantify Nonconfigurationality?
RRRecap

The Relational-Realizational Framework
Specifying and Learning Linguistic Descriptions
- Simple
- Formal
- Robust
- Implementable
- Interpretable
- Explanatory

Syntactic paradigms augmented with realization rules provide a powerful strategy
Special thanks to Ash Asudeh, Mary Dalrymple, Ida Toivonen, Josef van Genabith and LFG.

For more Information
Relational-Realizational Parsing
Reut Tsarfaty, University of Amsterdam
PhD Manuscript, 2010
Thank You!

Questions?
LFG vs. RR

LFG

- Parallel (⇝ Model-Theoretic)
- Form-to-Function
- Hierarchical Feature-Checking
- ‘Lexical’ treatment of morphosyntax

\[ \text{LEXICON (LI)} ; \text{c-str} \rightarrow \text{f-str} \rightarrow \text{s-str} \rightarrow \ldots \]

RR

- Integrated (⇝ Generative-Enumerative)
- Function-to-Form
- Local feature-checking
- ‘Realizational’ treatment of morphosyntax

\[ \ldots \text{s-str} \rightarrow \text{f-str} \rightarrow \text{c-str} \rightarrow \text{r-str} ; \text{LEXICON (IR)} \]