PARSING WITH PARADIGMS
A Relational-Realizational Architecture for Specifying and Learning Morphosyntactic Descriptions

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QUANTITATIVE MEASURES IN MORPHOLOGY AND MORPHOLOGICAL DEVELOPMENT
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Morphology and Syntax

"Morphology deviates in a number of important ways from the classical picture of word structure as simply the combinatory syntax of morphemes. [As we have seen,] morphology is best seen as a system that describes relations among word structural types in terms of the way the forms of words realize the properties that compose their content."

"In fact [ ... ] much of what we normally think of as clearly part of syntax seems to have some of this same character. [ ... ] Rather than being exclusively matters of the construction and manipulation of hierarchical constituent structure, a number of areas usually considered syntactic in character also turn out to be realizational, relational, and governed by a system of constraints rather than (solely) by rules of X-structure, displacement, and other manipulations of phrasal structure." (Anderson 2004)
Morphology and Syntax

“Morphology deviates in a number of important ways from the classical picture of word structure as simply the combinatory syntax of morphemes. [As we have seen,] morphology is best seen as a system that describes relations among word structural types in terms of the way the forms of words realize the properties that compose their content.”

“In fact [...] much of what we normally think of as clearly part of syntax seems to have some of this same character. [...] Rather than being exclusively matters of the construction and manipulation of hierarchical constituent structure, a number of areas usually considered syntactic in character also turn out to be realizational, relational, and governed by a system of constraints rather than (solely) by rules of X-structure, displacement, and other manipulations of phrasal structure.” (Anderson 2004)
My Contribution

The Idea
Applying the principles underlying W&P models to syntax

The Proposal
A Relational-Realizational (RR) modeling architecture

The Outcome
- Useful: Parsing less-configurational languages
- Interesting: Quantifying typological parameters
The Plan for Today

The Task:
Statistical Parsing

The Challenge:
Complex Form-Function Correspondence

The Method:
Following the footsteps of Morphology

The Proposal:
A Relational-Realizational Approach

⇒ A Stepping Stone
Towards computational typology and statistical UG
Part 1: The Task

Statistical Parsing
Statistical Parsing

"This is easy"
Statistical Parsing

"This is easy"
Statistical Parsing

S
  NP-SBJ  VP-PRD
    PRP     VB  ADJP
      “This” “is” ADJ
        “easy”
Statistical Parsing

S

NP-SBJ

NP-SBJ

PRP

"This"

VP-PRD

VP-PRD

VB

VB

"is"

ADJP

ADJP

ADJ

ADJ

"easy"
Constituency-Based Supervised Statistical Parsing

Model Study F-Score

- Treebank Charniak 75
- Grammar 1996
- Head-Driven Collins 1997 88.6
- Discriminative Collins 2000 89.7
- Reranking
- Discriminative Johnson & Charniak 2005 91.0
- Reranking McClosky 92.1 2006
- Self-Training
- State-Splits Petrov et al 90.1 2007
- Forest Liang Huang 91.7 2008
- Reranking
Constituency-Based Supervised Statistical Parsing

And what about this?

And this?

And this?

And this?

<table>
<thead>
<tr>
<th>Language</th>
<th>Parser</th>
<th>F-Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>German</td>
<td>Rafferty &amp; Manning 2008</td>
<td>79.2</td>
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<tr>
<td>Czech</td>
<td>Collins et al. 1999</td>
<td>79.3</td>
</tr>
<tr>
<td>Chinese</td>
<td>Levy &amp; Manning 2003</td>
<td>78.8</td>
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<tr>
<td>Arabic</td>
<td>Maamouri, Bies &amp; Kulick 2008</td>
<td>78.1</td>
</tr>
<tr>
<td>Hebrew</td>
<td>Tsarfaty &amp; Sima’an 2007</td>
<td>74.4</td>
</tr>
</tbody>
</table>

And? ...
So What Is Going On?

Often Considered

- **Corpora Size**
  E.g., For *Chinese* (Bikel & Chiang 2000)

- **Annotation Idiosyncrasies**
  E.g., For *Arabic* (Maamouri, Bies & Kulick 2008, 2009)

- **Evaluation Matters**
  E.g., For *German* (Rehiben & van Genabith 2007, Kübler 2008)
So What Is Going On?

Often Considered

- Corpora Size
  E.g., For *Chinese* (Bikel & Chiang 2000)

- Annotation Idiosyncrasies
  E.g., For *Arabic* (Maamouri, Bies & Kulick 2008, 2009)

- Evaluation Matters
  E.g., For *German* (Rehiben & van Genabith 2007, Kübler 2008)

Not so often..

- Parsers’ Parameterization

- Language Variation
Parsers’ Parameterization

"He likes her" = P(NP VP | S) × ... × P("her" | PRP .ACC) = 0.25
Parsers’ Parameterization

\[
P(\text{NP VP}|S) \times \ldots \times P(\text{"her"}|\text{PRP.ACC}) = 0.25
\]
Parsers’ Parameterization

P(“Her likes he”) = P(NP VP|S) × ... × P(“her”|PRP.ACC) = 0.25
Example 1: Parent Encoding (Johnson 1998)

S

NP@S

PRP.NOM

“He”

VP@S

VB

“likes”

NP@VP

PRP.ACC

“her”

⇒

P(NP@S VP@S | S) 1
P(PRP.NOM | NP@S) 1
P(PRP.ACC | NP@VP) 1
P(VB NP@VP | VP@S) 1

P(”He” | PRP.NOM) 1
P(”likes” | VP) 1
P(”her” | PRP.ACC) 1
Example 1: Parent Encoding (Johnson 1998)

P(NP@S VP@S|S) 1
P(PRP.NOM |NP@S) 1
P(PRP.ACC |NP@VP) 1
P(VB NP@VP| VP@S) 1
P(”He”|PRP.NOM) 1
P(”likes”|VP) 1
P(”her”|PRP.ACC) 1
Example 2: Head-Driven Processes (Collins 1999)

\[
\begin{align*}
\Rightarrow & \\
& P(<VB>|S) & 1 \\
& P(L\Delta_{L_1}, H\Delta_0|<VB>, S) & 1 \\
& P(PRP.NOM|L, \Delta_{L_1}, <VB>, S) & 1 \\
& P(VP|H, \Delta_0, <VB>, S) & 1 \\
& P(<VB>|VP) & 1 \\
& P(PRP.ACC|R, \Delta_{R_1}, <VB>, S) & 1 \\
& P(VB|H, \Delta_0, <VB>, S) & 1 \\
& P("He"|PRP.NOM) & 1 \\
& P("likes"|VB) & 1 \\
& P("her"|PRP.ACC) & 1
\end{align*}
\]
Example 2: Head-Driven Processes (Collins 1999)

$$\Rightarrow$$

- $P(<\text{VB}|S)$ 1
- $P(\text{L}, \Delta_{L_1}, \text{H}, \Delta_0|<\text{VB}, S)$ 1
- $P(\text{PRP.NOM}|\text{L}, \Delta_{L_1},<\text{VB}, S)$ 1
- $P(\text{VP}|\text{H}, \Delta_0, <\text{VB}, S)$ 1
- $P(<\text{VB}|\text{VP})$ 1
- $P(\text{PRP.ACC}|\text{R}, \Delta_{R_1}, <\text{VB}, S)$ 1
- $P(\text{VB}|\text{H}, \Delta_0, <\text{VB}, S)$ 1
- $P(\"\text{He}\"|\text{PRP.NOM})$ 1
- $P(\"\text{likes}\"|\text{VB})$ 1
- $P(\"\text{her}\"|\text{PRP.ACC})$ 1
An Observation

- Parsers for configurational languages:
  - Parameters use configurations to approximate functions
- Parsers for less-configurational languages:
  - Parameters need to explicitly relate functions to forms

A Question

What kind of form-function correspondence patterns our parser needs to learn from the data?
Part 2: The Challenge

Modeling Form-Function Correspondence
Language Types

Typological Dimensions of Variation

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

Morphological Typology (Sapir 1921, Greenberg 1954)

Nonconfigurality (Hale 1983, Austin and Bresnan 1996)
Language Types

Typological Dimensions of Variation

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

Morphological Typology
(Sapir 1921, Greenberg 1954)

Nonconfigurationality
(Hale 1983, Austin and Bresnan 1996)
Nonconfigurationality as Misalignment

Predicate-Argument Relations

‘SBJ’ did ‘PRD’ to ‘OBJ’

Syntactic Configuration

```
S
  NP  VP
   PRP.NOM VB NP
   "He"  "likes"  'her'
```
Nonconfigurationality as Misalignment

Predicate-Argument Relations

‘SBJ’ did ‘PRD’ to ‘OBJ’

Configurational Languages

```
(He) likes her
```

Diagram:
```
S
  /   \  
NP    VP
  |    |
PRP.NOM VB NP
  |   |
   "He" "likes" NN.ACC
       |       |
       "her"
```
Nonconfigurationality as Misalignment

Predicate-Argument Relations

‘SBJ’ did ‘PRD’ to ‘OBJ’

Less-Configurational Languages
Morphosyntactic Exponence in 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)
Exponence Relations in Hebrew (1:1)

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
Exponent Relations in Hebrew (1:many)

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
Exponence Relations in Hebrew (1:many)

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]
Exponence Relations in Hebrew (1:many)

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
Exponence Relations in Hebrew (many:1)

Clitics and Null Anaphors

(6)  a. dani natan et hamatana ledina
     Dani.MS gave.3MS ACC DEF-present DAT-Dina
     “Dani gave the present to Dina”

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

    c. natatiha ledina
       gave.1S.ACC.3FS DAT-Dina
       “I gave it to Dina”
Recap:

**CONFIGURATIONAL** —— **NONCONFIGURATIONAL**

1:1 ———————————— many : many

▶ Exponence relations relate grammatical functions to the formal means that realize them in the syntactic structure

▶ Configurationality is a special case of a 1:1 mapping between grammatical functions to configurational positions

**Question:**

How can we model and statistically learn generally complex, many-to-many, form-function correspondence in syntax?
Part 3: The Proposal

Following the footsteps of morphology
Modeling Morphology (i): Terminology

Morphological Exponence (Matthews 1991)
- Simple Exponence (1:1)
- Cumulative Exponence (many:1)
- Extended Exponence (1:many)

Morpheme-Based Morphology (Bloomfield, 1933)

- ‘kid’ , ‘s’ , ‘ox’ , ‘en’ , ‘m..n’ , ‘e’ , ‘sheep’ , ∅
- KID plural OX plural MAN plural SHEEP plural
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
- REALIZATIONAL: property-bundles are pre-condition for spell-out
### Modeling Morphology (III): A Taxonomy

<table>
<thead>
<tr>
<th>Incremental</th>
<th>Lexical</th>
<th>Inferential</th>
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<tbody>
<tr>
<td>Item &amp; Arrangement</td>
<td>(Bloomfield 1933)</td>
<td>Item &amp; Processes</td>
</tr>
<tr>
<td></td>
<td>(Lieber 1992)</td>
<td>(Hocket 1954)</td>
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<tr>
<td></td>
<td></td>
<td>(Steele 1995)</td>
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<td>Realizational</td>
<td>Distributed Morphology</td>
<td>(Extended) Word &amp; Paradigm</td>
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<td>(Halle and Marantz 1993)</td>
<td>(Matthews 1972), (Anderson 1992)</td>
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<td></td>
<td>Lexical Phonology</td>
<td>(Stump 2001), (Blevins 2006)</td>
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</table>

**Table:** A Taxonomy of Models for Morphology (Stump 2001)
The Strategy (IV): (Extended) Word-and-Paradigm

Paradigmatic Organization

<table>
<thead>
<tr>
<th></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/, /EAT/, /EAT/, /EAT/, /EAT/
- +1SingPast, +3SingPast, +1SingPres, +3SingPres
- ‘ate’, ‘ate’, ‘eats’, ‘eat’
The Proposal (I): “Lifting” the Terminology

Morphological Exponence: Properties $\rightsquigarrow$ Words

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

Morphosyntactic Exponence: Relations $\rightsquigarrow$ Positions

- Simple (1:1, e.g., SBJ $\rightsquigarrow$ nominative)
- Cumulative (many:1, e.g., PRD,OBJ $\rightsquigarrow$ clitics)
- Distributed/Extended (1:many, e.g., SBJ $\rightsquigarrow$ agreement)
The Proposal (II): Modeling Assumptions

**CONFIGURATIONAL vs. RELATIONAL Approaches**

- **CONFIGURATIONAL:**
  configurations are primary, relations are derived

- **RELATIONAL:**
  relations are primary, configurations are computed

**INCREMENTAL vs. REALIZATIONAL Approaches**

- **INCREMENTAL:**
  constructive operations,
  incrementally define/add relations

- **REALIZATIONAL:**
  interpretive operations,
  sets of relations are precondition to realization
## The Proposal (III): A Taxonomy

<table>
<thead>
<tr>
<th></th>
<th><strong>CONFIGURATIONAL</strong></th>
<th><strong>RELATIONAL</strong></th>
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<tr>
<td><strong>INCREMENTAL</strong></td>
<td>X-Bar Theory</td>
<td>Dependency Grammar</td>
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<td>Head-Driven Grammars</td>
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<tr>
<td><strong>REALIZATION</strong></td>
<td>Tree Adjoining Grammar</td>
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</tr>
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<td>Combinatory-Categorial Grammar</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Construction Grammar</td>
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</table>

**Table:** A Taxonomy of Syntactic Frameworks (Tsarfaty 2010)
The Proposal (III): A Taxonomy

<table>
<thead>
<tr>
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<th>CONFIGURATIONAL</th>
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<tr>
<td><strong>REALIZATIONAL</strong></td>
<td>Tree Adjoining Grammar</td>
<td>⟨ This Work ⟩</td>
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<tr>
<td></td>
<td>Combinatory-Categorial Grammar</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Construction Grammar</td>
<td></td>
</tr>
</tbody>
</table>

Table: A Taxonomy of Syntactic Frameworks (Tsarfaty 2010)
The Proposal (IV): Relational-Realizational Modeling

The *Relational* Assumption

- Paradigms organize the syntactic domain
- Cells in paradigms define sets of relations
- Sets of relations are realized in different configurations

The *Realizational* Assumption

- Sets of relations (Arg-St) are primitives
- Rules interpret sets of relations as surface forms
- Rules can refer to multiple relations and span clauses

Realization in Syntax is Recursive!

Realization of a cells refers to function cells in other paradigms
The Proposal (IV): Relational-Realizational Modeling

<table>
<thead>
<tr>
<th>ARG-ST</th>
<th>S\langle PRED\rangle FEATS</th>
<th>Affirmative</th>
<th>Interrogative</th>
<th>Imperative</th>
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<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>

**Figure: Paradigmatic Organization**

\[ S_{affirm}+\{SBJ,PRD,OBJ,COM\} \]

**Figure: Realization Rules**

\[ \langle \text{Dani, natan, et hamatana, ledina} \rangle \text{ Dani gave ACC-the-present to-Dina} \]

\[ \langle \text{et hamatana, natan, Dani, ledina} \rangle \text{ ACC-the-present gave Dani to-Dina} \]
Realization Rules
Realization Rules

Segmentation and Classification

S

NP-SBJ

dani
Dani

VB-PRD

natan
gave

ADVP

etmol
yesterday

NP_{Def+Acc}-OBJ

et hamatana
Acc Def-present

PP-COM

Iedina
to Dina
Realization Rules

Form-Function Separation

S

{SBJ,PRD,OBJ,COM}@S

NP

VB

ADVP

NP_{Def+Acc}

PP

dani

natan
gave

etmol

yesterday

et hamatana
Acc Def-present

ledina
to Dina
Realization Rules

Morphological and Syntactic Realization

S

{SBJ, PRD, OBJ, COM}@S

SBJ@S

PRD@S

PRD:OBJ@S

OBJ@S

COM@S

NP

VB

ADVP

PP

dani

natan
gave

etmol

et hamatana

ledina
to Dina

Acc Def-present

Acc Def-present

Acc Def-present
Realization Rules: Economy and Generalization

S

{PRD,SBJ,OBJ,COM}@S

SBJ@S
NP
dani
Dani

PRD@S
VB
natan
gave

PRD:OBJ@S
ADVP
etmol
yesterday

OBJ@S
NP_{Def,Acc}
et hamatana
Acc Def-present

COM@S
PP-COM
ledina
to Dina

S

{PRD,SBJ,OBJ,COM}@S

OBJ@S
NP_{Def,Acc}
et hamatana
Acc Def-present

PRD@S
VB
natan
gave

PRD:OBJ@S
ADVP
etmol
yesterday

SBJ@S
NP
dani
Dani

COM@S
PP-COM
ledina
to Dina
The Generative Model

Projection:

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

Configuration:

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

Realization:

\[
gr_1 \odot P \quad gr_1 : gr_2 \odot P \quad \ldots \quad gr_n \odot P
\]

\[
C_1 \quad \ldots \quad C_{1:2} \ldots \quad C_n
\]
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 \[ \prod_{i=1}^n P_{r_1}(C_i | gr_i, P) \times \]

\[ P_{r_2}(\langle C_{0_1}, \ldots, C_{0_{m_0}} \rangle | gr_0 : gr_1, P) \times \]

\[ \prod_{i=1}^n P_{r_2}(\langle C_{i_1}, \ldots, C_{i_{m_i}} \rangle | gr_i : gr_{i+1}, P) \]

The RR Parser:

\[ \pi^* = \arg\max_{\pi} P(\pi) = \arg\max_{\pi} \prod_{r \in \pi} P_{RR}(r) \]
Part IV: Applications

- Parsing Modern Hebrew
- Quantifying Universal Grammar
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/Gender

Estimation
Relative Frequency + Simple Unknown Words Smoothing

Parsing
Exhaustive Viterbi Parsing (using BitPar, Schmid 2004)

Evaluation
PARSEVAL (i) Overall, and (ii) Per Category Evaluation
A Taxonomy of PCFG-based Parsers

<table>
<thead>
<tr>
<th></th>
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<td></td>
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<td></td>
<td>(Collins 1999)</td>
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<tr>
<td><strong>REALIZATIONAL</strong></td>
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<td>Relational-Realizational</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Tsarfaty et al. 2009)</td>
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</table>

**Table:** A Taxonomy of PCFG-Based Parsing Frameworks
<table>
<thead>
<tr>
<th></th>
<th>Overall Results</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>74.66/74.35</td>
</tr>
<tr>
<td></td>
<td>(7385)</td>
</tr>
<tr>
<td></td>
<td>73.52/74.84</td>
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<tr>
<td></td>
<td>(21399)</td>
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<tr>
<td></td>
<td>76.32/76.51</td>
</tr>
<tr>
<td></td>
<td>(13618)</td>
</tr>
</tbody>
</table>
Overall Results

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 Model</th>
<th>Second Model</th>
<th>Third Model</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><strong>79.37 / 78.96</strong></td>
<td>78.47 / 77.14</td>
<td>78.69 / 78.18</td>
</tr>
<tr>
<td><strong>S</strong></td>
<td><strong>73.25 / 79.07</strong></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><strong>55.56 / 17.86</strong></td>
</tr>
<tr>
<td><strong>PREDP</strong></td>
<td>36.31 / 39.63</td>
<td><strong>44.74 / 39.63</strong></td>
<td>44.51 / 46.95</td>
</tr>
</tbody>
</table>
## Results Using Gold Standard Input

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>83.06</td>
<td>83.49</td>
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<tr>
<td>(5914)</td>
<td>(6688)</td>
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<td><strong>gender</strong></td>
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<td>83.70</td>
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<tr>
<td>(10765)</td>
<td>(10063)</td>
<td></td>
</tr>
<tr>
<td><strong>case/def</strong></td>
<td>79.53</td>
<td>83.66</td>
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<tr>
<td>(12700)</td>
<td>(12386)</td>
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</tr>
<tr>
<td><strong>gender/case/def</strong></td>
<td>80.89</td>
<td>84.13</td>
</tr>
<tr>
<td>(13028)</td>
<td>(13618)</td>
<td></td>
</tr>
</tbody>
</table>
Application II: Probabilistic Computational Typology

1: Apply the model to different languages, e.g.,
   - Hebrew: a Semitic Language
   - Swedish: a Germanic Language

2: Learn the distribution of model parameters
   - RR-Projection
   - RR-Configuration
   - RR-Realization

3: Instantiate typological parameters for UG
Application II: Probabilistic Computational Typology

1: Apply the model to different languages, e.g.,

- **Hebrew**: a Semitic Language
- **Swedish**: a Germanic Language

2: Learn the distribution of model parameters

- RR-Projection
- RR-Configuration
- RR-Realization

3: Instantiate typological parameters for UG
Parameter 1: Basic Word-Order (Greenberg 1963)

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

<table>
<thead>
<tr>
<th>Probability</th>
<th>Configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>35.3%</td>
<td>SBJ PRD OBJ □</td>
</tr>
<tr>
<td>15.6%</td>
<td>SBJ PRD □ OBJ □</td>
</tr>
<tr>
<td>12.3%</td>
<td>□ PRD SBJ OBJ □</td>
</tr>
<tr>
<td>10.3%</td>
<td>SBJ □ PDR OBJ □</td>
</tr>
<tr>
<td>6.5%</td>
<td>□ SBJ PRD OBJ □</td>
</tr>
<tr>
<td>4.1%</td>
<td>SBJ □ PRD □ OBJ □</td>
</tr>
<tr>
<td>3.7%</td>
<td>□ PRD SBJ □ OBJ □</td>
</tr>
<tr>
<td>3%</td>
<td>OBJ PRD SBJ □</td>
</tr>
<tr>
<td>1.7%</td>
<td>□ SBJ PRD □ OBJ □</td>
</tr>
<tr>
<td>1.7%</td>
<td>□ PRD OBJ SBJ □</td>
</tr>
<tr>
<td>1.3%</td>
<td>SBJ □ PRD OBJ □</td>
</tr>
<tr>
<td>1%</td>
<td>□ PRD □ SBJ OBJ □</td>
</tr>
</tbody>
</table>
Parameter 1: Basic Word-Order (Greenberg 1963)

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

<table>
<thead>
<tr>
<th>Probability</th>
<th>Configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>35.5%</td>
<td>SBJ PRD OBJ □</td>
</tr>
<tr>
<td>18.9%</td>
<td>SBJ PRD □ OBJ □</td>
</tr>
<tr>
<td>13.9%</td>
<td>□ PRD SBJ PBJ □</td>
</tr>
<tr>
<td>8.1%</td>
<td>SBJ PRD OBJ</td>
</tr>
<tr>
<td>4.7%</td>
<td>□ PRD SBJ □ OBJ</td>
</tr>
<tr>
<td>3.5%</td>
<td>OBJ PRD SBJ</td>
</tr>
<tr>
<td>2.6%</td>
<td>SBJ PRD OBJ □</td>
</tr>
<tr>
<td>1.7%</td>
<td>OBJ PRD SBJ COM □</td>
</tr>
<tr>
<td>1.6%</td>
<td>PRD SBJ OBJ □</td>
</tr>
<tr>
<td>1.6%</td>
<td>□ PRD SBJ OBJ</td>
</tr>
<tr>
<td>1%</td>
<td>□ PRD SBJ □ OBJ</td>
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</table>
Parameter 2: Inflectional Systems

The Object-Marking Parameter in Hebrew: $P(<\text{morphosyntactic representation} >|\text{OBJ@S})$

<table>
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<tr>
<th>Probability</th>
<th>Realization</th>
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<tbody>
<tr>
<td>43.5%</td>
<td>NP.$\langle NN \rangle$</td>
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<tr>
<td>14.7%</td>
<td>NP.DEF.ACC.$\langle NN \rangle$</td>
</tr>
<tr>
<td>8.8%</td>
<td>NP.$\langle NNT \rangle$</td>
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<tr>
<td>7.4%</td>
<td>NP.DEF.ACC.$\langle NNP \rangle$</td>
</tr>
<tr>
<td>6.7%</td>
<td>NP.DEF.ACC.$\langle NN.DEF \rangle$</td>
</tr>
<tr>
<td>6.5%</td>
<td>NP.DEF.ACC.$\langle NNT \rangle$</td>
</tr>
<tr>
<td>5.8%</td>
<td>NP.DEF.ACC.$\langle PRP \rangle$</td>
</tr>
</tbody>
</table>
Parameter 2: Inflectional Systems

The Object-Marking Parameter in Swedish: $P(<\text{morphosyntactic representation}>|\text{OBJ@S})$

<table>
<thead>
<tr>
<th>Probability</th>
<th>Realization</th>
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<tbody>
<tr>
<td>46%</td>
<td>NP.IND.NOM</td>
</tr>
<tr>
<td>20%</td>
<td>NP.DEF.NOM</td>
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<tr>
<td>13.4%</td>
<td>S</td>
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<tr>
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<td>NP.DEF.NOM-OBJ</td>
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<tr>
<td>4.9%</td>
<td>VP</td>
</tr>
<tr>
<td>3.6%</td>
<td>NP.IND</td>
</tr>
<tr>
<td>2.8%</td>
<td>NP.NOM</td>
</tr>
</tbody>
</table>
Towards Computational Typology and Statistical UG

We can potentially use the RR parameters to...

- Quantify Intra-Language Variation
- Quantify Cross-Linguistic Variation
- Quantify Nonconfigurationality
- Learn Probabilistic P&P
Conclusion

We presented a Relational-Realizational Architecture for Specifying and Learning Morphosyntactic Descriptions

- Simple
- Formal
- Robust
- Implementable
- Interpretable
- Explanatory

Paradigms augmented with realization rules constitute a useful and powerful modeling strategy also for (Morpho)Syntax.
Thank You!

Questions?

For more Information
Relational-Realizational Parsing
Reut Tsarfaty, University of Amsterdam
Swedish Parsing Results Using Gold Standard Input

<table>
<thead>
<tr>
<th></th>
<th>78.65</th>
<th>77.71</th>
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<tbody>
<tr>
<td>Ø</td>
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<tr>
<td>(8696)</td>
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<td>gender</td>
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