Stat-XFER: A General Framework for Search-based Syntax-driven MT

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Outline

- Context and Rationale
- CMU Statistical Transfer MT Framework
- Extracting Syntax-based MT Resources from Parallel-corpora
- Integrating Syntax-based and Phrase-based Resources
- Open Research Problems
- Conclusions

Rule-based vs. Statistical MT

- Traditional Rule-based MT:
  - Expressive and linguistically-rich formalisms capable of describing complex mappings between the two languages
  - Accurate “clean” resources
  - Everything constructed manually by experts
  - Main challenge: obtaining and maintaining broad coverage
- Phrase-based Statistical MT:
  - Learn word and phrase correspondences automatically from large volumes of parallel data
  - Search-based “decoding” framework:
    - Models propose many alternative translations
    - Effective search algorithms find the “best” translation
  - Main challenge: obtaining and maintaining high translation accuracy

Research Goals

- Long-term research agenda (since 2000) focused on developing a unified framework for MT that addresses the core fundamental weaknesses of previous approaches:
  - Representation – explore richer formalisms that can capture complex divergences between languages
  - Ability to handle morphologically complex languages
  - Methods for automatically acquiring MT resources from available data and combining them with manual resources
  - Ability to address both rich and poor resource scenarios
- Main research funding sources: NSF (AVENUE and LETRAS projects) and DARPA (GALE)

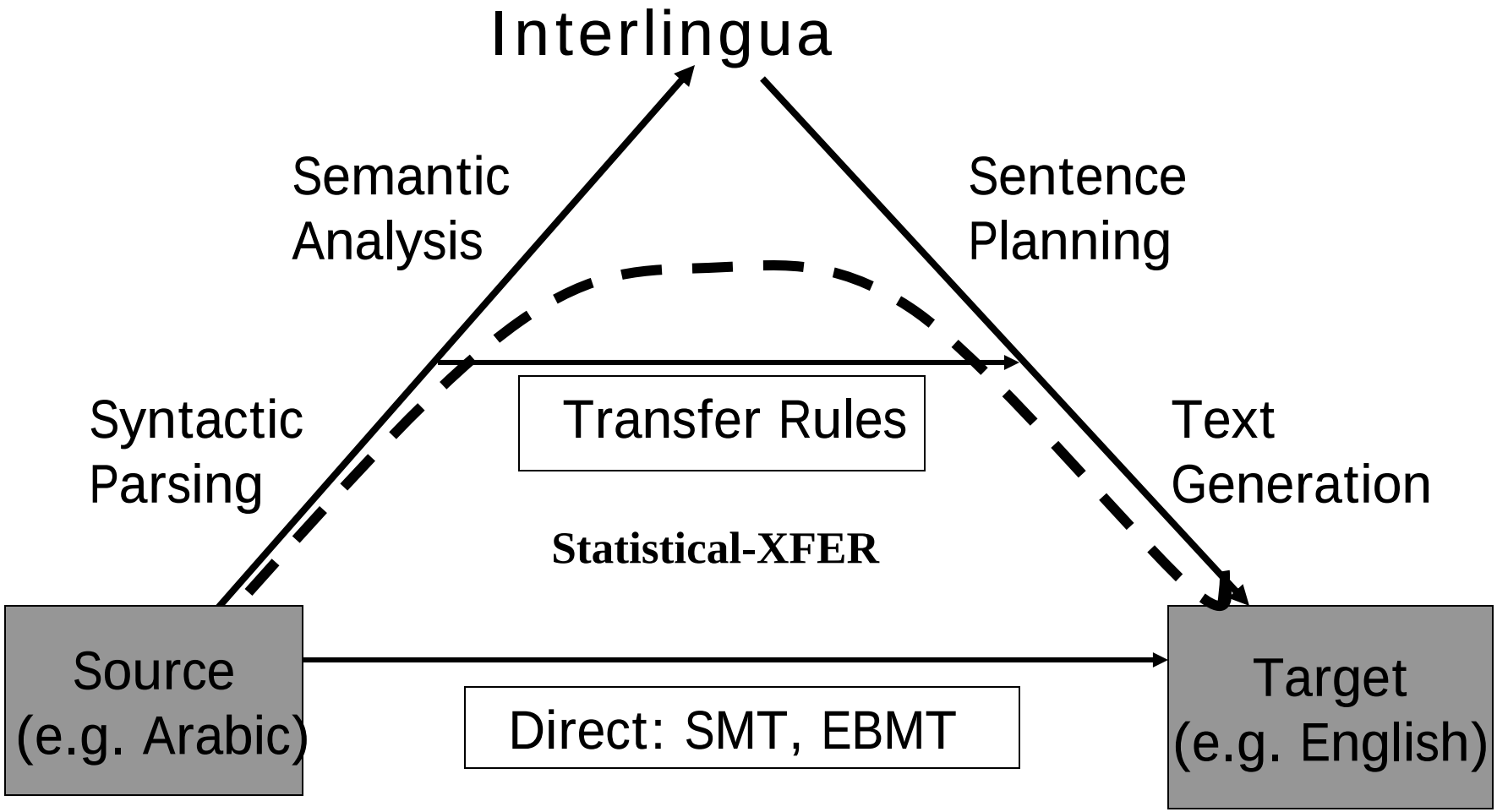
CMU Statistical Transfer (Stat-XFER) MT Approach

- Integrate the major strengths of rule-based and statistical MT within a common framework:
  - Linguistically rich formalism that can express complex and abstract compositional transfer rules
  - Rules can be written by human experts and also acquired automatically from data
  - Easy integration of morphological analyzers and generators
  - Word and syntactic-phrase correspondences can be automatically acquired from parallel text
  - Search-based decoding from statistical MT adapted to find the best translation within the search space: multi-feature scoring, beam-search, parameter optimization, etc.
  - Framework suitable for both resource-rich and resource-poor language scenarios

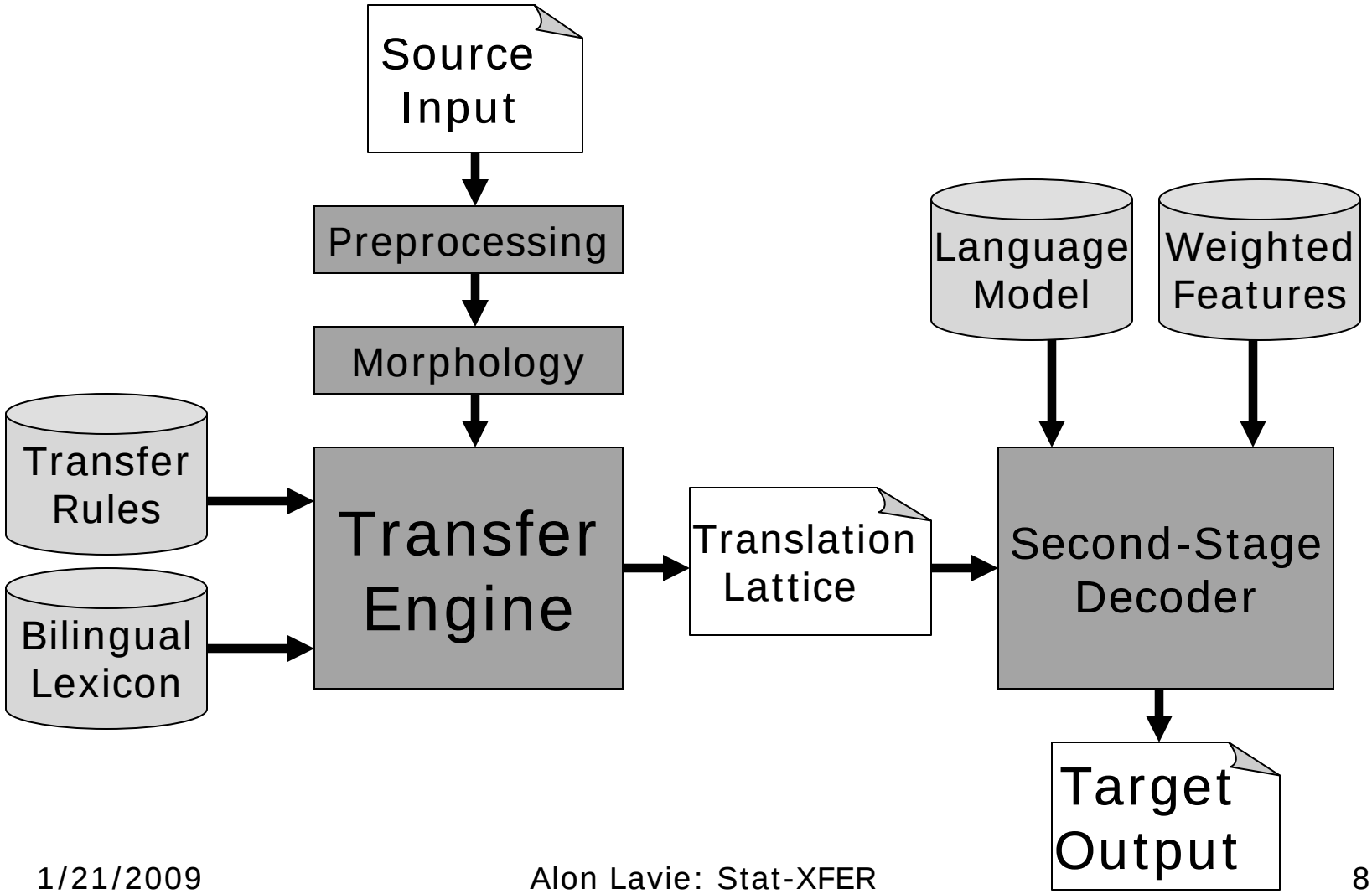
Stat-XFER Main Principles

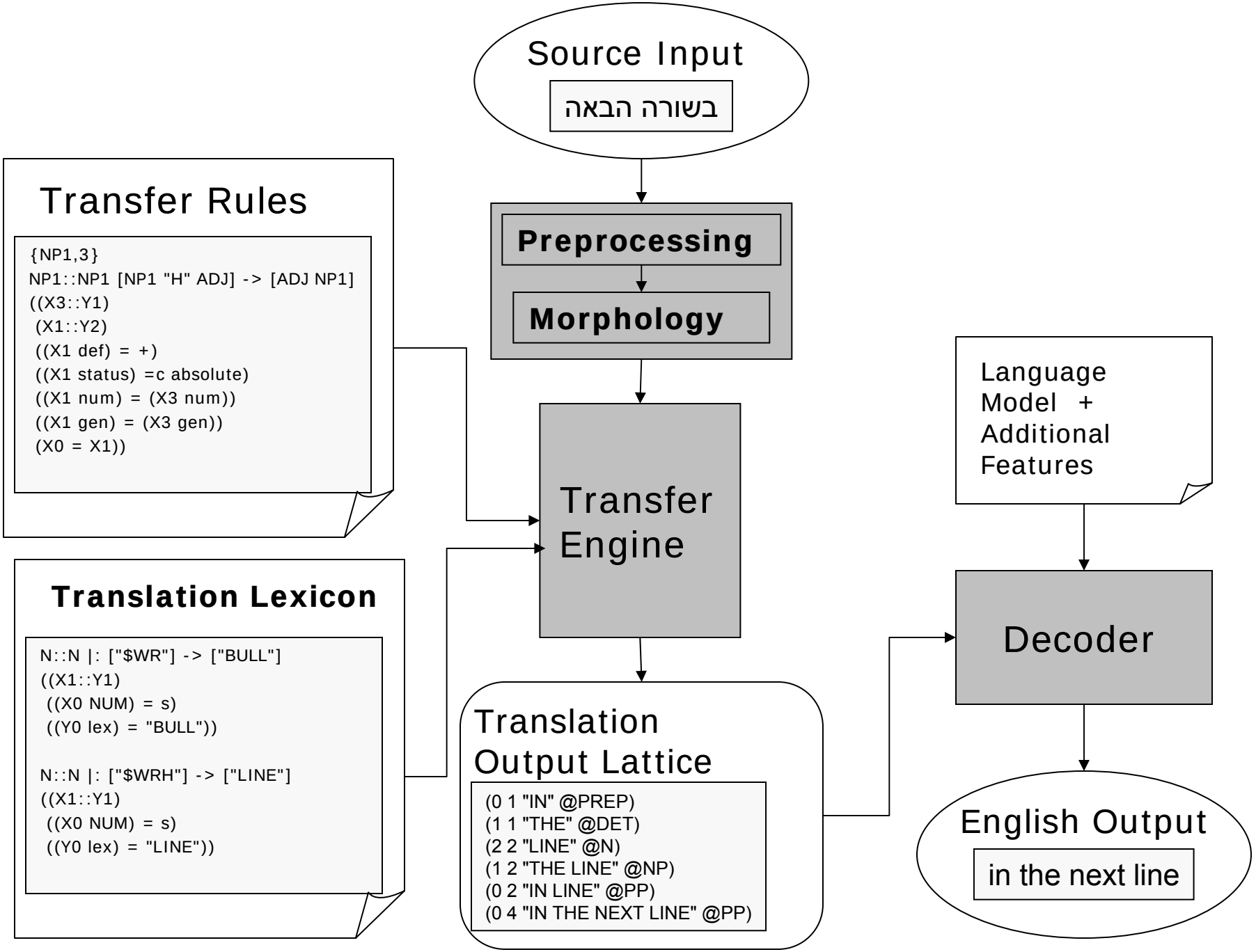
- Framework: Statistical search-based approach with syntactic translation transfer rules that can be acquired from data but also developed and extended by experts
- Automatic Word and Phrase translation lexicon acquisition from parallel data
- Transfer-rule Learning: apply ML-based methods to automatically acquire syntactic transfer rules for translation between the two languages
- Elicitation: use bilingual native informants to produce a small high-quality word-aligned bilingual corpus of translated phrases and sentences
- Rule Refinement: refine the acquired rules via a process of interaction with bilingual informants
- XFER + Decoder:
  - XFER engine produces a lattice of possible transferred structures at all levels
  - Decoder searches and selects the best scoring combination

Stat-XFER MT Approach

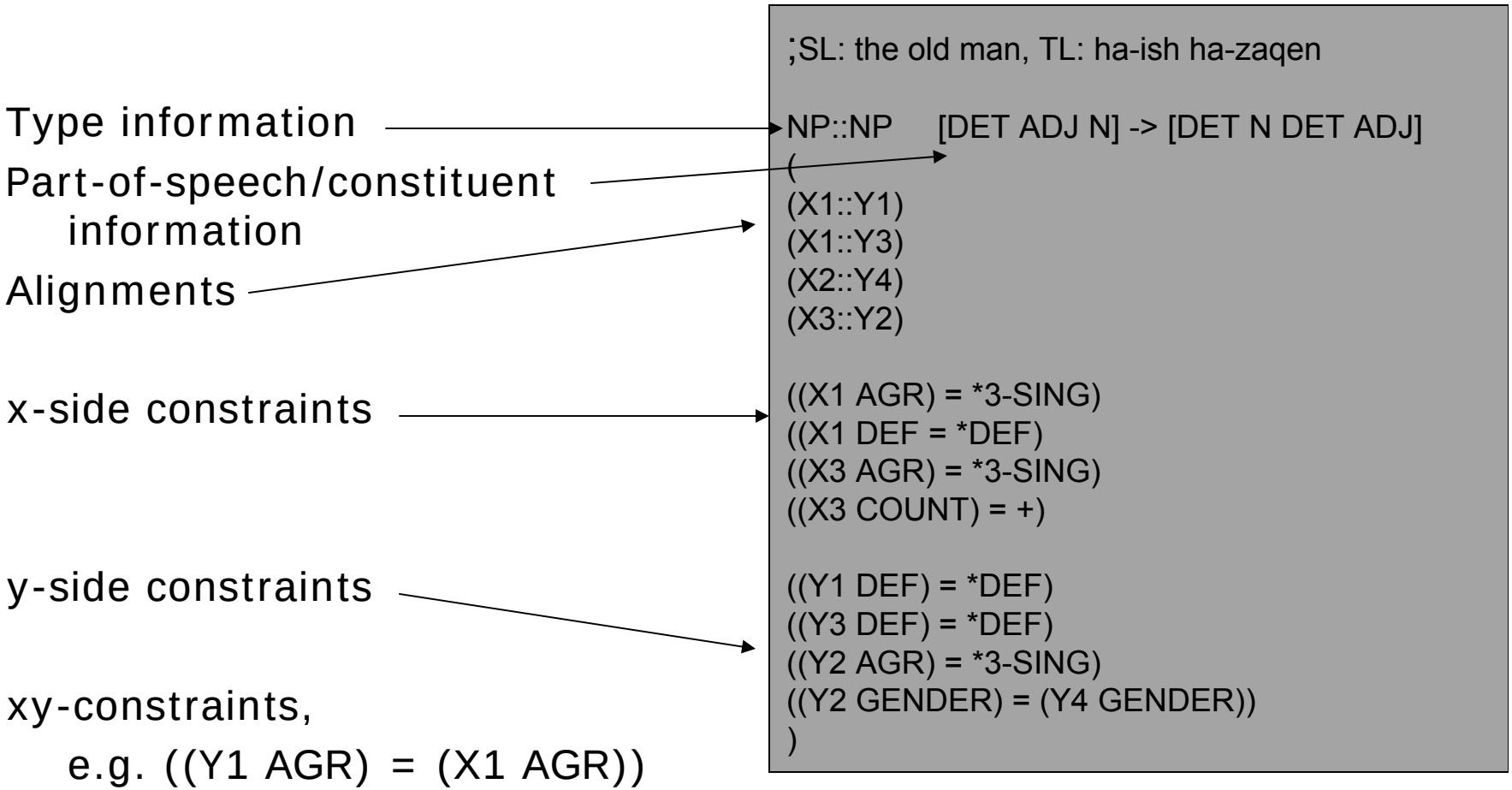


Stat-XFER Framework

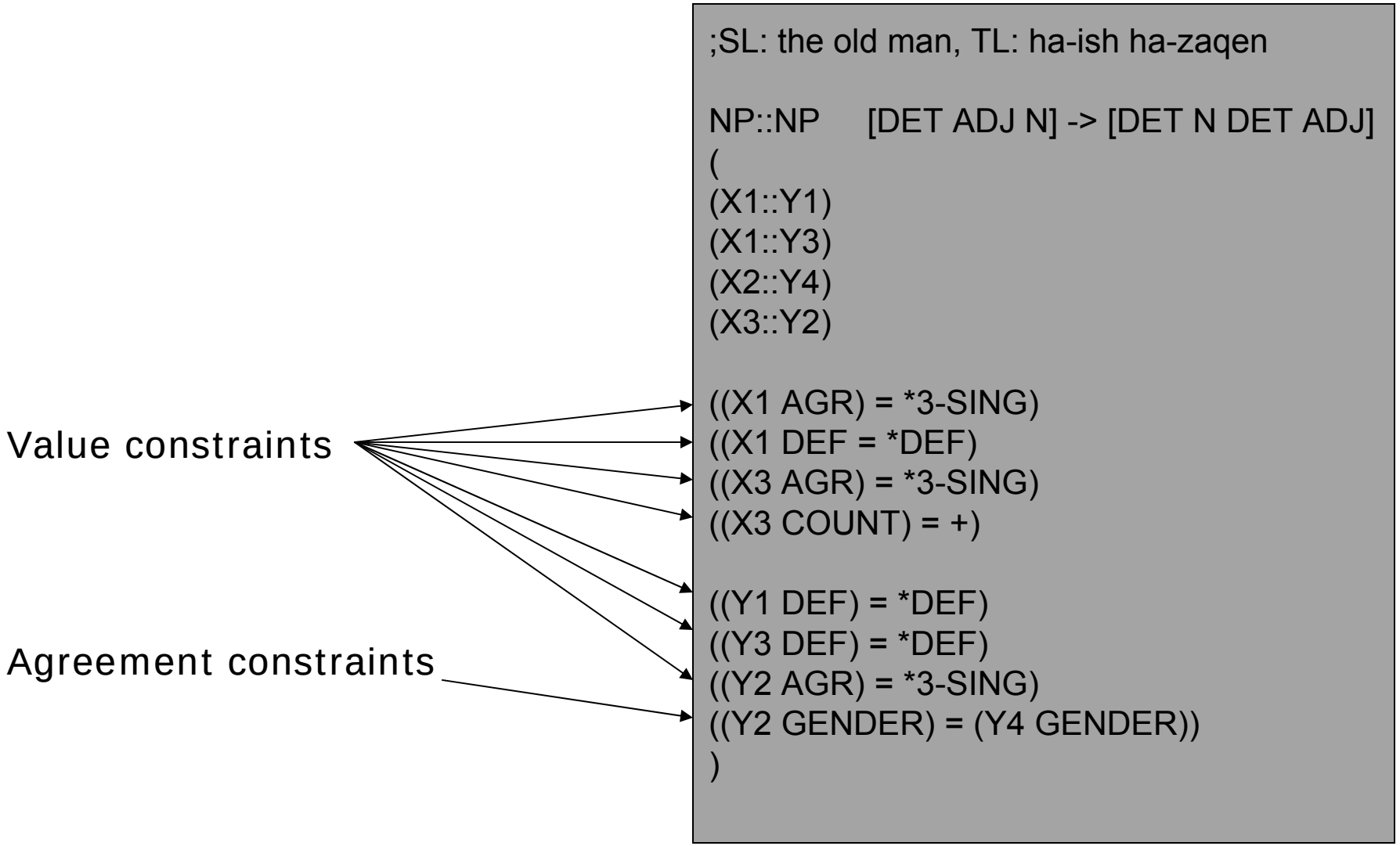



Source Input
בשורה הבאה
Transfer Rules
{NP1,3}
NP1::NP1 [NP1 "H" ADJ] -> [ADJ NP1]
((X3::Y1)
(X1::Y2)
((X1 def) = +)
((X1 status) =c absolute)
((X1 num) = (X3 num))
((X1 gen) = (X3 gen))
(X0 = X1))
Preprocessing
Morphology
Language Model + Additional Features
Transfer Engine
Translation Lexicon
N::N |: ["$WR"] -> ["BULL"]
((X1::Y1)
((X0 NUM) = s)
((Y0 lex) = "BULL"))
N::N |: ["$WRH"] -> ["LINE"]
((X1::Y1)
((X0 NUM) = s)
((Y0 lex) = "LINE"))
Translation Output Lattice
(0 1 "IN" @PREP)
(1 1 "THE" @DET)
(2 2 "LINE" @N)
(1 2 "THE LINE" @NP)
(0 2 "IN LINE" @PP)
(0 4 "IN THE NEXT LINE" @PP)
Decoder
English Output
in the next line

Transfer Rule Formalism



Transfer Rule Formalism



Translation Lexicon: Hebrew-to-English Examples (Semi-manually-developed)

```
PRO::PRO |: ["ANI"] -> ["I"]
(
(X1::Y1)
((X0 per) = 1)
((X0 num) = s)
((X0 case) = nom)
)

PRO::PRO |: ["ATH"] -> ["you"]
(
(X1::Y1)
((X0 per) = 2)
((X0 num) = s)
((X0 gen) = m)
((X0 case) = nom)
)
```

```
N::N |: ["$&H"] -> ["HOUR"]
(
(X1::Y1)
((X0 NUM) = s)
((Y0 NUM) = s)
((Y0 lex) = "HOUR")
)

N::N |: ["$&H"] -> ["hours"]
(
(X1::Y1)
((Y0 NUM) = p)
((X0 NUM) = p)
((Y0 lex) = "HOUR")
)
```

Translation Lexicon: French-to-English Examples (Automatically-acquired)

```
DET::DET |: [“le"] -> [“the"]
(
(X1::Y1)
)

Prep::Prep |:[“dans”] -> [“in”]
(
(X1::Y1)
)

N::N |: [“principes"] -> [“principles"]
(
(X1::Y1)
)

N::N |: [“respect"] -> [“accordance"]
(
(X1::Y1)
)
```

```
NP::NP |: [“le respect"] -> [“accordance"]
(
)

PP::PP |: [“dans le respect"] -> [“in accordance"]
(
)

PP::PP |: [“des principes"] -> [“with the principles"]
(
)
```

Hebrew-English Transfer Grammar Example Rules (Manually-developed)

```
{NP1,2}
;;SL: $MLH ADWMH
;;TL: A RED DRESS

NP1::NP1 [NP1 ADJ] -> [ADJ NP1]
(
(X2::Y1)
(X1::Y2)
((X1 def) = -)
((X1 status) =c absolute)
((X1 num) = (X2 num))
((X1 gen) = (X2 gen))
(X0 = X1)
)
```

```
{NP1,3}
;;SL: H $MLWT H ADWMWT
;;TL: THE RED DRESSES

NP1::NP1 [NP1 "H" ADJ] -> [ADJ NP1]
(
(X3::Y1)
(X1::Y2)
((X1 def) = +)
((X1 status) =c absolute)
((X1 num) = (X3 num))
((X1 gen) = (X3 gen))
(X0 = X1)
)
```

French-English Transfer Grammar Example Rules (Automatically-acquired)

```
{PP,24691}
;;SL: des principes
;;TL: with the principles

PP::PP [“des” N] -> [“with the” N]
(
(X1::Y1)
)
```

```
{PP,312}
;;SL: dans le respect des principes
;;TL: in accordance with the principles

PP::PP [Prep NP] -> [Prep NP]
(
(X1::Y1)
(X2::Y2)
)
```

The Transfer Engine

- Input: source-language input sentence, or source-language confusion network
- Output: lattice representing collection of translation fragments at all levels supported by transfer rules
- Basic Algorithm: "bottom-up" integrated "parsing-transfer-generation" chart-parser guided by the synchronous transfer rules
  - Start with translations of individual words and phrases from translation lexicon
  - Create translations of larger constituents by applying applicable transfer rules to previously created lattice entries
  - Beam-search controls the exponential combinatorics of the search-space, using multiple scoring features

The Transfer Engine

- Some Unique Features:
  - Works with either learned or manually-developed transfer grammars
  - Handles rules with or without unification constraints
  - Supports interfacing with servers for morphological analysis and generation
  - Can handle ambiguous source-word analyses and/or SL segmentations represented in the form of lattice structures

Hebrew Example
(From [Lavie et al., 2004])

- Input word: B$WRH

```
0      1      2      3      4
|--------B$WRH--------|
|-----B-----|$WR|--H--|
|--B--|-H--|--$WRH---|
```

Hebrew Example

(From [Lavie et al., 2004])

```
Y0: ((SPANSTART 0)
     (SPANEND 4)
     (LEX B$WRH)
     (POS N)
     (GEN F)
     (NUM S)
     (STATUS ABSOLUTE))

Y1: ((SPANSTART 0)
     (SPANEND 2)
     (LEX B)
     (POS PREP))

Y2: ((SPANSTART 1)
     (SPANEND 3)
     (LEX $WR)
     (POS N)
     (GEN M)
     (NUM S)
     (STATUS ABSOLUTE))

Y3: ((SPANSTART 3)
     (SPANEND 4)
     (LEX $LH)
     (POS POSS))

Y4: ((SPANSTART 0)
     (SPANEND 1)
     (LEX B)
     (POS PREP))

Y5: ((SPANSTART 1)
     (SPANEND 2)
     (LEX H)
     (POS DET))

Y6: ((SPANSTART 2)
     (SPANEND 4)
     (LEX $WRH)
     (POS N)
     (GEN F)
     (NUM S)
     (STATUS ABSOLUTE))

Y7: ((SPANSTART 0)
     (SPANEND 4)
     (LEX B$WRH)
     (POS LEX))
```

XFER Output Lattice

```
(28 28 "AND" -5.6988 "W" "(CONJ,0 'AND')")
(29 29 "SINCE" -8.20817 "MAZ " "(ADVP,0 (ADV,5 'SINCE')) ")
(29 29 "SINCE THEN" -12.0165 "MAZ " "(ADVP,0 (ADV,6 'SINCE THEN')) ")
(29 29 "EVER SINCE" -12.5564 "MAZ " "(ADVP,0 (ADV,4 'EVER SINCE')) ")
(30 30 "WORKED" -10.9913 "&BD " "(VERB,0 (V,11 'WORKED')) ")
(30 30 "FUNCTIONED" -16.0023 "&BD " "(VERB,0 (V,10 'FUNCTIONED')) ")
(30 30 "WORSHIPPED" -17.3393 "&BD " "(VERB,0 (V,12 'WORSHIPPED')) ")
(30 30 "SERVED" -11.5161 "&BD " "(VERB,0 (V,14 'SERVED')) ")
(30 30 "SLAVE" -13.9523 "&BD " "(NP0,0 (N,34 'SLAVE')) ")
(30 30 "BONDSMAN" -18.0325 "&BD " "(NP0,0 (N,36 'BONDSMAN')) ")
(30 30 "A SLAVE" -16.8671 "&BD " "(NP,1  (LITERAL 'A') (NP2,0 (NP1,0 (NP0,0
          (N,34 'SLAVE')) ) ) ) ")
(30 30 "A BONDSMAN" -21.0649 "&BD " "(NP,1  (LITERAL 'A') (NP2,0 (NP1,0
          (NP0,0 (N,36 'BONDSMAN')) ) ) ) ")
```

The Lattice Decoder

- Stack Decoder, similar to standard Statistical MT decoders
- Searches for best-scoring path of non-overlapping lattice arcs
- No reordering during decoding
- Scoring based on log-linear combination of scoring features, with weights trained using Minimum Error Rate Training (MERT)
- Scoring components:
  - Statistical Language Model
  - Bi-directional MLE phrase and rule scores
  - Lexical Probabilities
  - Fragmentation: how many arcs to cover the entire translation?
  - Length Penalty: how far from expected target length?

XFER Lattice Decoder

```
0 0     ON THE FOURTH DAY THE LION ATE THE RABBIT TO A MORNING MEAL
Overall: -8.18323, Prob: -94.382, Rules: 0, Frag: 0.153846, Length: 0,
          Words: 13,13
235 < 0 8 -19.7602: B H IWM RBI&I  (PP,0 (PREP,3 'ON')(NP,2 (LITERAL 'THE')
          (NP2,0 (NP1,1 (ADJ,2 (QUANT,0 'FOURTH'))(NP1,0 (NP0,1 (N,6 'DAY')))))))>
918 < 8 14 -46.2973: H ARIH AKL AT H $PN  (S,2 (NP,2 (LITERAL 'THE') (NP2,0
          (NP1,0 (NP0,1 (N,17 'LION')))))(VERB,0 (V,0 'ATE'))(NP,100
          (NP,2 (LITERAL 'THE') (NP2,0 (NP1,0 (NP0,1 (N,24 'RABBIT')))))))>
584 < 14 17 -30.6607: L ARWXH BWQR  (PP,0 (PREP,6 'TO')(NP,1 (LITERAL 'A')
          (NP2,0 (NP1,0 (NNP,3 (NP0,0 (N,32 'MORNING'))(NP0,0 (N,27 'MEAL')))))))>
```

Stat-XFER MT Systems

- General Stat-XFER framework under development for past seven years
- Systems so far:
  - Chinese-to-English
  - French-to-English
  - Hebrew-to-English
  - Urdu-to-English
  - German-to-English
  - Hindi-to-English
  - Dutch-to-English
  - Turkish-to-English
  - Mapudungun-to-Spanish
- In progress or planned:
  - Arabic-to-English
  - Brazilian Portuguese-to-English
  - English-to-Arabic
  - Hebrew-to-Arabic
  - Czech-to-English

Syntax-based MT Resource Acquisition in Resource-rich Scenarios

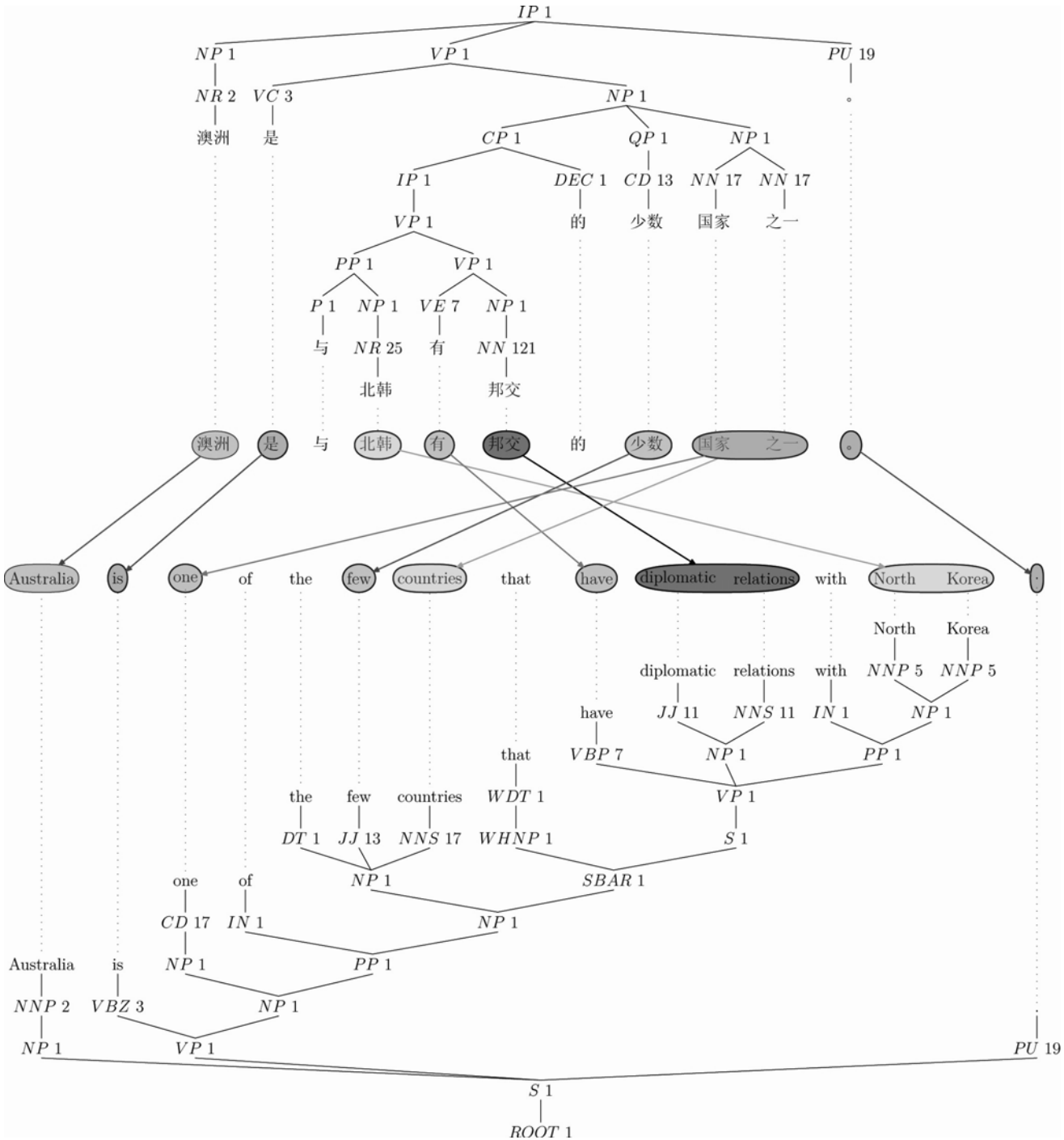
- Scenario: Significant amounts of parallel-text at sentence-level are available
  - Parallel sentences can be word-aligned and parsed (at least on one side, ideally on both sides)
- Goal: Acquire both broad-coverage translation lexicons and transfer rule grammars automatically from the data
- Syntax-based translation lexicons:
  - Broad-coverage constituent-level translation equivalents at all levels of granularity
  - Can serve as the elementary building blocks for transfer trees constructed at runtime using the transfer rules

Syntax-driven Resource Acquisition Process

- Automatic Process for Extracting Syntax-driven Rules and Lexicons from sentence-parallel data:
  1. Word-align the parallel corpus (GIZA++)
  2. Parse the sentences **independently** for both languages
  3. Tree-to-tree Constituent Alignment:
     a) Run our new **Constituent Aligner** over the parsed sentence pairs
     b) Enhance alignments with additional Constituent Projections
  4. Extract all **aligned constituents** from the parallel trees
  5. Extract all **derived synchronous transfer rules** from the constituent-aligned parallel trees
  6. Construct a **"data-base"** of all extracted parallel constituents and synchronous rules **with their frequencies** and model them statistically (assign them **relative-likelihood probabilities**)

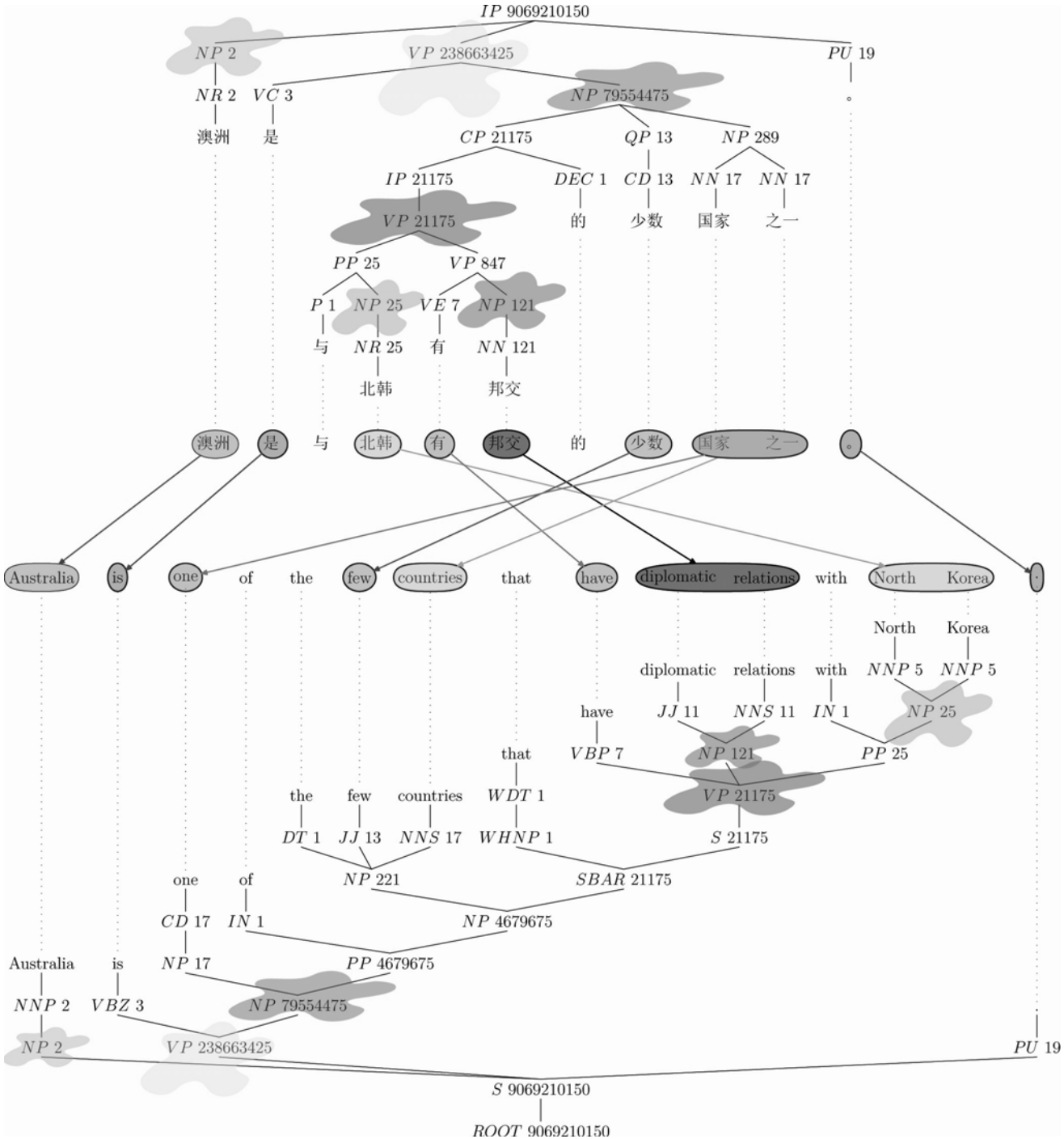
PFA Constituent Node Aligner

- Input: a bilingual pair of parsed and word-aligned sentences
- Goal: find all sub-sentential constituent alignments between the two trees which are translation equivalents of each other
- Equivalence Constraint: a pair of constituents <S,T> are considered translation equivalents if:
  - All words in yield of <S> are aligned only to words in yield of <T> (and vice-versa)
  - If <S> has a sub-constituent <S1> that is aligned to <T1>, then <T1> must be a sub-constituent of <T> (and vice-versa)
- Algorithm is a bottom-up process starting from word-level, marking nodes that satisfy the constraints



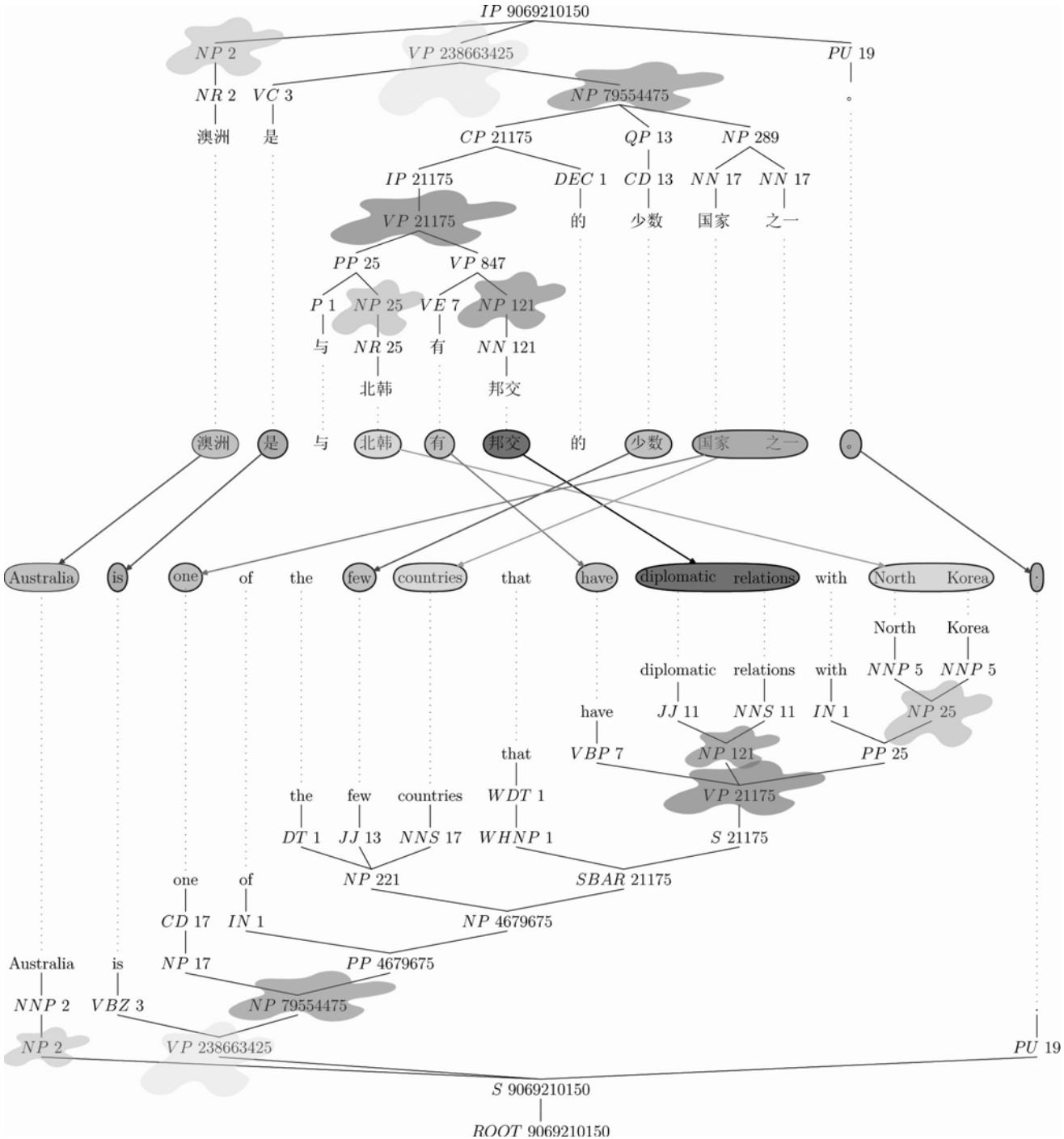
PFA Node Alignment Algorithm Example

- Words don't have to align one-to-one
- Constituent labels can be different in each language
- Tree Structures can be highly divergent



PFA Node Alignment Algorithm Example

- Aligner uses a clever arithmetic manipulation to enforce equivalence constraints
- Resulting aligned nodes are highlighted in figure



PFA Node Alignment Algorithm Example

Extraction of Phrases:

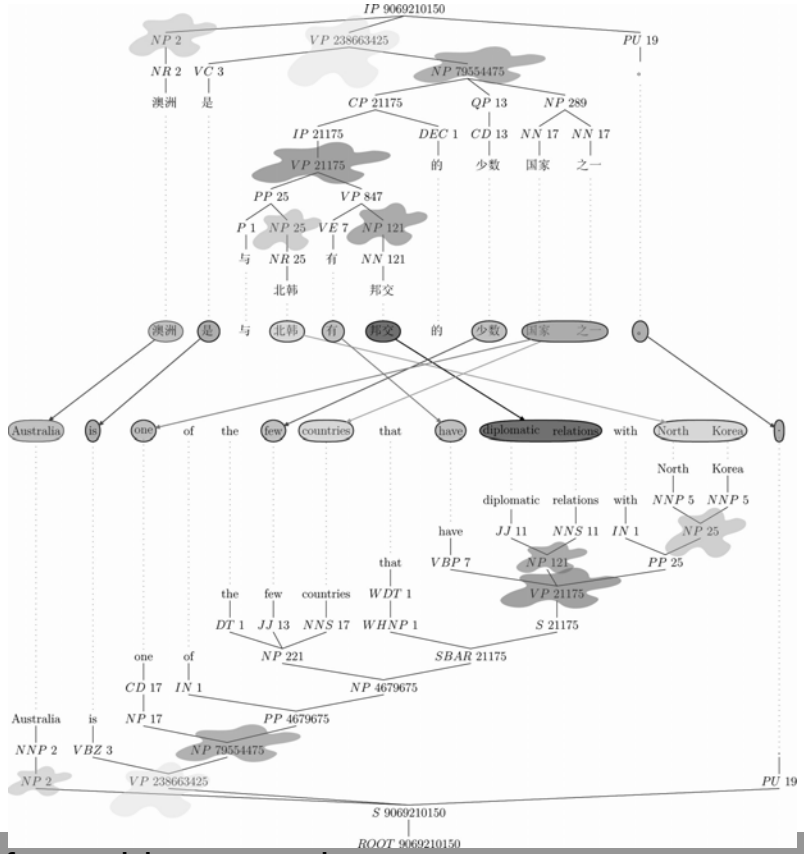
- Get the **yields** of the aligned nodes and add them to a phrase table tagged with **syntactic categories** on both source and target sides

- Example:

NP # NP ::

澳洲 # Australia

PFA Node Alignment Algorithm Example



All Phrases from this tree pair:

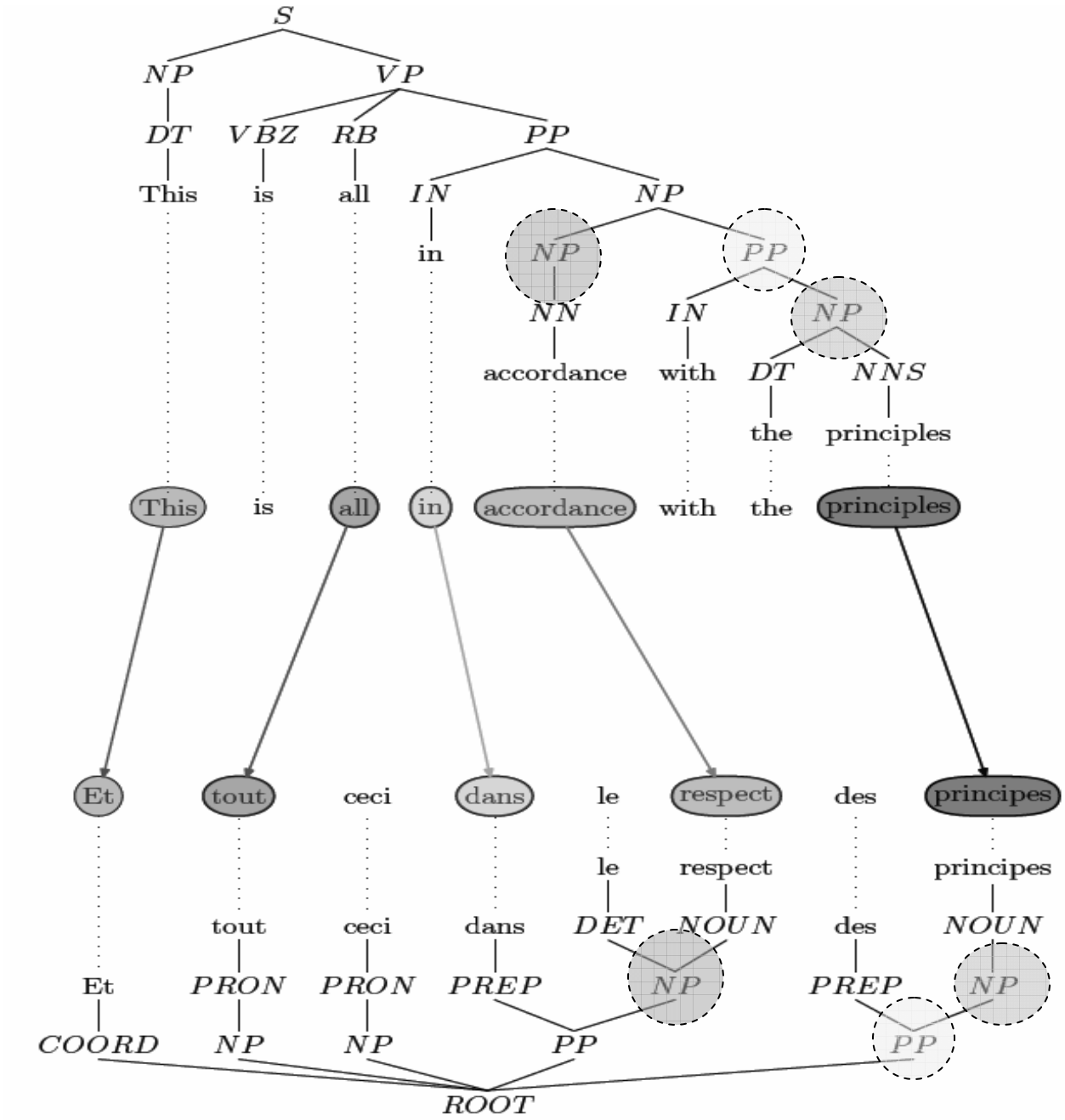
1.IP # S :: 澳洲 是 与 北**韩** 有 邦交 的 少数 国家 之一 。 # Australia is one of the few countries that have diplomatic relations with North Korea .
2.VP # VP :: 是 与 北**韩** 有 邦交 的 少数 国家 之一 # is one of the few countries that have diplomatic relations with North Korea
3.NP # NP :: 与 北**韩** 有 邦交 的 少数 国家 之一 # one of the few countries that have diplomatic relations with North Korea
4.VP # VP :: 与 北**韩** 有 邦交 # have diplomatic relations with North Korea
5.NP # NP :: 邦交 # diplomatic relations
6.NP # NP :: 北**韩** # North Korea
7.NP # NP :: 澳洲 # Australia

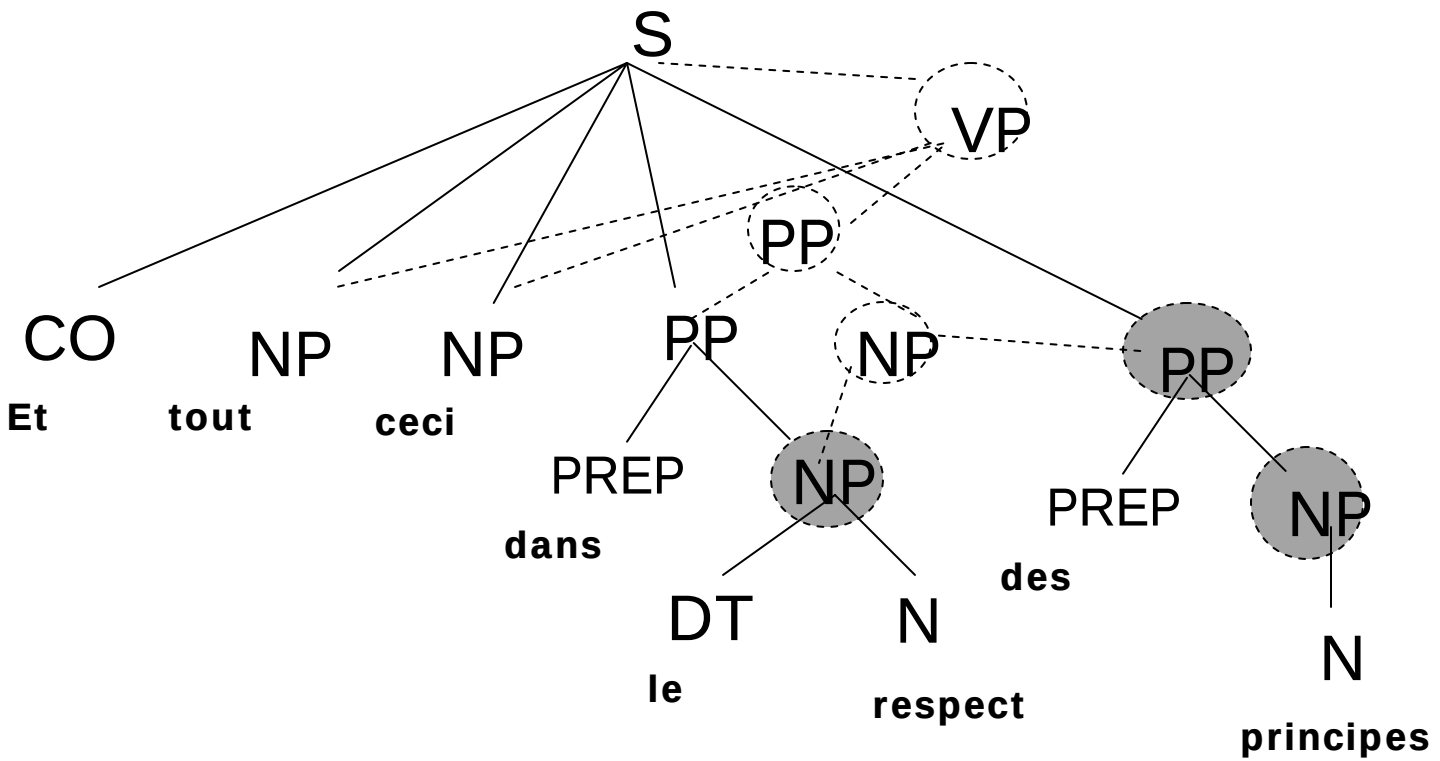
Recent Improvements

- The **Tree-to-Tree** (T2T) method is high precision but suffers from low recall
- Alternative: **Tree-to-String** (T2S) methods (i.e. [Galley et al., 2006]) use trees on ONE side and project the nodes based on word alignments
  - High recall, but lower precision
- Recent work by Vamshi Ambati [Ambati and Lavie, 2008]: combine both methods (**T2T***) by seeding with the T2T correspondences and then adding in additional consistent projected nodes from the T2S method
  - Can be viewed as restructuring target tree to be maximally isomorphic to source tree
  - Produces richer and more accurate syntactic phrase tables that improve translation quality (versus T2T and T2S)

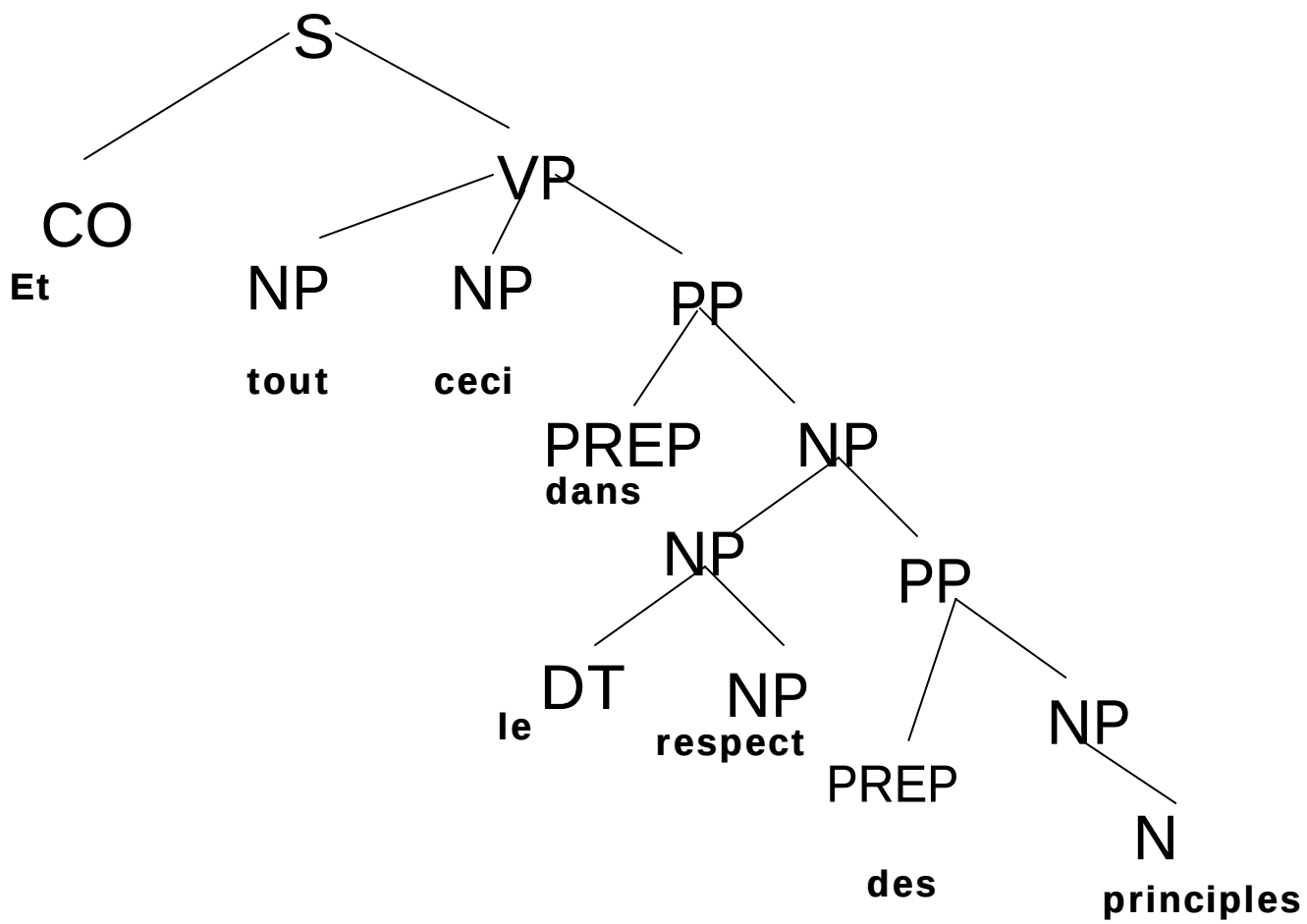
TnS vs TnT Comparison French-English

TYPE	Total	TnS	%	TnT	%	O%
ADJP	600104	412250	68.6	176677	29.4	90.7
ADVP	1010307	696106	68.9	106532	10.5	83.1
NP	11204763	8377739	74.7	4152363	37.1	93.8
VP	4650093	2918628	62.7	238659	5.1	67.9
PP	3772634	2766654	73.3	842308	22.3	89.4
S	2233075	1506832	67.4	248281	11.1	94.5
SBAR	912240	591755	64.8	42407	4.6	91.9
SBARQ	19935	9084	45.5	7576	38	99.6


S
NP
VP
DT
VBZ
RB
PP
This
is
all
IN
NP
in
NP
PP
NN
IN
NP
accordance
with
DT
NNS
the
principles
This
is
all
in
accordance
with
the
principles
Et
tout
ceci
dans
le
respect
des
principes
le
respect
principes
tout
ceci
dans
DET
NOUN
des
NOUN
Et
PRON
PRON
PREP
NP
PREP
NP
COORD
NP
NP
PP
PP
ROOT



- Add consistent projected nodes from source tree
- Tree Restructuring:
  - Drop links to a higher parent in the tree in favor of a lower parent
  - In case of a tie, prefer a node projected or aligned over an unaligned node



T*: Restructured target tree

Extracted Syntactic Phrases

English	French
The principles	Principes
With the principles	Principes
Accordance with the..	Respect des principes
Accordance	Respect
In accordance with the…	Dans le respect des principes
Is all in accordance with..	Tout ceci dans le respect…
This	et

TnS

English	French
The principles	Principes
With the principles	des Principes
Accordance	Respect

TnT

English	French
The principles	Principes
With the principles	des Principes
Accordance with the..	Respect des principes
Accordance	Respect
In accordance with the…	Dans le respect des principes
Is all in accordance with..	Tout ceci dans le respect…
This	et

TnT*

Comparative Results French-to-English

	Dev-Set	Test-Set	
System	BLEU	BLEU	METEOR
Xfer-TnS	26.57	27.02	57.68
Xfer-TnT	21.75	22.23	54.05
Xfer-TnT'	27.34	27.76	57.82
Xfer-Moses	29.54	30.18	58.13

- MT Experimental Setup
  - Dev Set: 600 sents, WMT 2006 data, 1 reference
  - Test Set: 2000 sents, WMT 2007 data, 1 reference
  - NO transfer rules, Stat-XFER monotonic decoder
  - SALM Language Model (430M words)

Combining Syntactic and Standard Phrase Tables

- Recent work by Greg Hanneman, Alok Parlikar and Vamshi Ambati
- Syntax-based phrase tables are still significantly lower in coverage than “standard” heuristic-based phrase extraction used in Statistical MT
- Can we combine the two approaches and obtain superior results?
- Experimenting with two main combination methods:
  - Direct Combination: Extract phrases using both approaches and then jointly score (assign MLE probabilities) them
  - Prioritized Combination: For source phrases that are syntactic – use the syntax-extracted method, for non-syntactic source phrases - take them from the “standard” extraction method
- Direct Combination appears to be slightly better so far
- Grammar builds upon syntactic phrases, decoder uses both

Recent Comparative Results French-to-English

Condition	BLEU	METEOR
Syntax Phrases Only	27.34	56.54
Non-syntax Phrases Only	30.18	58.35
Syntax Prioritized	29.61	58.00
Direct Combination	30.08	58.35

- MT Experimental Setup
  - Dev Set: 600 sents, WMT 2006 data, 1 reference
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  - SALM Language Model (430M words)

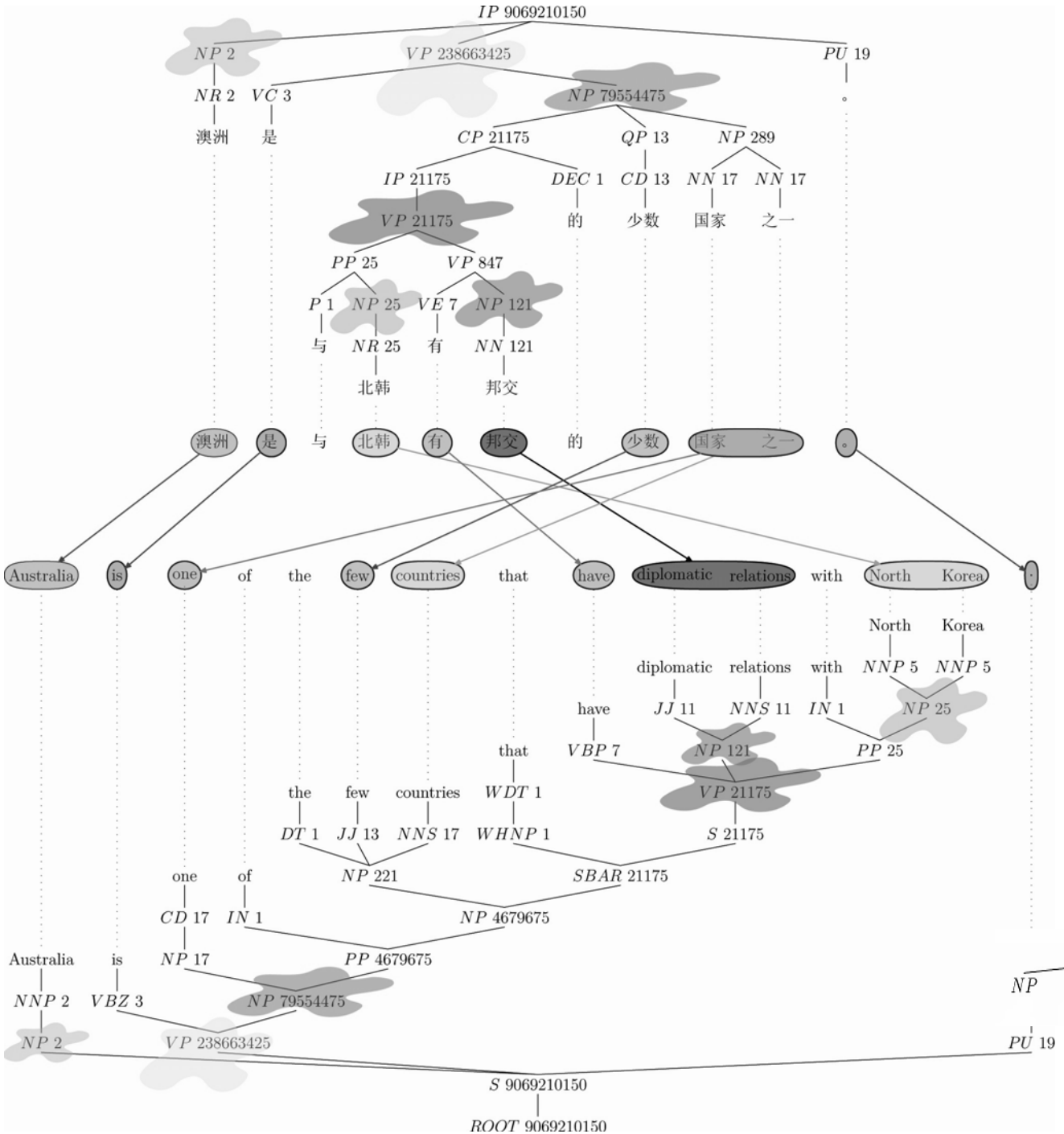
Transfer Rule Learning

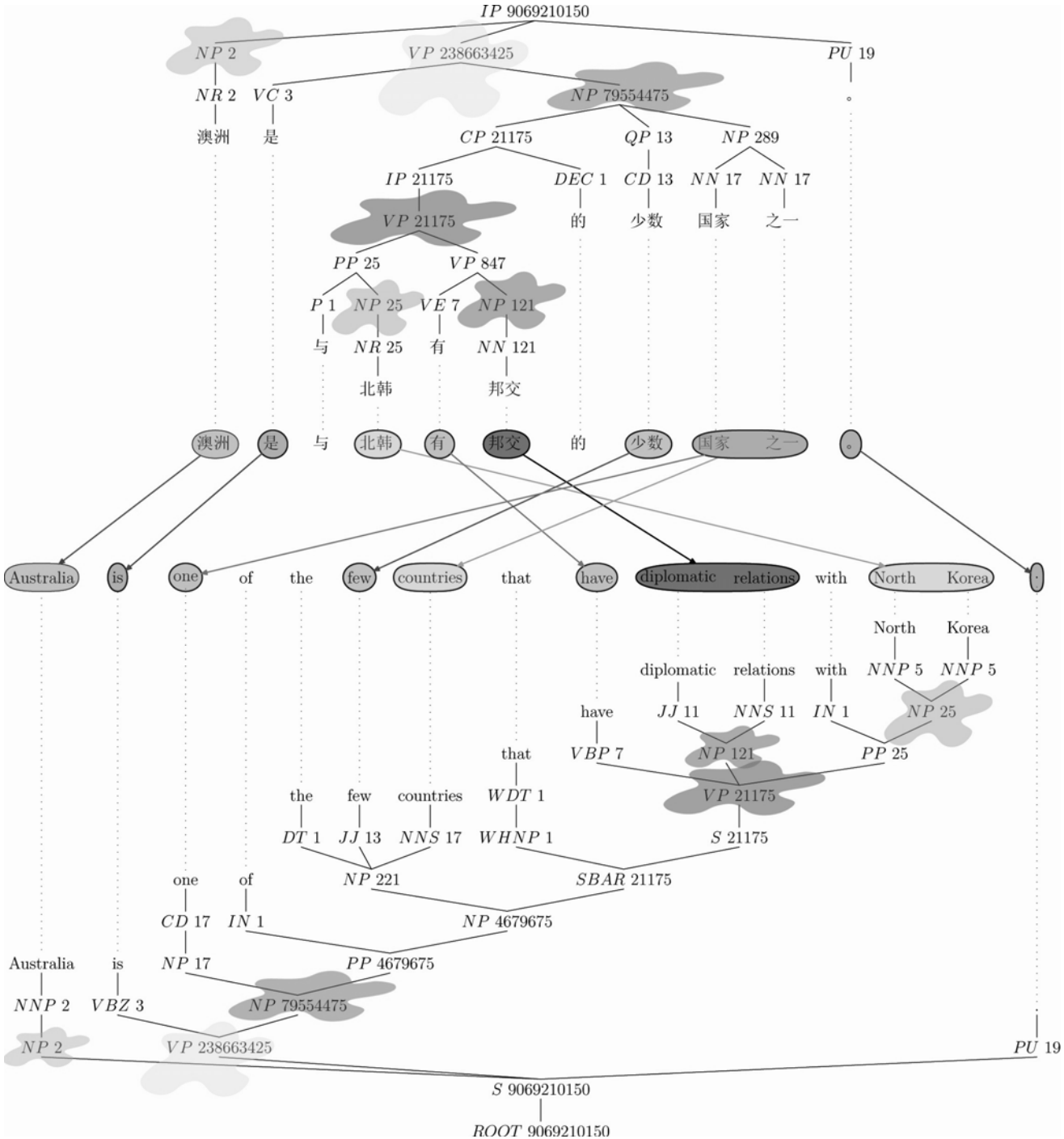
- Input: Constituent-aligned parallel trees
- Idea: Aligned nodes act as possible decomposition points of the parallel trees
  - The sub-trees of any aligned pair of nodes can be broken apart at any lower-level aligned nodes, creating an inventory of “treelet” correspondences
  - Synchronous “treelets” can be converted into synchronous rules
- Algorithm:
  - Find all possible treelet decompositions from the node aligned trees
  - “Flatten” the treelets into synchronous CFG rules

Rule Extraction Algorithm

Sub-Treelet extraction:

Extract Sub-tree segments including synchronous alignment information in the target tree. All the sub-trees and the super-tree are extracted.





Rule Extraction Algorithm

Flat Rule Creation:

Each of the treelets pairs is flattened to create a Rule in the 'Stat-XFER Formalism' –

Four major parts to the rule:

1. Type of the rule: Source and Target side type information

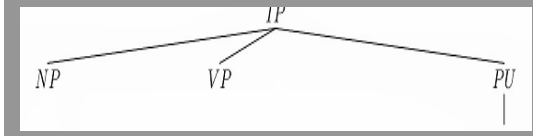
2. Constituent sequence of the synchronous flat rule

3. Alignment information of the constituents

4. Constraints in the rule (Currently not extracted)

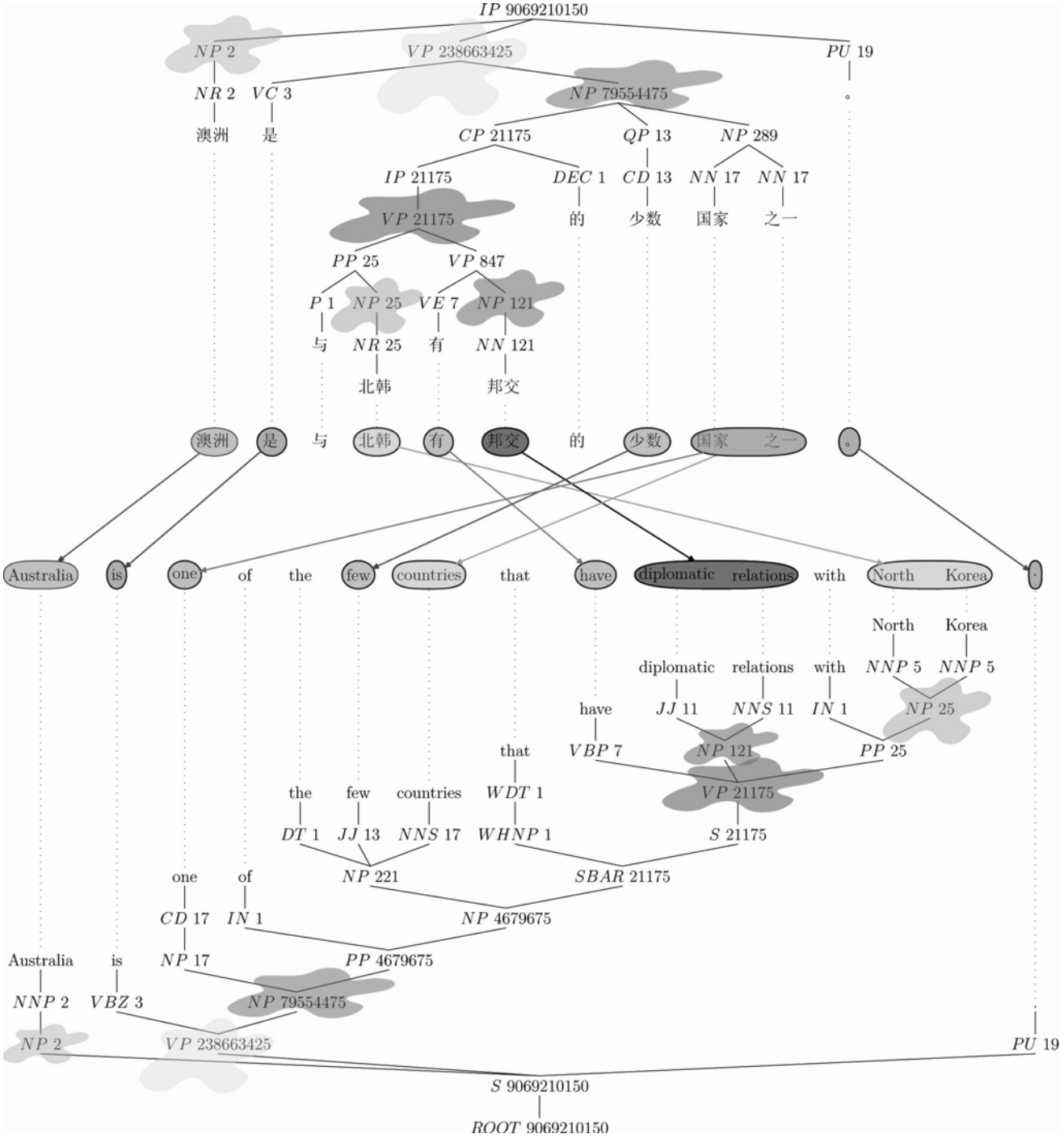
Rule Extraction Algorithm

Flat Rule Creation:



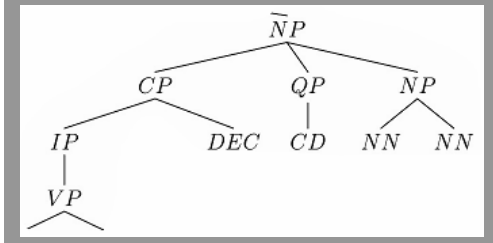
Sample rule:

IP::S [NP VP .] -> [NP VP .]
(
;; Alignments
(X1::Y1)
(X2::Y2)
;;Constraints
)



Rule Extraction Algorithm

Flat Rule Creation:



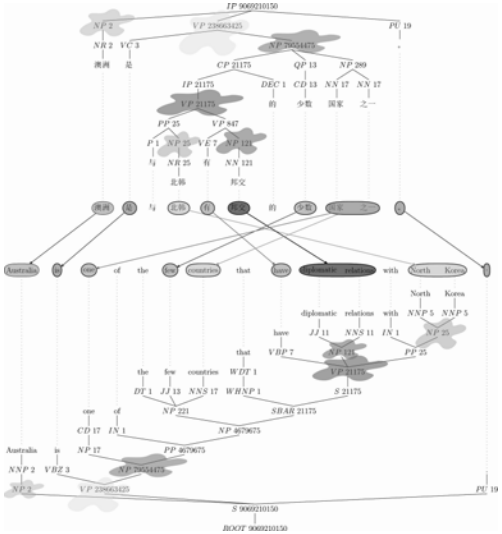
Sample rule:

NP::NP [VP 北 CD 有 邦交] -> [one of the CD countries that VP]
(
;; Alignments
(X1::Y7)
(X3::Y4)
)

Note:

1. Any one-to-one aligned words are elevated to Part-Of-Speech in flat rule.
2. Any non-aligned words on either source or target side remain lexicalized

Rule Extraction Algorithm



All rules extracted:
NP::NP [VP 北 CD 有 邦交] -> [one of the CD countries that VP]
(
(*score* 0.5)
;; Alignments
(X1::Y7)
(X3::Y4)
)

IP::S [NP VP] -> [NP VP]
(
(*score* 0.5)
;; Alignments
(X1::Y1)
(X2::Y2)
)

NP::NP [“北韩”] -> [“North” “Korea”]
(
;Many to one alignment is a phrase
)

All rules extracted:
VP::VP [VC NP] -> [VBZ NP]
(
(*score* 0.5)
;; Alignments
(X1::Y1)
(X2::Y2)
)

VP::VP [VC NP] -> [VBZ NP]
(
(*score* 0.5)
;; Alignments
(X1::Y1)
(X2::Y2)
)

NP::NP [NR] -> [NNP]
(
(*score* 0.5)
;; Alignments
(X1::Y1)
(X2::Y2)
)
VP::VP [北 NP VE NP] -> [VBP NP with NP]
(
(*score* 0.5)
;; Alignments
(X2::Y4)
(X3::Y1)
(X4::Y2)
)

French-English System

- Large-scale broad-coverage system, developed for research experimentation
- Participated in WMT-08 and WMT-09 Evaluations
- Latest version integrates our most up-to-date processing methods:
  - French and English parsing using Berkeley Parser
  - Moses phrase tables combined with syntactic phrase tables using syntax-prioritized method
  - Very small grammar (26 rules) selected from large extracted rule set

French-English System Data Resources

- Europarl corpus v. 4:
  - European parliamentary proceedings
  - 1.43 million sentences (36 MW)
- News Commentary corpus:
  - Editorials, columns
  - 0.06 million sentences (1 MW)
- Giga-FrEn corpus, pre-release version:
  - Crawled Canadian, European websites in various domains
  - 8.60 million sentences (191 MW)
- TOTAL:
  - about 10M sentence pairs
  - 9.57M sentence pairs after cleaning and filtering

French-English System Phrase Tables

- After complete phrase pair extraction, filtering and collapsing:
  - 424 million standard SMT phrases
  - 27 million syntactic phrases
- Combined in a syntax-prioritized combination

French-English System Example Grammar Rules

```
{NP,5256912}
NP::NP [N "de" N ] -> [N N ]
(
      (*sgtrule* 0.736382560)
      (*tgsrule* 0.292253105)
;     (*freq* 232772)
      (X3::Y1)
      (X1::Y2)
)
```

```
{NP,5782420}
NP::NP [N ADJ ] -> [ADJ N ]
(
      (*sgtrule* 0.726698577)
      (*tgsrule* 0.628385699)
;     (*freq* 1279387)
      (X2::Y1)
      (X1::Y2)
)
```

```
{VP,2042518}
VP::VP ["ne" V "pas" VP ] -> [V "not" VP ]
(
      (*sgtrule* 0.97076900)
      (*tgsrule* 0.55735608)
;     (*freq* 45332)
      (X2::Y1)
      (X4::Y3)
)
```

English-French System Translation Example

```
SrcSent 1
L' extrême droite européenne est caractérisée par son racisme et son
utilisation de la question de l' immigration en tant que divergence politique .

1 0     The extreme right in Europe is characterised by its racism and use of
the immigration as a political difference .

Overall: -1105.41, Prob: -94.7024, Rules: -9.9594, RuleSGT: -14.8736,
RuleTGS: -9.9594, TransSGT: -75.2431, TransTGS: -34.7368, Frag: -0.20412,
Length: -0.0398972, Words: 24,20
SGT -1.61107 TGS -0.745873

( 0 3 "The extreme right" -188.191 "L' extrême droite"
        "(PHRS,14515871 'The extreme right')")
( 3 5 "in Europe is" -187.021 "européenne est"
        "(PHRS,113195218 'in Europe is')")
( 5 6 "characterised" -125.731 "caractérisée" "(VS,331391 'characterised')")
( 6 8 "by its" -118.707 "par son" "(PHRS,62116997 'by its')")
( 8 9 "racism" -101.507 "racisme" "(NS,300037 'racism')")
( 9 12 "and use" -176.864 "et son utilisation" "(PHRS,112444704 'and use')")
( 12 17 "of the" -192.468 "de la question de l'" "(PHRS,150075588 'of the')")
( 17 21 "immigration as a" -205.369 "immigration en tant que"
         "(PHRS,316257845 'immigration as a')")
( 21 23 "political difference" -209.152 "divergence politique "
         "(NP,5782420 (ADJS,29478 'political') (NS,158428 'difference') ) ")
( 23 24 "." -39.2412 "." "(PUNCTS,3074 '.')")
```

Current and Future Research Directions

- Automatic Transfer Rule Learning:
  - Under different scenarios:
    - From large volumes of automatically word-aligned “wild” parallel data, with parse trees on one or both sides
    - From manually word-aligned elicitation corpus
    - In the absence of morphology or POS annotated lexica
  - Compositionality and generalization
    - Granularity of constituent labels – what works best for MT?
    - Lexicalization of grammars
  - Identifying “good” rules from “bad” rules
  - Effective models for rule scoring for
    - Decoding: using scores at runtime
    - Pruning the large collections of learned rules
  - Learning Unification Constraints

Current and Future Research Directions

- Advanced Methods for Extracting and Combining Phrase Tables from Parallel Data:
  - Leveraging from both syntactic and non-syntactic extraction methods
  - Can we "syntactify" the non-syntactic phrases or apply grammar rules on them?
- Syntax-aware Word Alignment:
  - Current word alignments are naïve and unaware of syntactic information
  - Can we remove incorrect word alignments to improve the syntax-based phrase extraction?
  - Develop new syntax-aware word alignment methods

Current and Future Research Directions

- Syntax-based LMs:
  - Our syntax-based MT approach performs parsing and translation as integrated processes
  - Our translations come out with syntax trees attached to them
  - Add syntax-based LM features that can discriminate between good and bad trees, on both target and source sides!

Current and Future Research Directions

- Algorithms for XFER and Decoding
  - Integration and optimization of multiple features into search-based XFER parser
  - Complexity and efficiency improvements
  - Non-monotonicity issues (LM scores, unification constraints) and their consequences on search

Current and Future Research Directions

- Building Elicitation Corpora:
  - Feature Detection
  - Corpus Navigation
- Automatic Rule Refinement
- Translation for highly polysynthetic languages such as Mapudungun and Iñupiaq

Conclusions

- Stat-XFER is a promising general MT framework, suitable to a variety of MT scenarios and languages
- Provides a complete solution for building end-to-end MT systems from parallel data, akin to phrase-based SMT systems (training, tuning, runtime system)
- No open-source publically available toolkits, but extensive collaboration activities with other groups
- Complex but highly interesting set of open research issues

Questions?