A Syntax-Based Statistical Model for Machine Translation

Brooke Cowan

Thesis Defense
April 23, 2008

What is Machine Translation (MT)?

Ich hoffe, dass wir Slowenien in der ersten Gruppe der neuen Mitglieder begrüßen können.

↓

↓

I hope that we can welcome Slovenia in the first group of new members.

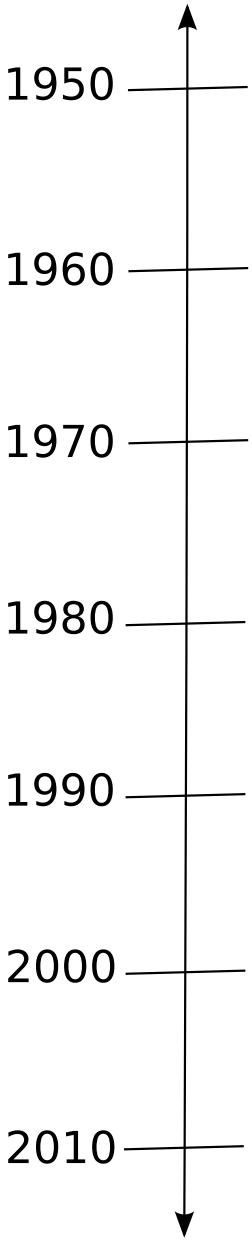
Why is MT Important?

A Little Bit of History

Russian was translated into English by an electronic "brain" today for the first time... A girl who didn’t understand a word of the language of the Soviets punched out the Russian messages on IBM cards. The "brain" dashed off its English translations on an automatic printer at the breakneck speed of two and a half lines per second.

--IBM Press Release, January 1954

Timeline



1954: Georgetown-IBM Experiment
"MT will be solved within 3-5 years"

1966: Alpac Report
MT research nearly abandoned for 10+ years

rule-based systems

IBM Models 1-5
first statistical MT models

phrase-based models

syntax-based models

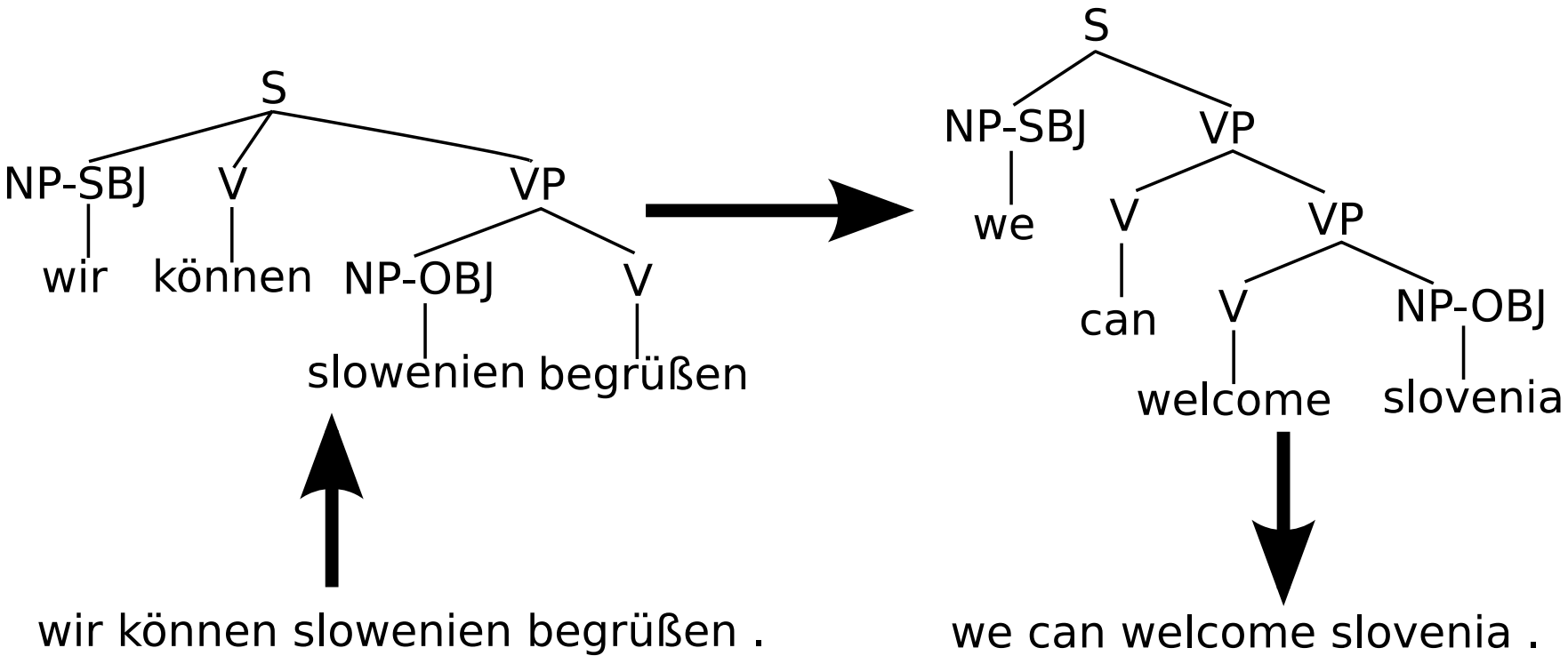
The Machine Learning Problem for MT

- bilingual parallel corpus

Wiederaufnahme der Sitzungsperiode.	Resumption of the session.
Gibt es Einwände?	Are there any comments?
Wissenschaftlich betrachtet haben Sie recht.	Scientifically you are right.
Sie sind äußerst wichtig.	They are extremely important.
Das Wort hat Herr Simpson.	Mr Simpson has the floor.
Bedauerlicherweise wurde dies nicht eingehalten.	Sadly, that has not been the case.
Vielen Dank, Herr Simpson.	Thank you very much, Mr Simpson.

- learn a model that can predict an English translation given a German sentence

A Tree-to-Tree Statistical Model



Outline

The Phrase-Based Model

gestatten sie mir auch ein konkretes problem aus dem bereich des familienlebens zu erwähnen .

gestatten	allow
gestatten sie mir	please allow me
sie	you
mir	me
mir auch	me
auch	also
auch ein	a
ein konkretes	a specific
konkretes problem	specific problem
problem	problem
aus	from
aus dem	from the
aus dem bereich	in the area
des familienlebens	of family life
zu erwähnen	to mention
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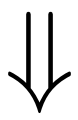

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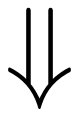

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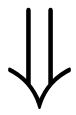

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German Verbs

gestatten	*sie*	*mir*
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auch	*ein*	*konkretes*	*problem*	*aus*	*dem*	*bereich*	*des*	*familienlebens*	*zu*	*erwähnen*	.
also	a	specific	problem	in	the	area	of	family life	to	mention	.

German Verbs

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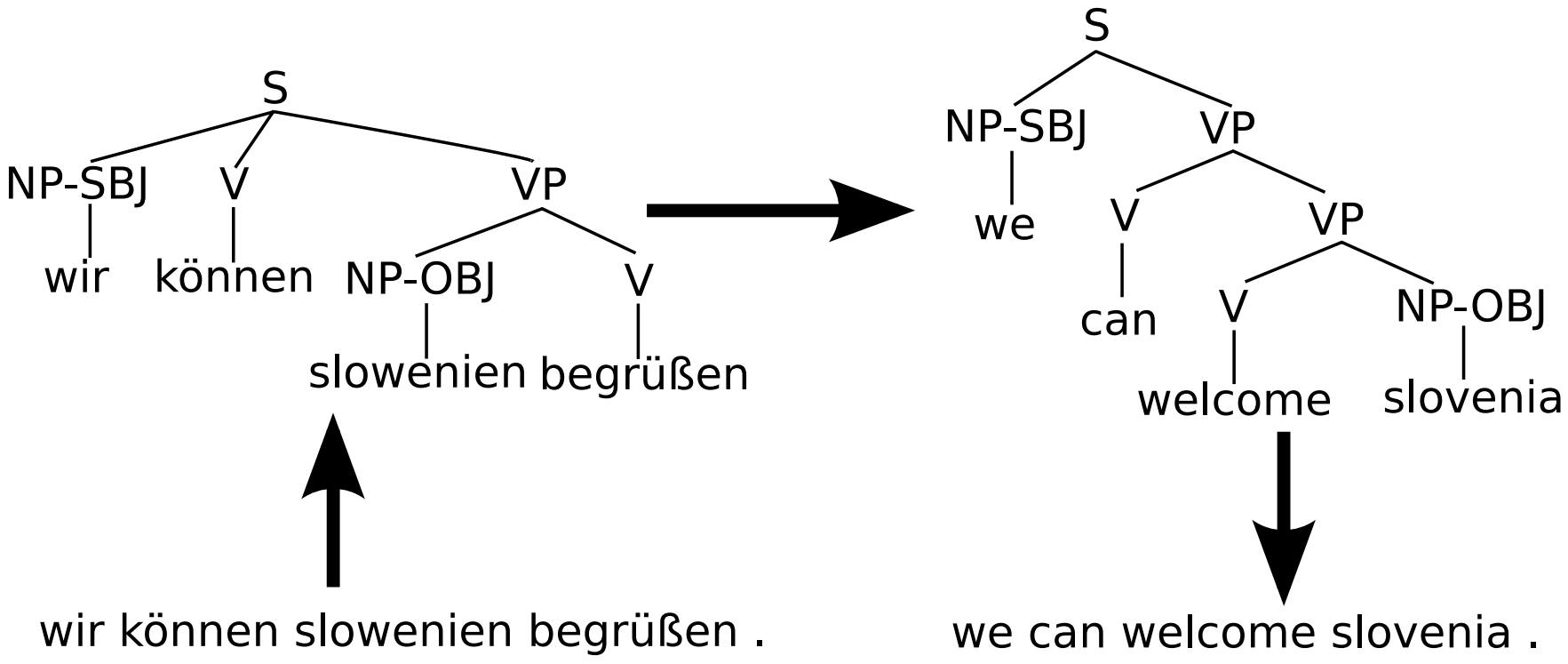
- German verbs often appear at the end of a clause
- Different from English, therefore must *reorder* English words
- Reordering is a problem for many language pairs
- My model uses syntax to address this problem

Related Work in Syntax-Based Statistical MT

- **tree-to-string**
  - Learn a mapping from trees to strings
  - [Menezes and Quirk 07, Collins et al. 05, Xia and McCord 04]
- **string-to-tree**
  - Learn a mapping from strings to trees
  - [Marcu et al. 06, Galley et al. 06, Yamada and Knight 01]
- **synchronous grammar formalisms**
  - Learn a grammar that can simultaneously generate two trees
  - [Chiang 05, Wu 97]
- **tree-to-tree**
  - Learn a mapping from trees to trees
  - [Nesson et al. 06, Riezler and Maxwell 06, Ding and Palmer 05, Gildea 03]

Outline

Tree-to-Tree Prediction



My Approach: Aligned Extended Projections (AEP)

ich	*hoffe*	*,*	*dass*	*wir*	*slowenien*	*in*	*der*	*ersten*	*gruppe*
i	hope	,	that	we	slovenia	in	the	first	group
der	*neuen*	*mitglieder*	*begrüßen*	*können*	*.*				
of the	new	members	welcome	can	.				

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REF: i hope slovenia will be in the first group of new member states .

AEP: i hope we can welcome slovenia in the first group of new member states .

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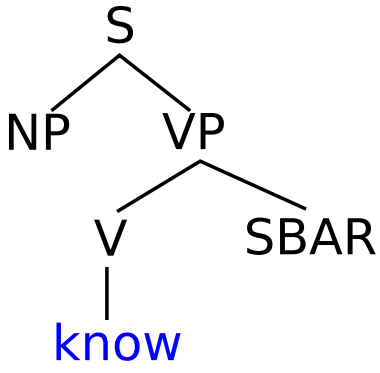
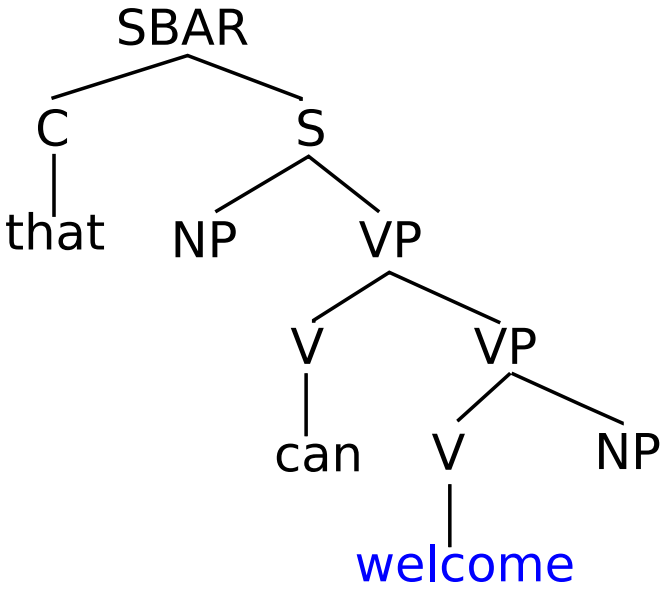
AEP: i hope we can welcome slovenia in the first group of new member states .

- **Predict one or more *aligned extended projections* (AEPs)**
- **Predict a translation from the AEPs**

What is an AEP?

- An object with two parts. . .
  1. the *extended projection* of a verb [Grimshaw 91, Frank 04]





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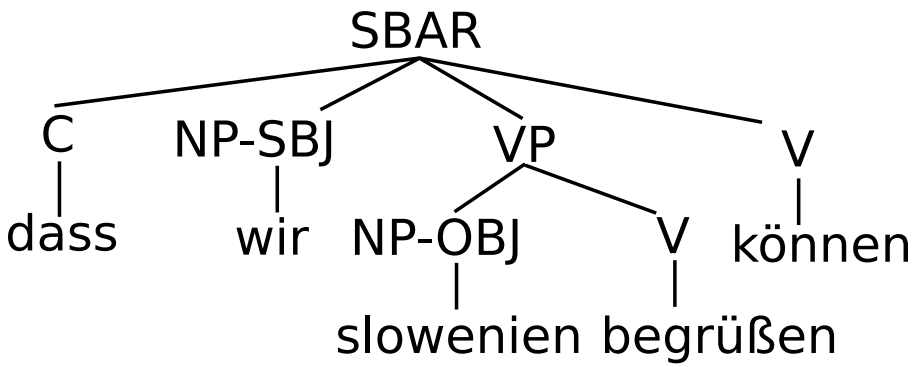
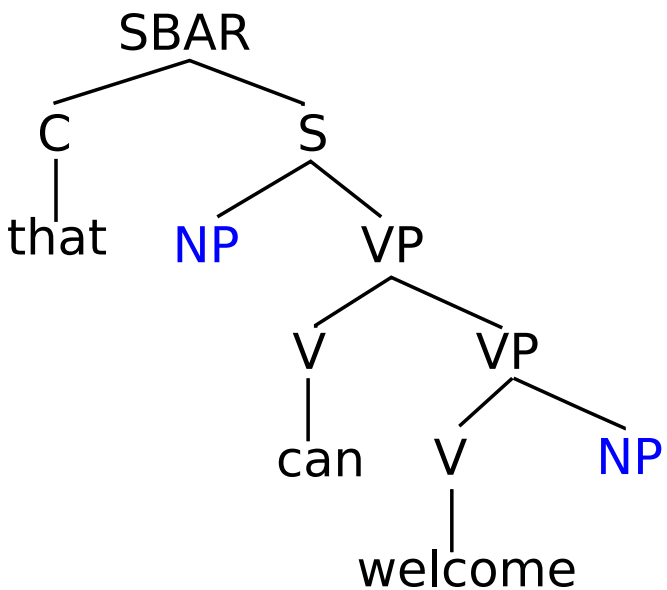
- An object with two parts. . .
  1. the *extended projection* of a verb [Grimshaw 91, Frank 04]
  2. *alignment information* with references to the German clause





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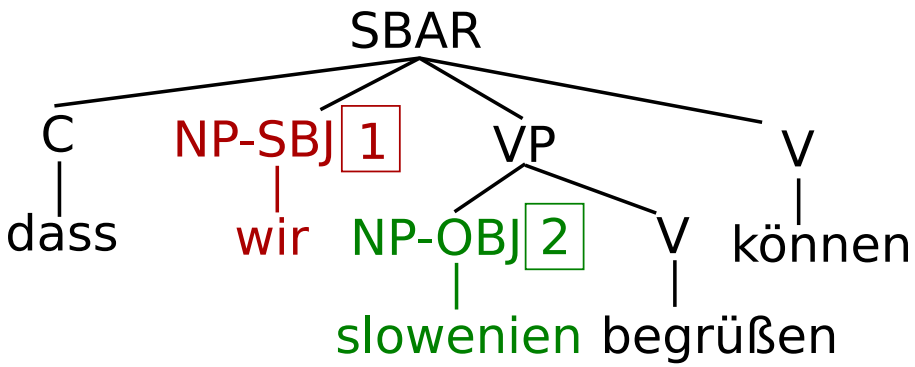

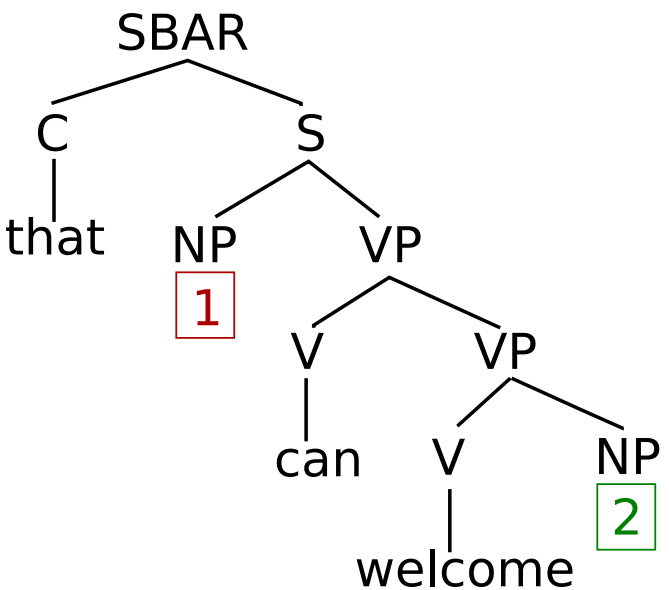

Back to the Example...

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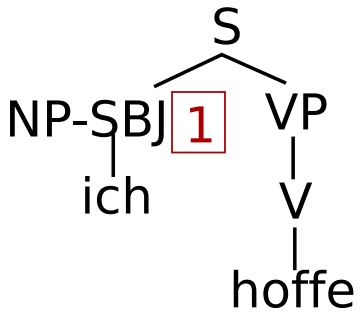
der	*neuen*	*mitglieder*	*begrüßen*	*können*	*.*
of the	new	members	welcome	can	.

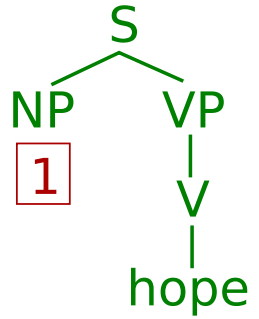
- One AEP per clause
- Two clauses: *ich hoffe ,* and *dass wir slowenien...*

AEP for First Clause

German Clause:



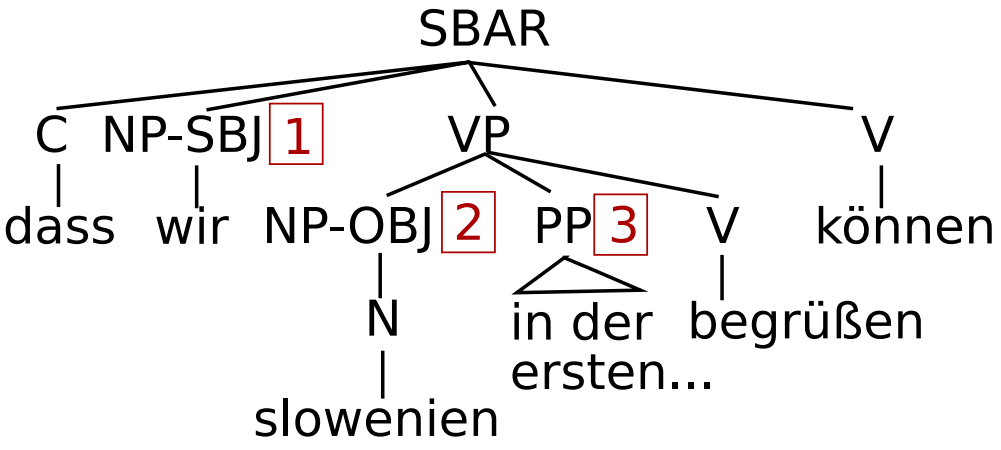
English AEP:



ich **hope**

AEP for Second Clause

German Clause:



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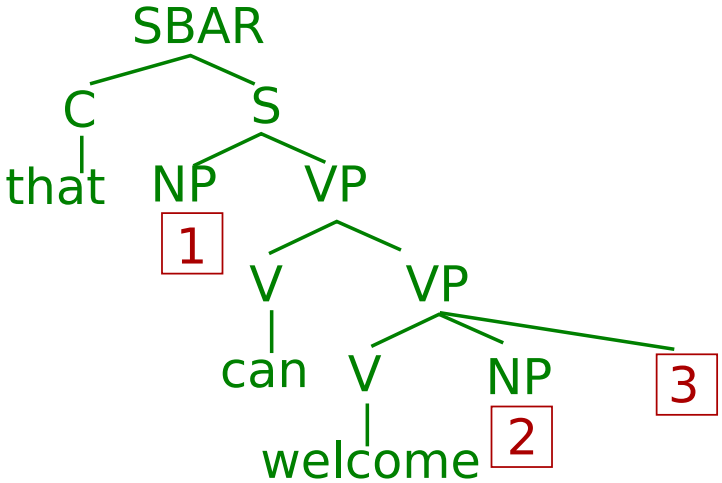
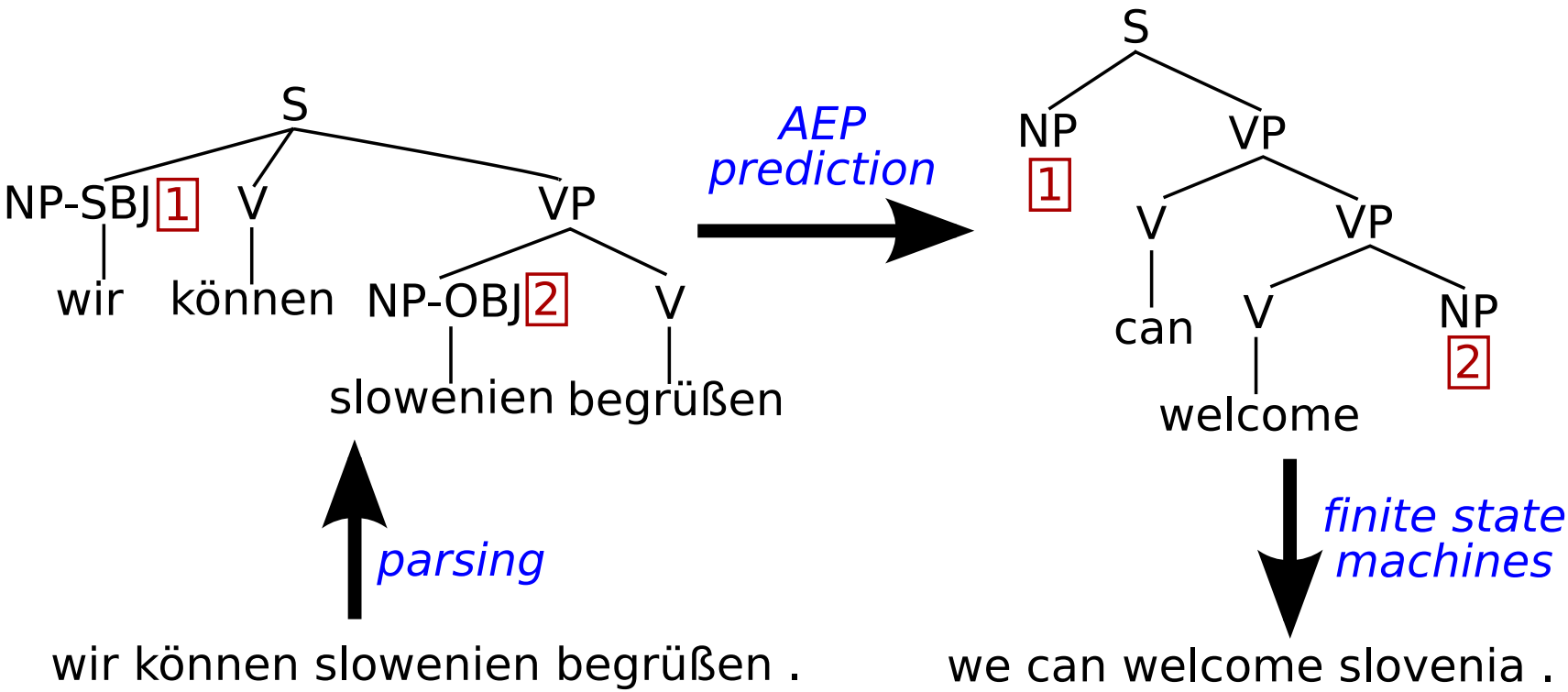


that *wir* can welcome *slowenien*

in der ersten gruppe der neuen mitglieder

Solving Tree-to-Tree Prediction with AEPs



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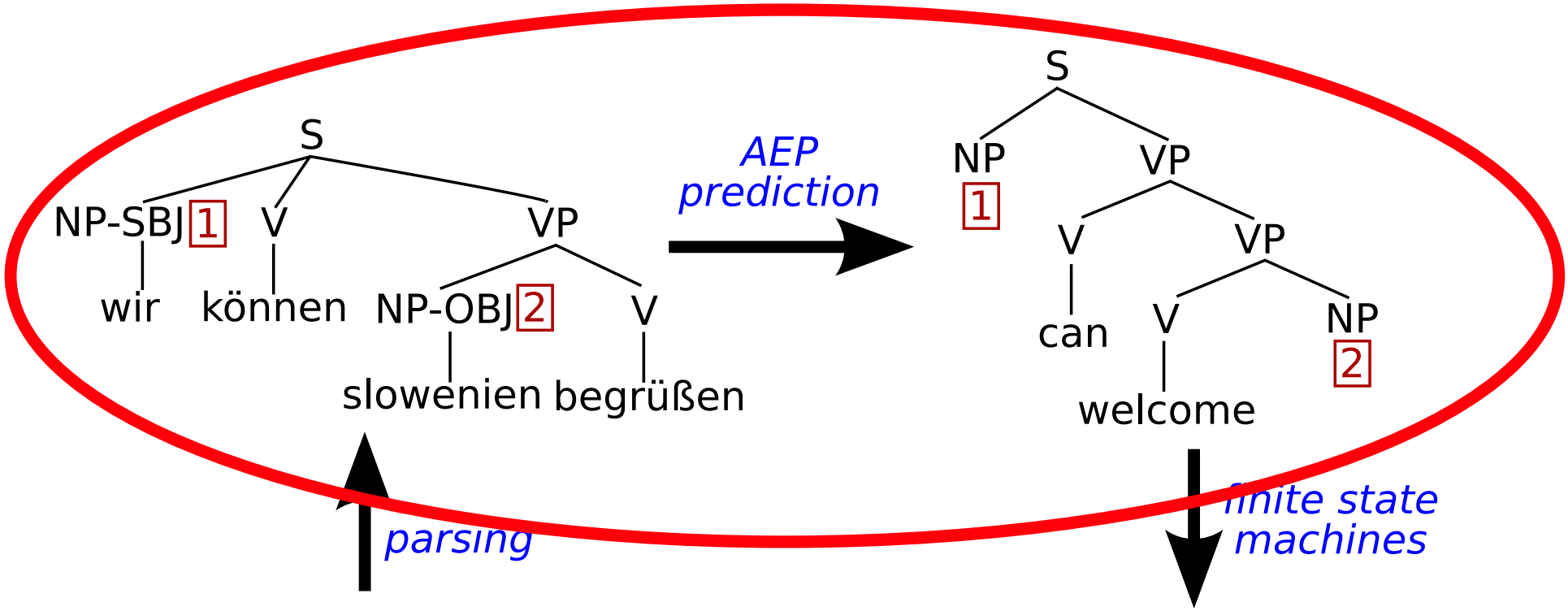
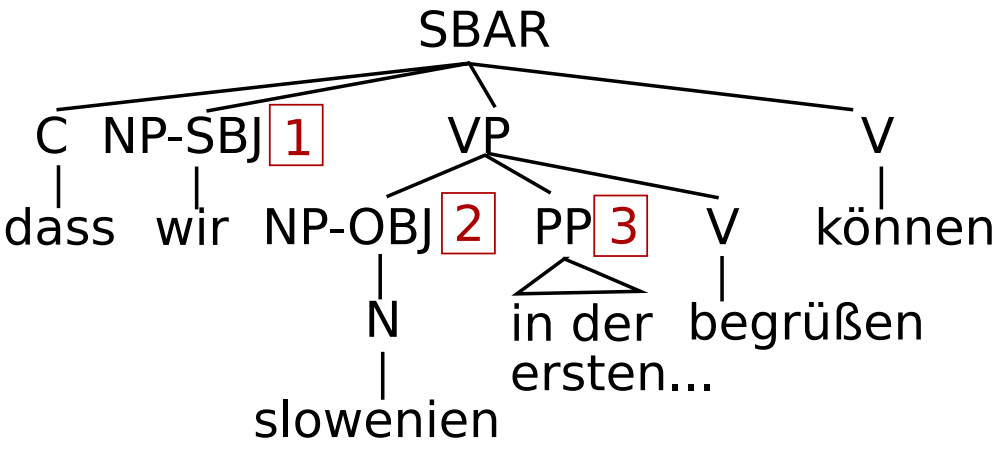


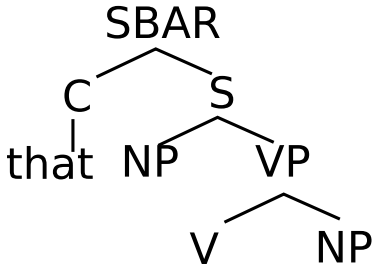
Representing AEPs as Decision Sequences

German Clause:



English AEP:

STEM	welcome
SPINE	



VOICE	active
SUBJECT	1
OBJECT	2
WH	`null`
MODALS	can
INFLECTION	welcome
MOD(3)	*post-verb*

Representing AEPs as Decision Sequences

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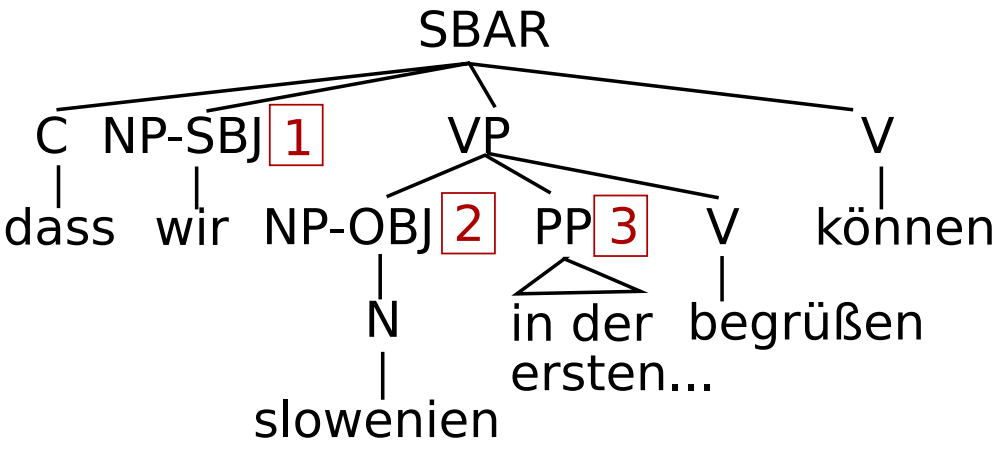

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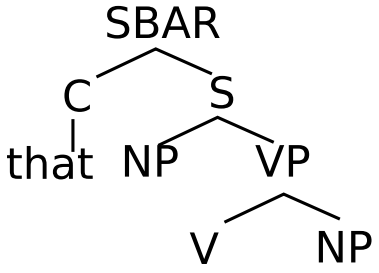
SPINE	
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SUBJECT	1
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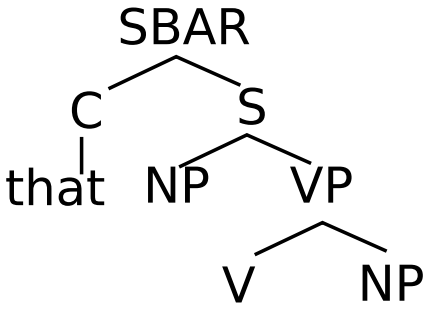
The Stem Decision

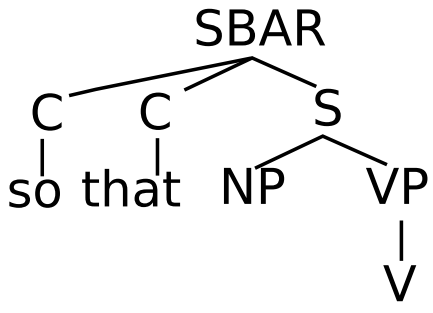
- around 1600 candidate stems (taken from training data)
- for example:

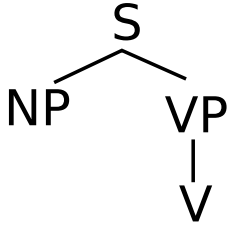
abandon, accommodate, accumulate, advise, allot, astonish, avail, be, beware, broaden, burden, calm, clash, classify, declare, delay, deliver, eat, echo, endanger, endure, flag, freeze, globalise, grant, harm, hinder, import, include, indulge, inflict, lie, lift, manifest, mistreat, modify, motivate, name, notice, nourish, obey, object, obtain, organize, oversee, paint, pay, penalize, prove, qualify, quantify, quote, ratify, re-elect, react, reassess, recreate, rectify, redress, refine, refund, refuse, retreat, revise, shape, share, shock, shorten. . .

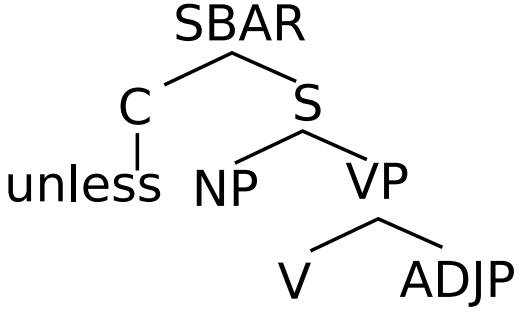
The Spine Decision

- around 400 candidate spines (taken from training data)
- for example:









The Subject Decision

Three possible values:

-
-
-

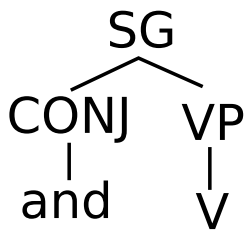
Depending on which spine selected in earlier decision:

The Subject Decision

Three possible values:

- `null`
-
-

Depending on which spine selected in earlier decision:



The Subject Decision

Three possible values:

- `null`
- 1,2,3...
-

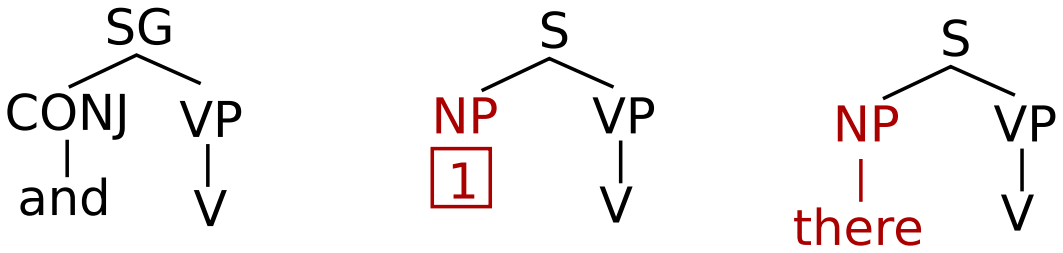
Depending on which spine selected in earlier decision:

The Subject Decision

Three possible values:

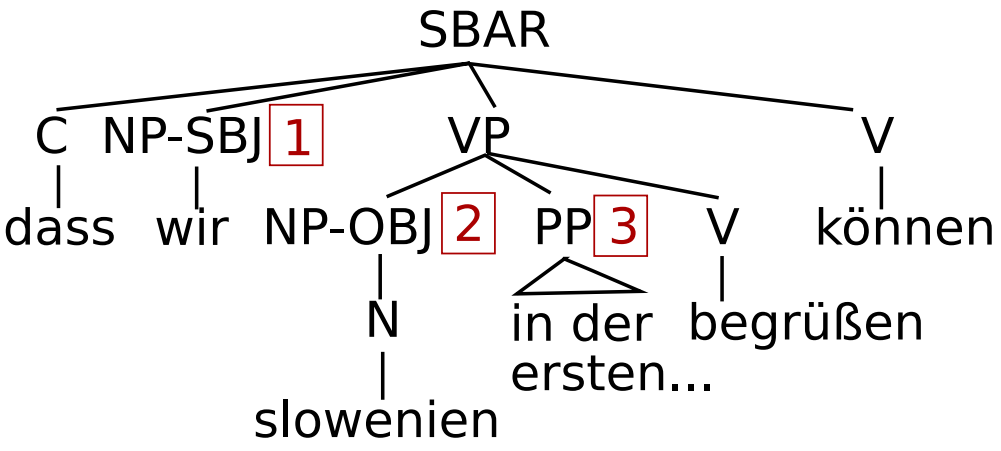
- `null`
- 1,2,3...
- *there, no one, we all, i, it, that*... (45, taken from training data)

Depending on which spine selected in earlier decision:



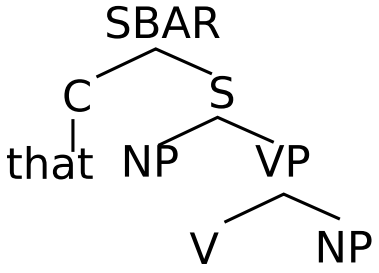
Representing AEPs as Decision Sequences

German Clause:



English AEP:

STEM	welcome
SPINE	



VOICE	active
SUBJECT	1
OBJECT	2
WH	`null`
MODALS	can
INFLECTION	welcome
MOD(3)	*post-verb*

The AEP Prediction Model

$$F(x) = \underset{y \in \text{GEN}(x)}{\text{argmax}} \ \mathbf{f}(x, y) \cdot \mathbf{w}$$

- x: a German clause
- y: an English AEP
- $\mathbf{f}(x, y) \in \mathbb{R}^N$: a feature vector
- $\mathbf{w} \in \mathbb{R}^N$: a parameter vector
- GEN(x): a set of candidate AEPs for German clause x

The AEP Prediction Model

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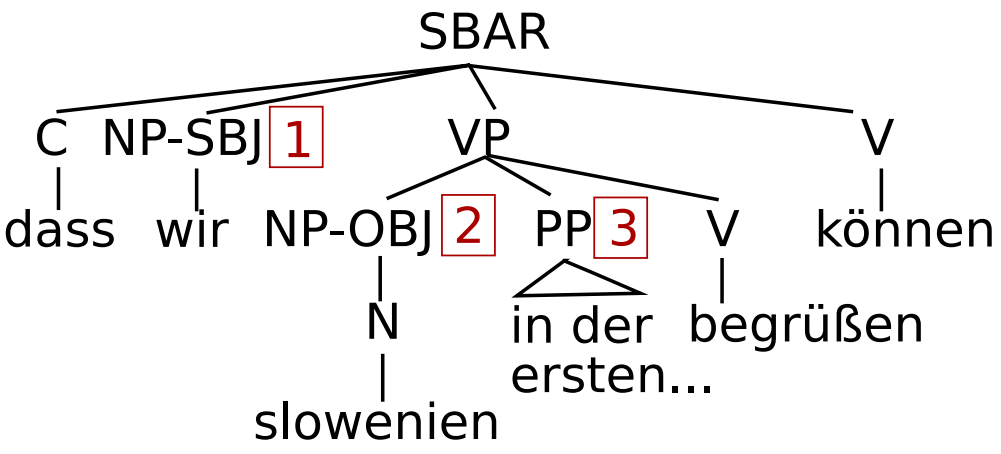
Example Feature Types and Features

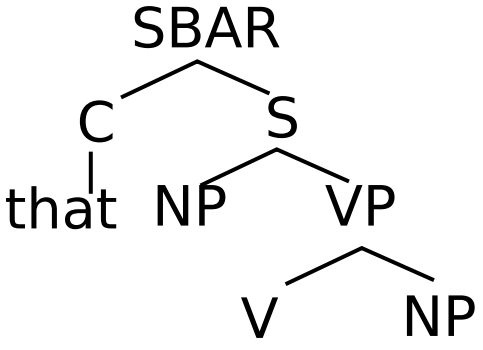
German Clause:



English AEP:

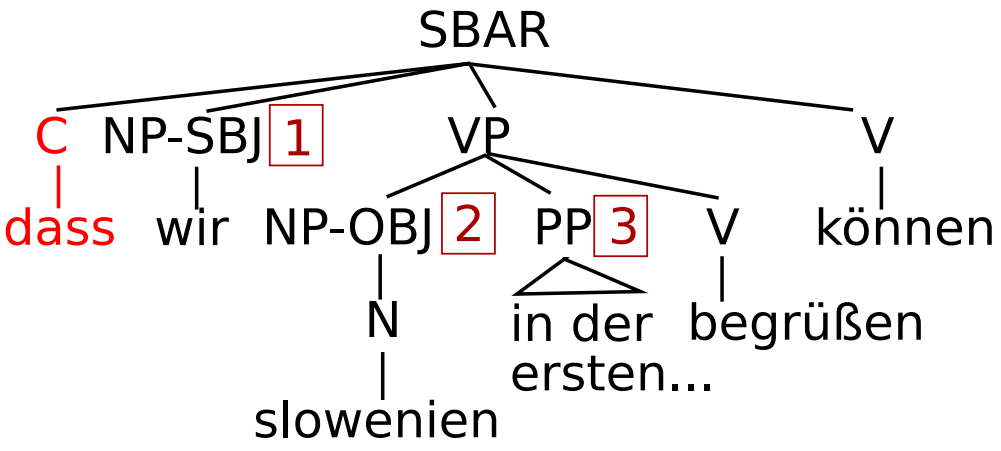
STEM welcome

SPINE



Example Feature Types and Features

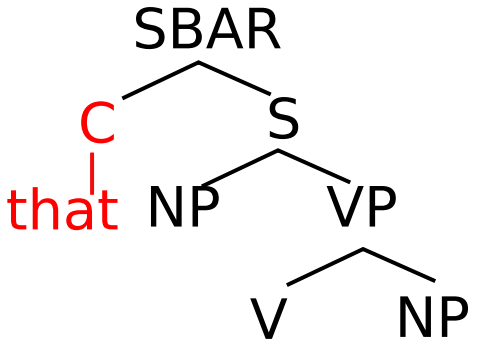
German Clause:



English AEP:

STEM welcome

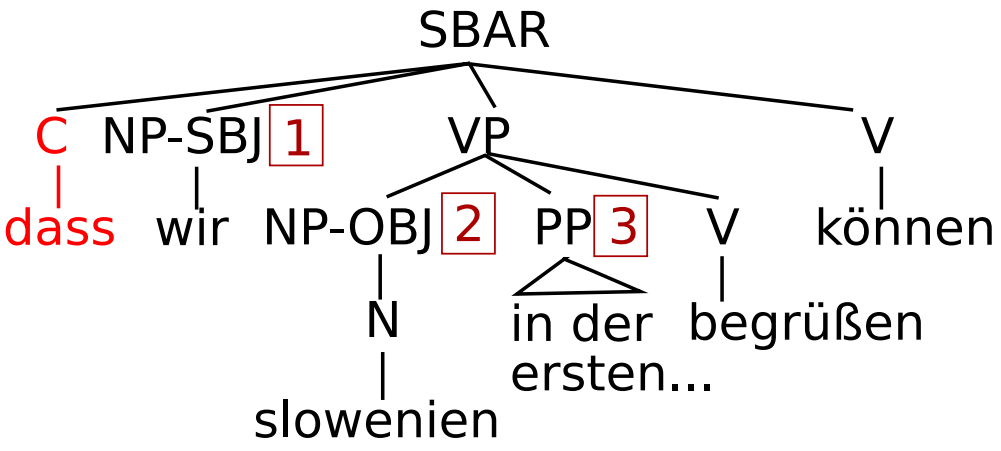
SPINE



complementizer in spine candidate + complementizer in German tree

Example Feature Types and Features

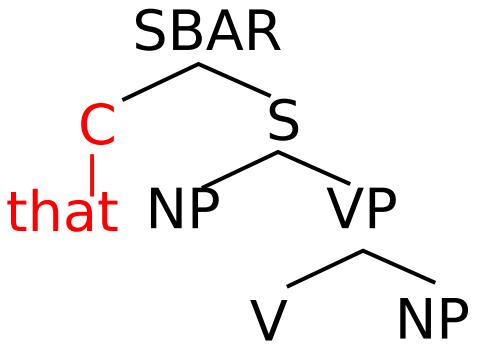
German Clause:



English AEP:

STEM welcome

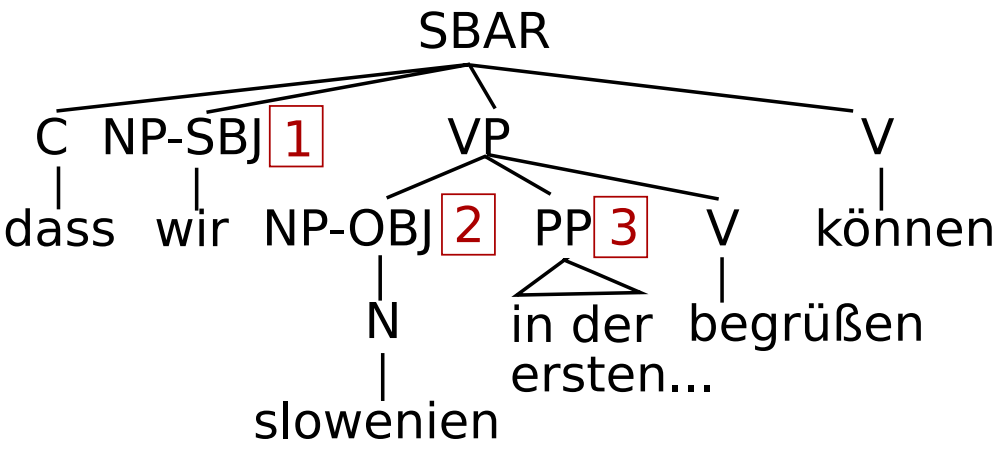
SPINE



$$f_{3000}(x,y) = \begin{cases} 1 & \text{if spine candidate contains } \texttt{C}\rightarrow\texttt{that} \\ & \text{and German clause contains } \texttt{C}\rightarrow\texttt{dass} \\ 0 & \text{otherwise} \end{cases}$$

Example Feature Types and Features

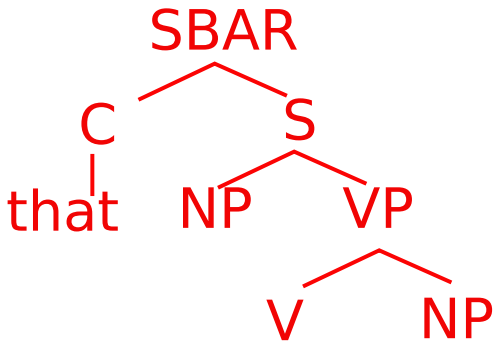
German Clause:



English AEP:

STEM welcome

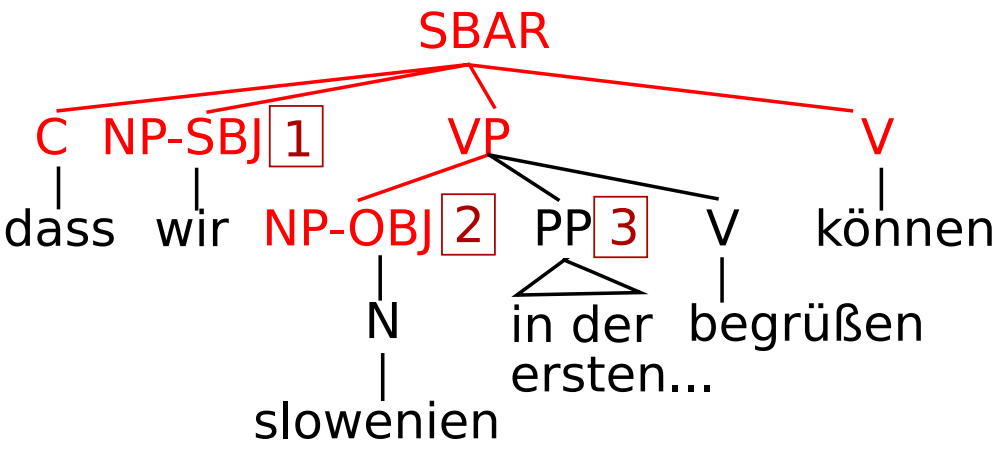
SPINE



spine candidate + value of STEM

Example Feature Types and Features

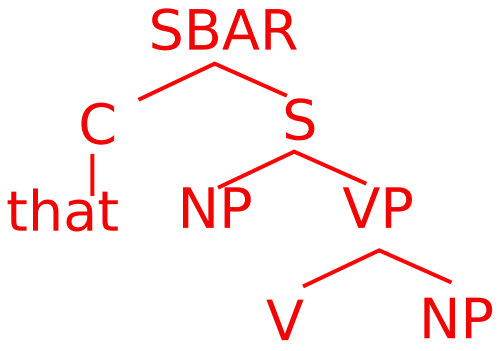
German Clause:



English AEP:

STEM welcome

SPINE



spine candidate + German spine

The AEP Prediction Model

Averaged Perceptron Algorithm
[Rosenblatt 58, Freund and Schapire 98, Collins 02]

$$F(x) = \underset{y \in \text{GEN}(x)}{\text{argmax}} \ \mathbf{f}(x, y) \cdot \mathbf{w}$$

- x: a German clause
- y: an English AEP
- $\mathbf{f}(x, y) \in \mathbb{R}^N$: a feature vector
- $\mathbf{w} \in \mathbb{R}^N$: a parameter vector
- $\text{GEN}(x)$: a set of candidate AEPs for German clause x

The AEP Prediction Model

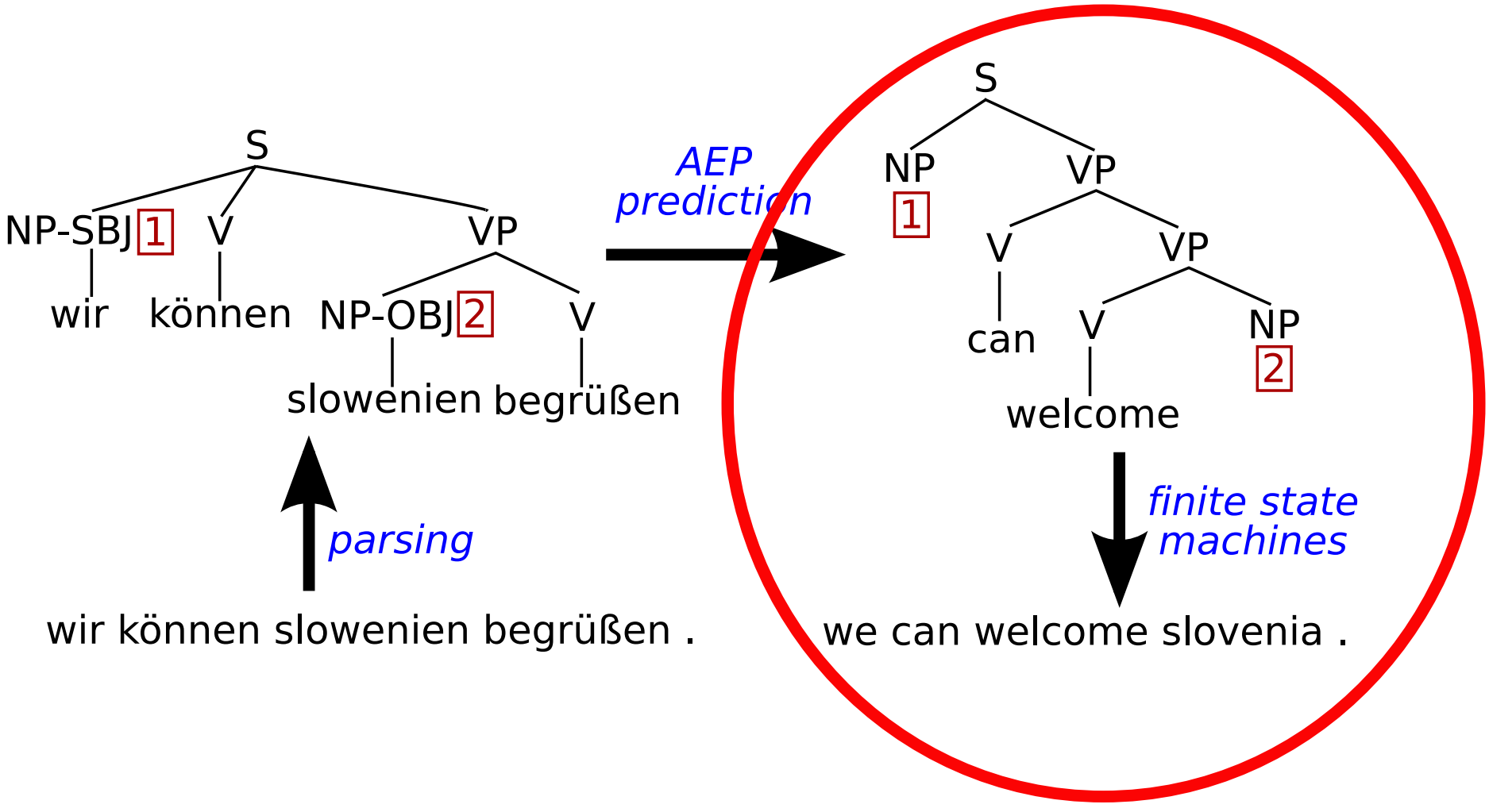
Incremental Beam Search Algorithm
[Jelinek et al. 94, Ratnaparkhi 97, Collins and Roark 04]

$$F(x) = \underset{y \in \text{GEN}(x)}{\text{argmax}} \; \mathbf{f}(x, y) \cdot \mathbf{w}$$

- x: a German clause
- y: an English AEP
- $\mathbf{f}(x, y) \in \mathbb{R}^N$: a feature vector
- $\mathbf{w} \in \mathbb{R}^N$: a parameter vector
- GEN(x): a set of candidate AEPs for German clause x

Outline

Generating A Translation from an AEP



Generate Translations for Arguments and Modifiers

ich hope

that *wir* can welcome
slowenien in der ersten gruppe der neuen mitglieder .

Generate Translations for Arguments and Modifiers

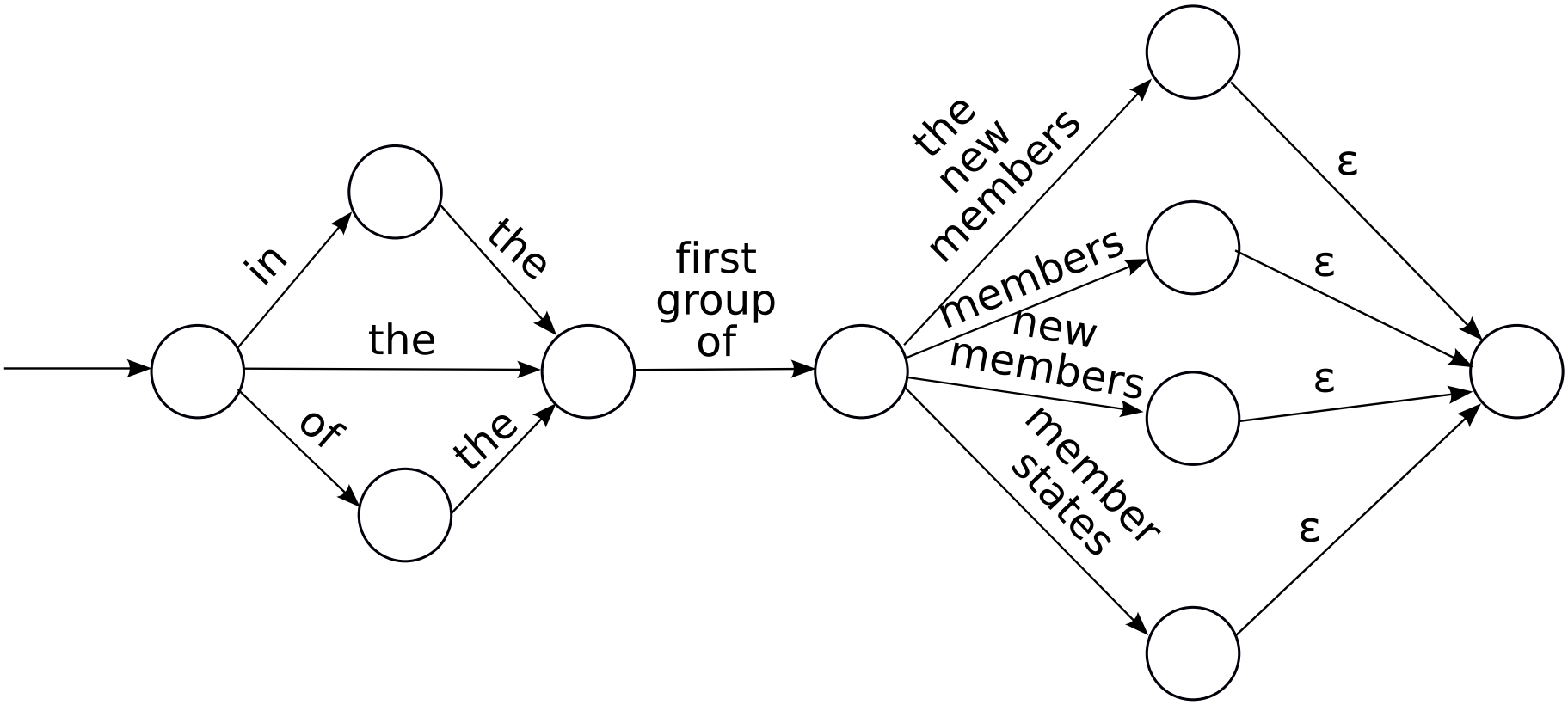
ich hope

that *wir* can welcome
slowenien in der ersten gruppe der neuen mitglieder .

ich	“i”, “me”, “and i”, “if i”, “i have”. . .
wir	“we”, “us”, “our”, “we , the”, “we also”. . .
slowenien	“slovenia”, “it”. . .
in der ersten gruppe der neuen mitglieder	“in the first group of new member states”, “in the first group of new members”, “the first group of the new members”. . .

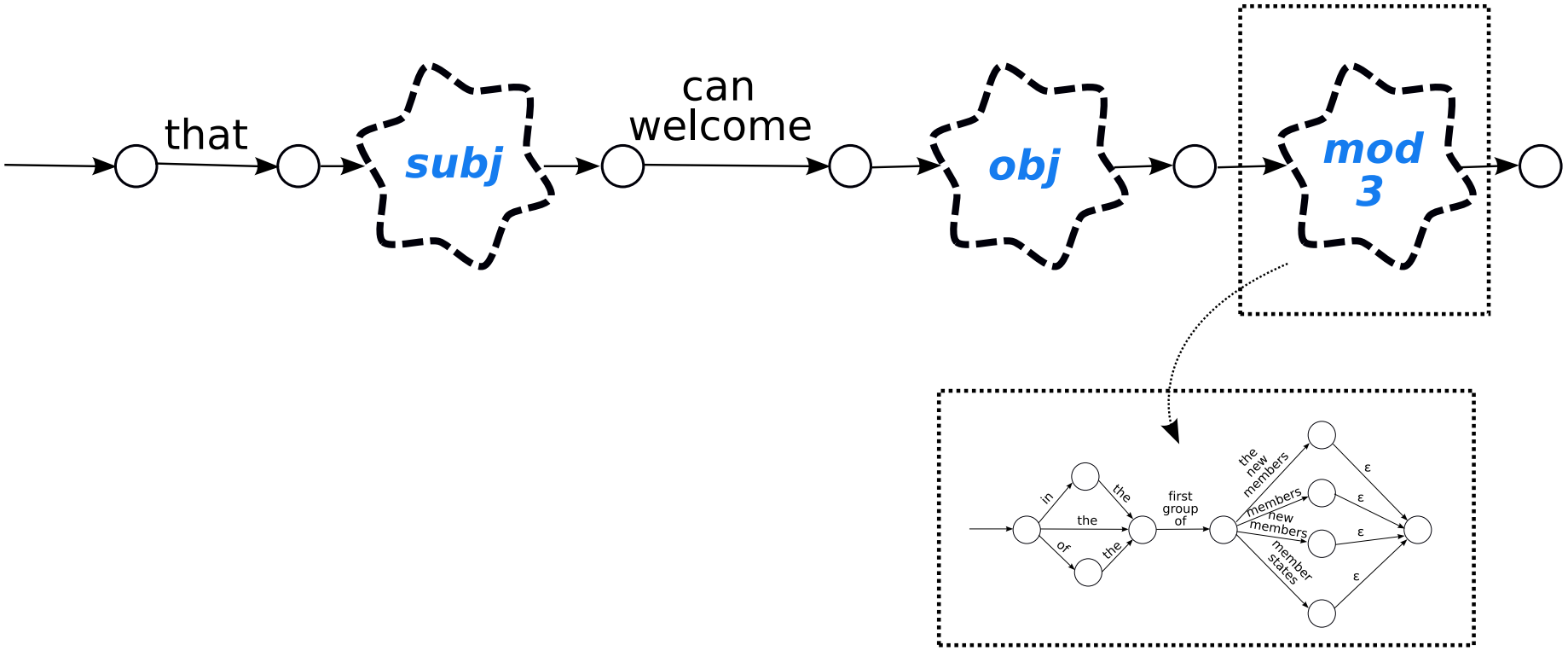
[Koehn et al. 03]

Lattices



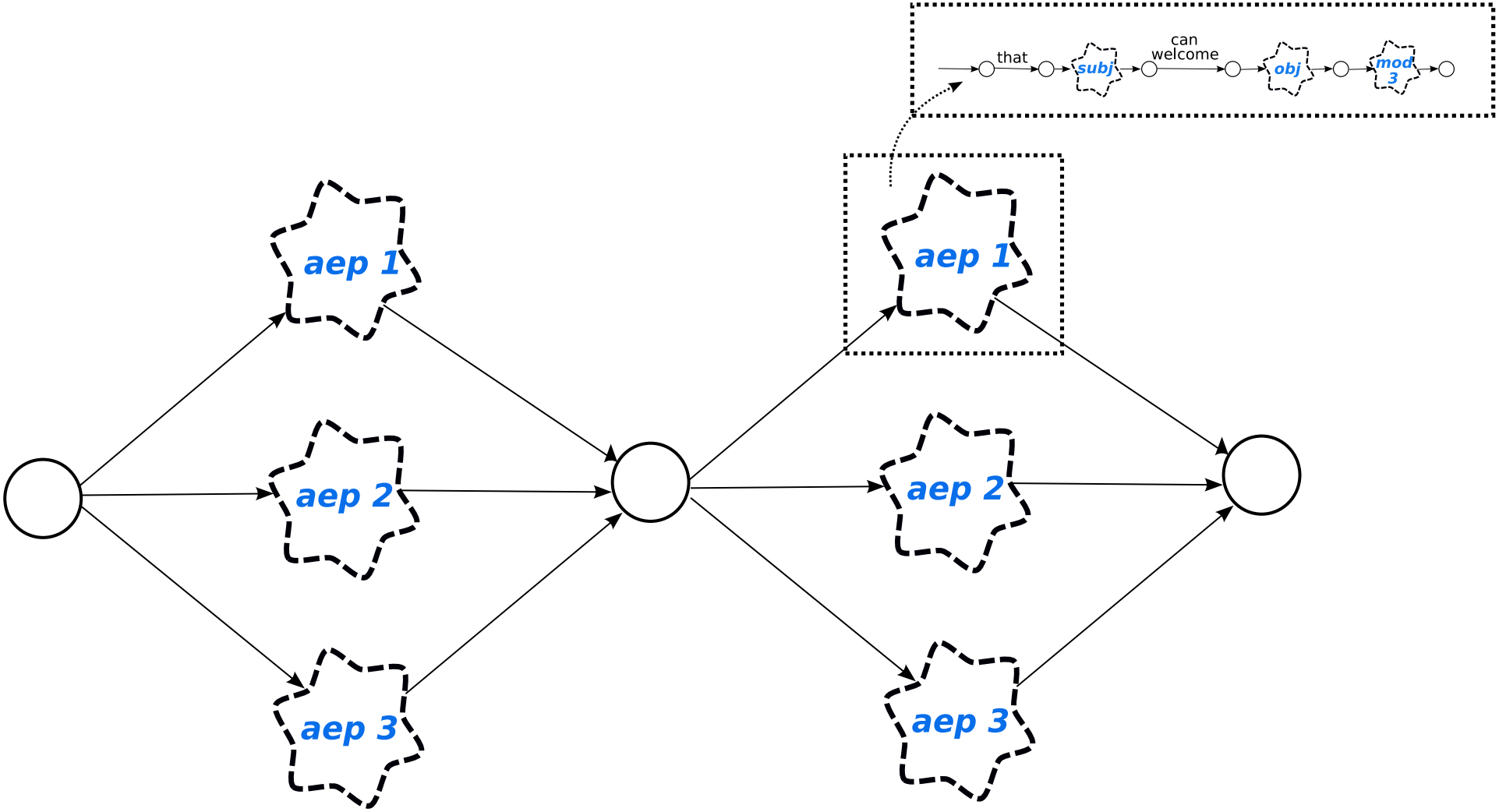
Modifier Lattice

Lattices



AEP (Clause) Lattice

Lattices



Sentence Lattice

Advantages to Using Lattices

It's easy to integrate...

- *n*-best AEPs
- an English language model
  - e.g., *n*-gram language model
  - likelihood of a sentence in English

Good optimization techniques for combining language model and phrase-based model scores.

Efficient algorithms for finding best translation. [Viterbi algorithm]

Outline

The Input

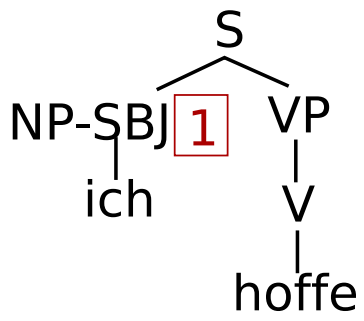
ich	*hoffe*	*,*	*dass*	*wir*	*slowenien*	*in*	*der*	*ersten*	*gruppe*
i	hope	,	that	we	slovenia	in	the	first	group

der	*neuen*	*mitglieder*	*begrüßen*	*können*	*.*
of the	new	members	welcome	can	.

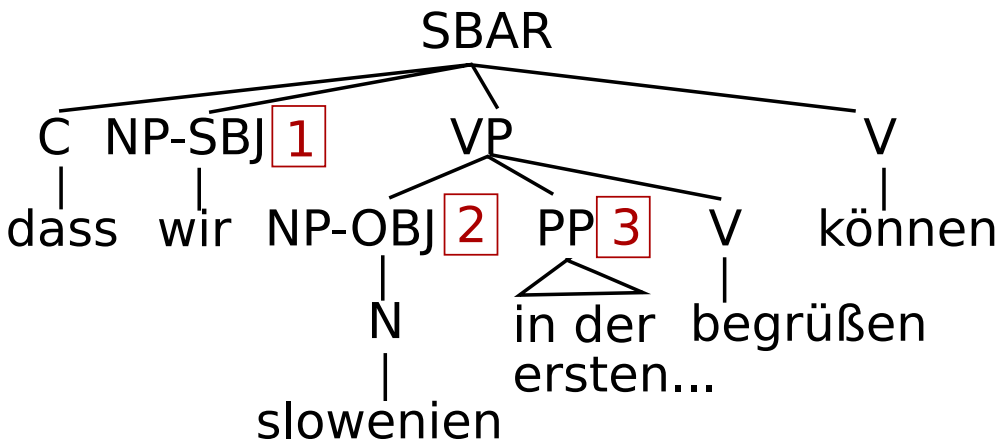
Translation Using AEPs

Step 1: Parse German and break into a sequence of clauses.

Clause 1:



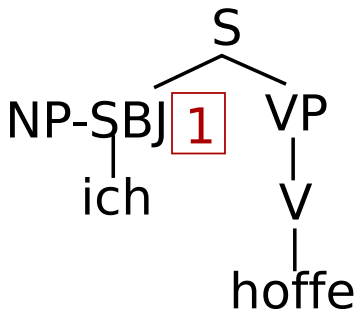
Clause 2:



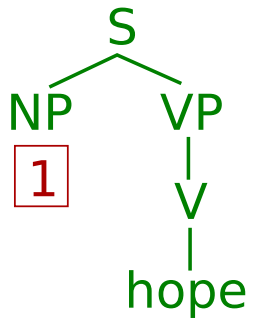
Translation Using AEPs

Step 2: For each German clause, predict an AEP.

German Clause:



English AEP:

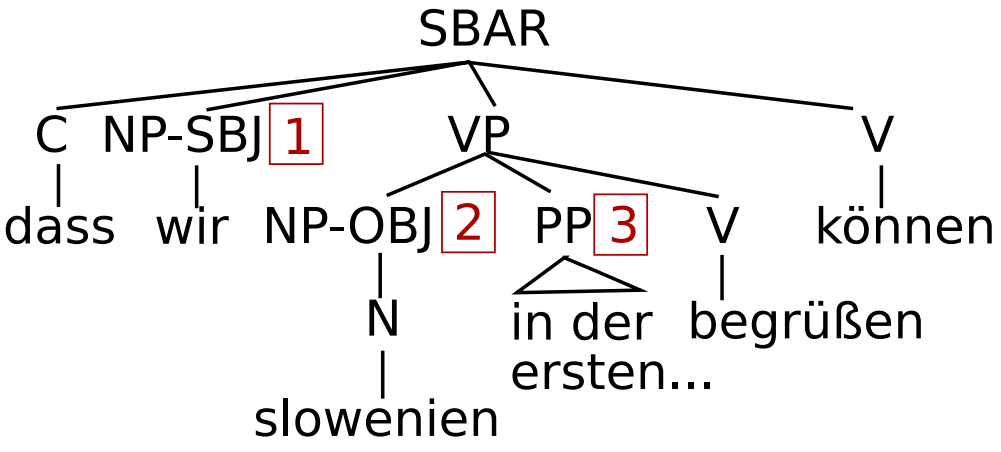


***ich* hope**

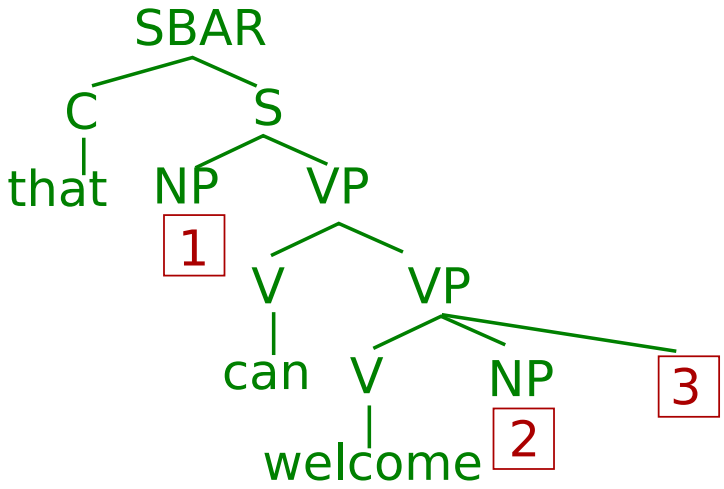
Translation Using AEPs

Step 2: For each German clause, predict an AEP.

German Clause:



English AEP:



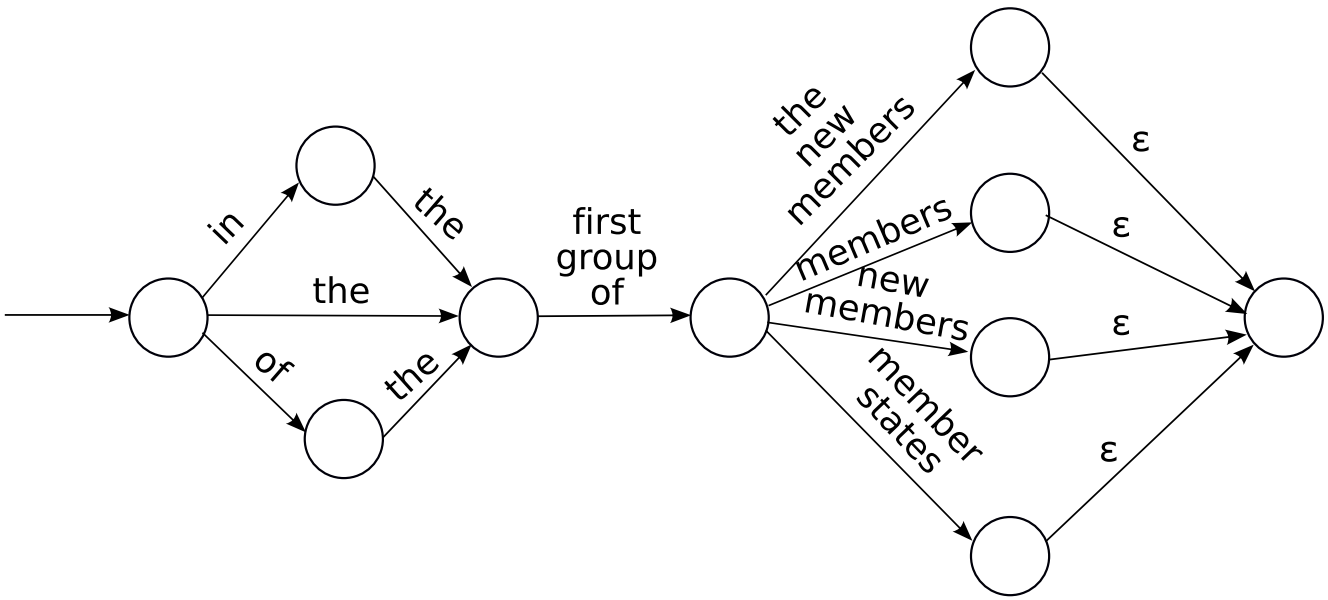
that *wir* can welcome *slowenien*
in der ersten gruppe der neuen mitglieder

Translation Using AEPs

Step 3: Translate arguments and modifiers.

ich hope

that *wir* can welcome
slowenien in der ersten gruppe der neuen mitglieder .

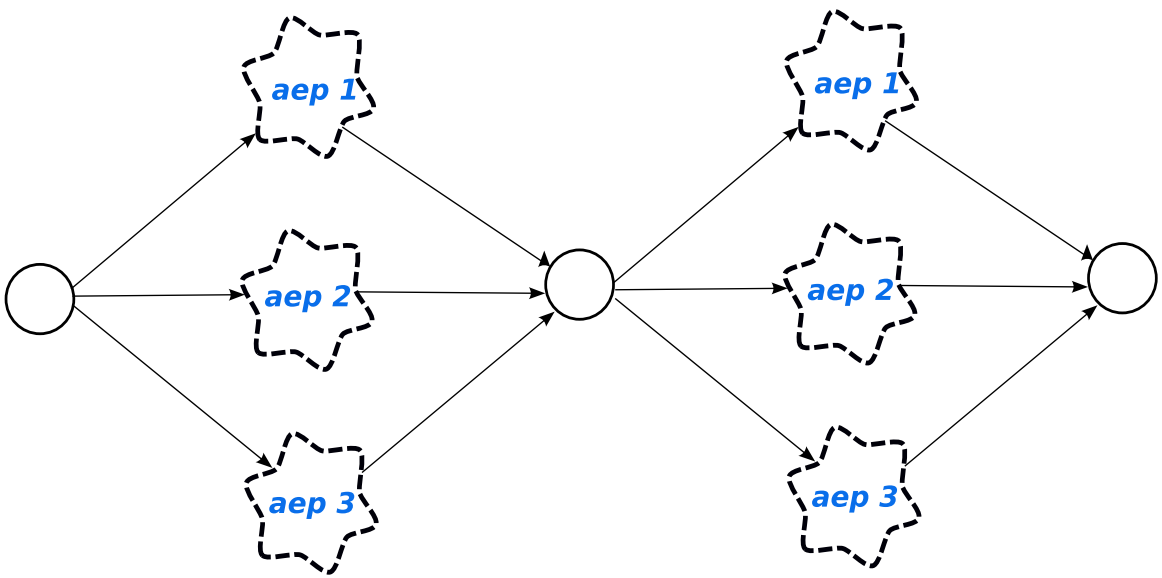


Translation Using AEPs

Step 4: Combine the clauses and select a translation.

ich hope that *wir* can welcome
slowenien in der ersten gruppe der neuen mitglieder .

i hope we can welcome slovenia
in the first group of member states .



Outline

Experimental Setup

- German-English European Parliament data
- AEP-Based System (**AEP**)
  - 5-best AEP model with lattices
  - German parser [Dubey 05], English parser [Collins 99]
  - Phrase-based system [Koehn et al. 03]
  - TRAIN: 700K sentences (410K parse/AEP pairs)
  - DEV1: 50K sentences (AEP prediction model)
  - DEV2: 2K sentences (lattice weights)
- Baseline System (**BASE**)
  - phrase-based model [Koehn et al. 03]
  - TRAIN: 730K German/English sentences
- TEST: 8K sentences

Measuring MT performance

- Automatic scoring metrics
  - imperfect, but cheap!
  - BLEU [Papineni et al. 01]:
    geometric mean of n-gram precisions, n=1...4
- Human evaluation
  - also imperfect, and expensive...
  - but probably the best method for evaluating syntax-based systems

BLEU Scores on Test Set

	BLEU
BASE	22.66
AEP	21.42

- One BLEU point: minor but appreciable difference in recovery of *n*-grams

Human Evaluation: Setup

- 6 judges, 600 randomly-selected examples from test set (length=10-20)
- each judge: fluency and adequacy judgments for 200 examples
- each example: 2 fluency, 2 adequacy judgments

Human Evaluation: Setup

- 6 judges, 600 randomly-selected examples from test set (length=10-20)
- each judge: fluency and adequacy judgments for 200 examples
- each example: 2 fluency, 2 adequacy judgments

```
Fluency refers to the degree to which a translation
is well-formed according to the rules of standard
written English. A fluent sentence is one that is
well-formed grammatically, contains correct
spellings, adheres to common use of terms, titles,
and names, is intuitively acceptable and can be
sensibly interpreted by a native speaker of English.
```

Human Evaluation: Setup

- 6 judges, 600 randomly-selected examples from test set (length=10-20)
- each judge: fluency and adequacy judgments for 200 examples
- each example: 2 fluency, 2 adequacy judgments

```
In this stage, you should decide which translation
is better, the first or the second, or whether they
are of the same quality, given the reference
translation. Use your intuition when deciding
whether one translation is better than the other:
an ideal translation should correctly communicate
the meaning of the reference translation and
should also be fluent/grammatically well-formed.
```

Fluency and Adequacy

- Fluency: 1 better, 2 better, or equal?
- Adequacy: 1 better, 2 better, or equal?

```
15------------------------------
```

```
1. in my brief speech , i would like to exclusively
   on the report refer .

2. in my brief speech , i should like to refer only
   to the report .

------------------------------
```

Fluency and Adequacy

- Fluency: 1 better, 2 better, or equal?
- Adequacy: 1 better, 2 better, or equal?

```
15------------------------------

REF: i should like in my brief intervention
     to confine myself to the report .

1. in my brief speech , i would like to exclusively
   on the report refer .

2. in my brief speech , i should like to refer only
   to the report .

------------------------------
```

Fluency and Adequacy Judgments

	FLUENCY		ADEQUACY	
	better	**worse**	**better**	**worse**
AEP	45%	29%	36%	33%

Fluency Judgments

	BASE	AEP	=
Judge 1	34.5%	49.0%*	16.5%
Judge 2	28.5%	41.5%*	30.0%
Judge 3	36.0%	53.0%*	11.0%
Judge 4	24.5%	50.0%*	25.5%
Judge 5	30.0%	36.0%	34.0%
Judge 6	21.0%	38.5%*	40.5%

*Statistically significant according to the sign test.

Adequacy Judgments

	BASE	AEP	=
Judge 1	39.0%	45.5%	15.5%
Judge 2	35.5%	30.5%	34.0%
Judge 3	41.5%	40.5%	18.0%
Judge 4	27.5%	35.5%	37.0%
Judge 5	32.0%	30.0%	38.0%
Judge 6	23.0%	35.0%*	42.0%

*Statistically significant according to the sign test.

Strengths of the AEP-Based System

	judge 1	judge 2
fluency	AEP	AEP
adequacy	AEP	AEP

BASE	the european parliament has its commitment to a balanced approach is not fulfilled .
AEP	the european parliament has not fulfilled its commitment to a balanced approach .
REF	the european parliament has failed in its duty to reflect a balanced approach .

Both Judges Say AEP More Fluent (33% of 600)

BASE	a sensitive area has already mentioned , the nuclear power .
AEP	a sensitive area has already been raised today in the nuclear power .
REF	a sensitive area has already been addressed today : nuclear power .

Both Judges Say AEP More Fluent (33% of 600)

BASE	a sensitive area has already mentioned , the nuclear power .
AEP	a sensitive area has already been raised today in the nuclear power .
REF	a sensitive area has already been addressed today : nuclear power .

BASE	as a french citizen is me such a point of view of the world , particularly alien .
AEP	as a french citizen such a point of view of the world is particularly alien .
REF	as a french woman and citizen , this vision of the world is particularly alien to me .

Error Analysis

	judge 1	judge 2
fluency	AEP	AEP
adequacy	BASE	BASE

BASE	i hope that lithuania in the not too distant future , join the union .
AEP	i hope they will join lithuania in the not too distant future of the european union .
REF	i look forward to lithuania joining the union in the not too distant future .

Both Judges Say BASE More Fluent (18% of 600)

BASE	in relation to the survivors and affected are already two conclusions .
AEP	we are required to draw two already in relation to the survivors and those conclusions .
REF	judging from the survivors and those involved , we can already draw two conclusions .

Both Judges Say BASE More Fluent (18% of 600)

BASE	in relation to the survivors and affected are already two conclusions .
AEP	we are required to draw two already in relation to the survivors and those conclusions .
REF	judging from the survivors and those involved , we can already draw two conclusions .

BASE	the independence of the new audit service is unfortunately not beyond reproach .
AEP	unfortunately , the independence of the new audit service is not on any doubt .
REF	nor , unfortunately , is the independence of the new audit service beyond all doubt .

One Last Example...

BASE it is therefore important to start with preventive measures and a part of these products from the chain isolate any .

One Last Example...

BASE it is therefore important to start with preventive measures and a part of these products from the chain isolate any .

AEP therefore , it is important to start with preventive measures and to remove some of these products from the chain .

One Last Example...

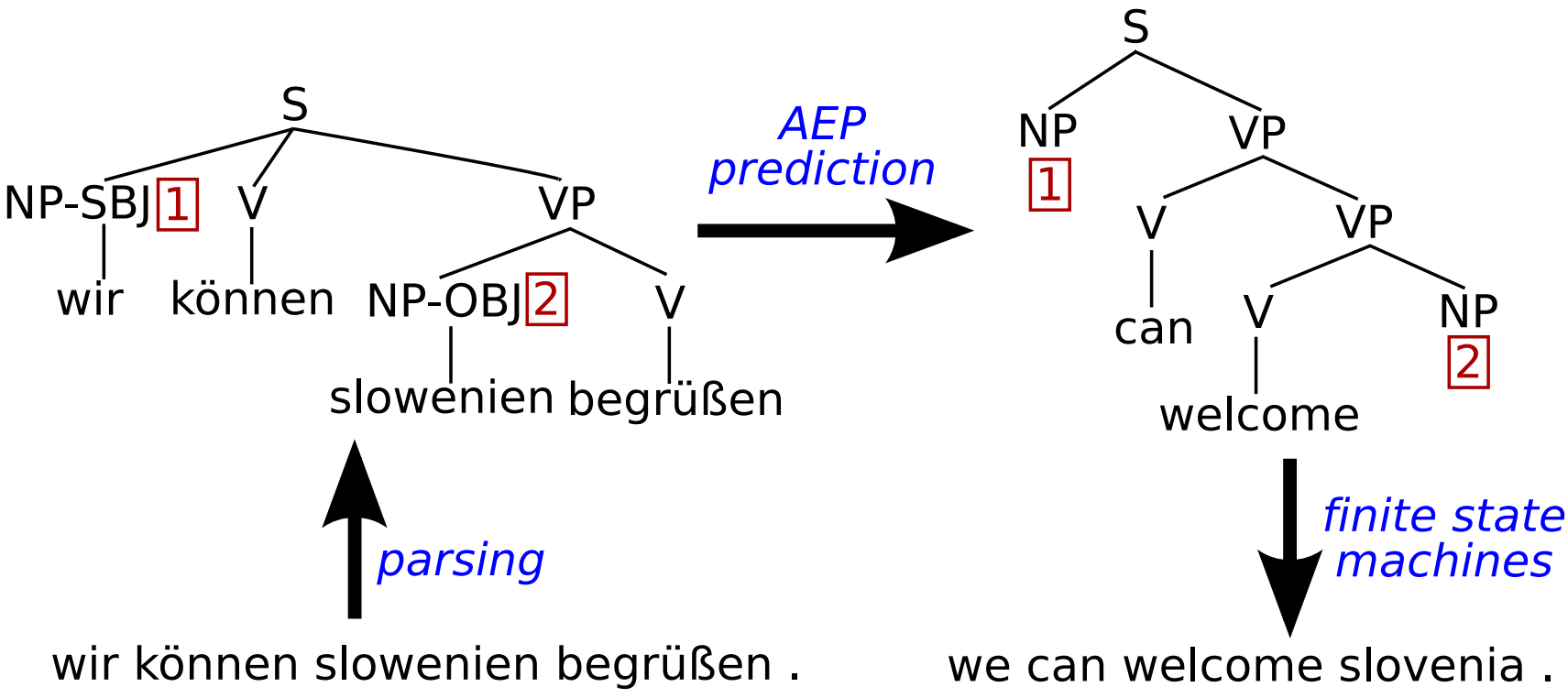
BASE it is therefore important to start with preventive measures and a part of these products from the chain isolate any .

AEP therefore , it is important to start with preventive measures and to remove some of these products from the chain .

REF it is therefore important that we start the preventive process by removing a portion of these products from the chain .

Outline

What You've Seen



Contributions

- A statistical framework for machine translation that integrates source and target syntactic information
  - An object for representing syntactic correspondences (AEP)
  - A feature set for German-to-English translation
  - An algorithm for extracting AEPs from a bilingual parallel corpus
  - Two methods for generating full translations from AEPs
- A statistical parser for Spanish