A Weighted Finite State Transducer Implementation of the Alignment Template Model for Statistical Machine Translation

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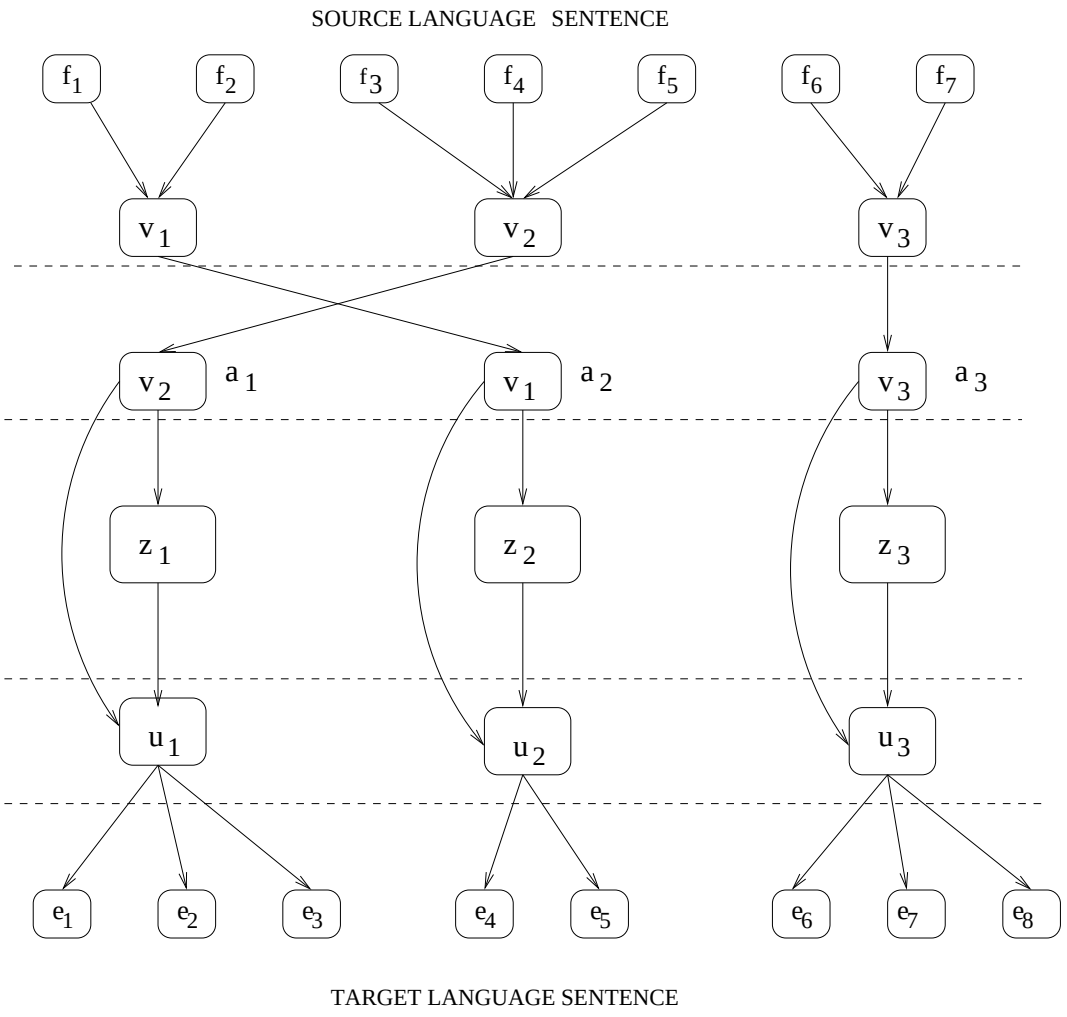
Motivation and Goals

- Alignment Template Translation Model (ATTM) (Och, Tillmann and Ney '99) has emerged as a promising model for Statistical MT
- Goal Reformulate the ATTM so that bitext-word alignment and translation can be implemented using Weighted Finite State Transducer operations
- Advantages
  - FSM formulation reduces cost of implementation
  - FSM implementation makes it unnecessary to develop a specialized decoder
    - This decoder can even generate alignment/translation lattices and N-best lists
  - FSM architecture provides support for generating bitext word alignments and alignment lattices
    - These will form the basis for ATTM parameter estimation procedures

Alignment Template Translation Model Architecture



Component Models

Segmentation Model

$P(v_1^K, K|f_1^J)$

Phrase Permutation Model

$P(a_1^K|v_1^K, K, f_1^J)$

Template Sequence Model

$P(z_1^K|a_1^K, v_1^K, K, f_1^J)$

Phrasal Translation Model

$P(u_1^K|z_1^K, a_1^K, v_1^K, K, f_1^J)$

Target Language Model

$P(e_1^I)$

ATTM Joint Distribution

$P(e_1^I, u_1^K, z_1^K, a_1^K, v_1^K, K, f_1^J)$

Source Segmentation Model

- The WFST-ATTM assumes that sentence to be translated is first segmented into a sequence of phrases in the word order of the source language
- Segmentation Model A joint distribution over phrase segmentations:

$$P(v_1^K, K|f_1^J) = P(v_1^K|K, f_1^J)P(K|f_1^J)$$

  – Distribution of # of phrases:

$$P(K|f_1^J) = \frac{\binom{J-1}{K-1}}{2^{J-1}}$$

  – Phrase unigram model:

$$P(v_1^K|K, f_1^J) = \begin{cases} \frac{1}{Z_K}\prod_{k=1}^{K} p_u(v_k) & v_1^K = f_1^J \\ 0 & otherwise \end{cases}$$

- Computing optimal segmentation

$$\{\hat{v}_1^{\hat{K}}, \hat{K}\} = \text{argmax}_{v_1^K, K}\, P(v_1^K|K, f_1^J)P(K|f_1^J)$$

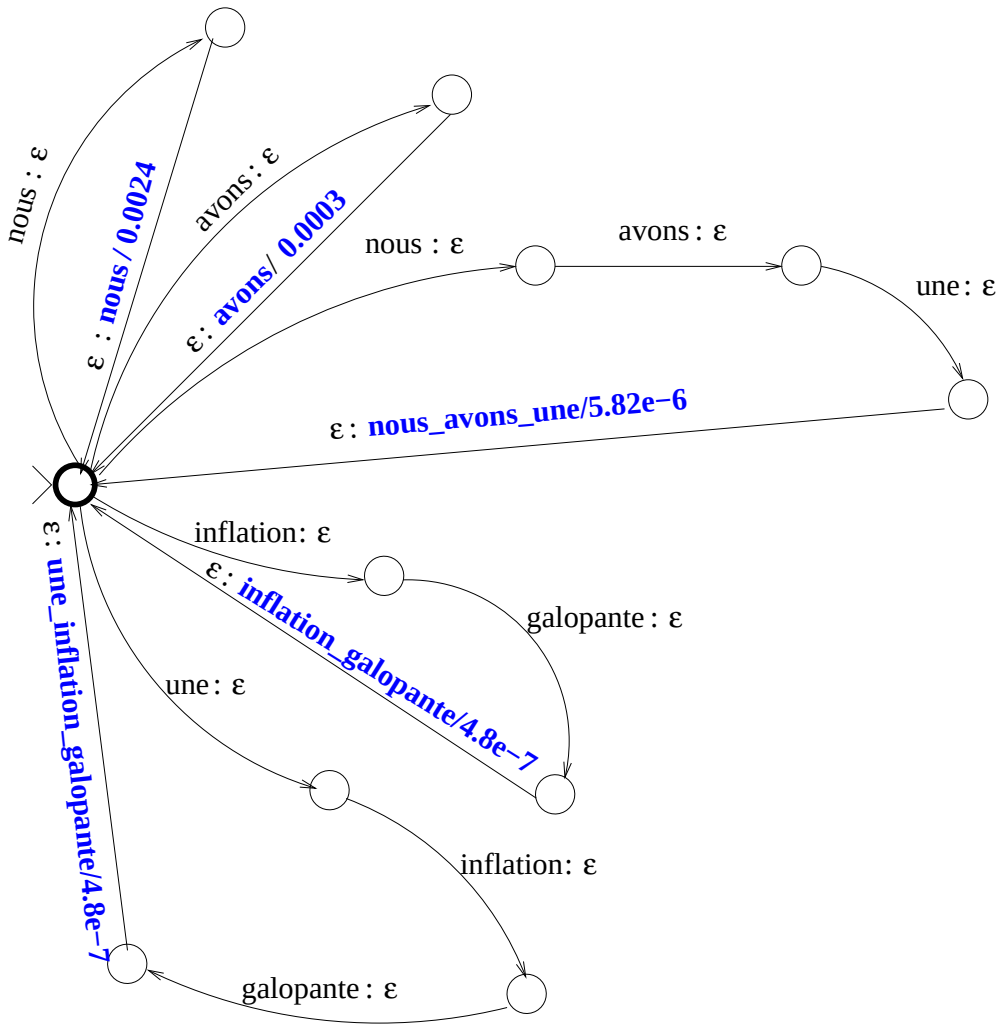
Segmentation Transducer Ω

French Sentence S:

- nous avons une inflation galopante

$S \circ \Omega$:

- nous avons une_inflation_galopante
- nous_avons_une inflation_galopante



Phrase Permutation Model

Reorder the source-language phrase sequence $v_1, v_2, ..., v_K$ into target-language word order $v_{a_1}, v_{a_2}, ..., v_{a_K}$.

1st-order Markov model on permutation indices $a_1, a_2, ..., a_K$

$$P(a_1^K | v_1^K, K, f_1^J) = P(a_1) \prod_{k=2}^{K} P(a_k | a_{k-1}, v_1^K).$$

The Markov-Chain probabilities are assigned so as to penalize reorderings that diverge from original word order (Och '02)

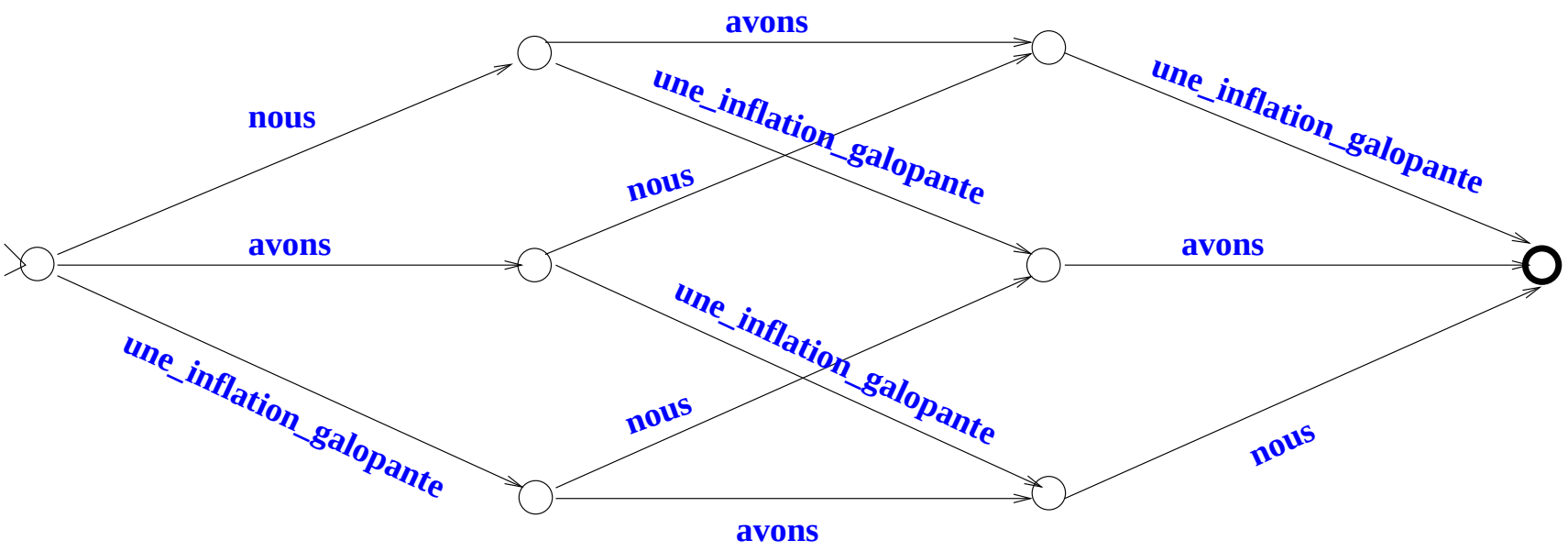
Weighted FSTs to implement the Phrase Permutation Model

- Permutation Acceptor Π_V to generate all permutations of source-language phrase sequence
- Phrase Permutation Model Acceptor H to assign probabilities to any permutation of the source-language phrase sequence

Permutation Acceptor Π_V

- Generates all re-orderings of source-language phrase sequence
- Construction similar to Permutation Acceptor (Knight and Al-Onaizan '98)
- Pruning required while construction (details in paper)

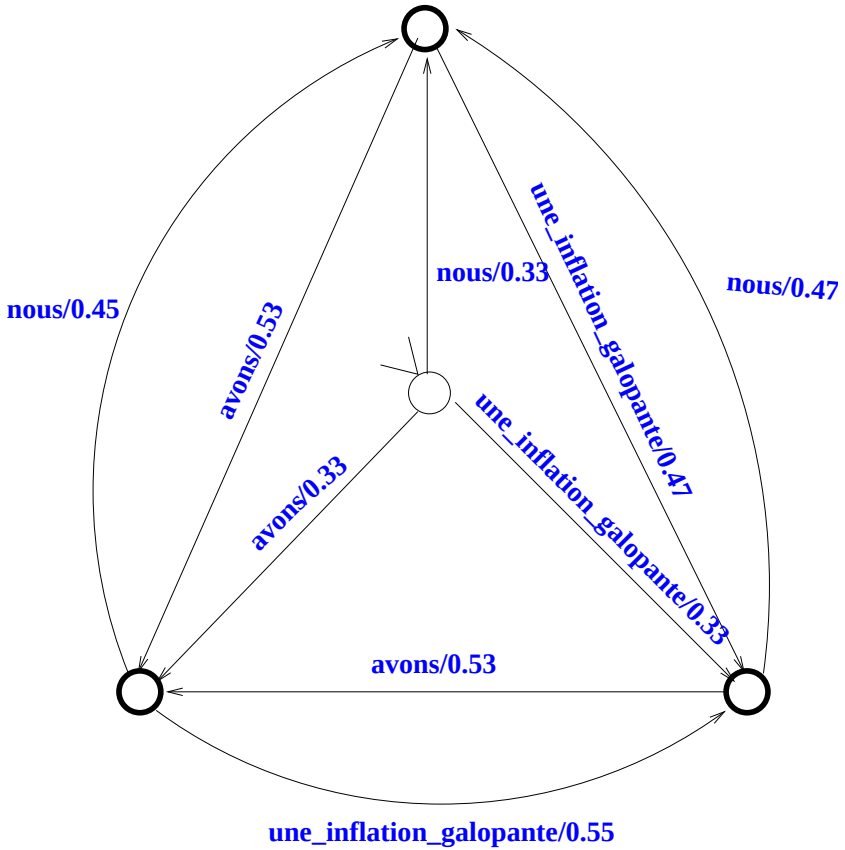
Source Phrase Sequence: nous avons une_inflation_galopante



Phrase-Permutation Model Acceptor H

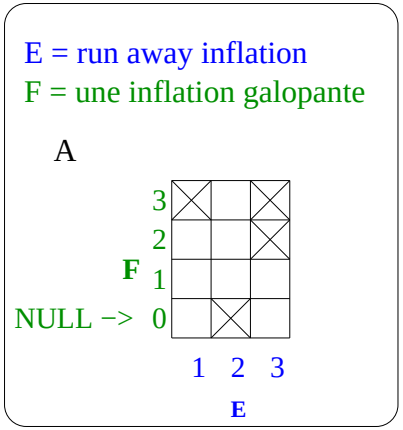
- Acceptor assigns permutation model probabilities to any permutation of the source-language phrase sequence
- The 1st-order Markov-model results in a simple structure for this FSA

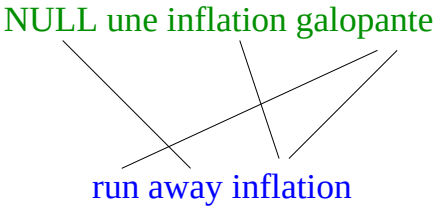
Source Phrase Sequence: nous avons une_inflation_galopante



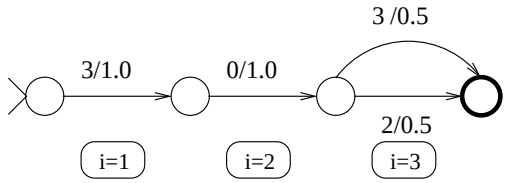
WFST Implementation of Alignment Templates

- Each word in the source & target language is assigned to a unique class
- Alignment Template $z = (E_1^M, F_0^N, A)$ specifies word alignments between class sequences E_1^M and F_0^N through a 0/1 valued matrix A.
  - For simplicity, the presentation is in terms of words and not classes





WFST Implementation



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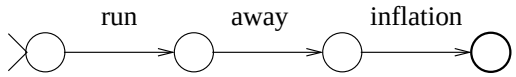


C

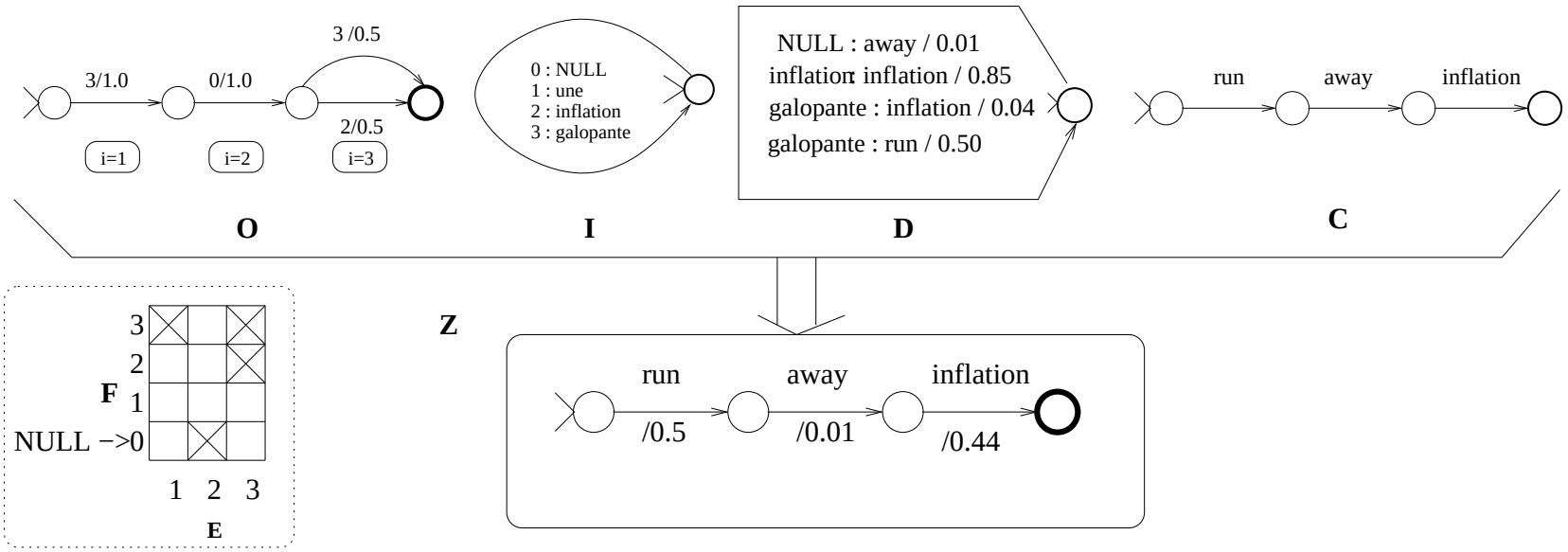
Map source phrase into one or more alignment templates via WFST Y

Phrase-to-Phrase Translation Model

Map an alignment template (and its associated source phrase) to a consistent target phrase

$$P(u|v,z) \quad u = e_1^M, v = f_0^N$$

- Build an Acceptor Z that assigns scores $P(u|v,z)$ for a given z and v



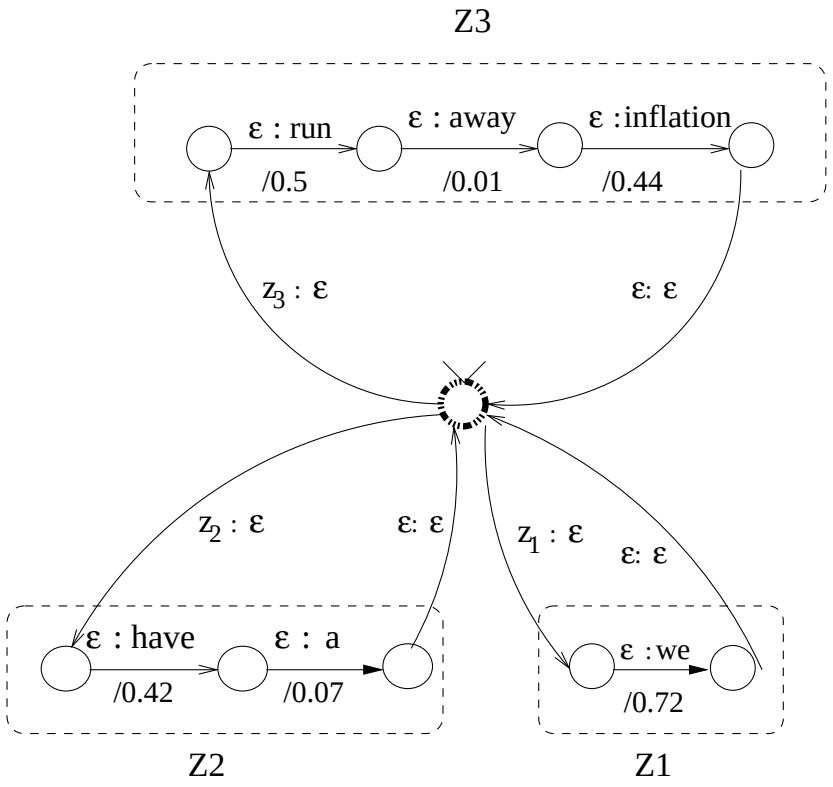
- $P(u|z = (E_1^M, F_0^N, A), v) = \prod_{i=1}^{M} \sum_{j=0}^{N} P(\phi_i = j|A) P(e_i|f_j)$
- $Z = \text{Determinize}_{+,X}(\text{Project-output}(O \circ I \circ D \circ C))$

Phrasal Translation Model

- Realize the alignment template library as a single transducer
- Restrict the transducer to templates consistent with phrases in the source-language phrase sequence v_1^K

A sample template library

z_1	nous $\Rightarrow$ we
z_3	avons $\Rightarrow$ have_a
z_2	une_inflation_galopante $\Rightarrow$ run_away_inflation



- $P(u_1^K|z_1^K, a_1^K, v_1^K, K, f_1^J) = \prod_{k=1}^{K} P(u_k|z_k, v_{a_k})$

An Overview of WFSTs for ATTM

Given a source sentence f_1^J we first segment it into K-length phrase sequence $\hat{v}_1^K$

- Permutation Acceptor $\Pi_{\hat{V}}$ allows permutations of phrase sequence
- Permutation Model Acceptor H that assigns permutation probabilities to any re-ordering of source-phrase sequence
- WFST Y that maps source phrases to templates
- WFST W that maps templates to target-language phrase sequences

Build a transducer that maps the source language phrase sequence to target language phrase sequences

$$X = \Pi_{\hat{V}} \circ H \circ Y \circ W$$

Bitext Word Alignment and Translation Via WFSTs

Alignment of a sentence pair f_1^J,e_1^I

$$\{\hat{u}_1^{\hat{K}}, \hat{z}_1^{\hat{K}}, \hat{a}_1^{\hat{K}}, \hat{v}_1^{\hat{K}}, \hat{K}\} = \underset{u_1^K, z_1^K, a_1^K, v_1^K, K}{\operatorname{argmax}} P(u_1^K, z_1^K, a_1^K, v_1^K, K | e_1^I, f_1^J)$$

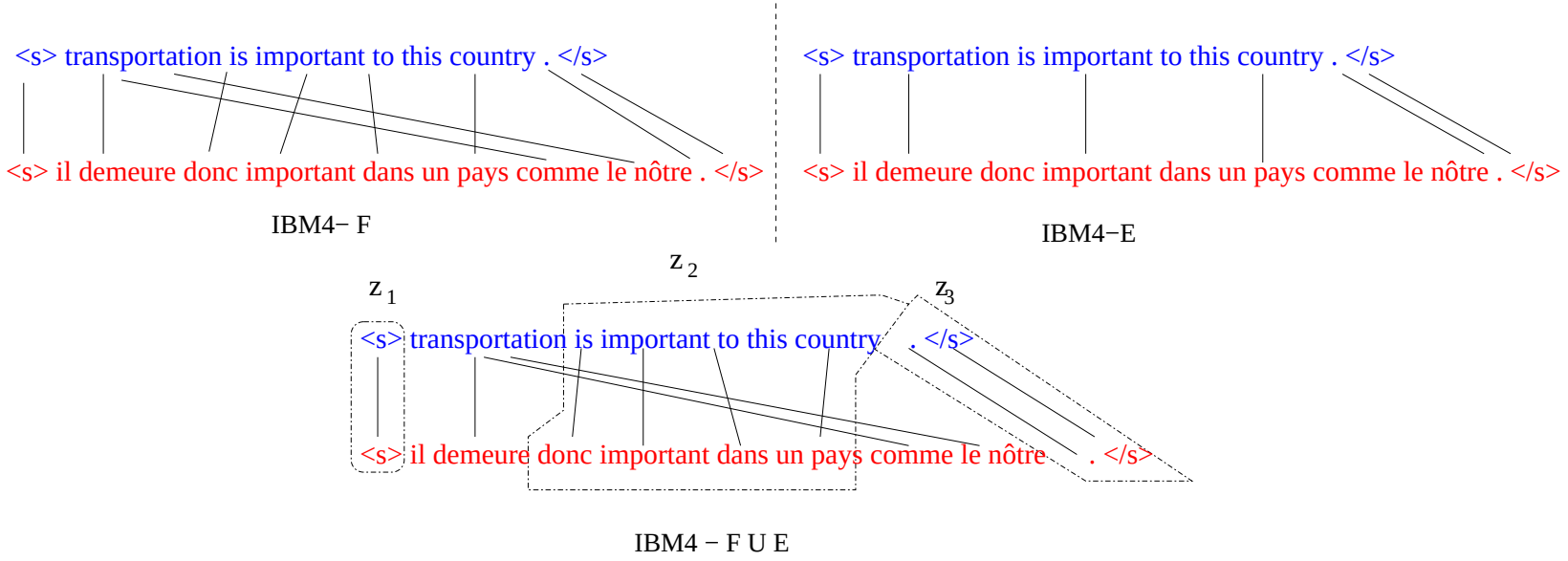
Translation of a source sentence f_1^J

$$\{\hat{e}_1^{\hat{I}}, \hat{u}_1^{\hat{K}}, \hat{z}_1^{\hat{K}}, \hat{a}_1^{\hat{K}}, \hat{v}_1^{\hat{K}}, \hat{K}\} = \underset{e_1^I, u_1^K, z_1^K, a_1^K, v_1^K, K}{\operatorname{argmax}} P(e_1^I, u_1^K, z_1^K, a_1^K, v_1^K, K | f_1^J)$$

- Stage 1: Segment source sentence f_1^J into phrase sequence v_1^K
- Stage 2: Alignment Via Finite State Composition
  - Build Acceptor T for the Target sentence e_1^I
  - Obtain the alignment lattice $\mathcal{B} = X \circ T$
- Stage 2: Translation Via Finite State Composition
  - Compile a n-gram language model as a weighted acceptor G
  - Obtain the translation lattice $\mathcal{T} = X \circ G$

Bitext Word Alignments Under ATTM

Generate alignment template library from IBM-4 alignments (Och '02)



- The model does not guarantee alignment between every sentence pair in bitext and most sentence pairs are assigned zero probability
- *Solution*: Add "dummy" templates to the template library
  - These templates allow alignment of any source phrase to any target word, deletion of source phrases and insertion of target words
  - The probability of "dummy" templates is fixed to a value that discourages their use except when regular templates are unavailable

Alignment and Translation Performance

Experiment Setup (Och and Ney '00)

- Task: French to English Canadian Hansards
- Training Bitext: $50,000$ sentence pairs
- Test Set: 500 unseen sentence pairs

Alignment Performance

Model		Alignment Metrics (%)		
		Precision	Recall	AER
IBM-4 F		88.9	89.8	10.8
IBM-4 E		89.2	89.4	10.7
IBM-4 $F \cup E$		84.3	93.8	12.3
ATTM	- Include "Dummy" Links	64.2	63.8	36.2
	- Exclude "Dummy" Links	94.5	55.8	27.3

Translation Performance

Model	BLEU	NIST	WER (%)
IBM-4	0.1711	5.0823	67.5
ATTM	0.1941	5.3337	64.7

Oracle-Best BLEU scores on N-best Lists

N	Oracle-best BLEU
1	0.1941
10	0.2264
100	0.2550
400	0.2657
1000	0.2735

Conclusions and Future Work

- Salient features of ATTM WFST Modeling Framework
  - Simple translation process compared to DP/A^* decoders
    - Generating lattices/N-best lists requires no additional effort
  - A novel approach to generate bitext word alignments and alignment lattices
    - Facilitate development of ATTM parameter estimation procedures
  - Modular implementation of component distributions
- Future Work
  - Iterative parameter estimation for ATTM
  - New Strategies for Template Selection to improve coverage on test set
  - Decoupling of segmentation and alignment/translation may lead to search errors
  - Refining the component distributions