# Models of Synchronous Grammar Induction for SMT

Workshop 2010

The Center for Speech and Language Processing
Johns Hopkins University

June 21, 2010

# Team members

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**Undergraduate Students**

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Desai Chen (CMU)

# Statistical machine translation

## Urdu → English

As Hmlh kY bEd brRy tEdAd myN mqAmy bA$ndwN nY ElAqwN kw xAly krdyA hY .

↓

- Statistical machine translation: Learn how to translate from parallel corpora.

# Statistical machine translation:

## Urdu → English

As Hmlh kY bEd brRy tEdAd myN mqAmy bA$ndwN nY ElAqwN kw xAly krdyA hY .

↓

After this incident , a large number of local residents fled from these areas .

- Statistical machine translation: Learn how to translate from parallel corpora

# Statistical machine translation: Before

## Urdu → English

As Hmlh kY bEd brRy tEdAd myN mqAmy bA$ndwN nY ElAqwN kw xAly krdyA hY .

↓

In this attack a large number of local residents has should vacate areas .

- Current state-of-the-art translation models struggle with language pairs which exhibit large differences in structure.

# Statistical machine translation: After

## Urdu → English

As Hmlh kY bEd brRy tEdAd myN mqAmy bA$ndwN nY ElAqwN kw xAly krdyA hY .

↓

After this attack in a large number local residents have left the area .

- In this workshop we've made some small steps towards better translations for difficult language pairs.

# Statistical machine translation: limitations

## Structural divergence between languages:

| **English** | **Who wrote this letter?** |
|---|---|
| Arabic | من الذي كتب هذه الرسالة؟<br>(function-word) (who) (wrote) (this) (the-letter) |
| Chinese | 这封 信 是 谁 写 的 ？<br>(this) (letter) (be) (who) (write) (come-from) (function-word) |

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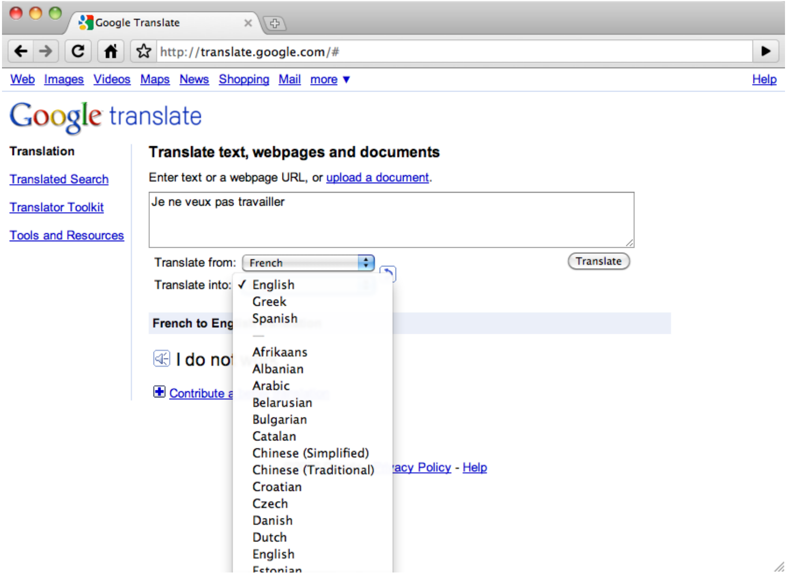
- Phrasal translation equivalences (existing models)
- **Constituent reordering (this workshop!)**
- Morphology (Next year?)

# Statistical machine translation: successes



Google Translate

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Google translate

Translation

Translated Search

Translator Toolkit

Tools and Resources

**Translate text, webpages and documents**

Enter text or a webpage URL, or upload a document.

Je ne veux pas travailler

Translate from: French

Translate into: ✓ English

Translate

French to Eng

I do not

Contribute a

acy Policy - Help

# Workshop overview

Input:

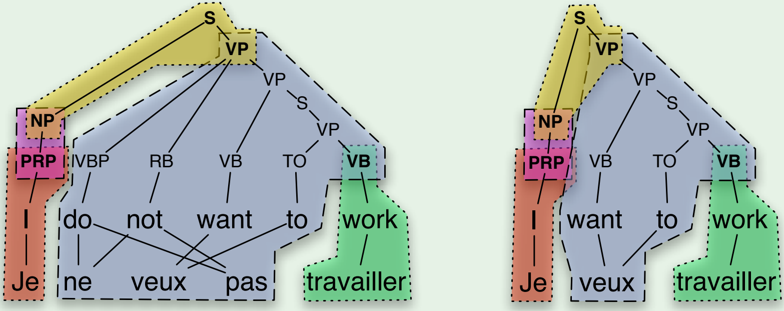
- Existing procedures for synchronous grammar extraction

Output:

- New unsupervised models for large scale synchronous grammar extraction,
- A comparison and analysis of the existing and proposed models,
- Extended decoders (cdec/Joshua) capable of working efficiently with these models.

# Models of translation

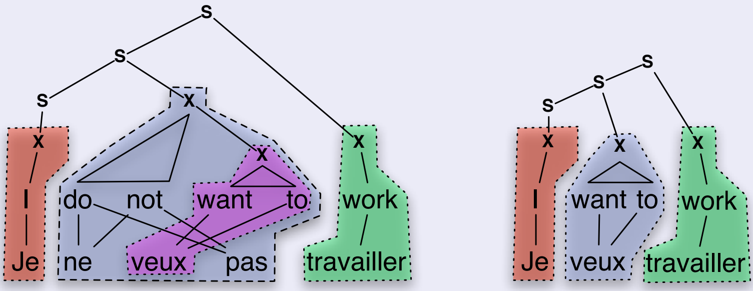
## Supervised SCFG: Syntactic Tree-to-String



- Strong model of sentence structure.
- Reliant on a treebank to train the parser.

# Models of translation

## Unlabelled SCFG: Hiero



- Only requires the parallel corpus.
- But weak model of sentence structure.

# Using syntax in Machine Translation:

## Synchronous Context Free Grammar (SCFG)

$S \rightarrow \langle X_{\boxed{1}},\ X_{\boxed{1}} \rangle$

$X \rightarrow \langle X_{\boxed{1}}\ X_{\boxed{2}},\ X_{\boxed{2}}\ X_{\boxed{1}} \rangle$

$X \rightarrow \langle \textit{Sie},\ \textit{She} \rangle$

$X \rightarrow \langle \textit{eine Tasse Kaffee},\ \textit{a cup of coffee} \rangle$

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# Models of translation

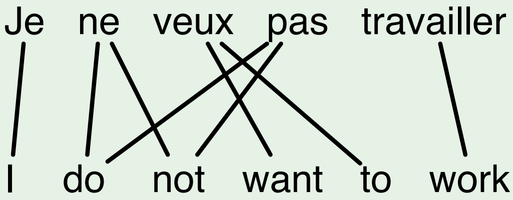
## Phrase extraction:

Je ne veux pas travailler

I do not want to work

# Models of translation

Phrase extraction:



- Use a word-based translation model to annotate the parallel corpus with word-alignments

# Models of translation

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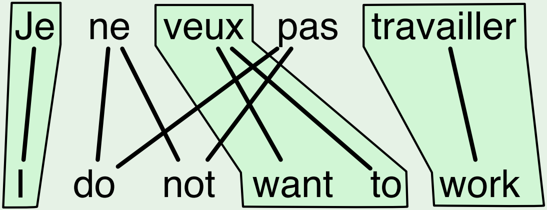

- ⟨ Je, I ⟩, ⟨ veux, want to ⟩, ⟨ travailler, work ⟩

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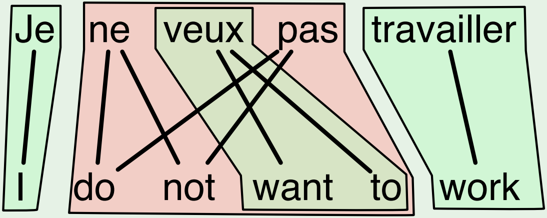

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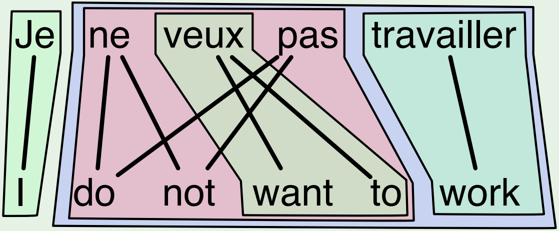

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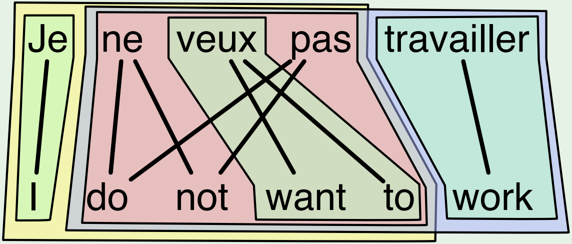

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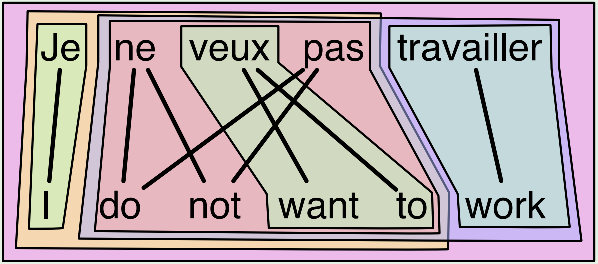

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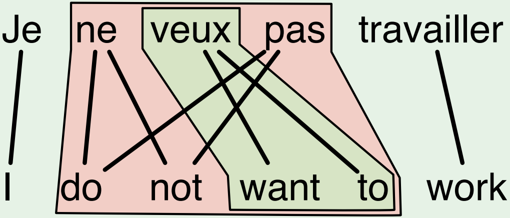
# Models of translation

## SCFG Rule extraction:



- X -> ⟨ ne veux pas, do not want to ⟩

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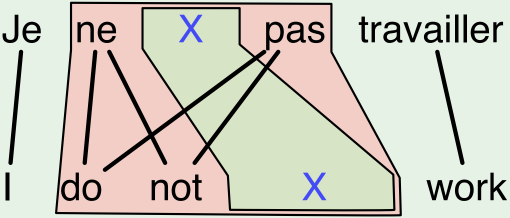
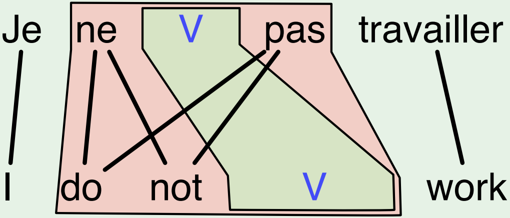


- X -> ⟨ ne veux pas, do not want to ⟩,
- X -> ⟨ ne $X_{\boxed{1}}$ pas, do not $X_{\boxed{1}}$ ⟩

# Models of translation

## SCFG Rule extraction:



- VP/NN -> $\langle$ ne veux pas, do not want to $\rangle$,
- VP/NN -> $\langle$ ne $V_{\boxed{1}}$ pas, do not $V_{\boxed{1}}$ $\rangle$

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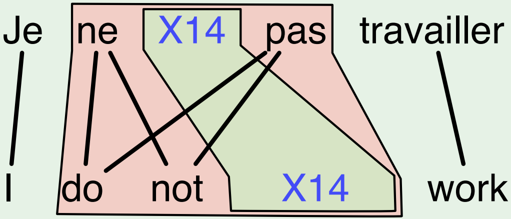


- X10 -> ⟨ ne veux pas, do not want to ⟩,
- X10 -> ⟨ ne $X14_{\boxed{1}}$ pas, do not $X14_{\boxed{1}}$ ⟩

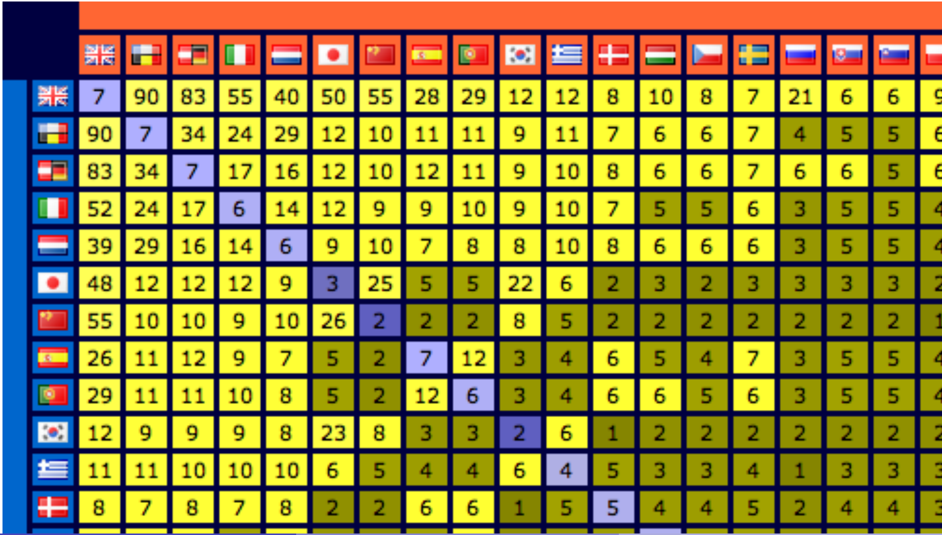
# Impact

| Language | Words | Domain |
|---|---:|---:|
| English | 4.5M | Financial news |
| Chinese | 0.5M | Broadcasting news |
| Arabic | 300K (1M planned) | News |
| Korean | 54K | Military |

Table: Major treebanks: data size and domain

# Impact

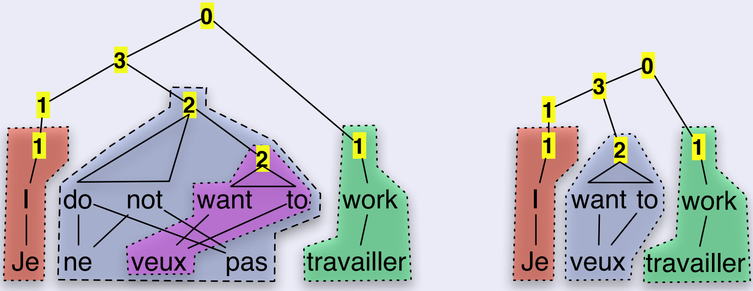
Parallel corpora far exceed treebanks (millions of words):



| | 🇬🇧 | 🇫🇷🇧🇪 | 🇦🇹🇩🇪 | 🇮🇹 | 🇳🇱 | 🇯🇵 | 🇨🇳 | 🇪🇸 | 🇵🇹 | 🇰🇷 | 🇬🇷 | 🇩🇰 | 🇭🇺 | 🇨🇿 | 🇸🇪 | 🇷🇺 | 🇸🇰 | 🇸🇮 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 🇬🇧 | 7 | 90 | 83 | 55 | 40 | 50 | 55 | 28 | 29 | 12 | 12 | 8 | 10 | 8 | 7 | 21 | 6 | 6 | 9 |
| 🇫🇷🇧🇪 | 90 | 7 | 34 | 24 | 29 | 12 | 10 | 11 | 11 | 9 | 11 | 7 | 6 | 6 | 7 | 4 | 5 | 5 | 6 |
| 🇦🇹🇩🇪 | 83 | 34 | 7 | 17 | 16 | 12 | 10 | 12 | 11 | 9 | 10 | 8 | 6 | 6 | 7 | 6 | 6 | 5 | 6 |
| 🇮🇹 | 52 | 24 | 17 | 6 | 14 | 12 | 9 | 9 | 10 | 9 | 10 | 7 | 5 | 5 | 6 | 3 | 5 | 5 | 4 |
| 🇳🇱 | 39 | 29 | 16 | 14 | 6 | 9 | 10 | 7 | 8 | 8 | 10 | 8 | 6 | 6 | 6 | 3 | 5 | 5 | 4 |
| 🇯🇵 | 48 | 12 | 12 | 12 | 9 | 3 | 25 | 5 | 5 | 22 | 6 | 2 | 3 | 2 | 3 | 3 | 3 | 3 | 2 |
| 🇨🇳 | 55 | 10 | 10 | 9 | 10 | 26 | 2 | 2 | 2 | 8 | 5 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 |
| 🇪🇸 | 26 | 11 | 12 | 9 | 7 | 5 | 2 | 7 | 12 | 3 | 4 | 6 | 5 | 4 | 7 | 3 | 5 | 5 | 4 |
| 🇵🇹 | 29 | 11 | 11 | 10 | 8 | 5 | 2 | 12 | 6 | 3 | 4 | 6 | 6 | 5 | 6 | 3 | 5 | 5 | 4 |
| 🇰🇷 | 12 | 9 | 9 | 9 | 8 | 23 | 8 | 3 | 3 | 2 | 6 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| 🇬🇷 | 11 | 11 | 10 | 10 | 10 | 6 | 5 | 4 | 4 | 6 | 4 | 5 | 3 | 3 | 4 | 1 | 3 | 3 | 3 |
| 🇩🇰 | 8 | 7 | 8 | 7 | 8 | 2 | 2 | 6 | 6 | 1 | 5 | 5 | 4 | 4 | 5 | 2 | 4 | 4 | 3 |

# Models of translation

## Hierarchical



- AIM: Implement a large scale open-source synchronous constituent learning system.
- AIM: Investigate and understand the relationship between the choice of synchronous grammar and SMT performance,
- AIM: and fix our decoders accordingly.

# Evaluation goals

We will predominately evaluate using BLEU, but also use automatic structured metrics and perform small scale human evaluation:

- Evaluate phrasal, syntactic, unsupervised syntactic,
- Aim 1: Do no harm (not true of existing syntactic approach)
- Aim 2: Exceed the performance of current non-syntactic systems.
- Aim 3: Meet or exceed performance of existing syntactic systems.

# Workshop Streams

- Implement scalable SCFG grammar extraction algorithms.
- Improve SCFG decoders to effieciently handle the grammars produce.
- Investigate discriminative training regimes the leverage features extracted from these grammars.

# Unsupervised grammar induction

There has been significant research into monolingual grammar induction: Constituent context is a prime indicator of constituency.

- Alexander Clark. Unsupervised induction of stochastic context-free grammars using distributional clustering, 2001
- Dan Klein and Chris Manning. A Generative Constituent-Context Model for Improved Grammar Induction, 2002

We can formalise this notion in algebraic structures

- Alexander Clark. A learnable representation for syntax using residuated lattices, 2009

Deep connections to unsupervised word sense disambiguation, thesaurus extraction etc.

# SCFG Grammar Induction

## Distributional Hypothesis

> Words that occur in the same contexts tend to have similar meanings
>
> (Zellig Harris, 1954)

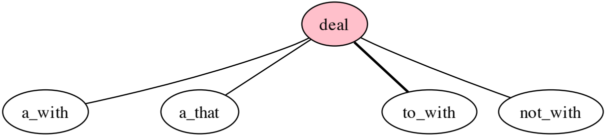
We will leverage this in a translation setting:

- Use the contexts to cluster translation units into groups
- Units in the same group expected to be semantically and syntactically similar
- Then use these cluster labels to guide translation
  - lexical selection: translating ambiguous source word/s
  - reordering: consistent syntactic patterns of reordering

# Monolingual Example

Task: cluster words into their parts-of-speech.

Illustrate by starting with the word ‘deal’ (noun or verb):



Step 1: Find contexts for ‘deal’

# Monolingual Example

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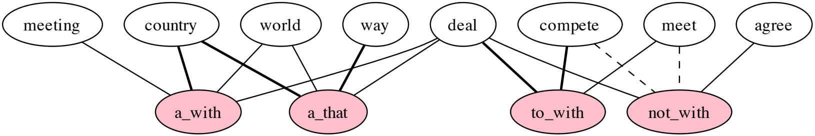

Step 2: Find other words which occur in these contexts

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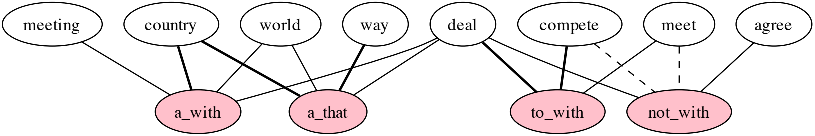


Step 2: Find other words which occur in these contexts

Notice that the instances of deal can be split into two connected sub-graphs:

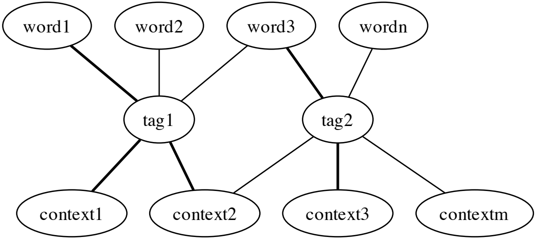
- noun: the left two contexts “a …with” and “a …that”
- verb: the right two contexts “to …with” and “not …with”
- neighbouring words of these contexts share the same PoS

# Clustering

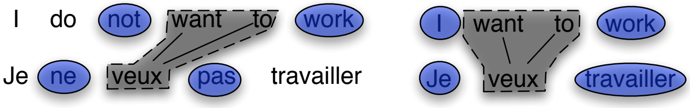
Task is to cluster the graph into sub-graphs. Nodes in the sub-graphs should be

- strongly connected to one another
- weakly connected to nodes outside the sub-graph
- could formulate as either *hard* or *soft* clustering

Choose soft clustering to allow for syntactic and semantic ambiguity

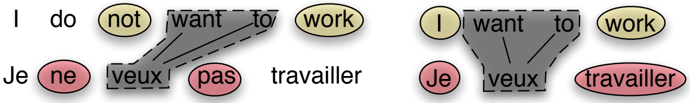


# Constituency and context



- Design and apply large scale scale clustering and topic modelling algorithms (LDA, HDPs, HPYPs etc),
- identify sets of frequent contexts that distinguish synchronous constituent properties.
- Motivated by successful models of monolingual grammar induction,
- deep connections to unsupervised word sense disambiguation, thesaurus extraction etc.

# Constituency and context



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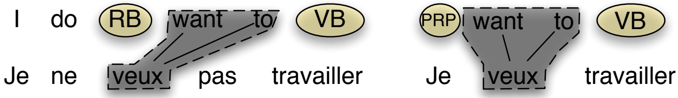

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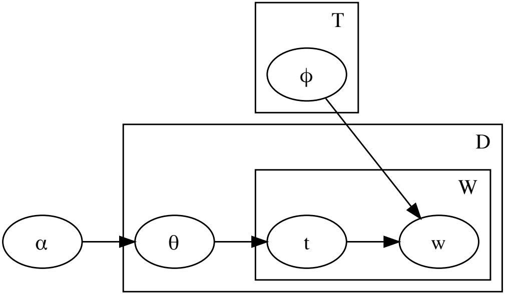
# Latent Dirichlet Allocation (LDA)

LDA is a generative model which treats documents as bags of words

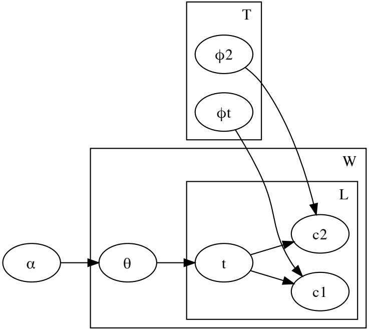
- each word is assign a topic (cluster tag)
- words are generated from a topic-specific multinomial
- topics are tied across a document using a Dirichlet prior
- $\alpha < 1$ biases towards sparse distributions, i.e., topic reuse
- inferred $\theta_d$ describes a document and $\phi_t$ describes a topic



# LDA over Contexts

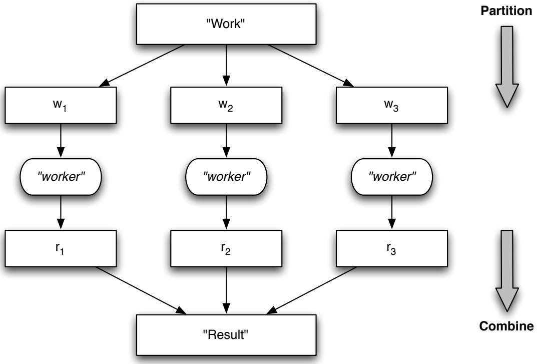
Generative story:

- for each word type $w$
- for each of the $L$ contexts
- first we draw a topic $t$, then generate the context $\vec{c}$ given the topic
- the Dirichlet prior ties the topics for each $w$
- we're primarily interested in the learnt $\theta$ values



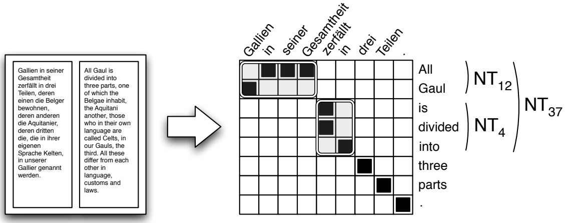
# Scalable grammar extraction with MapReduce

- Divide and conquer approach to...counting
  - map function $\mathcal{M}(x) \rightarrow \langle k_1, v_1 \rangle, \langle k_2, v_2 \rangle, \ldots$
  - write a reduce function $\mathcal{R}(k_i : v_7, v_{13}, \ldots) \rightarrow \langle k_i, \overline{v} \rangle$



# Scalable grammar extraction with MapReduce : mapper

## MAP INPUT



Gallien in seiner Gesamtheit zerfällt in drei Teilen, deren einen die Belger bewohnen, deren anderen die Aquitanier, deren dritten die, die in ihrer eigenen Sprache Kelten, in unserer Gallier genannt werden.

All Gaul is divided into three parts, one of which the Belgae inhabit, the Aquitani another, those who in their own language are called Celts, in our Gauls, the third. All these differ from each other in language, customs and laws.

parallel corpus

consists of

annotated word alignments

## MAP OUTPUT

| key | value |
|---|---|
| $NT_{37} \rightarrow NT_{12}\ NT_4 : \boxed{1}\ \boxed{2}$ | 1 |
| $NT_{12} \rightarrow$ *Gallien in seiner Gesamtheit* : *All Gaul* | 1 |
| $NT_4 \rightarrow$ *zerfällt in* : *is divided into* | 1 |
| $NT_{37} \rightarrow NT_{12}$ *zerfällt in* : $\boxed{1}$ *is divided into* | 1 |
| ... | |
| ... | |

# Scalable grammar extraction with MapReduce : reducer

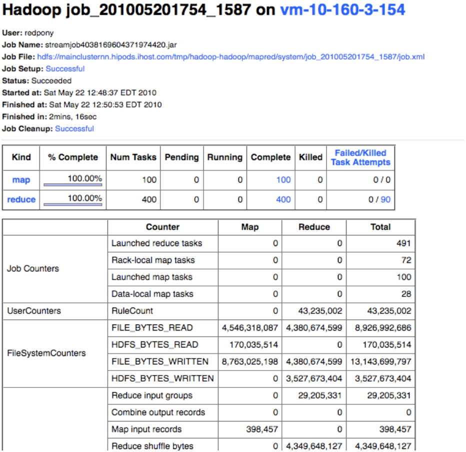
## REDUCE INPUT

| key | value |
|---|---|
| $NT_{37}$ → $NT_{12}$ $NT_{4}$ : $\boxed{1}$ $\boxed{2}$ | 1 |
| $NT_{37}$ → $NT_{12}$ $NT_{4}$ : $\boxed{1}$ $\boxed{2}$ | 1 |
| $NT_{37}$ → $NT_{12}$ $NT_{4}$ : $\boxed{1}$ $\boxed{2}$ | 1 |
| $NT_{37}$ → $NT_{6}$ $NT_{4}$ : $\boxed{2}$ $\boxed{1}$ | 1 |
| $NT_{12}$ → *Gallien in seiner Gesamtheit* : *All Gaul* | 1 |
| $NT_{4}$ → *zerfällt in* : *is divided into* | 1 |
| $NT_{4}$ → *zerfällt in* : *is divided into* | 1 |
| $NT_{37}$ → $NT_{12}$ *zerfällt in* : $\boxed{1}$ *is divided into* | 1 |

## REDUCE OUTPUT

| | |
|---|---|
| $NT_{37}$ → $NT_{12}$ $NT_{4}$ : $\boxed{1}$ $\boxed{2}$ | 3 |
| $NT_{37}$ → $NT_{6}$ $NT_{4}$ : $\boxed{2}$ $\boxed{1}$ | 1 |
| $NT_{12}$ → *Gallien in seiner Gesamtheit* : *All Gaul* | 1 |
| $NT_{4}$ → *zerfällt in* : *is divided into* | 2 |
| $NT_{37}$ → $NT_{12}$ *zerfällt in* : $\boxed{1}$ *is divided into* | 1 |

# Scalable grammar extraction with MapReduce : Hadoop



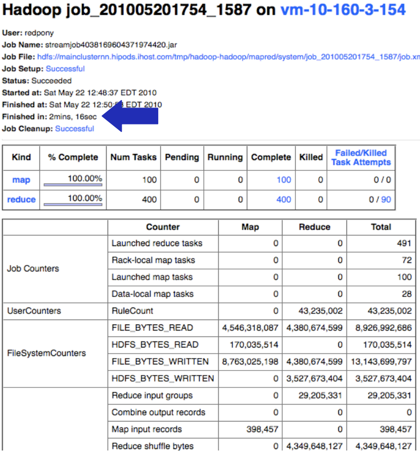
## Hadoop job_201005201754_1587 on vm-10-160-3-154

**User:** redpony
**Job Name:** streamjob4038169604371974420.jar
**Job File:** hdfs://mainclusternn.hipods.ihost.com/tmp/hadoop-hadoop/mapred/system/job_201005201754_1587/job.xml
**Job Setup:** Successful
**Status:** Succeeded
**Started at:** Sat May 22 12:48:37 EDT 2010
**Finished at:** Sat May 22 12:50:53 EDT 2010
**Finished in:** 2mins, 16sec
**Job Cleanup:** Successful

| Kind | % Complete | Num Tasks | Pending | Running | Complete | Killed | Failed/Killed Task Attempts |
|---|---|---|---|---|---|---|---|
| map | 100.00% | 100 | 0 | 0 | 100 | 0 | 0 / 0 |
| reduce | 100.00% | 400 | 0 | 0 | 400 | 0 | 0 / 90 |

| | Counter | Map | Reduce | Total |
|---|---|---|---|---|
| Job Counters | Launched reduce tasks | 0 | 0 | 491 |
| | Rack-local map tasks | 0 | 0 | 72 |
| | Launched map tasks | 0 | 0 | 100 |
| | Data-local map tasks | 0 | 0 | 28 |
| UserCounters | RuleCount | 0 | 43,235,002 | 43,235,002 |
| FileSystemCounters | FILE_BYTES_READ | 4,546,318,087 | 4,380,674,599 | 8,926,992,686 |
| | HDFS_BYTES_READ | 170,035,514 | 0 | 170,035,514 |
| | FILE_BYTES_WRITTEN | 8,763,025,198 | 4,380,674,599 | 13,143,699,797 |
| | HDFS_BYTES_WRITTEN | 0 | 3,527,673,404 | 3,527,673,404 |
| | Reduce input groups | 0 | 29,205,331 | 29,205,331 |
| | Combine output records | 0 | 0 | 0 |
| | Map input records | 398,457 | 0 | 398,457 |
| | Reduce shuffle bytes | 0 | 4,349,648,127 | 4,349,648,127 |

# Scalable grammar extraction with MapReduce : Hadoop



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| Kind | % Complete | Num Tasks | Pending | Running | Complete | Killed | Failed/Killed Task Attempts |
|---|---|---|---|---|---|---|---|
| map | 100.00% | 100 | 0 | 0 | 100 | 0 | 0 / 0 |
| reduce | 100.00% | 400 | 0 | 0 | 400 | 0 | 0 / 90 |

| | Counter | Map | Reduce | Total |
|---|---|---|---|---|
| Job Counters | Launched reduce tasks | 0 | 0 | 491 |
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| | Map input records | 398,457 | 0 | 398,457 |
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# Language pairs (small)

- BTEC Chinese-English:
  - 44k sentence pairs, short sentences
  - Widely reported 'prototyping' corpus
  - Hiero baseline score: 52.4 (16 references)
  - Prospects: BTEC always gives you good results
- NIST Urdu-English:
  - 50k sentence pairs
  - Hiero baseline score: MT05 - 23.7 (4 references)
  - Major challenges: major long-range reordering, SOV word order
  - Prospects: small data, previous gains with supervised syntax

# Language pairs (large)

- NIST Chinese-English:
  - 1.7M sentence pairs, Standard NIST test sets
  - Hiero baseline score: MT05 - 33.9 (4 references)
  - Major challenges: large data, mid-range reordering, lexical ambiguity
  - Prospects: supervised syntax gains reported
- NIST Arabic-English:
  - 900k sentence pairs
  - Hiero baseline score: MT05 - 48.9 (4 references)
  - Major challenges: strong baseline, local reordering, VSO word order
  - Prospects: difficult
- Europarl Dutch-French:
  - 1.5M sentence pairs, standard Europarl test sets
  - Hiero baseline score: Europarl 2008 - 26.3 (1 reference)
  - Major challenges: V2 / V-final word order, many non-literal translations
  - Prospects: ???

# Pre-workshop experiments

We have implemented a baseline constituent modelling and distrbuted grammar extraction pipeline. Initial results on the small BTEC corpora:

| Categories | 1-gram | 2-grams | 3-grams | 4-grams | BP | BLEU |
|---|---|---|---|---|---|---|
| 1 | 84.7 | 62.0 | 47.2 | 36.4 | 0.969 | 53.10 |
| 10 | 84.0 | 60.9 | 46.4 | 35.9 | 0.979 | 52.88 |
| 25 | 84.4 | 61.8 | 47.6 | 36.7 | 0.973 | 53.47 |
| 50 | 84.8 | 61.2 | 46.6 | 36.2 | 0.971 | 52.83 |
| 100 | 83.5 | 60.1 | 45.7 | 35.3 | 0.972 | 51.86 |

# Summary

- Scientific Merit:
  - A systematic comparison of existing syntactive approaches to SMT.
  - An empirical study of how constituency is useful in SMT.
  - An evaluation of existing theories of grammar induction in a practical application (end-to-end evaluation).
- Potential Impact:
  - Better MT systems, for more languages, across a range of domains.
  - More accessible high performance translation models for researchers.
- Feasibility:
  - A great team with a wide range of both theoretical and practical experience.
  - Solid preparation.
- Novelty:
  - First attempt at large scale unsupervised synchronous grammar induction.