

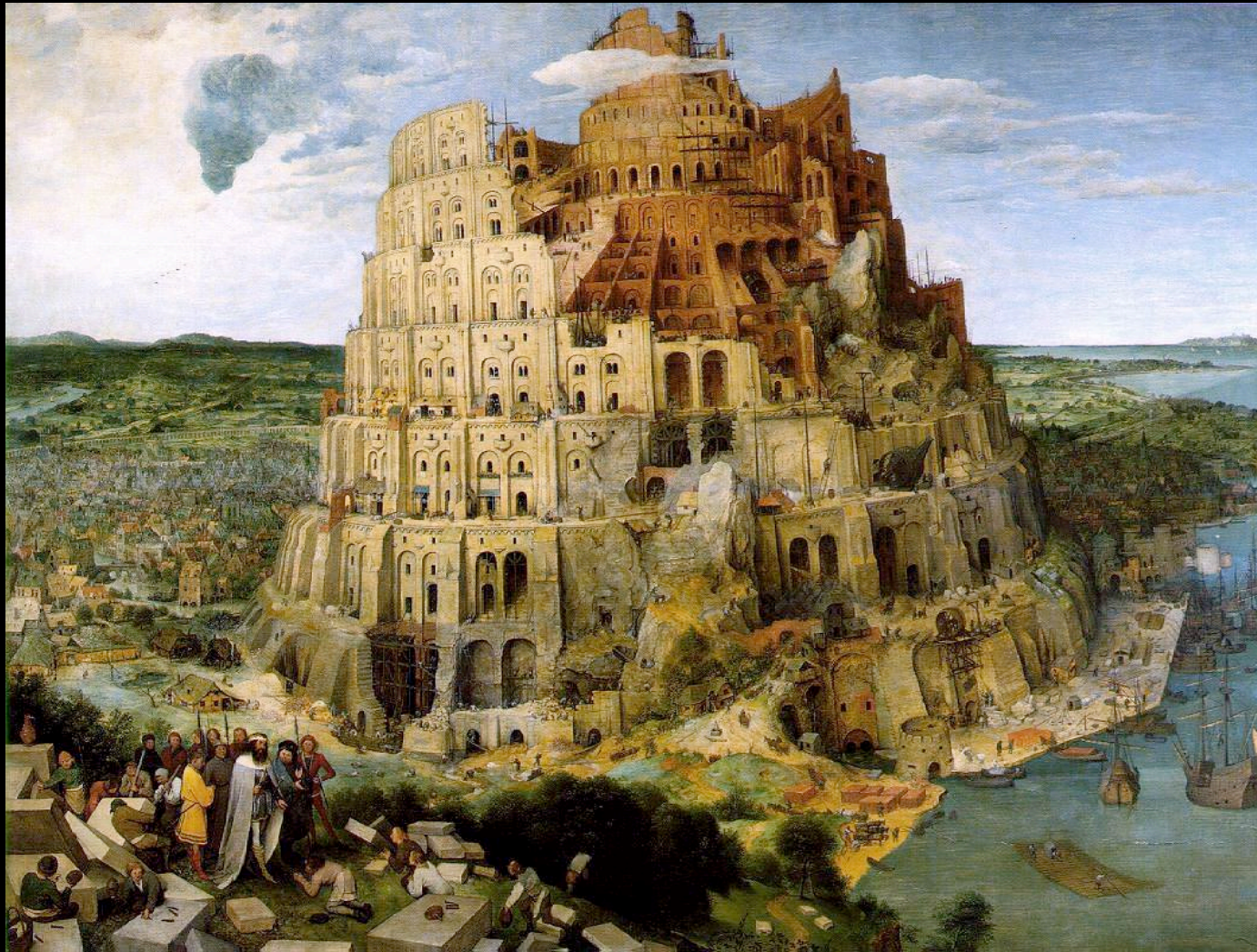
Machine Translation: Models, Search, and Evaluation

Adam Lopez
University of Edinburgh

虽然北风呼啸，但天空依然十分清澈。

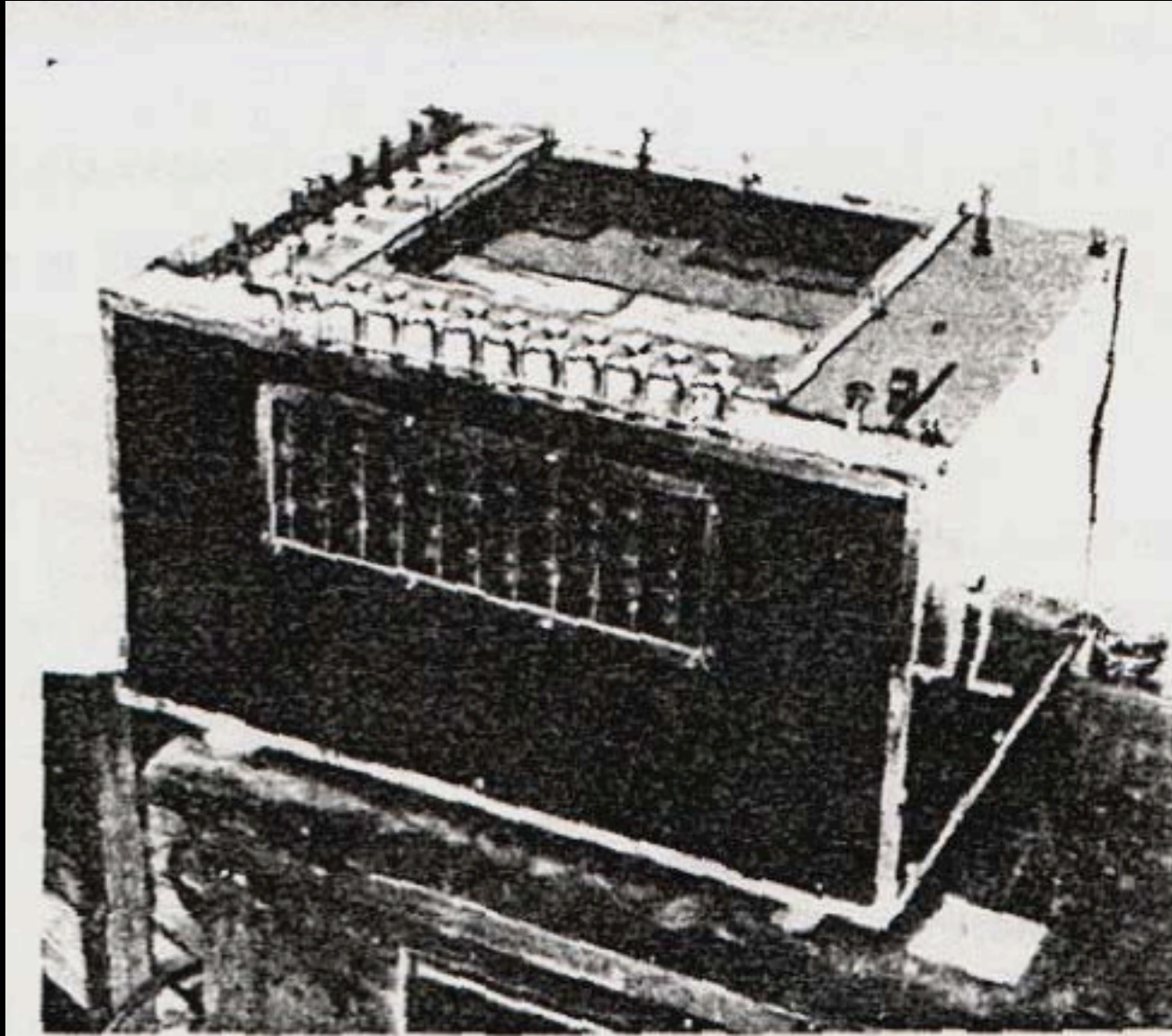
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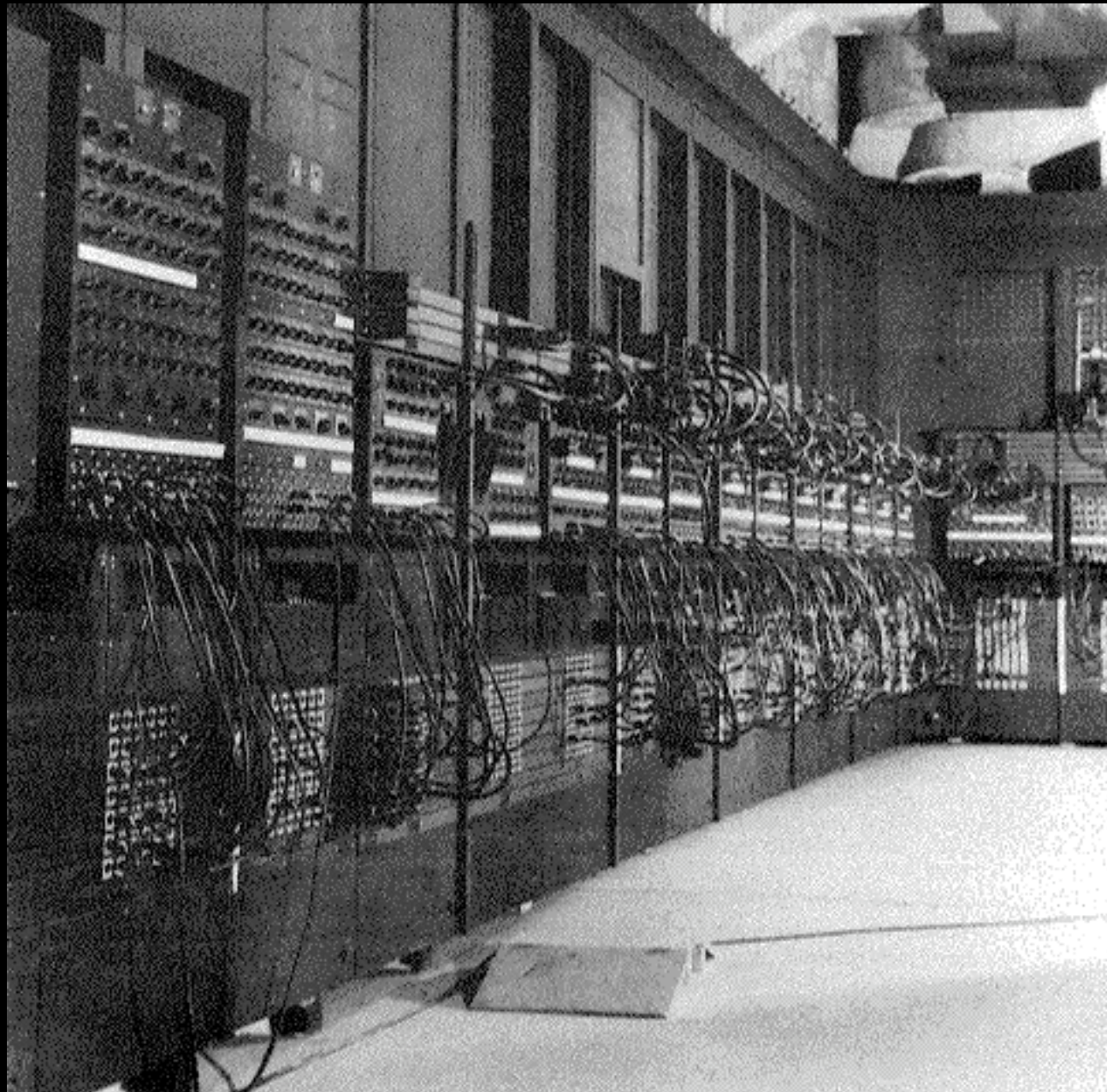


The Tower of Babel

Pieter Bruegel the Elder (1563)



Georges Artsrouni's "mechanical brain",
patented 1933 (France)



ENIAC (1946)



When I look at an article in Russian, I say: "This is really written in English, but it has been coded in some strange symbols. I will now proceed to decode."

Warren Weaver (1949)

COMIT

METAL

Systran

TITUS

SPANAM

ENGSPAN

CUKT

Ariane

GETA

SUSY

AMPAR

NERPA

FRAP

Logos

LUTE

KANT

Candide

SDL

Eurotra

CATALYST

UNITRAN

Rewrite

Pharoah

Moses

Hiero

SAMT

Joshua

Google Translate

Interlingua-Based MT
Constraint-Based MT
Knowledge-Based MT
Lexical-Based MT
Rule-Based MT
Principle-Based MT
Shake-and-Bake MT
Statistical MT
Example-Based MT
Memory-Based MT
Dialogue-Based MT
Neural-Network-Based MT
Context-Based MT



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However , the sky remained clear under the strong north wind .

Despite the strong northerly winds , the sky remains very clear .

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However , the sky remained clear under the strong north wind .

Despite the strong northerly winds , the sky remains very clear .

The sky was still crystal clear , though the north wind was howling .

Although a north wind was howling , the sky remained clear and
blue .

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Statistical Machine Translation Live

4/28/2006 03:40:00 PM

Franz Och

Because we want to provide everyone with access to all the world's information, including information written in every language, one of the exciting projects at Google Research is machine translation...

Now you can see the results for yourself. We recently launched an online version of our system for Arabic-English and English-Arabic. Try it out!

Statistical Machine Translation

Statistical Machine Translation

Develop a *model* of translation that can be *learned* from *data* and used to *predict* the correct English translation of new Chinese sentences.

Statistical Machine Translation

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this talk

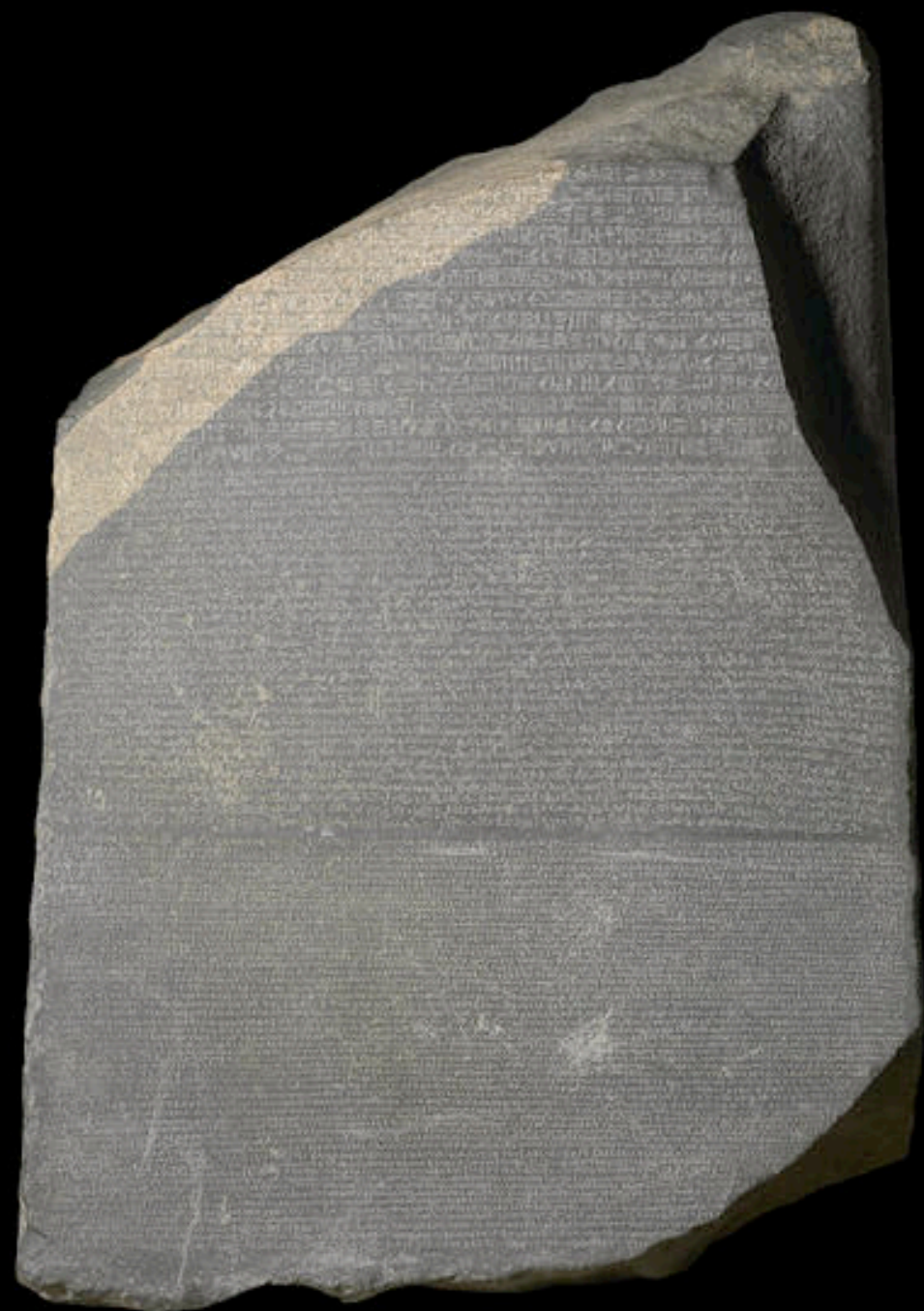
Statistical Machine Translation

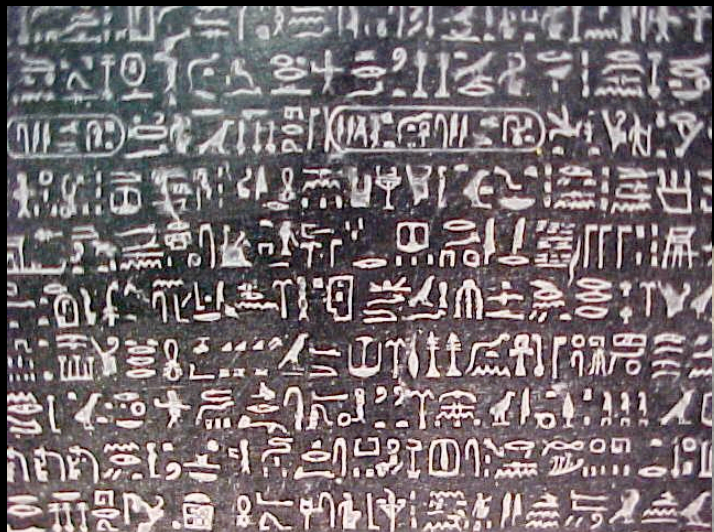
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John's talk

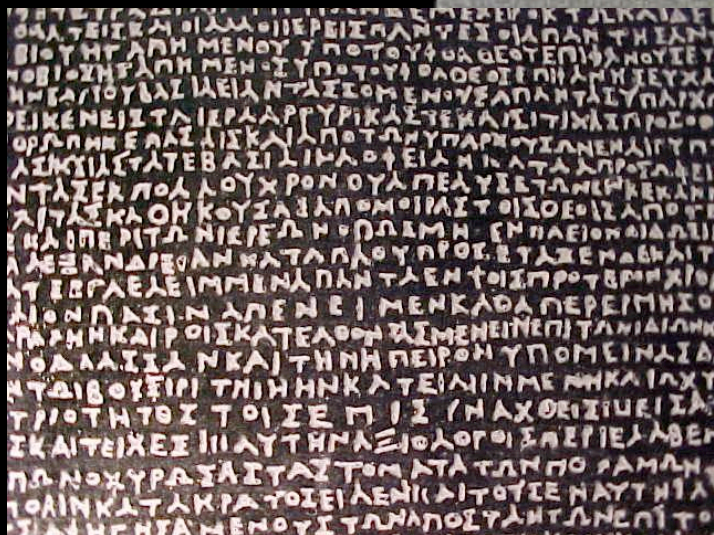
Statistical Machine Translation

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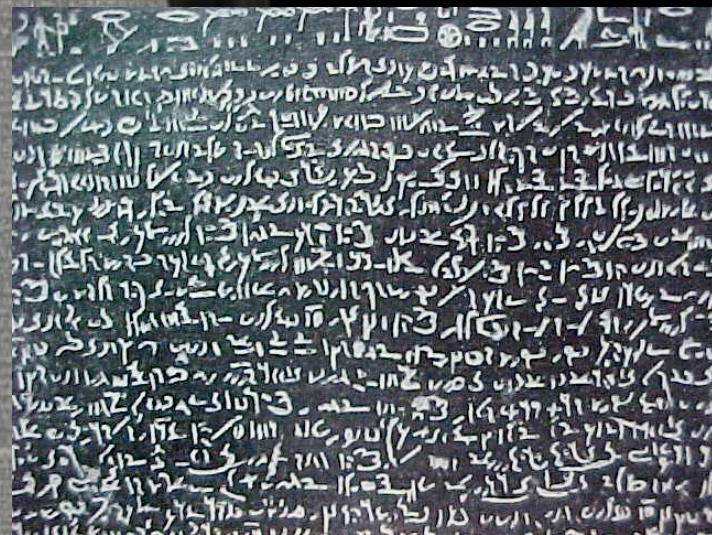




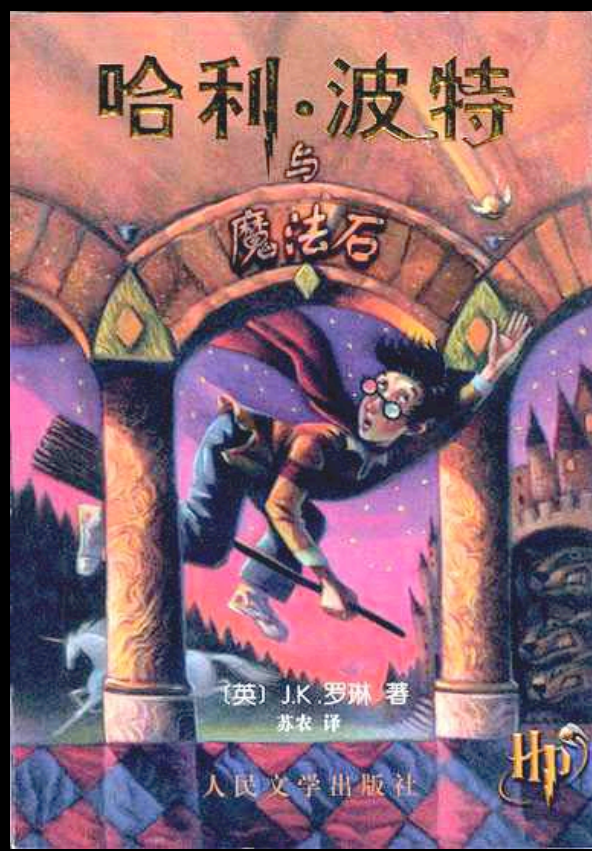
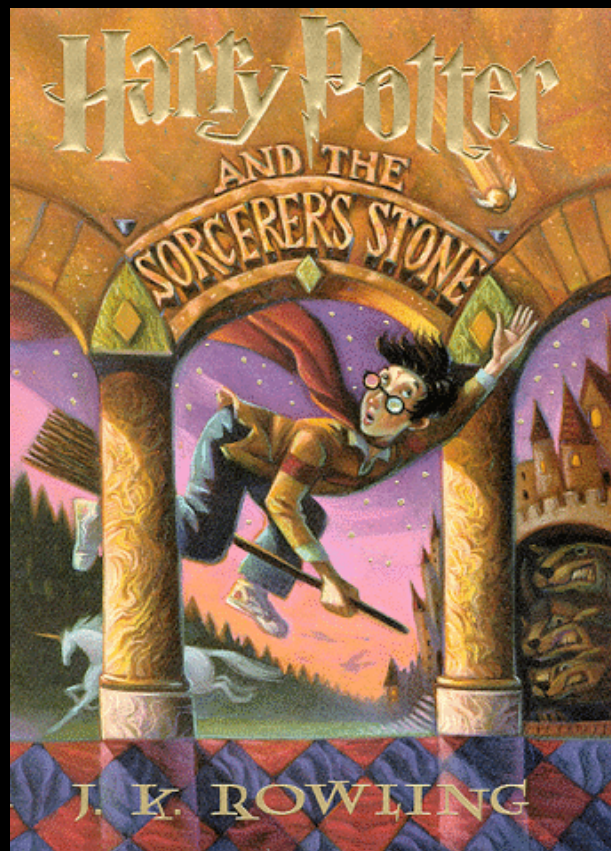
Fragment of an ancient Greek inscription, likely from the Parthenon pediment. It shows several lines of text in an ancient Greek dialect, possibly Doric, with some characters appearing to be in red ink (porphyry).

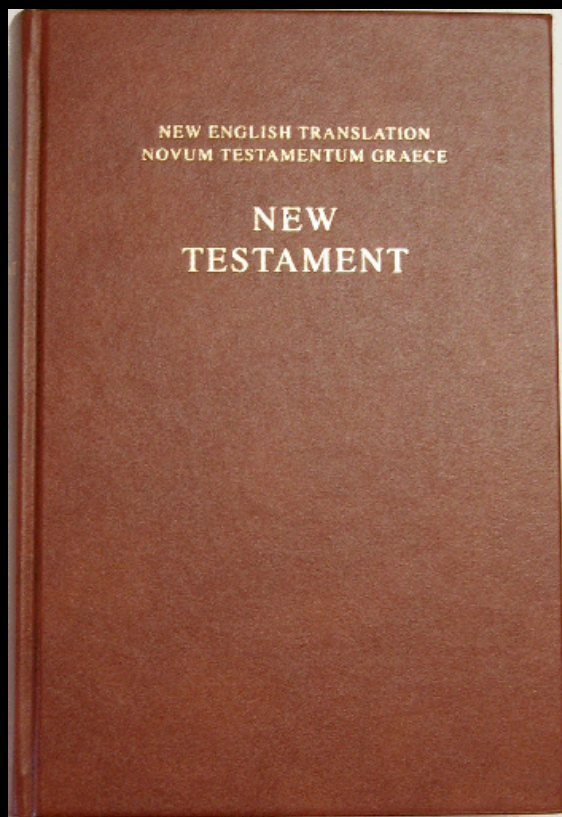


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Producers' Price Index For Manufactured Goods

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 Monthly Data Updated(08.23)

中华人民共和国国家统计局
 National Bureau of Statistics of China
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105年9月18日 星期日
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- 1-8月浙江规模以上固定资产投资同比增长18.4% (09.15)
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中文繁体

ENGLISH

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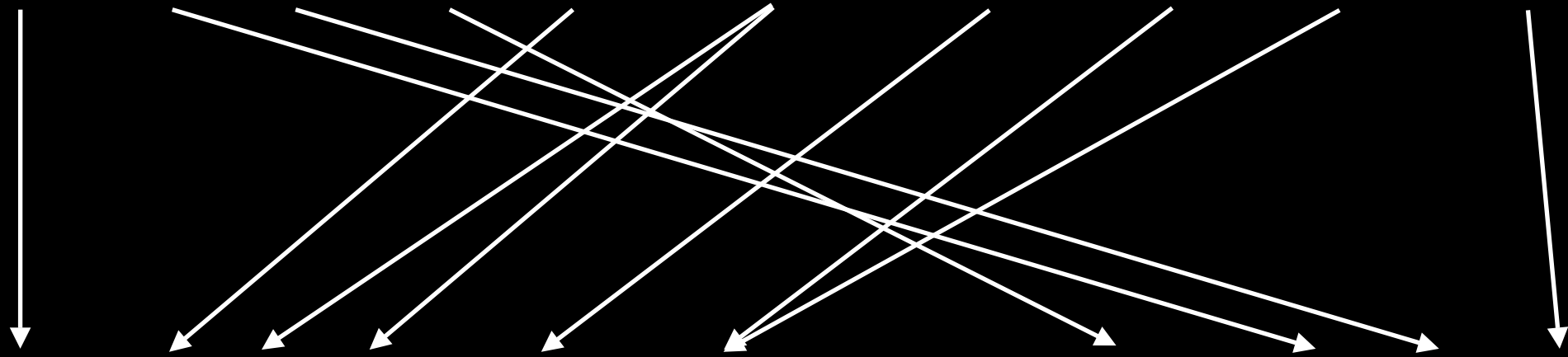


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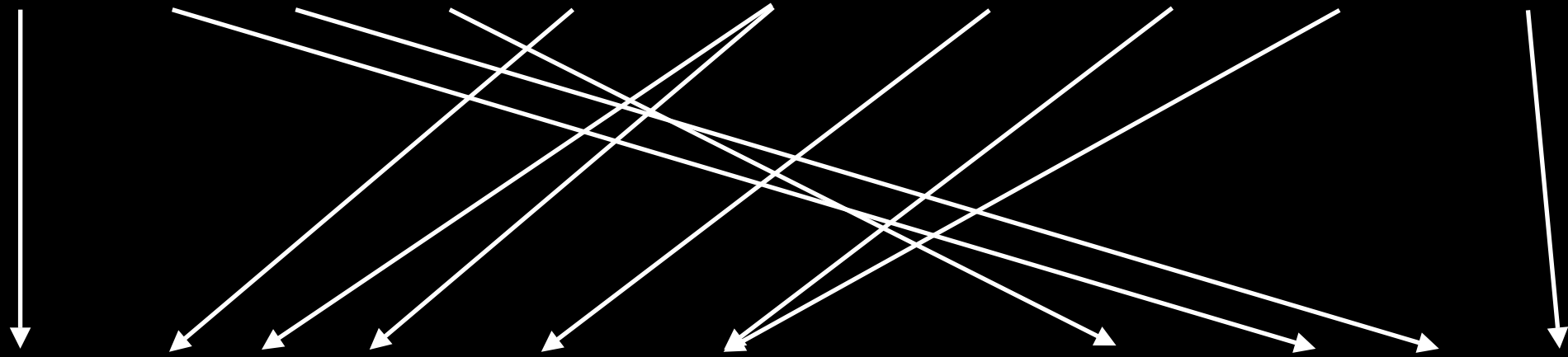
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$p_f(1|\text{虽然})$

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虽然 北 风 呼啸 ， 但 天空 依然 十分 清澈 。

↓ ↓ ↓ ↓ ↓
虽然 北 风 呼啸 ， 天空 天空 依然 清澈 。

Although north wind howls , but sky still very clear .

虽然 北 风 呼 啸 ， 但 天 空 依 然 十 分 清 澈 。

↓ ↓ ↓ ↓ ↓ ⊥ ↙ ↘ ⊥ ↙ ↘
虽然 北 风 呼 啸 ， 天 空 天 空 依 然 清 澈 。

Although north wind howls , but sky still very clear .

虽然 北 风 呼 啸 ， 但 天 空 依 然 十 分 清 澈 。 ε

↓ ↓ ↓ ↓ ↓ ⊥ ↙ ↘ ⊥ ↙ ↘
虽然 北 风 呼 啸 ， 天 空 天 空 依 然 清 澈 。

Although north wind howls , but sky still very clear .

虽然 北 风 呼啸 ， 但 天空 依然 十分 清澈 。 ϵ

↓ ↓ ↓ ↓ ↓ ⊥ ↙ ↘ ⊥ ↙ ↘ ↘
虽然 北 风 呼啸 ， 天空 天空 依然 清澈 。 ϵ ϵ

Although north wind howls , but sky still very clear .

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↓ ↓ ↓ ↓ ↓ ⊥ ↙ ↘ ⊥ ↙ ↘ ↘
虽然 北 风 呼啸 ， 天空 天空 依然 清澈 。 ϵ ϵ

↓
However

Although north wind howls , but sky still very clear .

虽然 北 风 呼啸 ， 但 天空 依然 十分 清澈 。 ϵ

↓ ↓ ↓ ↓ ↓ ⊥ ↙ ↘ ⊥ ↙ ↘ ↘
虽然 北 风 呼啸 ， 天空 天空 依然 清澈 。 ϵ ϵ

↓
However

$p_t(\text{However} | \text{虽然})$

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↓ ↓ ↓ ↓ ↓ ⊥ ↙ ↘ ⊥ ↙ ↘ ↙ ↘
虽然 北 风 呼 啸 ， 天 空 天 空 依 然 清 澈 。 ϵ ϵ

↓ ↘ ↘ ↘ ↘ ↘ ↘ ↘ ↘ ↘ ↘ ↘ ↘
However north wind strong , the sky remained clear . under the

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虽然 北 风 呼 啸 ， 但 天 空 依 然 十 分 清 澈 。 ε

↓ ↓ ↓ ↓ ↓ ⊥ ↙ ↘ ⊥ ↙ ↘ ↙ ↘
虽然 北 风 呼 啸 ， 天 空 天 空 依 然 清 澈 。 ε ε

↓ ↘ ↘ ↘ ↘ ↘ ↘ ↘ ↘ ↘ ↘ ↘
However north wind strong , the sky remained clear . under the

— — — — — — — — — — — — — — — — — —

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↓ ↓ ↓ ↓ ↓ ⊥ ↙ ↘ ⊥ ↙ ↘ ↘ ↘
虽然 北 风 呼 啸 ， 天 空 天 空 依 然 清 澈 。 ϵ ϵ

↓ ↘ ↘ ↘ ↘ ↘ ↘ ↘ ↘ ↘ ↘ ↘ ↘
However north wind strong , the sky remained clear . under the

↓
_ _ _ _ _

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↓ ↓ ↓ ↓ ↓ ⊥ ↙ ↘ ⊥ ↙ ↘ ↘ ↘
虽然 北 风 呼 啸 ， 天 空 天 空 依 然 清 澈 。 ϵ ϵ

↓ ↘ ↘ ↘ ↘ ↘ ↘ ↘ ↘ ↘ ↘ ↘ ↘
However north wind strong , the sky remained clear . under the



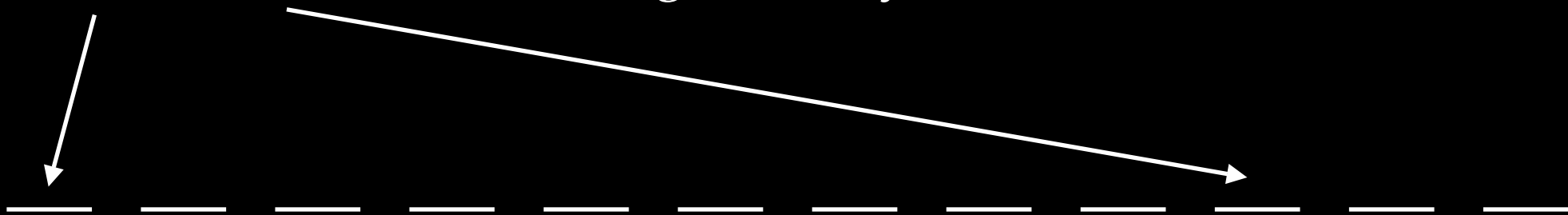
$$p_d(0|However)$$

Although north wind howls , but sky still very clear .

虽然 北 风 呼 啸 ， 但 天 空 依 然 十 分 清 澈 。 ϵ

↓ ↓ ↓ ↓ ↓ ⊥ ↙ ↘ ⊥ ↙ ↘ ↙ ↘
虽然 北 风 呼 啸 ， 天 空 天 空 依 然 清 澈 。 ϵ ϵ

↓ ↘ ↘ ↘ ↘ ↘ ↘ ↘ ↘ ↘ ↘ ↘ ↘
However north wind strong , the sky remained clear . under the



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↓ ↓ ↓ ↓ ↓ ⊥ ↙ ↘ ⊥ ↙ ↘ ↘ ↘
虽然 北 风 呼 啸 ， 天 空 天 空 依 然 清 澈 。 ϵ ϵ

↓ ↘ ↘ ↘ ↘ ↘ ↘ ↘ ↘ ↘ ↘ ↘ ↘
However north wind strong , the sky remained clear . under the



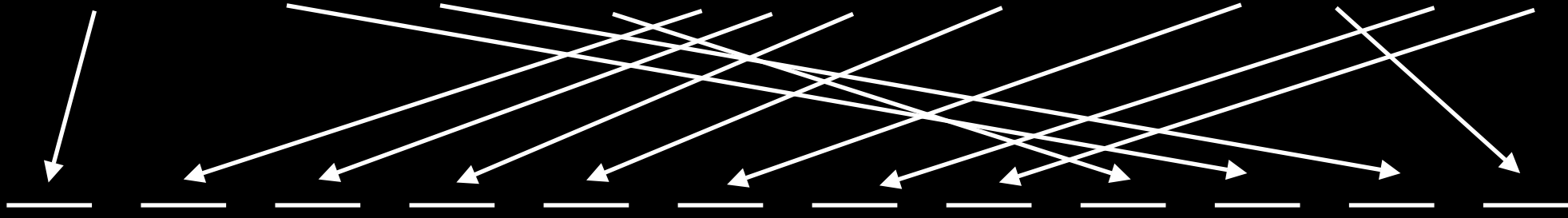
$$p_d(8|north)$$

Although north wind howls , but sky still very clear .

虽然 北 风 呼 啸 ， 但 天 空 依 然 十 分 清 澈 。 ε

↓ ↓ ↓ ↓ ↓ ⊥ ↙ ↘ ⊥ ↙ ↘ ↙ ↘
虽然 北 风 呼 啸 ， 天 空 天 空 依 然 清 澈 。 ε ε

↓ ↘ ↘ ↘ ↘ ↘ ↘ ↘ ↘ ↘ ↘ ↘ ↘
However north wind strong , the sky remained clear . under the

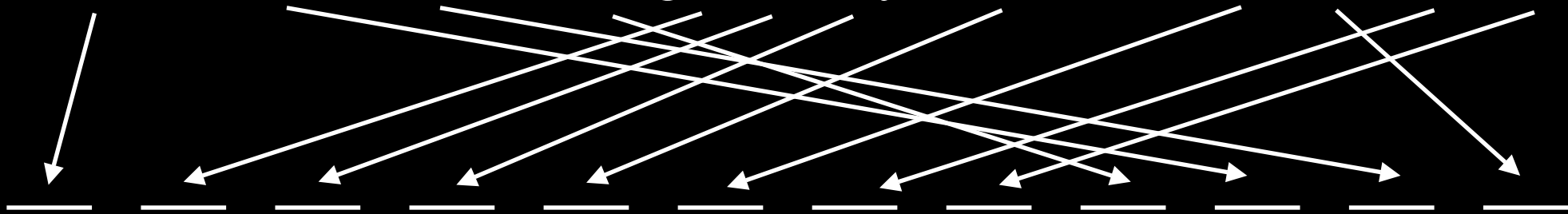


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↓ ↓ ↓ ↓ ↓ ⊥ ↙ ↘ ⊥ ↙ ↘ ↙ ↘
虽然 北 风 呼 啸 ， 天 空 天 空 依 然 清 澈 。 ϵ ϵ

↓ ↘ ↘ ↘ ↘ ↘ ↘ ↘ ↘ ↘ ↘ ↘ ↘ ↘
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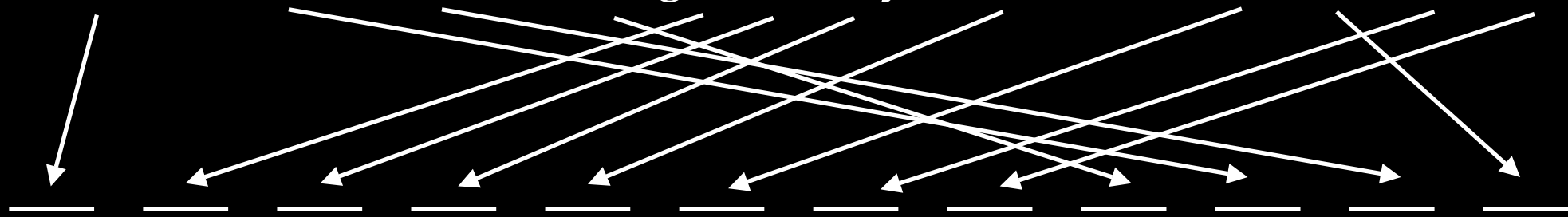
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↓ ↘ ↘ ↘ ↘ ↘ ↘ ↘ ↘ ↘ ↘ ↘ ↘ ↘
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However , the sky remained clear under the strong north wind .

$$p(\text{English, alignment}|\text{Chinese}) = \prod_{p_f} \prod_{p_t} \prod_{p_d}$$

虽然北风呼啸，但天空依然十分清澈。

However, the sky remained clear under the strong north wind.

$$p(\text{English, alignment} | \text{Chinese}) = \prod_{p_f} \prod_{p_t} \prod_{p_d}$$

虽然北风呼啸，但天空依然十分清澈。

However, the sky remained clear under the strong north wind.

$$p(\text{English}|\text{Chinese}) = \sum_{alignments} \prod_{p_f} \prod_{p_t} \prod_{p_d}$$

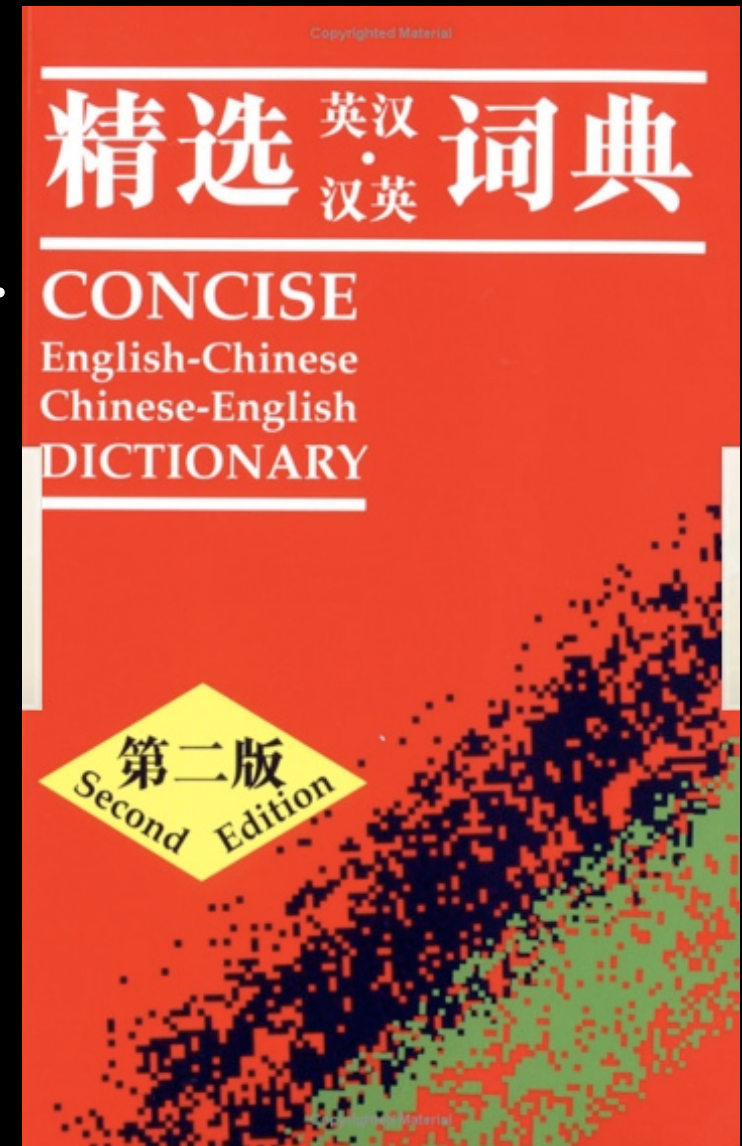
The IBM Models

The IBM Models

- Fertility probabilities.
- Word translation probabilities.
- Distortion probabilities.

The IBM Models

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The IBM Models

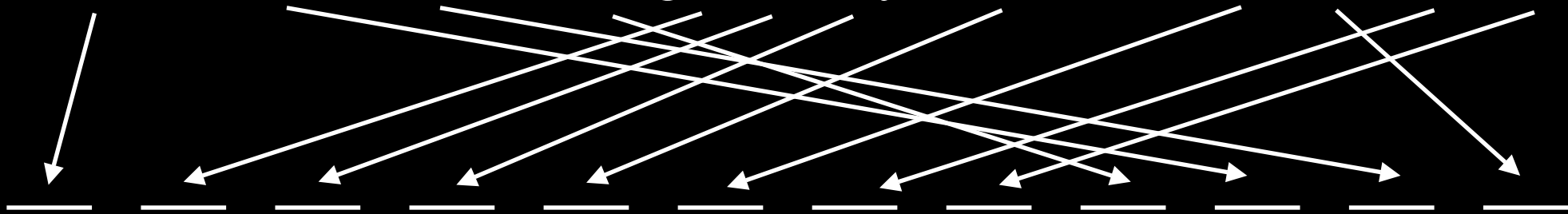
- Fertility probabilities.
- Word translation probabilities.
- Distortion probabilities.
- Some problems:
 - Complexity -- exponential in sentence length.
 - Weak reordering model -- output is not fluent.
 - Many decisions -- many things can go wrong.

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↓ ↓ ↓ ↓ ↓ ⊥ ↙ ↘ ⊥ ↙ ↘ ↙ ↘
虽然 北 风 呼 啸 ， 天 空 天 空 依 然 清 澈 。 ϵ ϵ

↓ ↘ ↘ ↘ ↘ ↘ ↘ ↘ ↘ ↘ ↘ ↘ ↘ ↘
However north wind strong , the sky remained clear . under the



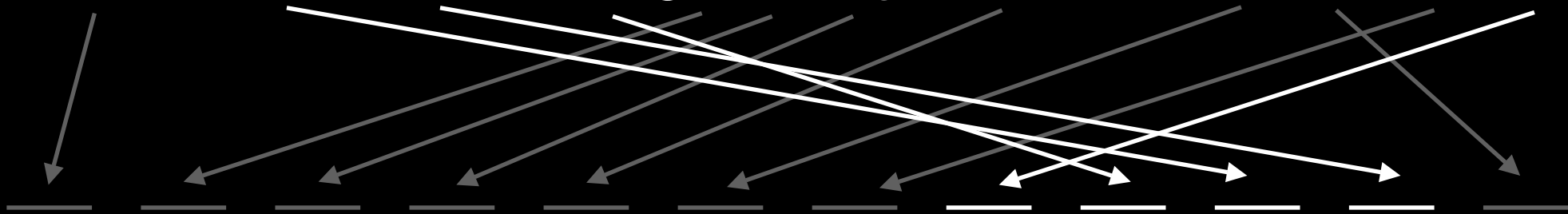
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However

Although north wind howls , but sky still very clear .

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However the strong north wind , the sky remained clear under .

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However the strong north wind , the sky remained clear under .

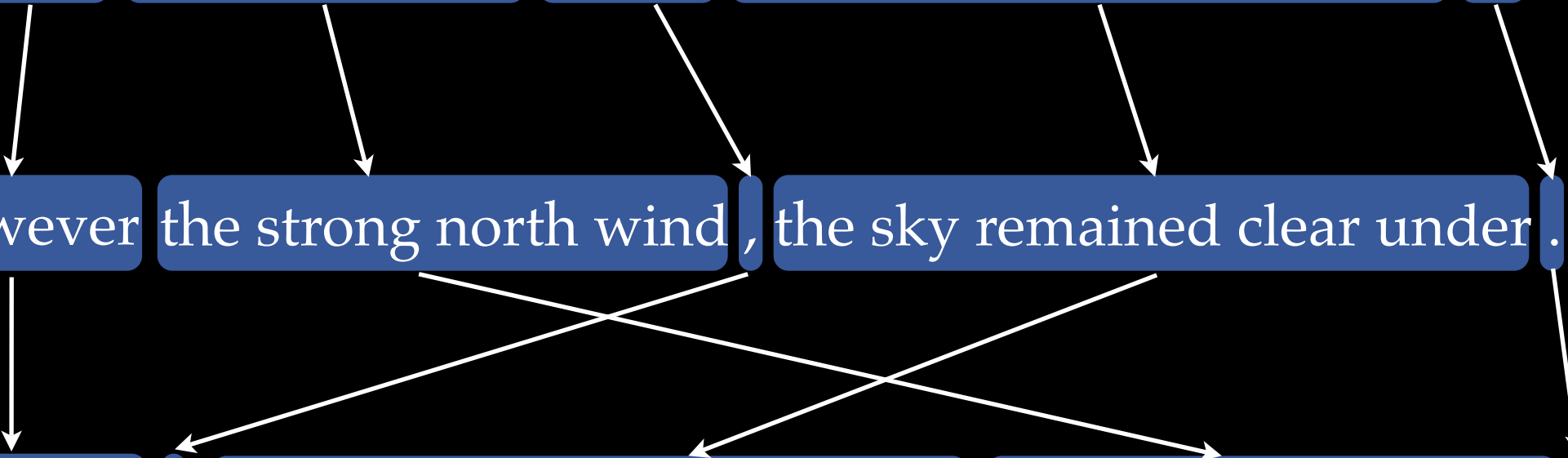
However ,

Although north wind howls , but sky still very clear .

虽然 北 风 呼 啸 ， 但 天 空 依 然 十 分 清 澈 。

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Although north wind howls , but sky still very clear .

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However the strong north wind , the sky remained clear under .

However , the sky remained clear under the strong north wind .

$$p(\text{English, alignment} | \text{Chinese}) = p(\text{segmentation}) \cdot p(\text{translations}) \cdot p(\text{reorderings})$$

Phrase-based Models

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- Segmentation probabilities.
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 - Complexity -- exponential in sentence length.
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$$p(\textit{English, alignment}|\textit{Chinese}) = \prod_{\textit{decision}} p(\textit{decision})$$

$$p(\textit{English}|\textit{Chinese}) = \sum_{\textit{alignments}} \prod_{\textit{decision}} p(\textit{decision})$$

$$\hat{p}(\textit{English}|\textit{Chinese}) = \prod_{\textit{decision}} p(\textit{decision})$$

$$\operatorname{argmax}_{\text{English}} \hat{p}(\text{English}|\text{Chinese}) = \prod_{\text{decision}} p(\text{decision})$$

$p(\textit{English}|\textit{Chinese})$



English



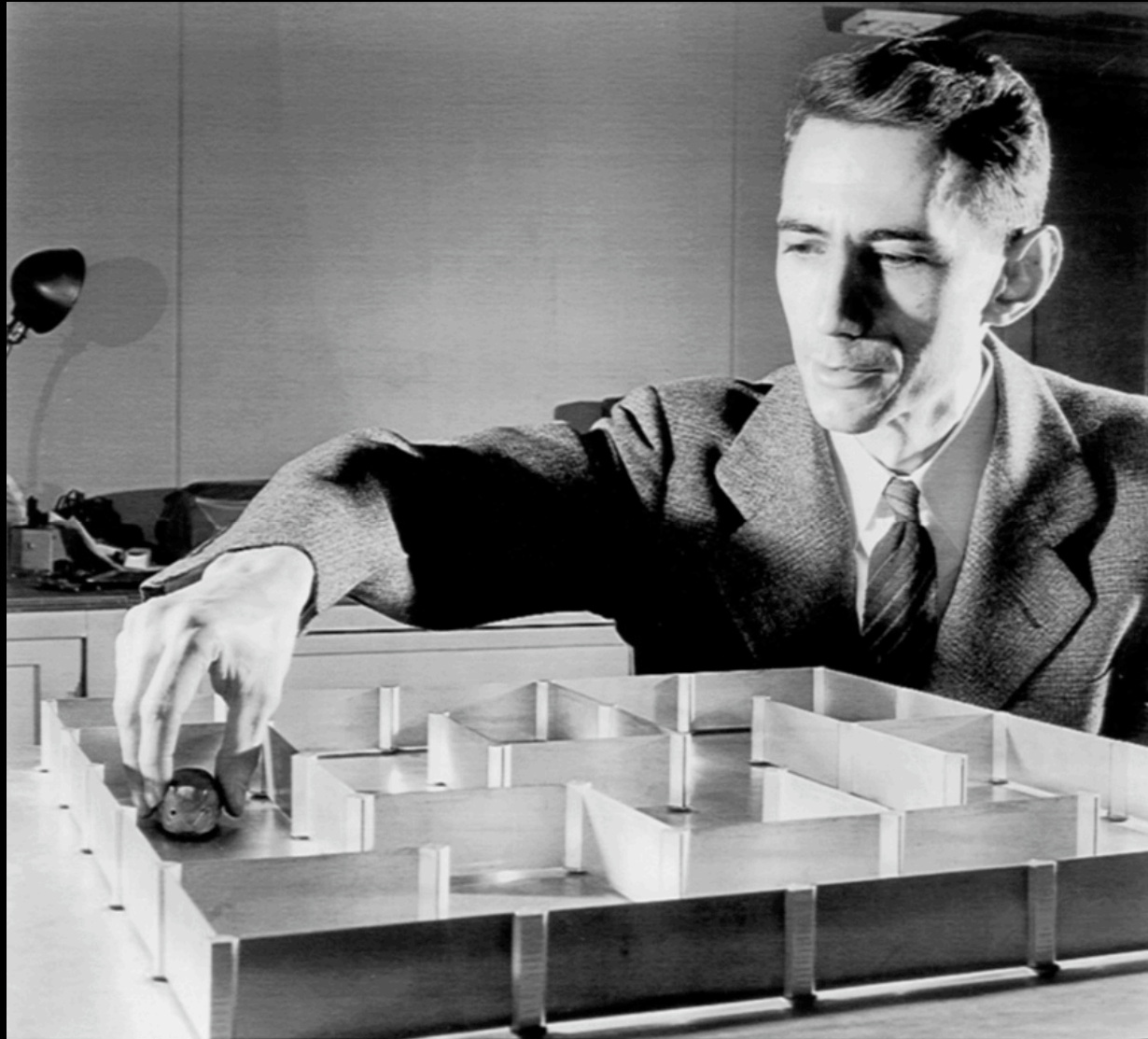
When I look at an article in Russian, I say: "This is really written in English, but it has been coded in some strange symbols. I will now proceed to decode."

Warren Weaver (1949)



THE MATHEMATICAL THEORY OF COMMUNICATION

by Claude E. Shannon and Warren Weaver



Claude Shannon

...But the probability that an event has happened is the same as the probability I have to guess right if I guess it has happened. Wherefore the following proposition is evident: If there be two subsequent events, the probability of the 2d b/N and the probability both together P/N , and it being 1st discovered that the 2d event has also happened, the probability I am right is P/b .



Thomas Bayes

Bayes' Theorem

$$p(\textit{English}|\textit{Chinese}) =$$

$$\frac{p(\textit{English}) \times p(\textit{Chinese}|\textit{English})}{p(\textit{Chinese})}$$

Bayes' Theorem

$$p(\textit{English}|\textit{Chinese}) =$$

$$\frac{p(\textit{English}) \times p(\textit{Chinese}|\textit{English})}{p(\textit{Chinese})}$$

translation model



Bayes' Theorem

$$p(\textit{English}|\textit{Chinese}) =$$

$$\frac{p(\textit{English}) \times p(\textit{Chinese}|\textit{English})}{p(\textit{Chinese})}$$

language model

translation model

Bayes' Theorem

$$p(\textit{English}|\textit{Chinese}) =$$

$$\frac{p(\textit{English}) \times p(\textit{Chinese}|\textit{English})}{p(\textit{Chinese})}$$

language model

translation model

normalization term (ensures we're working with valid probabilities).

Bayes' Theorem

$$p(\textit{English}|\textit{Chinese}) \sim$$

$$p(\textit{English}) \times p(\textit{Chinese}|\textit{English})$$

Bayes' Theorem

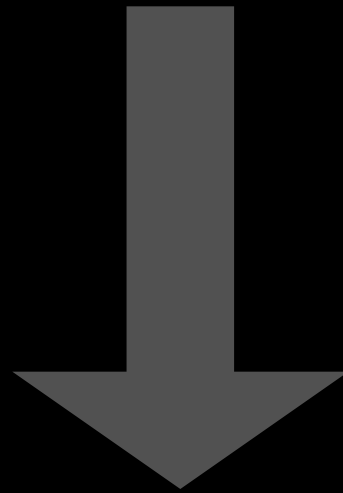


However, the sky remained clear under the strong north wind .

Bayes' Theorem

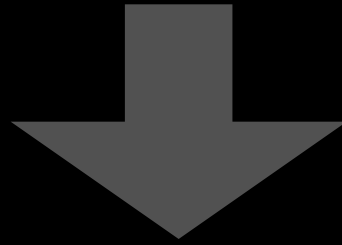


However, the sky remained clear under the strong north wind .



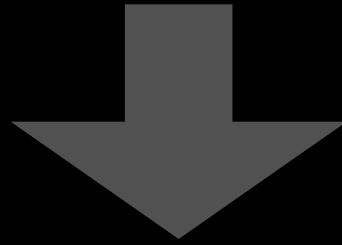
虽然北风呼啸，但天空依然十分清澈。

Bayes' Theorem

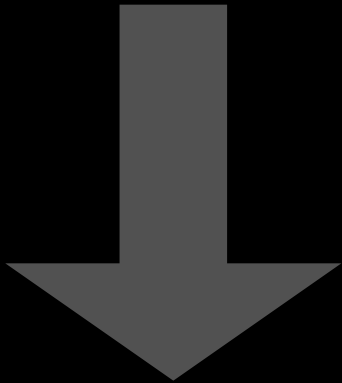


configuration

Bayes' Theorem

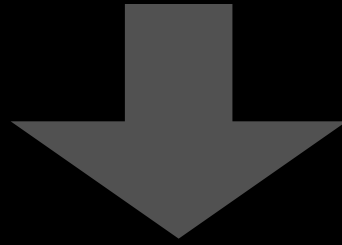


configuration



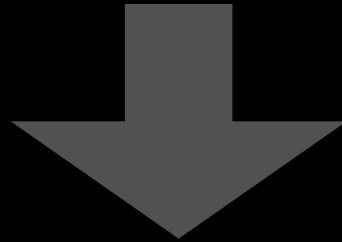
configuration

Bayes' Theorem



Our enemies are innovative and resourceful, and so are we. They never stop thinking about new ways to harm our country and our people, and neither do we.

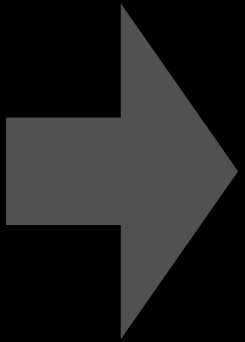
Bayes' Theorem



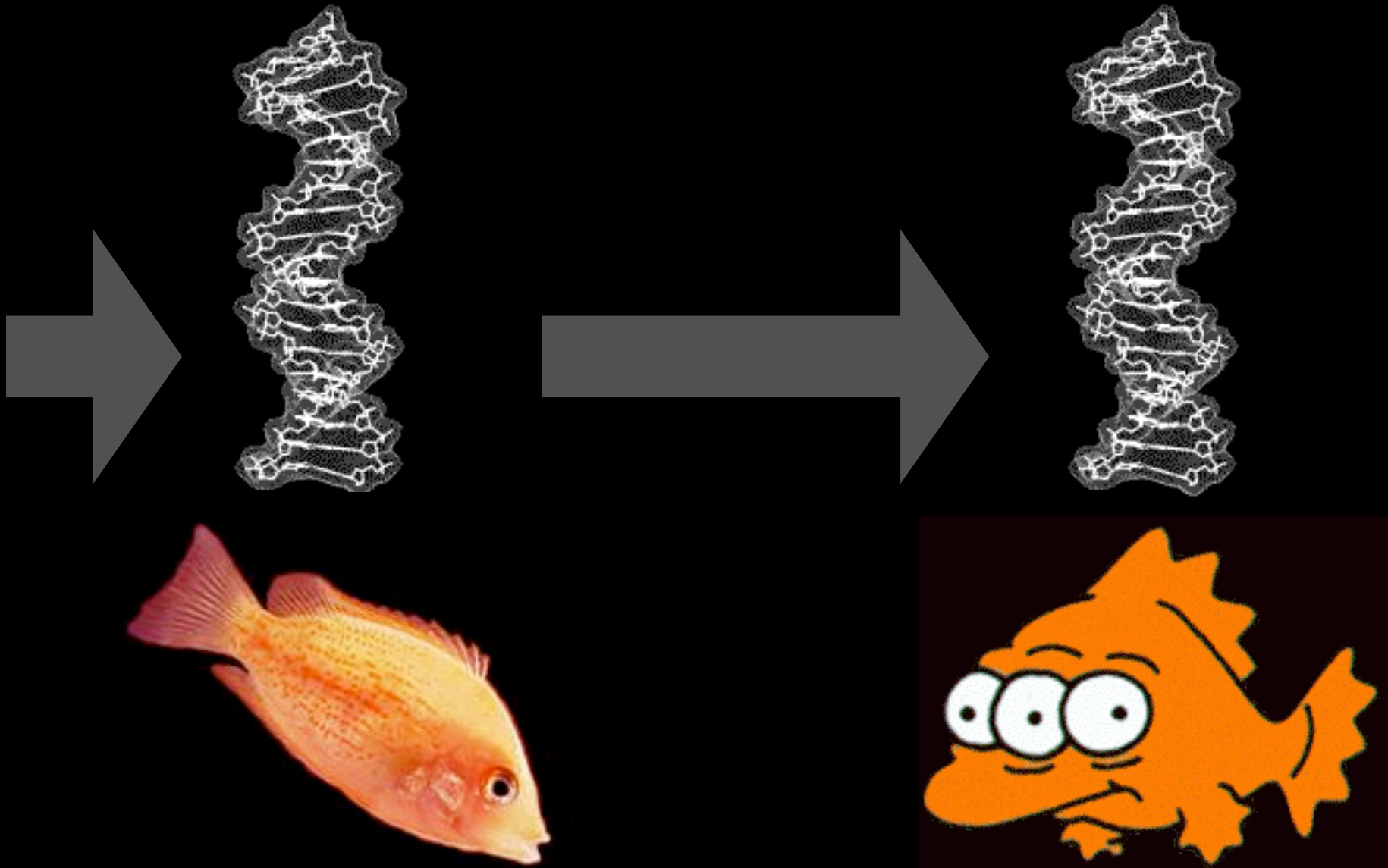
Our enemies are innovative and resourceful, and so are we. They never stop thinking about new ways to harm our country and our people, and neither do we.



Bayes' Theorem



Bayes' Theorem



Language Models

However

$$p(\textit{However} | \textit{START})$$

Language Models

However ,

$$p(, | \textit{However})$$

Language Models

However, the

$$p(\textit{the} | ,)$$

Language Models

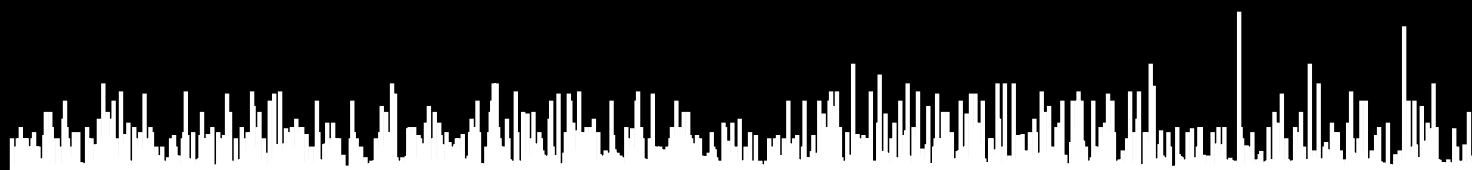
However , the sky

$$p(\textit{sky}|\textit{the})$$

Language Models

$$p(\textit{English}) = \prod_{i=1}^{\textit{length}(\textit{English})} p(\textit{word}_i | \textit{word}_{i-1})$$

$p(\textit{Chinese}|\textit{English})$

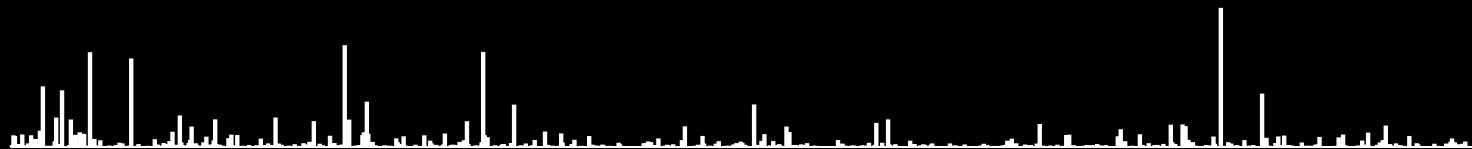


English

$p(\textit{Chinese}|\textit{English})$

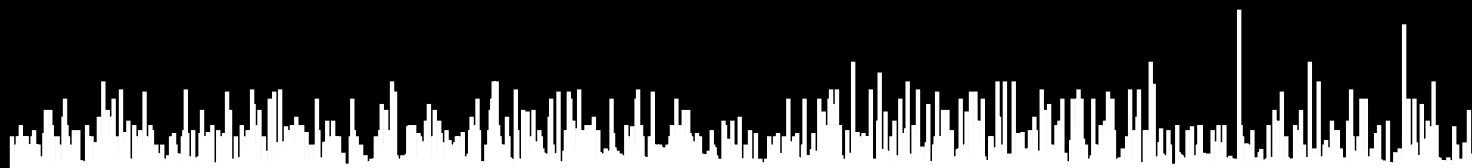


$\times p(\textit{English})$

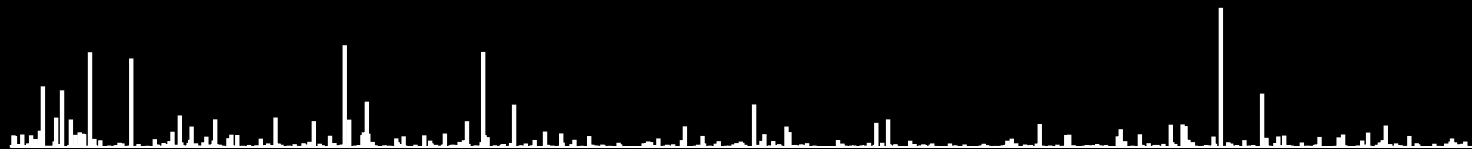


English

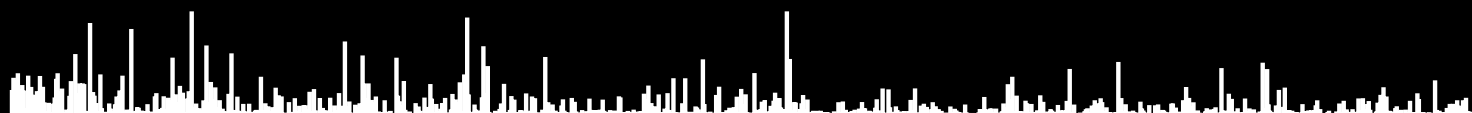
$p(\textit{Chinese}|\textit{English})$



$\times p(\textit{English})$

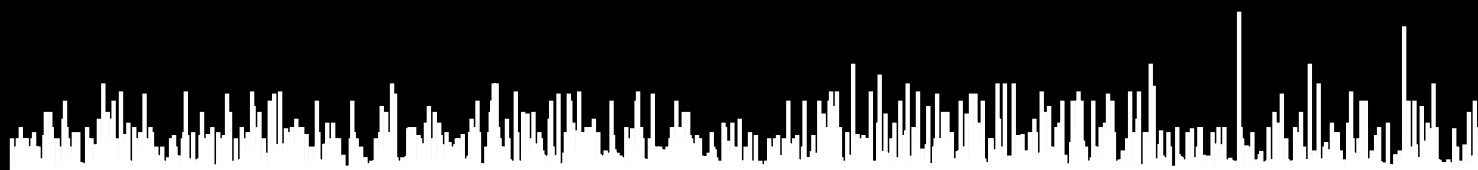


$\sim p(\textit{English}|\textit{Chinese})$

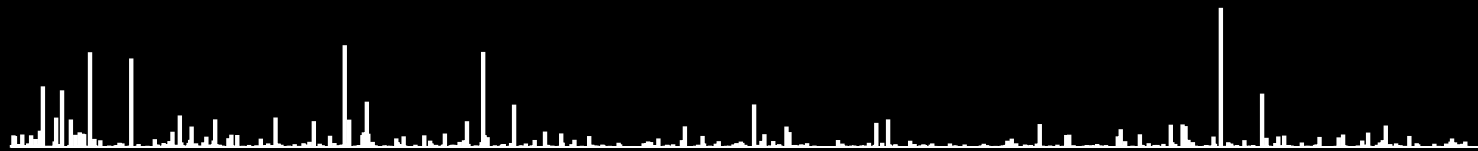


English

$$p(\textit{Chinese}|\textit{English})^1$$



$$\times p(\textit{English})^1$$

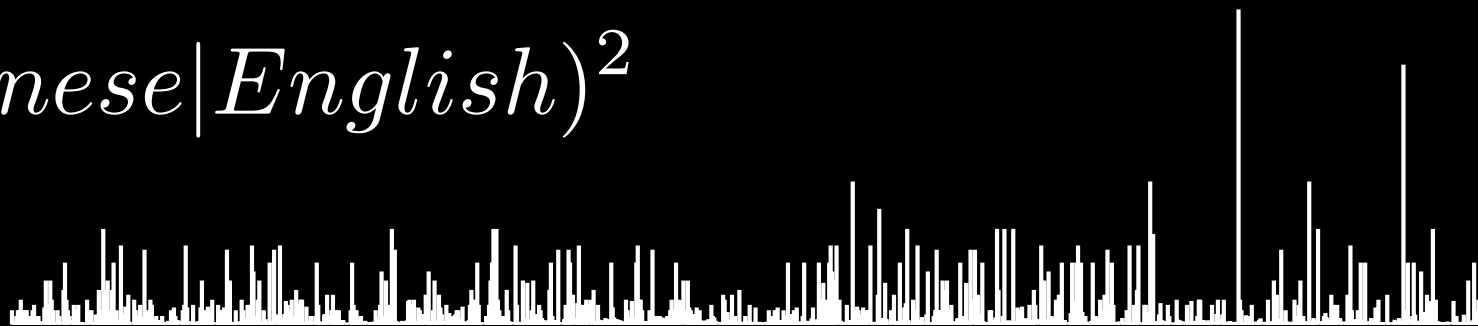


$$\sim p(\textit{English}|\textit{Chinese})$$

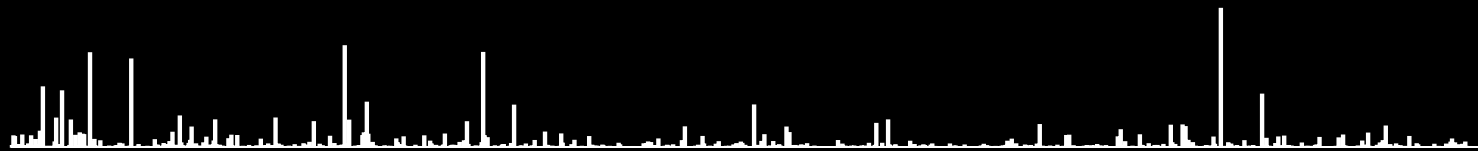


English

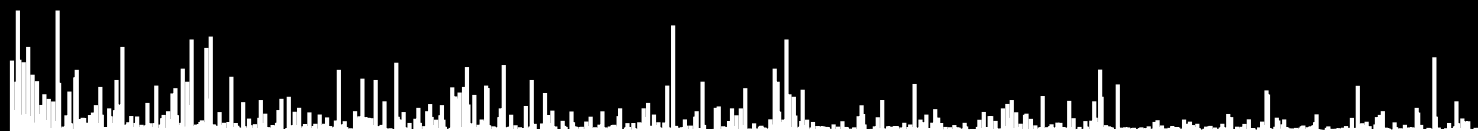
$$p(\textit{Chinese}|\textit{English})^2$$



$$\times p(\textit{English})^1$$



$$\sim p(\textit{English}|\textit{Chinese})$$

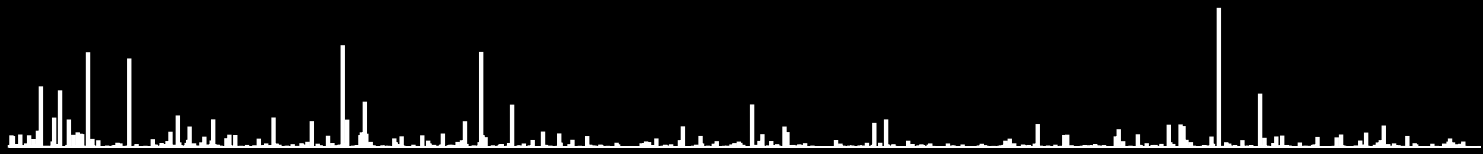


English

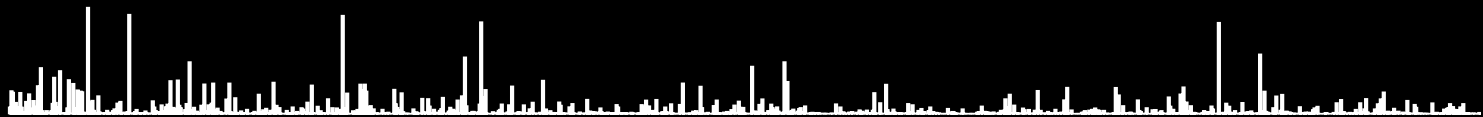
$$p(\textit{Chinese}|\textit{English})^{1/2}$$



$$\times p(\textit{English})^1$$



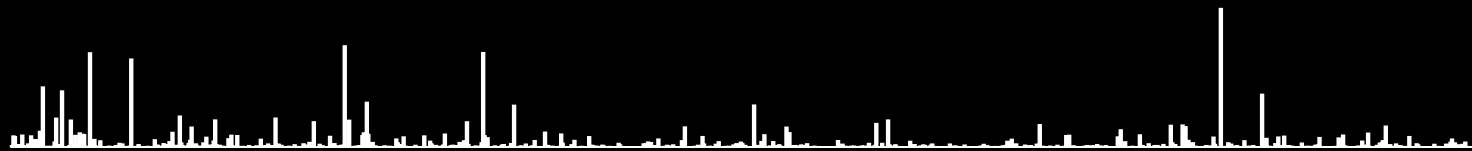
$$\sim p(\textit{English}|\textit{Chinese})$$



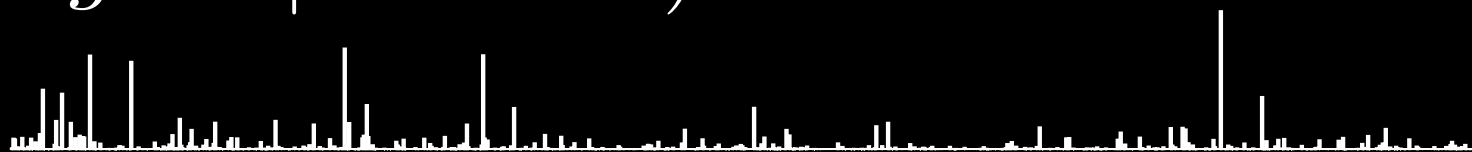
English

$$p(\textit{Chinese}|\textit{English})^0$$

$$\times p(\textit{English})^1$$



$$\sim p(\textit{English}|\textit{Chinese})$$

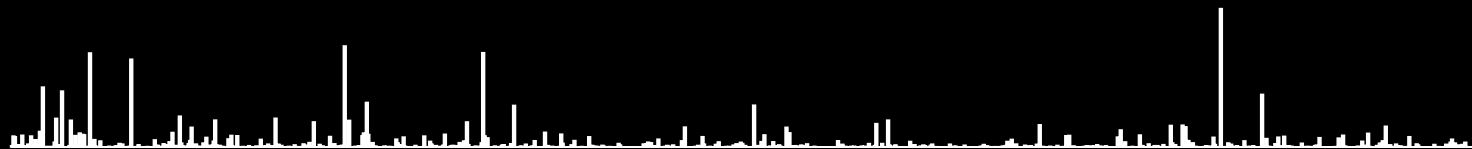


English

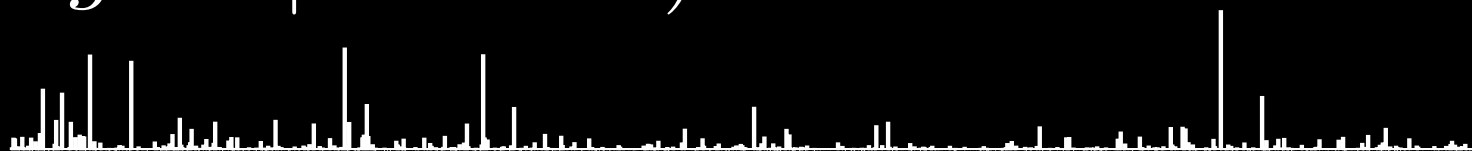
$$0 \cdot \log p(\textit{Chinese}|\textit{English})$$



$$+1 \cdot \log p(\textit{English})$$



$$\sim p(\textit{English}|\textit{Chinese})$$



English

$$p(\textit{English}|\textit{Chinese}) = \frac{1}{Z} [\lambda_1 \log p(\textit{Chinese}|\textit{English}) + \lambda_2 \log p(\textit{English})]$$

$$p(\textit{English}|\textit{Chinese}) =$$

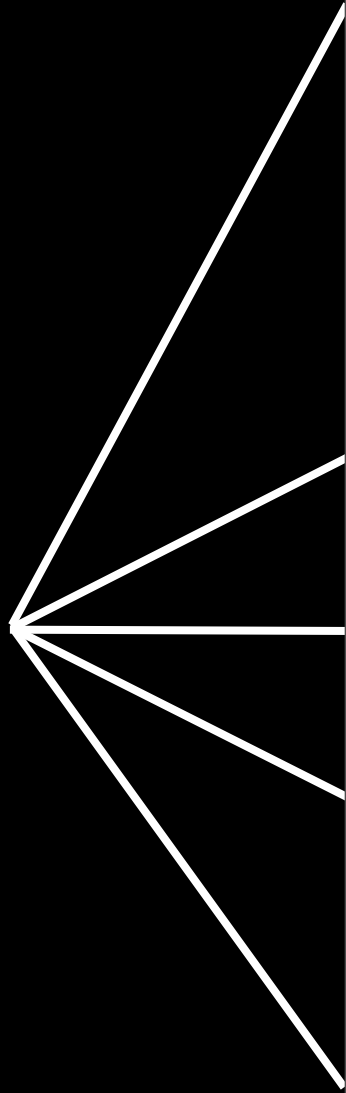
$$\frac{1}{Z} \left[\sum_i \lambda_i h_i(\textit{Chinese}, \textit{English}) \right]$$

$$\operatorname{argmax}_{\text{English}} p(\text{English}|\text{Chinese}) =$$

$$\frac{1}{Z} \left[\sum_i \lambda_i h_i(\text{Chinese}, \text{English}) \right]$$

虽然北风呼啸，但天空依然十分清澈。

虽然北风呼啸，但天空依然十分清澈。



START However

虽然北风呼啸，但天空依然十分清澈。

START Although

虽然北风呼啸，但天空依然十分清澈。

crystal clear

虽然北风呼啸，但天空依然十分清澈。

START However

虽然北风呼啸，但天空依然十分清澈。

START Although

虽然北风呼啸，但天空依然十分清澈。

crystal clear

虽然北风呼啸，但天空依然十分清澈。

wind screamed

虽然北风呼啸，但天空依然十分清澈。

wind shrieked

虽然北风呼啸，但天空依然十分清澈。

north wind

虽然北风呼啸，但天空依然十分清澈。

wind screamed

虽然北风呼啸，但天空依然十分清澈。

wind shrieked

虽然北风呼啸，但天空依然十分清澈。

north wind

虽然北风呼啸，但天空依然十分清澈。

shrieked ,

虽然北风呼啸, 但天空依然十分清澈。

the sky

虽然北风呼啸, 但天空依然十分清澈。

, yet

虽然北风呼啸, 但天空依然十分清澈。

shrieked ,

虽然北风呼啸，但天空依然十分清澈。

the sky

虽然北风呼啸，但天空依然十分清澈。

, yet

虽然北风呼啸，但天空依然十分清澈。

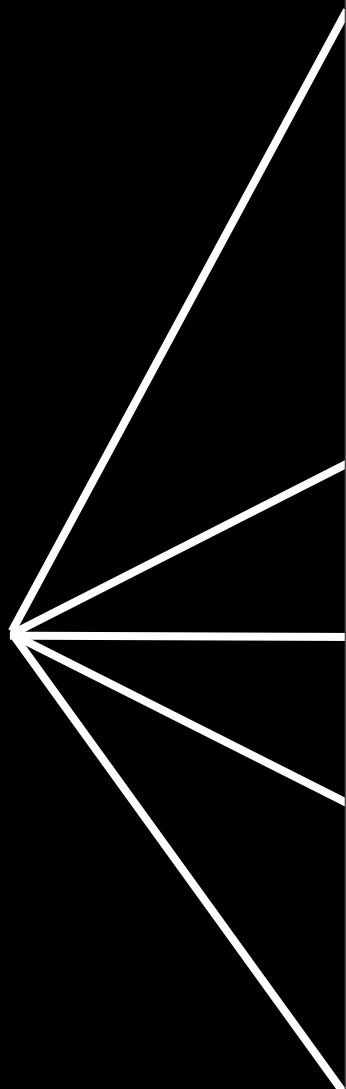
sky ,



虽然北 风呼啸，但天空 依然十分清澈。

sky,

虽然北风呼啸，但天空依然十分清澈。



still quite

虽然北风呼啸，但天空依然十分清澈。

clear .

虽然北风呼啸，但天空依然十分清澈。

blue .

虽然北风呼啸，但天空依然十分清澈。

still quite

虽然北风呼啸，但天空依然十分清澈。

clear .

虽然北风呼啸，但天空依然十分清澈。

blue .

虽然北风呼啸，但天空依然十分清澈。

Although the northern wind shrieked
across the sky, but was still very clear.

虽然北 风 呼 啸 ， 但 天 空 依 然 十 分 清 澈 。

the sky

虽然北风呼啸，但天空依然十分清澈。

number of vertices: $O(2^n)$

the sky

虽然北风呼啸，但天空依然十分清澈。

number of vertices: $O(2^n)$

the sky

虽然北风呼啸，但天空依然十分清澈。

$$d = 4$$

window

number of vertices: $O(2^n)$

the sky

虽然北风呼啸，但天空依然十分清澈。

outside window
to left: covered

$d = 4$
window

outside window
to right: uncovered

number of vertices: $O(n2^d)$

the sky

虽然北风呼啸，但天空依然十分清澈。

outside window
to left: covered

$d = 4$
window

outside window
to right: uncovered

Although north wind howls , but sky still very clear .

虽然北风呼啸，但天空依然十分清澈。

Although north wind howls , but sky still very clear .

虽然 北 风 呼 啸 ， 但 天 空 依 然 十 分 清 澈 。

Although north wind howls , but sky still very clear .

虽然 北风呼啸 ， 但 天空 依然 十分 清澈 。

However the strong north wind , the sky remained clear under .

Although north wind howls , but sky still very clear .

虽然 北风呼啸 , 但 天空 依然 十分 清澈 。

However the strong north wind , the sky remained clear under .

$X_1 X_2$

Although north wind howls , but sky still very clear .

虽然 北风呼啸 , 但 天空依然十分清澈 。

However the strong north wind , the sky remained clear under .

$X_1 X_2$

$X_2 X_1$

Although north wind howls , but sky still very clear .

虽然 北风呼啸 , 但 天空依然 十分 清澈 。

However the strong north wind , the sky remained clear under .

$X_1 X_2$

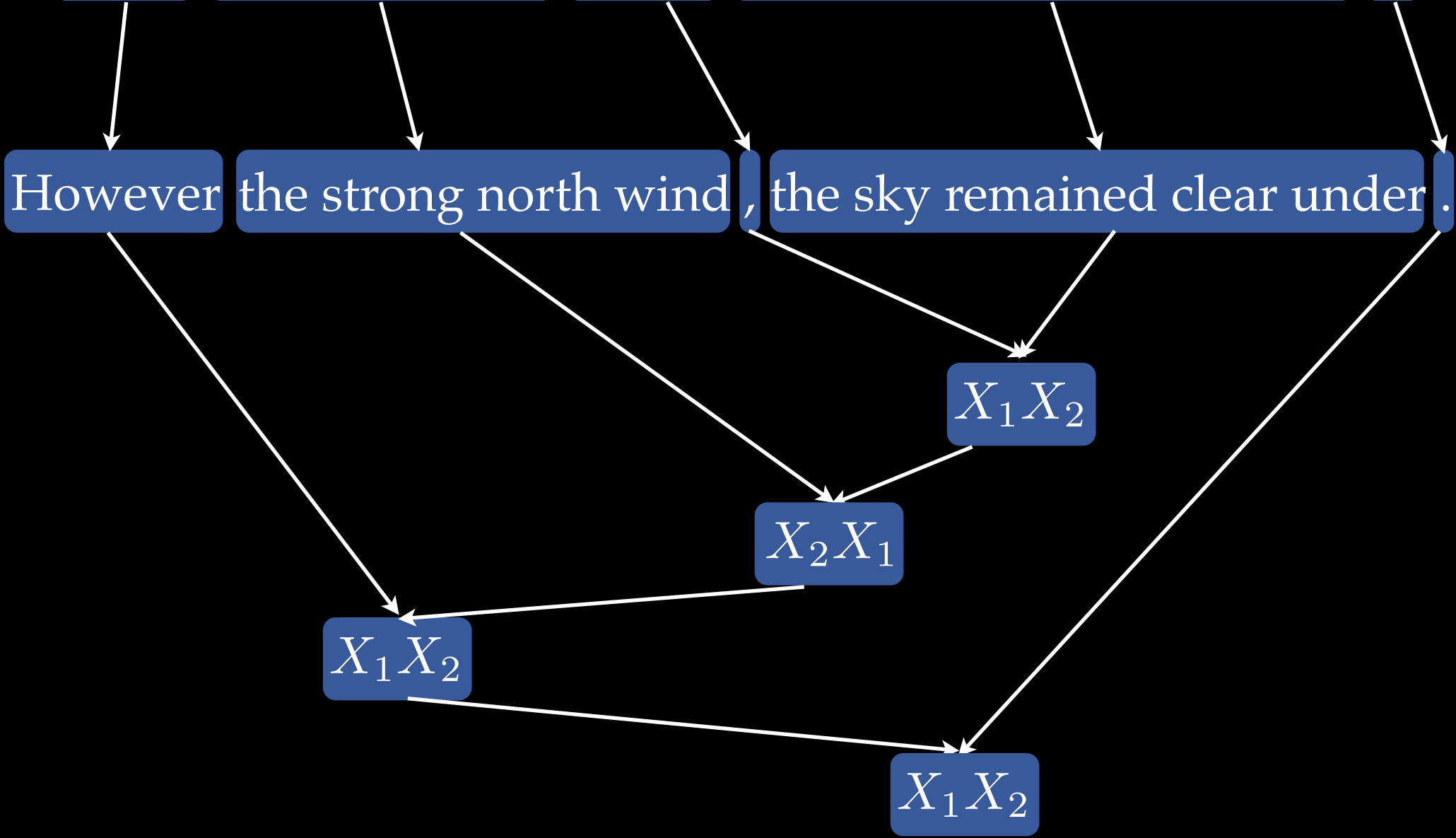
$X_2 X_1$

$X_1 X_2$

Although north wind howls , but sky still very clear .

虽然 北 风 呼 啸 ， 但 天 空 依 然 十 分 清 澈 。

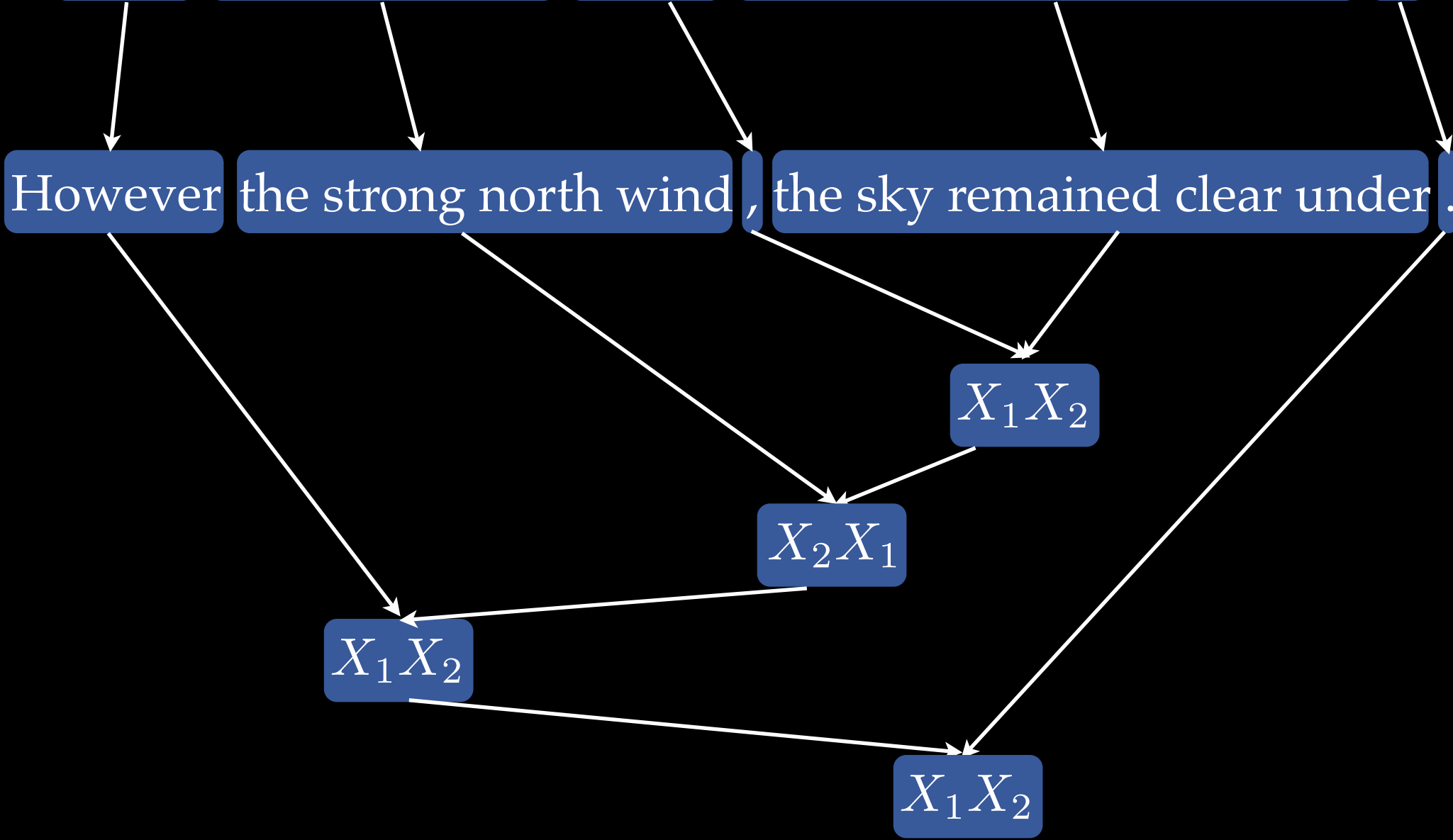
However the strong north wind , the sky remained clear under .



Although north wind howls , but sky still very clear .

虽然 北风呼啸 , 但 天空依然 十分 清澈 。

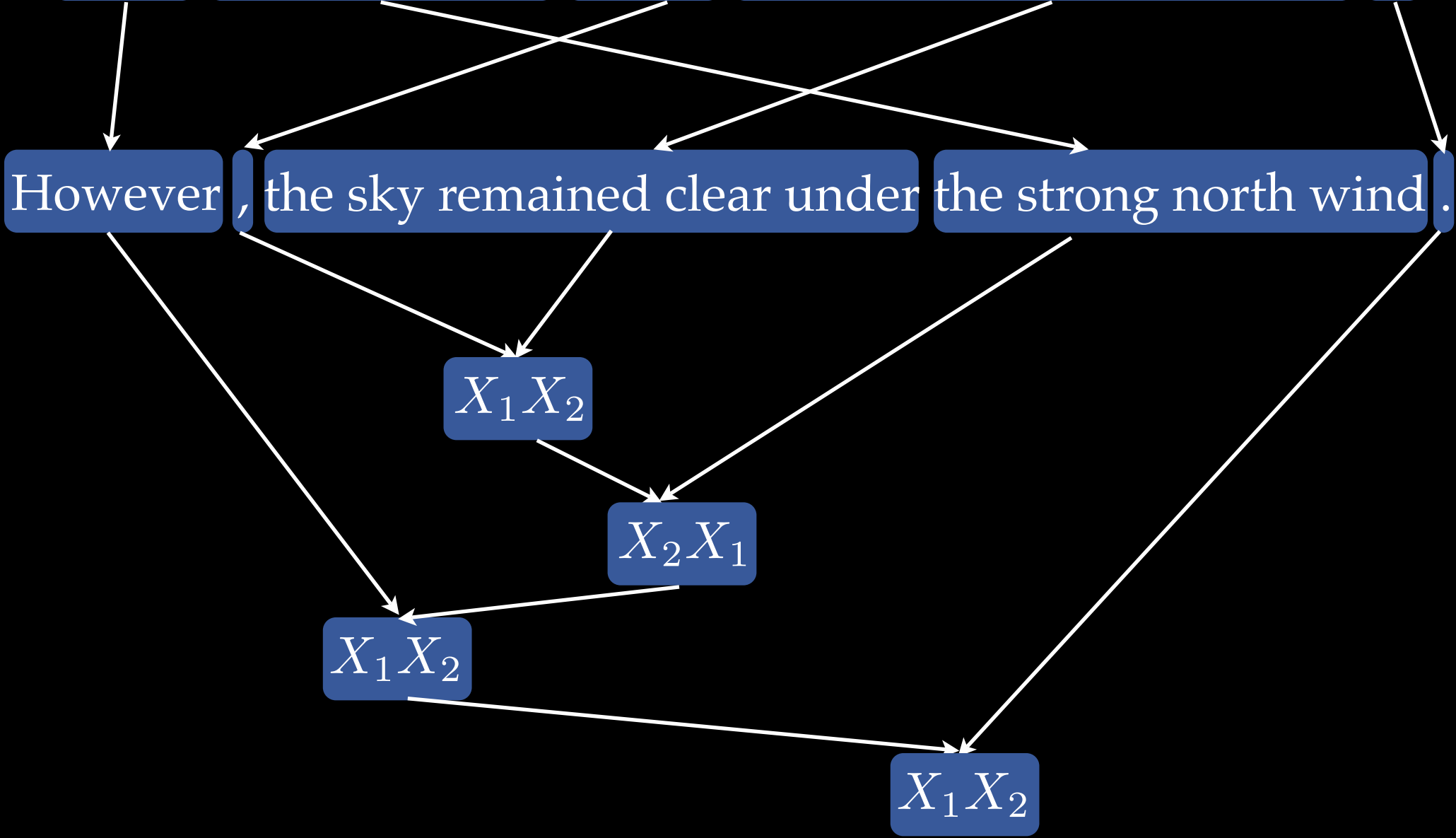
However the strong north wind , the sky remained clear under .



Although north wind howls , but sky still very clear .

虽然 北风呼啸 ， 但 天空 依然 十分 清澈 。

However , the sky remained clear under the strong north wind .



Synchronous CFG

$$X \rightarrow X_1 X_2 / X_1 X_2$$

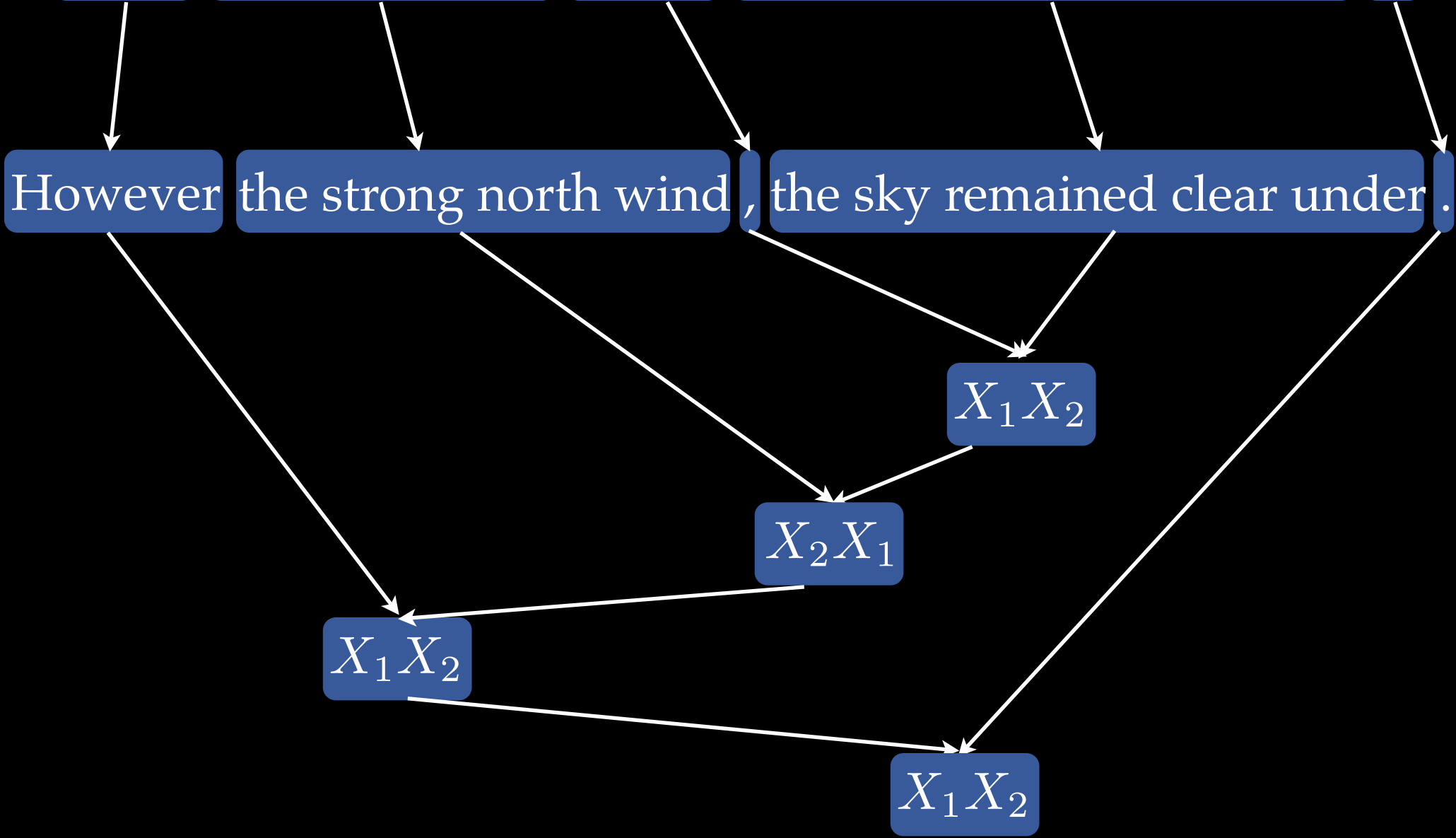
$$X \rightarrow X_1 X_2 / X_2 X_1$$

$$X \rightarrow \textit{Chinese phrase} / \textit{English phrase}$$

Although north wind howls , but sky still very clear .

虽然 北 风 呼 啸 ， 但 天 空 依 然 十 分 清 澈 。

However the strong north wind , the sky remained clear under .



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de			we
notre			all
parti			find
,			unacceptable
nous			,
trouvons			regardless
tous			of
cela			political
inacceptable			party

$X \rightarrow X_1 X_2 X_3 X_4 / X_2 X_4 X_1 X_3$

Although north wind howls , but sky still very clear .

虽然北风呼啸，但天空依然十分清澈。

Although north wind howls , but sky still very clear .

虽然 北风呼啸 ， 但 天空 依然 十分 清澈 。

Although north wind howls , but sky still very clear .

虽然 北风呼啸 ， 但 天空 依然 十分 清澈 。

the strong north wind

the sky remained clear under

Although north wind howls , but sky still very clear .

虽然 北风呼啸 ， 但 天空 依然 十分 清澈 。

the strong north wind

the sky remained clear under

Although north wind howls , but sky still very clear .

虽然 北风呼啸 ， 但 天空 依然 十分 清澈 。

However, the sky remained clear under the strong north wind .

Although north wind howls , but sky still very clear .

虽然 北风呼啸 ， 但 天空 依然 十分 清澈 。

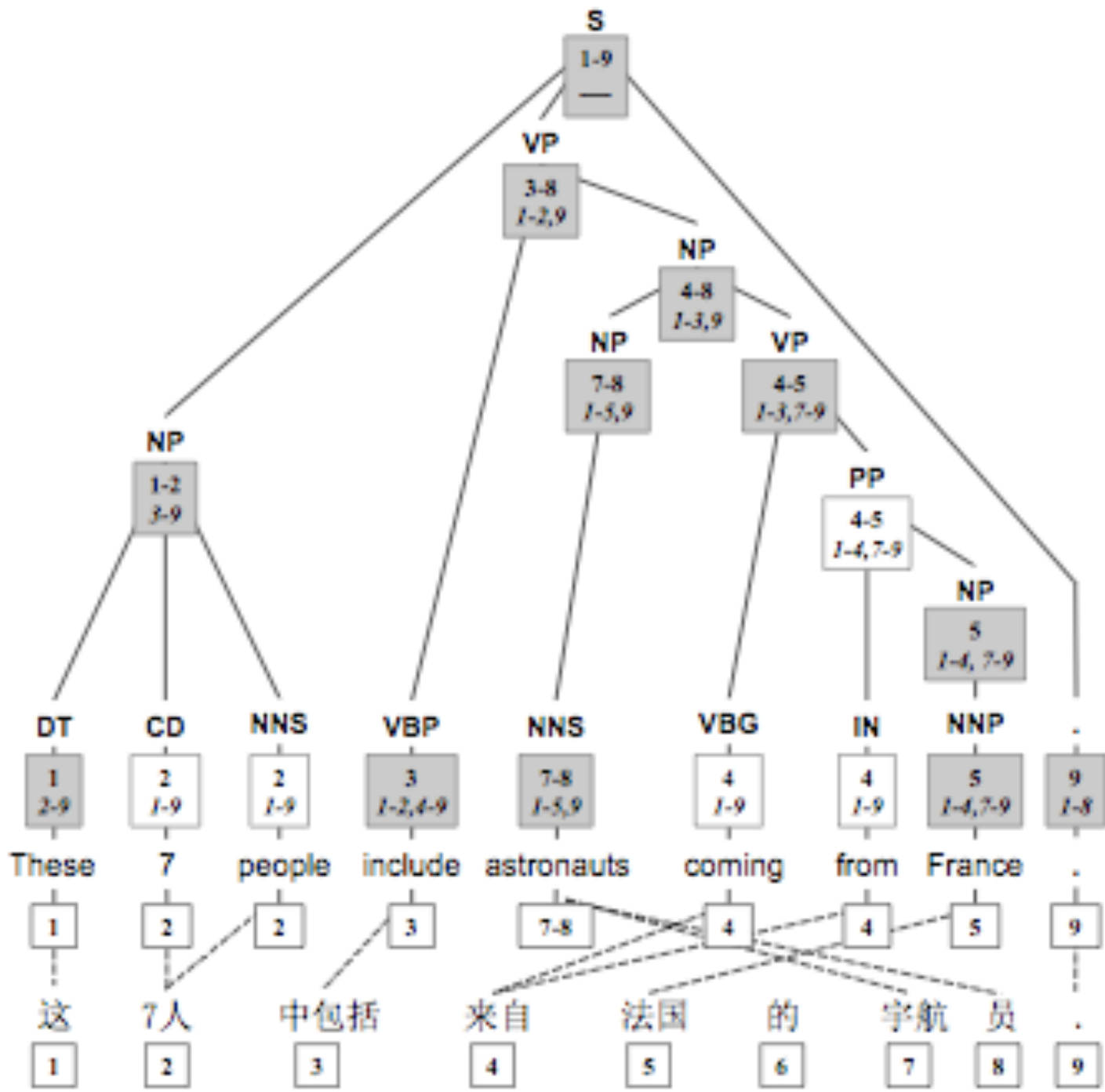
However, the sky remained clear under the strong north wind .

$X \rightarrow$ 虽然 X_1 , 但 X_2 / *However* , $X_2 X_1$

Synchronous CFG

Synchronous CFG

- Phrase translation probabilities.
- Hierarchical rewriting probabilities.
- Some solutions?
 - Complexity -- polynomial in sentence length.
 - Can it help with fluency?





*More has been written about
machine translation
evaluation than about
machine translation itself.*

Yorick Wilks

- Why evaluate?
 - Rank systems
 - Evaluate incremental changes
 - Assess new ideas objectively

美国愿和北韩谈判但拒绝再付出报酬

US willing to negotiate with North Korea
but not to pay more compensation.

美国愿和北韩谈判但拒绝再付出报酬

US willing to negotiate with North Korea
but not to pay more compensation.

The United States is willing to hold talks
with North Korea but refused to pay
remuneration.

“奋进”号因机械手故障推迟到升空

Launch of “Endeavour” delayed by
robotic arm problems.

“奋进”号因机械手故障推迟到升空

Launch of “Endeavour” delayed by
robotic arm problems.

“Progress” postponed because of mechanical
hand into the sky.

Chinese people in the traditional Spring Festival is approaching, the CPC Central Committee this afternoon in Zhongnanhai on the 22nd non-Party personages to convene a forum in Spring Festival, invited the central committees of democratic parties, the leadership of the National Federation of Industry and Commerce and personages without party affiliation on behalf of comrades gathered together State yes, talked in length about the friendship, to greet the Chinese New Year. CPC Central Committee General Secretary and State President and Central Military Commission Chairman Hu Jintao on behalf of the CPC Central Committee, the State Council, to the central committees of democratic parties, leaders of the National Federation of Industry and Commerce and personages without party affiliation, to members of the united front, to extend my New Year's blessing.

Although the northern wind shrieked across
the sky , it was still very clear .

Although the northern wind shrieked across
the sky , it was still very clear .

However , the sky remained clear under the strong
north wind .

Although the northern wind shrieked across
the sky, it was still very clear.

However, the sky remained clear under the strong
north wind.

Although the northern wind shrieked across the sky , it was still very clear .

However , the sky remained clear under the strong north wind .

Although a north wind was howling , the sky remained clear and blue .

The sky was still crystal clear , though the north wind was howling .

Despite the strong northerly winds , the sky remains very clear .

Although the northern wind shrieked across the sky, it was still very clear.

However, the sky remained clear under the strong north wind.

Although a north wind was howling, the sky remained clear and blue.

The sky was still crystal clear, though the north wind was howling.

Despite the strong northerly winds, the sky remains very clear.

Although the northern wind shrieked across
the sky, it was still very clear.

unigram: 11 / 15 bigram: 4 / 14 trigram: 1 / 13

However, the sky remained clear under the strong
north wind.

Although a north wind was howling, the sky
remained clear and blue.

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very clear .

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Although a north wind was howling , the sky remained clear and blue .

The sky was still crystal clear , though the north wind was howling .

Despite the strong northerly winds , the sky remains very clear .

very clear .

unigram: 3 / 3

bigram: 2 / 2

trigram: 1 / 1

However , the sky remained clear under the strong north wind .

Although a north wind was howling , the sky remained clear and blue .

The sky was still crystal clear , though the north wind was howling .

Despite the strong northerly winds , the sky remains very clear .

very clear .

brevity penalty: 3 / 12

However , the sky remained clear under the strong north wind .

Although a north wind was howling , the sky remained clear and blue .

The sky was still crystal clear , though the north wind was howling .

Despite the strong northerly winds , the sky remains very clear .



BiLingual Evaluation Understudy

BLEU-1	BEwT-E	RTE
BLEU-4	Badger	RTE-MT
BLEU-v11b	BadgerLite	SEPIA1
BLEU-v12	Bleu-sbp	SEPIA2
METEOR-v0.6	BleuSP	SNR
NIST-v11b	CDer	SR-Or
TER-v0.7.254-GRR	DP-Or	SVM-Rank
ATEC1	DP-Orp	TERp
ATEC2	DR-Or	ULCh
ATEC3	EDPM	ULCopt
ATEC4	LET	invWer
Meteor-v0.7	METEOR-ranking	mBLEU
	MaxSim	mTER

BLEU(MT output)

$BLEU(\operatorname{argmax}_{English} \operatorname{score}(English|Chinese))$

$$\sum_{\text{Chinese} \in \text{Test}} BLEU(\operatorname{argmax}_{\text{English}} \text{score}(\text{English} | \text{Chinese}))$$

- Statistical Machine Translation. In *ACM Computing Surveys* 40(3), Aug 2008.

<http://homepages.inf.ed.ac.uk/alopez>

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