Phrase-Based Translation

Machine Translation

$$p(English|Chinese) \sim$$

$$p(English) \times p(Chinese|English)$$

language model

translation model

Machine Translation

$$p(English|Chinese) \sim$$

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

language model

translation model

The IBM Models

The IBM Models

- Fertility probabilities.

The IBM Models

- Fertility probabilities.
- Word translation probabilities.

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- Fertility probabilities.
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- Distortion probabilities.

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  - Many decisions -- many things can go wrong.

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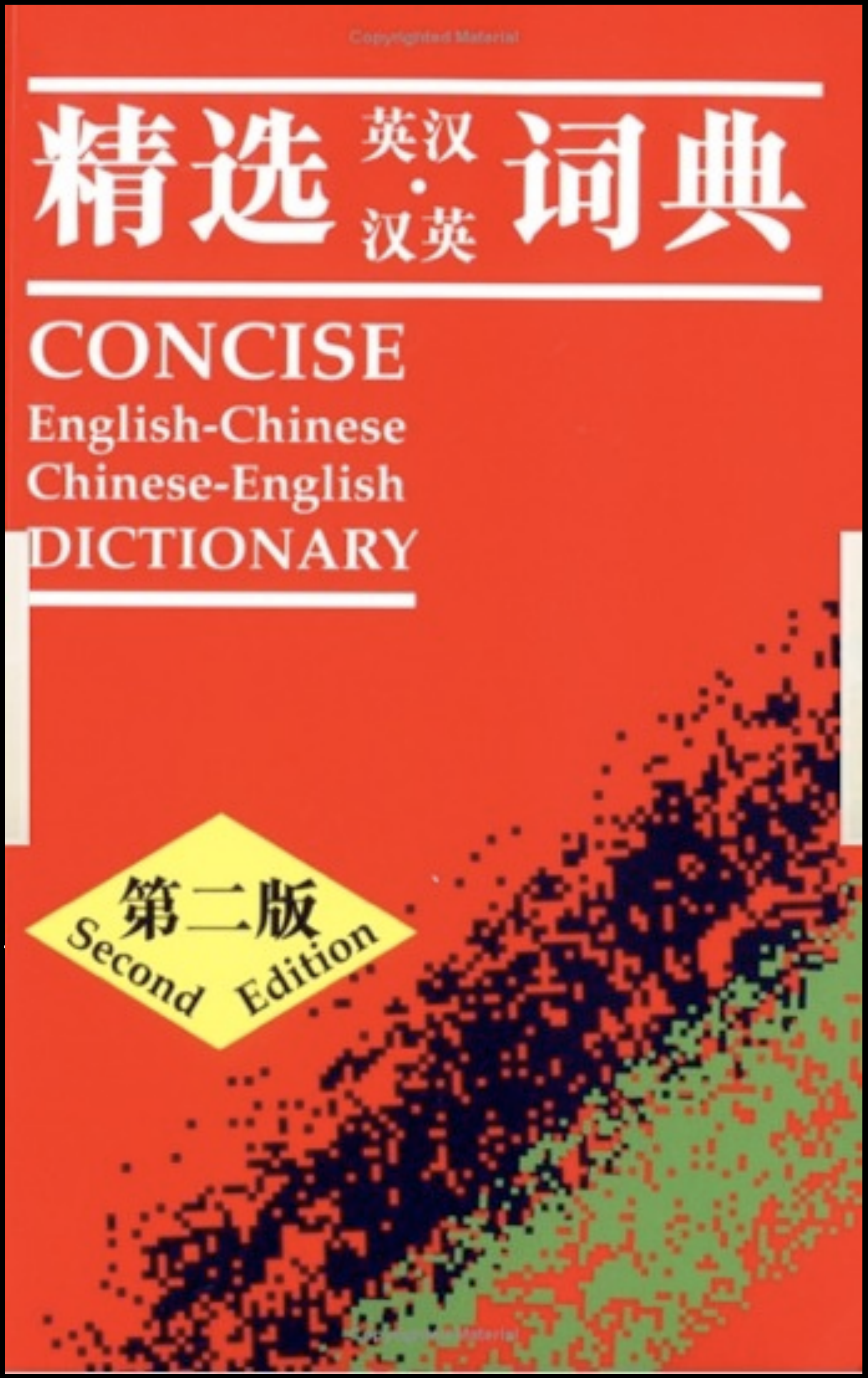

The IBM Models

- Fertility probabilities.
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IBM Model 4


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

Tradeoffs: Modeling v. Learning

	Lexical Translation	Local ordering dependency	Fertility	Convex	Tractable Exact Inference
IBM Model 1	✔	✘	✘	✔	✔
HMM	✔	✔	✘	✘	✔
IBM Model 4	✔	✔	✔	✘	✘

Tradeoffs: Modeling v. Learning

Lesson:
Trade exactness
for expressivity

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HMM	✔	✔	✘	✘	✔
IBM Model 4	✔	✔	✔	✘	✘

IBM Model 4

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

What are some things this model doesn't account for?

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Phrase-based Models

Although north wind howls , but sky still very clear .

虽然 北 风 呼啸 ， 但 天空 依然 十分 清澈 。

Phrase-based Models

Although north wind howls , but sky still very clear .

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Phrase-based Models

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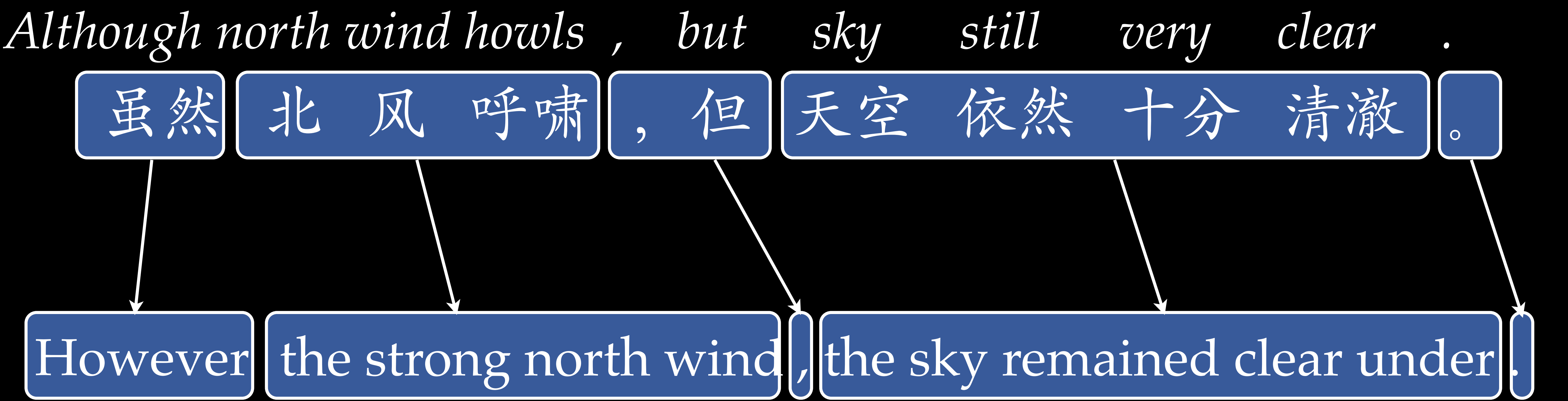
However

Phrase-based Models



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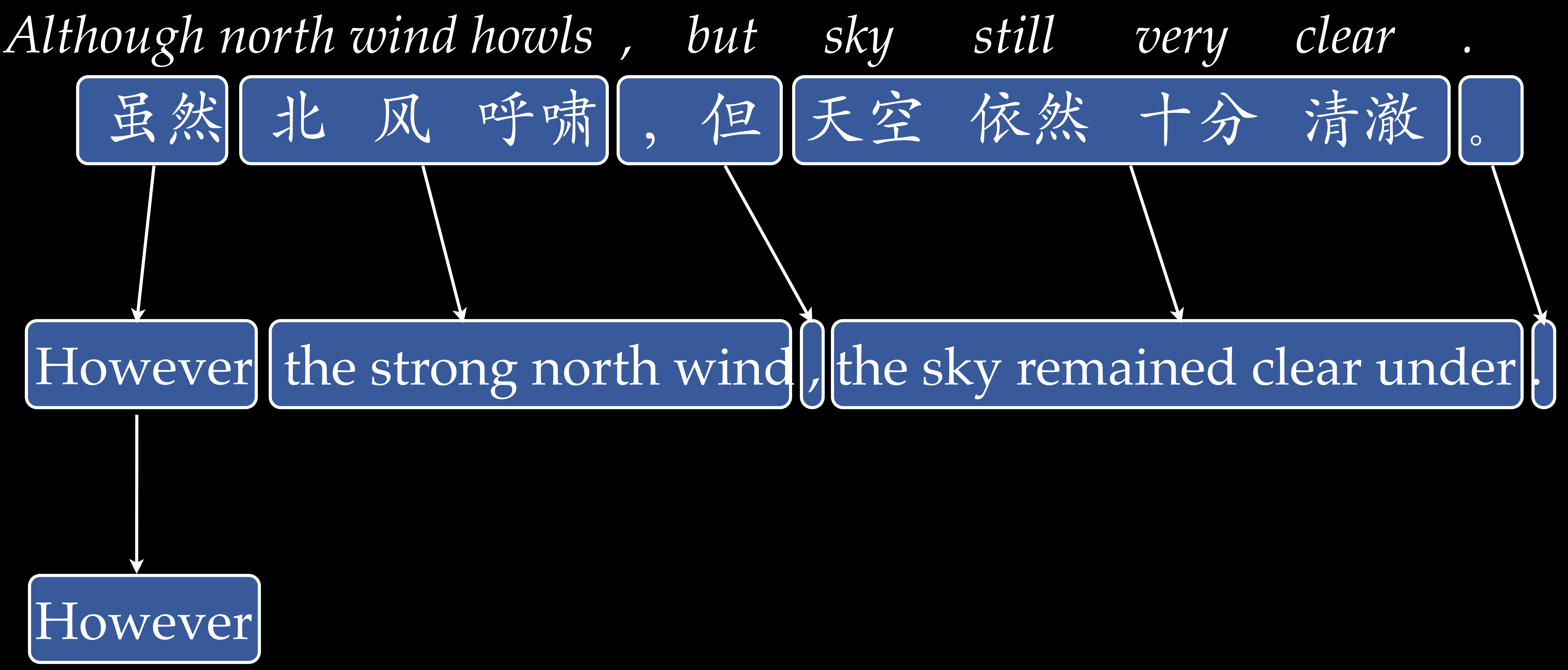

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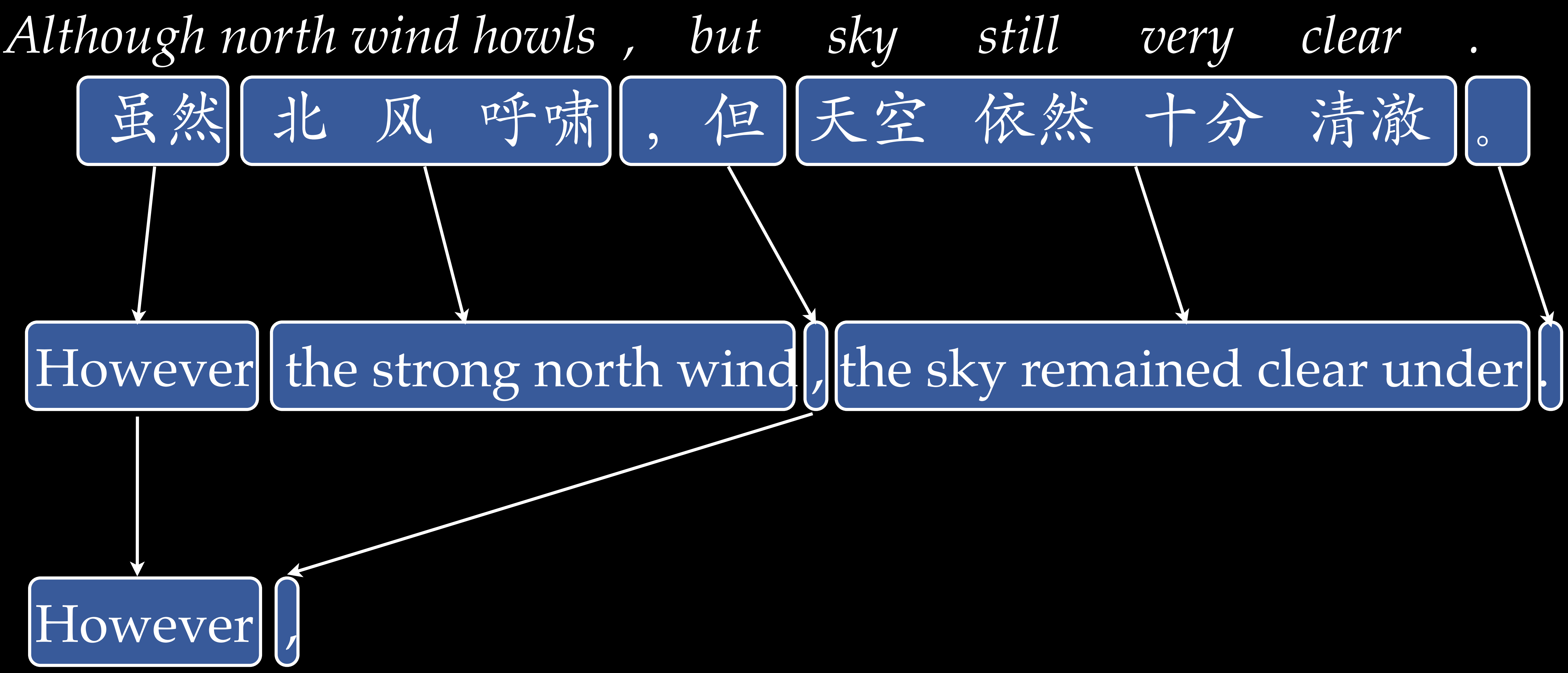

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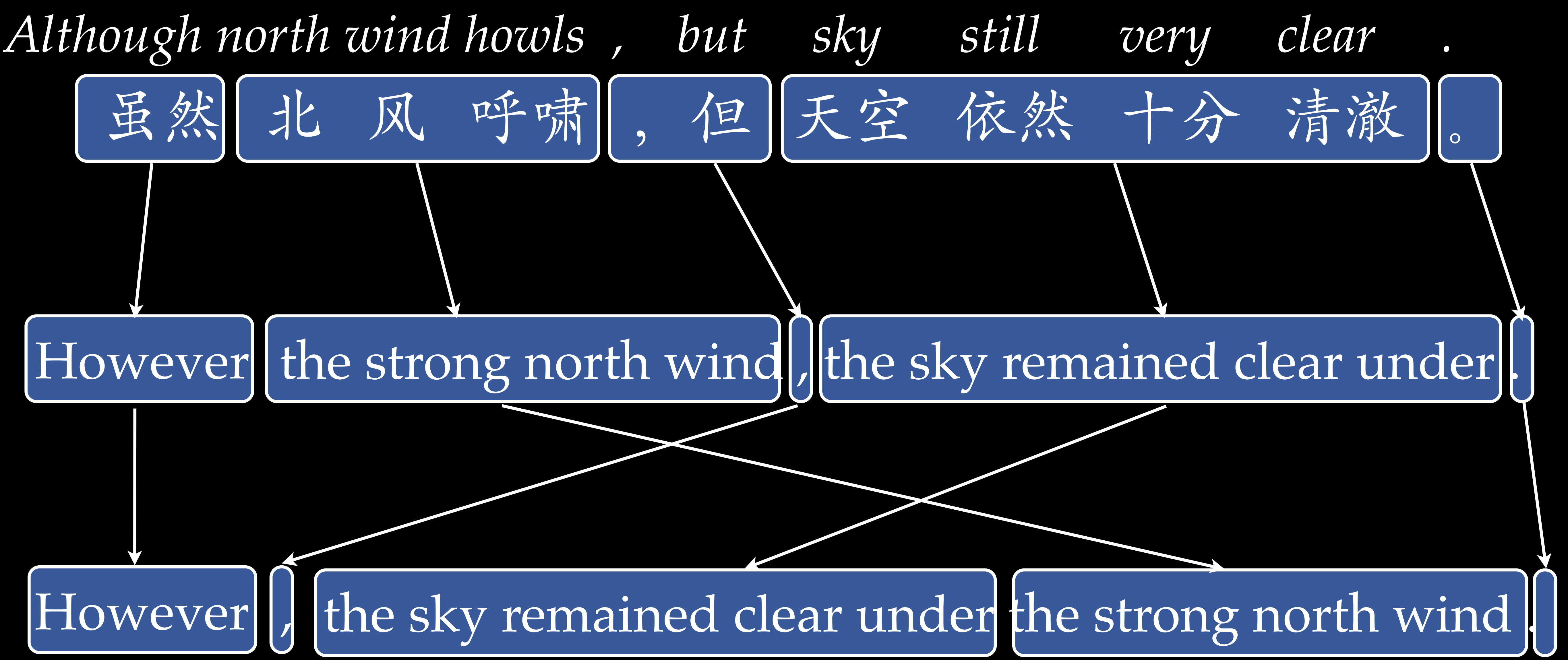

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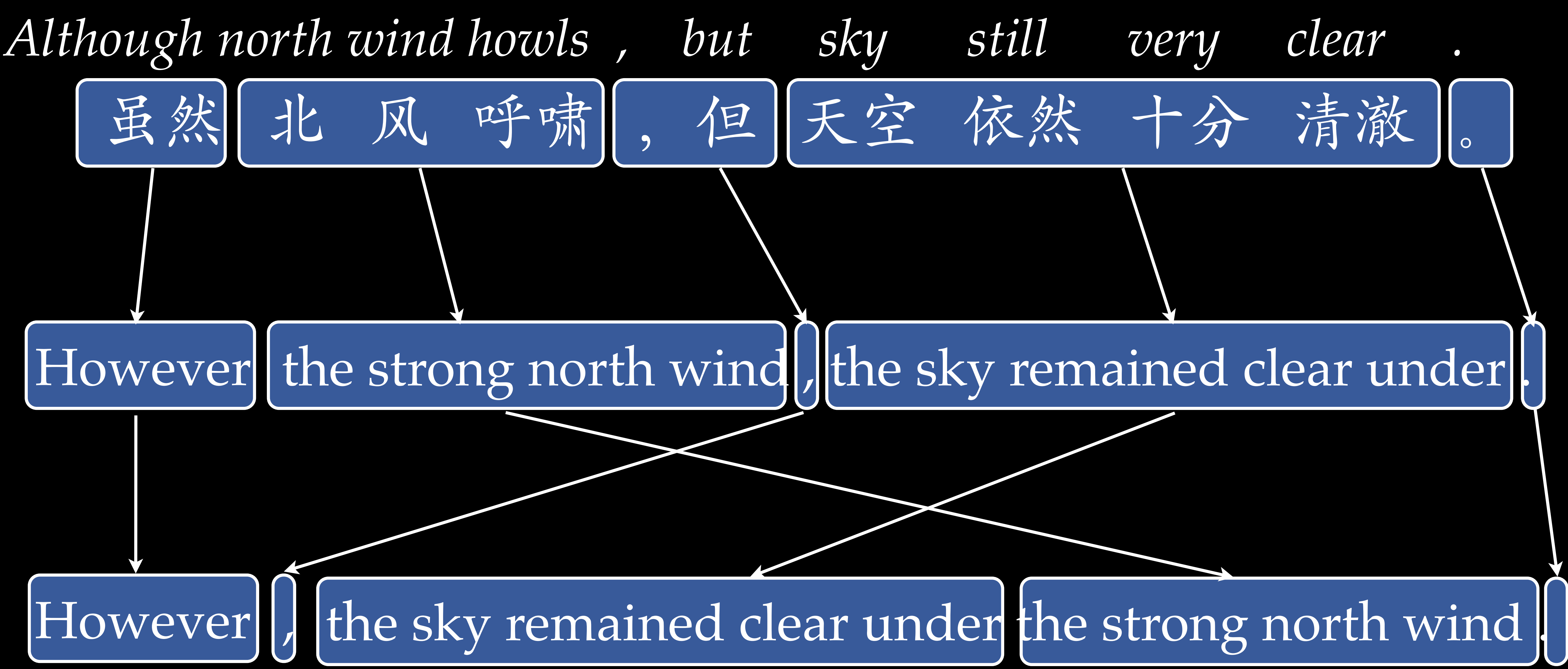
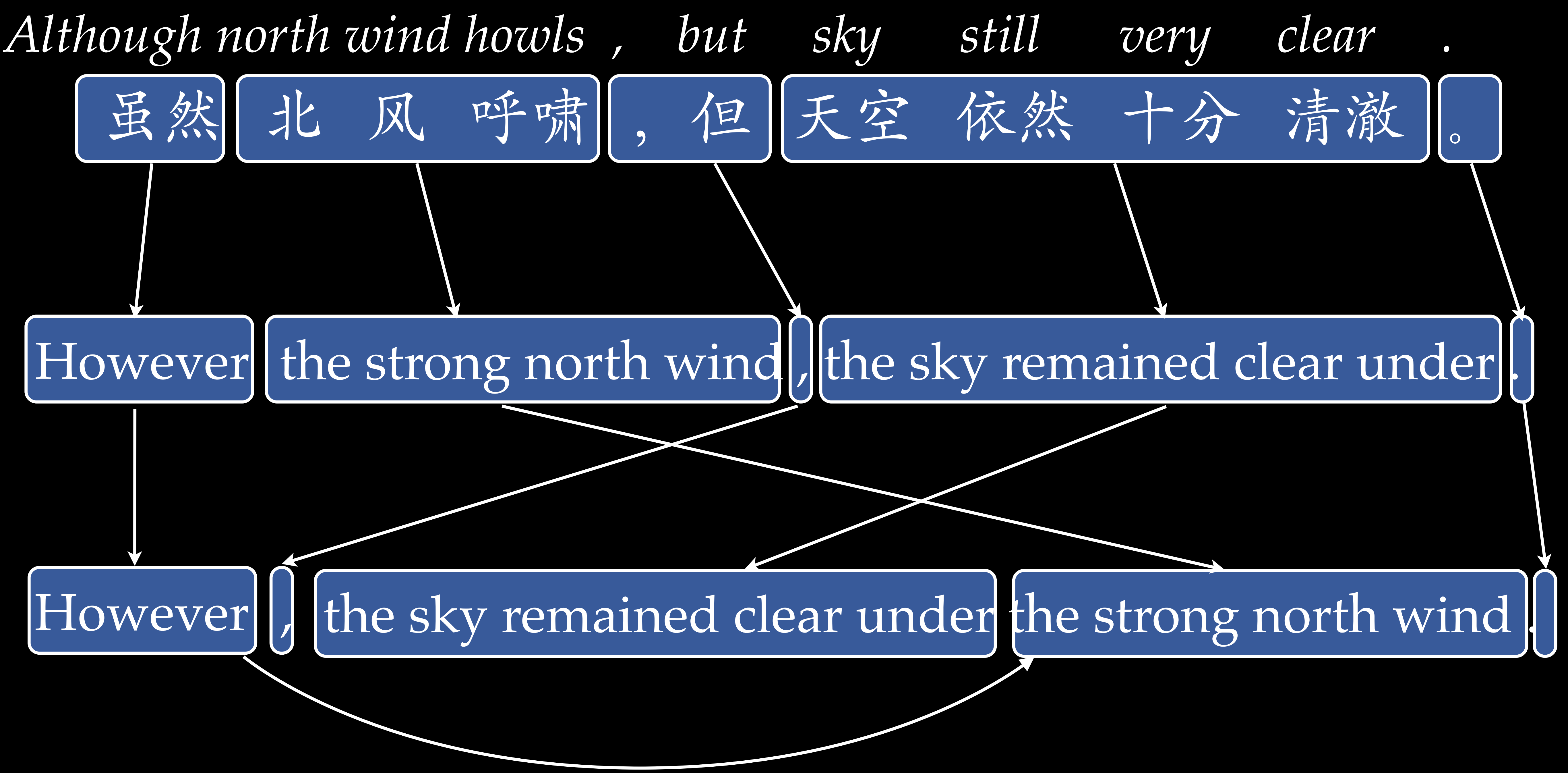


$$p(English, alignment|Chinese) =$$

$$p(segmentation) \cdot p(translations) \cdot p(reorderings)$$

Phrase-based Models



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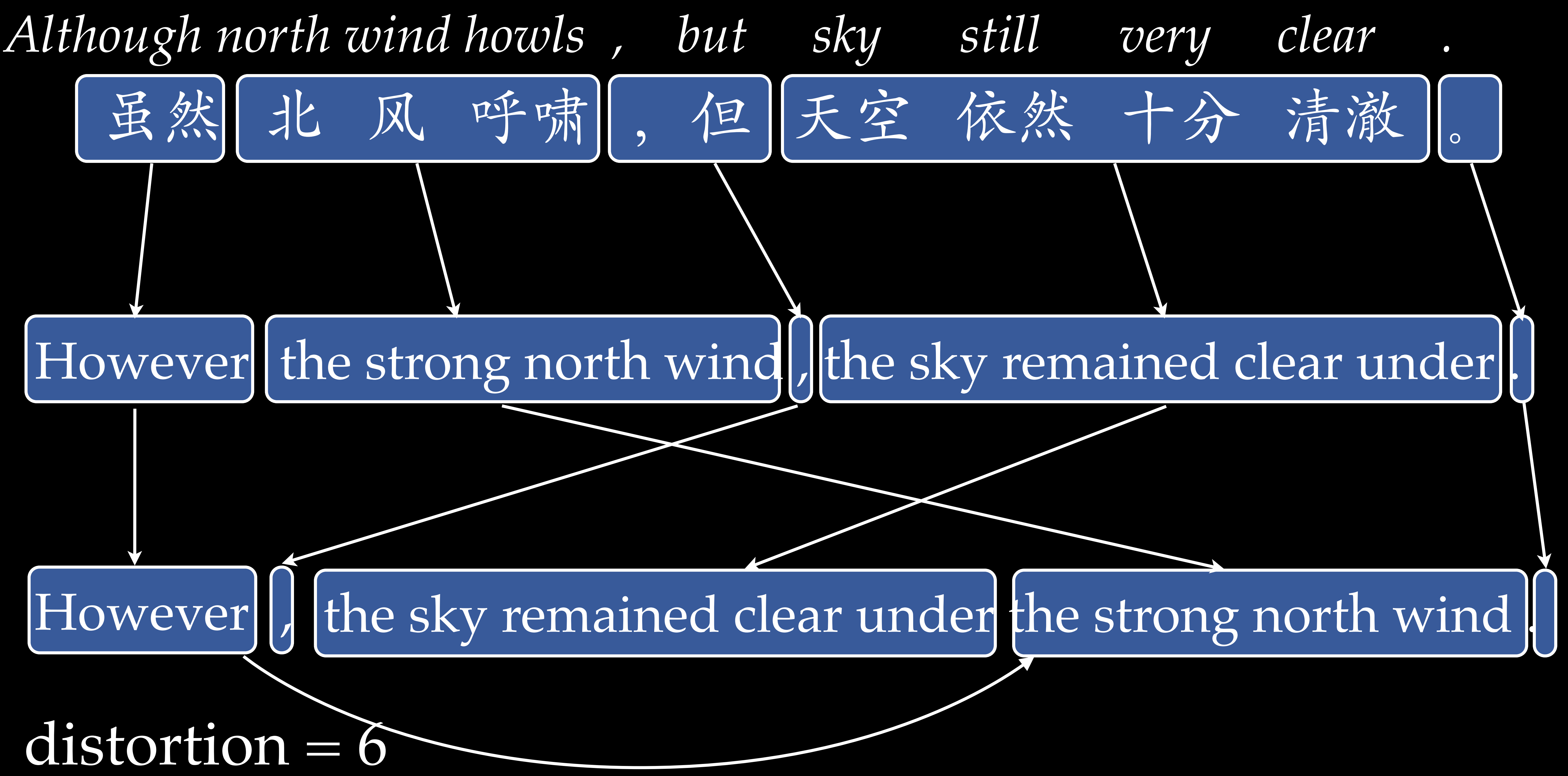

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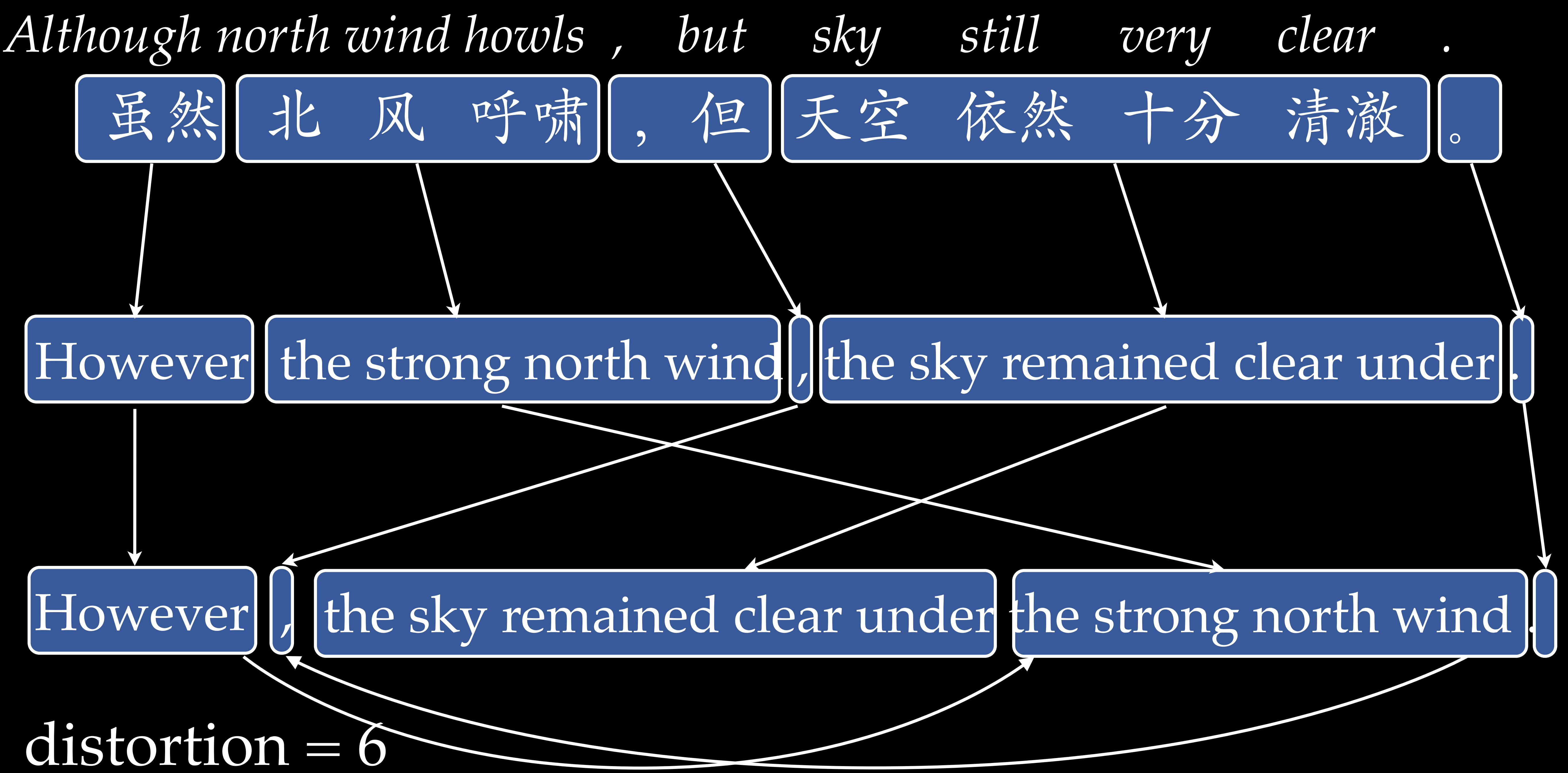

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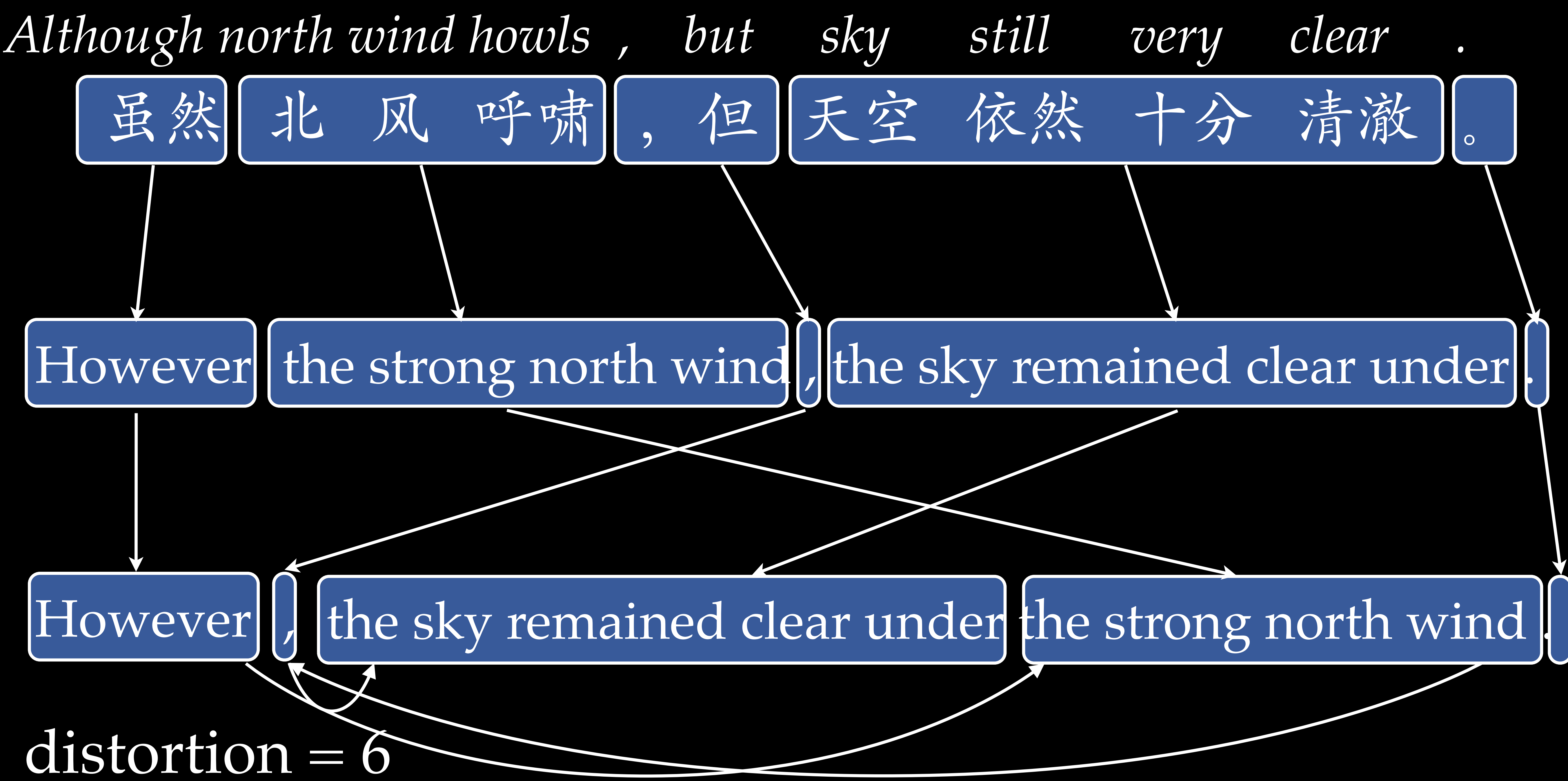

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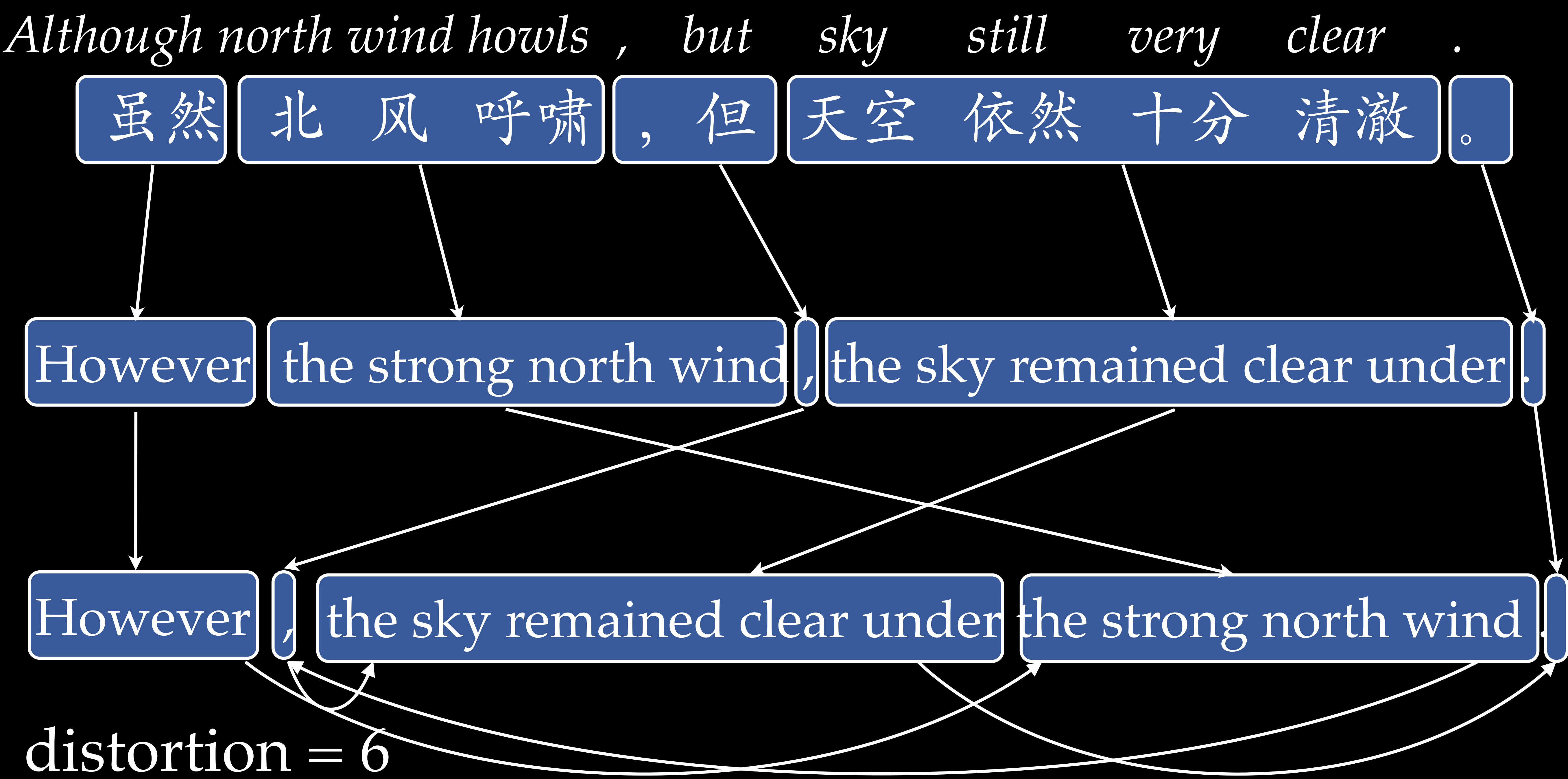

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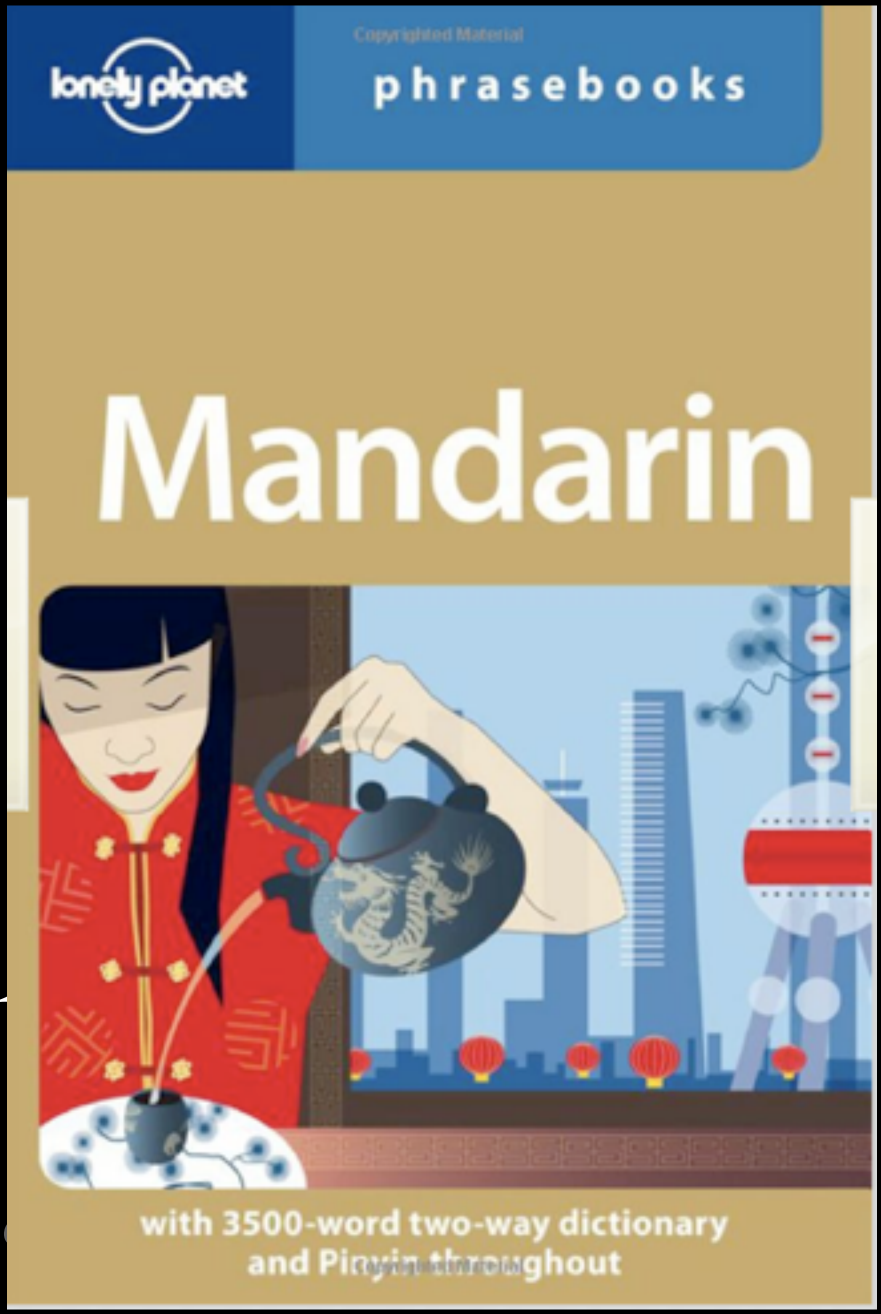

Phrase-based Models

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Phrase-based Models

- Segmentation probabilities: fixed (uniform)
- **Phrase translation probabilities.**
- Distortion probabilities: fixed (decaying)

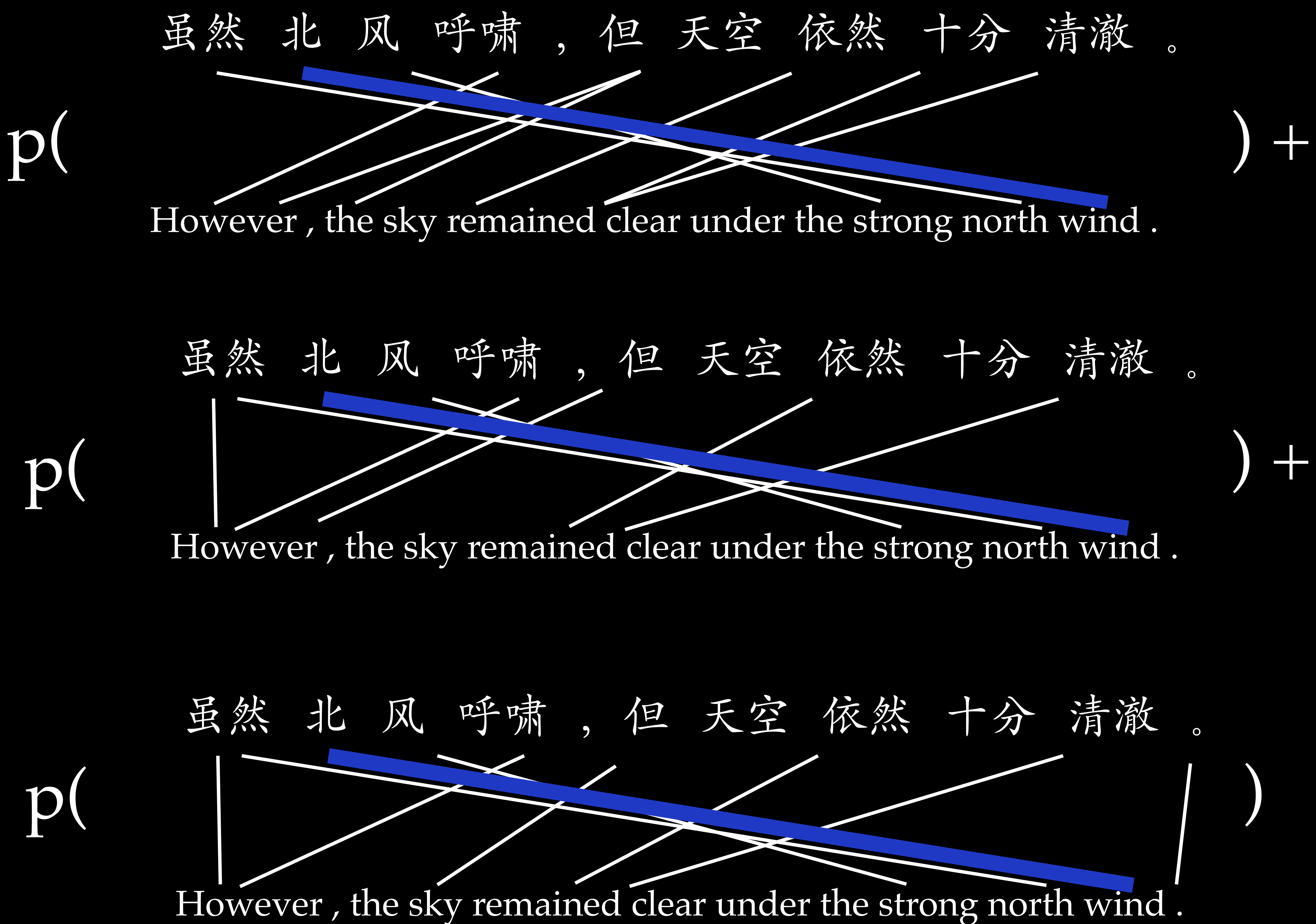
Learning *p(Chinese | English)*

- Reminder: (nearly) every problem comes down to computing either:
  - Sums: MLE or EM (learning)
  - Maximum: most probable (decoding)

Recap: Expectation Maximization

- Arbitrarily select a set of parameters (say, uniform).
- Calculate ***expected counts*** of the unseen events.
- Choose new parameters to maximize likelihood, using expected counts as proxy for observed counts.
- Iterate.
- Guaranteed that likelihood is monotonically nondecreasing.

Marginalize: sum all alignments containing the link



Divide by sum of all *possible* alignments

虽然 北 风 呼啸 ， 但 天空 依然 十分 清澈 。

p( ) +

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

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We have to sum over exponentially many alignments!

EM for Model 1

probability of an alignment.

$$p(F, A|E) = p(I|J) \prod_{a_i} p(a_i = j) p(f_i|e_j)$$

EM for Model 1

probability of an alignment.

$$p(F, A|E) = \underbrace{p(I|J)}_{\text{observed}} \prod_{a_i} \underbrace{p(a_i = j)}_{\text{uniform}} p(f_i|e_j)$$

EM for Model 1

probability of an alignment.

factors across words.

$$p(F, A|E) = p(I|J) \prod_{a_i} p(a_i = j) \boxed{p(f_i|e_j)}$$

observed

uniform

EM for Model 1

$$p(a_i = j|F, E) = \frac{p(a_i = j, F|E)}{p(F, E)} =$$

EM for Model 1

$$p(a_i = j|F, E) = \frac{p(a_i = j, F|E)}{p(F, E)} =$$

$$\sum_{a \in A: 北 \leftrightarrow north} p(north|北\ ) \cdot p(rest\ of\ a)$$

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marginal probability of
alignments containing link

EM for Model 1

marginal probability of
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$$p(north|\text{北}) \sum_{a \in A: \text{北} \leftrightarrow north} p(rest\ of\ a)$$

EM for Model 1

marginal probability of
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$$\frac{p(north|北) \sum_{a \in A: 北 \leftrightarrow north} p(rest\ of\ a)}{\sum_{c \in Chinese\ words} p(north|c) \sum_{a \in A: \ \leftrightarrow north} p(rest\ of\ a)}$$

marginal probability of all
alignments

EM for Model 1

marginal probability of
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marginal probability of
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identical!

marginal probability of all
alignments

EM for Model 1

$$\frac{p(north|\text{北})}{\sum_{c \in Chinese\ words} p(north|c)}$$

EM for Phrase-Based

- Model parameters: *p(E phrase | F phrase)*
- All we need to do is compute expectations:

$$p(a_i = j|F,E) = \frac{p(a_{i,i'} = \langle j, j' \rangle, F|E)}{p(F,E)}$$

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...which are one-to-one by definition.

EM for Phrase-Based

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 .

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Can we compute this quantity?

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Can we compute this quantity?

How many 1-to-1 alignments are there of the remaing 8 Chinese and 8 English words?

Recap: Expectation Maximization

- Arbitrarily select a set of parameters (say, uniform).
- Calculate ***expected counts*** of the unseen events.
- Choose new parameters to maximize likelihood, using expected counts as proxy for observed counts.
- Iterate.
- Guaranteed that likelihood is monotonically nondecreasing.

Recap: Expectation Maximization

- Arbitrarily select a set of parameters (say, uniform).
- Calculate ***expected counts*** of the unseen events.
- Choose new parameters to maximize likelihood, us… …nts.
- It…
- G… n…

Computing expectations from a phrase-based model, given a sentence pair, is #P-Complete (by reduction to counting perfect matchings; DeNero & Klein, 2008)

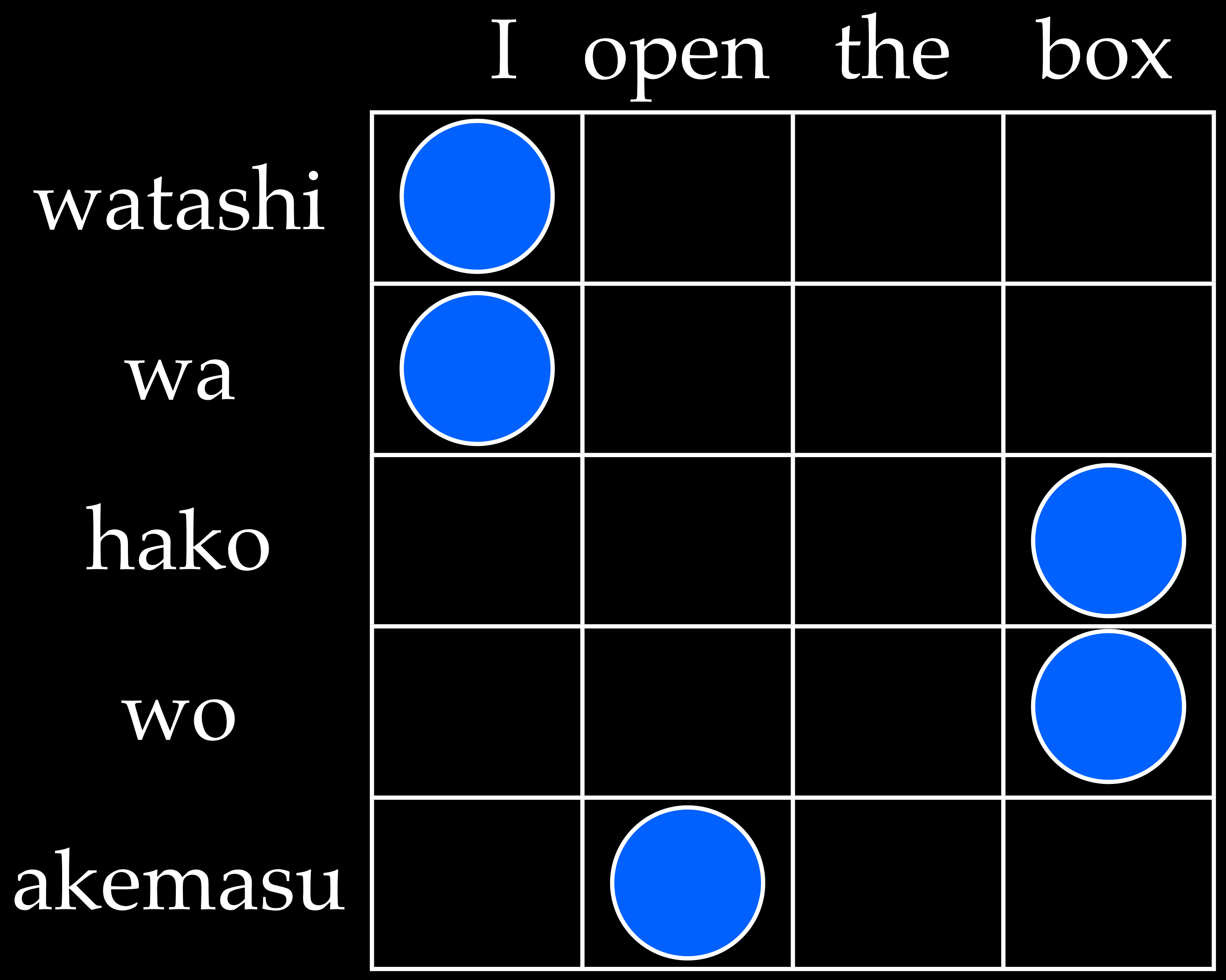
Now What?

- Option #1: approximate expectations
  - Restrict computation to some tractable subset of the alignment space (arbitrarily biased).
  - Markov chain Monte Carlo (very slow).

Now What?

- Change the problem definition
  - We already know how to learn word-to-word translation models efficiently.
  - Idea: learn word-to-word alignments, extract most probable alignment, then treat it as observed.
  - Learn phrase translations consistent with word alignments.
  - Decouples alignment from model learning -- is this a good thing?

Phrase Extraction



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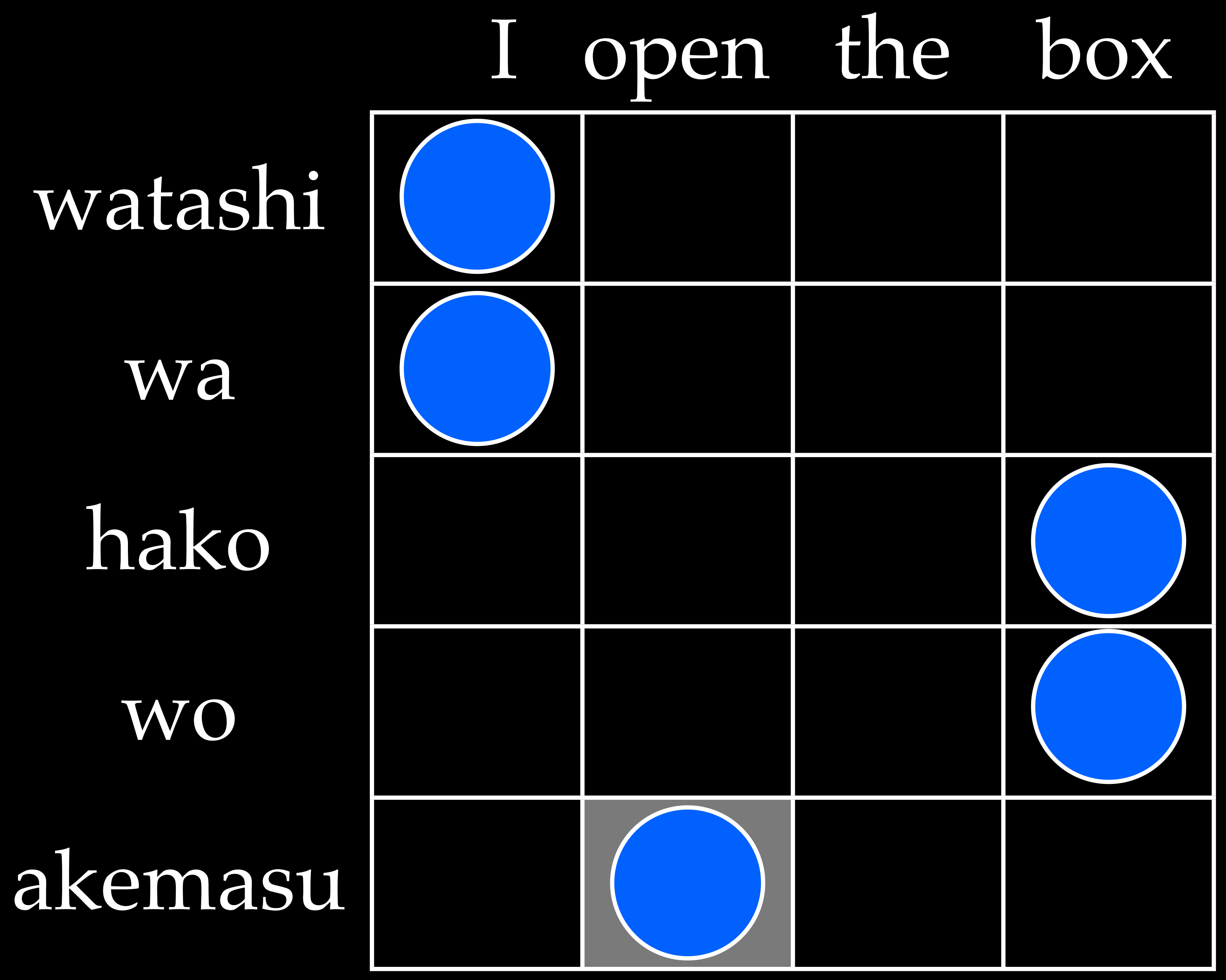
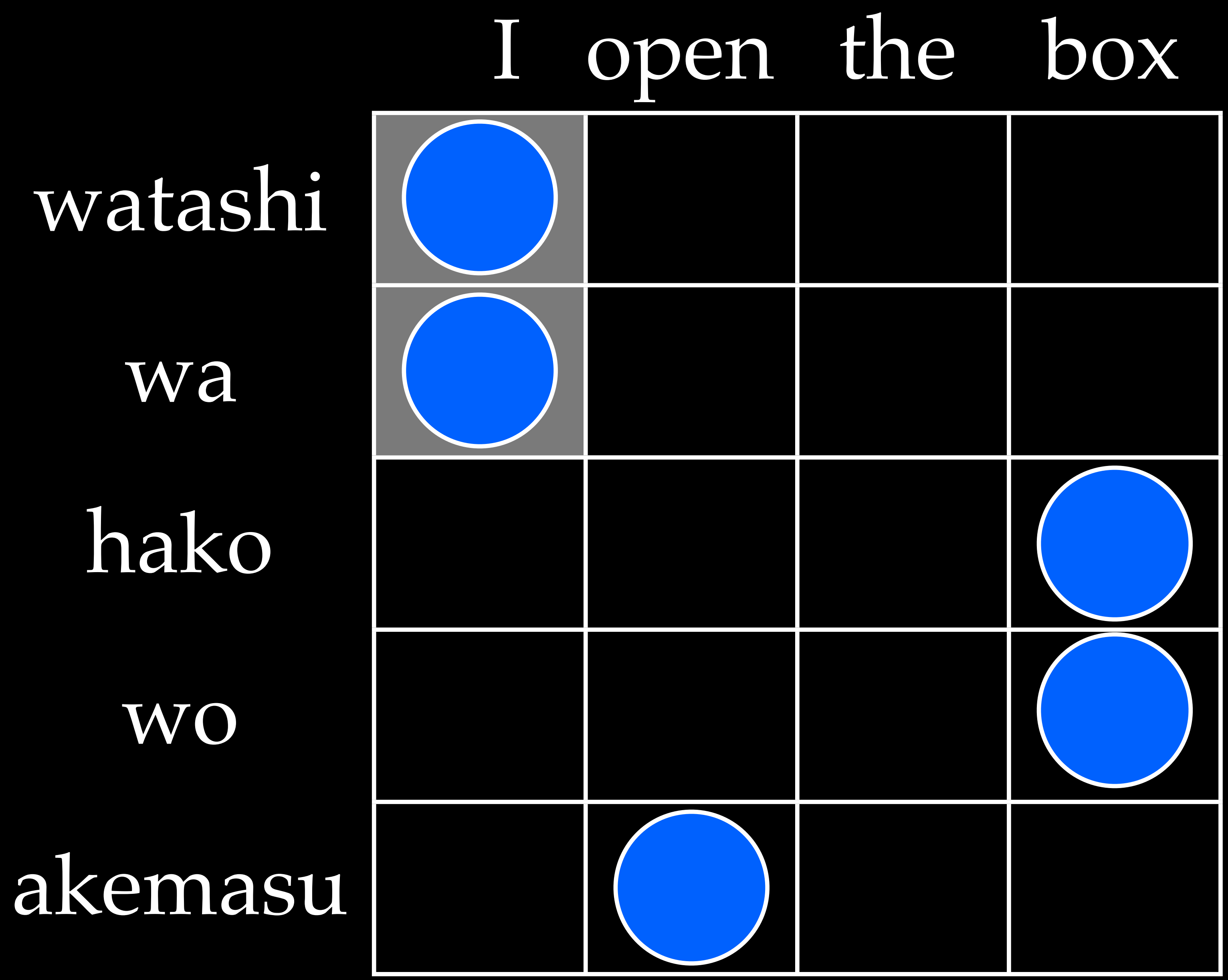


akemasu / open

Phrase Extraction



watashi wa / I

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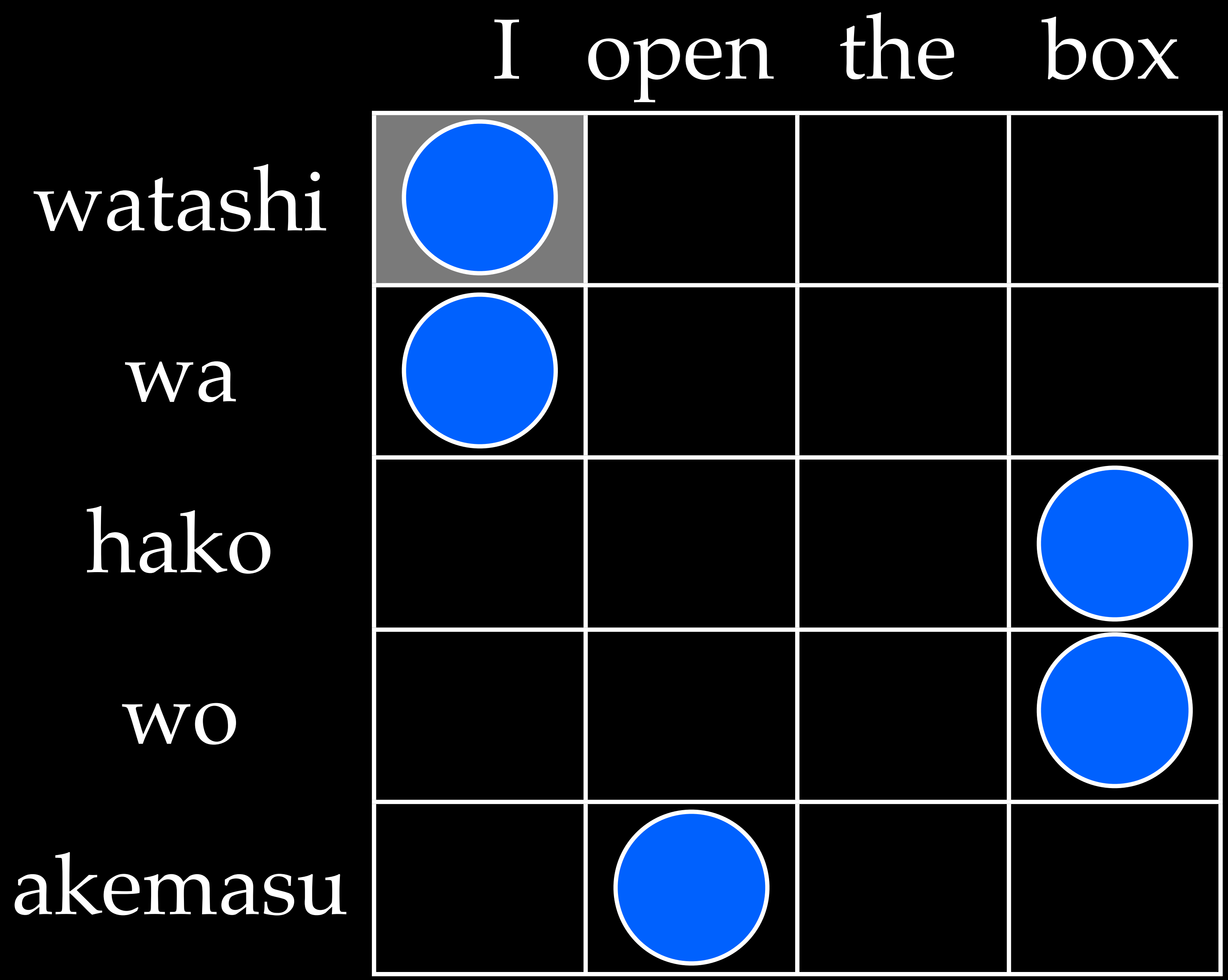

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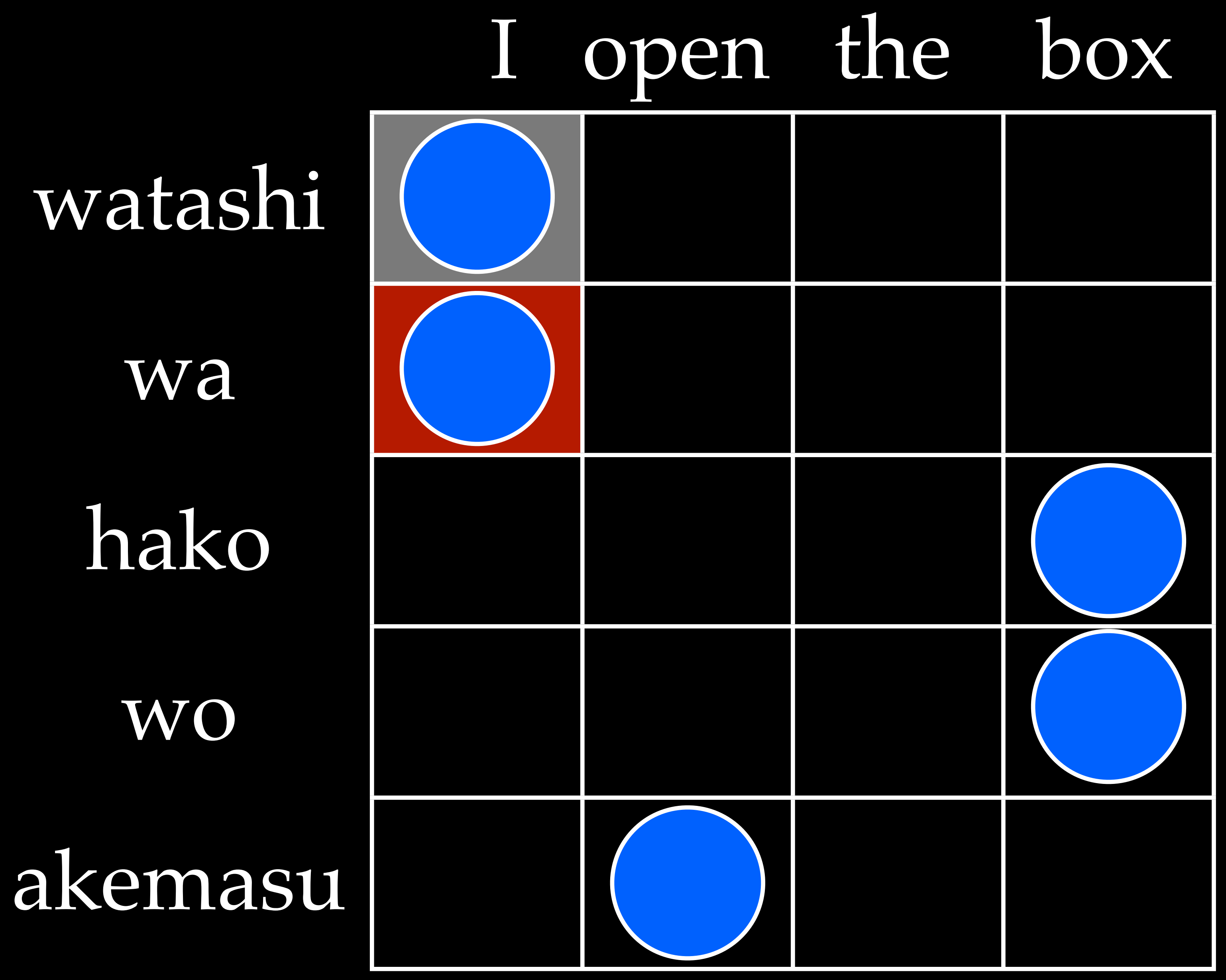

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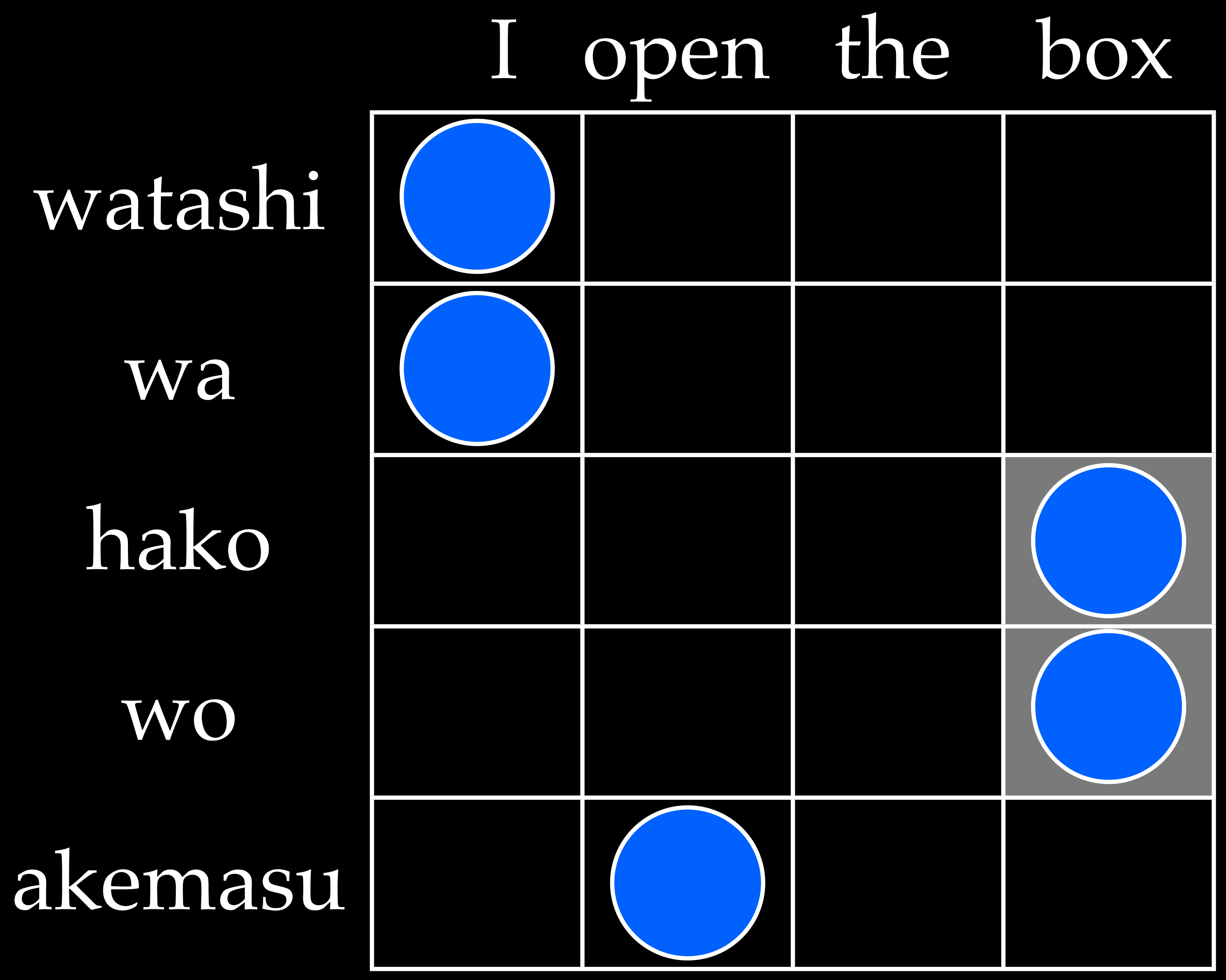
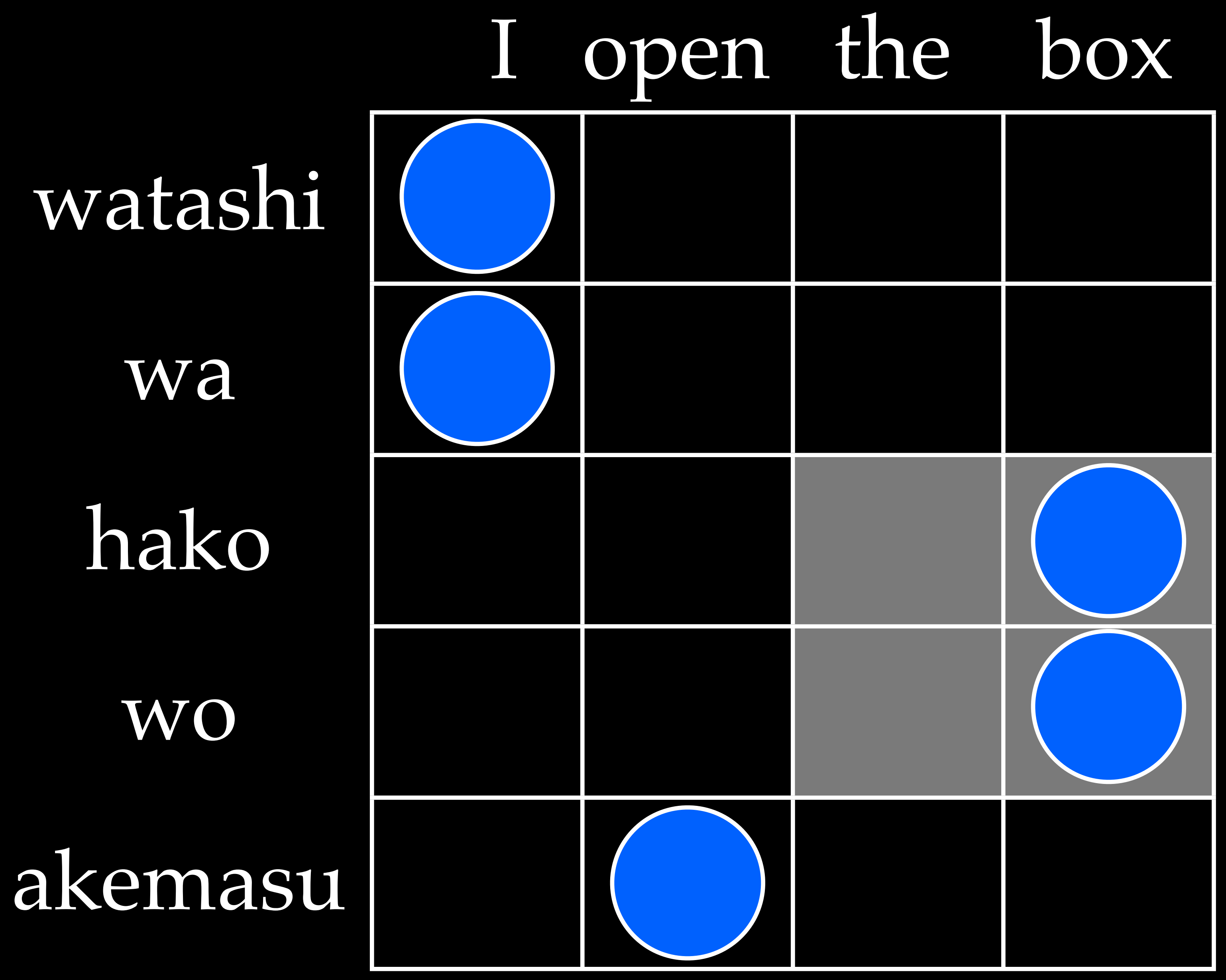


hako wo / box

Phrase Extraction



hako wo / the box

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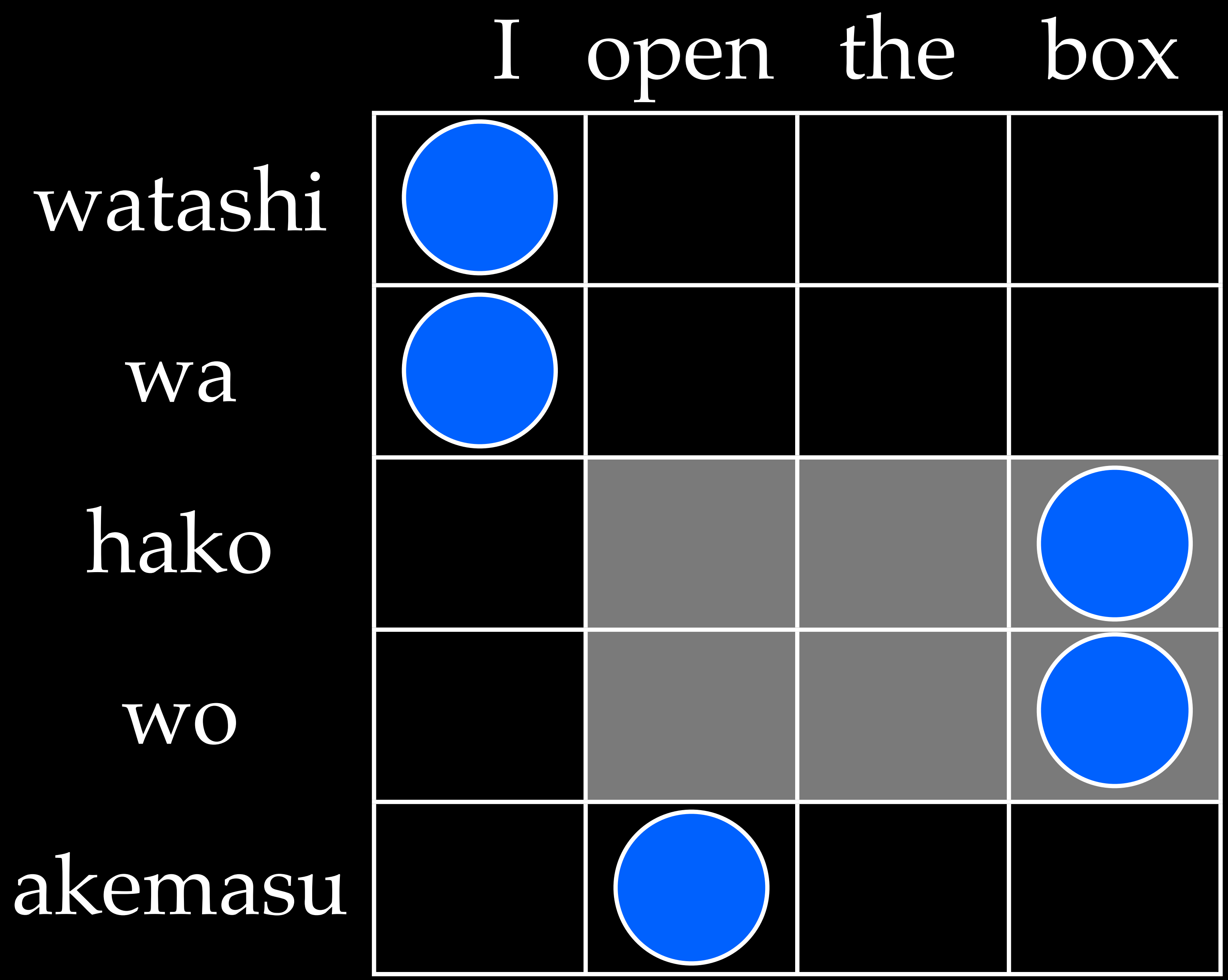

hako wo / open the box

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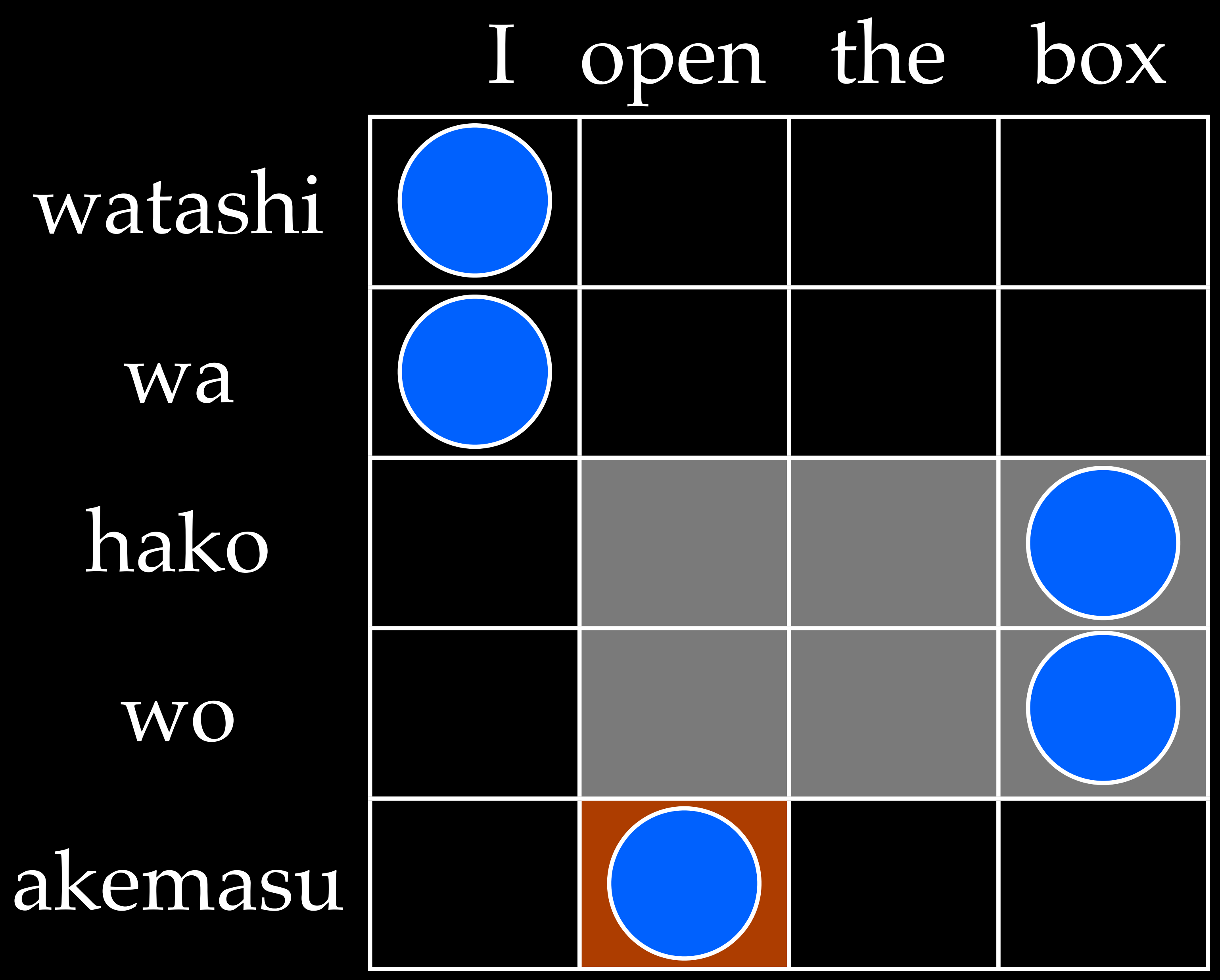

hako wo / ~~o~~pen the box

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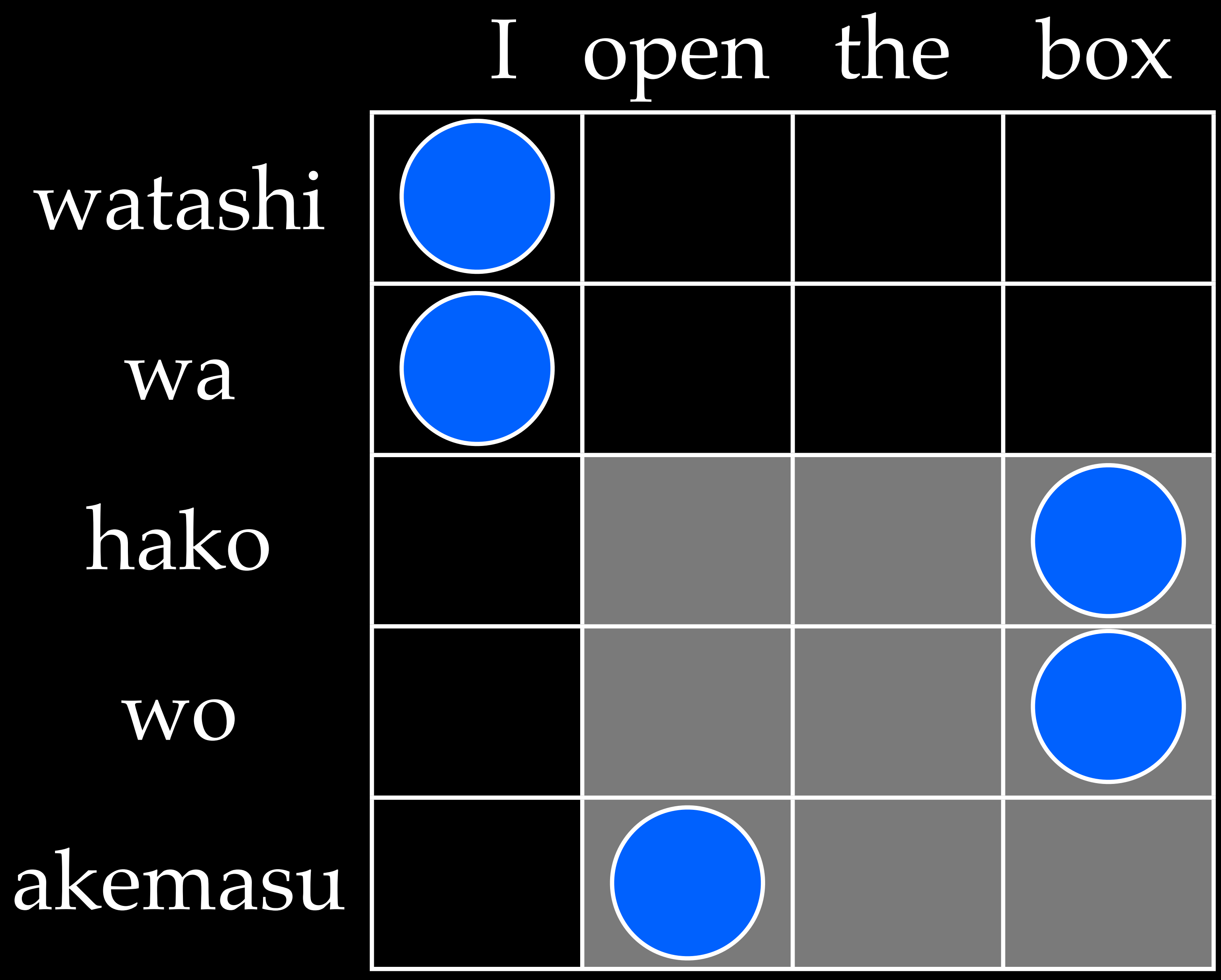

hako wo akemasu / open the box

Phrasal Translation Estimation

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- Option #1 (EM over restricted space)
  - Align with a word-based model.
  - Compute expectations only over alignments consistent with the alignment grid.

Phrasal Translation Estimation

- Option #1 (EM over restricted space)
  - Align with a word-based model.
  - Compute expectations only over alignments consistent with the alignment grid.
- Option #2 (Non-global estimation)
  - View phrase pairs as observed, irrespective of context or overlap.

北 风 呼啸 。

北 风 呼啸 。

segmentations
substitutions
permutations

北 风 呼啸 。

segmentations $O(2^n)$

substitutions

permutations

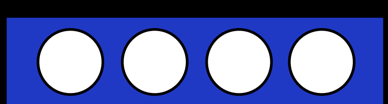
北 风 呼啸 。

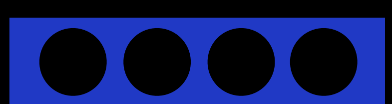
segmentations	$O(2^n)$
substitutions	$O(5^n)$
permutations	

北 风 呼啸 。

segmentations	$O(2^n)$
substitutions	$O(5^n)$
permutations	$O(n!)$

Key Idea





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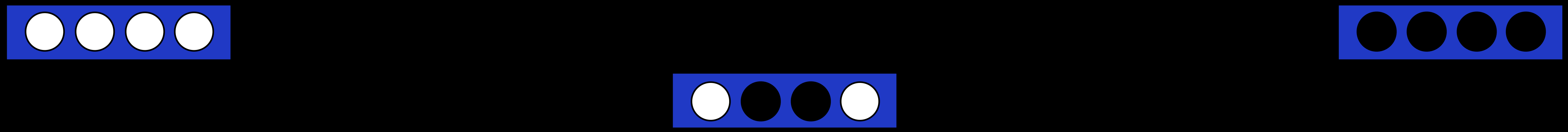

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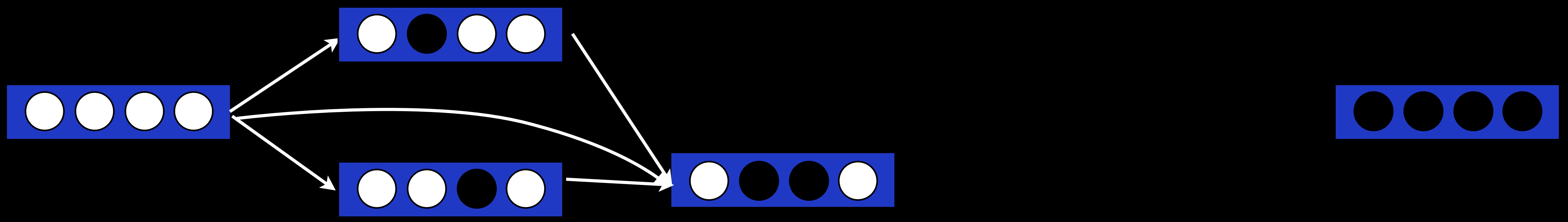

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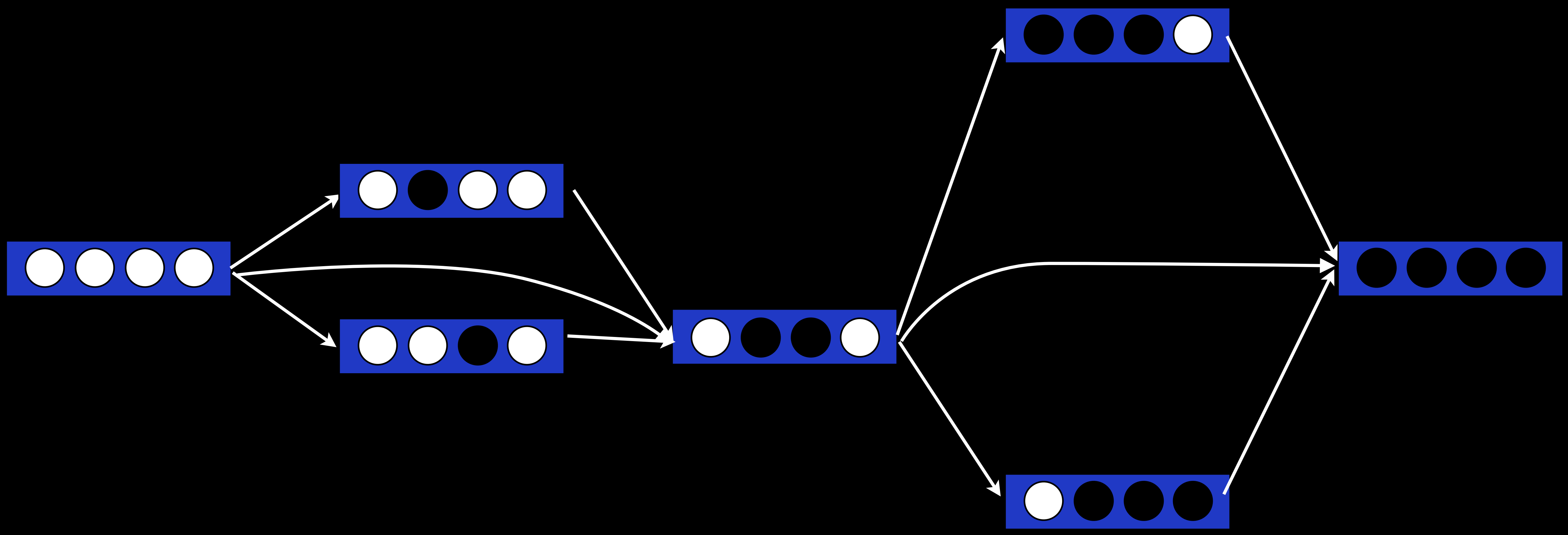

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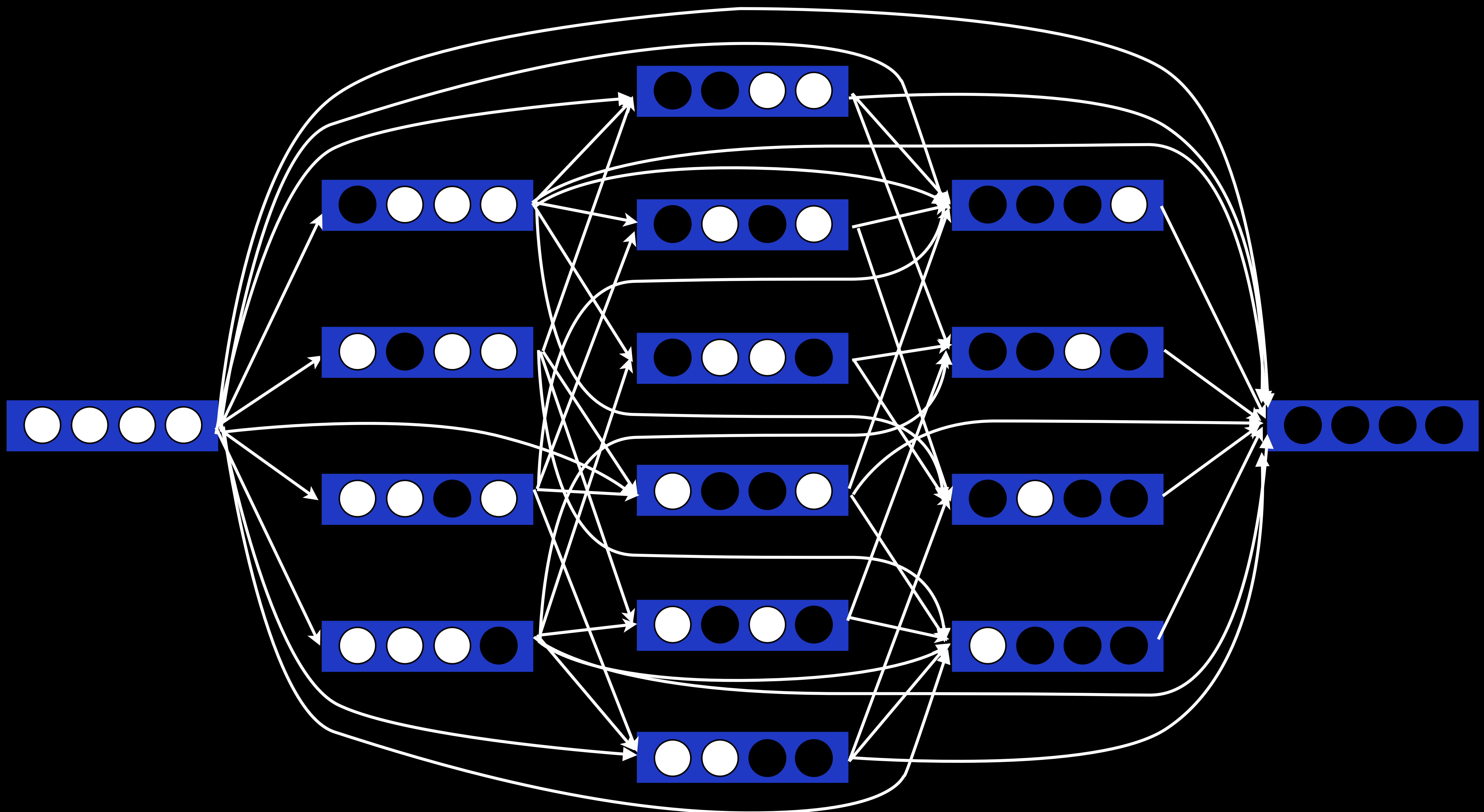

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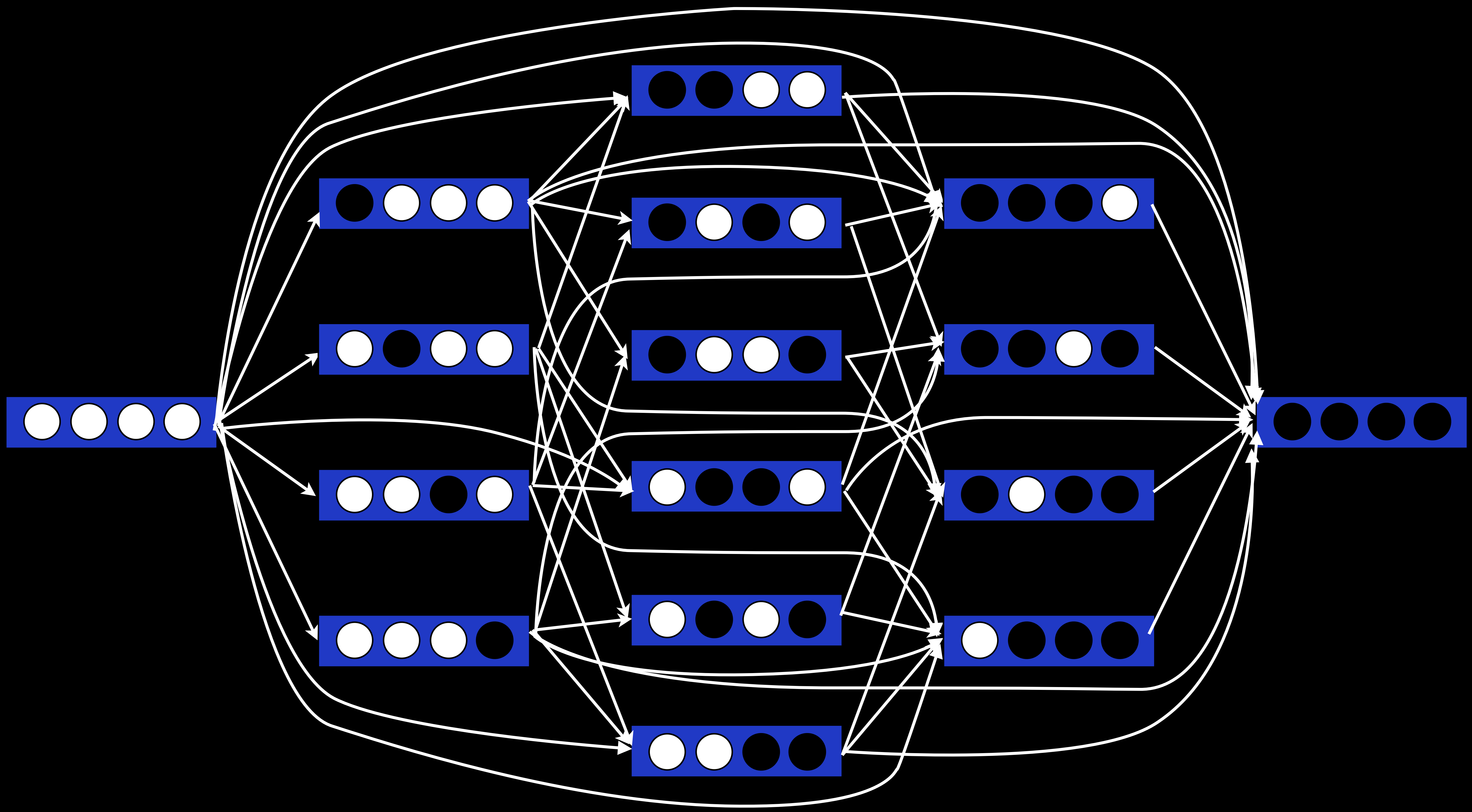

Dynamic Programming

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 。

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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

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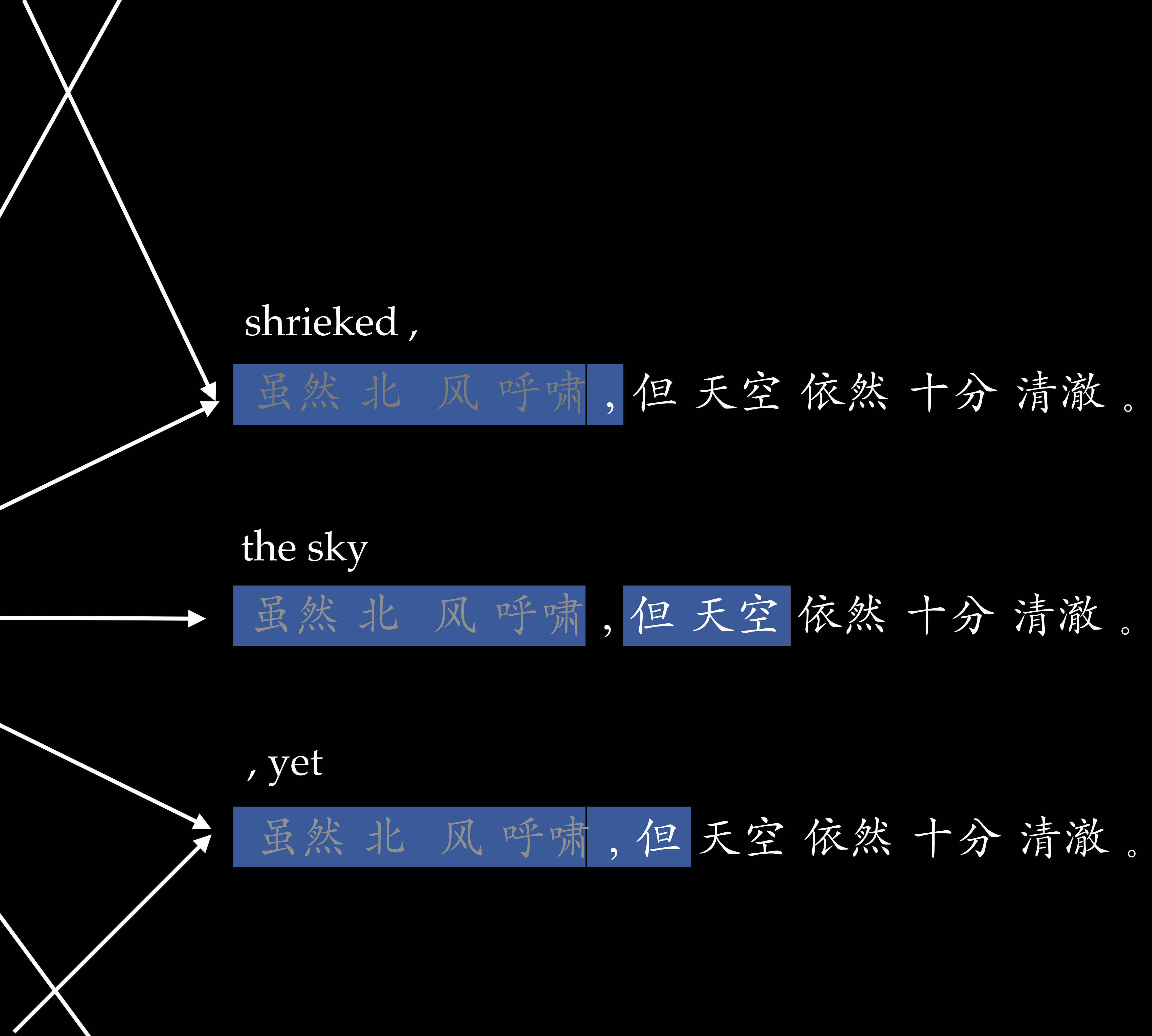
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the sky
虽然 北 风 呼啸 ，但 天空 依然 十分 清澈 。
, yet
虽然 北 风 呼啸 ，但 天空 依然 十分 清澈 。

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 。

Wait a second.

Wait a second.

$O(5n^2 2^n)$ is still far too much work.

Wait a second.

$O(5n^2 2^n)$ is still far too much work.

Can we do better?

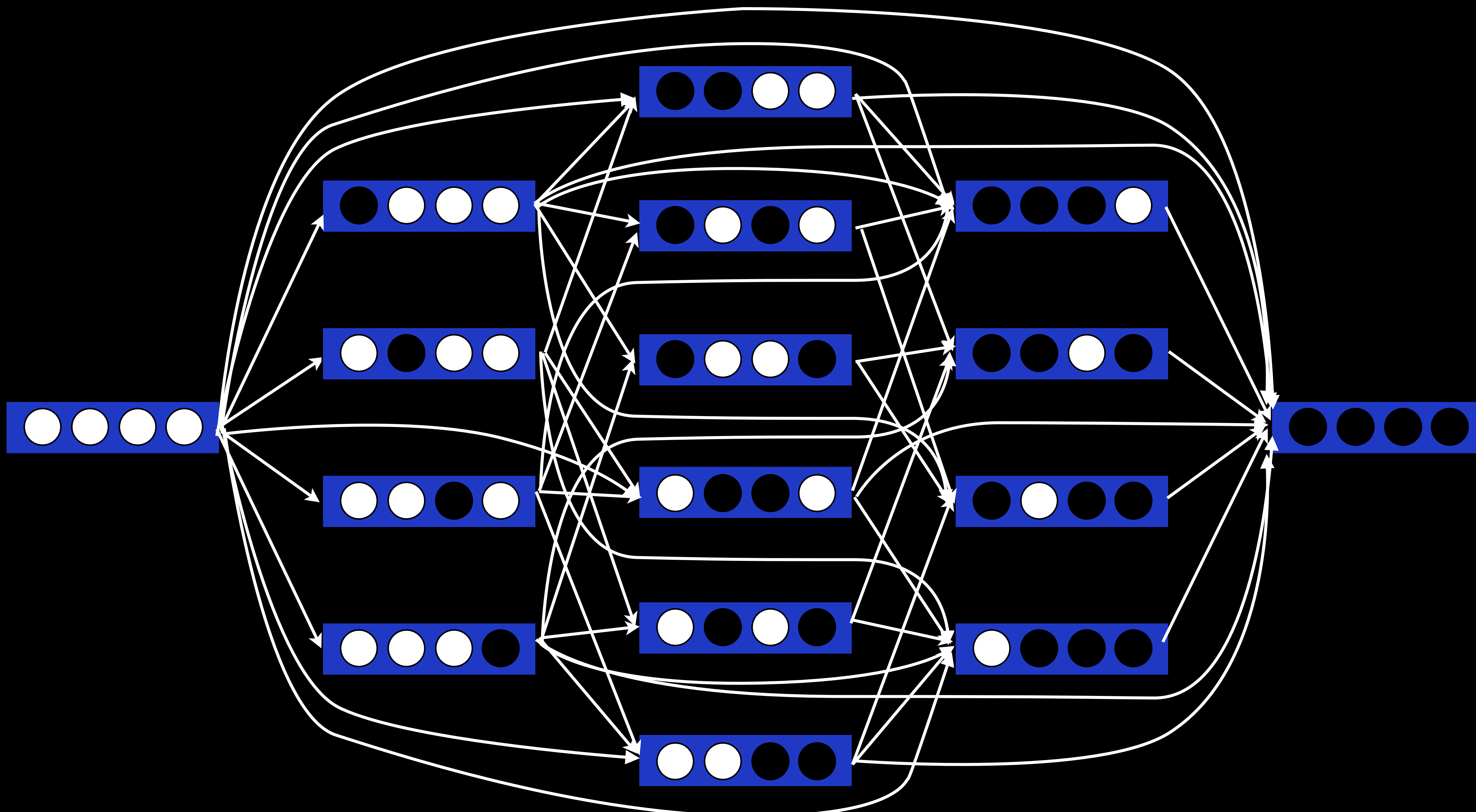
Wait a second.

$O(5n^2 2^n)$ is still far too much work.

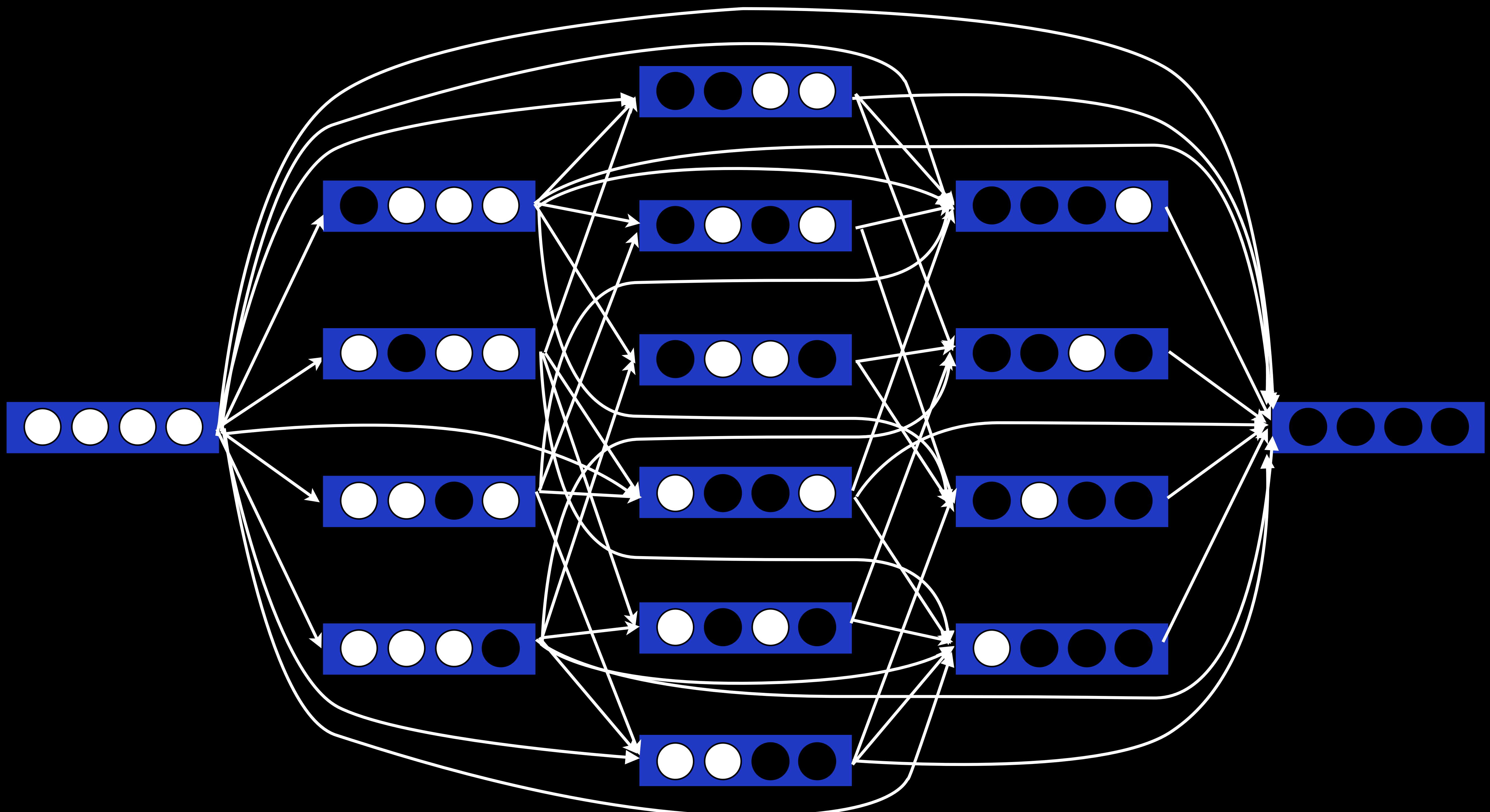
Can we do better?

NO! Knight (1999) shows that this is NP-Complete, by reduction to Hamiltonian Circuit.

Approximation: Pruning

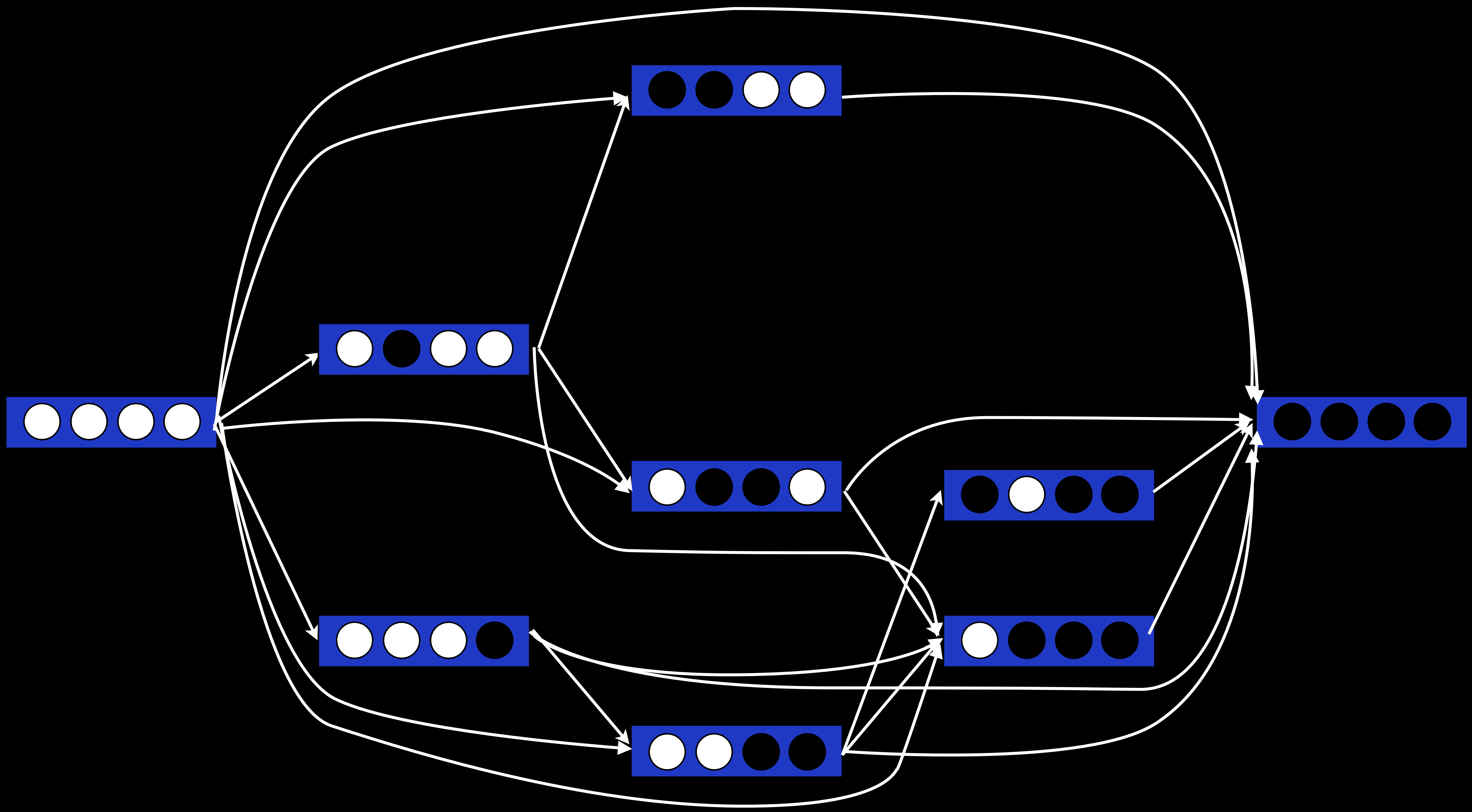


Approximation: Pruning

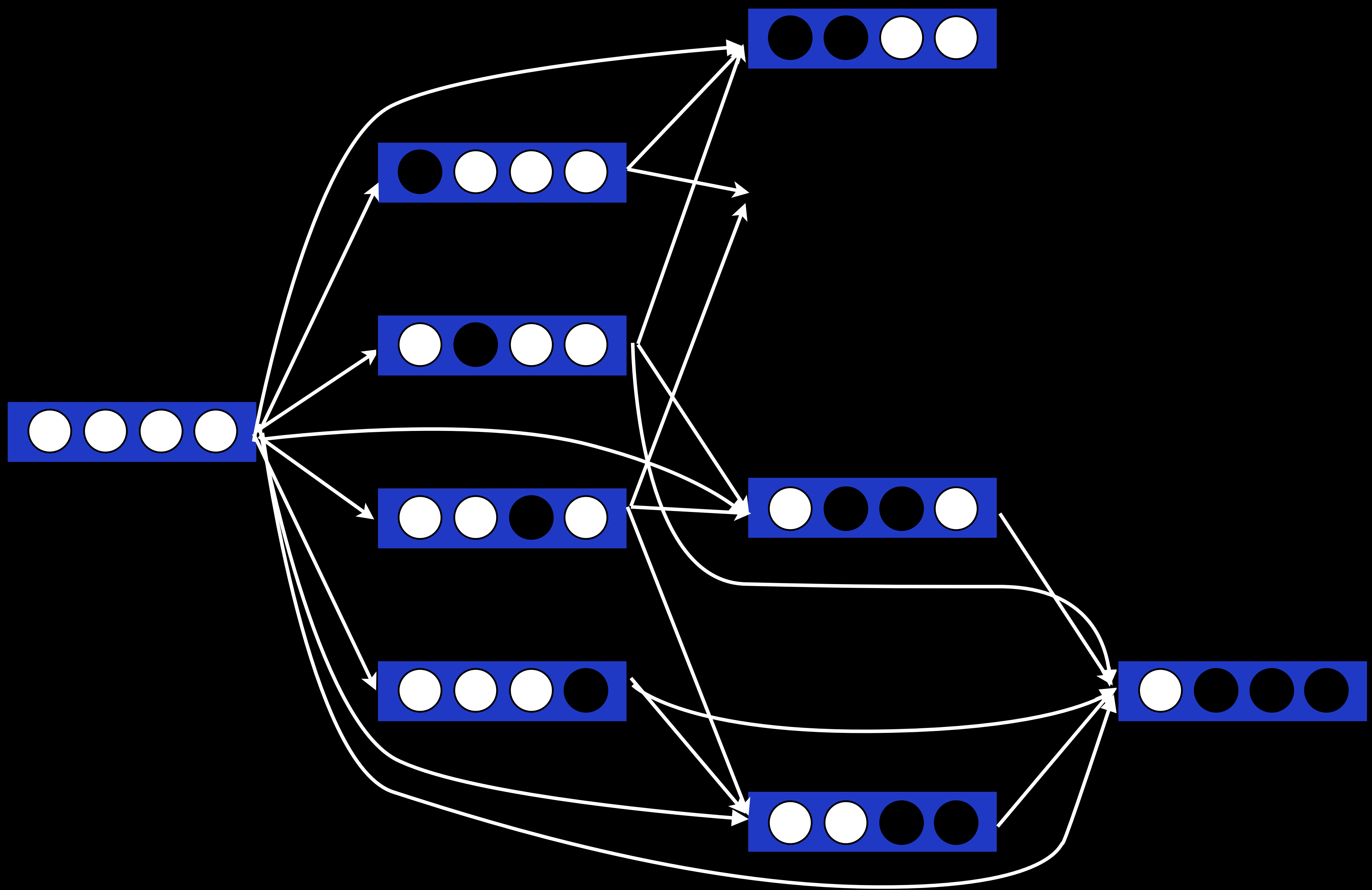


Idea: prune states by accumulated path length

Approximation: Pruning

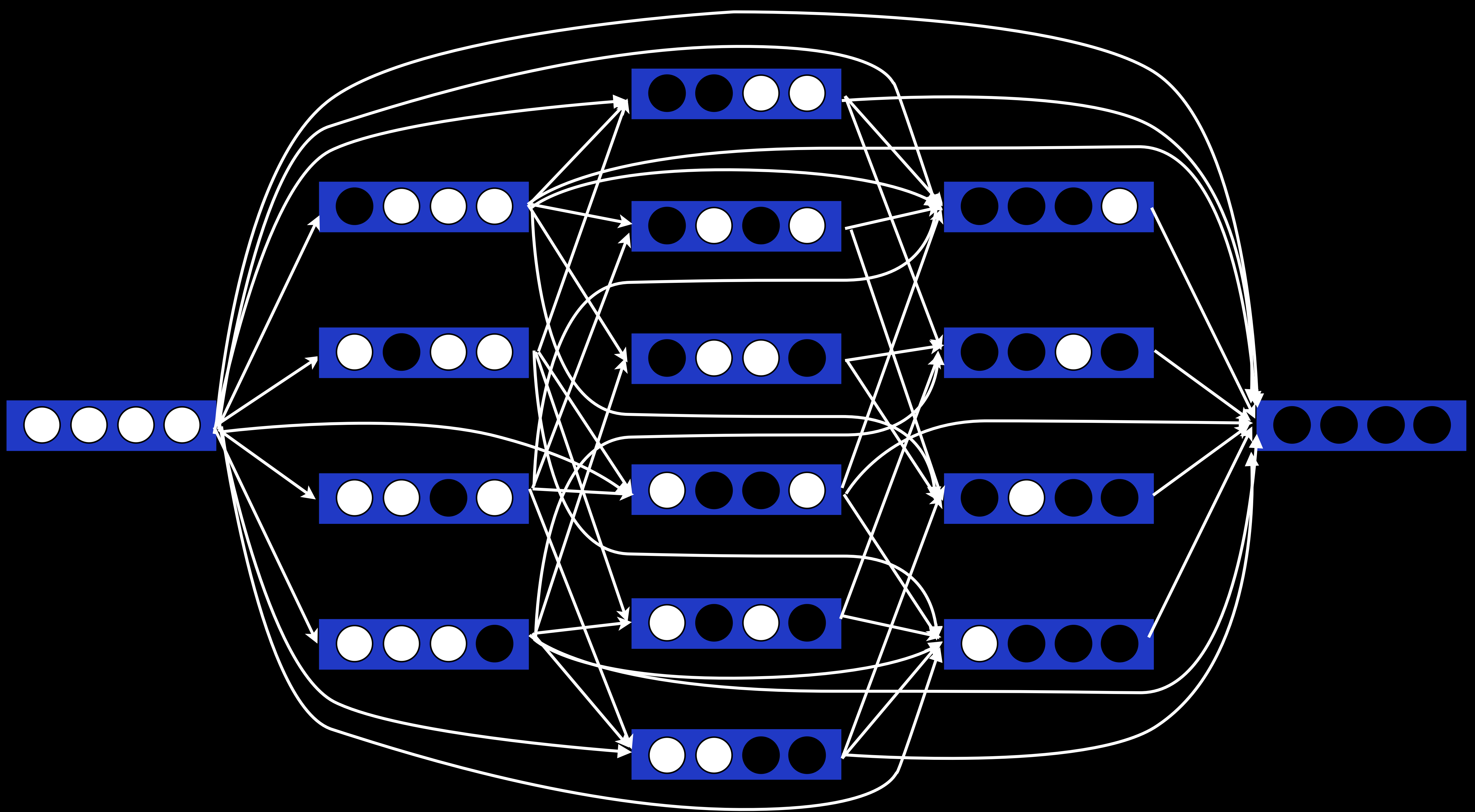


Approximation: Pruning

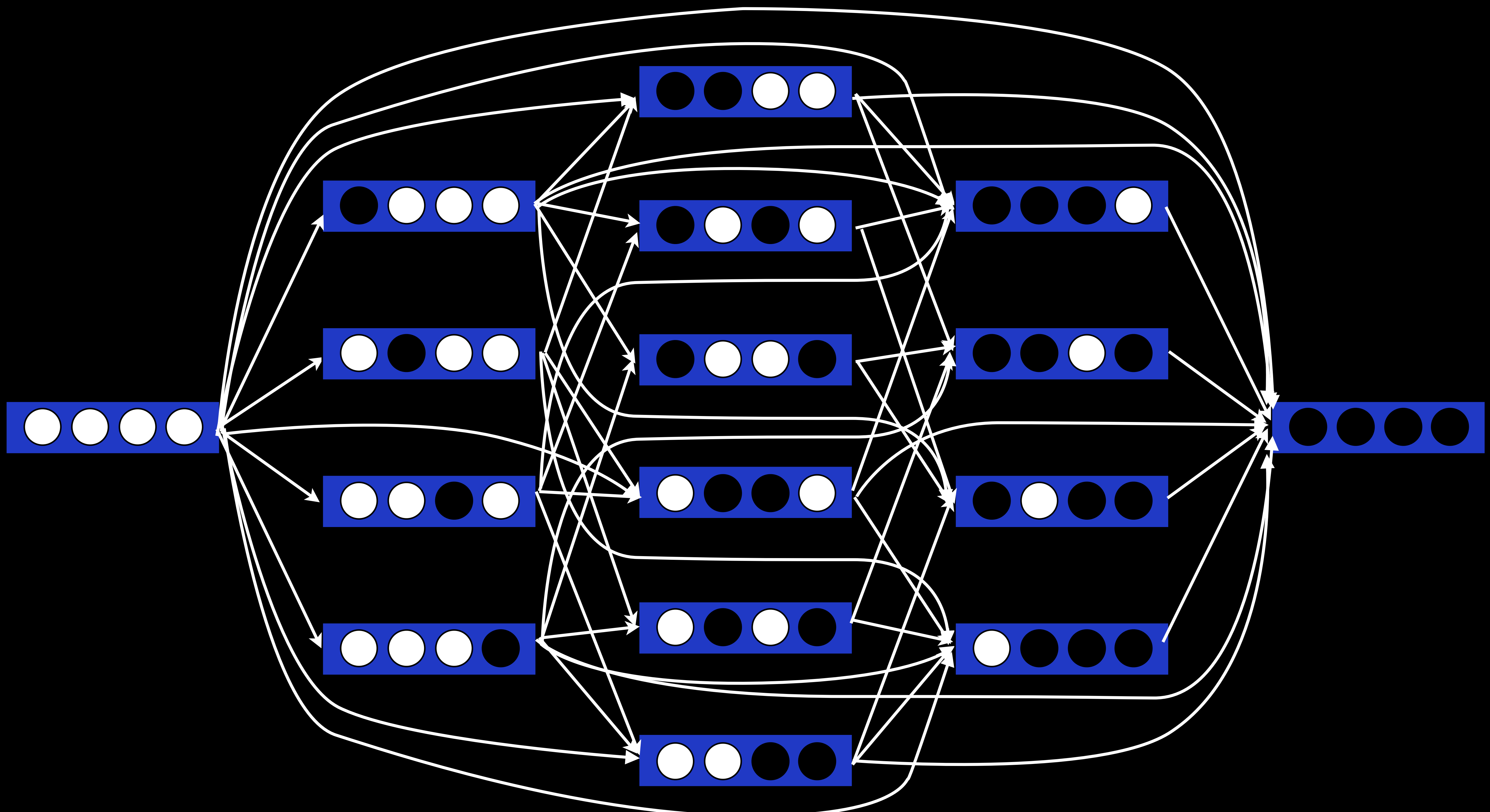


reality: longer paths have lower probability!

Approximation: Pruning

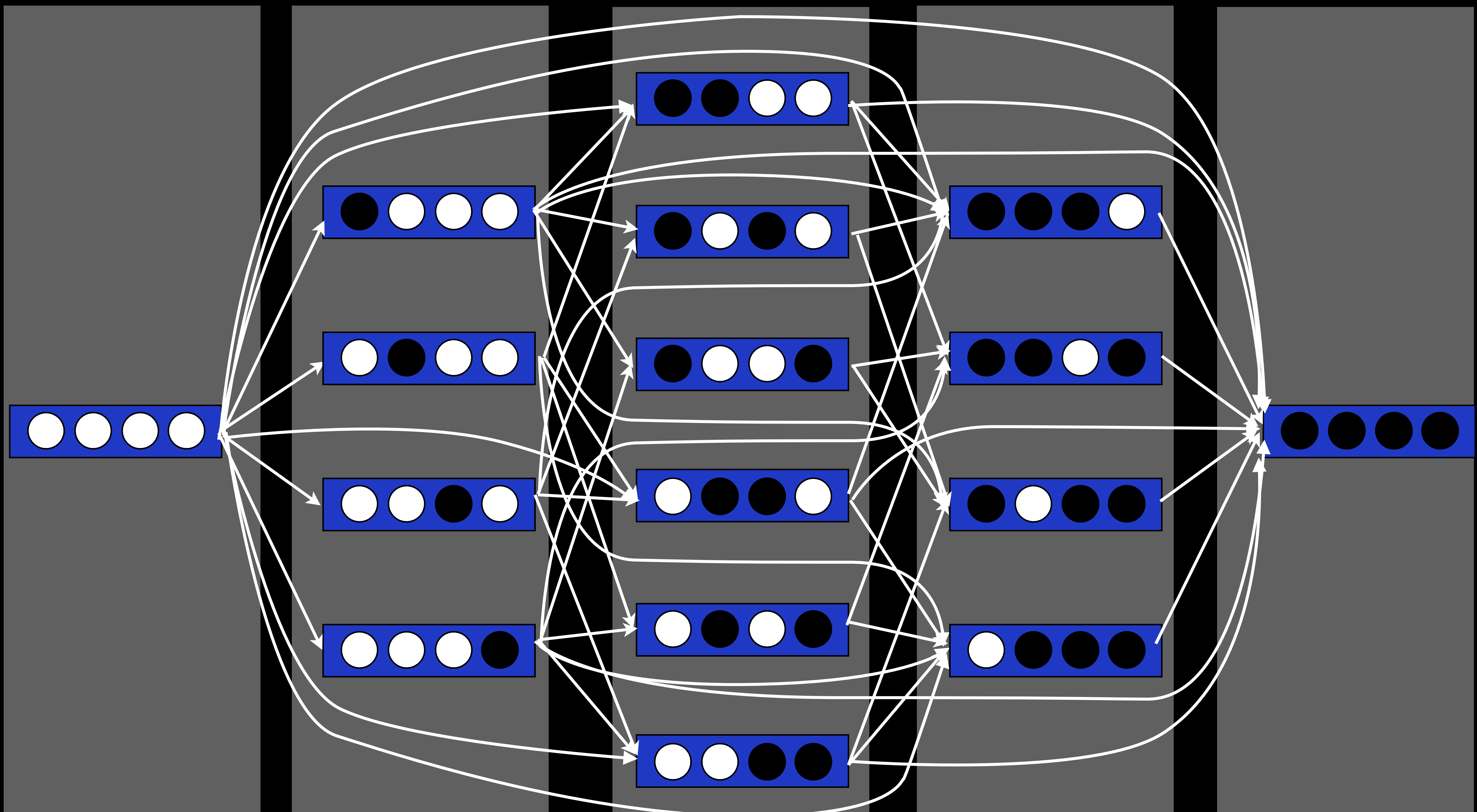


Approximation: Pruning



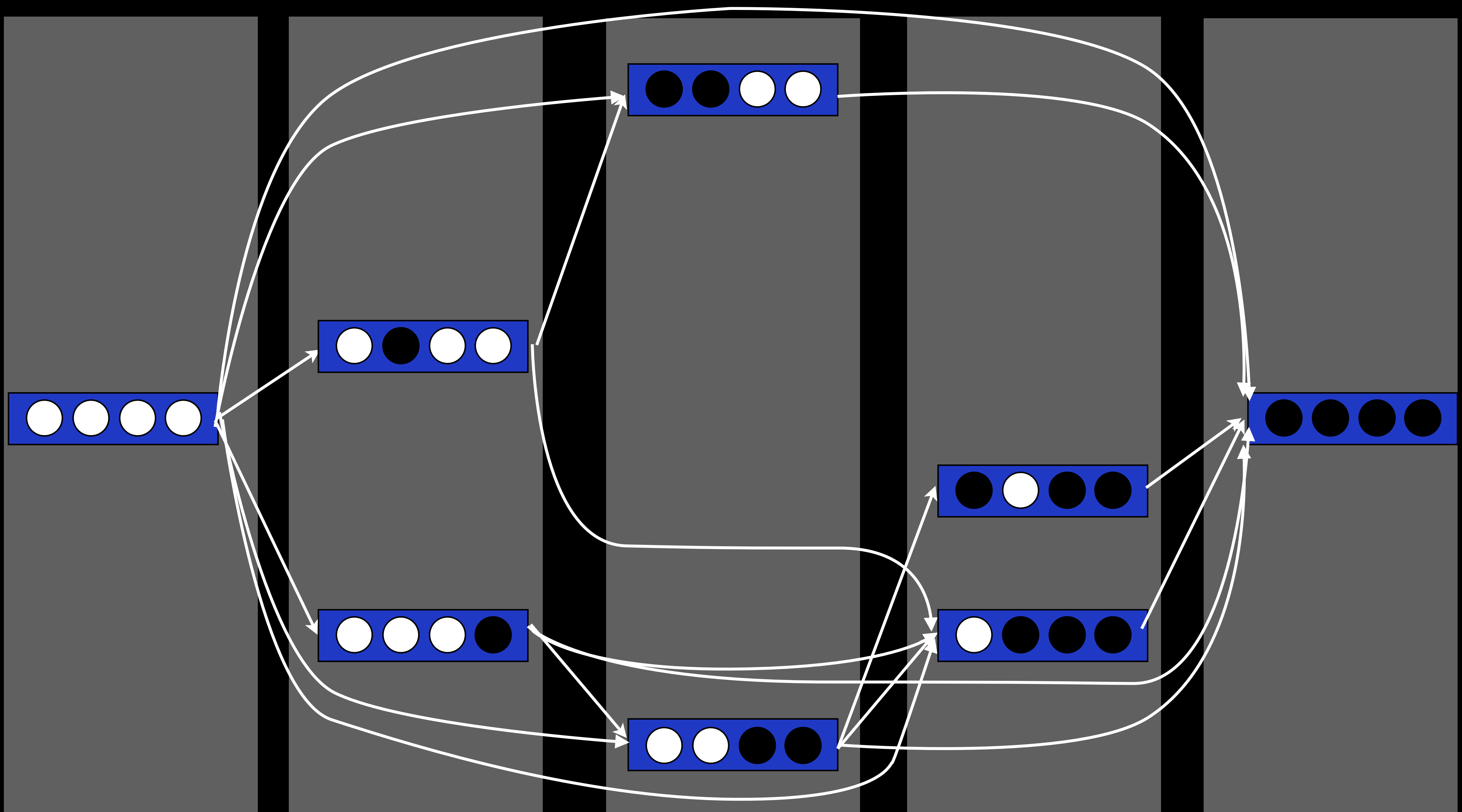
Solution: Group states by number of covered words.

Approximation: Pruning



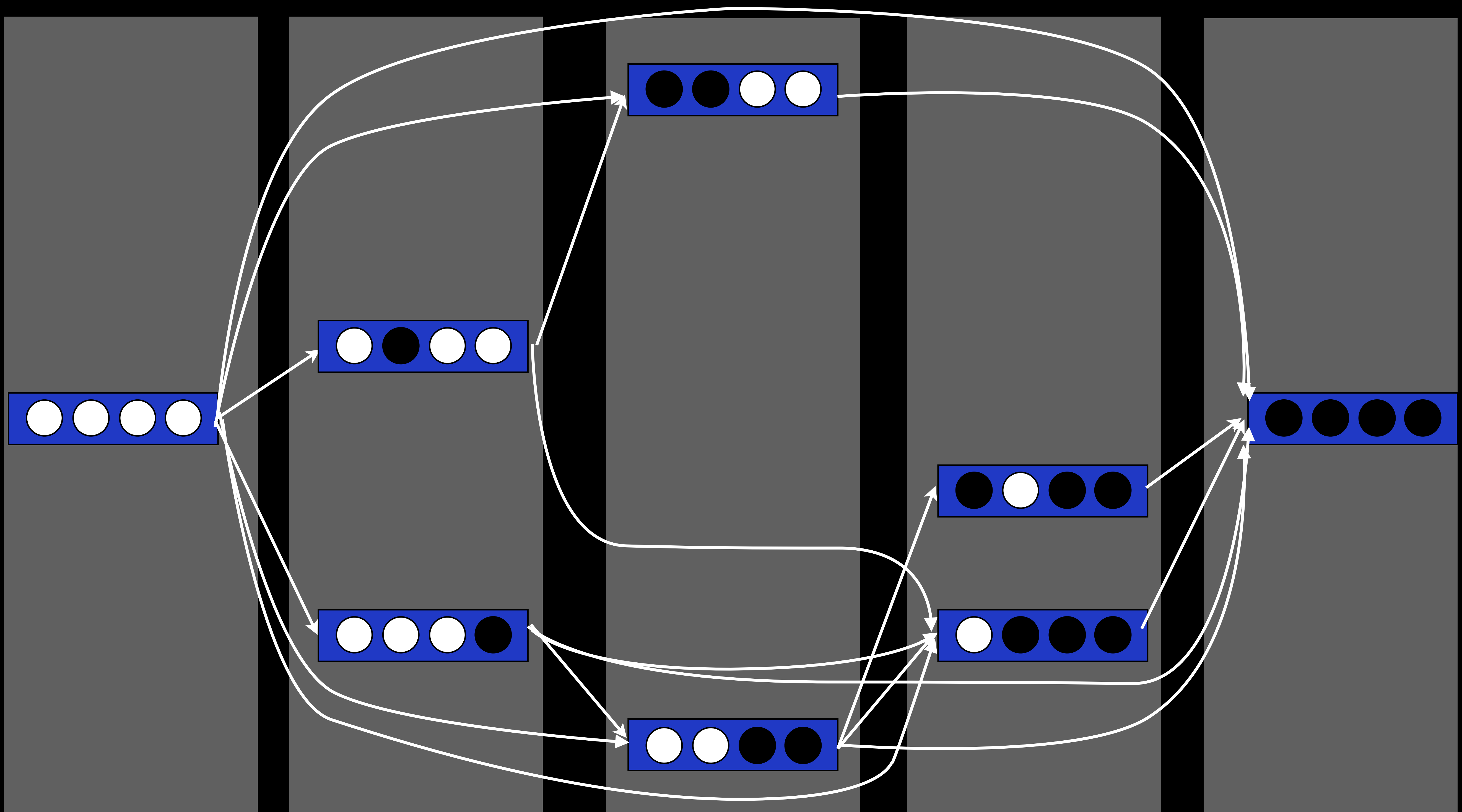
Solution: Group states by number of covered words.

Approximation: Pruning



Solution: Group states by number of covered words.

Approximation: Pruning



"Stack" decoding: a linear-time approximation

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

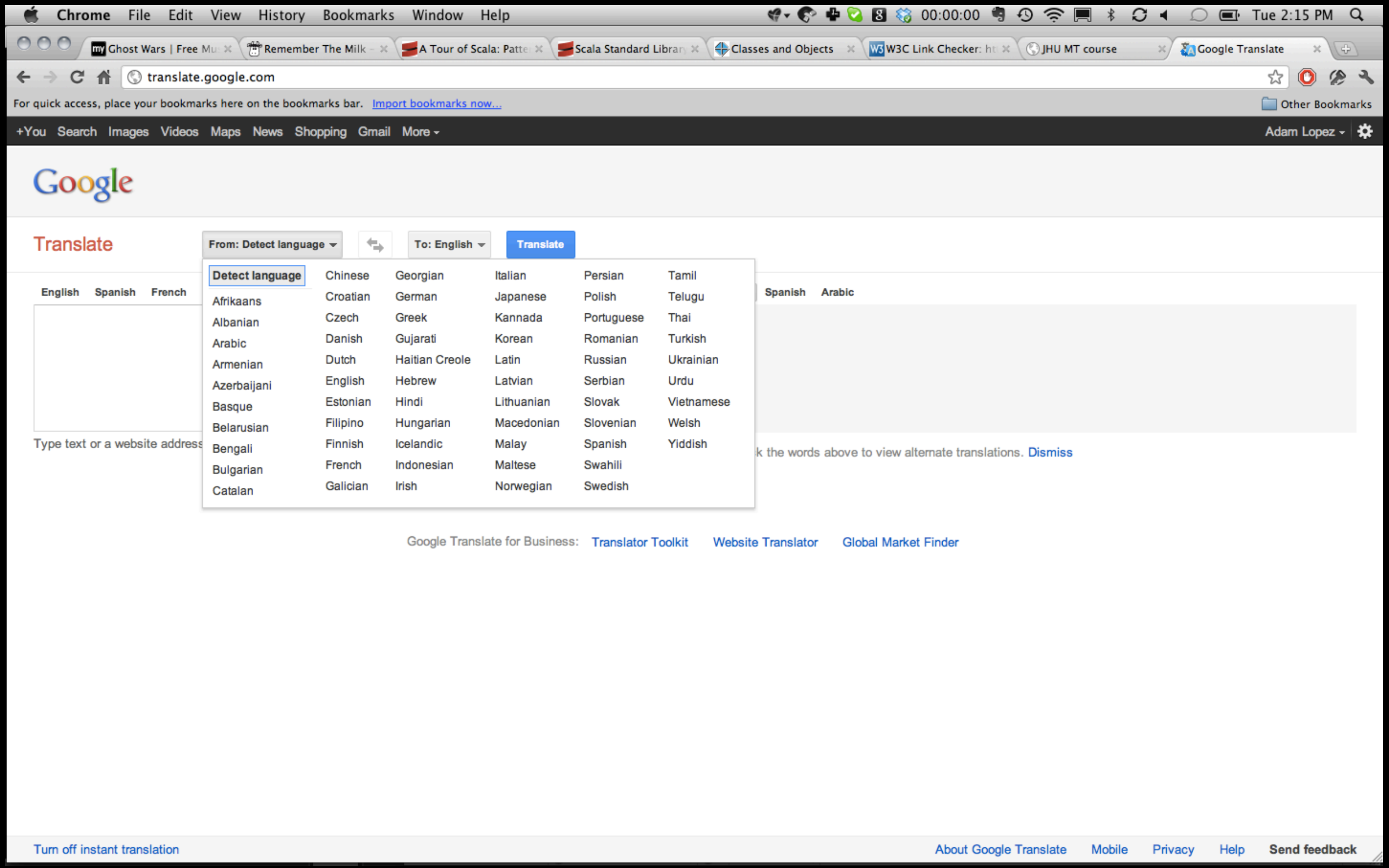
虽然 北 风 呼啸 , 但 天空 依然 十分 清澈 。

outside window
to left: covered

$d = 4$

window

outside window
to right: uncovered


Chrome File Edit View History Bookmarks Window Help
00:00:00 Tue 2:15 PM
Ghost Wars | Free Mu
Remember The Milk
A Tour of Scala: Patte
Scala Standard Librar
Classes and Objects
W3C Link Checker: ht
JHU MT course
Google Translate
translate.google.com
For quick access, place your bookmarks here on the bookmarks bar. Import bookmarks now...
Other Bookmarks
+You Search Images Videos Maps News Shopping Gmail More
Adam Lopez
Google
Translate
From: Detect language
To: English
Translate
English Spanish French
Spanish Arabic
Detect language
Afrikaans
Albanian
Arabic
Armenian
Azerbaijani
Basque
Belarusian
Bengali
Bulgarian
Catalan
Chinese
Croatian
Czech
Danish
Dutch
English
Estonian
Filipino
Finnish
French
Galician
Georgian
German
Greek
Gujarati
Haitian Creole
Hebrew
Hindi
Hungarian
Icelandic
Indonesian
Irish
Italian
Japanese
Kannada
Korean
Latin
Latvian
Lithuanian
Macedonian
Malay
Maltese
Norwegian
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Romanian
Russian
Serbian
Slovak
Slovenian
Spanish
Swahili
Swedish
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Telugu
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Type text or a website address
k the words above to view alternate translations. Dismiss
Google Translate for Business: Translator Toolkit Website Translator Global Market Finder
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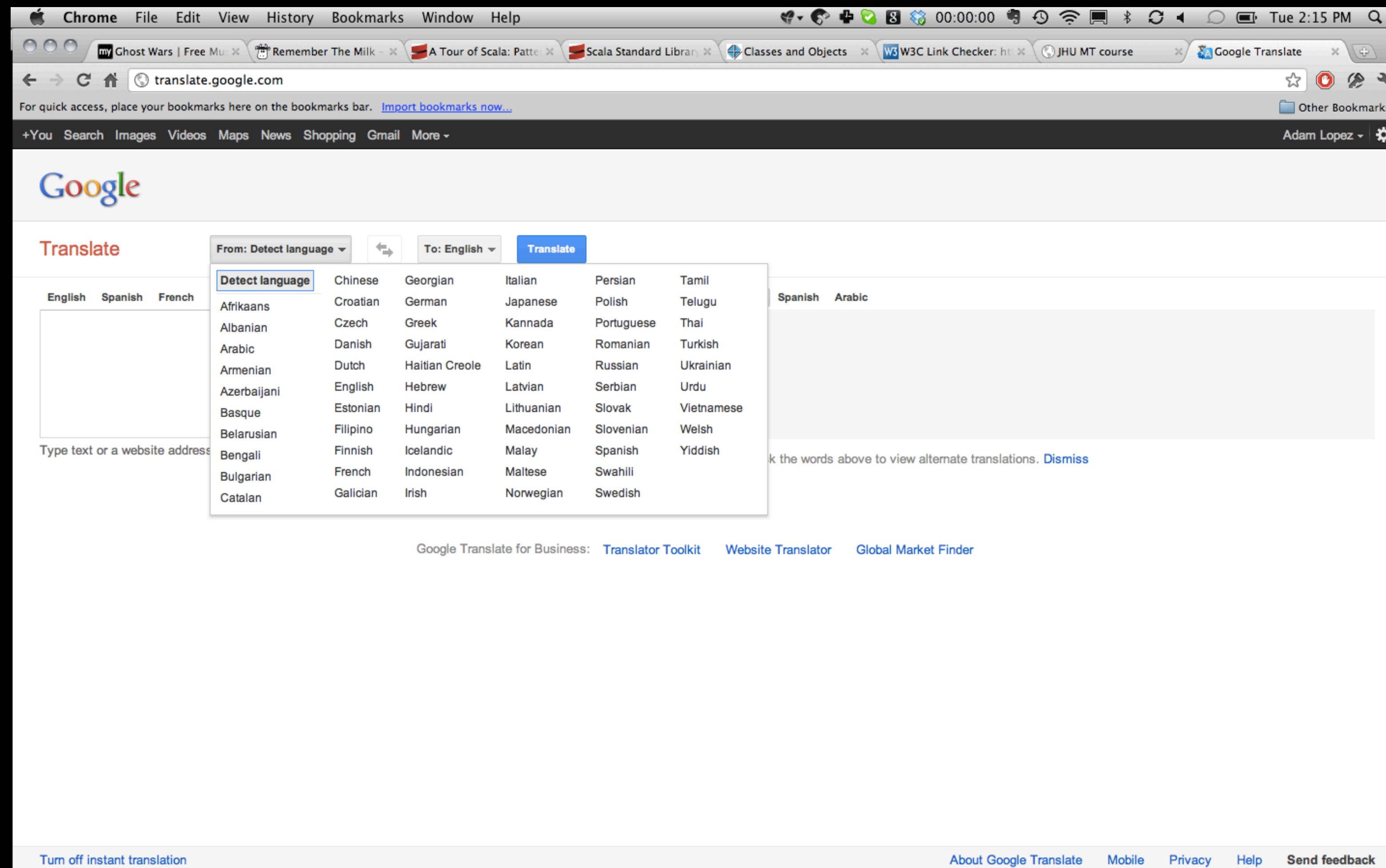
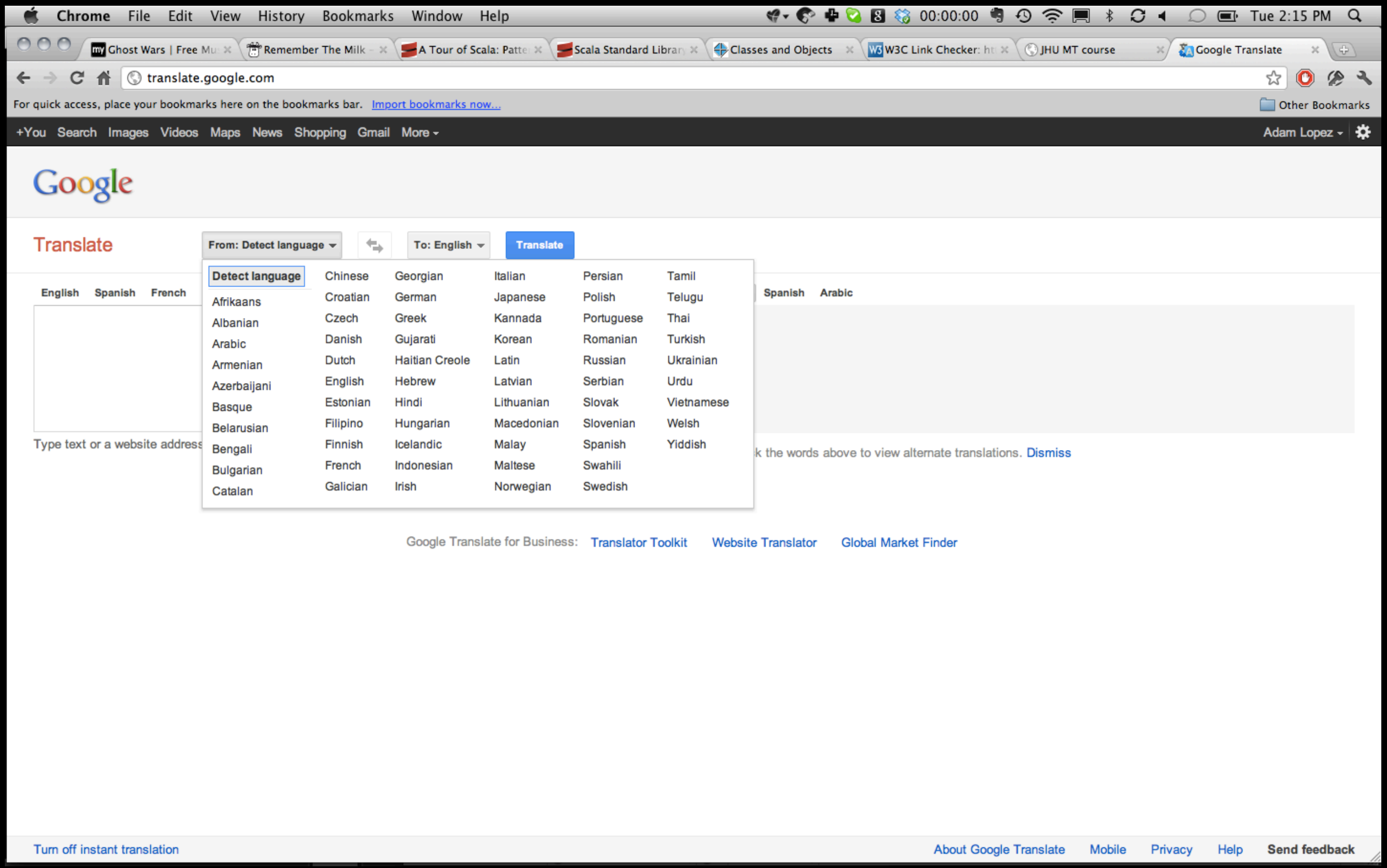
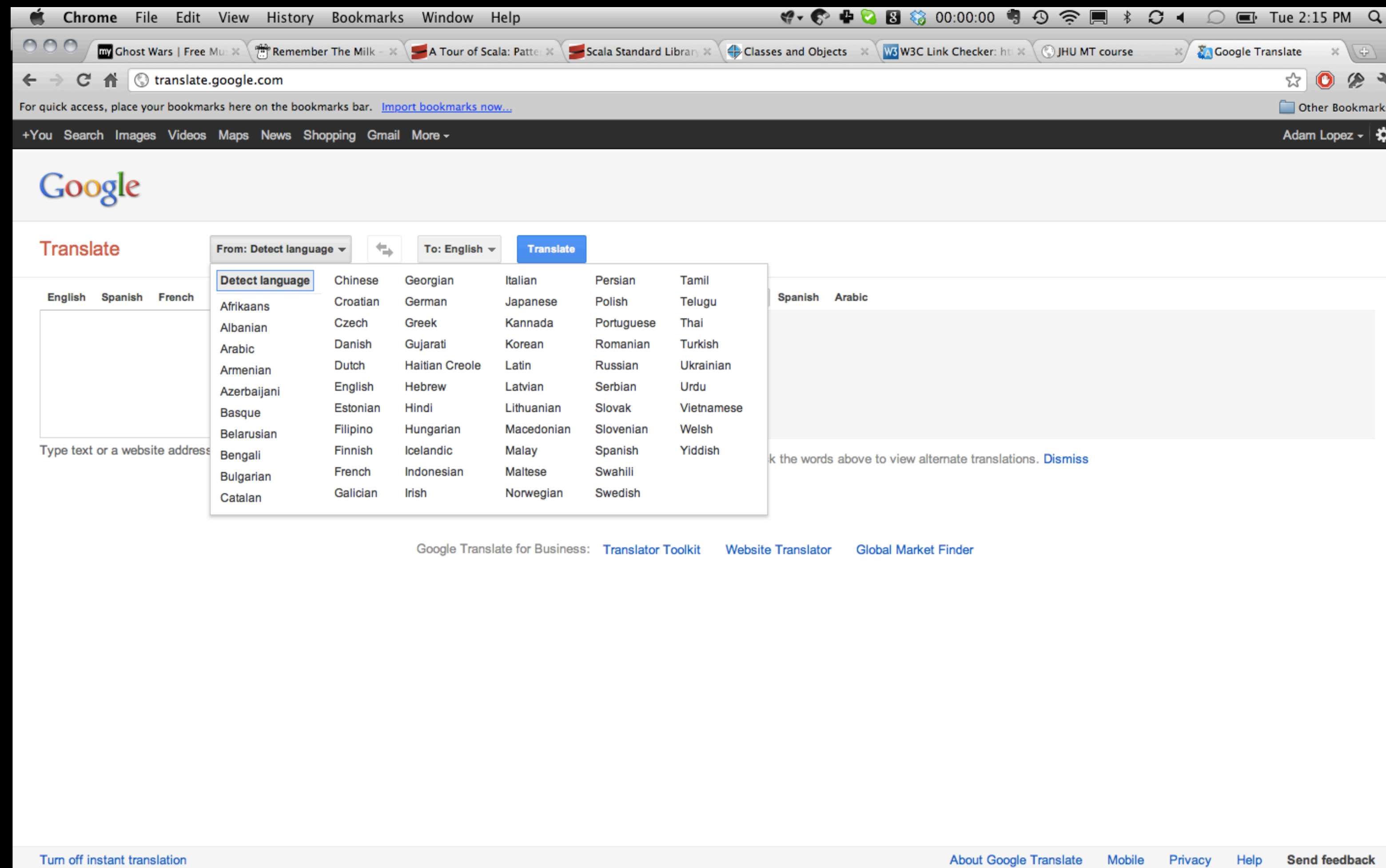


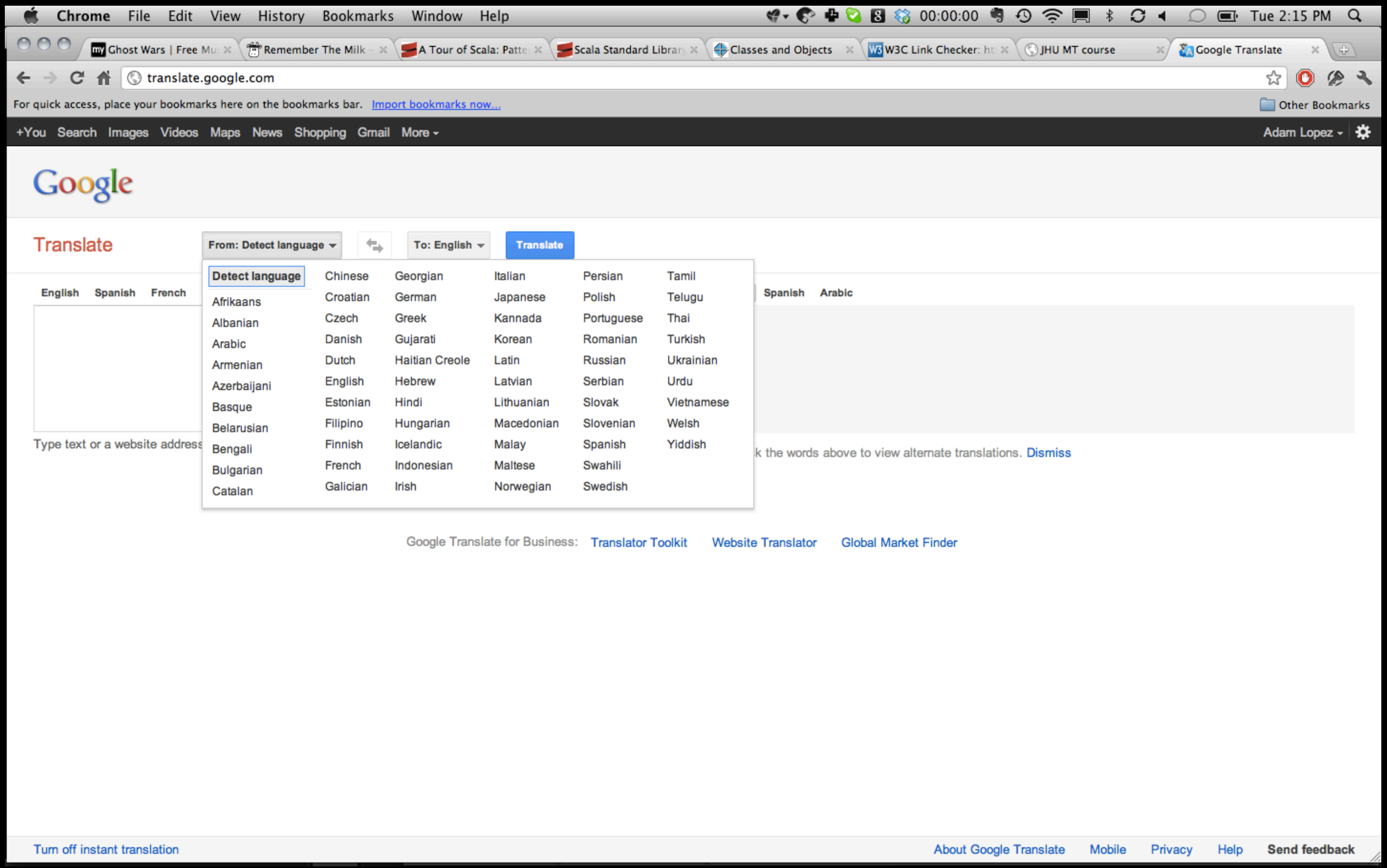
- Some (not all) key ingredients in Google Translate:



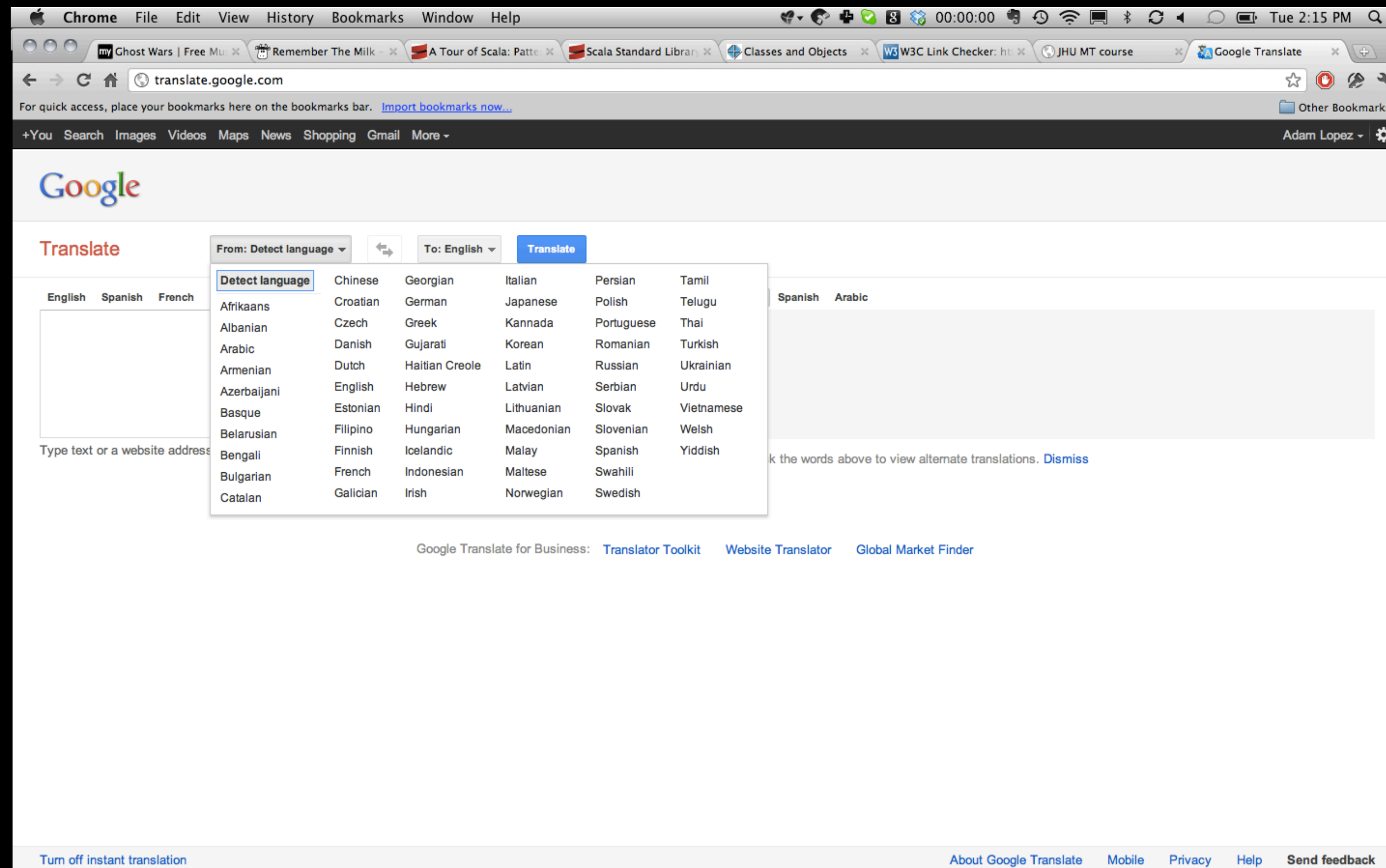
- Some (not all) key ingredients in Google Translate:
  - Phrase-based translation models



- Some (not all) key ingredients in Google Translate:
  - Phrase-based translation models
  - ... Learned heuristically from word alignments



- Some (not all) key ingredients in Google Translate:
  - Phrase-based translation models
  - ... Learned heuristically from word alignments
  - ... Coupled with a huge language model



- Some (not all) key ingredients in Google Translate:
  - Phrase-based translation models
  - ... Learned heuristically from word alignments
  - ... Coupled with a huge language model
  - ... And very tight pruning heuristics