Decoding continued + Phrase-based translation

The IBM Models

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- Fertility probabilities.

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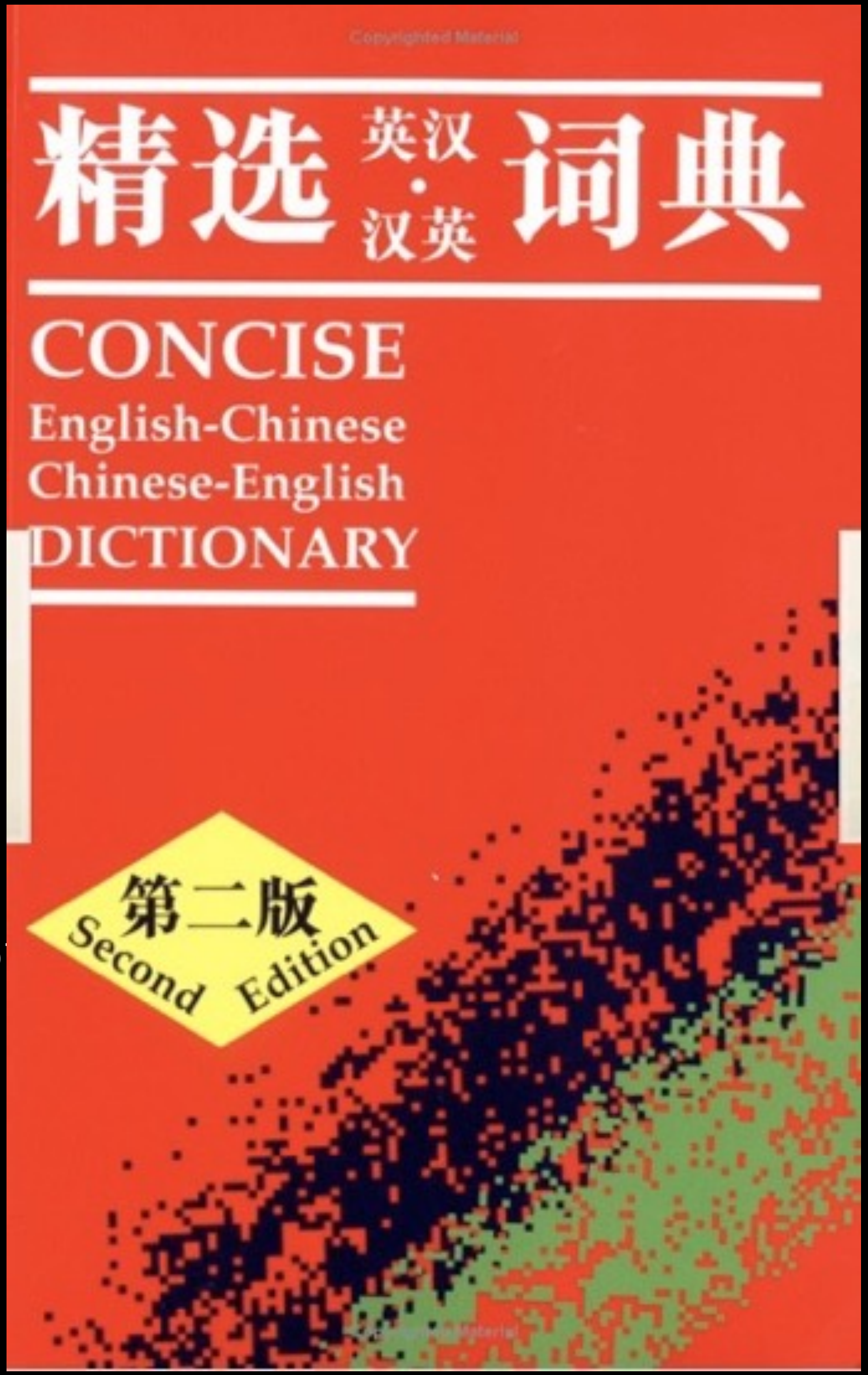

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IBM Model 4

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 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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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 .

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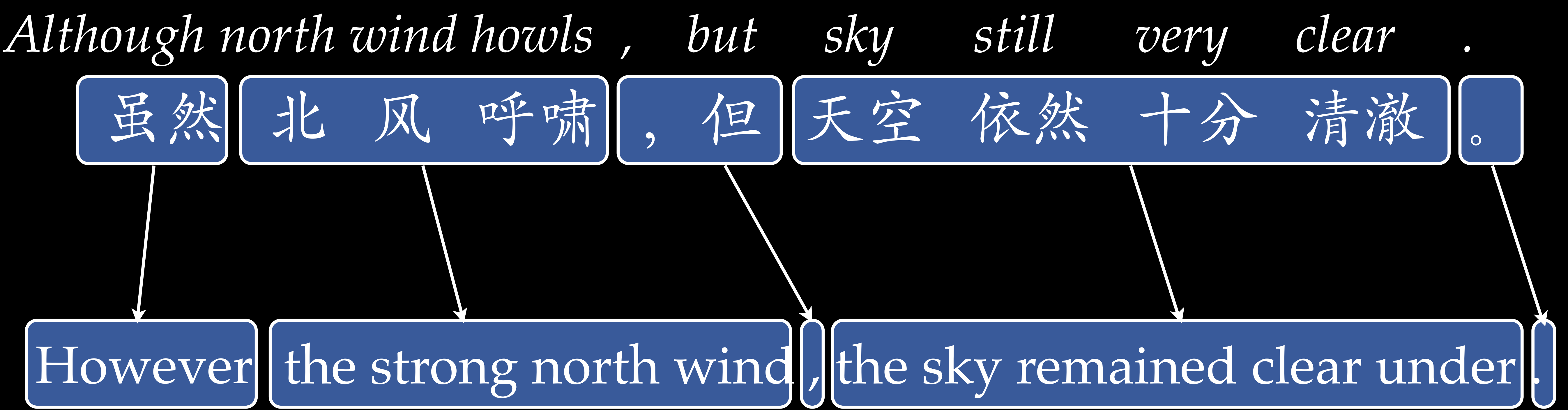

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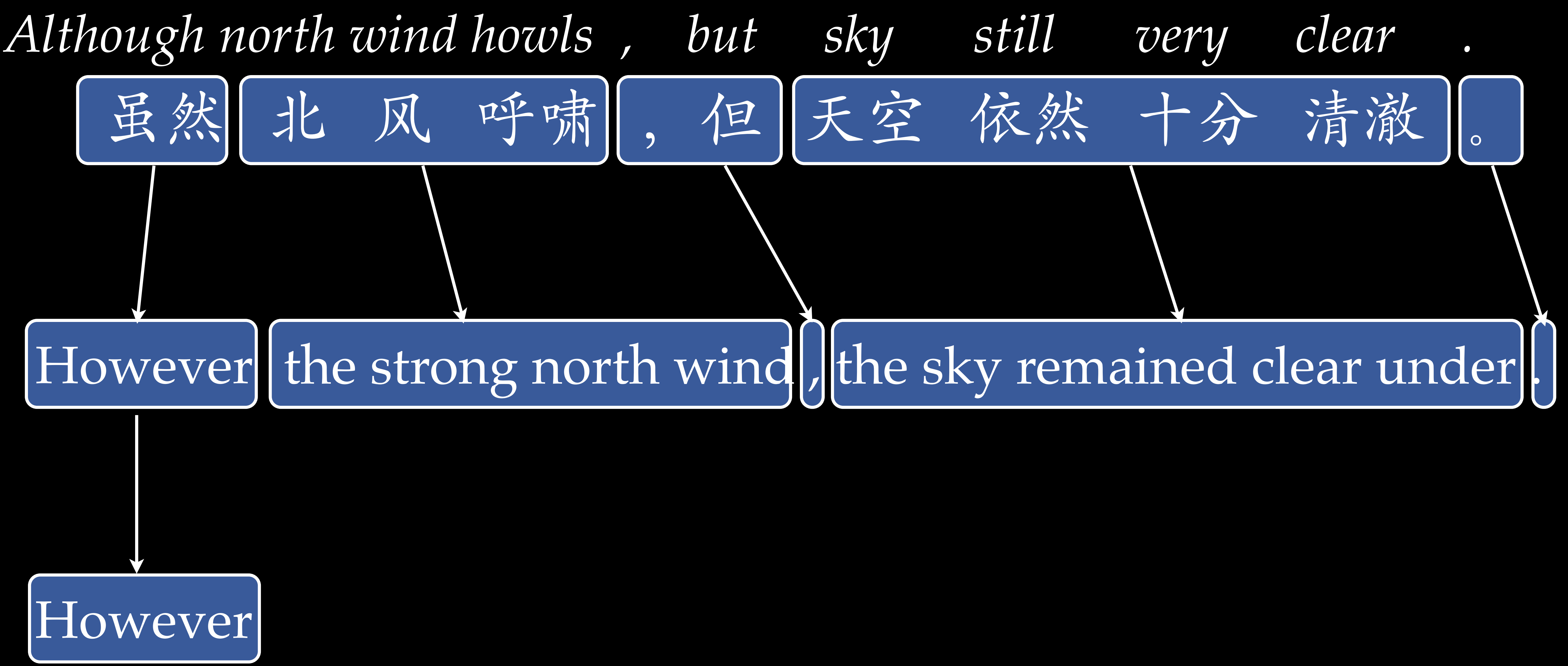
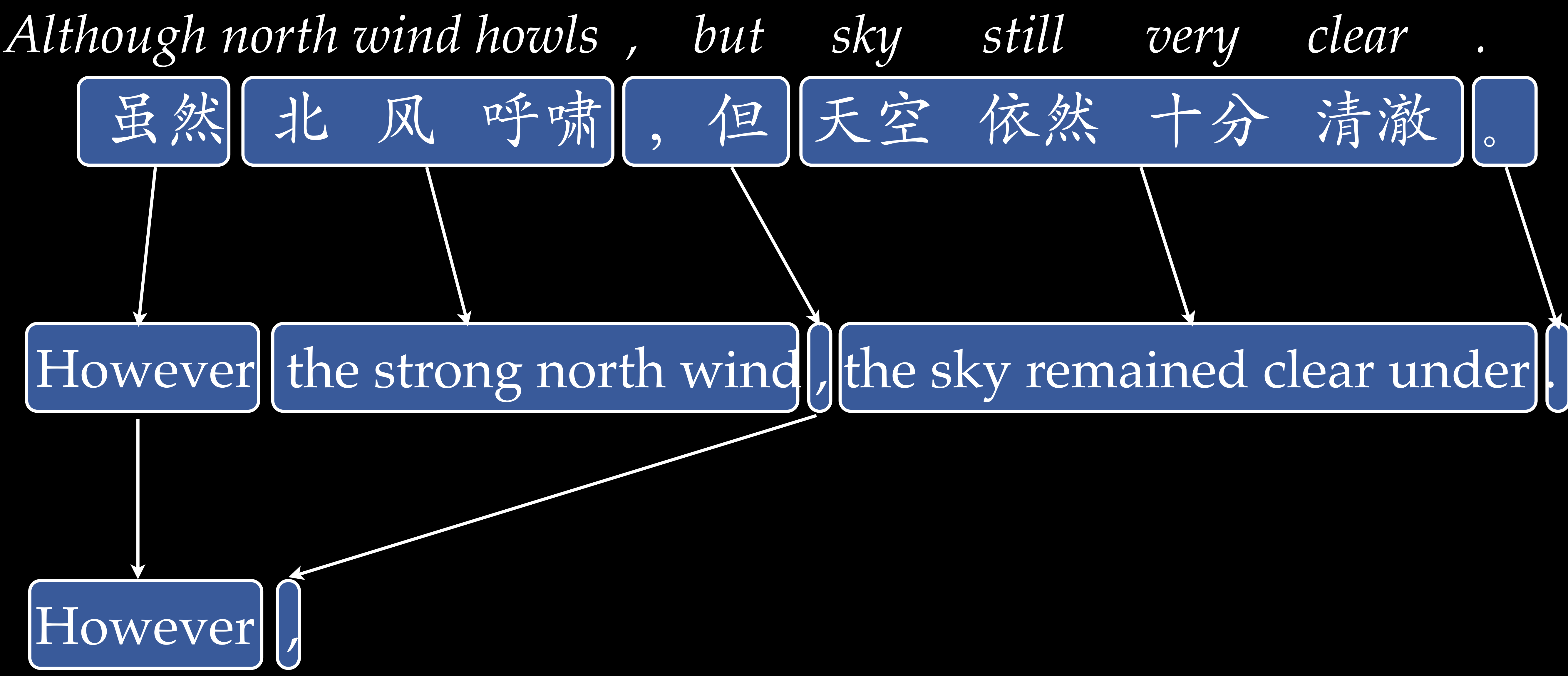


Phrase-based Models



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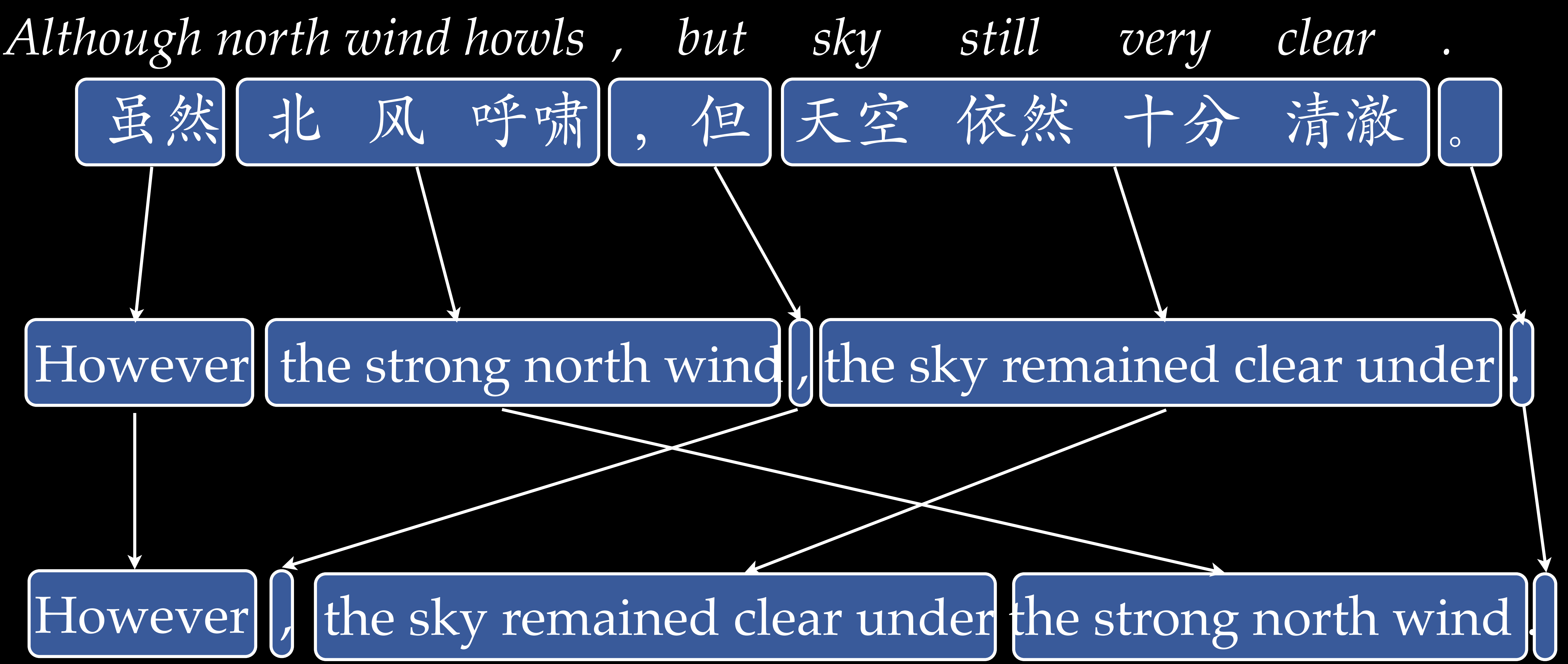

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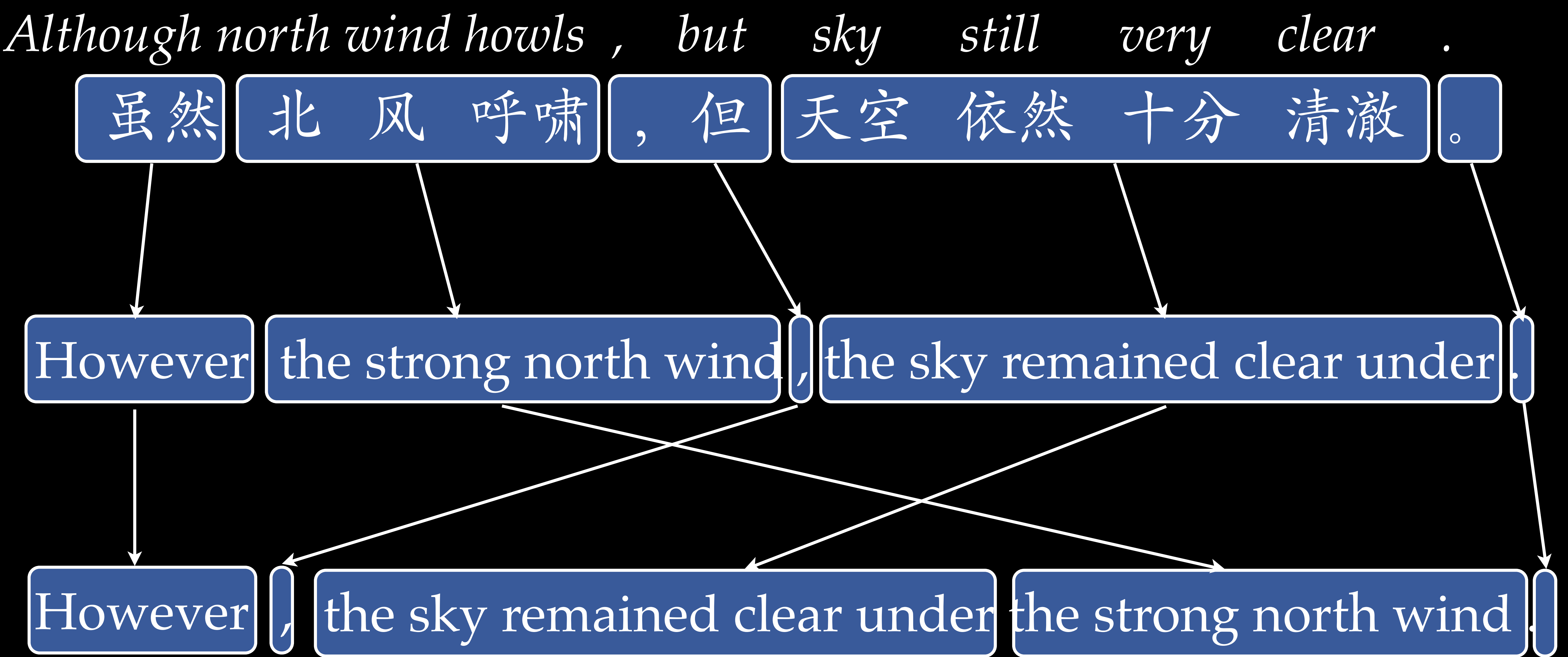
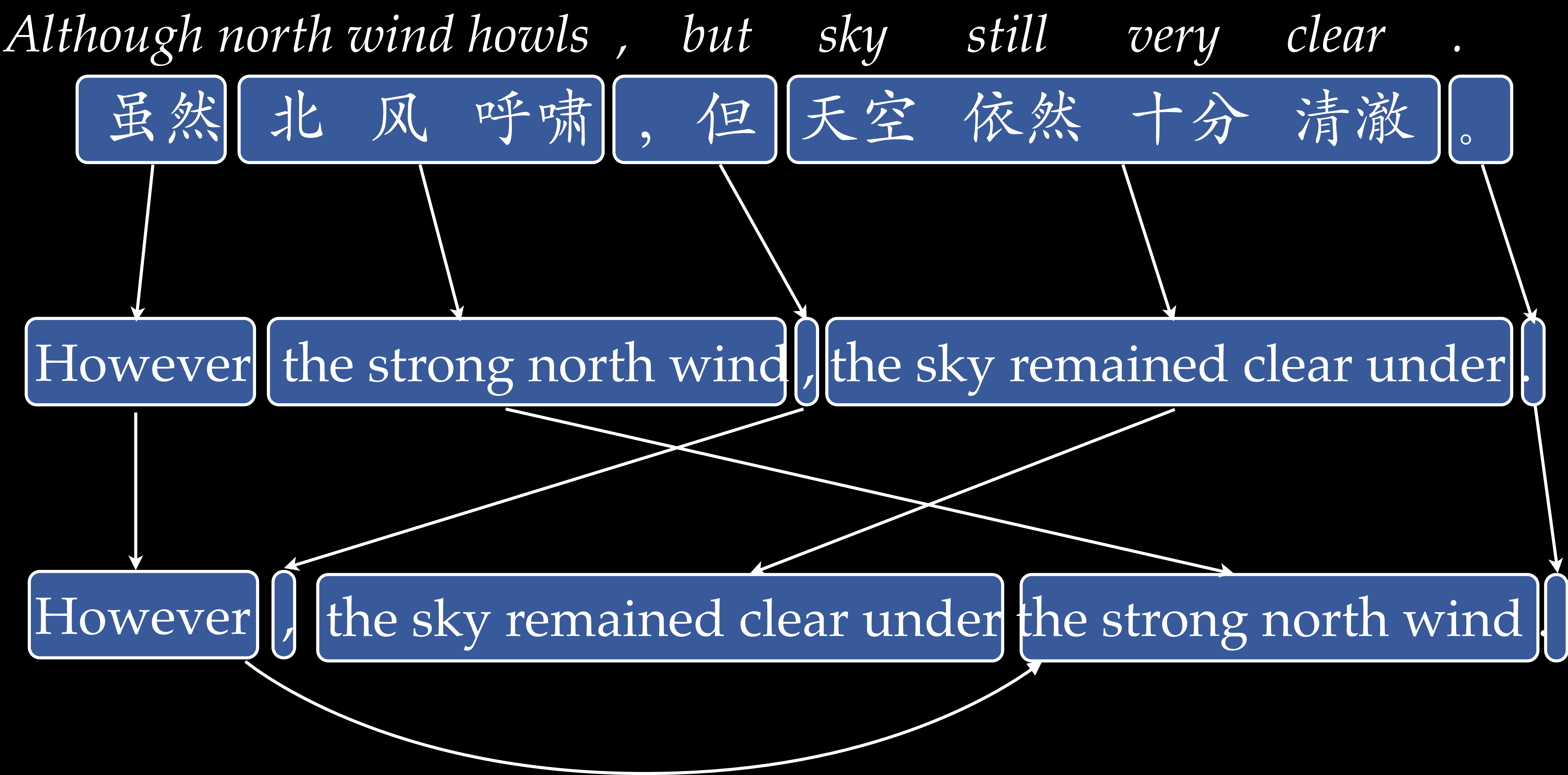


$$p(English, alignment|Chinese) =$$

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

Phrase-based Models



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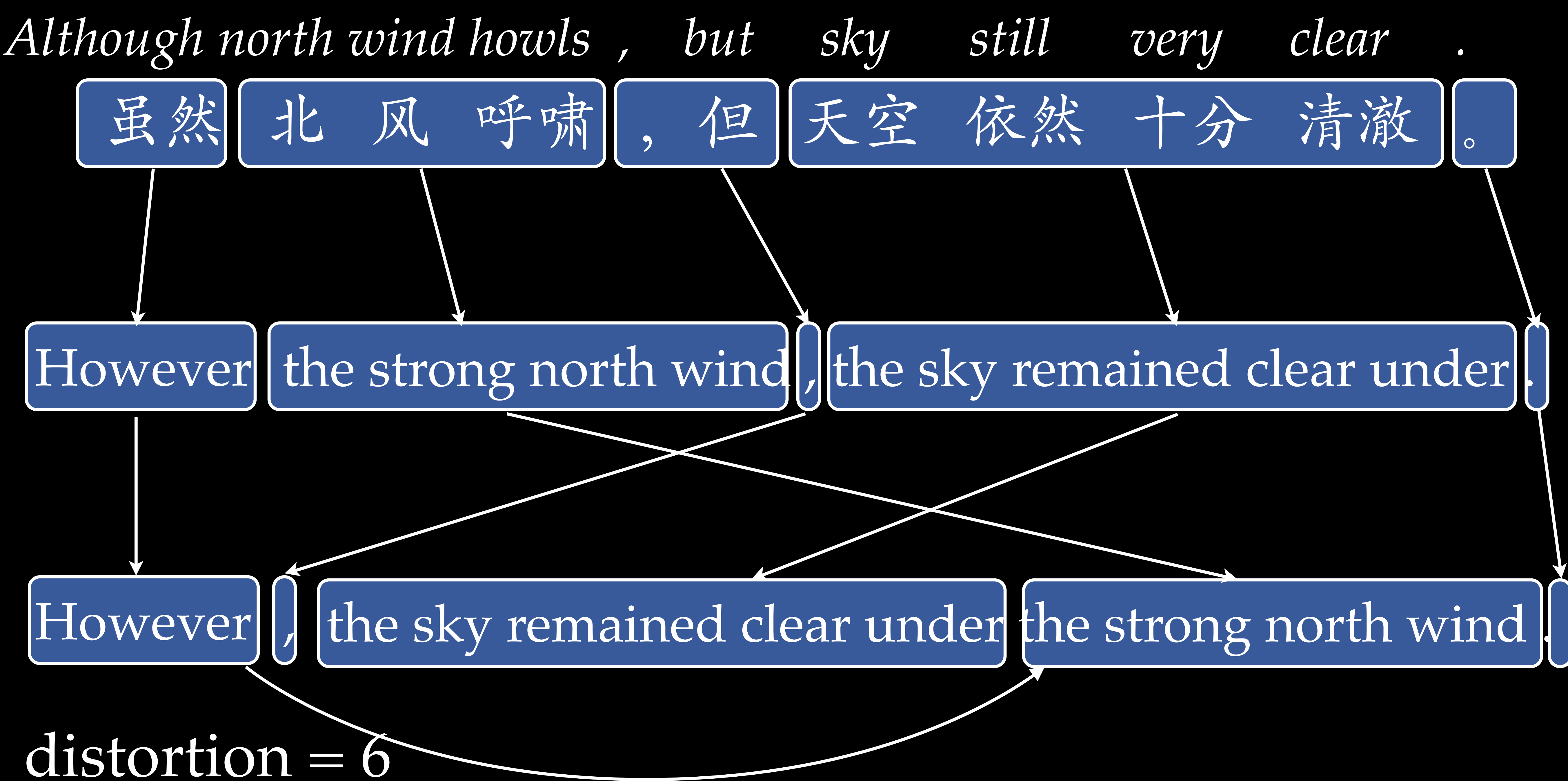

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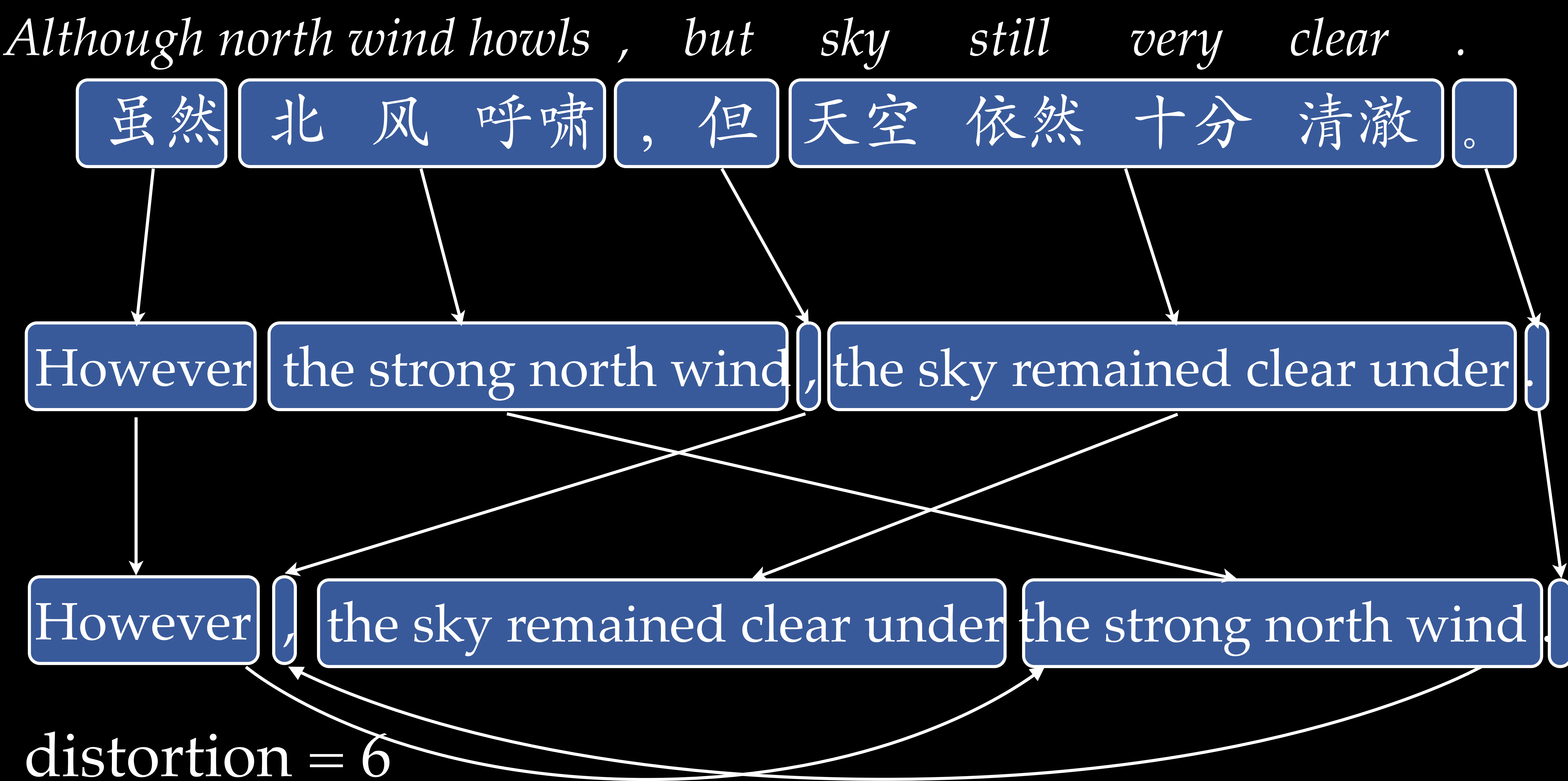

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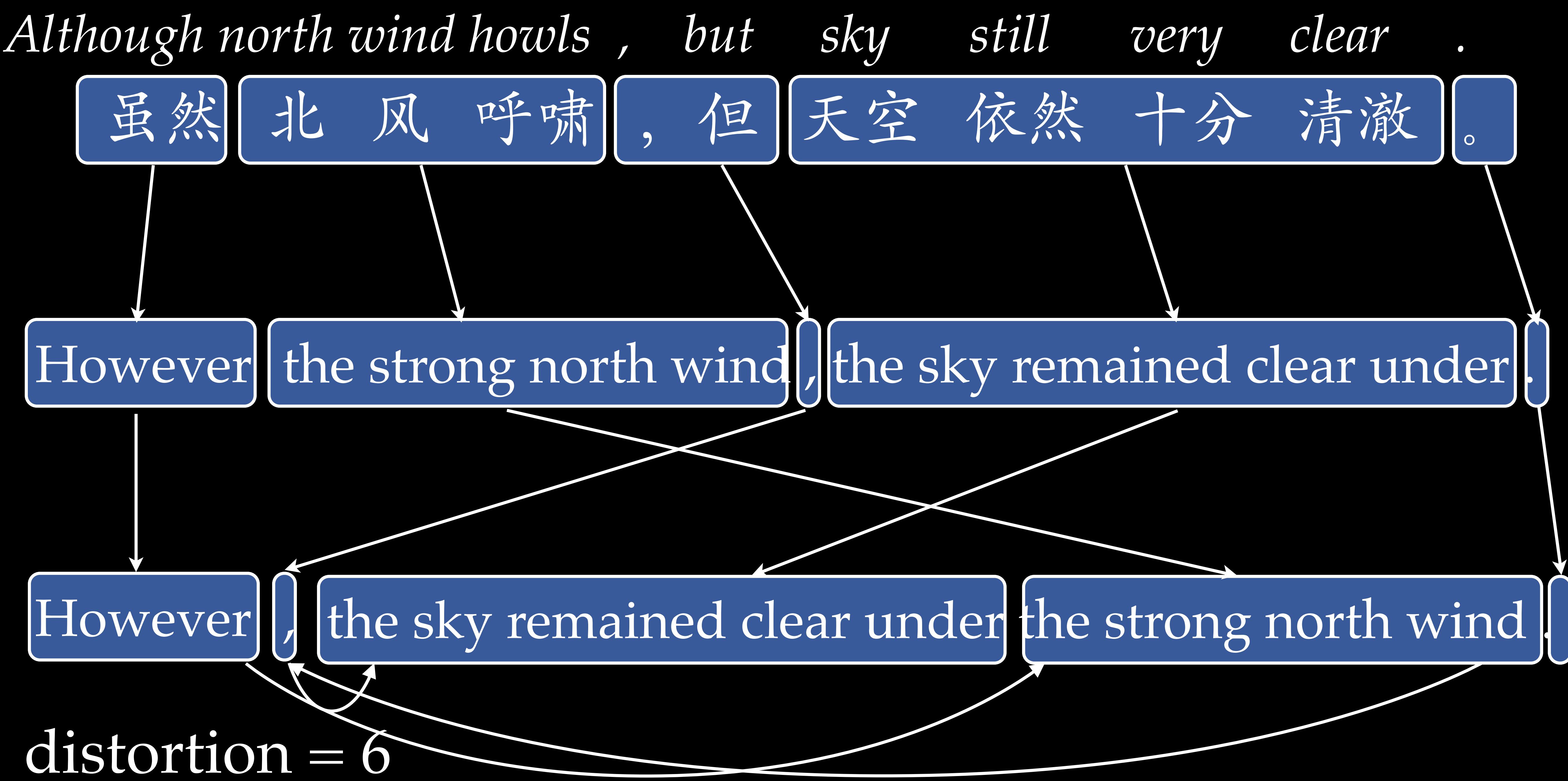

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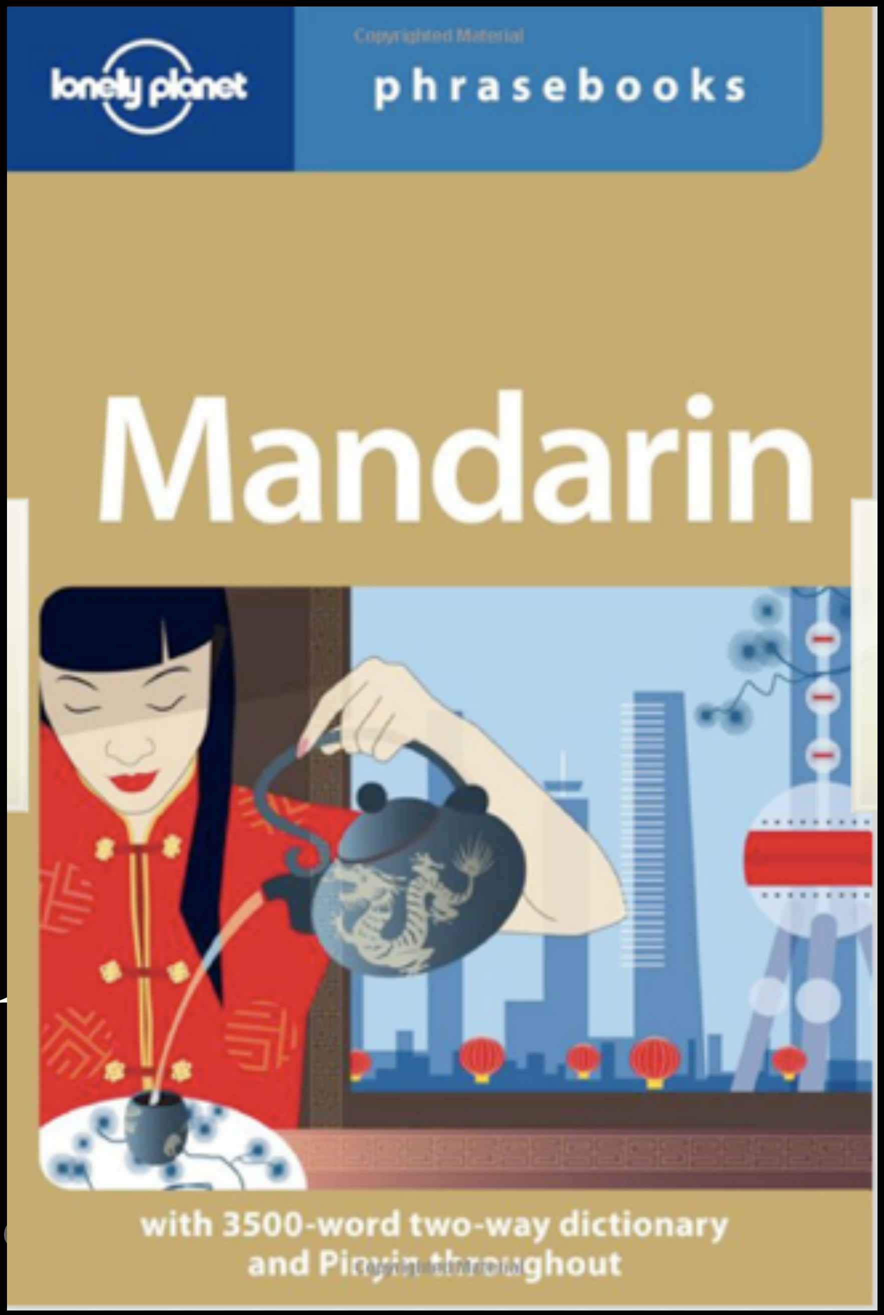

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Phrase-based Models

- 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.

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:

$$p(a_{i,i',j,j'} = 1 | F, E) = \frac{p(a_{i,i',j,j'} = 1, F | E)}{p(F|E)}$$

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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?

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Recap: Expectation Maximization

- Arbitrarily select a set of parameters (say, uniform).
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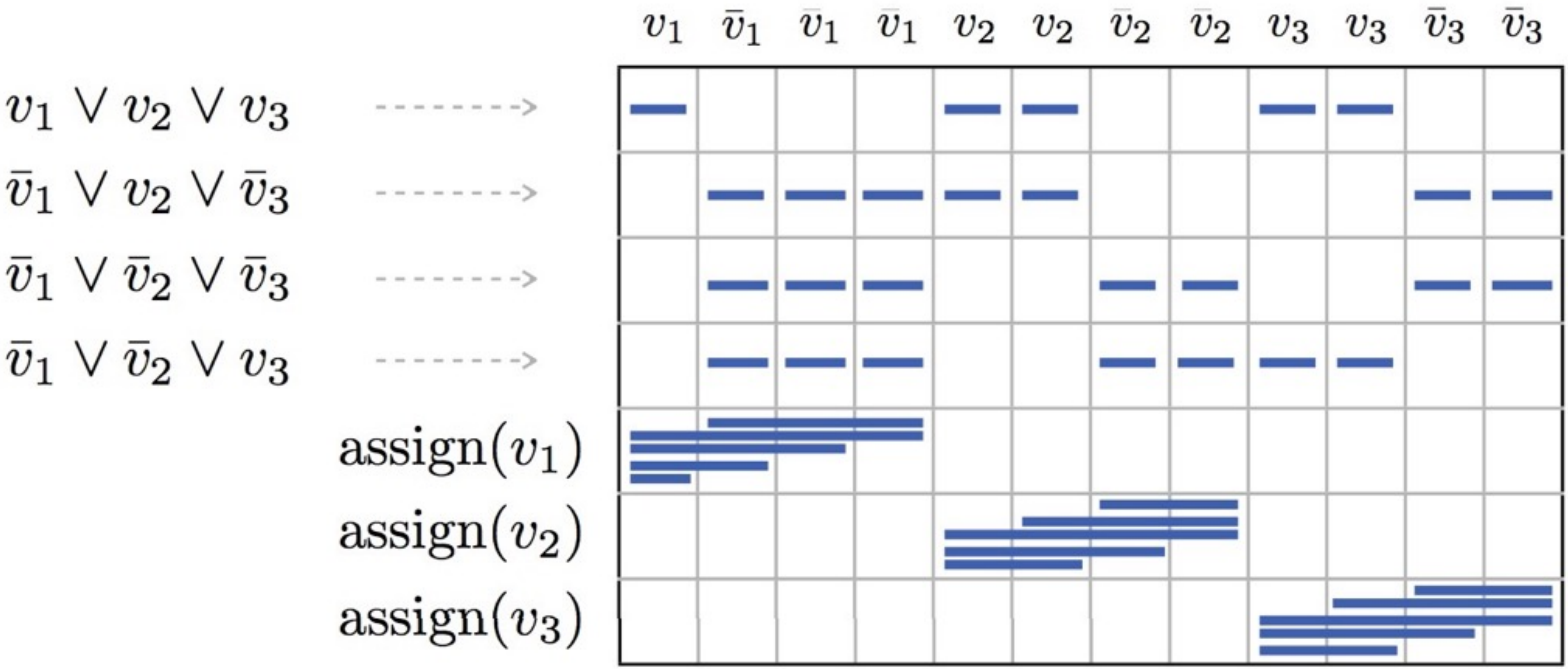
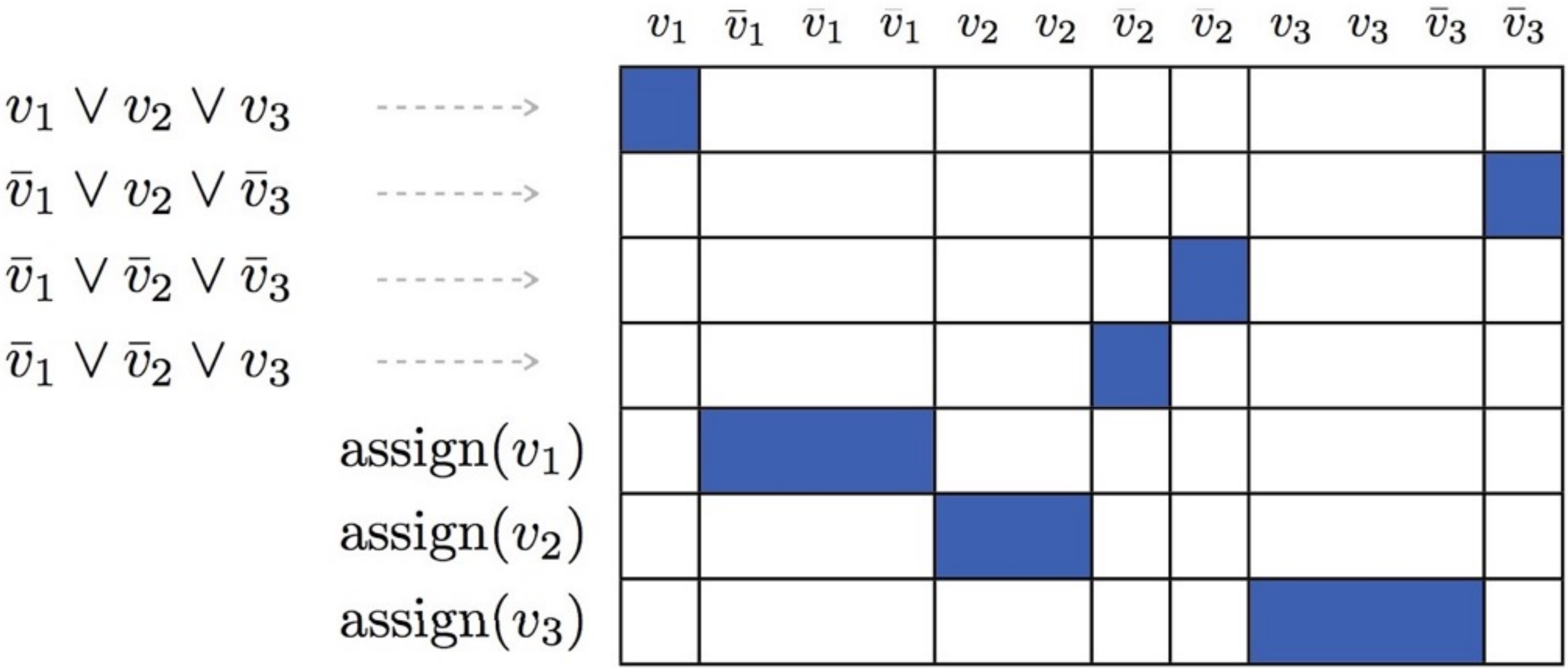
- It
- G n

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


v_1 $\bar{v}_1$ $\bar{v}_1$ $\bar{v}_1$ v_2 v_2 $\bar{v}_2$ $\bar{v}_2$ v_3 v_3 $\bar{v}_3$ $\bar{v}_3$
$v_1 \vee v_2 \vee v_3$
$\bar{v}_1 \vee v_2 \vee \bar{v}_3$
$\bar{v}_1 \vee \bar{v}_2 \vee \bar{v}_3$
$\bar{v}_1 \vee \bar{v}_2 \vee v_3$
$\mathrm{assign}(v_1)$
$\mathrm{assign}(v_2)$
$\mathrm{assign}(v_3)$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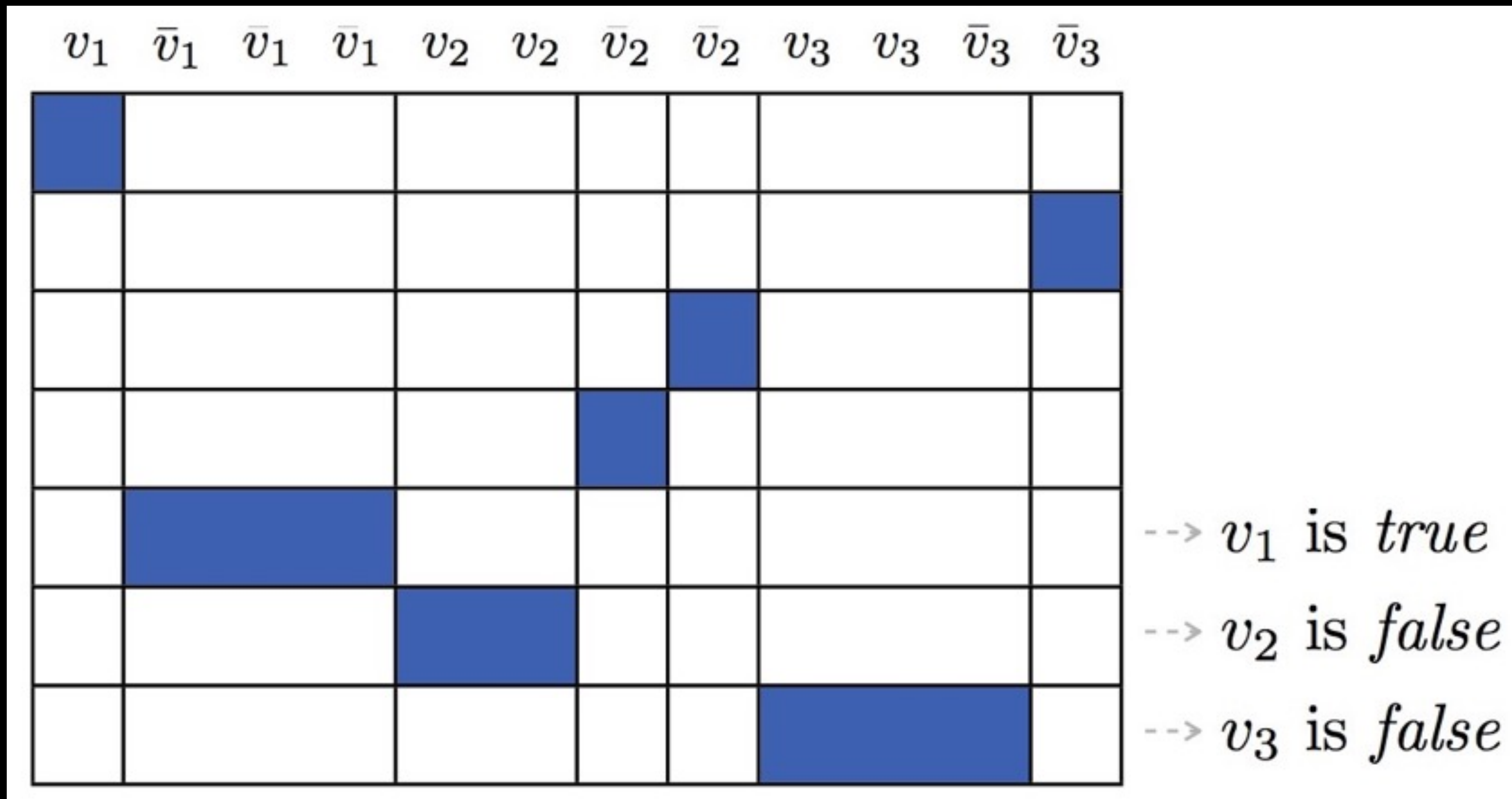


v_1 $\bar{v}_1$ $\bar{v}_1$ $\bar{v}_1$ v_2 v_2 $\bar{v}_2$ $\bar{v}_2$ v_3 v_3 $\bar{v}_3$ $\bar{v}_3$
v_1 is *true*
v_2 is *false*
v_3 is *false*

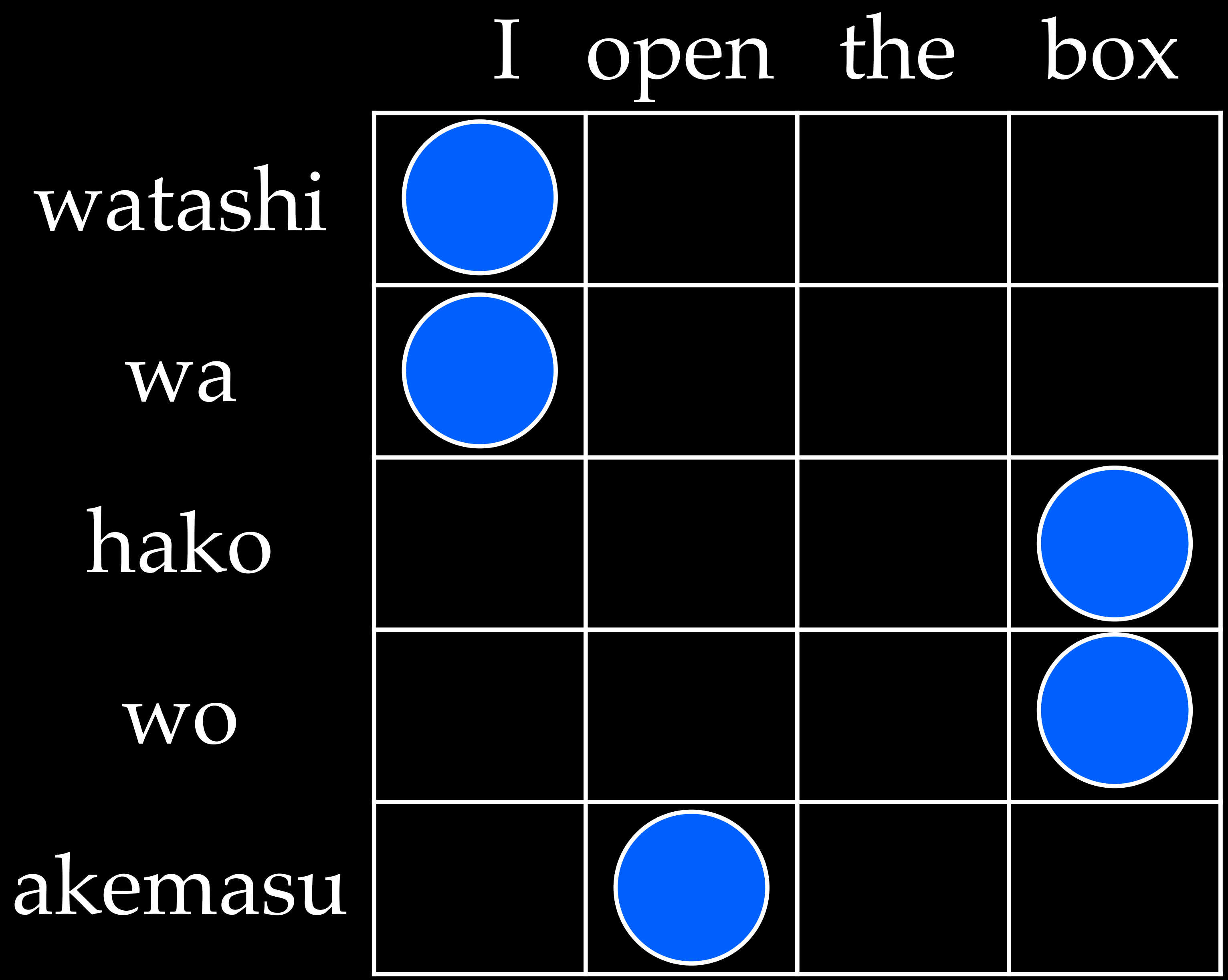
Now What?

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

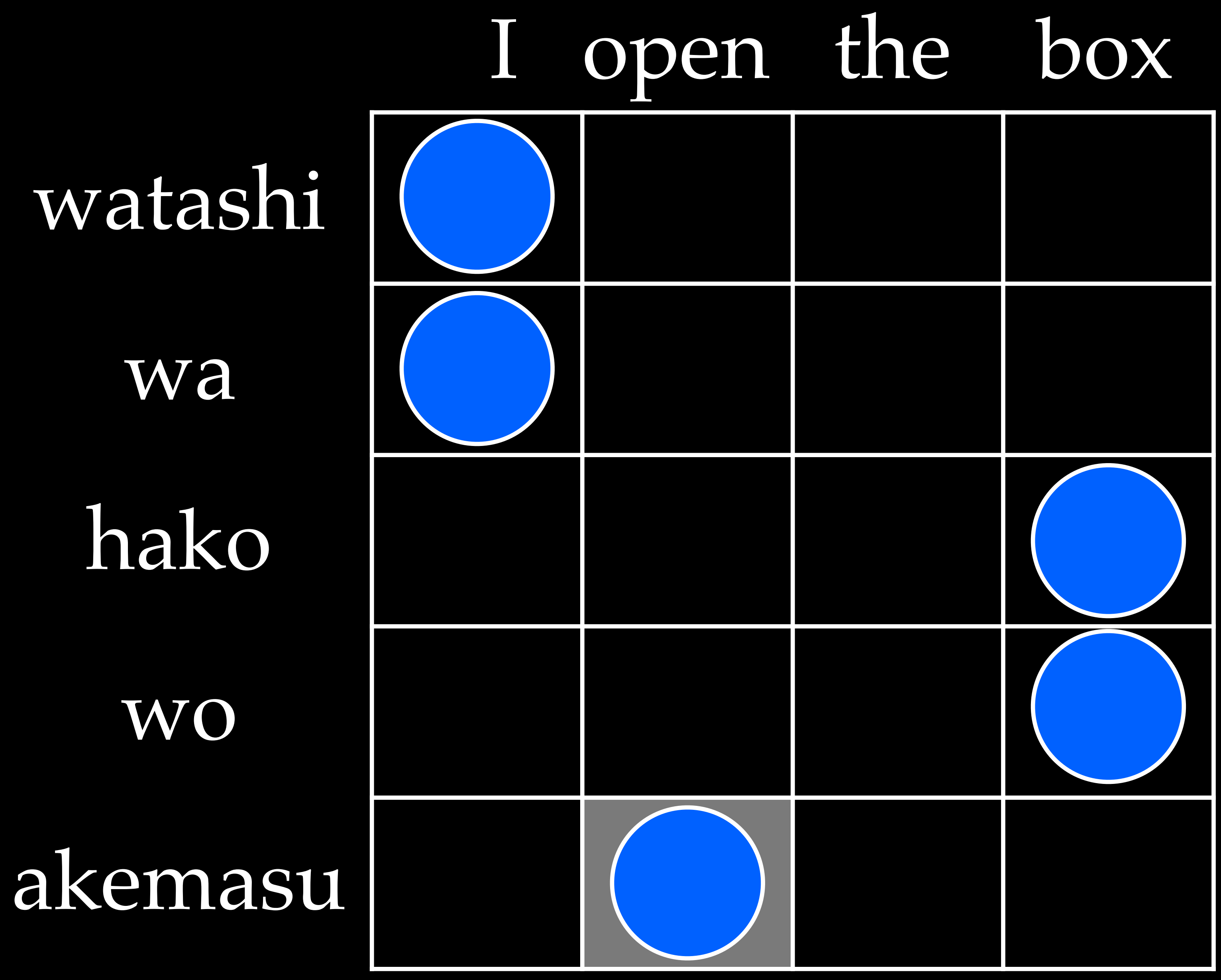
Now What?

- 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

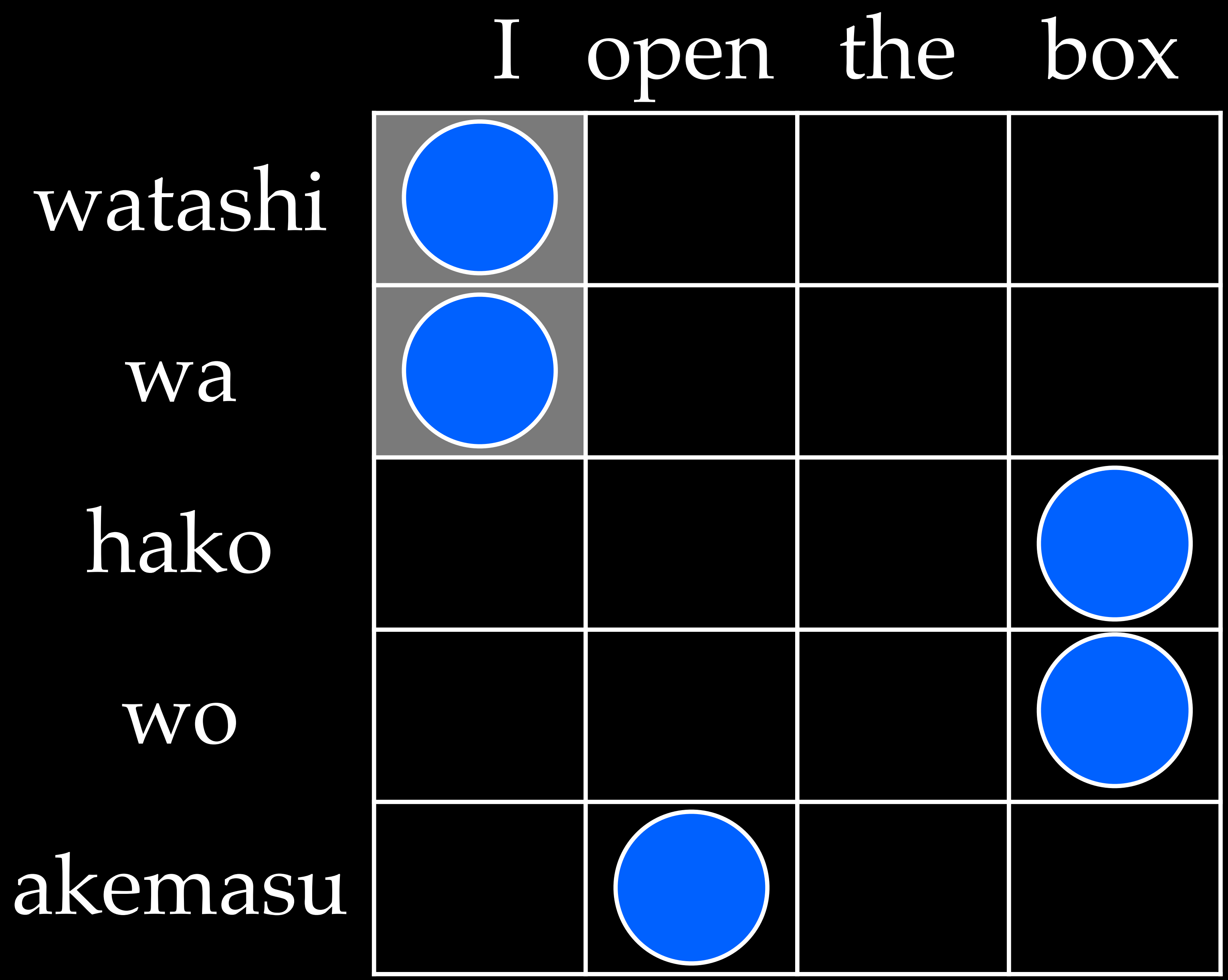


Phrase Extraction



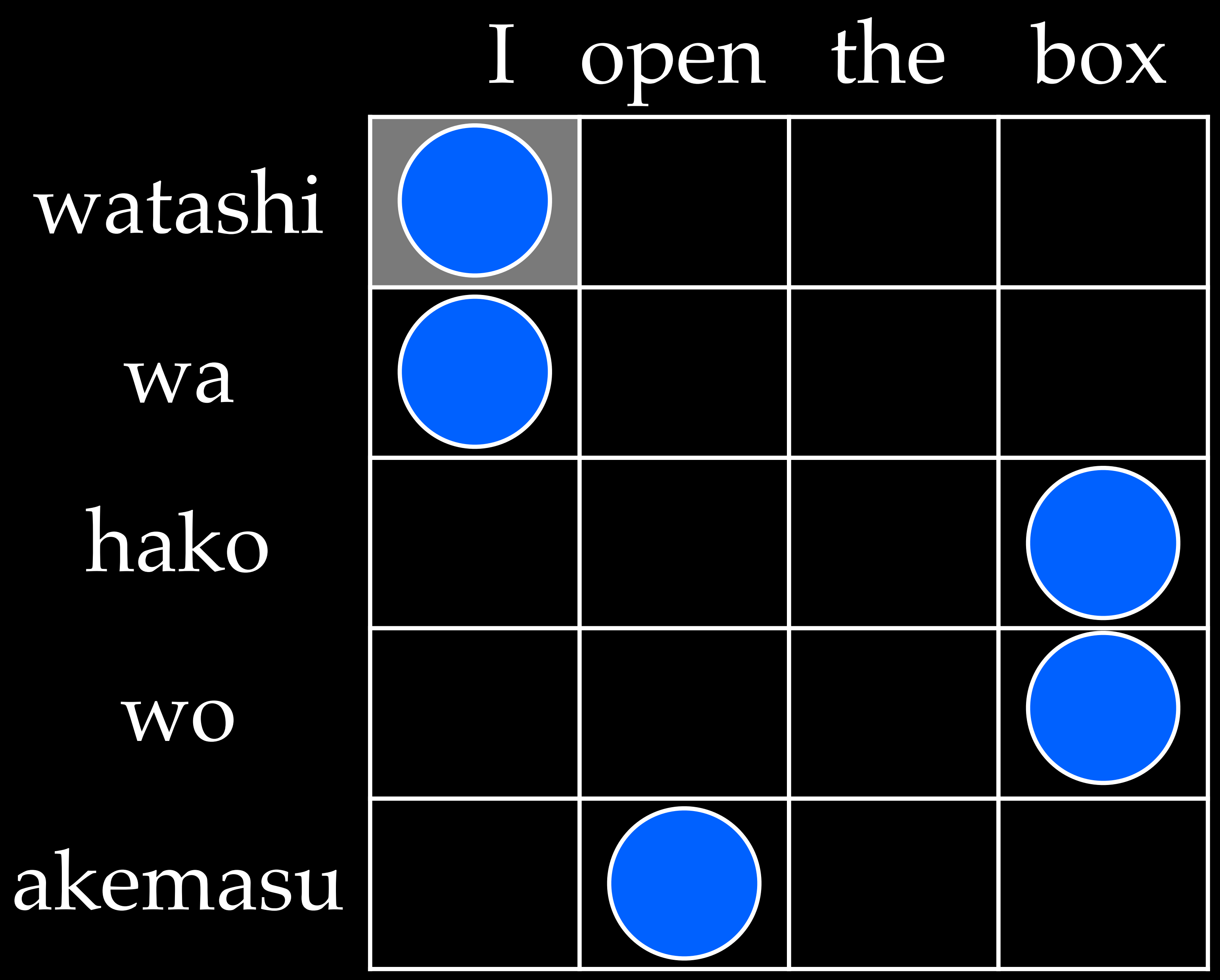
akemasu / open

Phrase Extraction



watashi wa / I

Phrase Extraction



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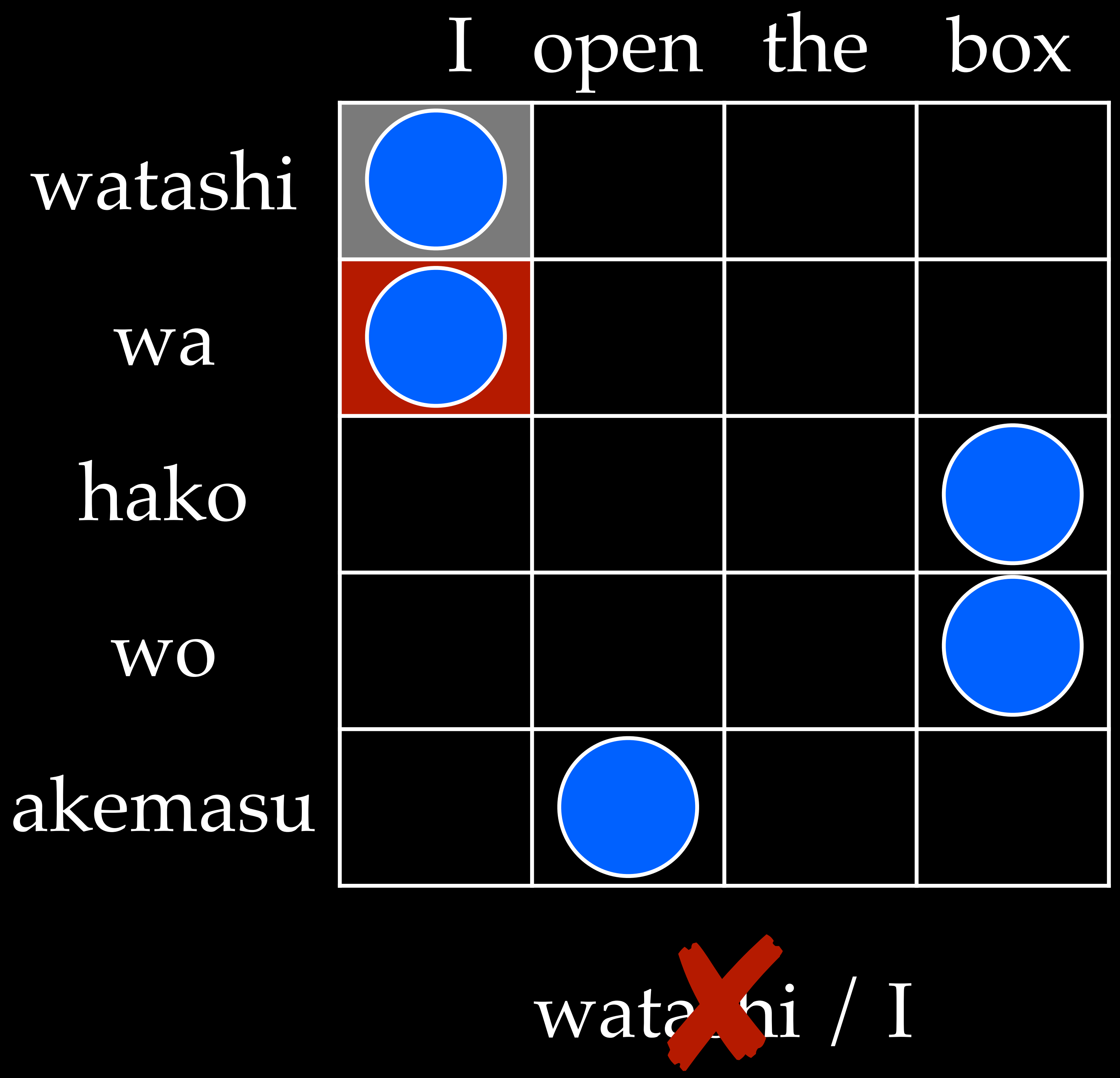

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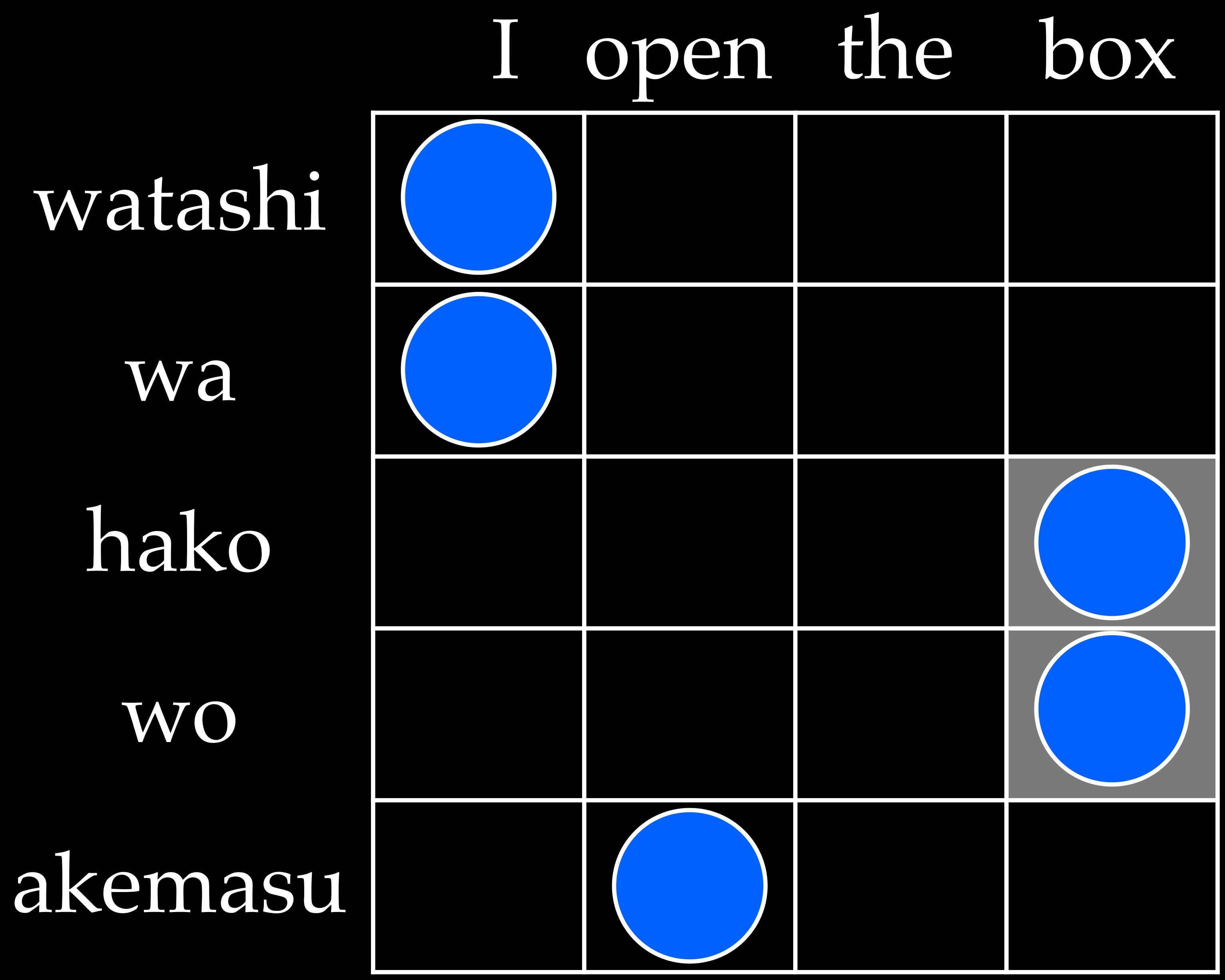
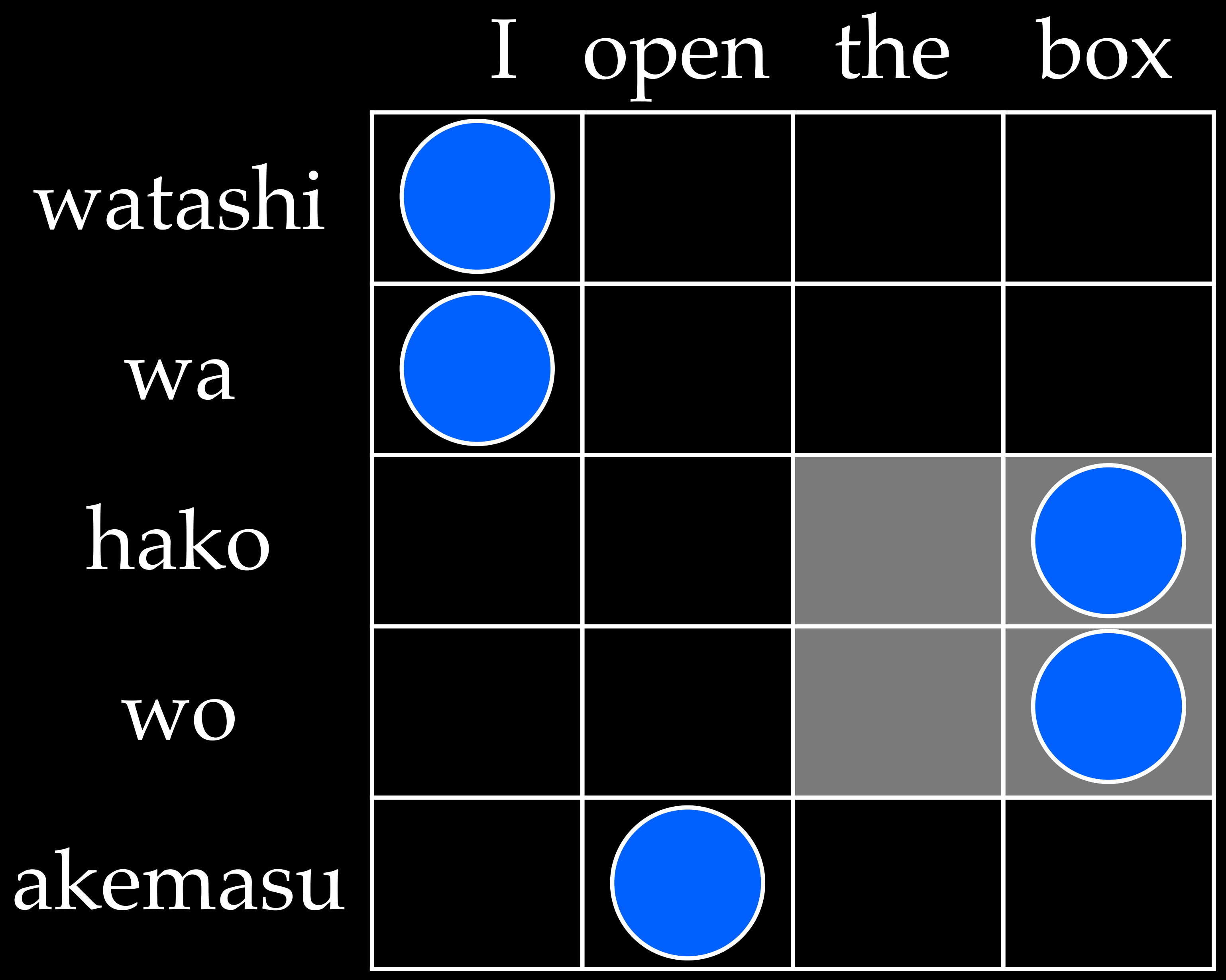


hako wo / box

Phrase Extraction



hako wo / the box

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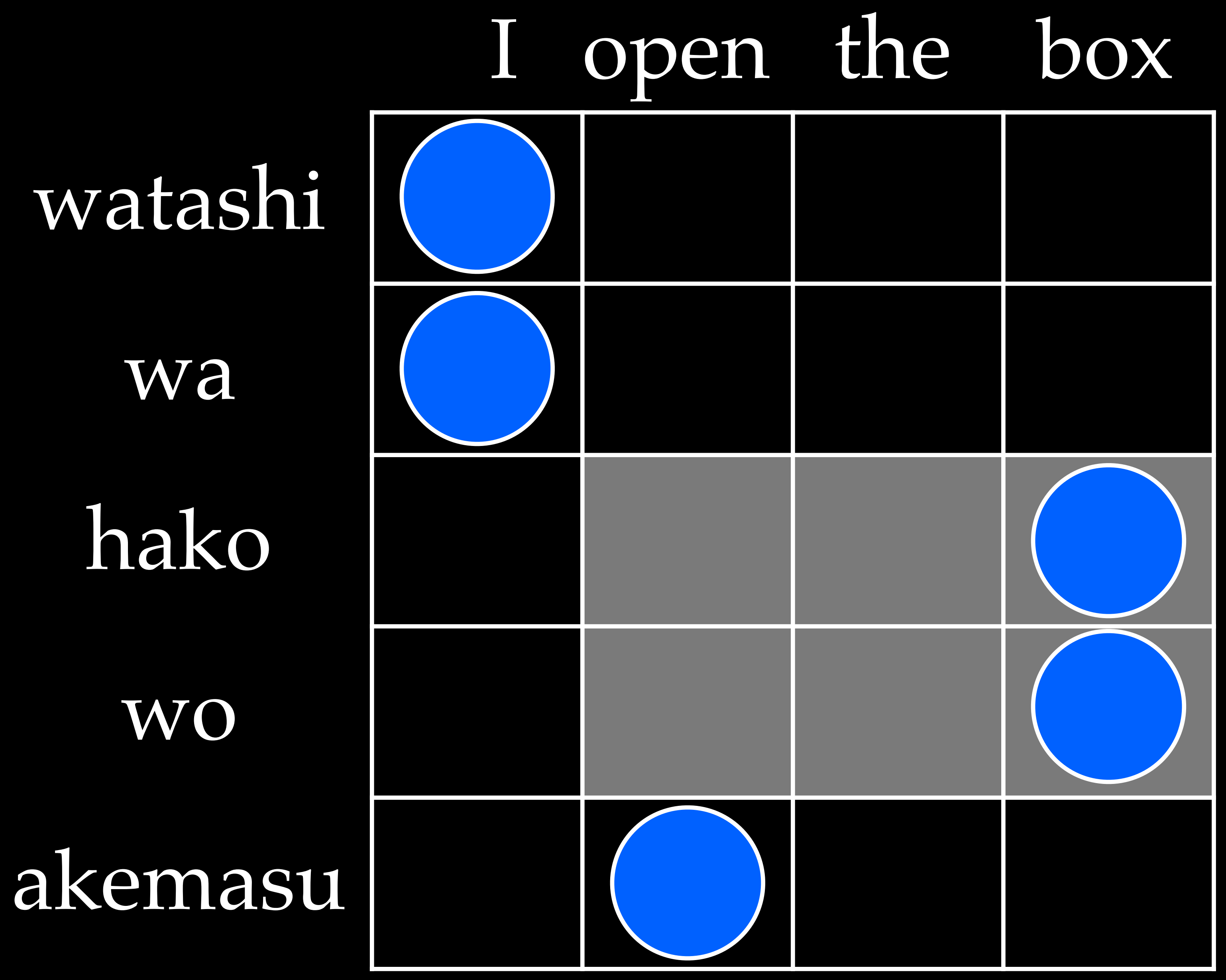

hako wo / open the box

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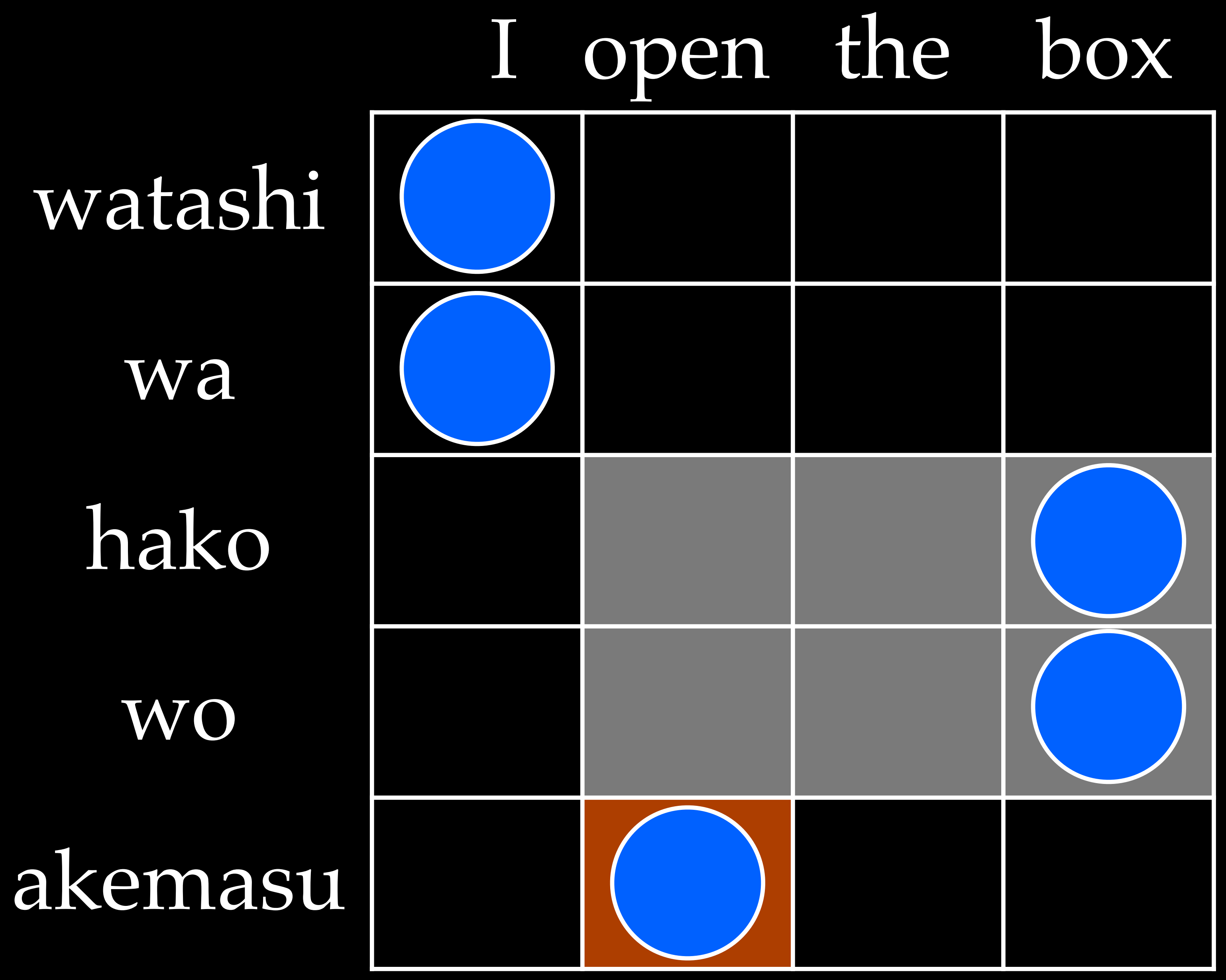

hako wo / ~~o~~pen the box

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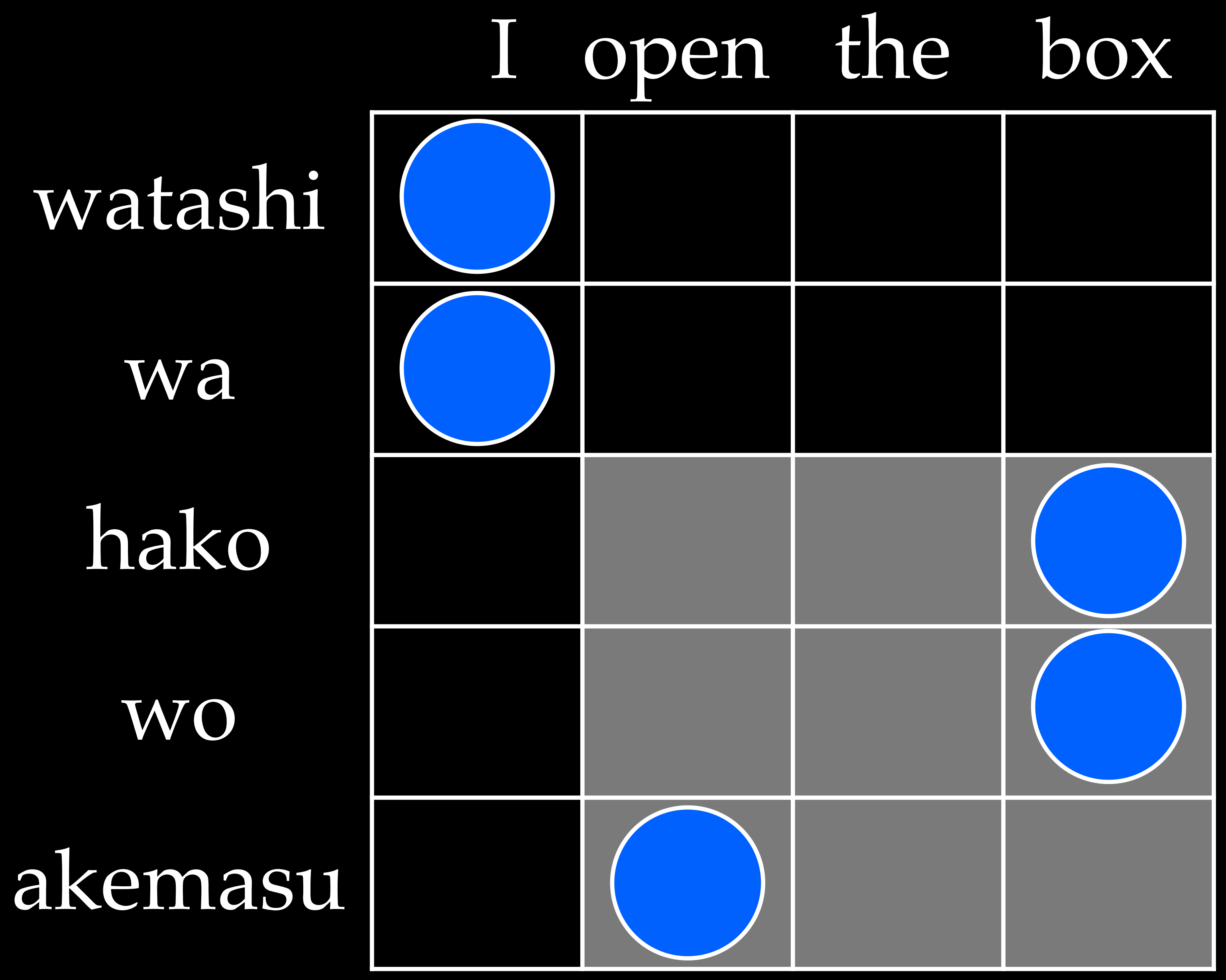

hako wo akemasu / open the box

Phrasal Translation Estimation

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- Option #1 (EM over restricted space)
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Phrasal Translation Estimation

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  - 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.

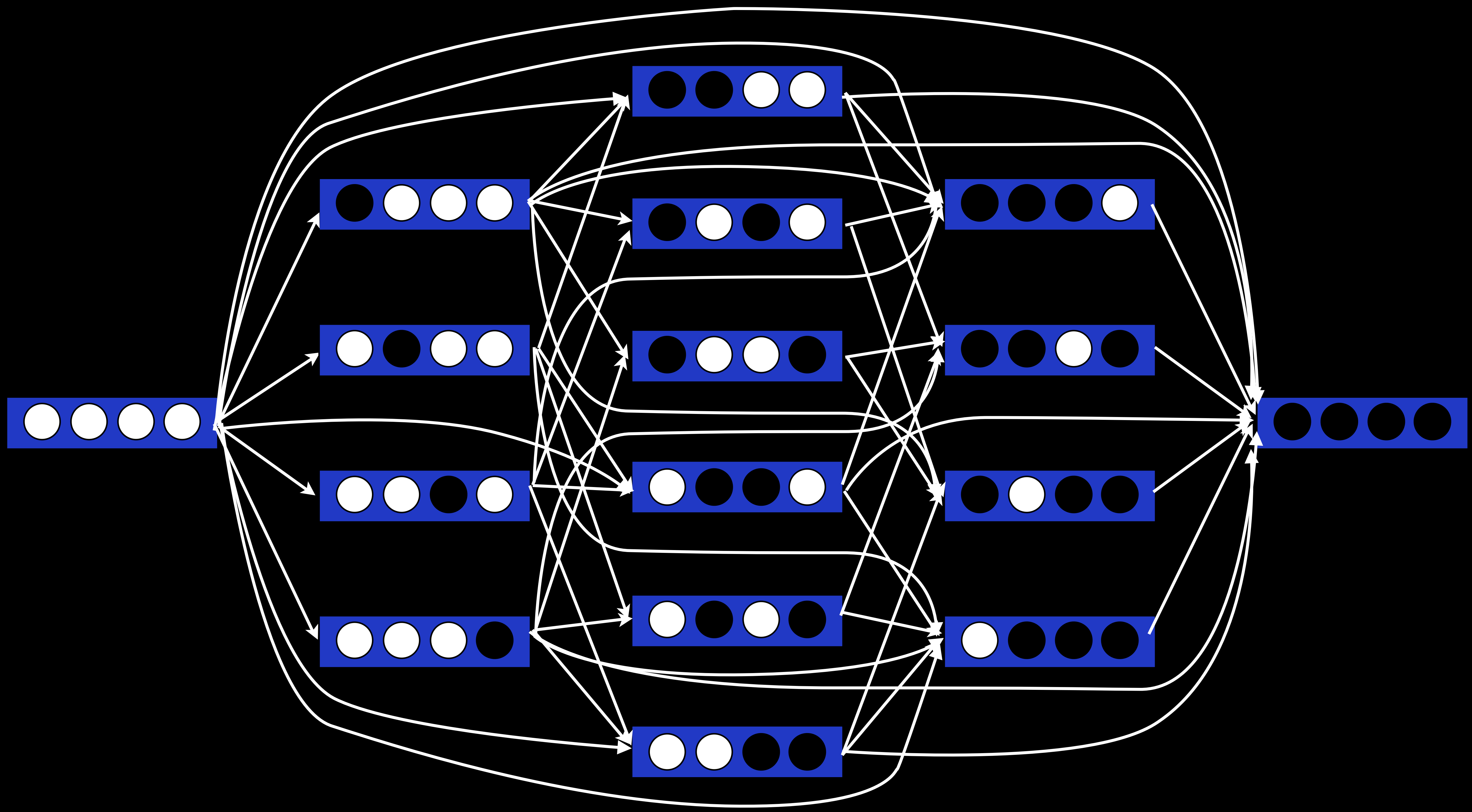
Decoding

We want to solve this problem:

$$e^* = \arg\max_e p(\mathbf{e}|\mathbf{f})$$

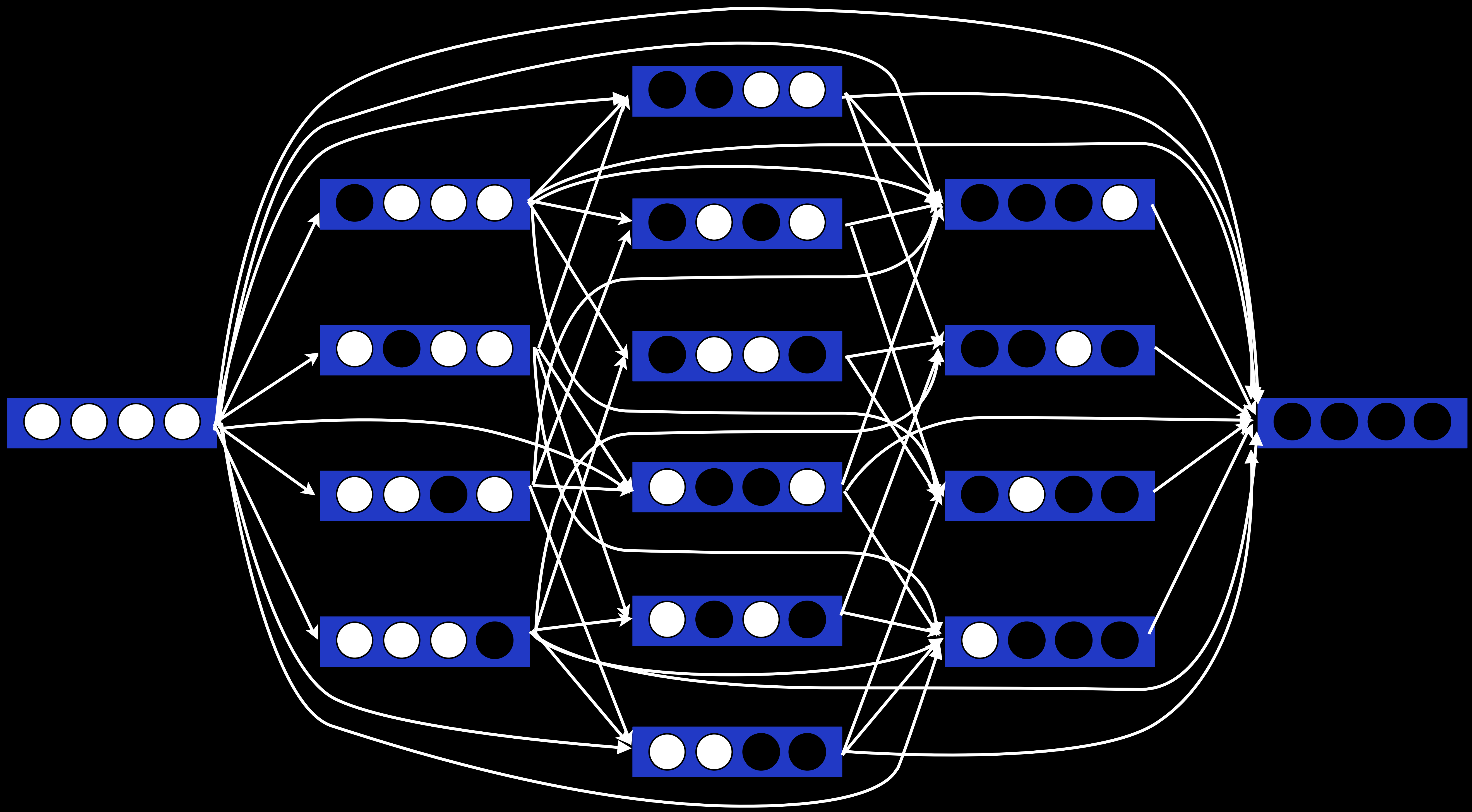
Does this problem look familiar?

Decoding similar to IBM4



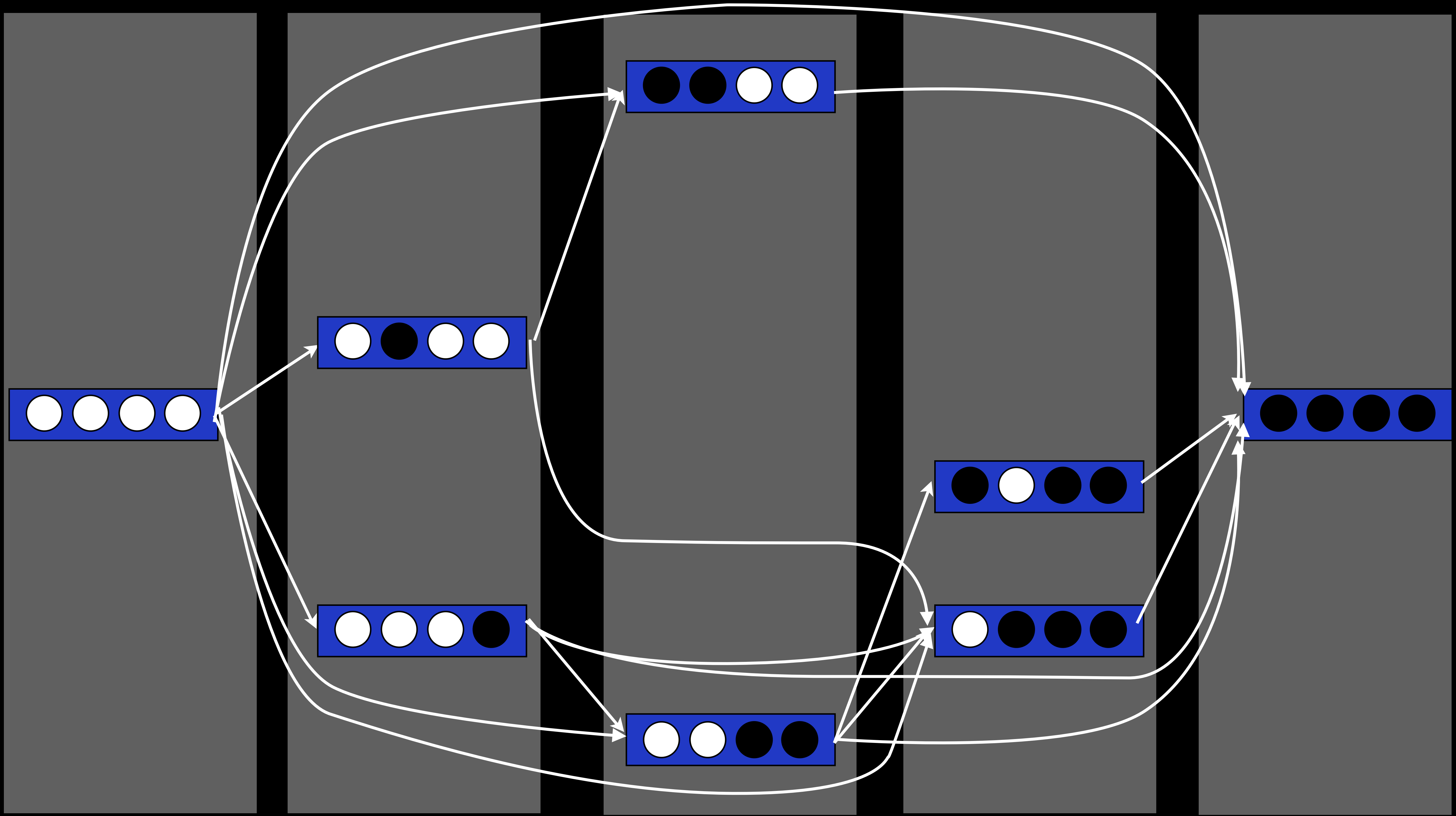
Dynamic Programming

Decoding similar to IBM4

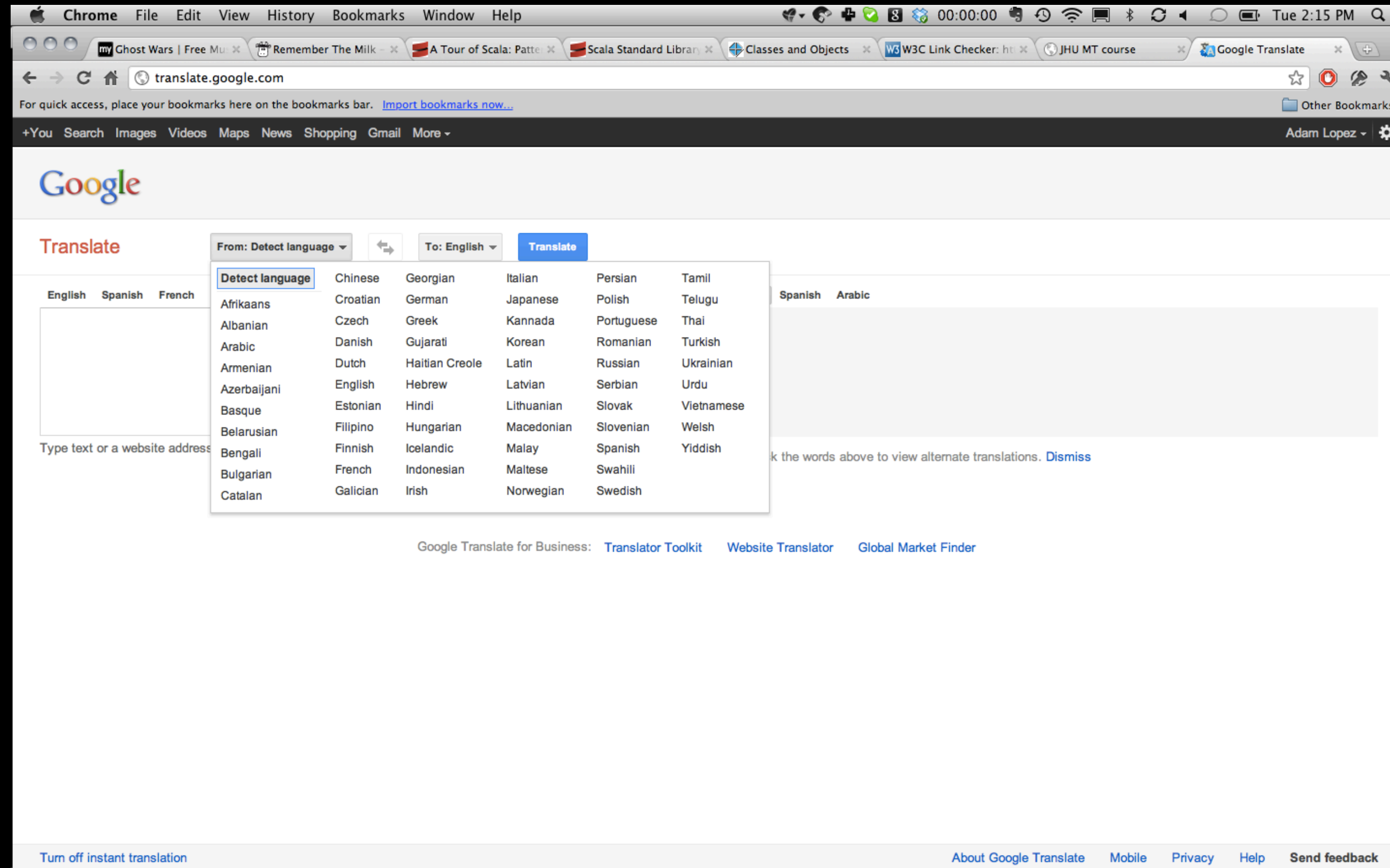


Dynamic Programming

Approximation: Pruning



Similar approximations applicable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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
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Armenian
Azerbaijani
Basque
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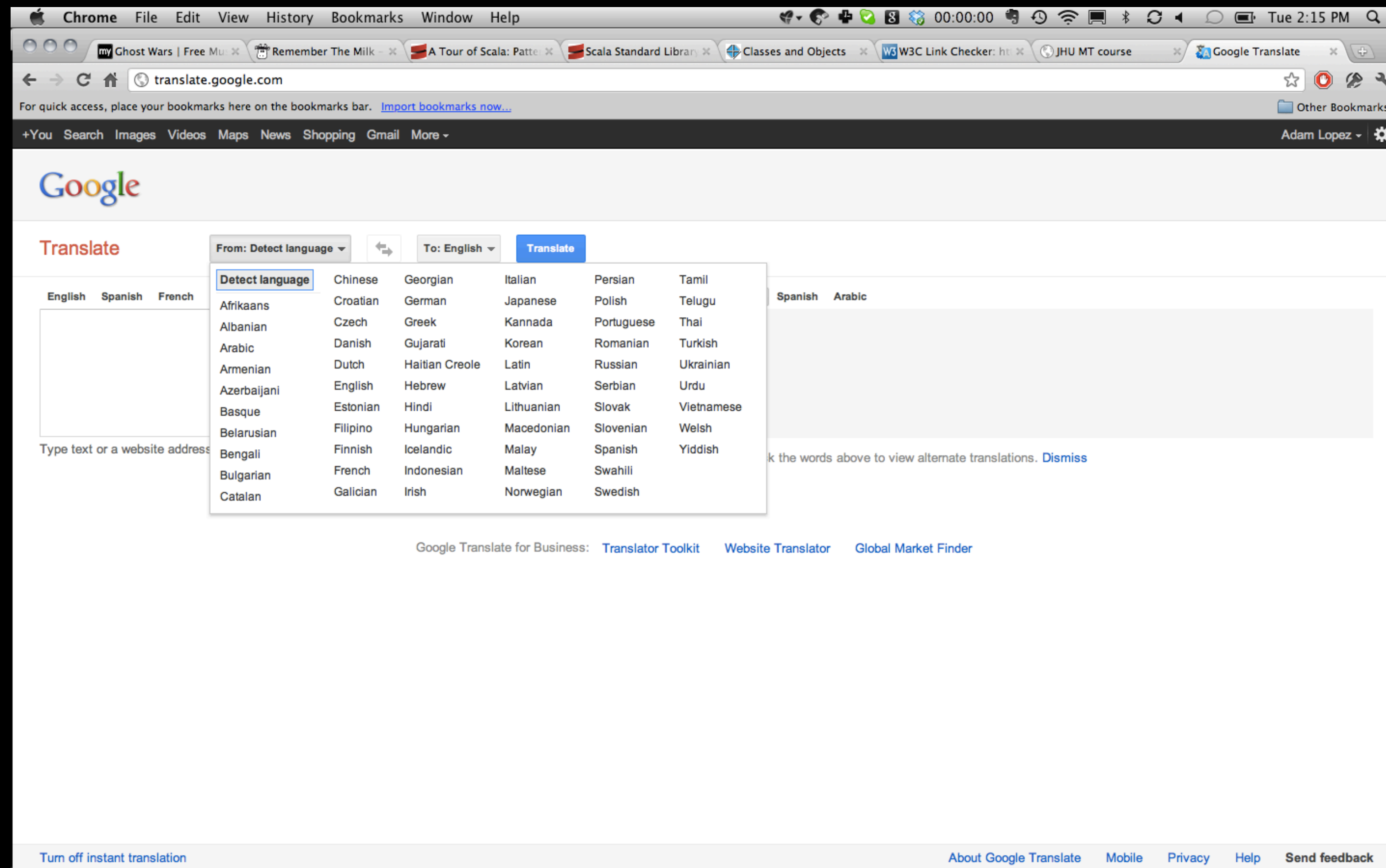
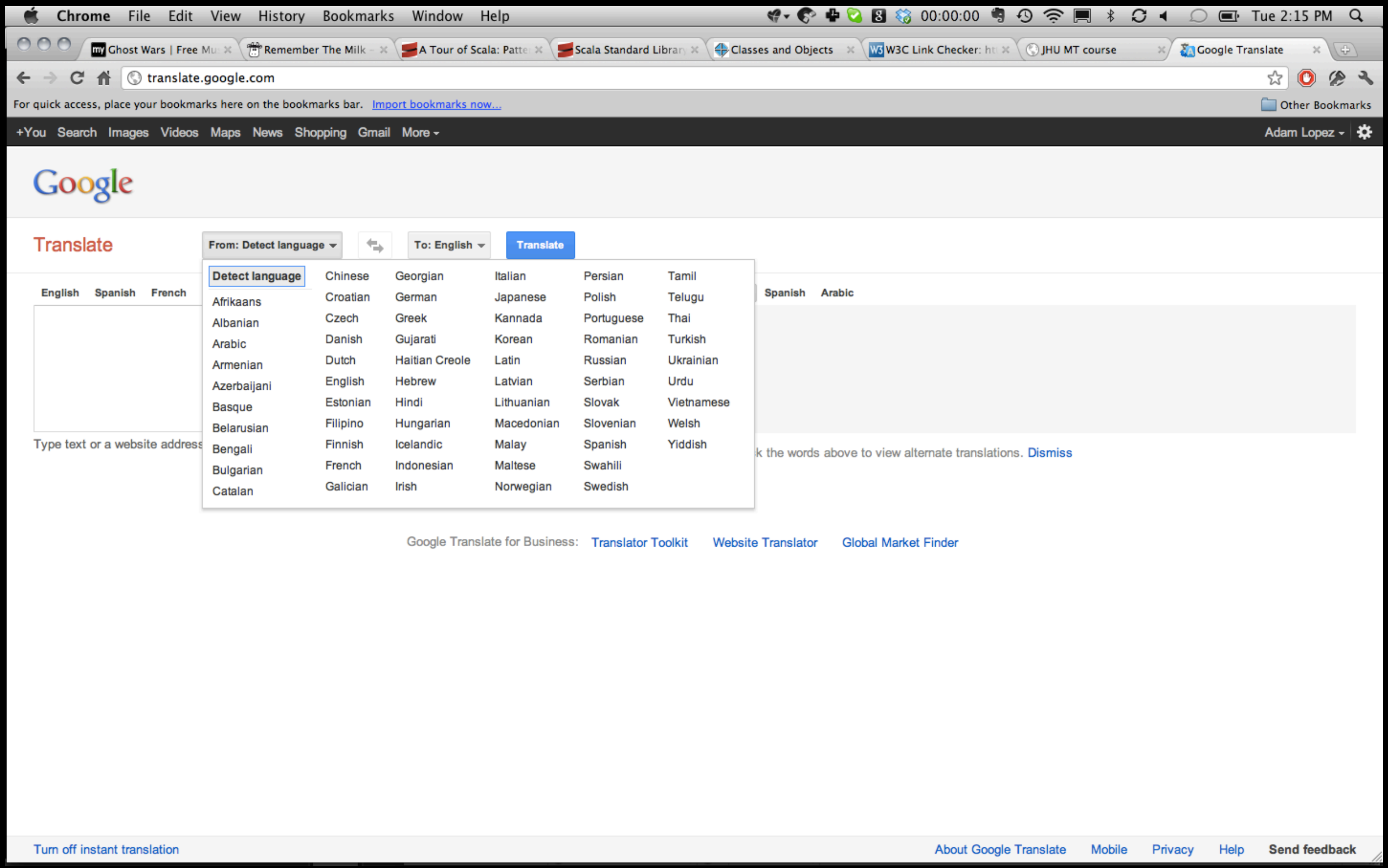


- Key ingredients in Google Translate (2006-2017):



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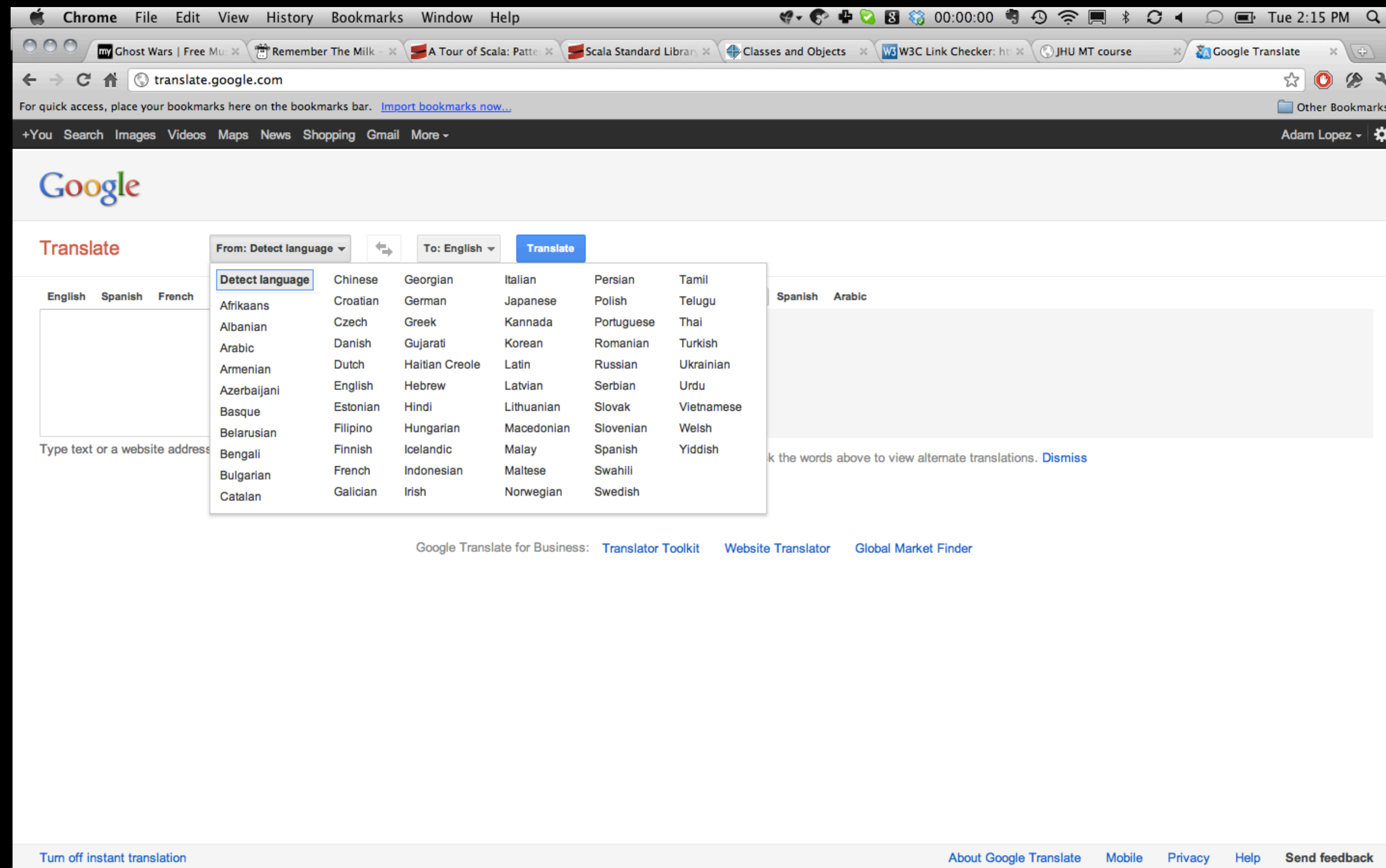

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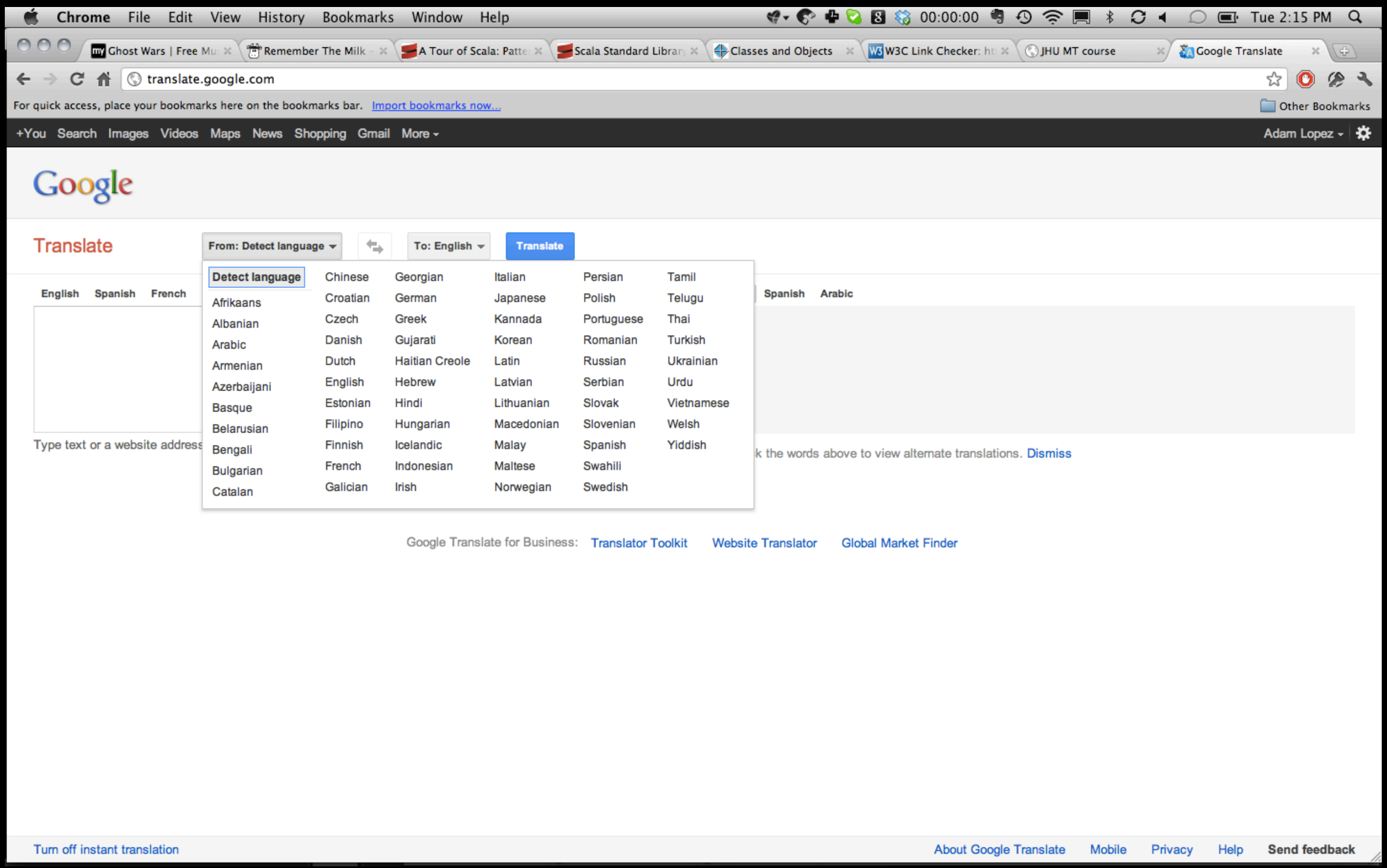

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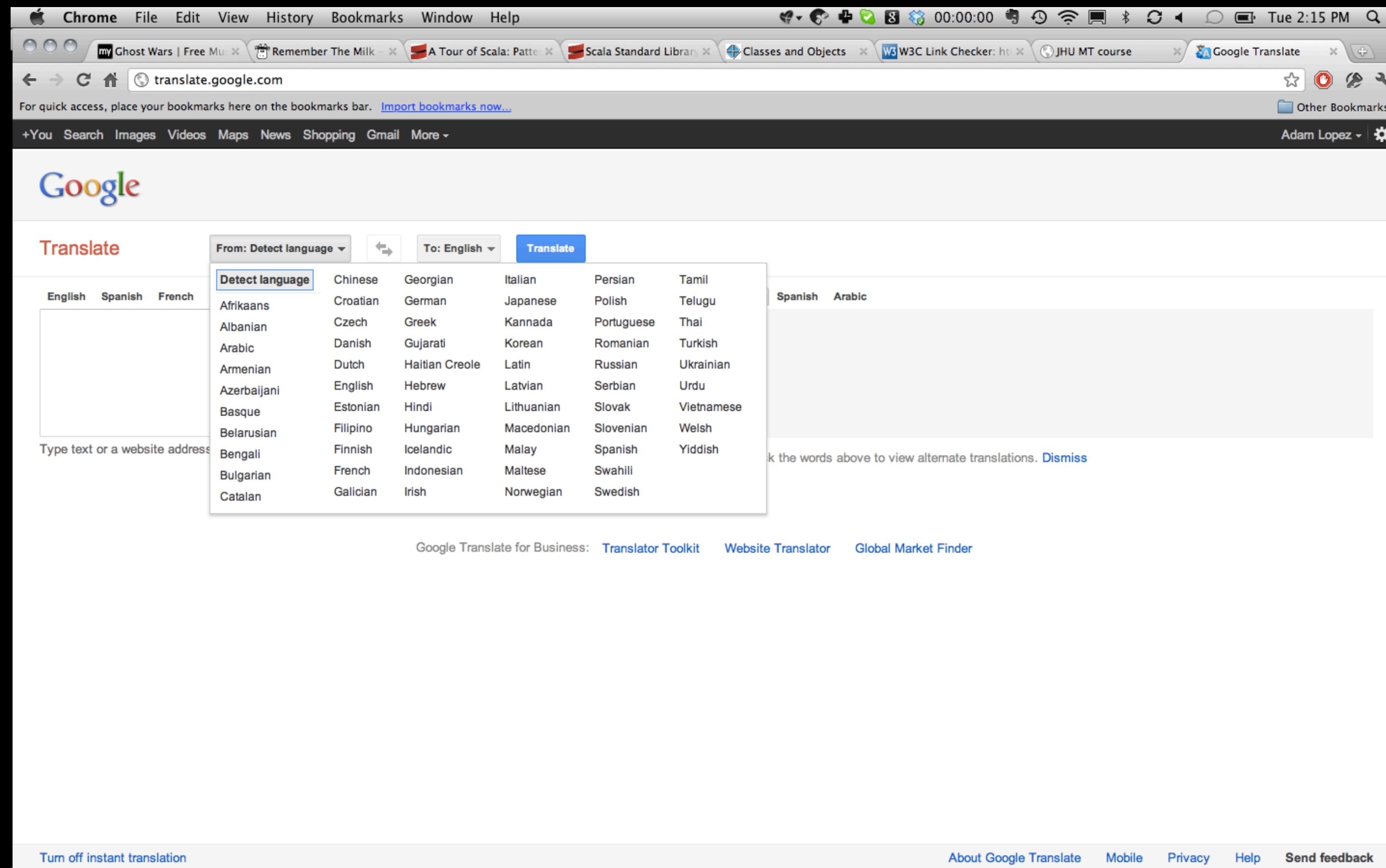


- Key ingredients in Google Translate (2006-2017):
  - Phrase-based translation models
  - ... Learned heuristically from word alignments
  - ... Coupled with a huge language model
  - ... And decoding with severe pruning heuristics

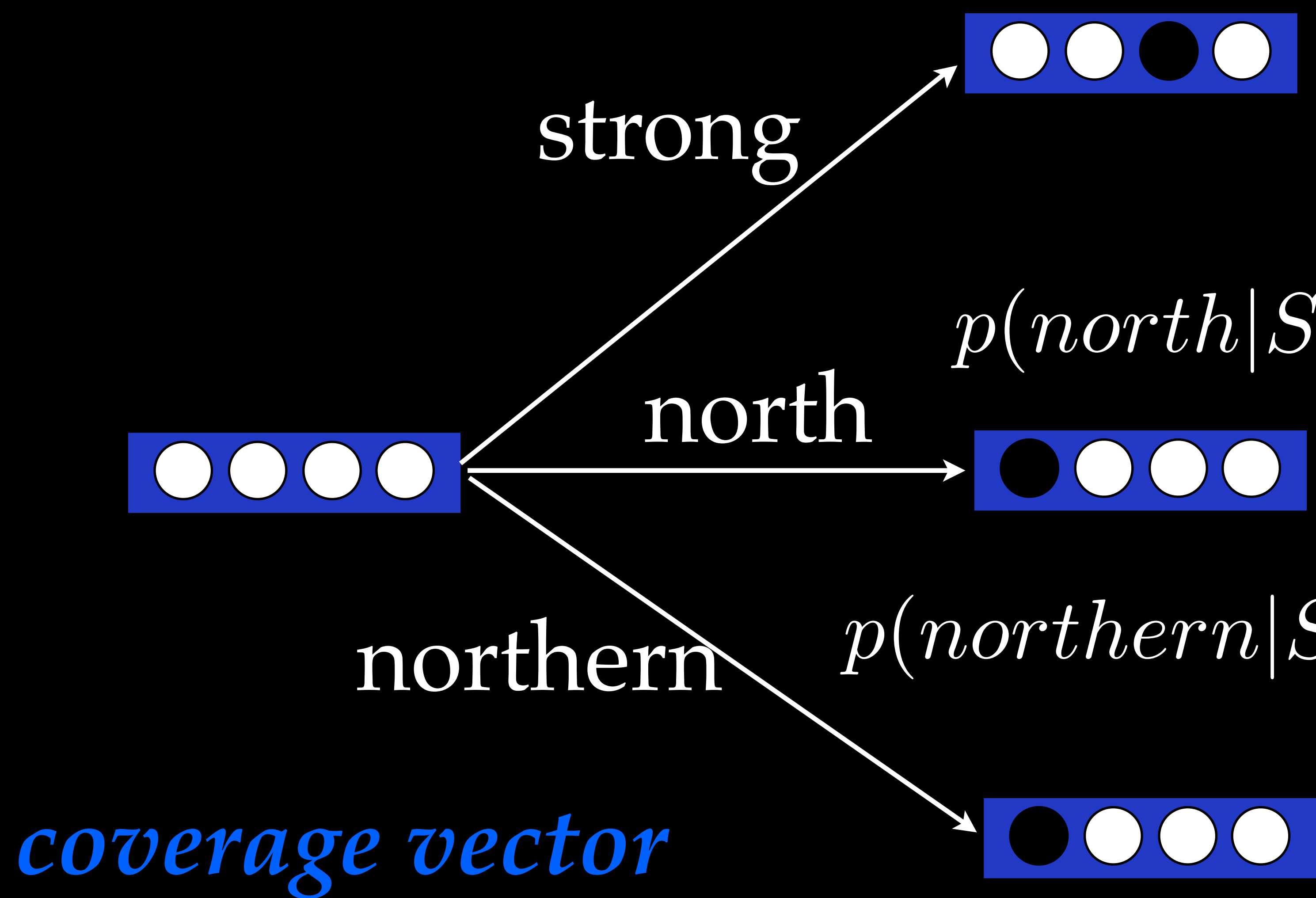
Dynamic programming

北 风 呼啸 。

There are $5^n n!$ target sentences.

But there are only $O(5n)$ ways to start them.

Dynamic programming

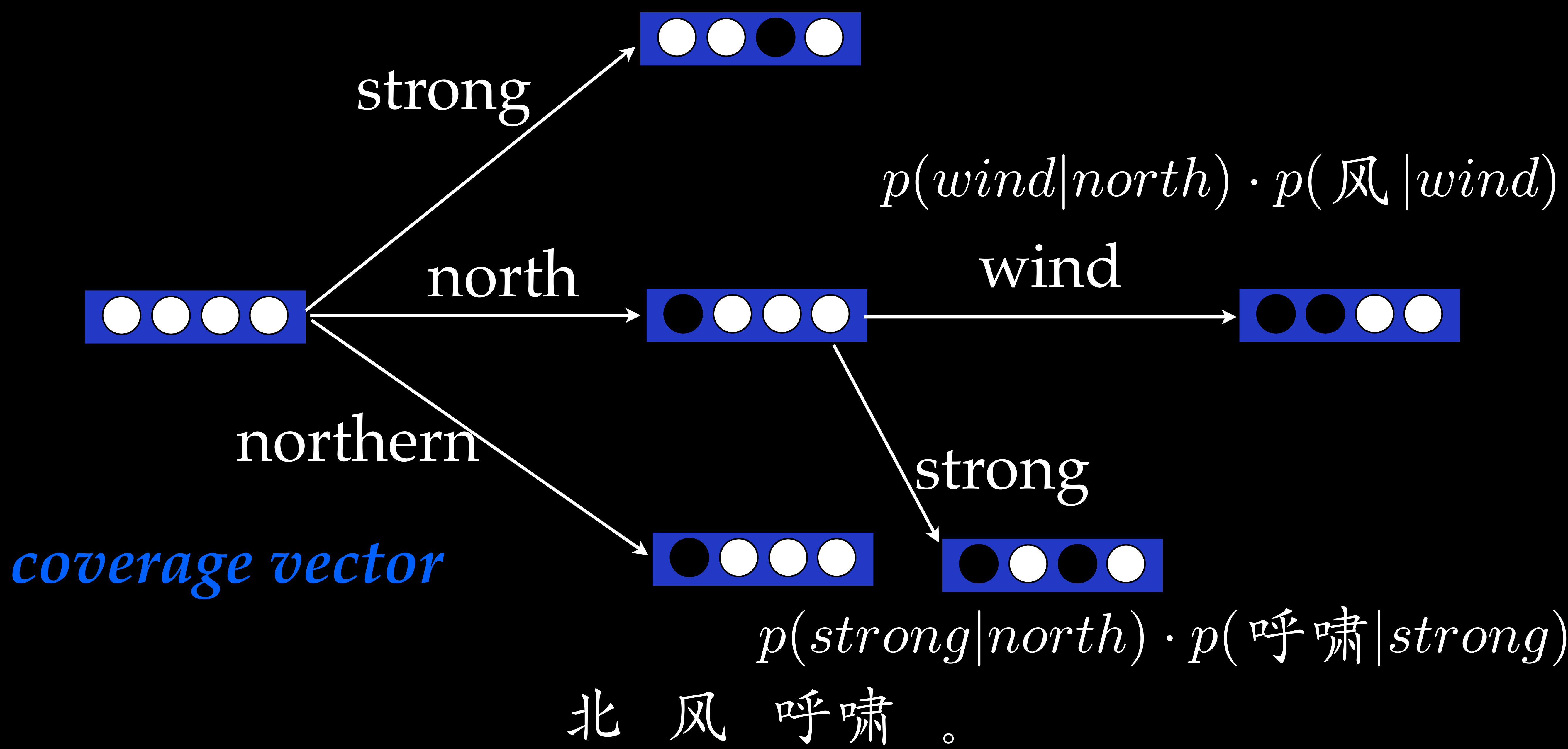


$$p(strong|START) \cdot p(呼啸|strong)$$

$$p(north|START) \cdot p(北|north)$$

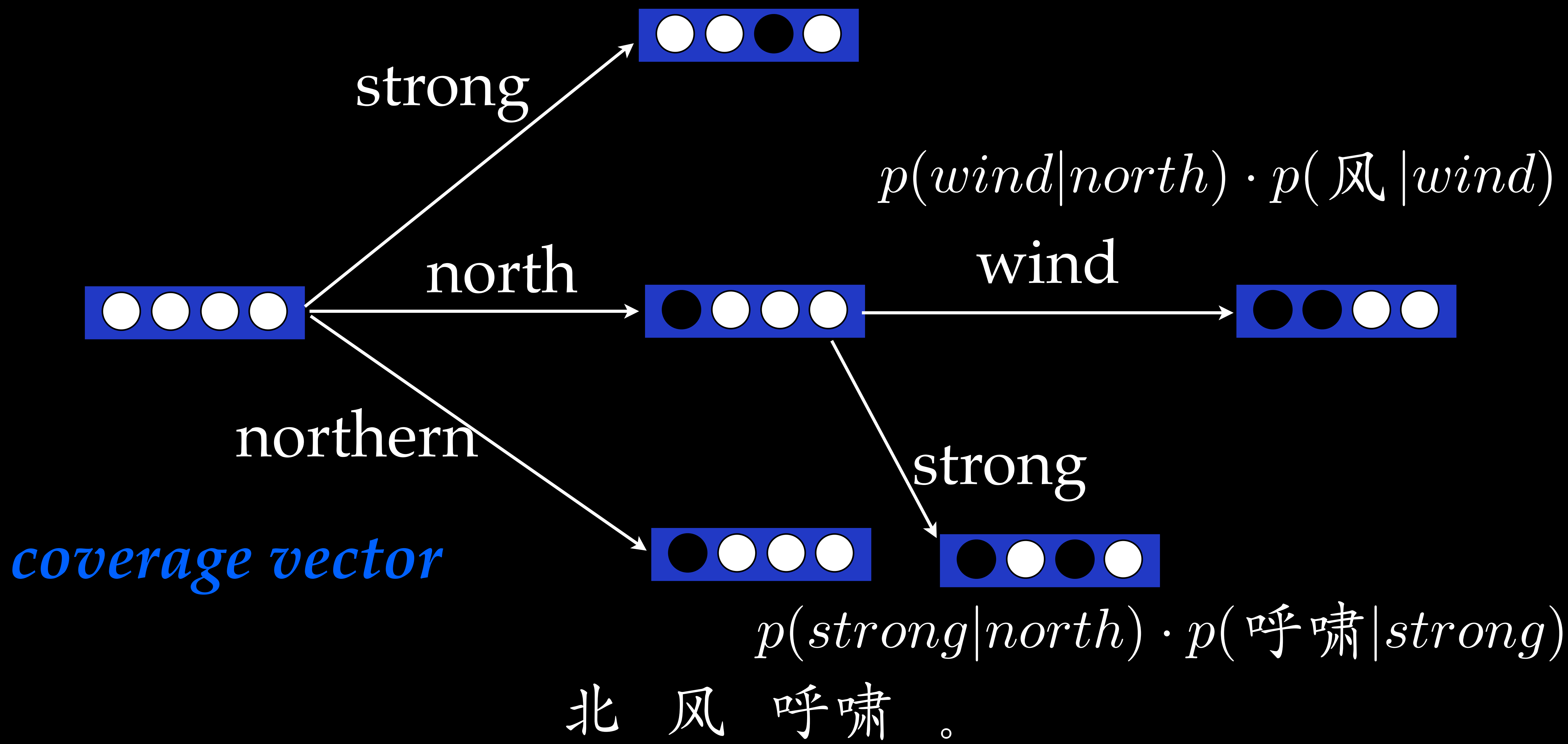
$$p(northern|START) \cdot p(北|northern)$$

Dynamic programming



Dynamic programming

This shares work among sentence beginnings



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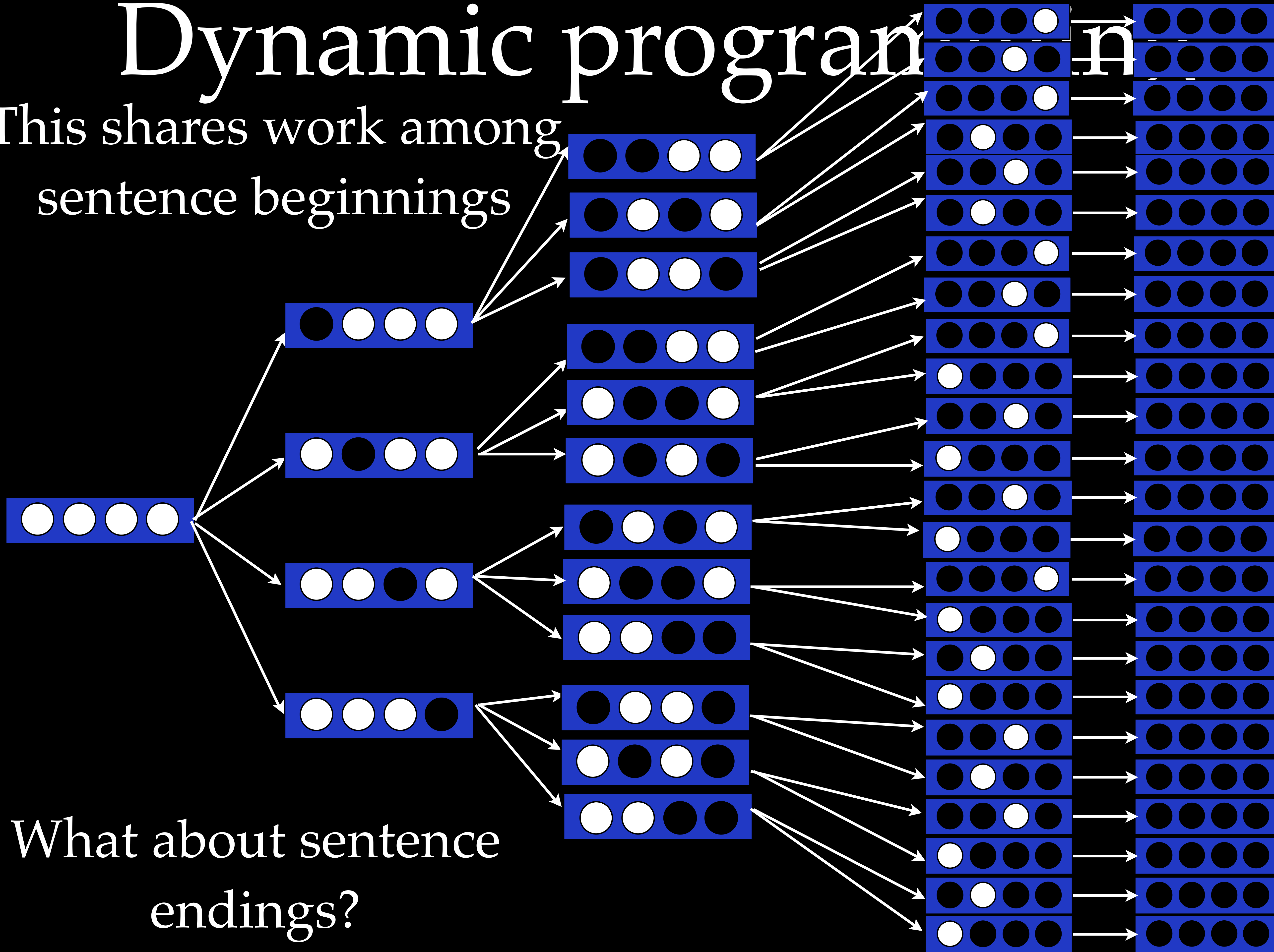
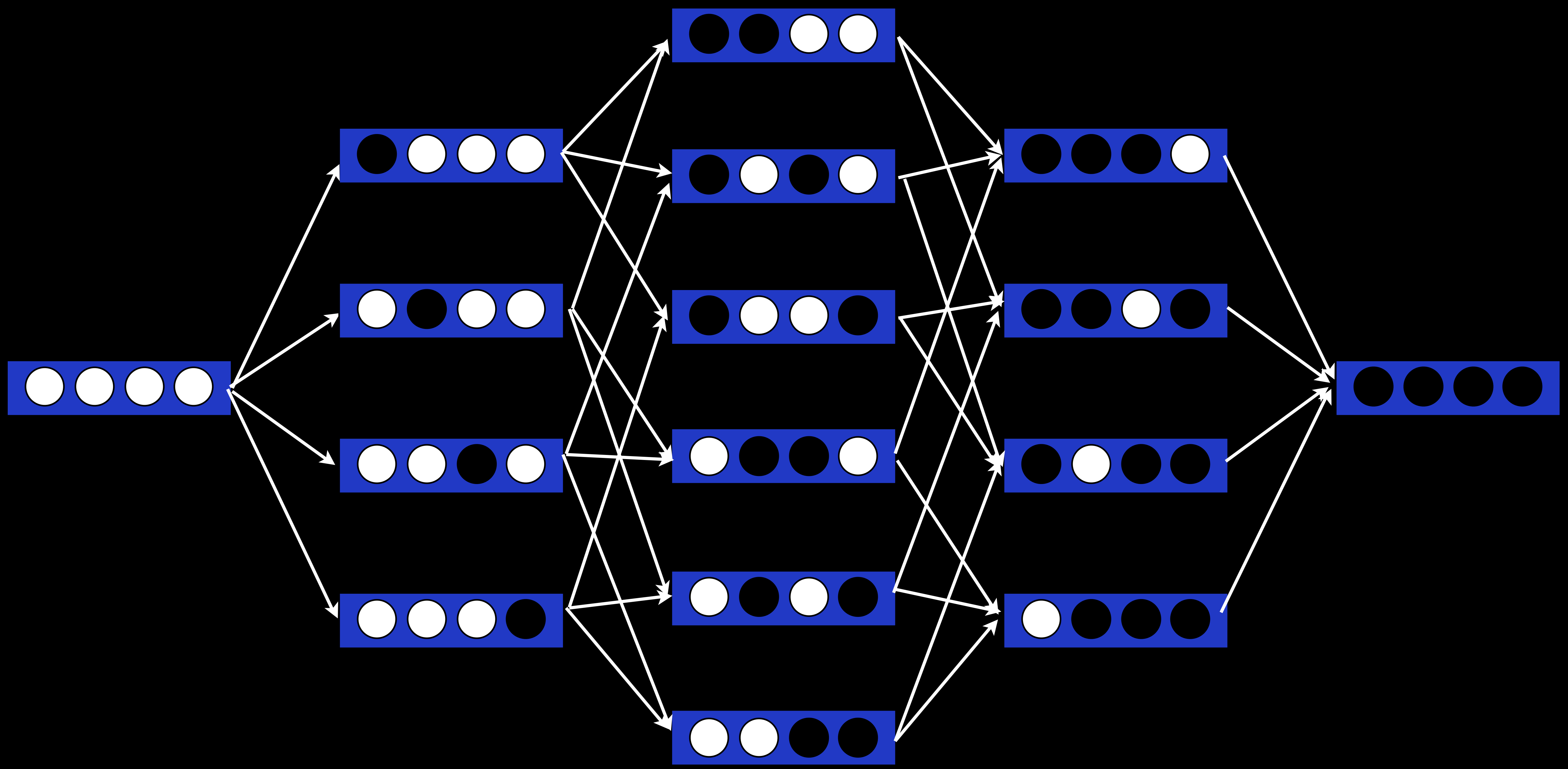
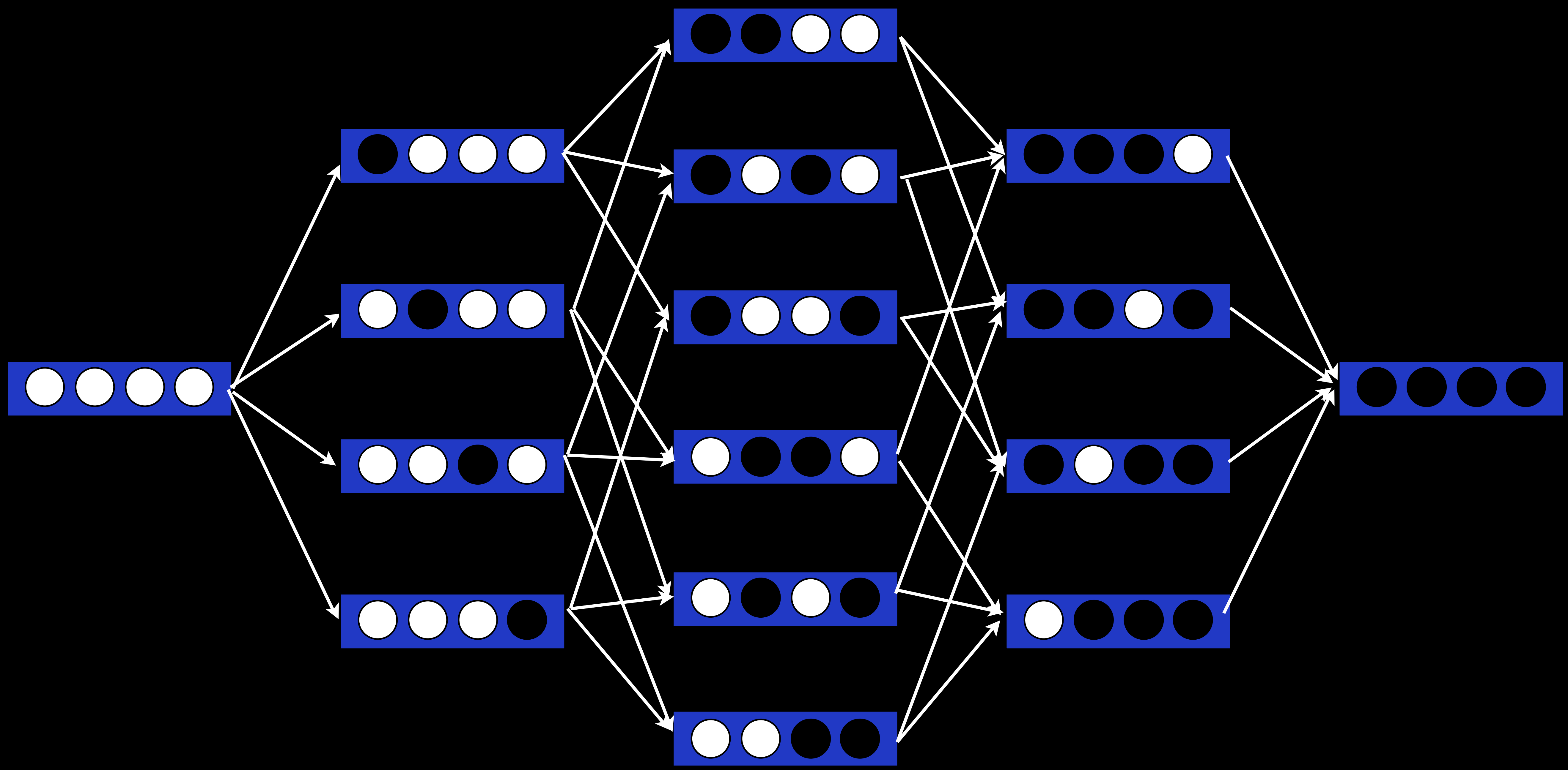


What about sentence endings?

Approximation: Pruning

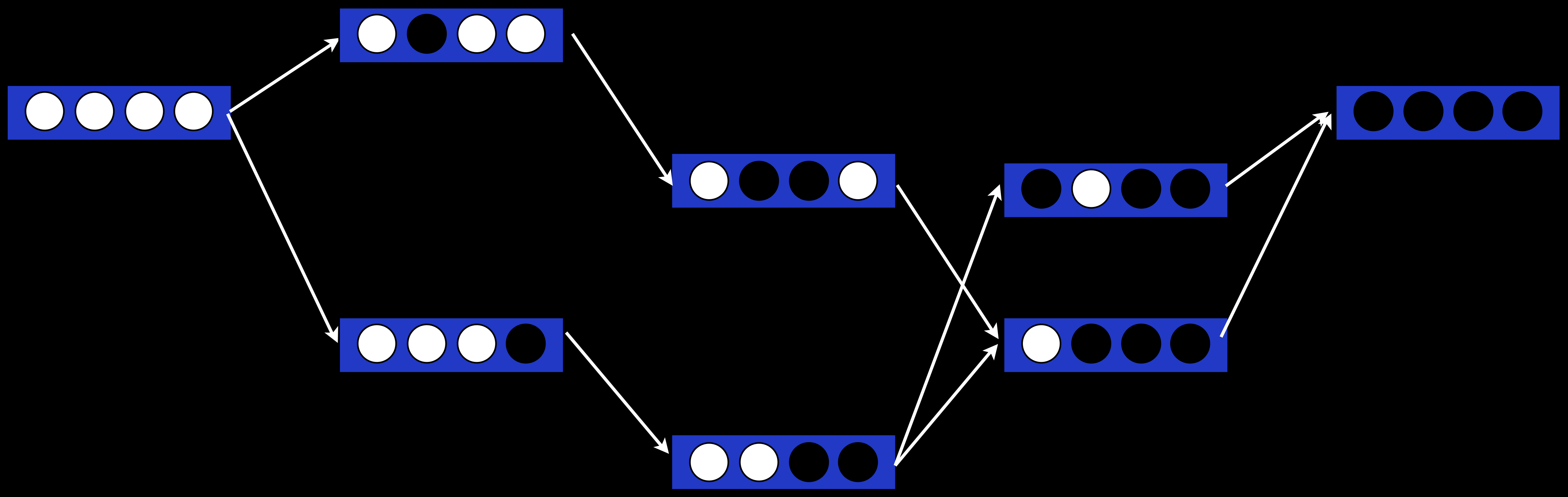


Approximation: Pruning



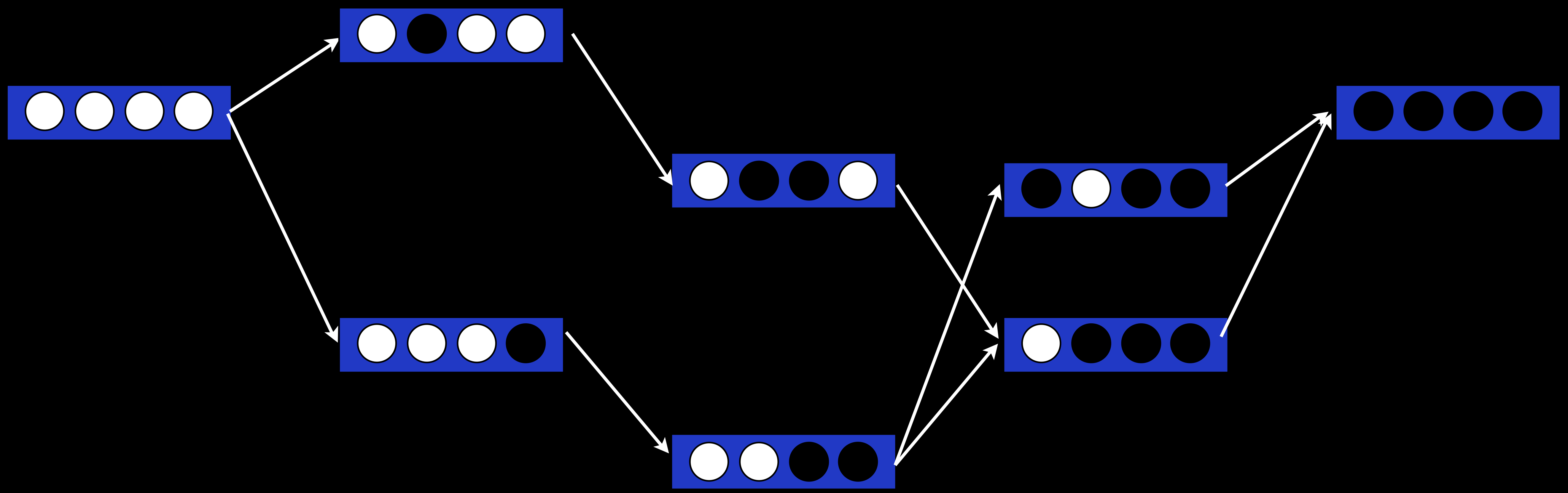
Idea: prune states by cost of shortest path to them

Approximation: Pruning



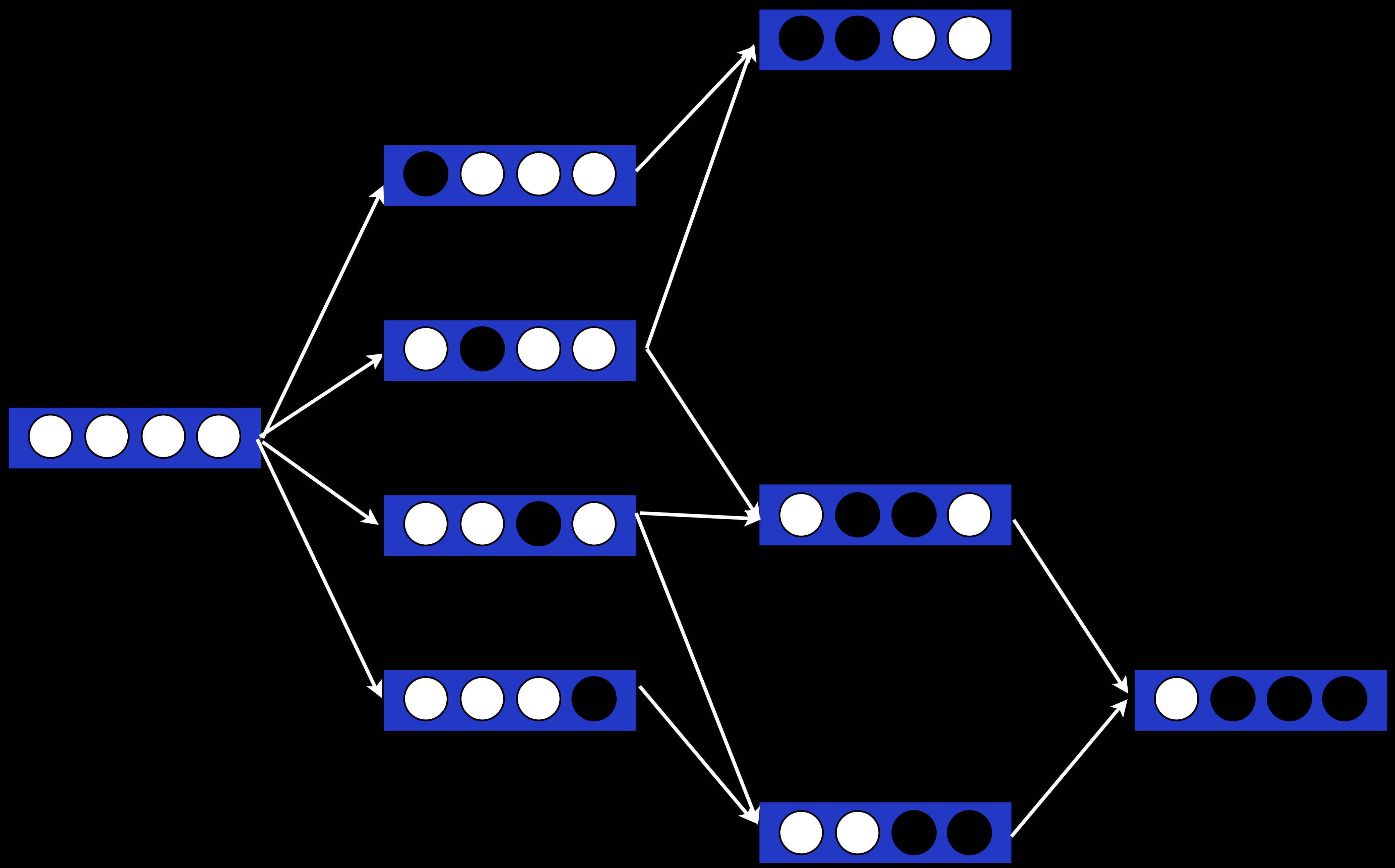
Idea: prune states by accumulated path length

Approximation: Pruning



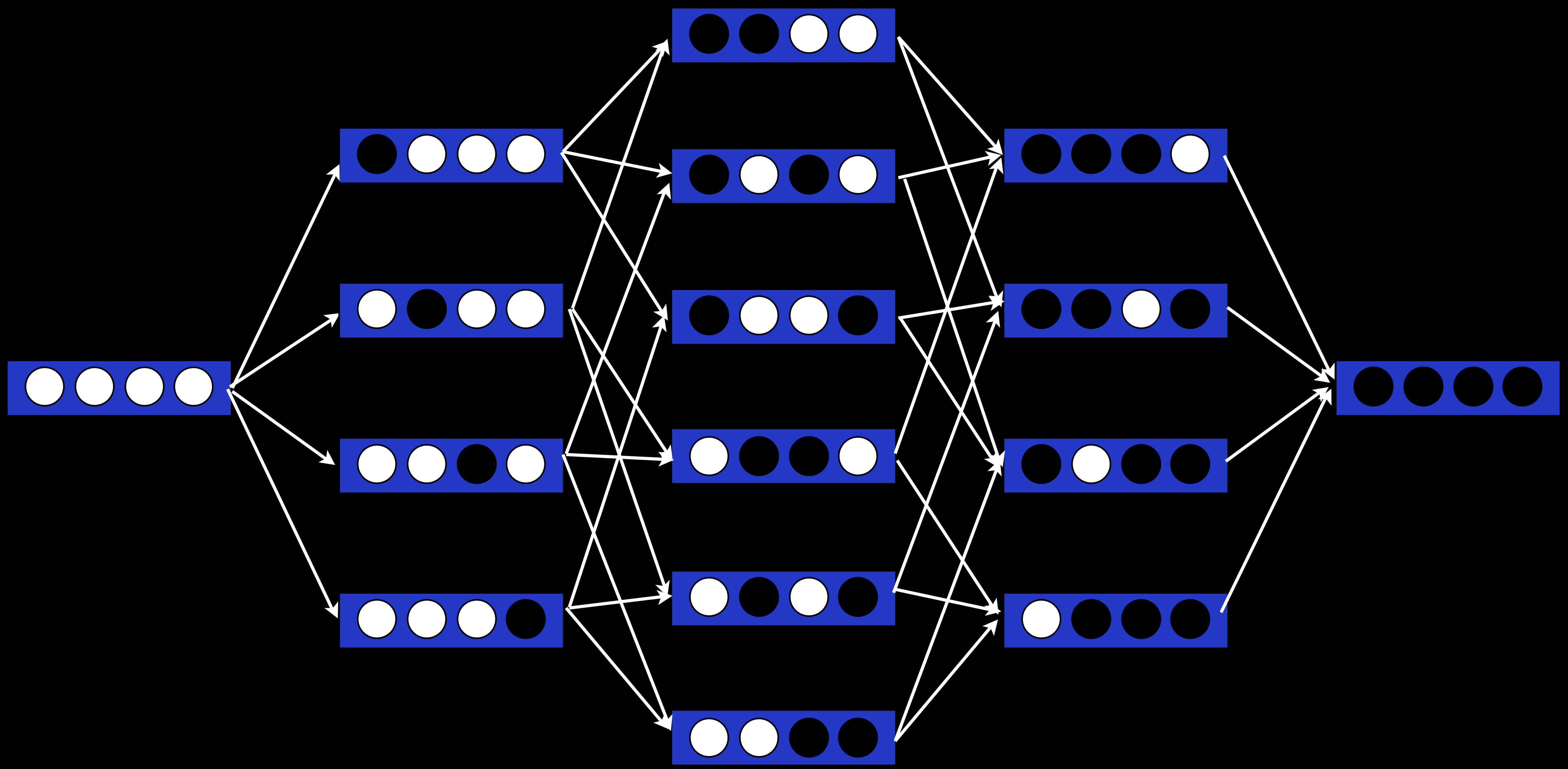
Ideal result: only high-probability paths enumerated

Approximation: Pruning

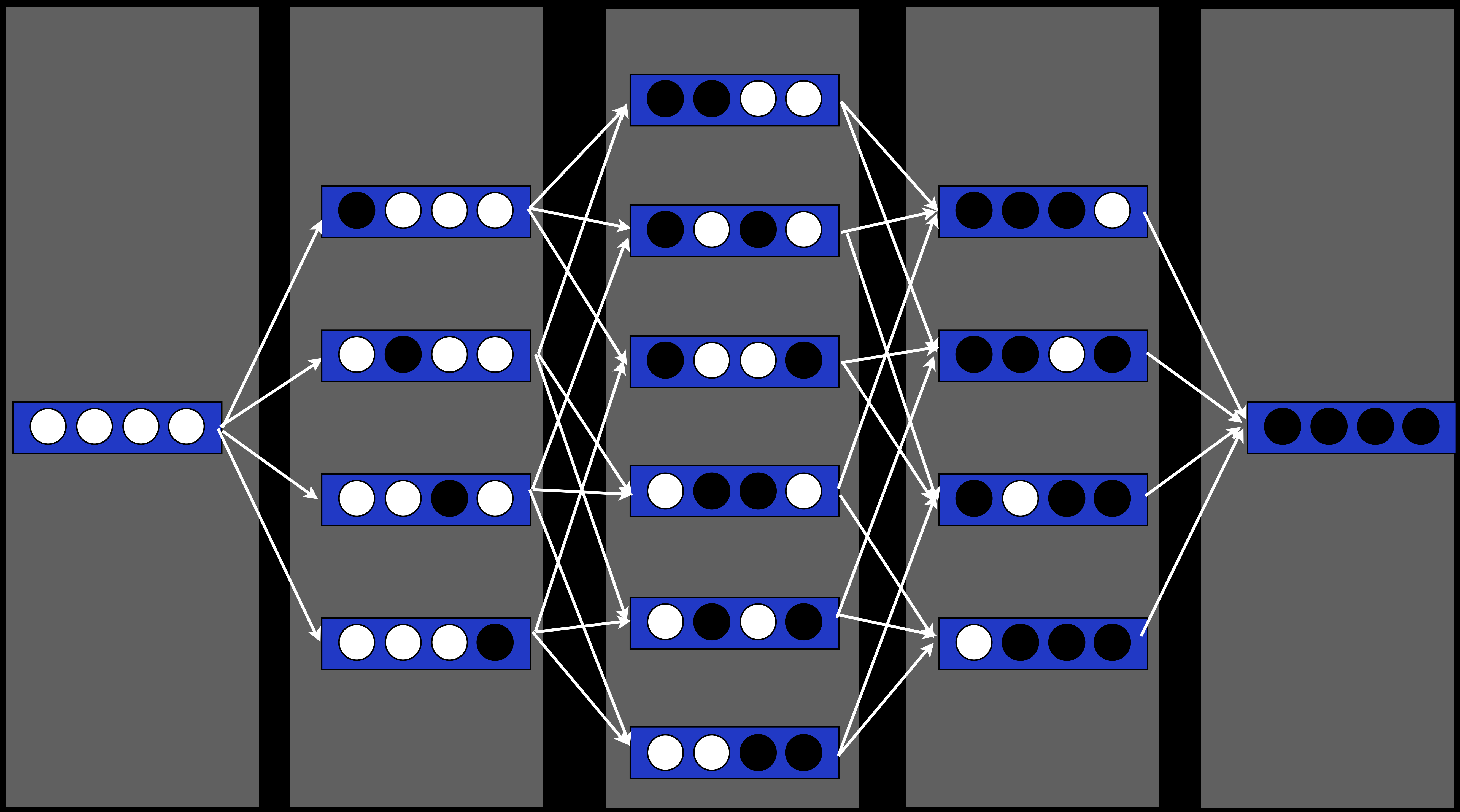


Actual result: longer paths have lower probability!

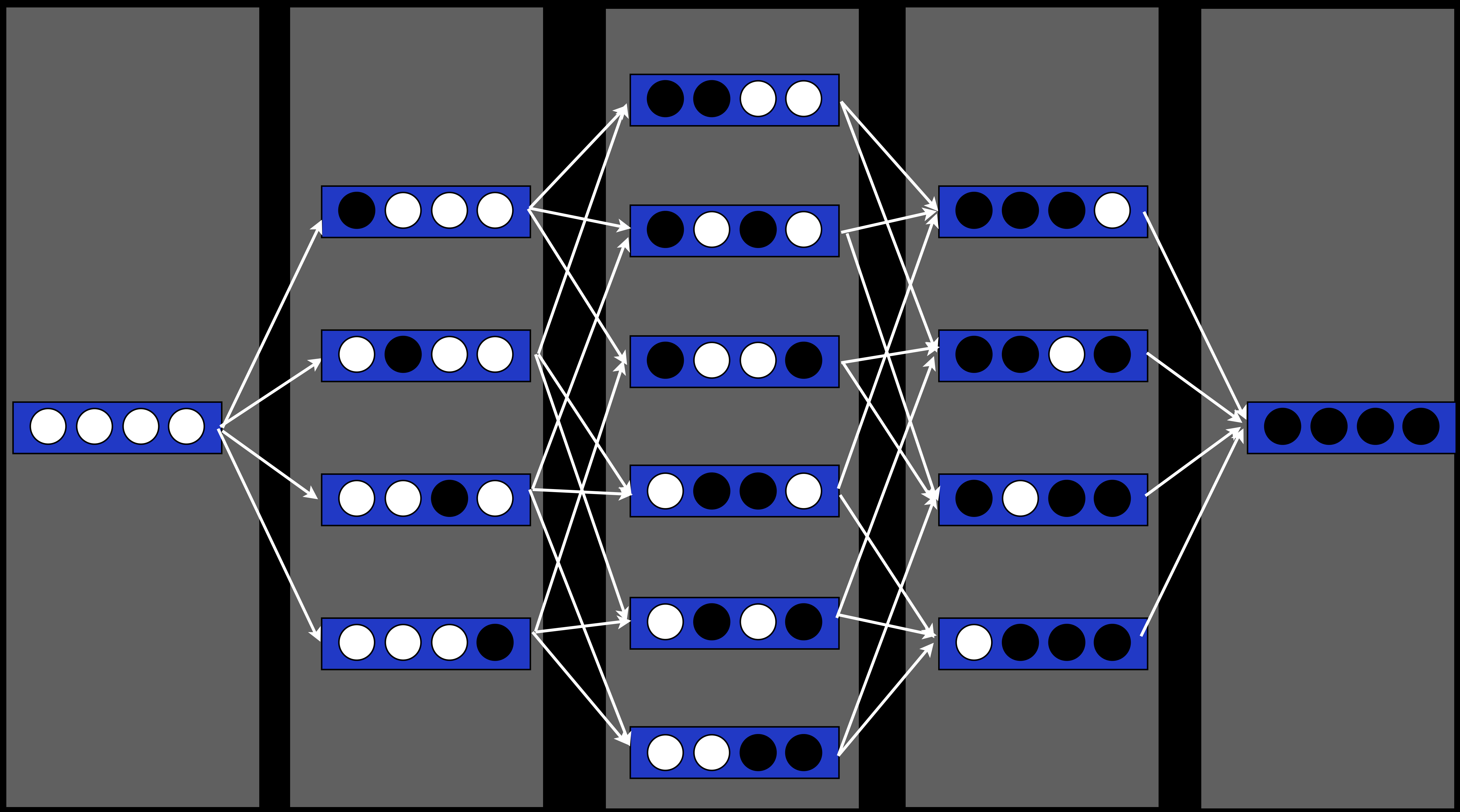
Approximation: Pruning



Approximation: Pruning

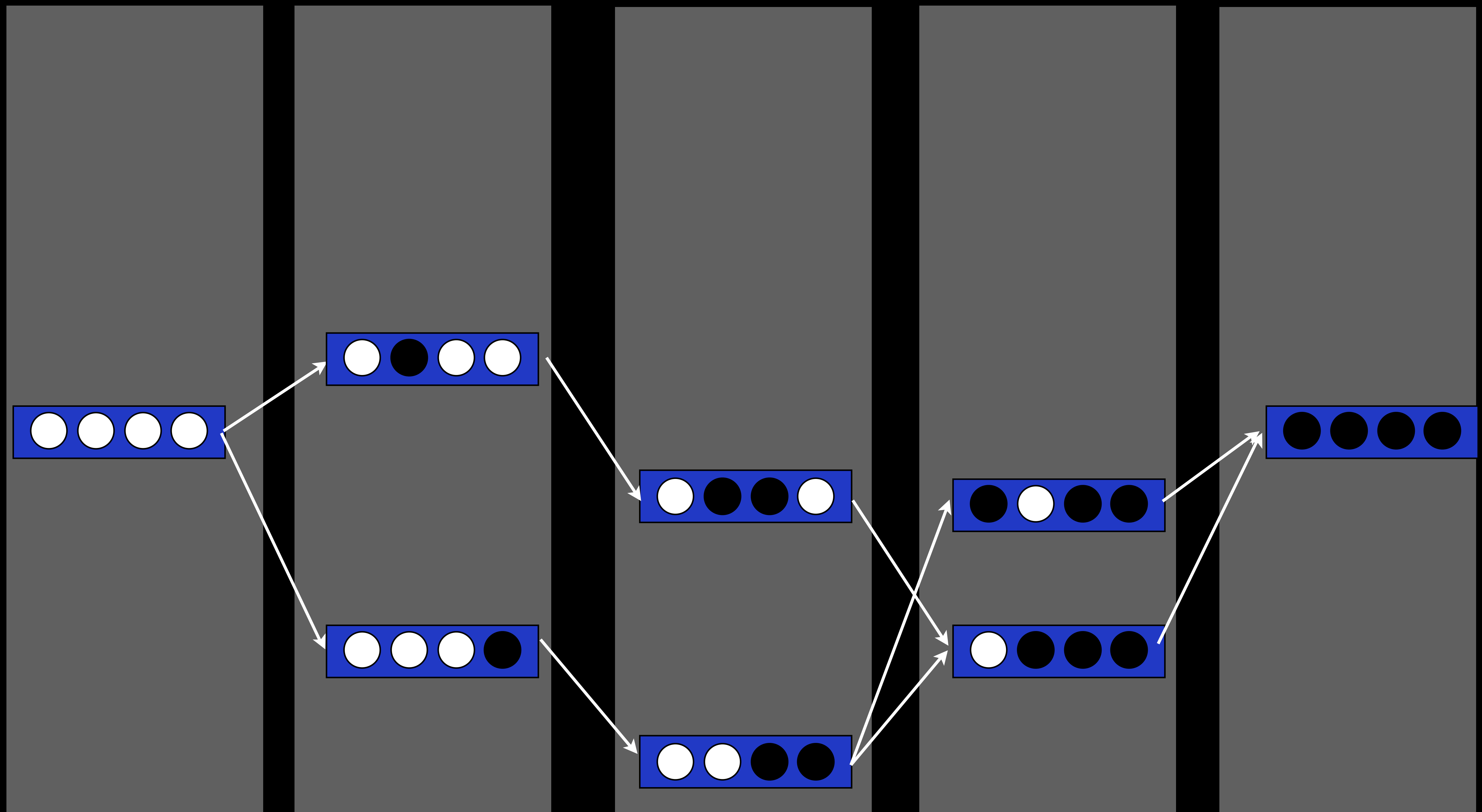


Approximation: Pruning



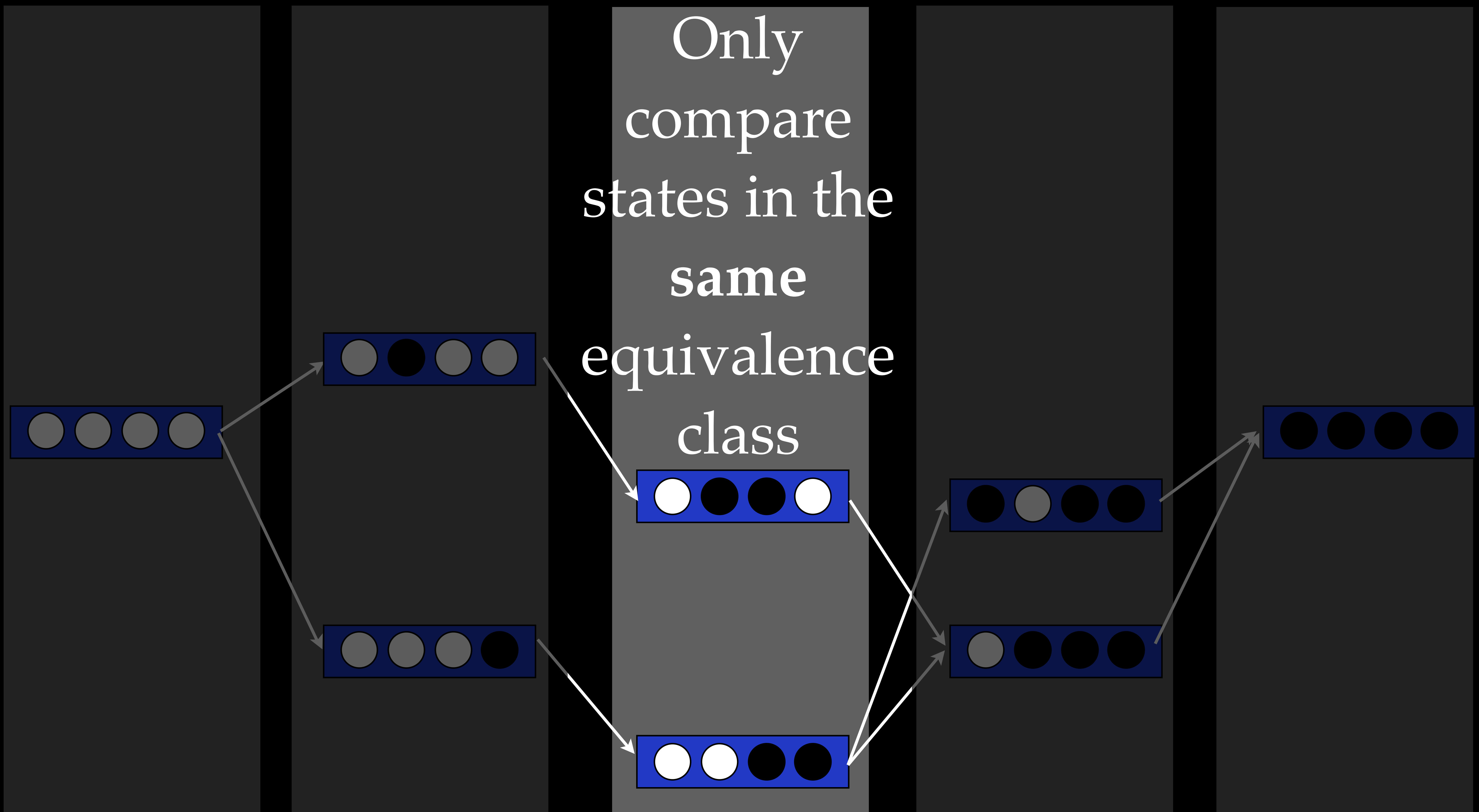
Solution: Group states by number of covered words.

Approximation: Pruning



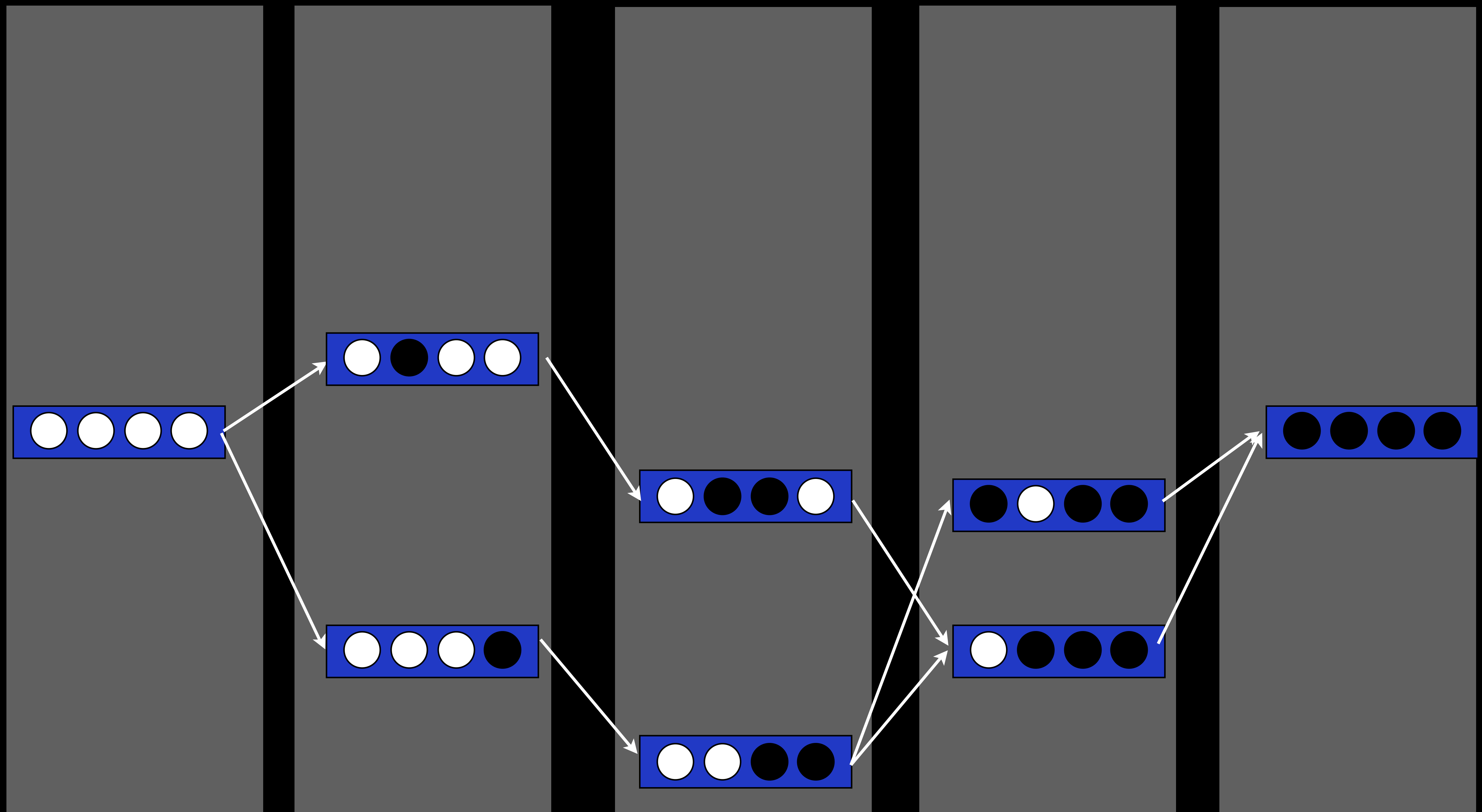
Solution: Group states by number of covered words.

Approximation: Pruning



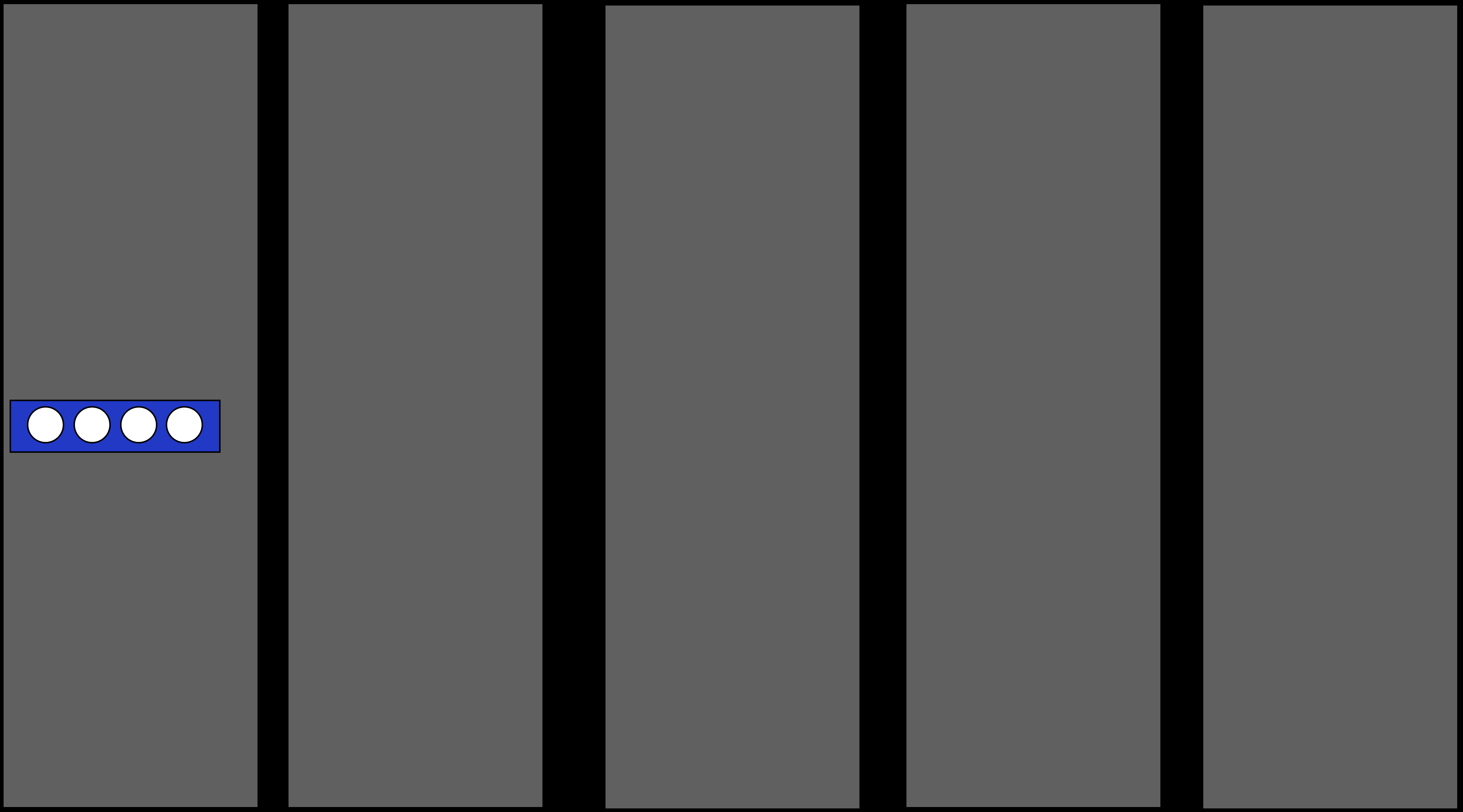
Solution: Group states by number of covered words.

Approximation: Pruning



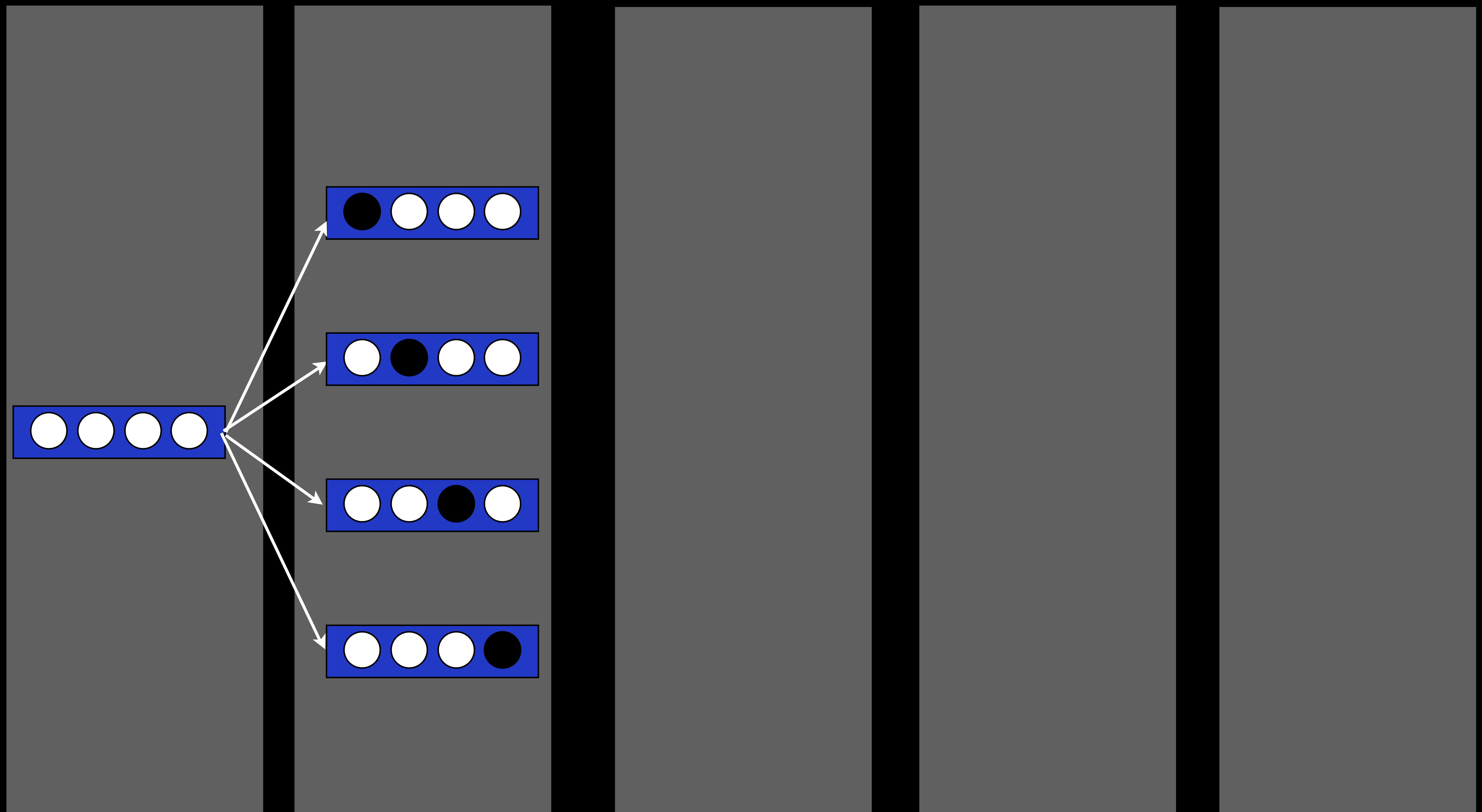
"Stack" decoding: a linear-time approximation

Approximation: Pruning



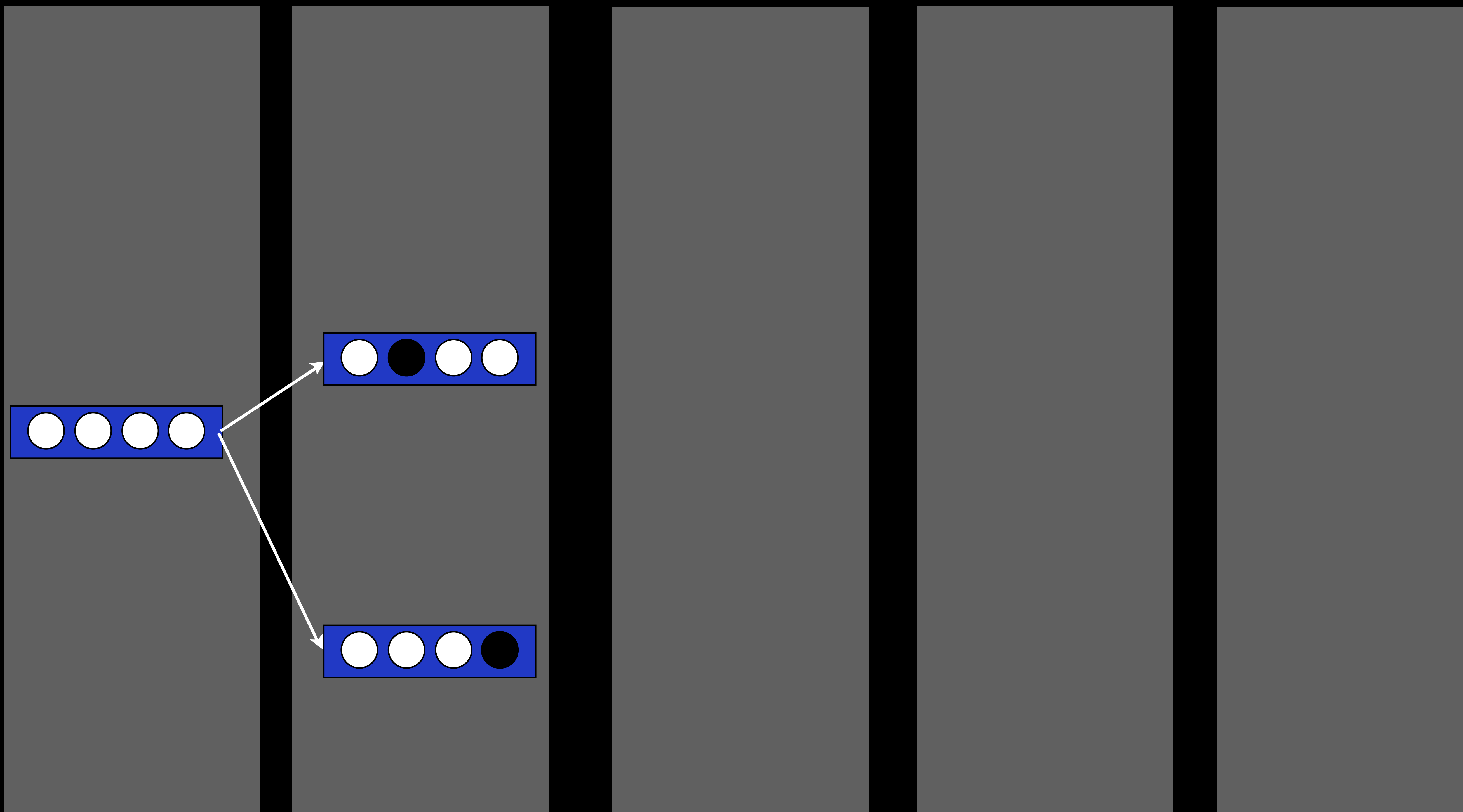
"Stack" decoding: a linear-time approximation

Approximation: Pruning



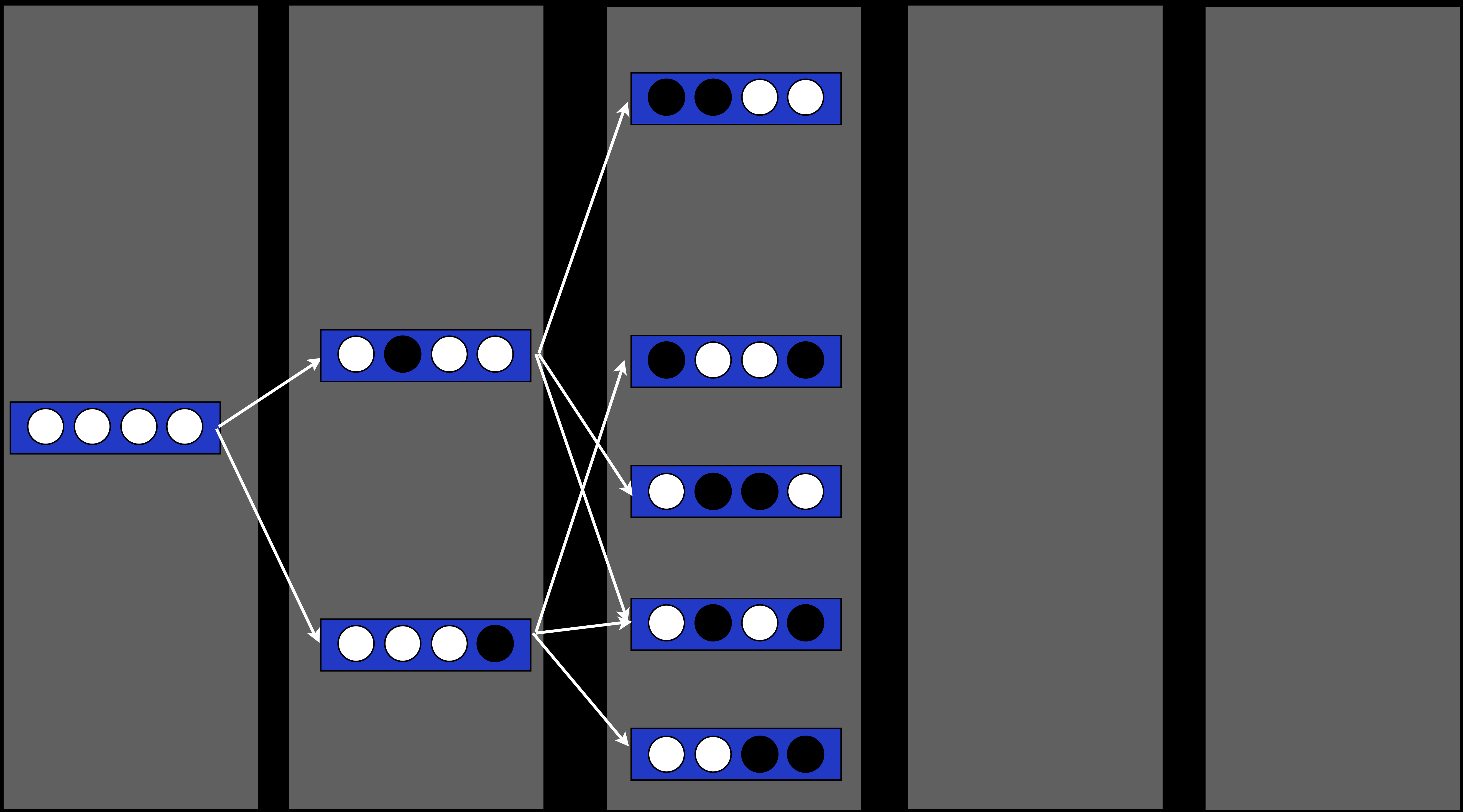
"Stack" decoding: a linear-time approximation

Approximation: Pruning



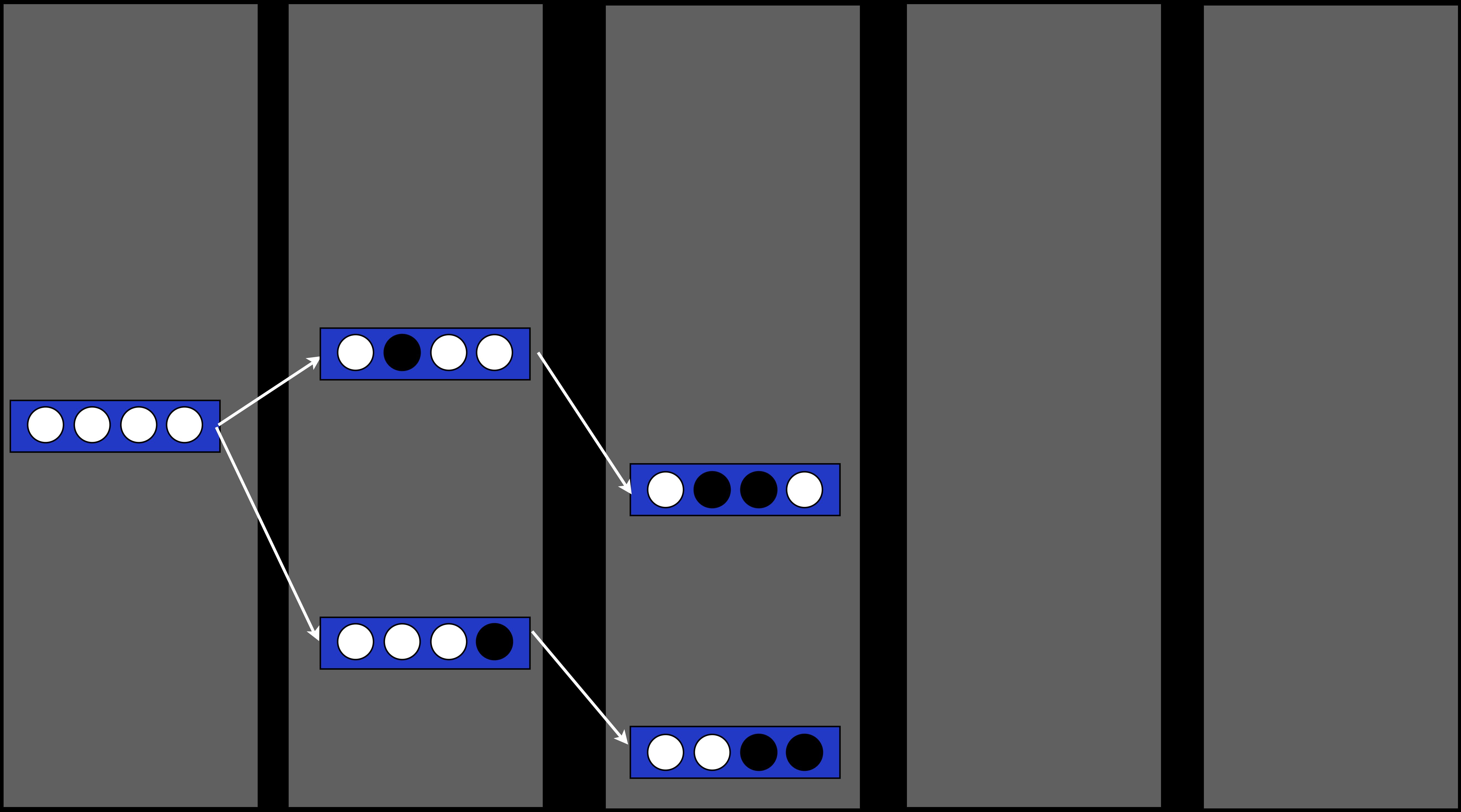
"Stack" decoding: a linear-time approximation

Approximation: Pruning



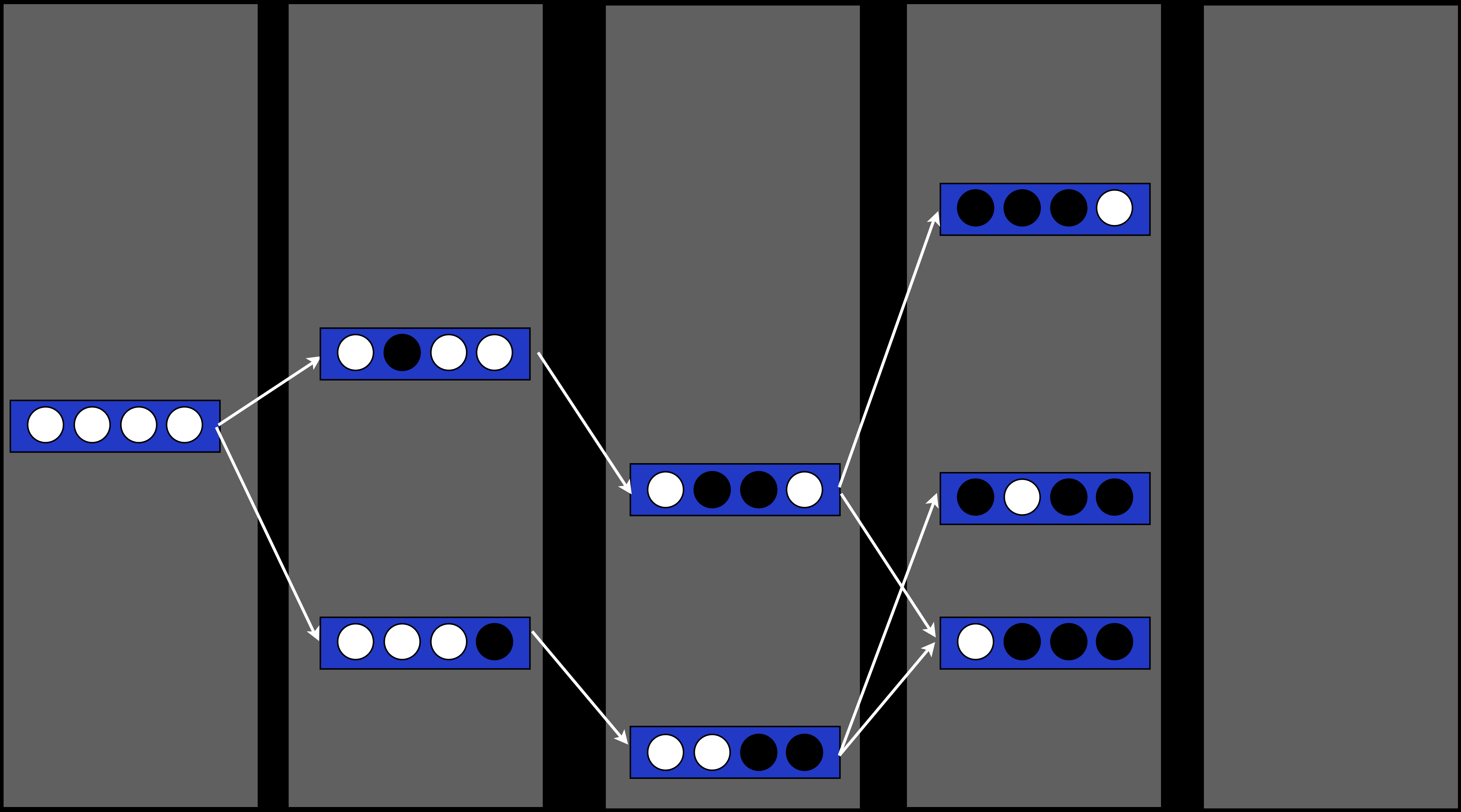
"Stack" decoding: a linear-time approximation

Approximation: Pruning



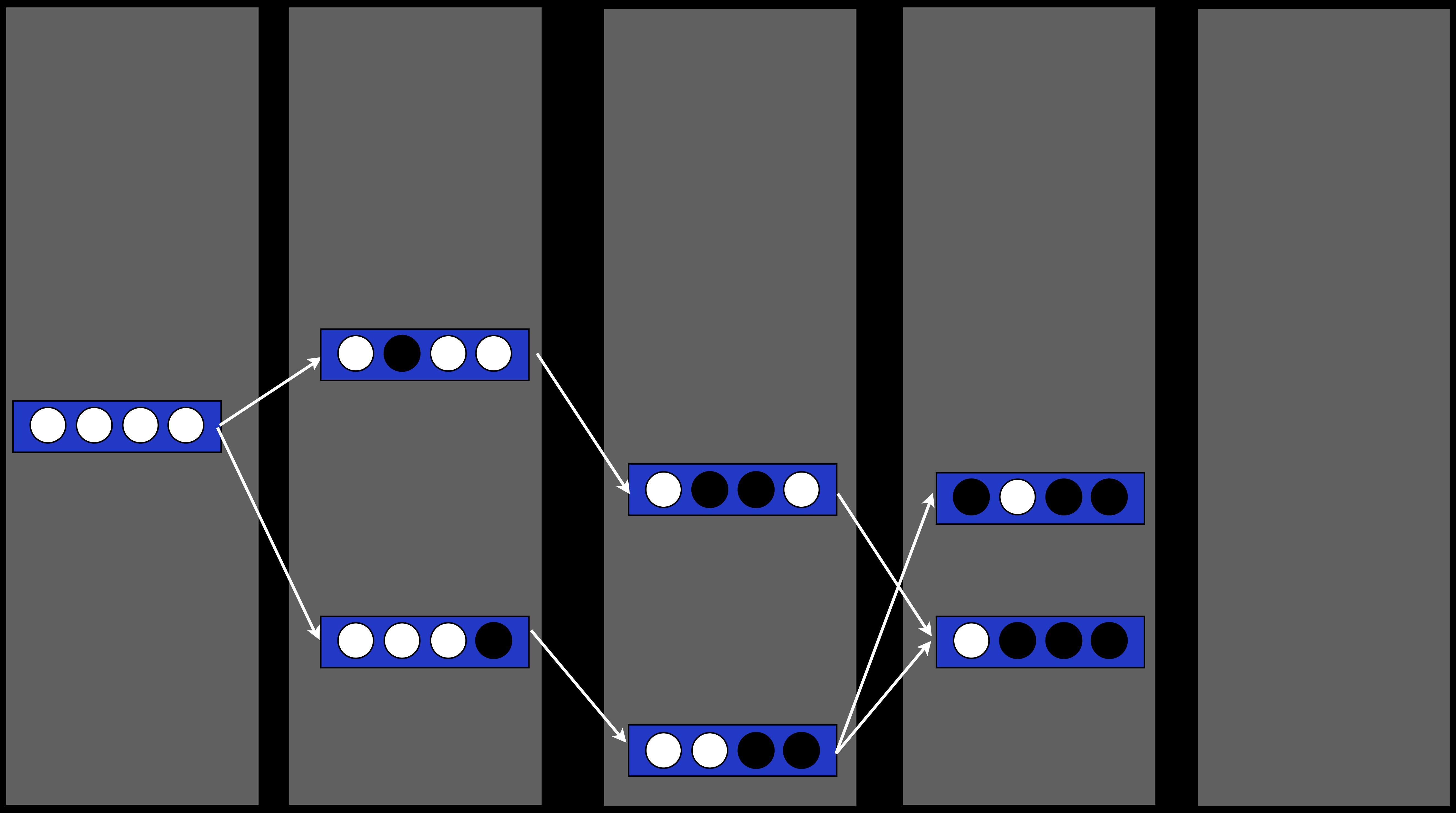
"Stack" decoding: a linear-time approximation

Approximation: Pruning



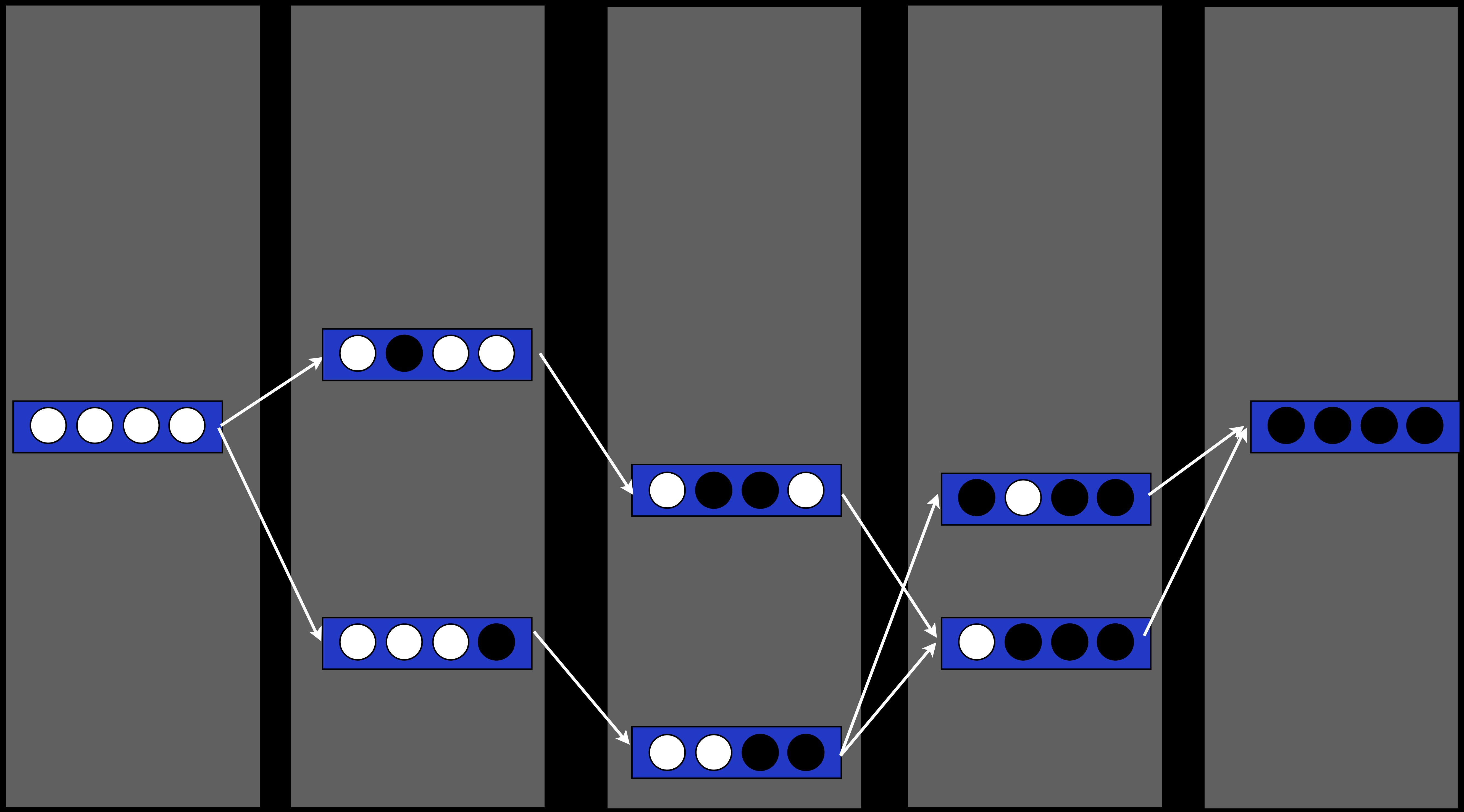
"Stack" decoding: a linear-time approximation

Approximation: Pruning



"Stack" decoding: a linear-time approximation

Approximation: Pruning



“Stack” decoding: a linear-time approximation

Approximation: distortion limits

the sky

虽然 北 风 呼啸 ， 但 天空 依然 十分 清澈 。

Approximation: distortion limits

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

the sky

虽然 北 风 呼啸 , 但 天空 依然 十分 清澈 。

Approximation: distortion limits

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

the sky

$\boxed{\text{虽然 北 风 呼啸}}$, $\boxed{\text{但 天空}}$ 依然 十分 清澈 。

$$d = 4$$

window

Approximation: distortion limits

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

the sky

虽然 北 风 呼啸 , 但 天空 依然 十分 清澈 。

$d = 4$

outside window to left: covered

window

outside window to right: uncovered

Approximation: distortion limits

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

the sky

虽然 北 风 呼啸 , 但 天空 依然 十分 清澈 。

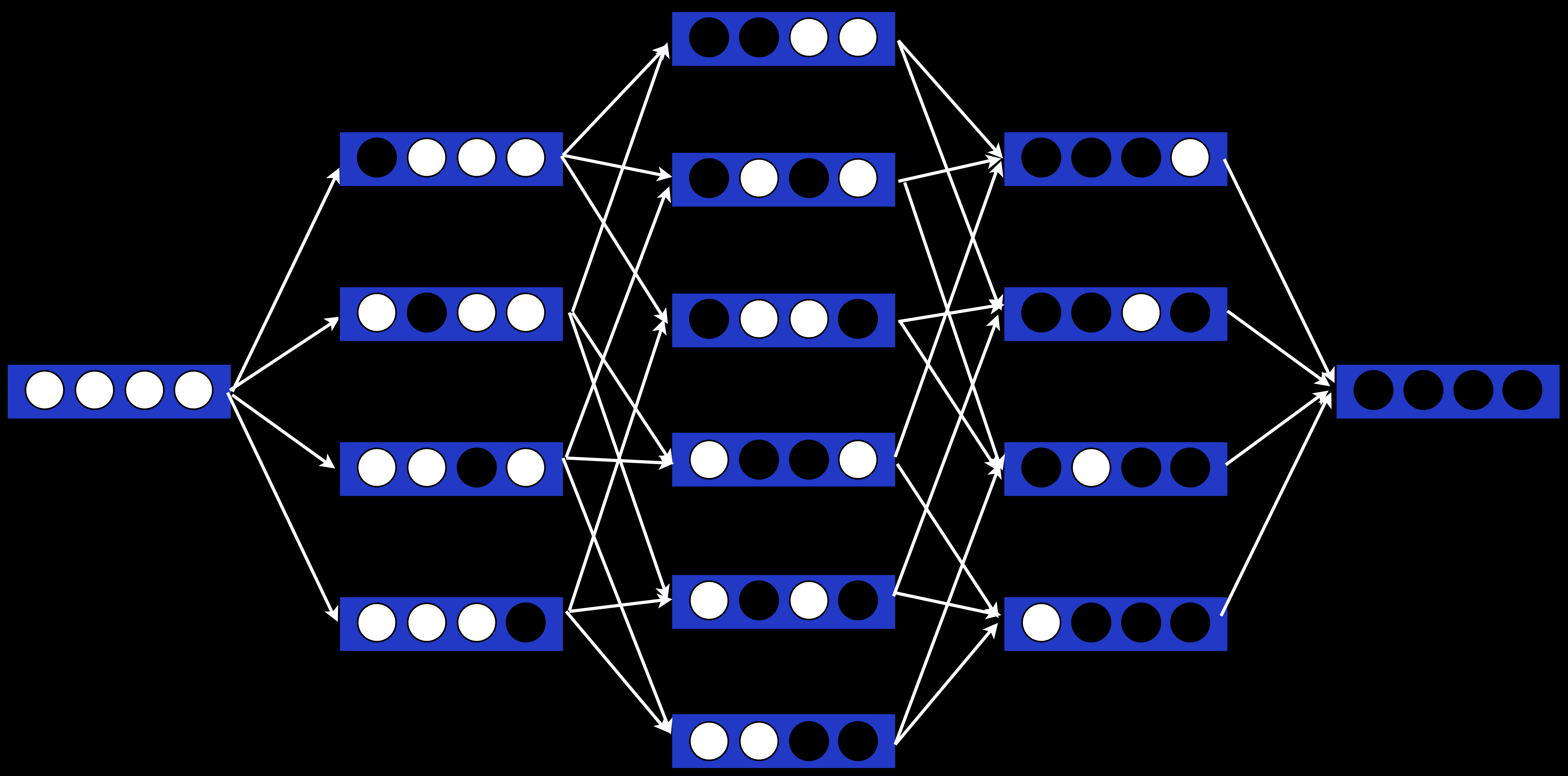
outside window
to left: covered

$d = 4$

window

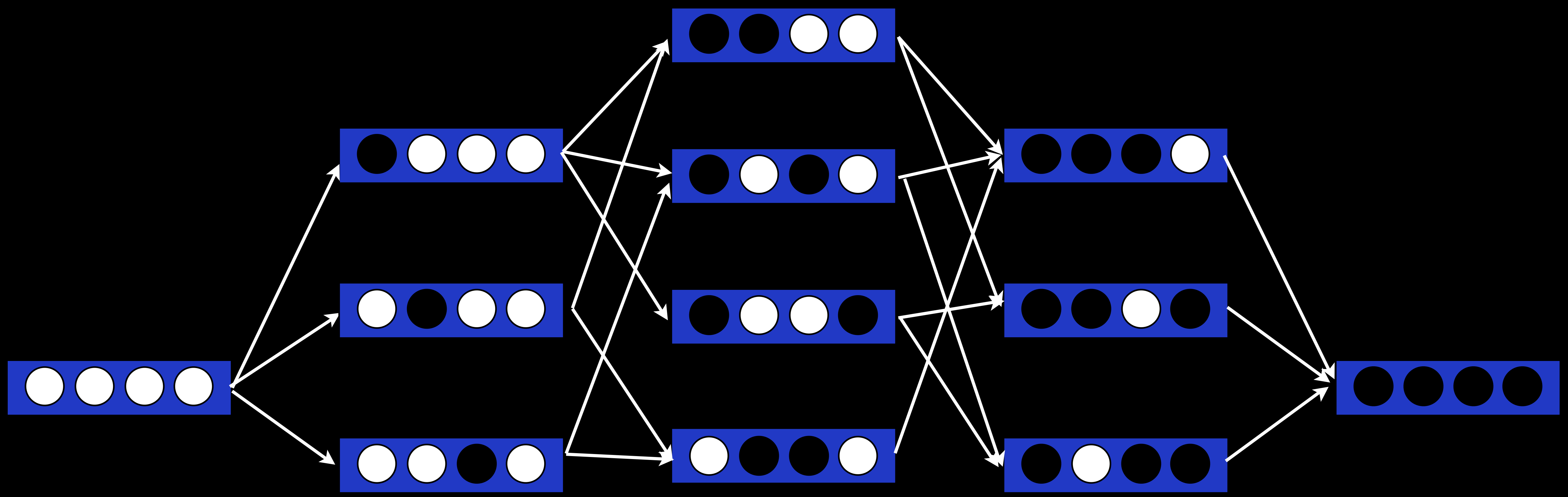
outside window
to right: uncovered

Approximation: distortion limits



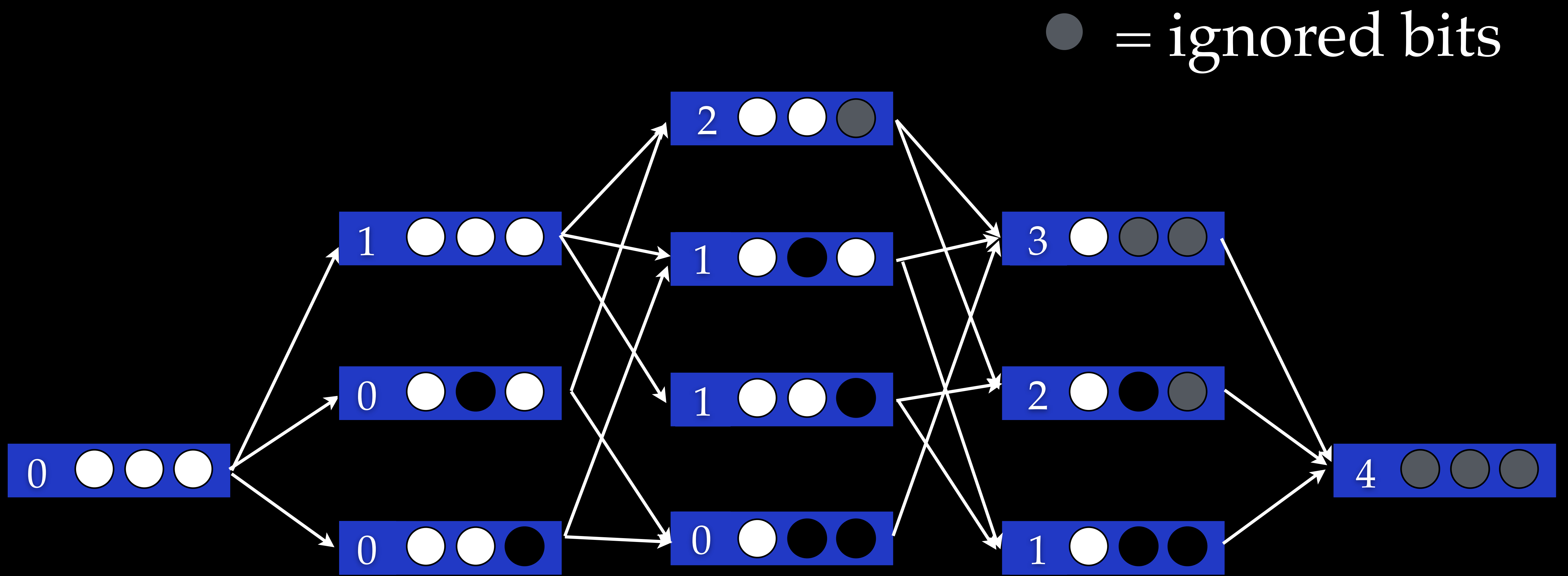
no distortion limit

Approximation: distortion limits



distortion limit = 3

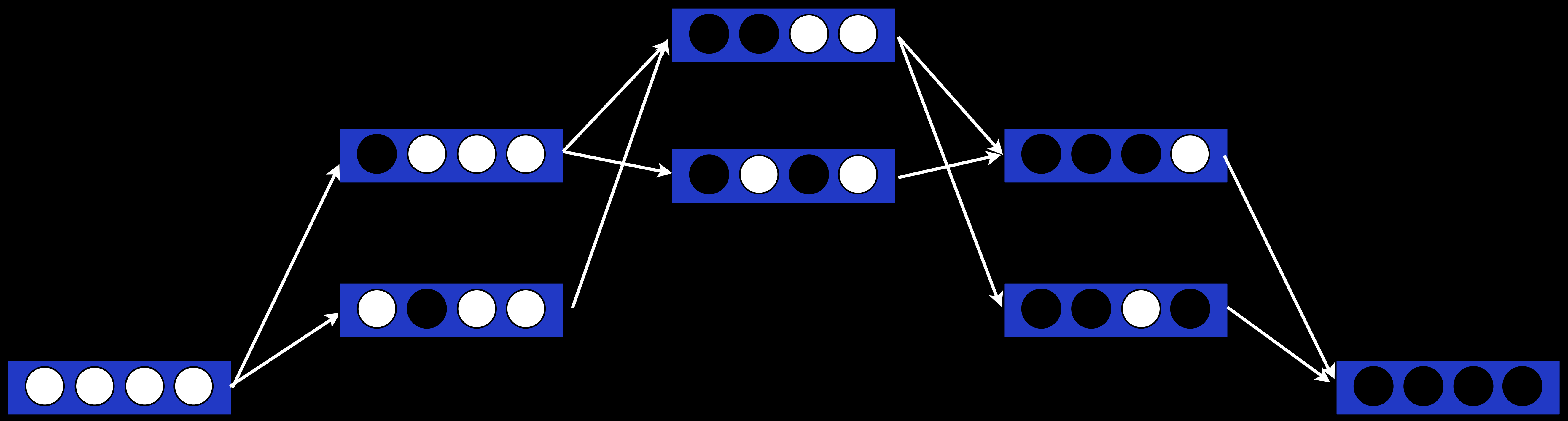
Approximation: distortion limits



alternative representation with length of covered section + bitmap of window

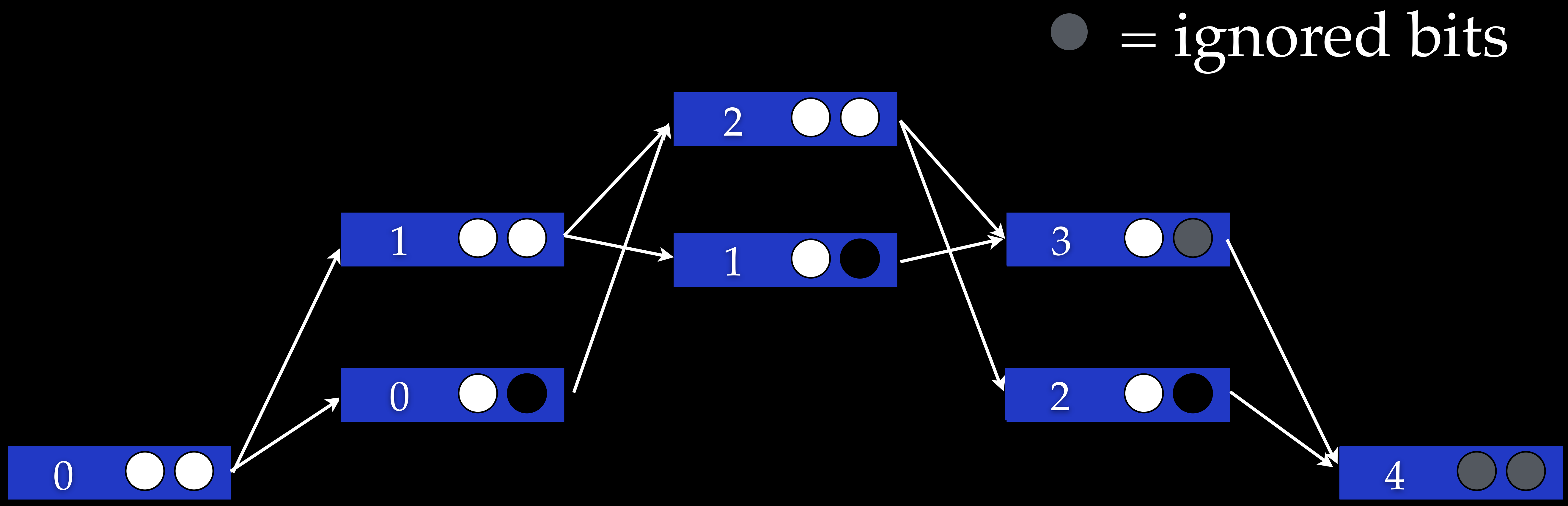
distortion limit = 3

Approximation: distortion limits



distortion limit = 2

Approximation: distortion limits

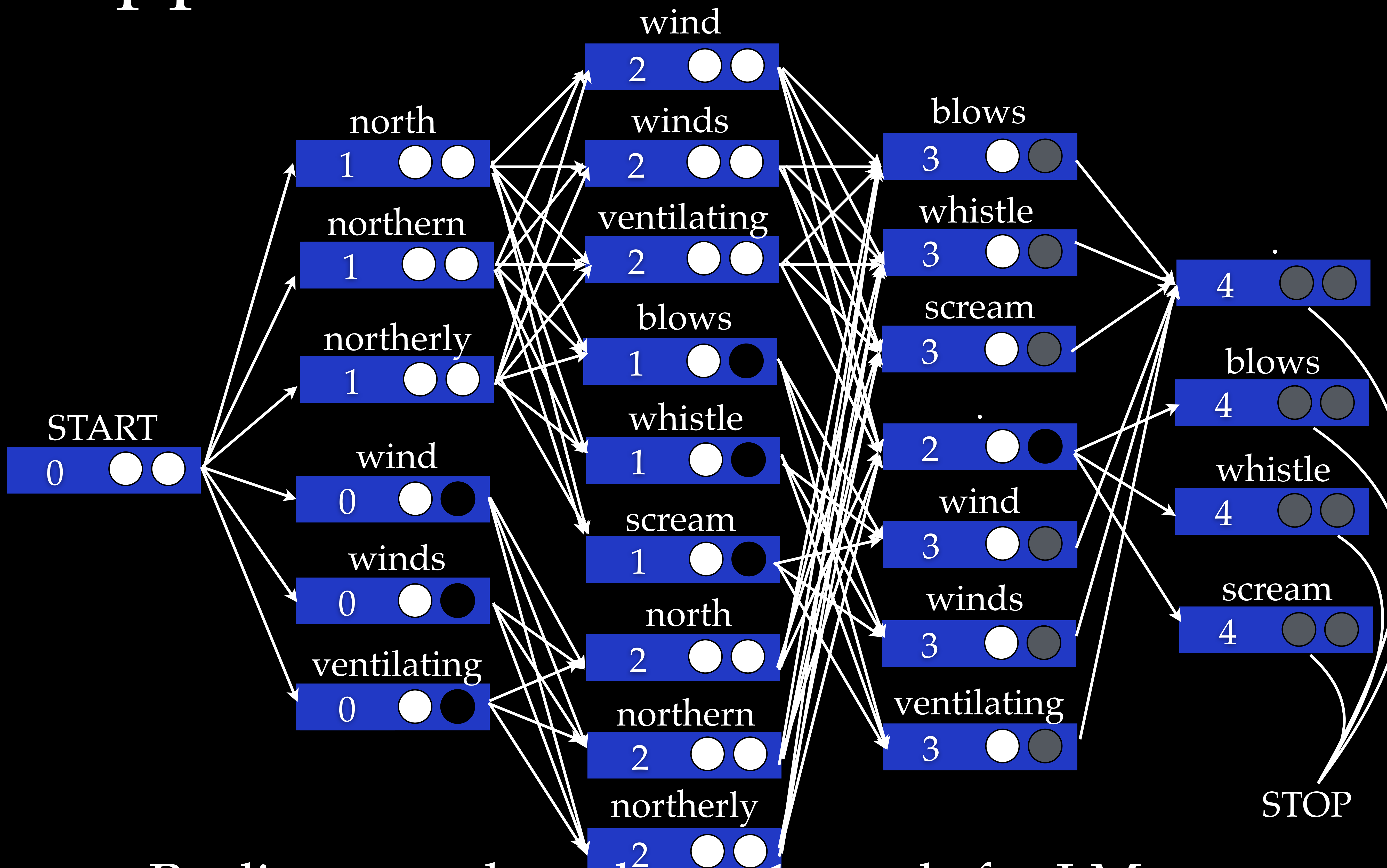


What is this representation missing?

alternative representation with length of covered section + bitmap of window

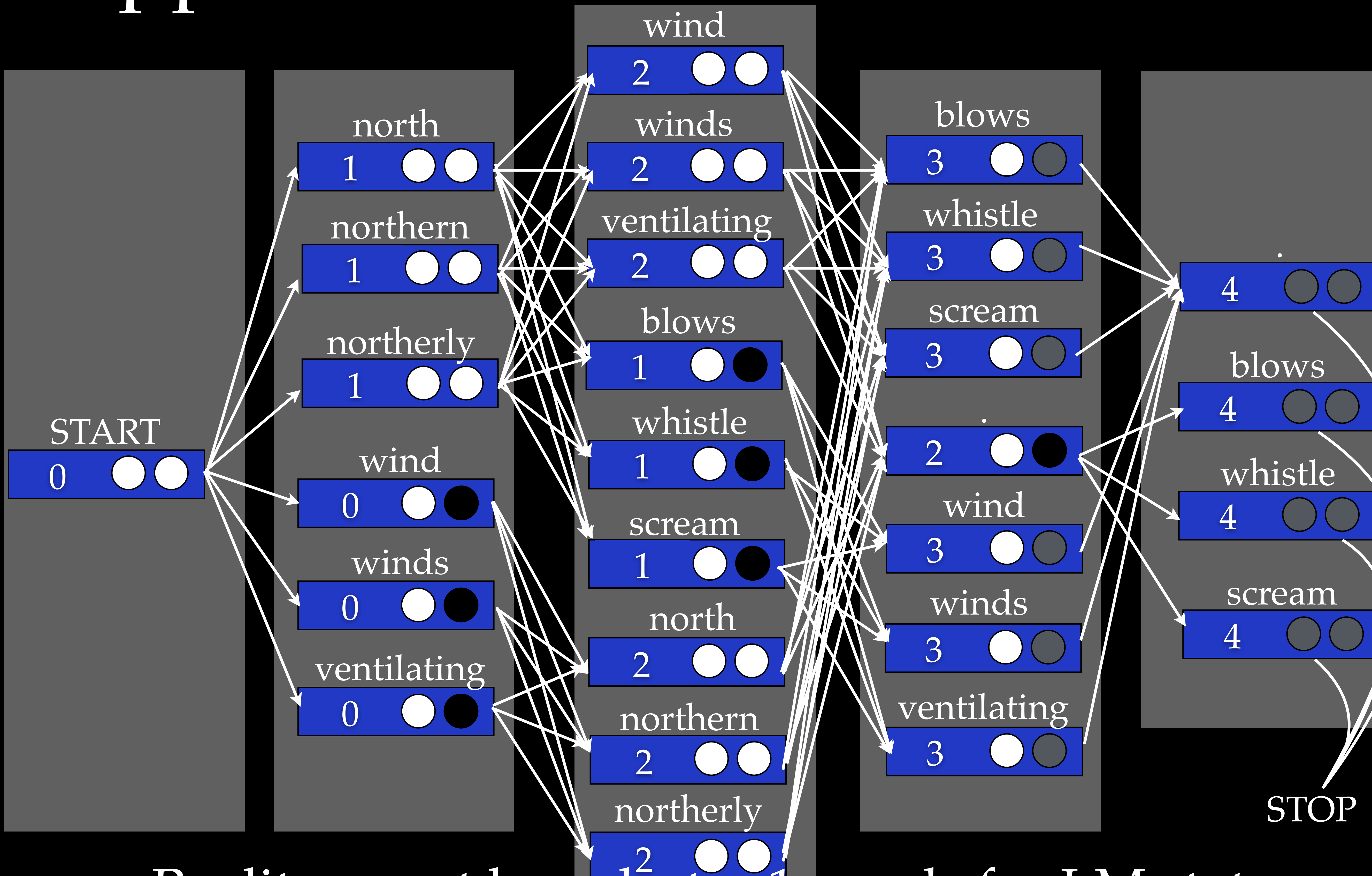
distortion limit = 2

Approximation: distortion limits



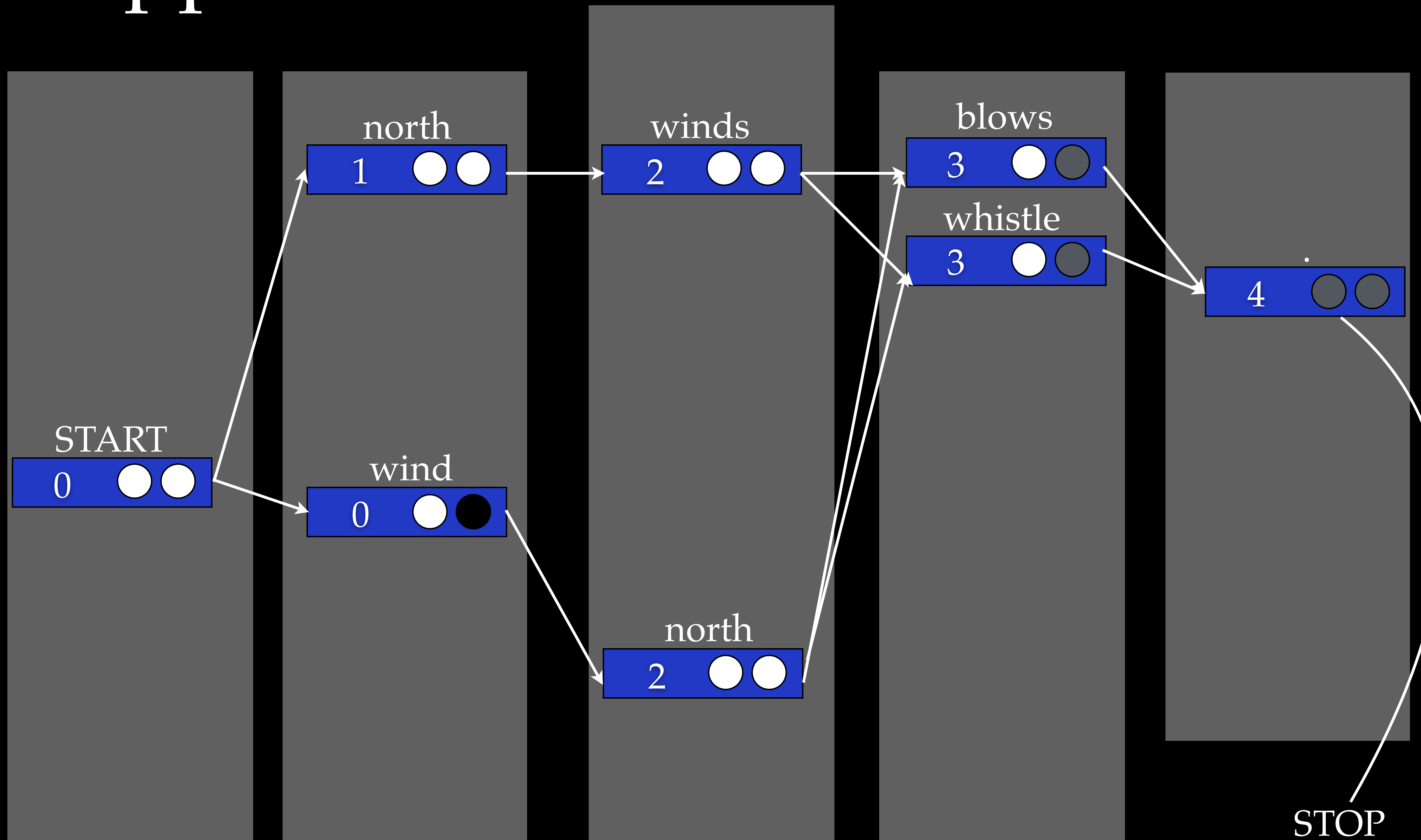
Reality: must keep last n-1 words for LM state

Approximation: distortion limits



Reality: must keep last n-1 words for LM state

Approximation: distortion limits



So, stack pruning is still useful

Putting it all together

```
place empty hypothesis into stack 0
for all stacks 0...n−1 do
  for all hypotheses in stack do
    for all translation options do
      if applicable then
        create new hypothesis
        place in stack
        recombine with existing hypothesis if possible
        prune stack if too big
      end if
    end for
  end for
end for
```

Things you need to determine:

What does a hypothesis (partial translation) look like?

What are all possible extensions of a hypothesis?

What is a reasonable equivalence class (stack)?