The Complexity of Phrase Alignment Problems

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University of California
Berkeley

The Phrase Alignment Problem

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Japan to freeze aid to Russia .

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日本

冻结

向

俄

提供

援助

。

The Phrase Alignment Problem

Japan to freeze aid to Russia .

	Pinyin	Gloss
日本	ri4 ben3	*Japan*
冻结	dong4 jie2	*freeze*
向	xiang4	*to*
俄	e2	*Russia*
提供	ti2 gong1	*supply*
援助	yuan2 zhu4	*assistance*
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The Phrase Alignment Problem

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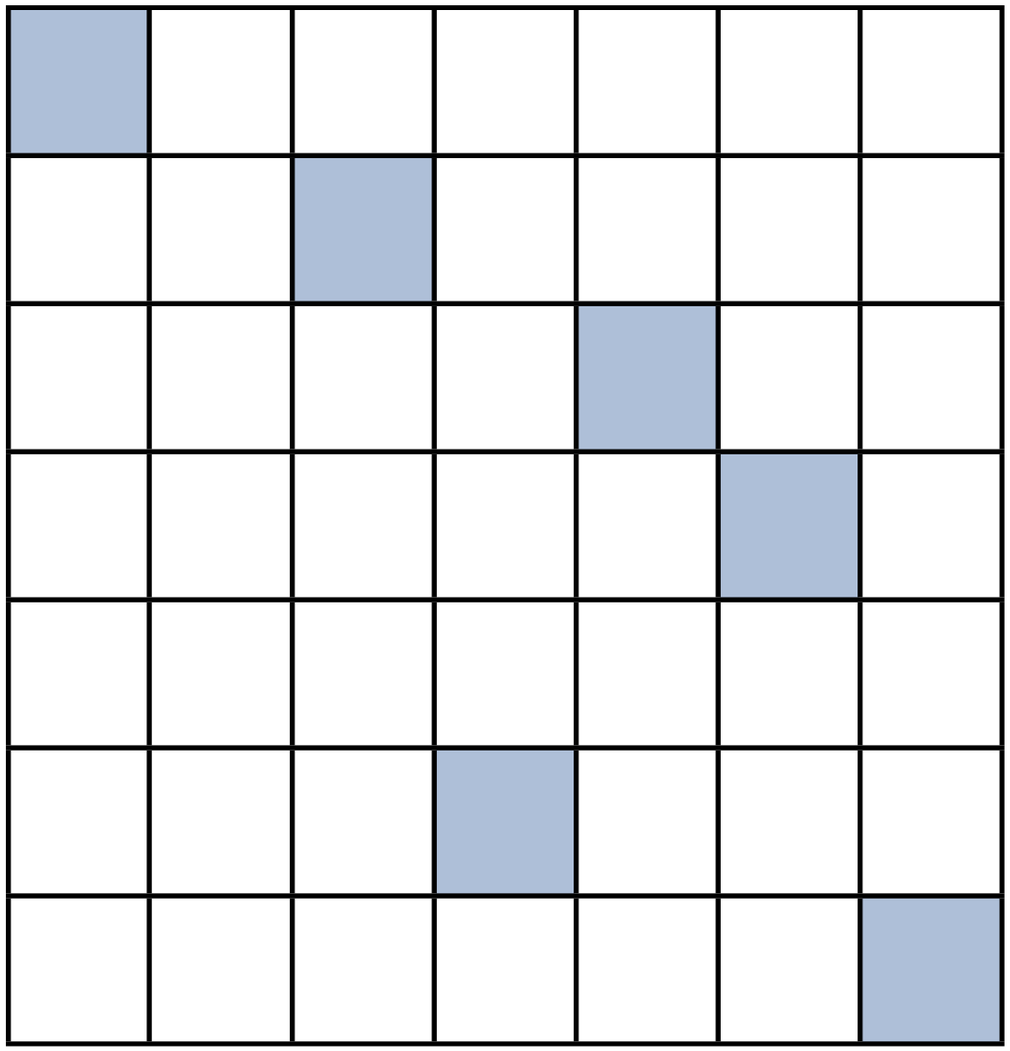

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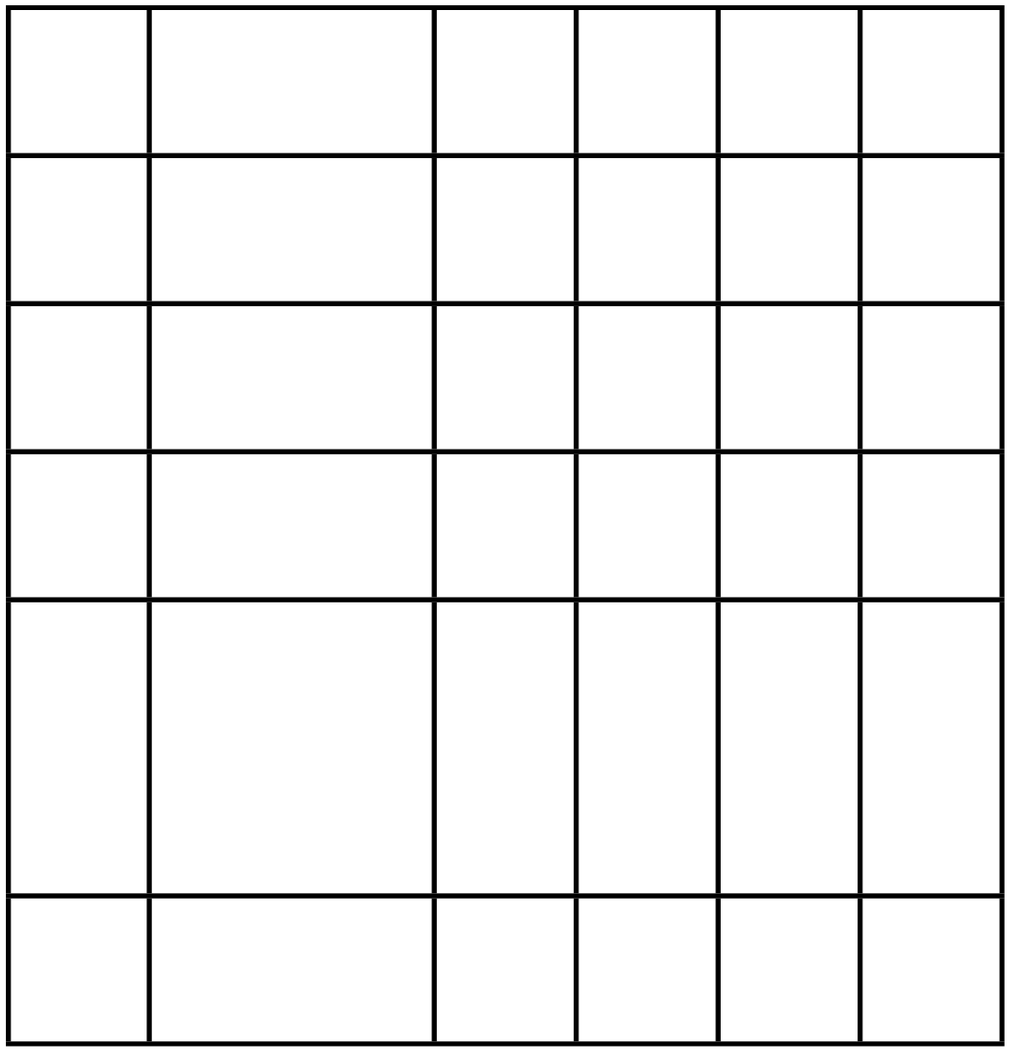

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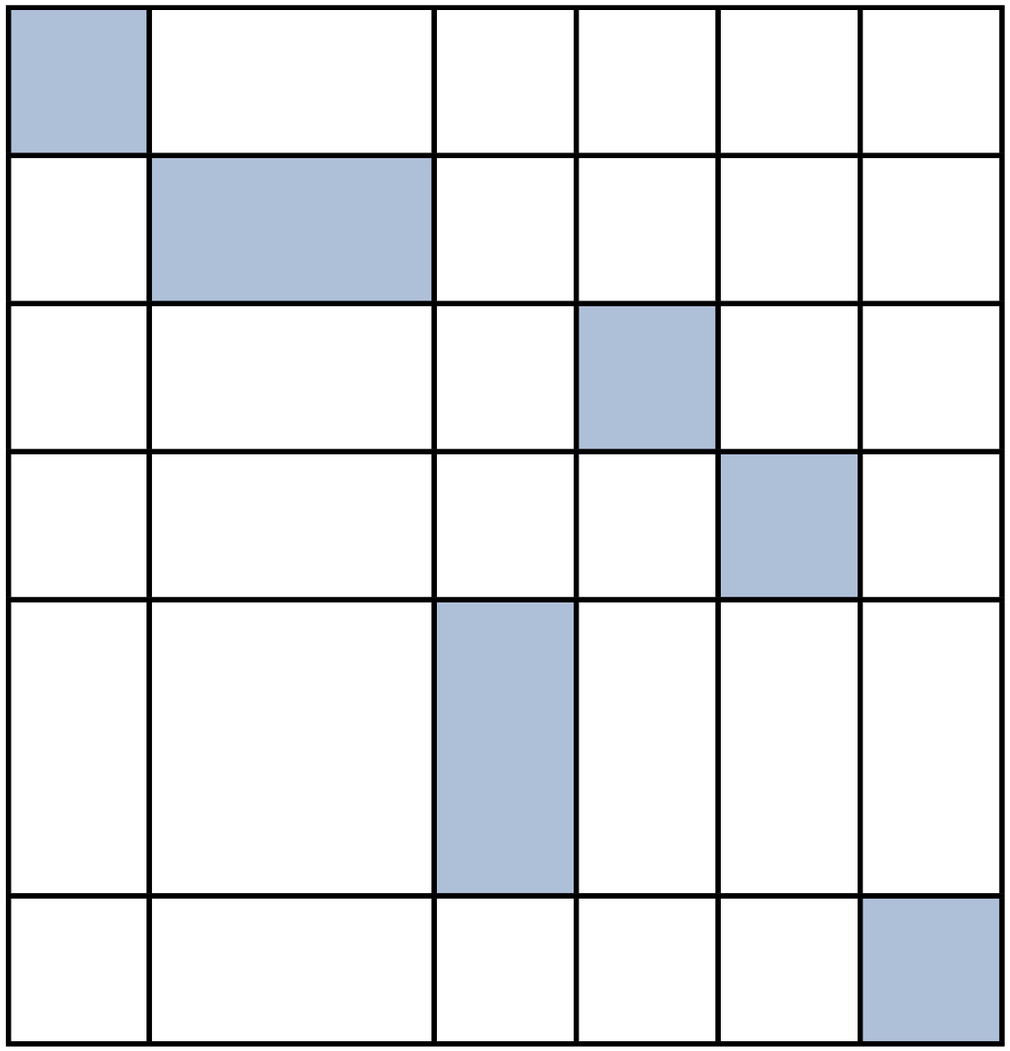

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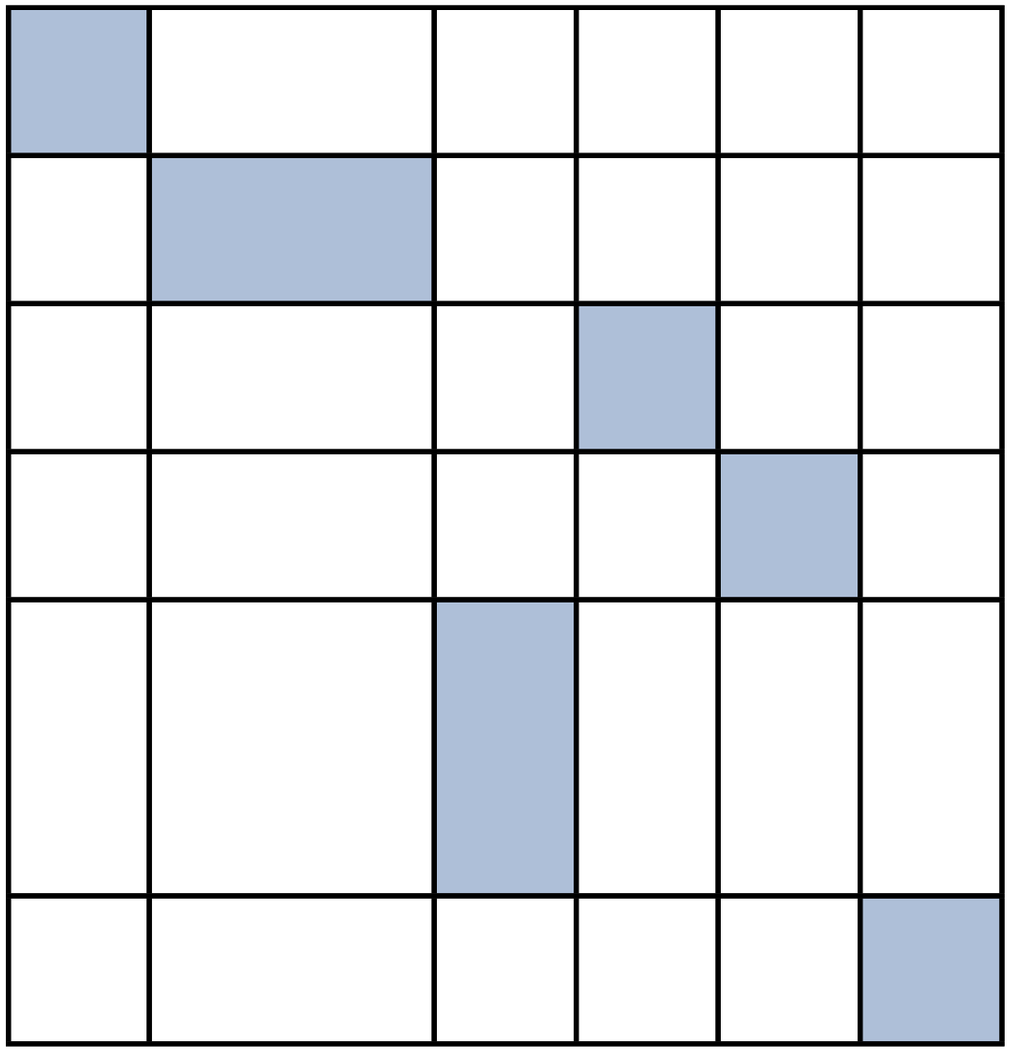

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Phrase alignments are one-to-one and onto

The Weighted Phrase Alignment Problem

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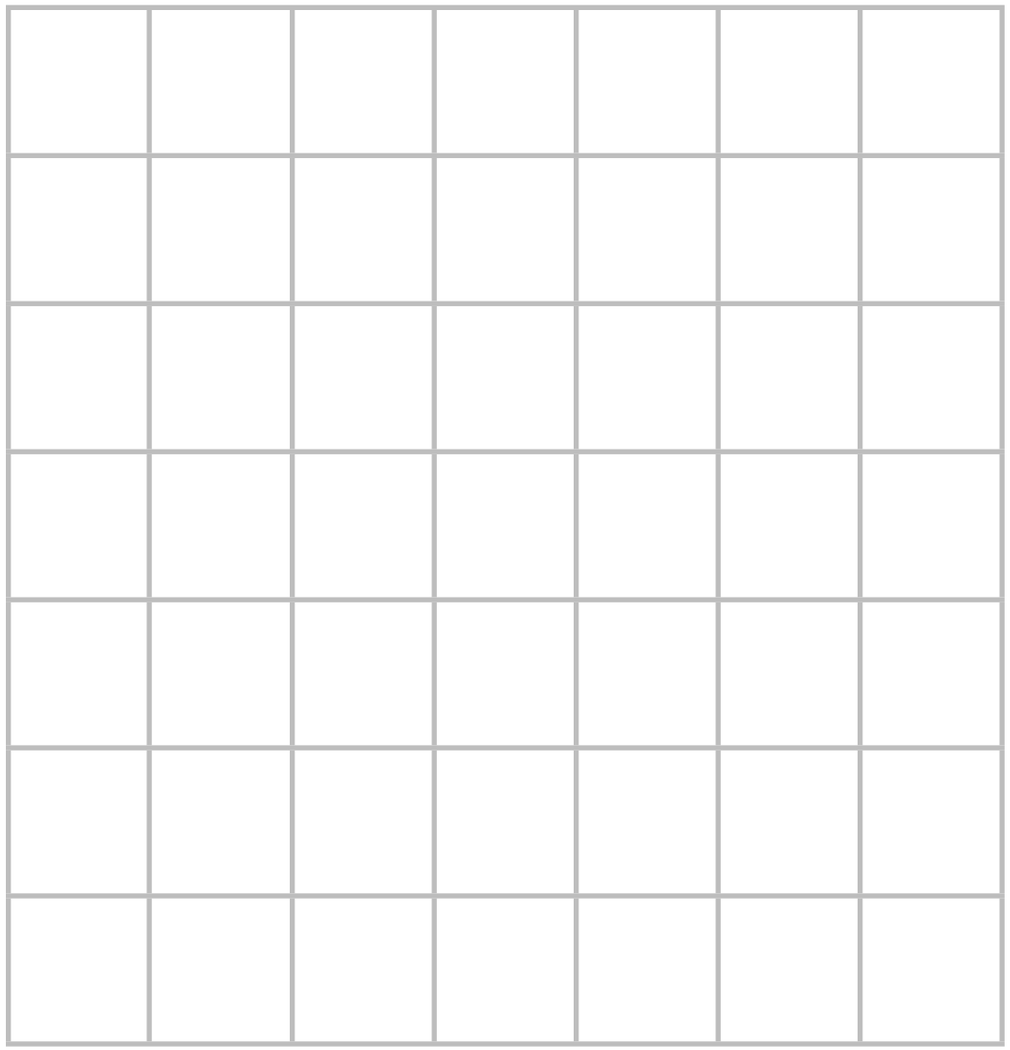

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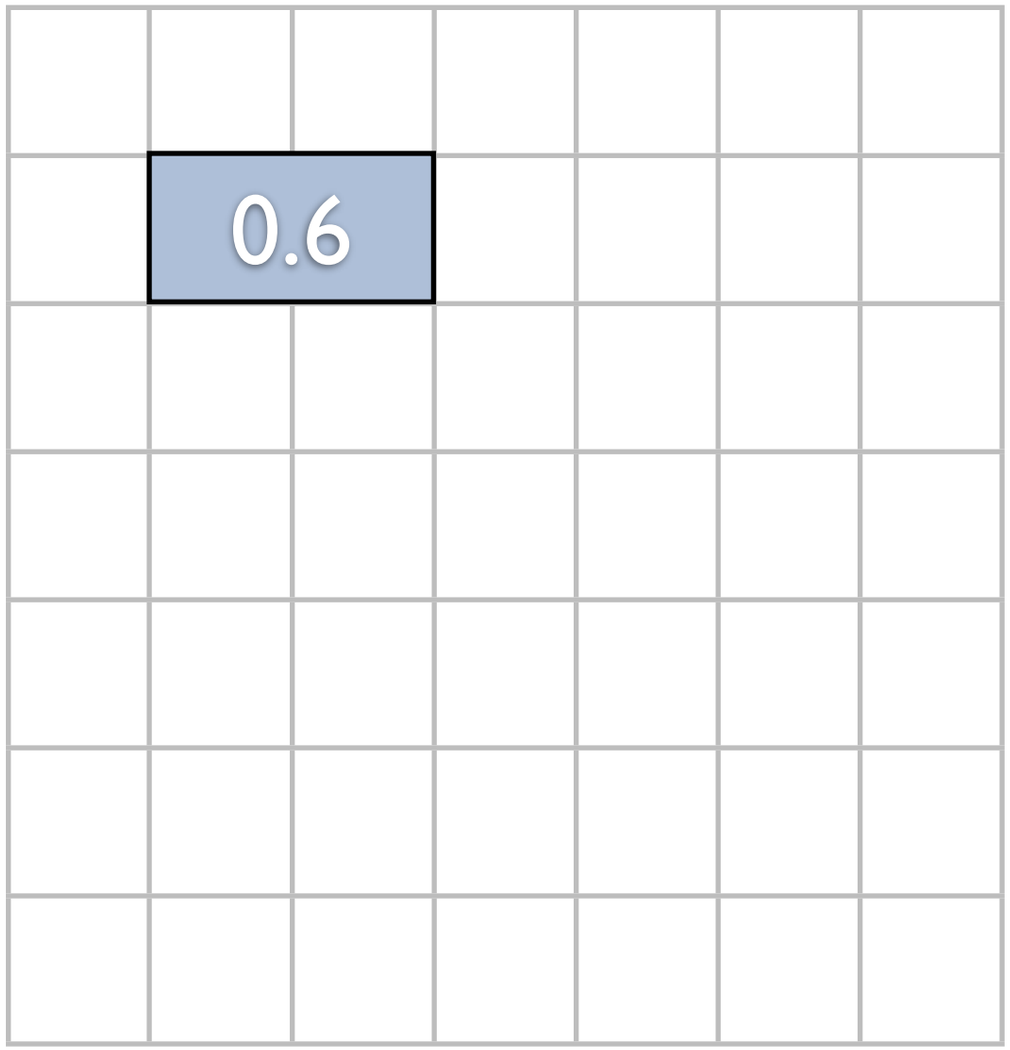

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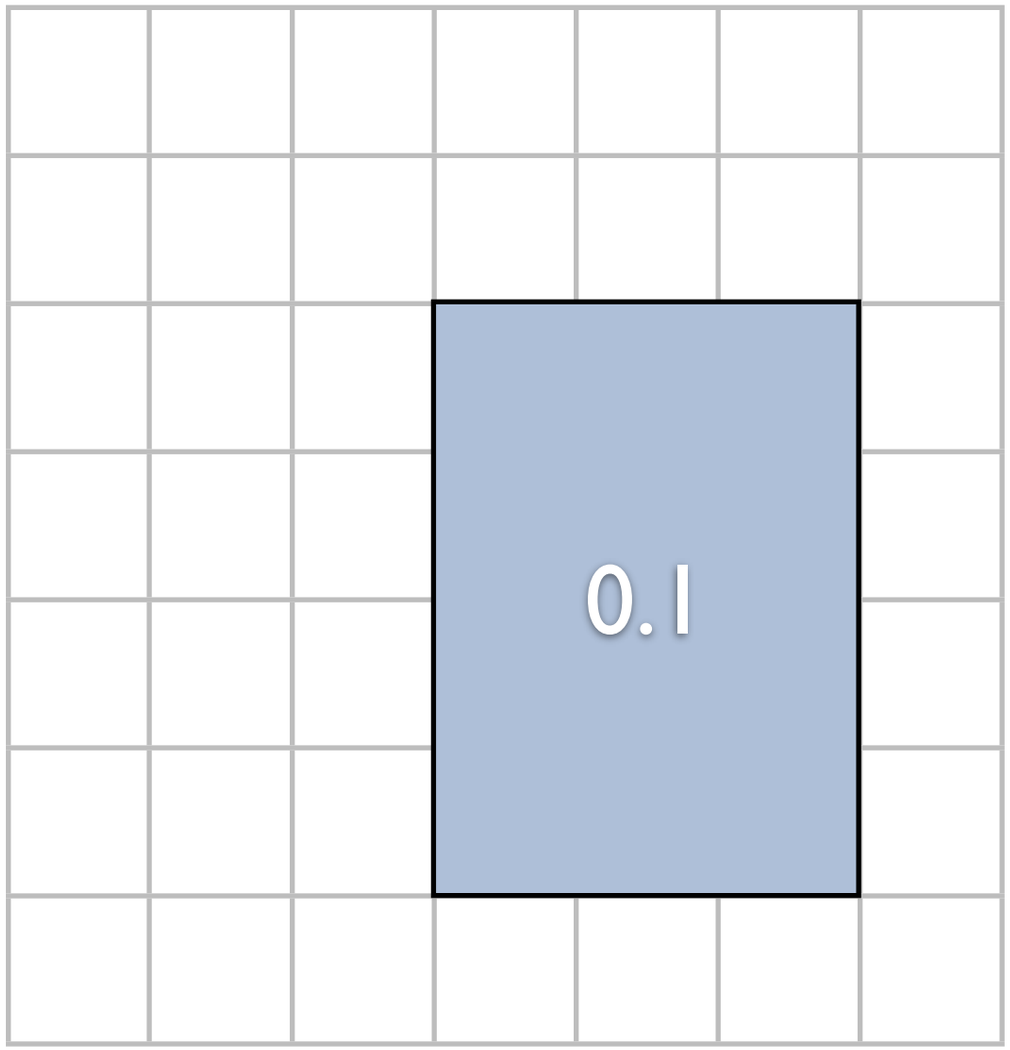

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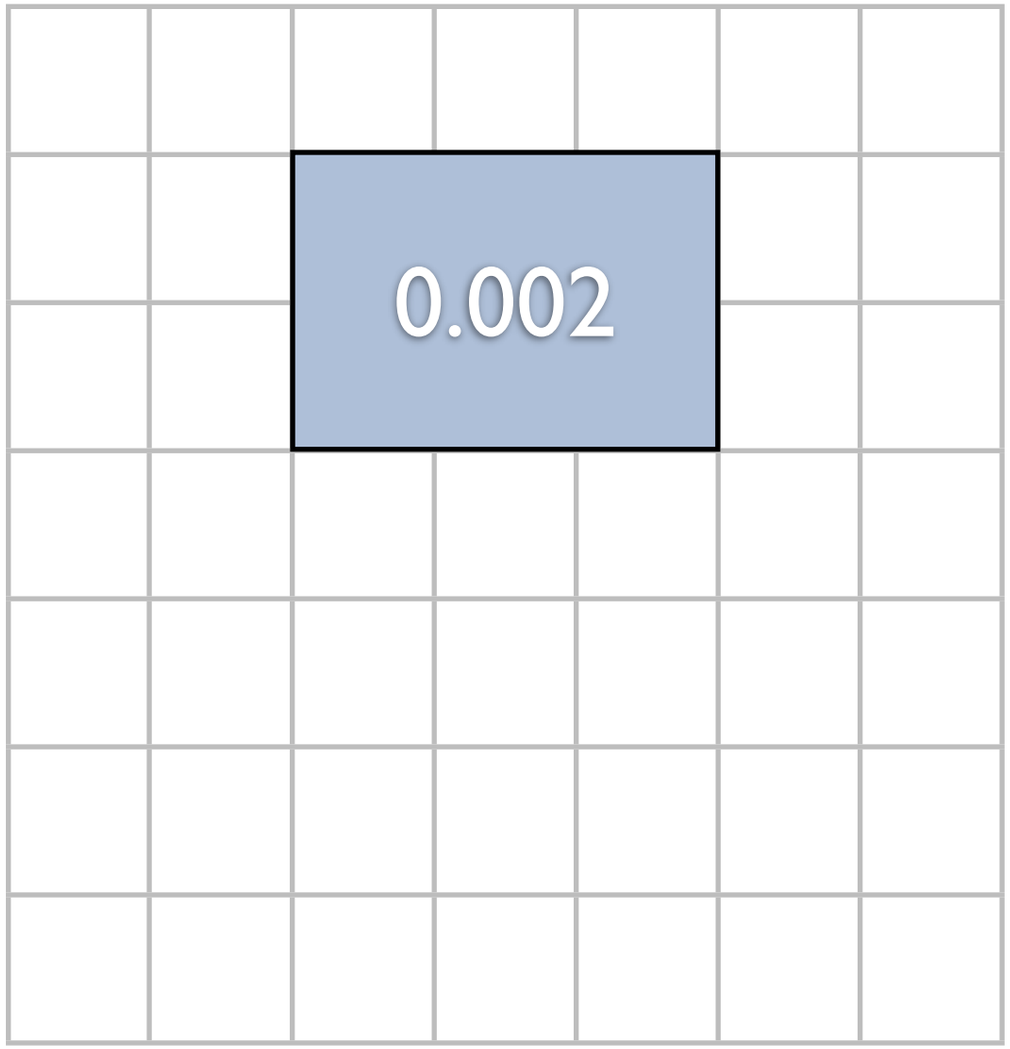

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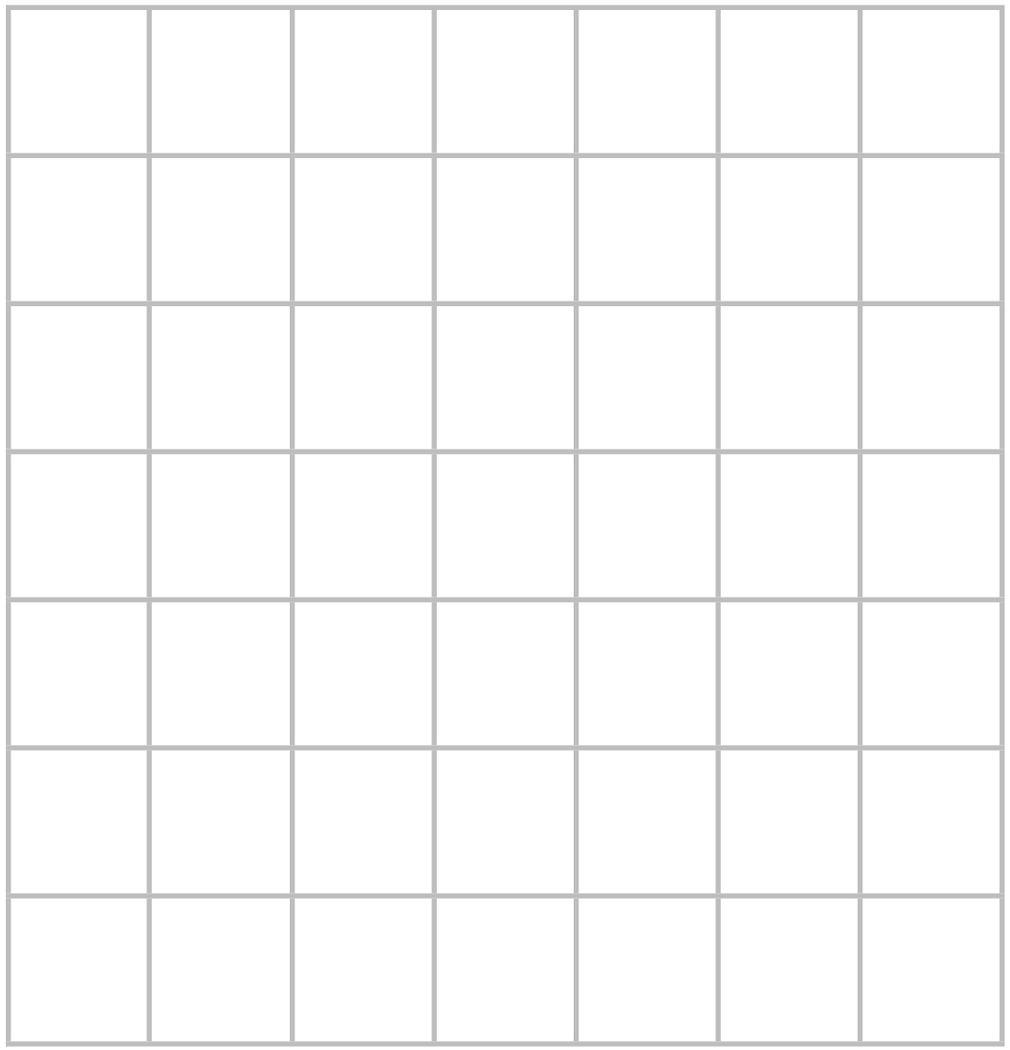

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$0.9 \cdot 0.6 \cdot 0.7 \cdot 0.8 \cdot 0.9 \cdot 0.9 = 0.24$

Applications Involving Phrase Alignments

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- Inference under a phrase alignment model

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- Inference under a phrase alignment model
- Viterbi Training for a phrase alignment model

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Applications Involving Phrase Alignments

- Inference under a phrase alignment model
- Viterbi Training for a phrase alignment model
- Forced decoding for phrase-based systems
- Improved decoding for word alignment models

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MATCHING: Given segmentations, find the maximal matching.

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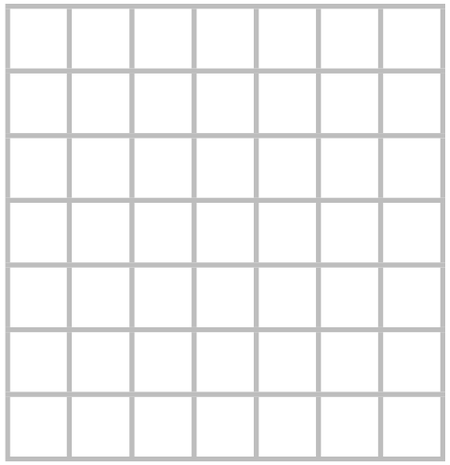

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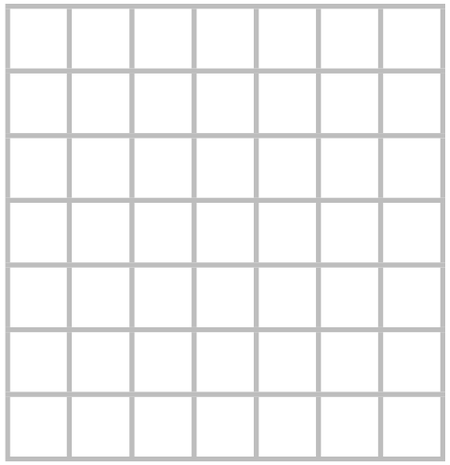

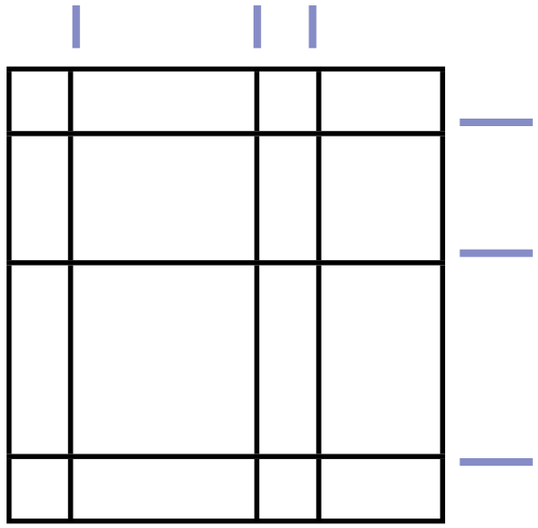

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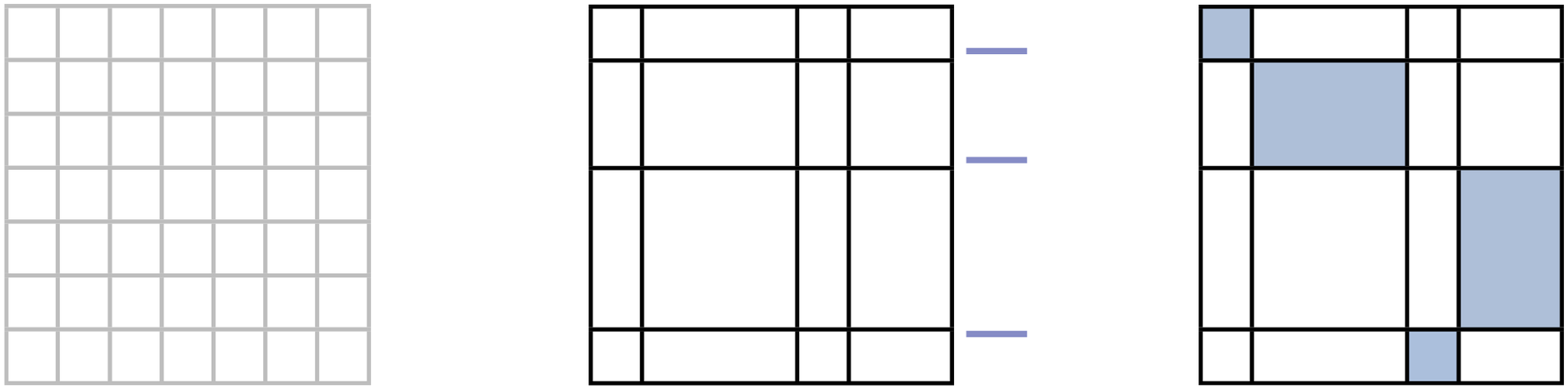

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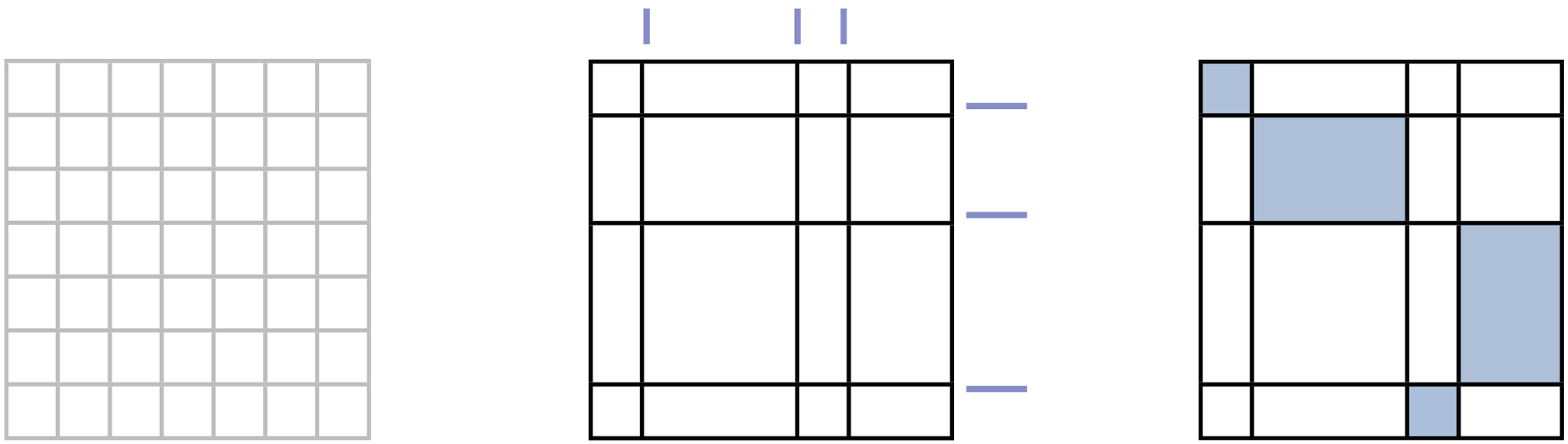

PARTITIONING: Given phrase weights, find the max segmentation.

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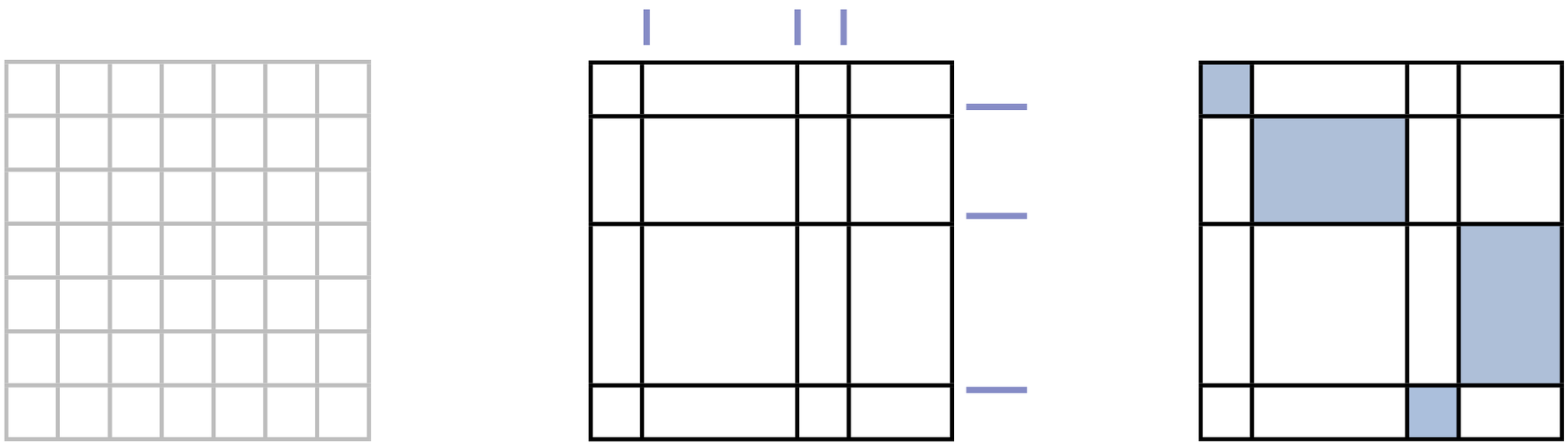

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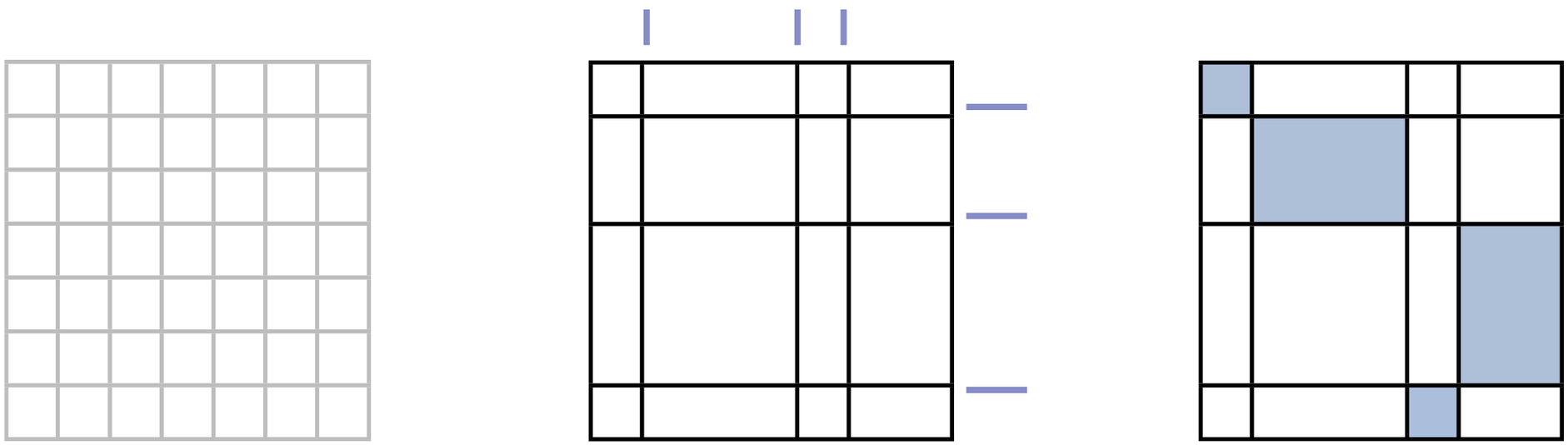

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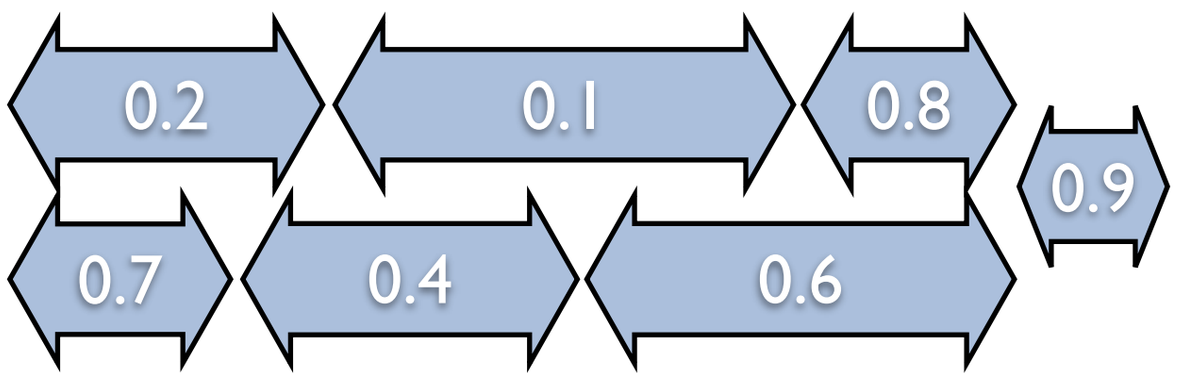

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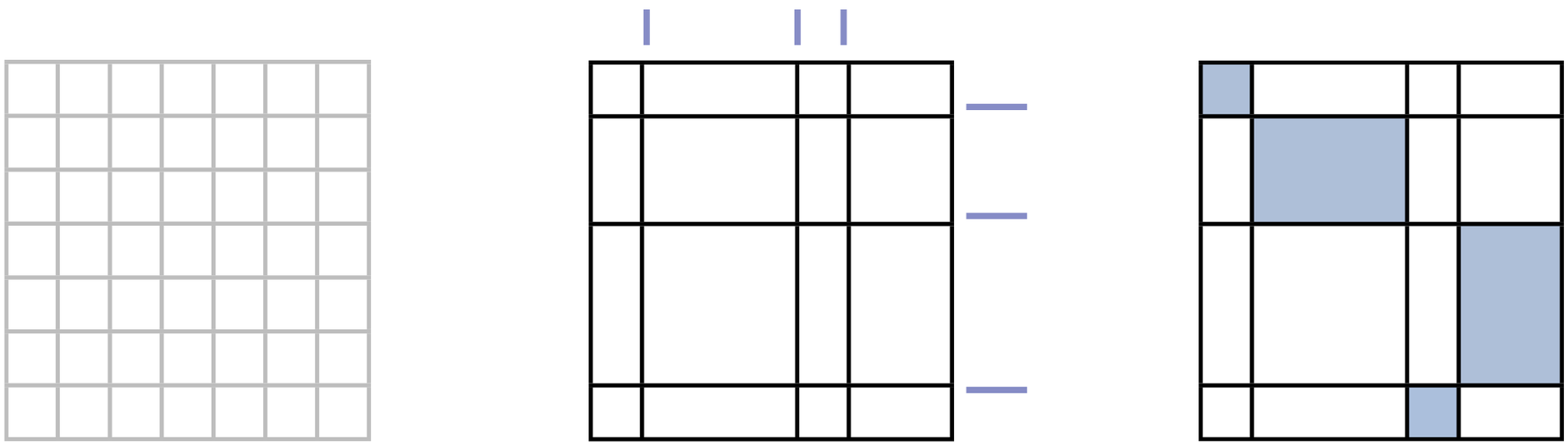

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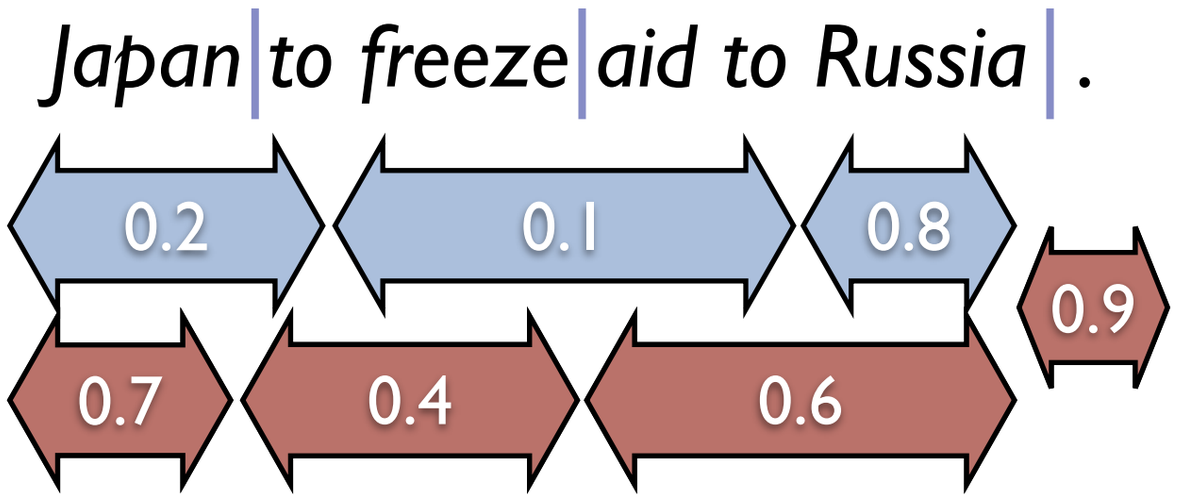

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- PHRASE OPTIMIZATION: Find the highest scoring phrase alignment.

- PHRASE DECISION: Determine if there is a phrase alignment with score $\geq$ t.

Reducing 3-SAT to PHRASE DECISION

Anatomy of a reduction

- Choose an old problem that is known to be NP-hard.
- Show that we can solve that old problem easily if we can solve our new problem.
- Conclude that if the new problem were in P, the old problem would be too (which it's not, we think).

Reducing 3-SAT to Phrase Decision

$$v_1 \vee v_2 \vee v_3$$

$$\bar{v}_1 \vee v_2 \vee \bar{v}_3$$

$$\bar{v}_1 \vee \bar{v}_2 \vee \bar{v}_3$$

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Satisfying assignment:

v_1 is *true*

v_2 is *false*

v_3 is *false*

Reducing 3-SAT to PHRASE DECISION

$$\boxed{v_1} \vee v_2 \vee v_3$$

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Reducing 3-SAT to Phrase Decision

	v_1	$\bar{v}_1$	v_2	$\bar{v}_2$	v_3	$\bar{v}_3$
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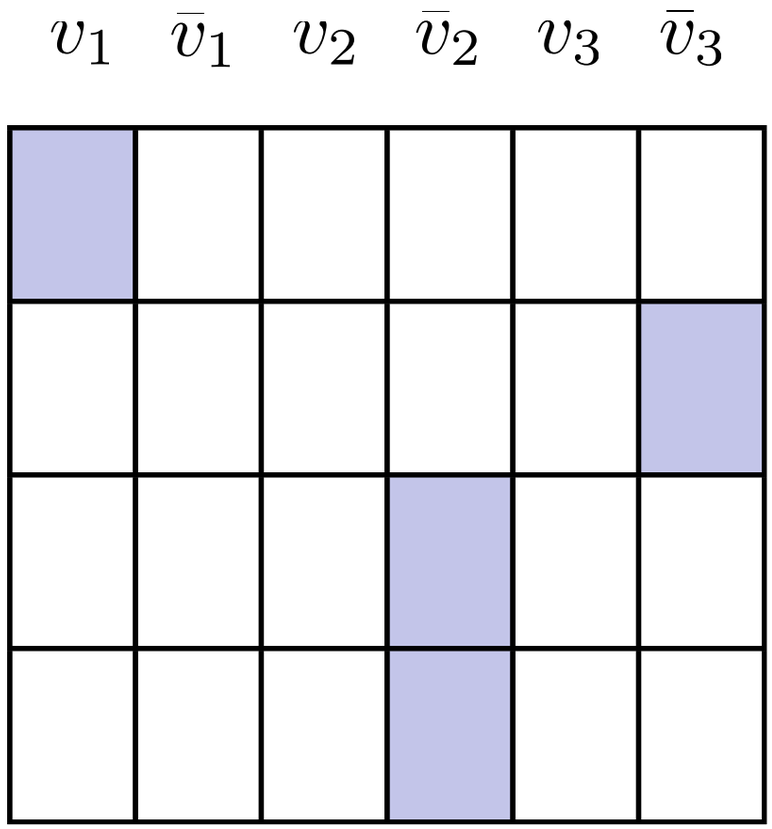

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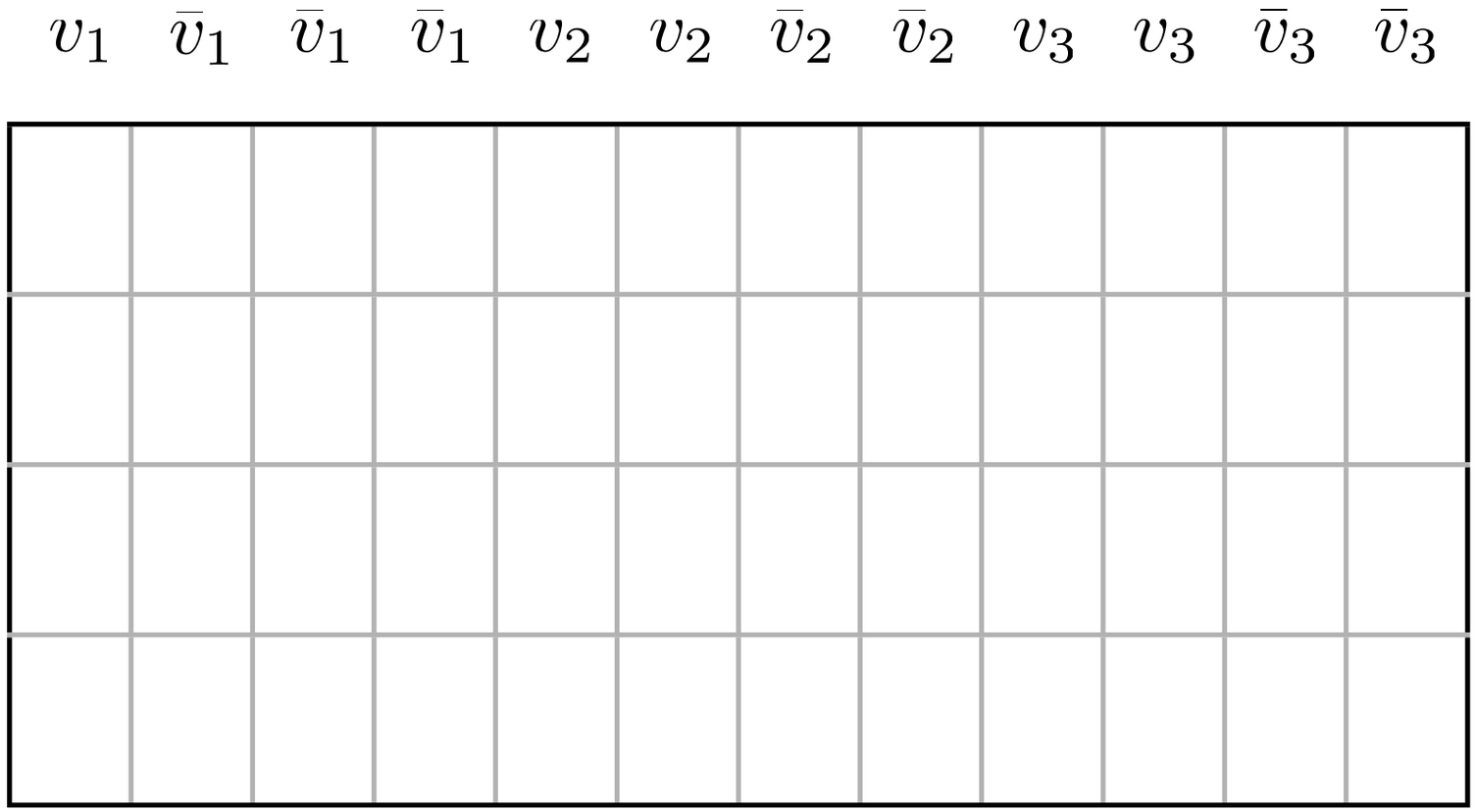

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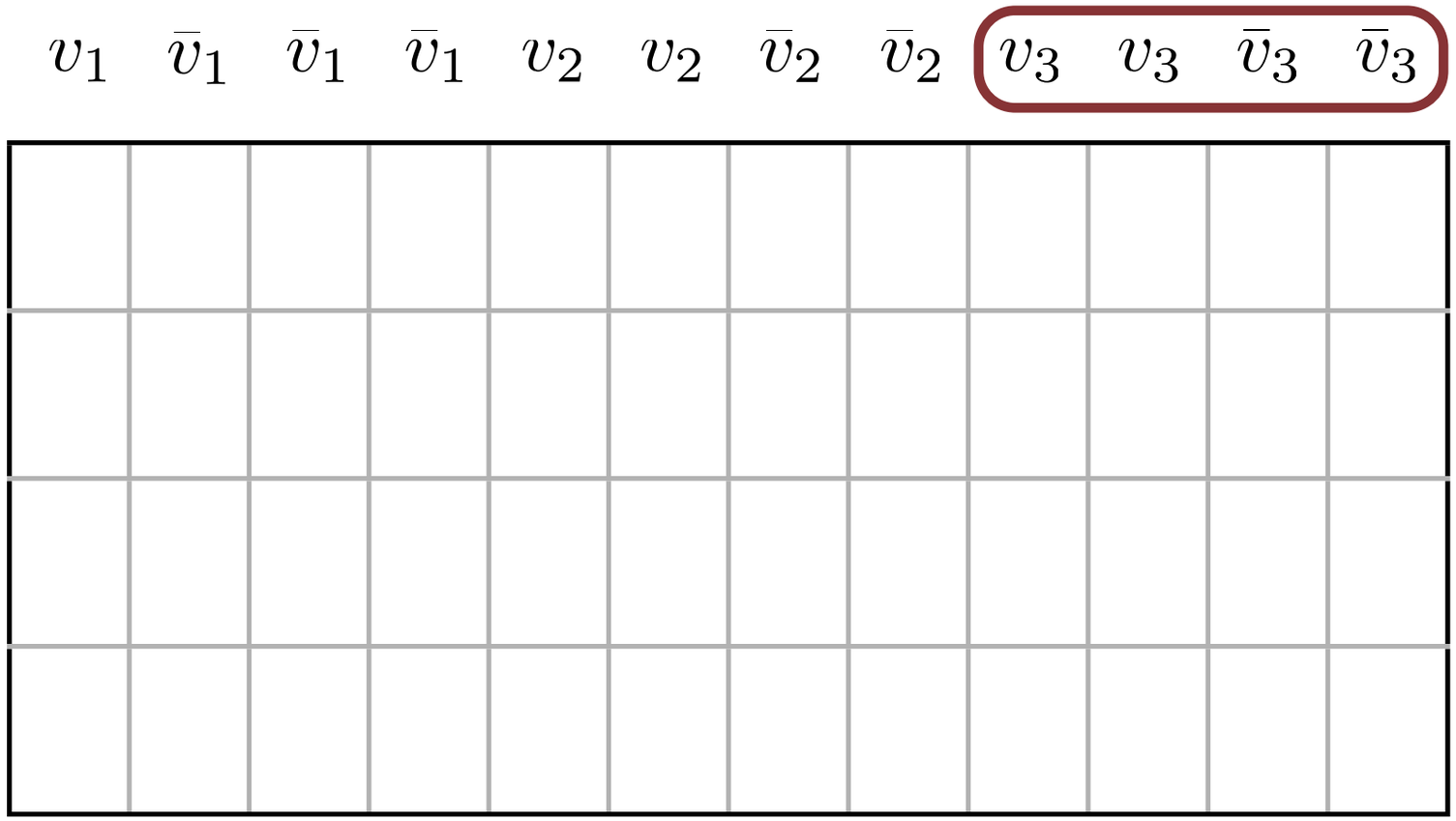

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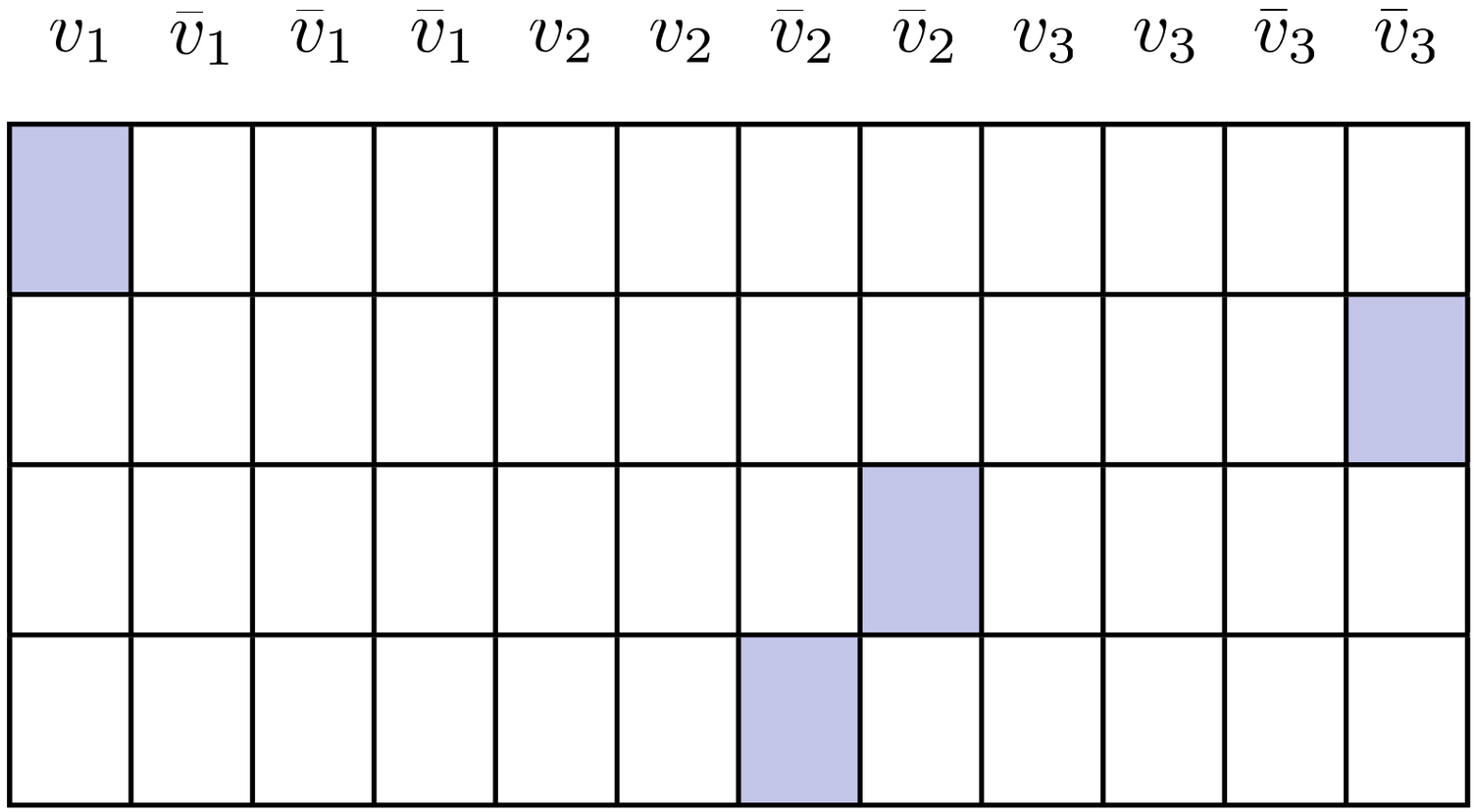

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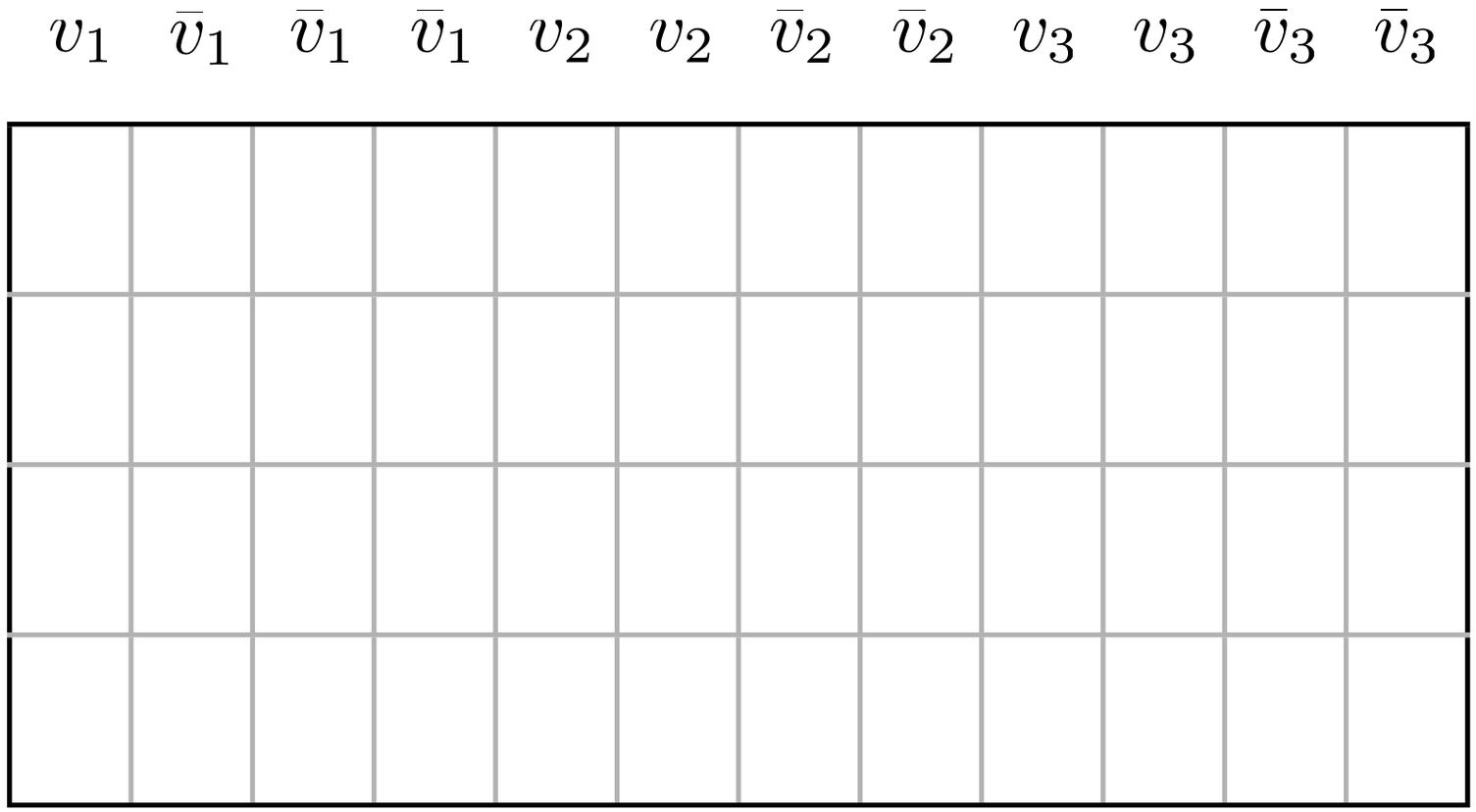

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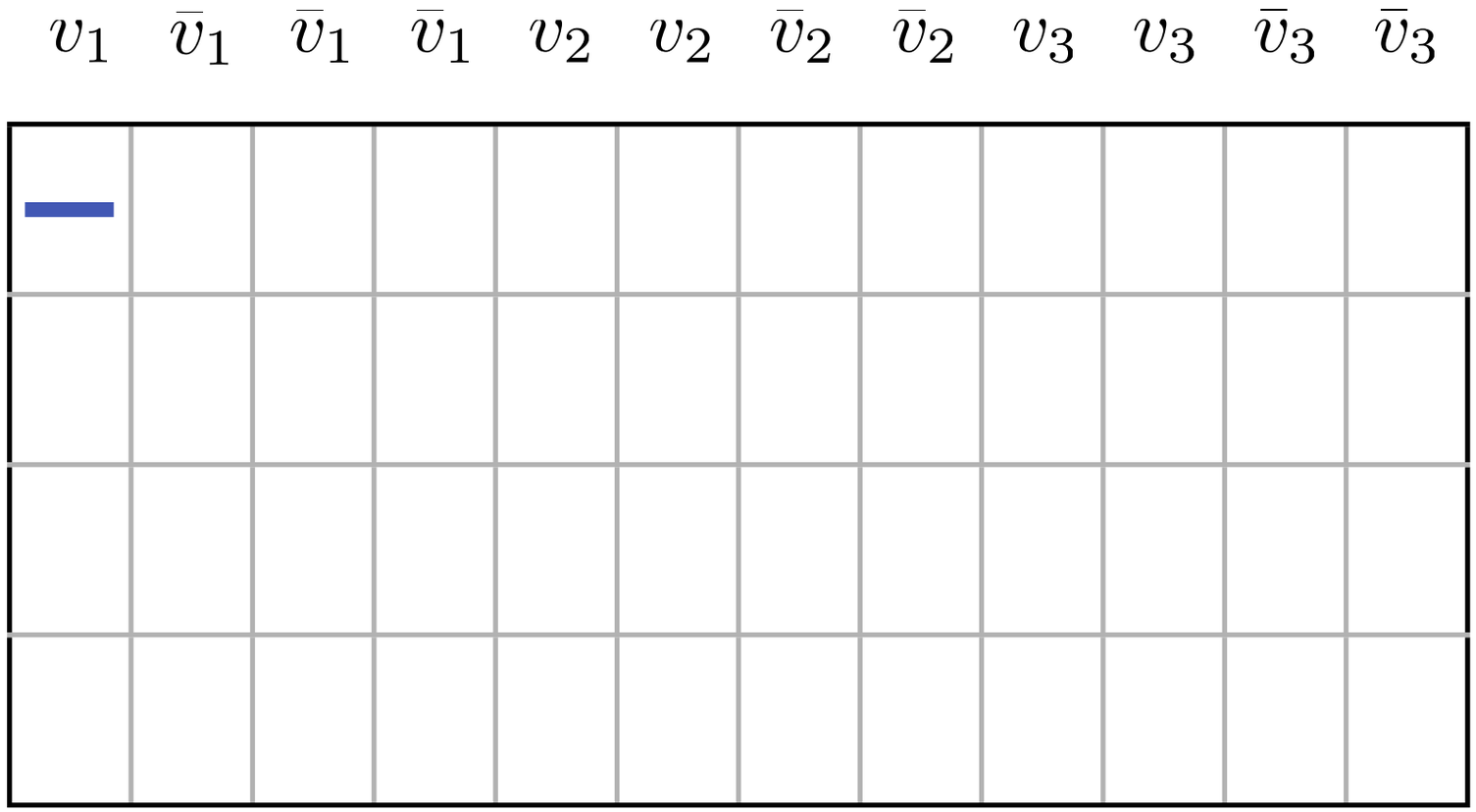

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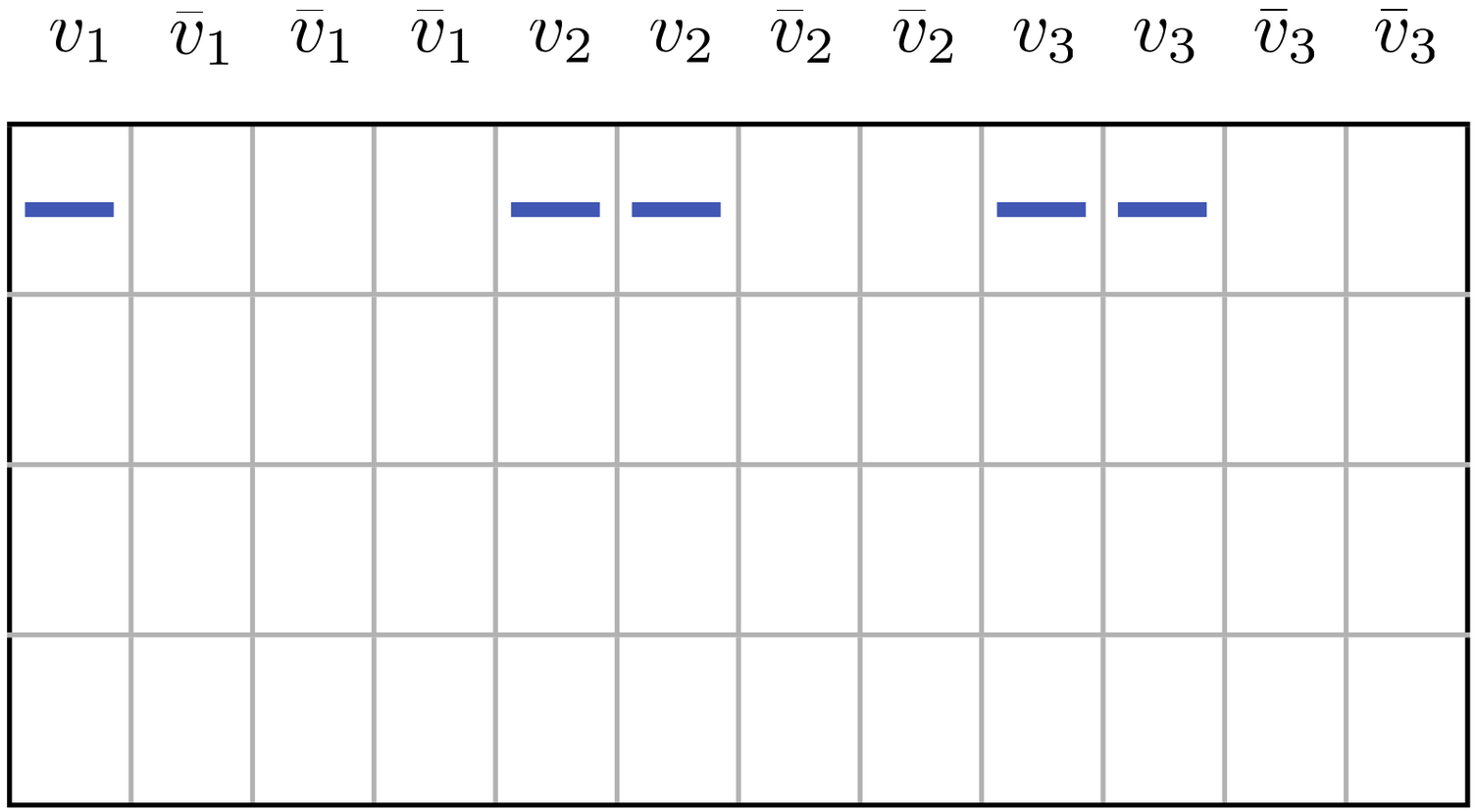

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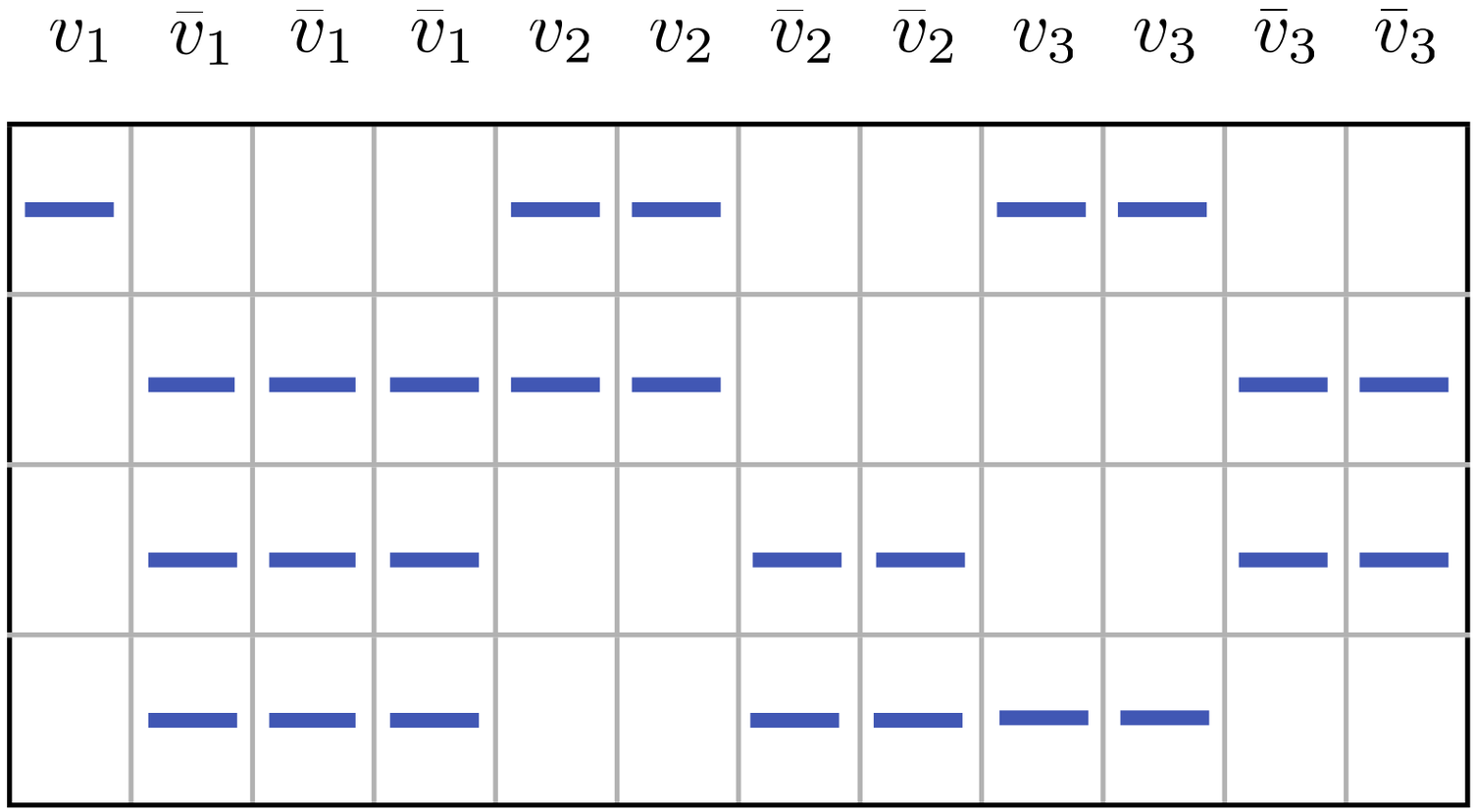

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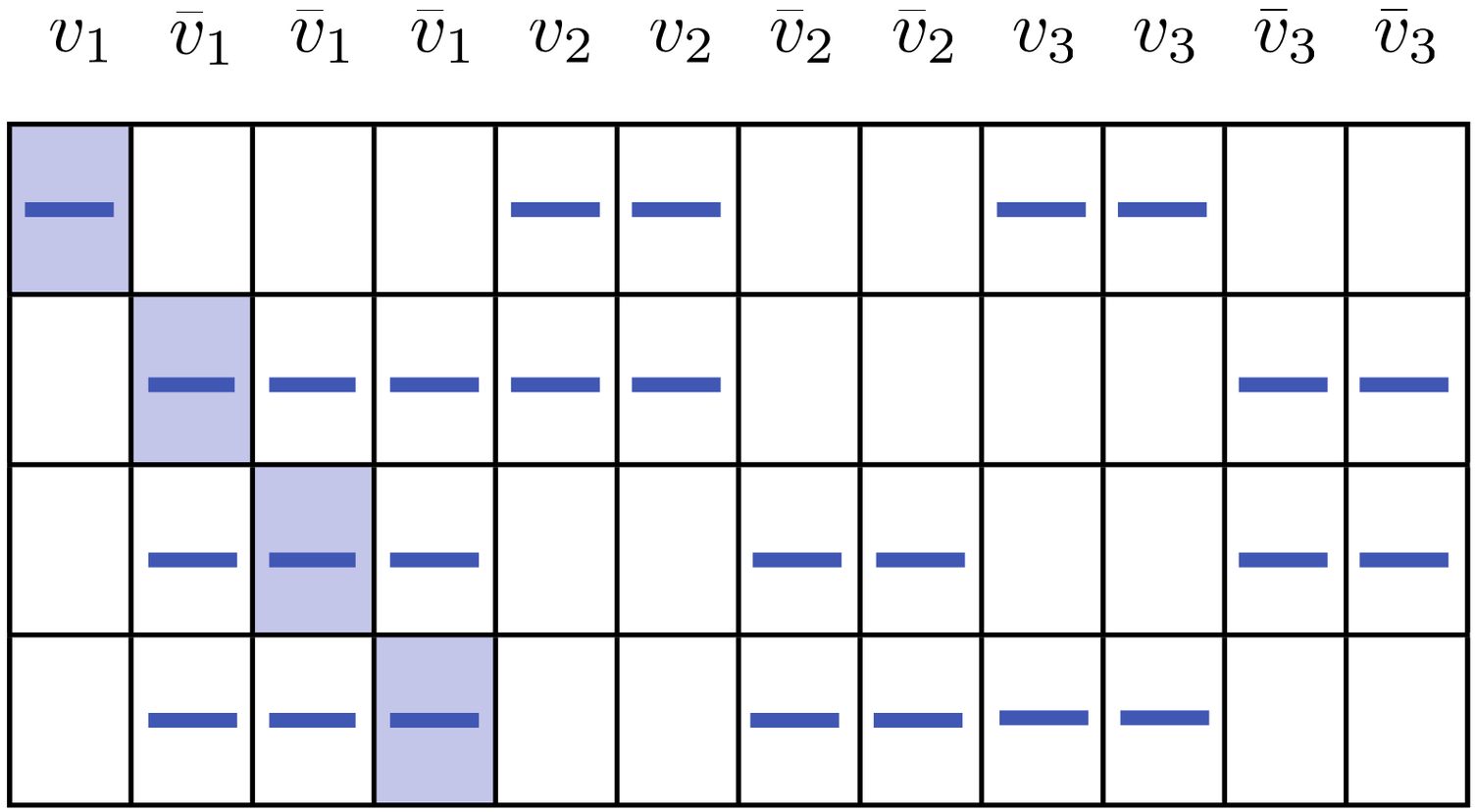

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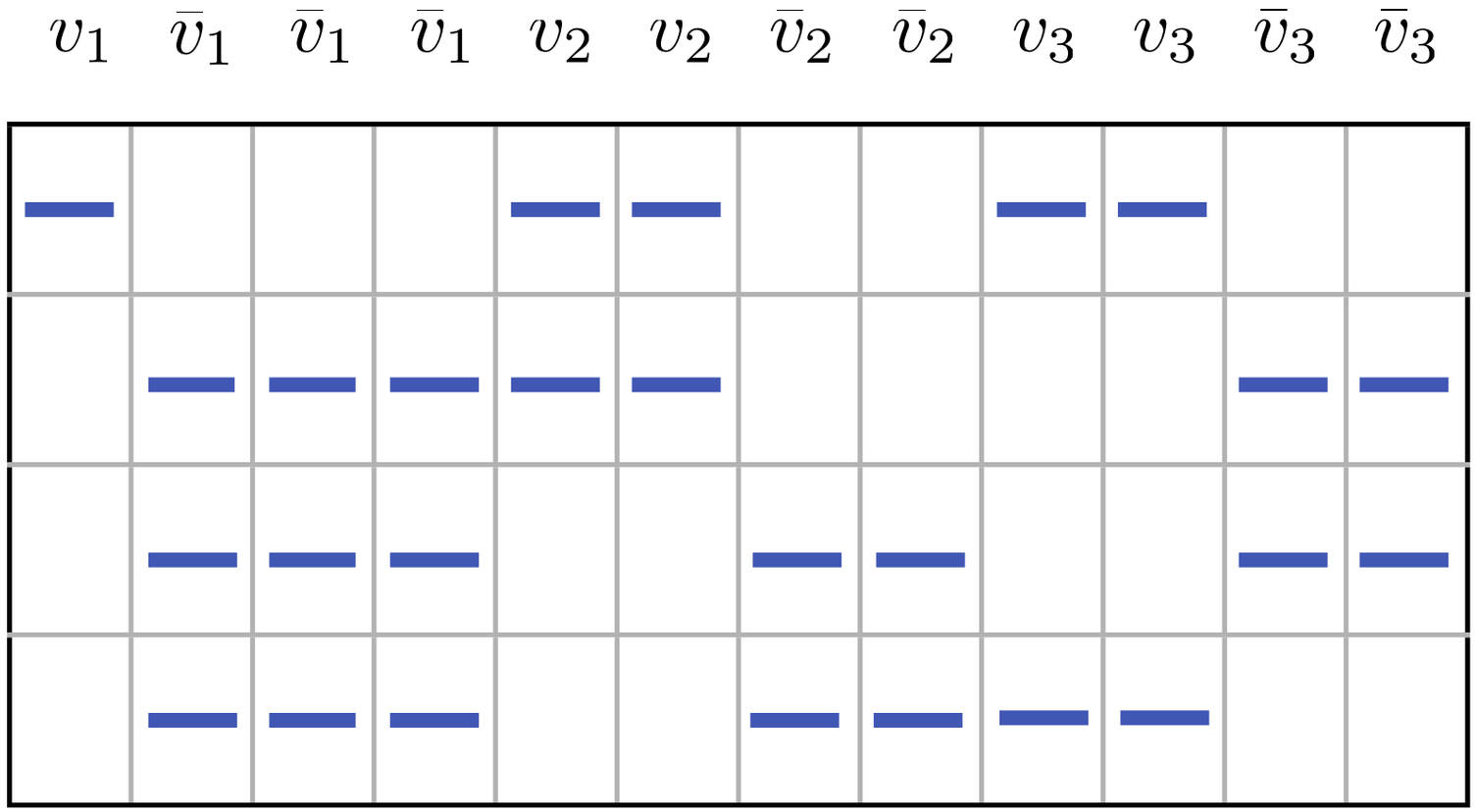
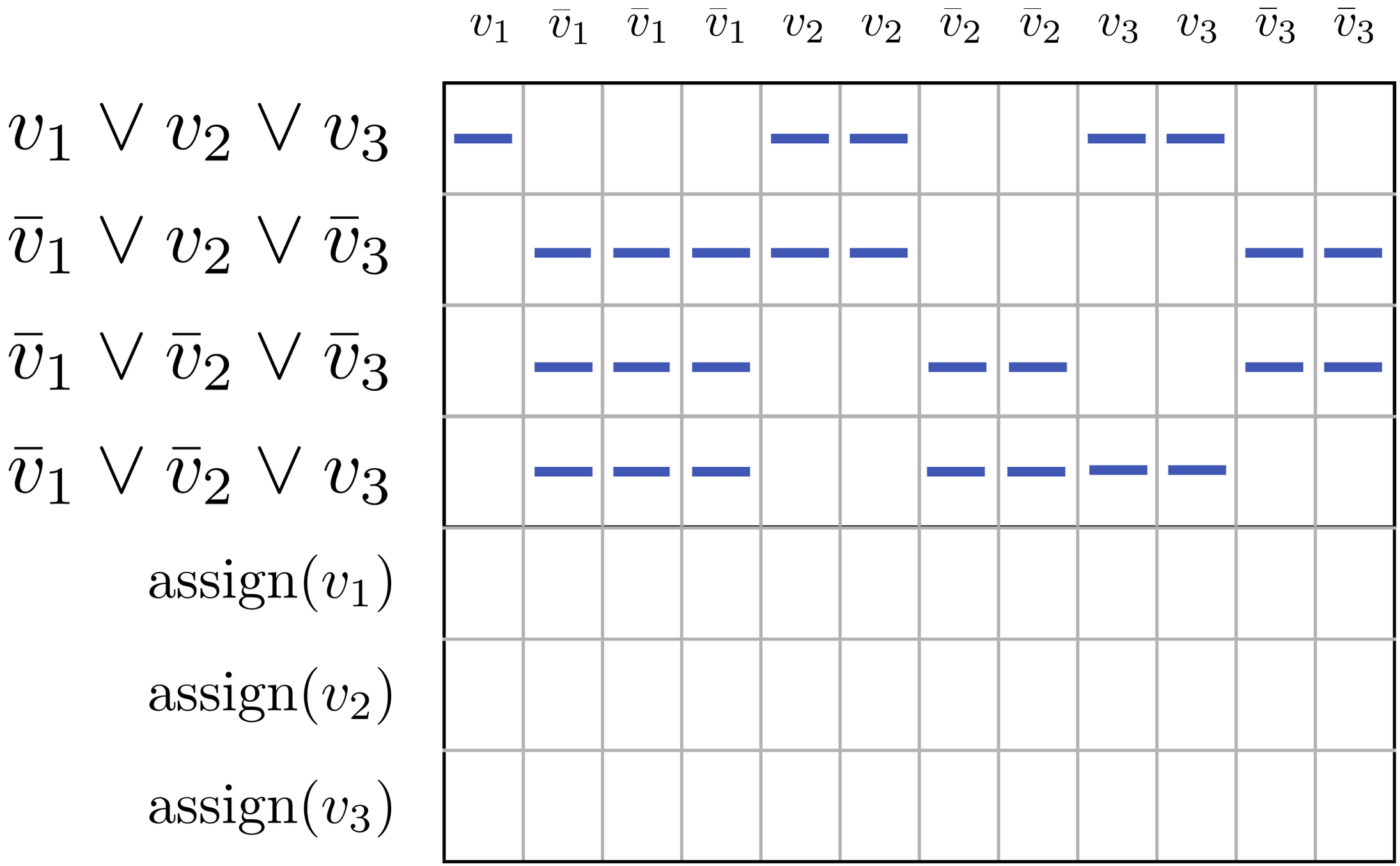


Reducing 3-SAT to Phrase Decision



Reducing 3-SAT to Phrase Decision

$v_1 \vee v_2 \vee v_3$

$\bar{v}_1 \vee v_2 \vee \bar{v}_3$

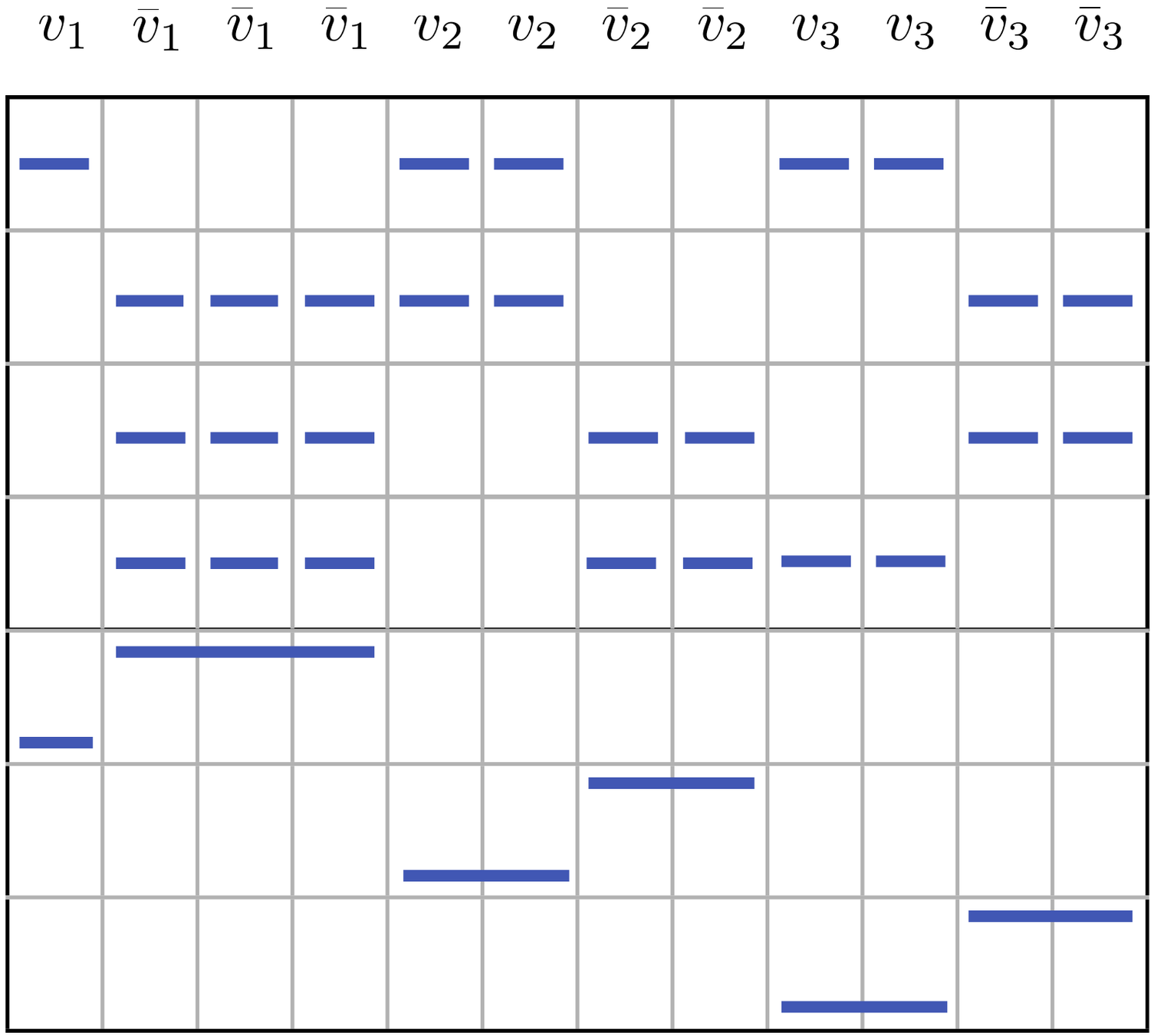
$\bar{v}_1 \vee \bar{v}_2 \vee \bar{v}_3$

$\bar{v}_1 \vee \bar{v}_2 \vee v_3$

$\text{assign}(v_1)$

$\text{assign}(v_2)$

$\text{assign}(v_3)$



Reducing 3-SAT to Phrase Decision

$v_1 \vee v_2 \vee v_3$

$\bar{v}_1 \vee v_2 \vee \bar{v}_3$

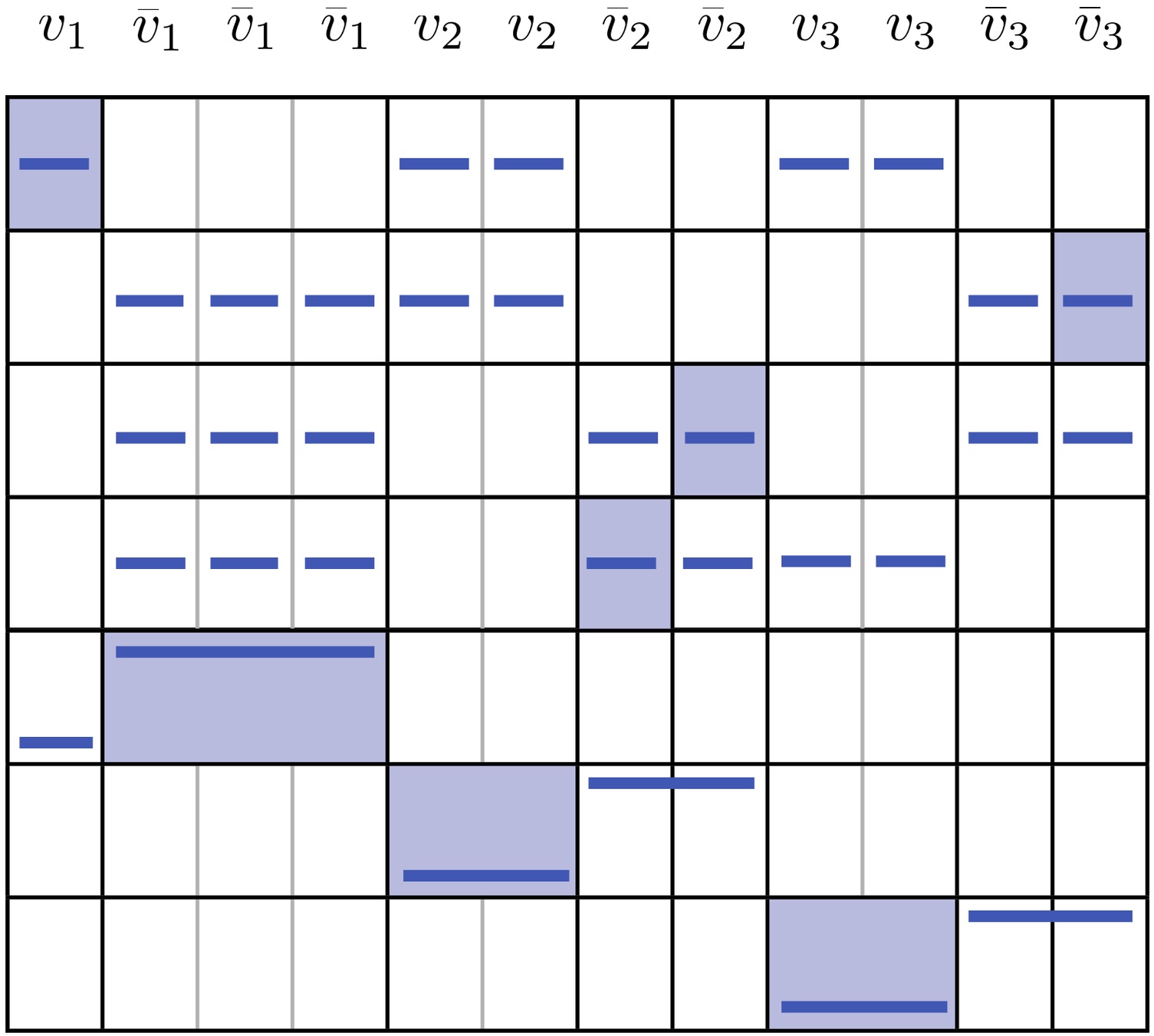
$\bar{v}_1 \vee \bar{v}_2 \vee \bar{v}_3$

$\bar{v}_1 \vee \bar{v}_2 \vee v_3$

$\text{assign}(v_1)$

$\text{assign}(v_2)$

$\text{assign}(v_3)$



Reducing 3-SAT to Phrase Decision

$v_1 \vee v_2 \vee v_3$

$\bar{v}_1 \vee v_2 \vee \bar{v}_3$

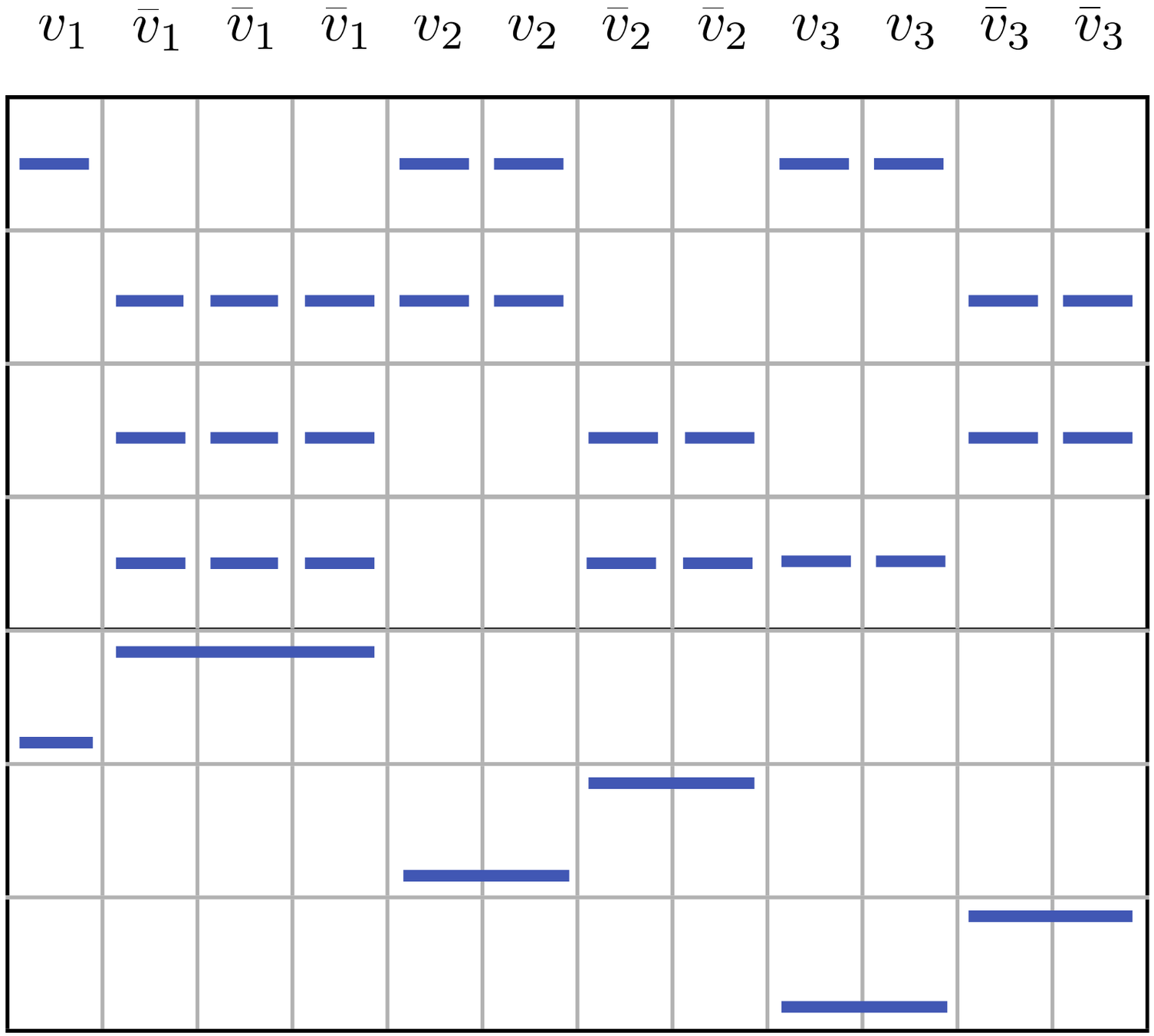
$\bar{v}_1 \vee \bar{v}_2 \vee \bar{v}_3$

$\bar{v}_1 \vee \bar{v}_2 \vee v_3$

$\text{assign}(v_1)$

$\text{assign}(v_2)$

$\text{assign}(v_3)$



Reducing 3-SAT to Phrase Decision

$v_1 \vee v_2 \vee v_3$

$\bar{v}_1 \vee v_2 \vee \bar{v}_3$

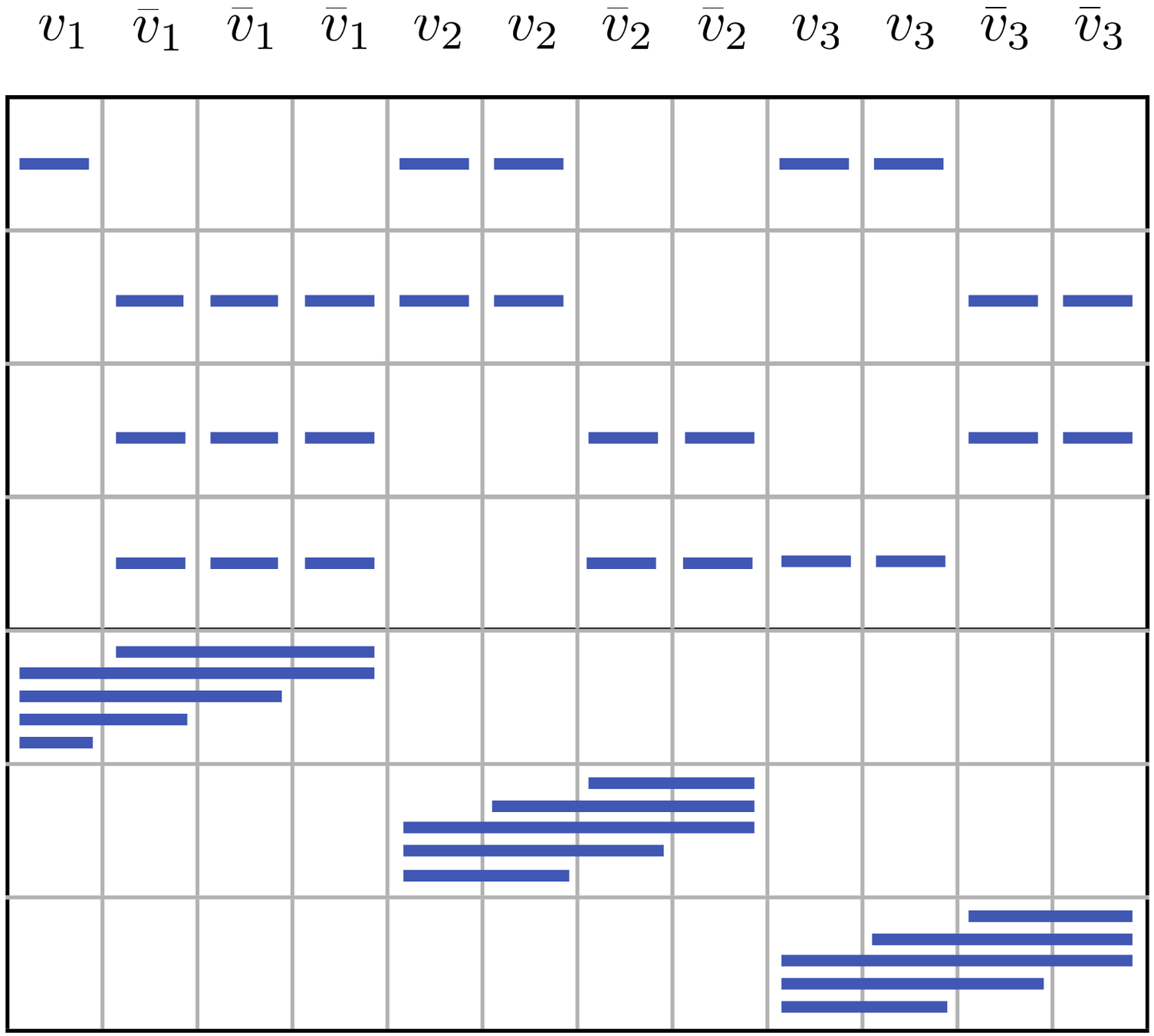
$\bar{v}_1 \vee \bar{v}_2 \vee \bar{v}_3$

$\bar{v}_1 \vee \bar{v}_2 \vee v_3$

$\text{assign}(v_1)$

$\text{assign}(v_2)$

$\text{assign}(v_3)$



Reducing 3-SAT to Phrase Decision

$v_1 \vee v_2 \vee v_3$

$\bar{v}_1 \vee v_2 \vee \bar{v}_3$

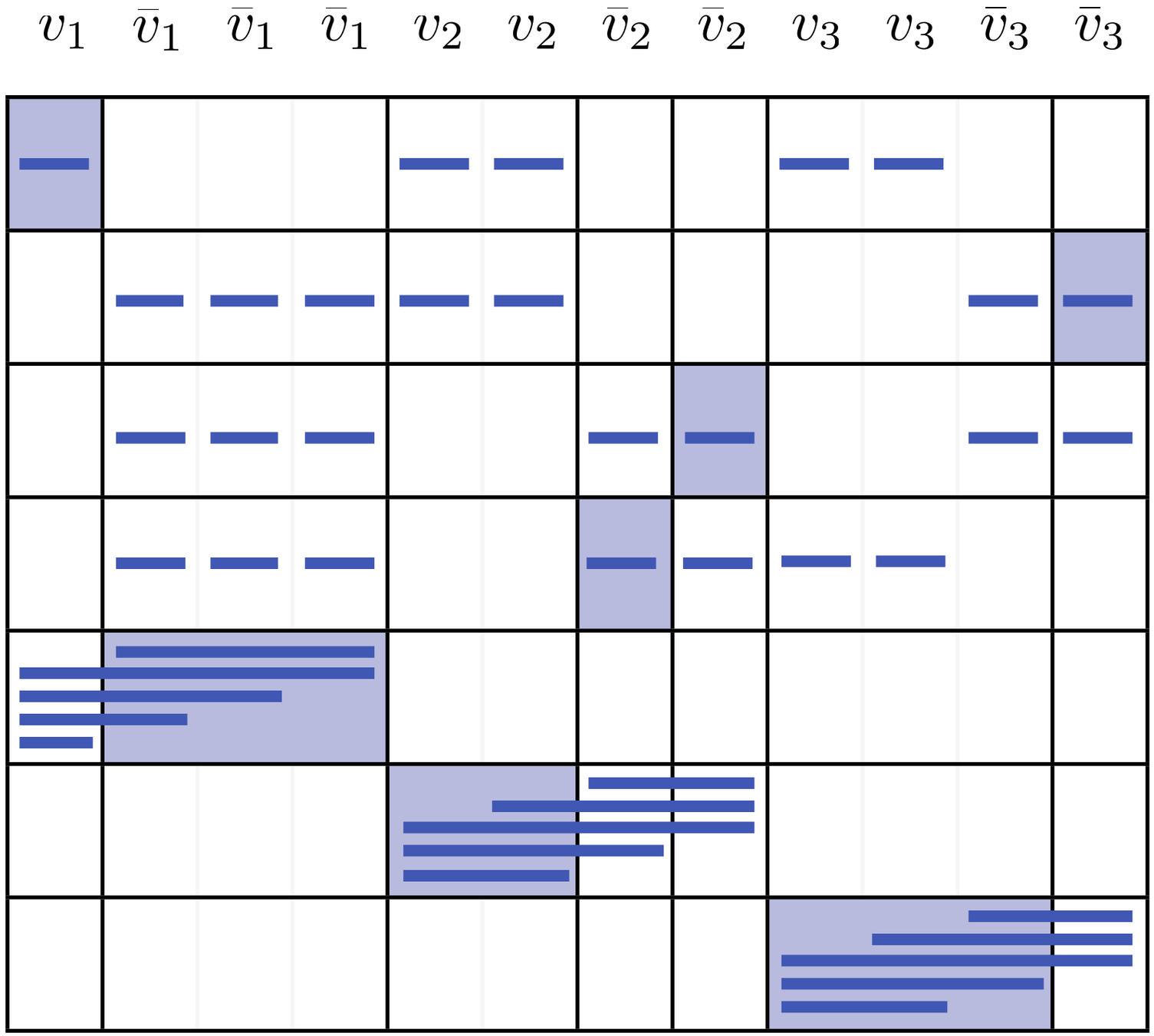
$\bar{v}_1 \vee \bar{v}_2 \vee \bar{v}_3$

$\bar{v}_1 \vee \bar{v}_2 \vee v_3$

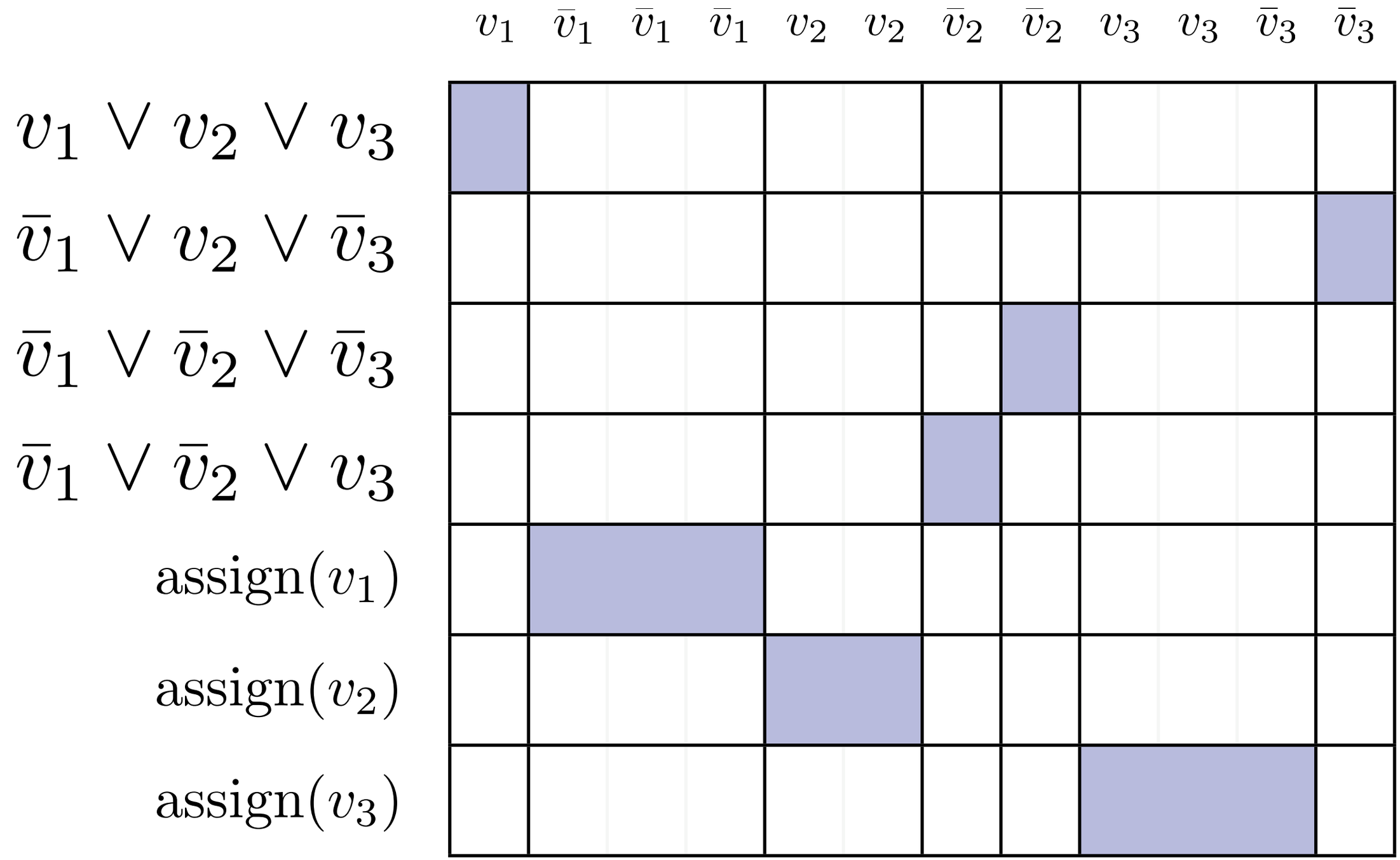
$\text{assign}(v_1)$

$\text{assign}(v_2)$

$\text{assign}(v_3)$



Reducing 3-SAT to Phrase Decision



Reducing 3-SAT to Phrase Decision

$v_1 \vee v_2 \vee v_3$

$\bar{v}_1 \vee v_2 \vee \bar{v}_3$

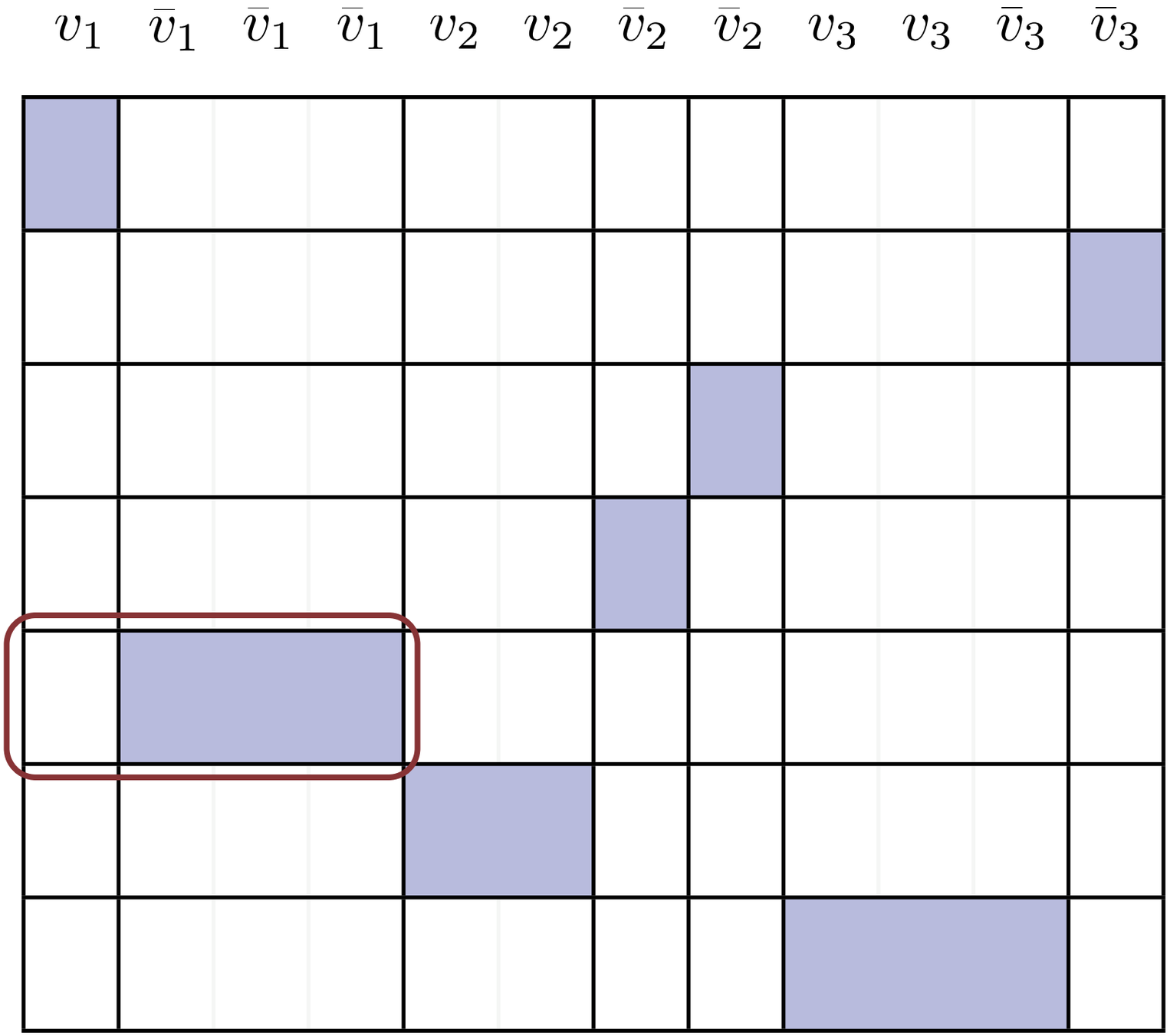
$\bar{v}_1 \vee \bar{v}_2 \vee \bar{v}_3$

$\bar{v}_1 \vee \bar{v}_2 \vee v_3$

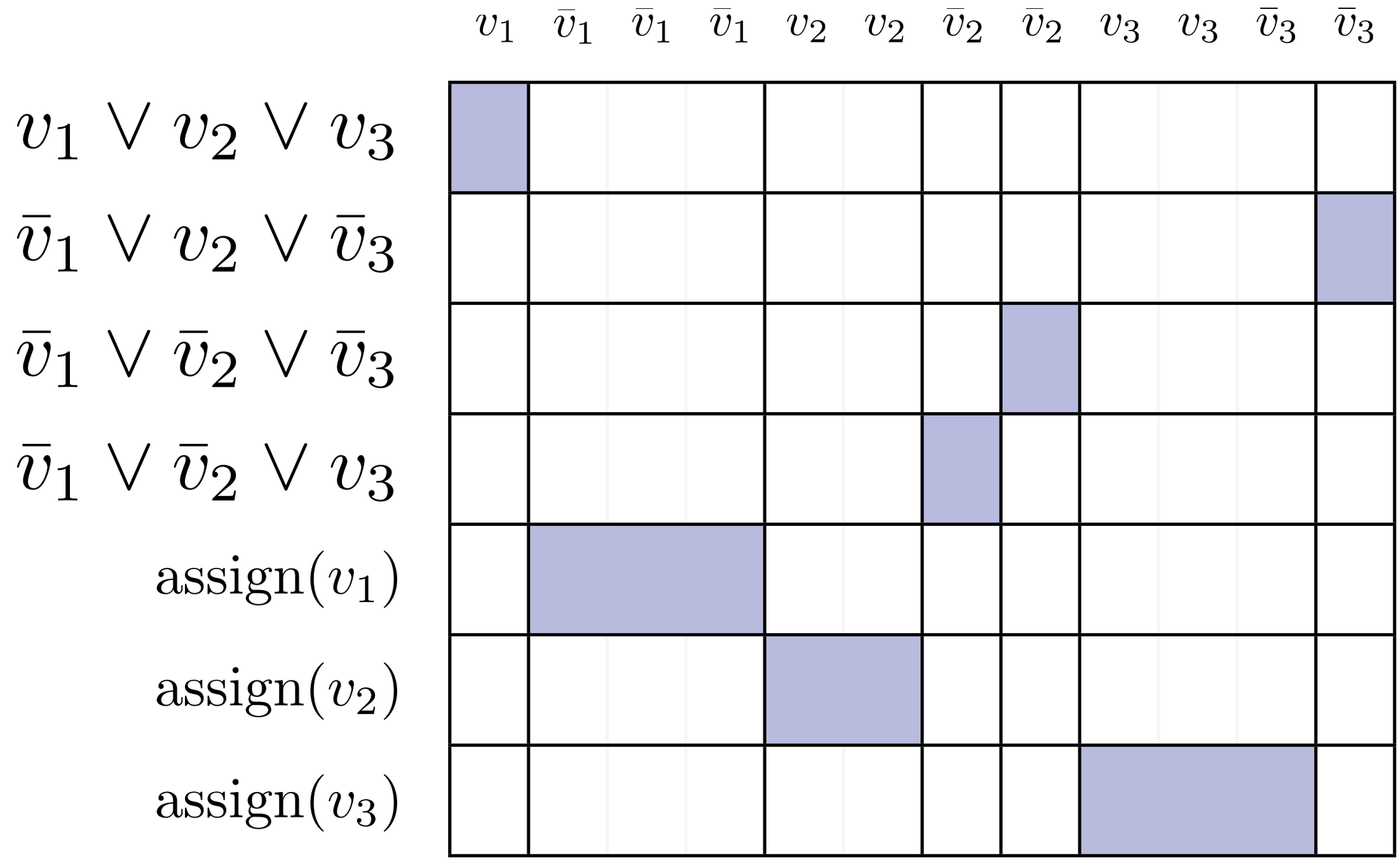
assign(v_1)

assign(v_2)

assign(v_3)



Reducing 3-SAT to Phrase Decision



Reducing 3-SAT to Phrase Decision

$v_1 \vee v_2 \vee v_3$

$\bar{v}_1 \vee v_2 \vee \bar{v}_3$

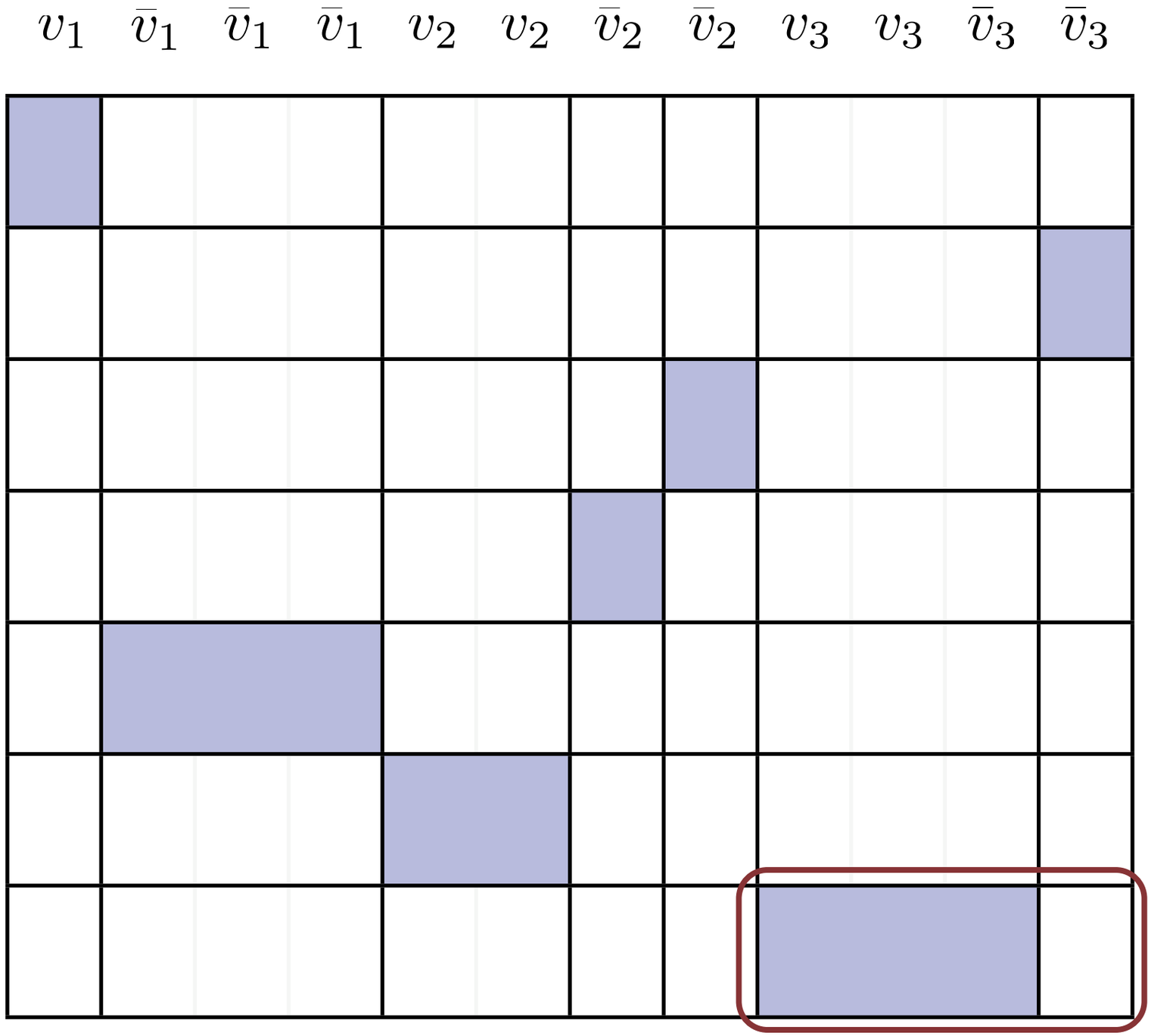
$\bar{v}_1 \vee \bar{v}_2 \vee \bar{v}_3$

$\bar{v}_1 \vee \bar{v}_2 \vee v_3$

$\text{assign}(v_1)$

$\text{assign}(v_2)$

$\text{assign}(v_3)$



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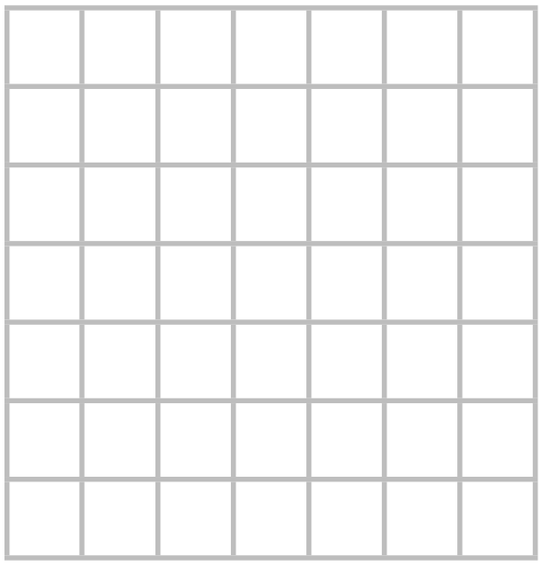
Taking Expectations is #P-hard

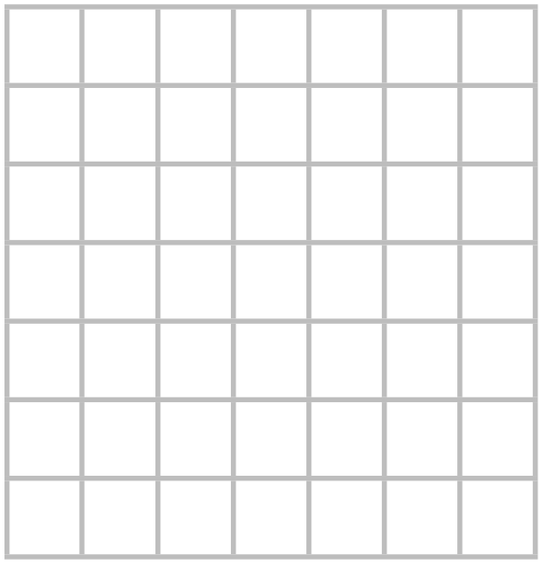
Taking Expectations is #P-hard

Weighted grid:



Taking Expectations is #P-hard

Weighted grid:



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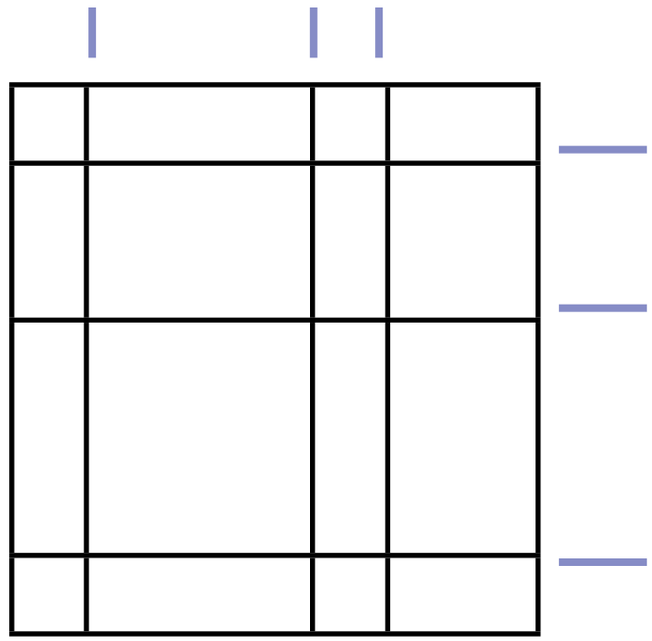
Segmentation:



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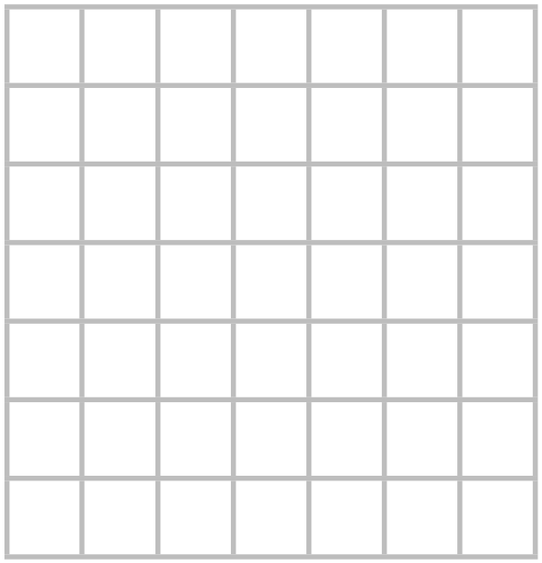
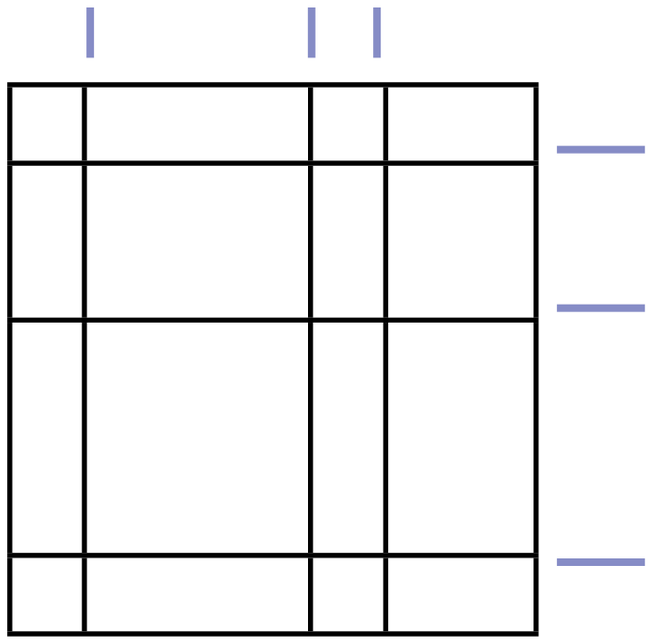
Taking Expectations is #P-hard

Weighted grid:

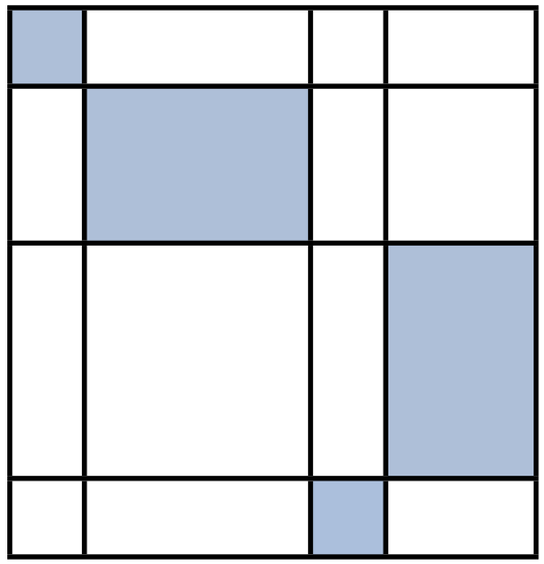


+

Segmentation:

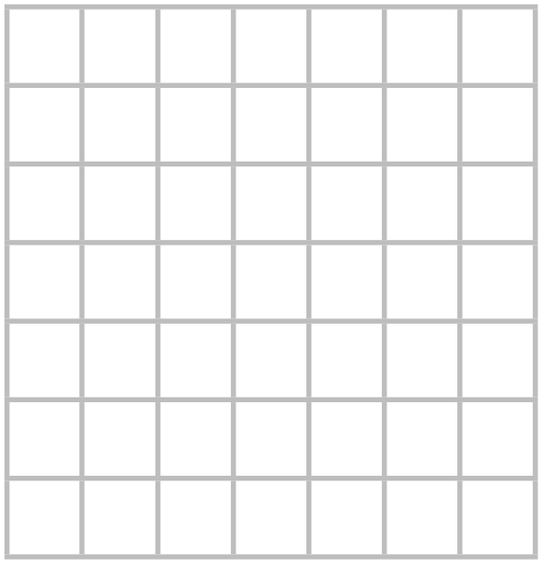


Find Maximal:



Taking Expectations is #P-hard

Weighted grid:



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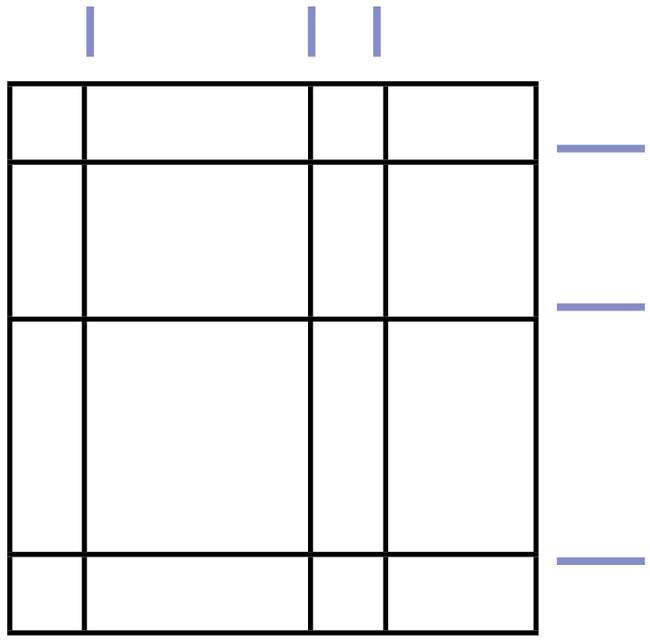
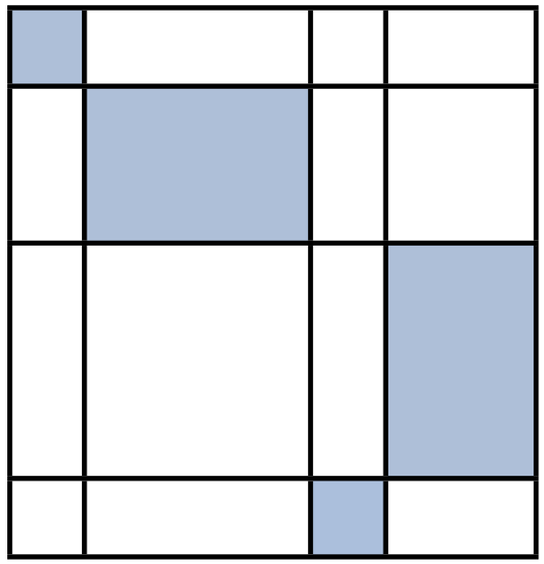
Segmentation:



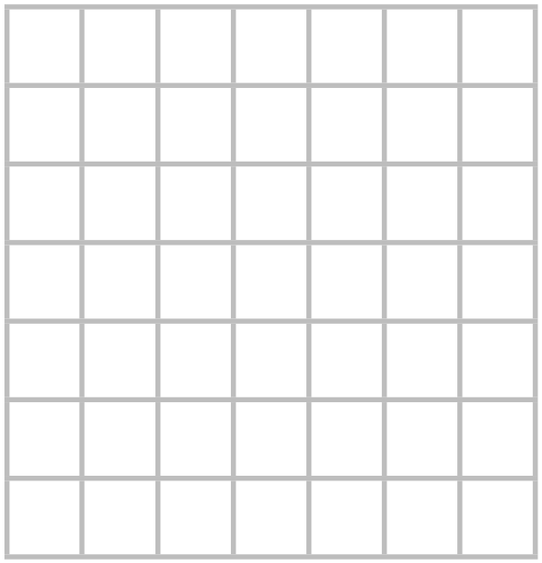
Find Maximal:



Summing over matching is #P-hard

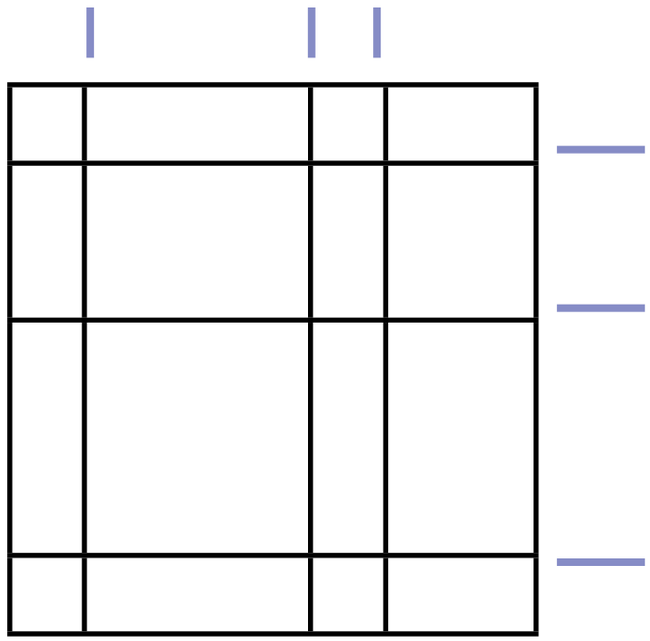
Taking Expectations is #P-hard

Weighted grid:

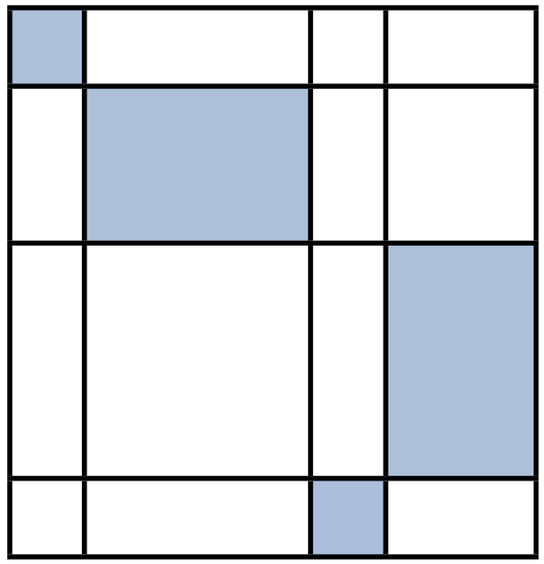


+

Segmentation:



Find Maximal:

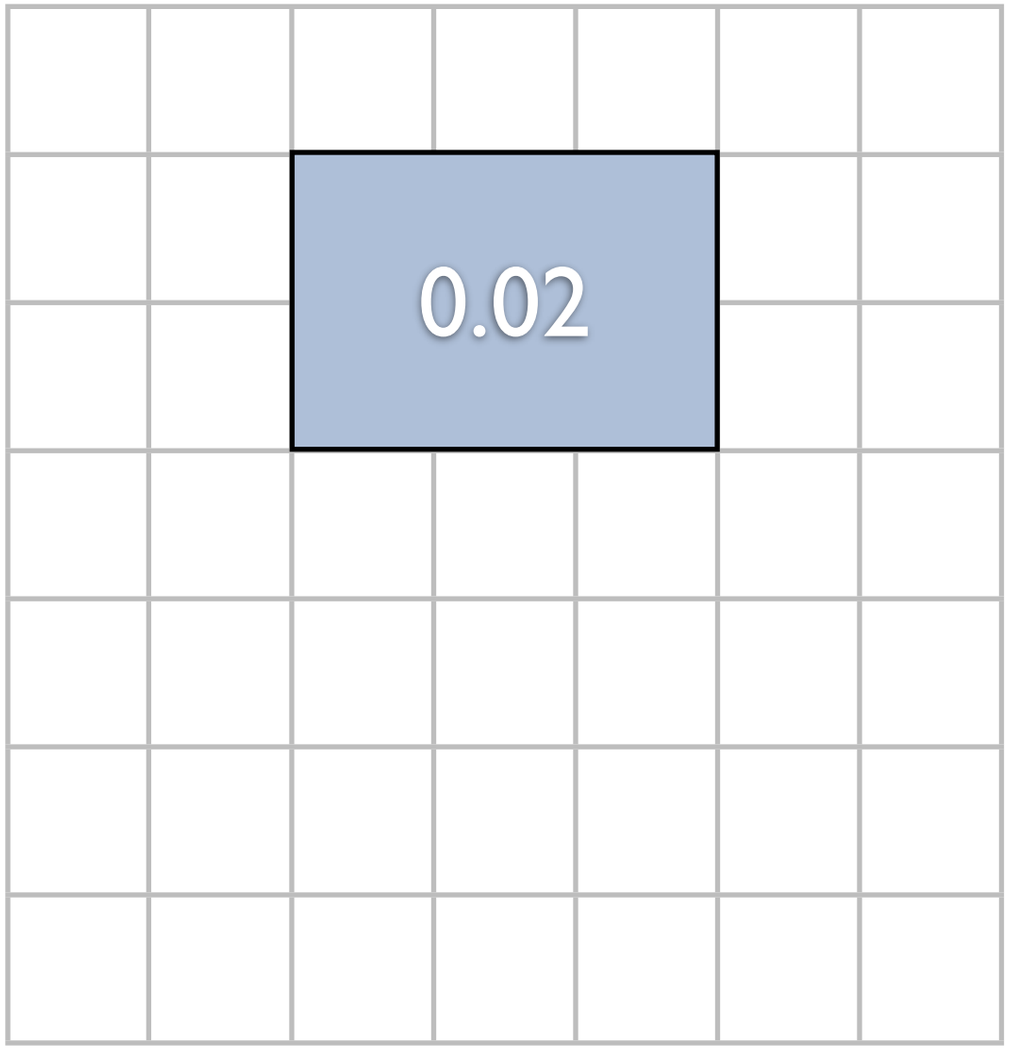


Summing over matching is #P-hard

Expectations of phrase alignments is at least as hard

Phrase Alignment as Integer Programming

Japan to freeze aid to Russia .



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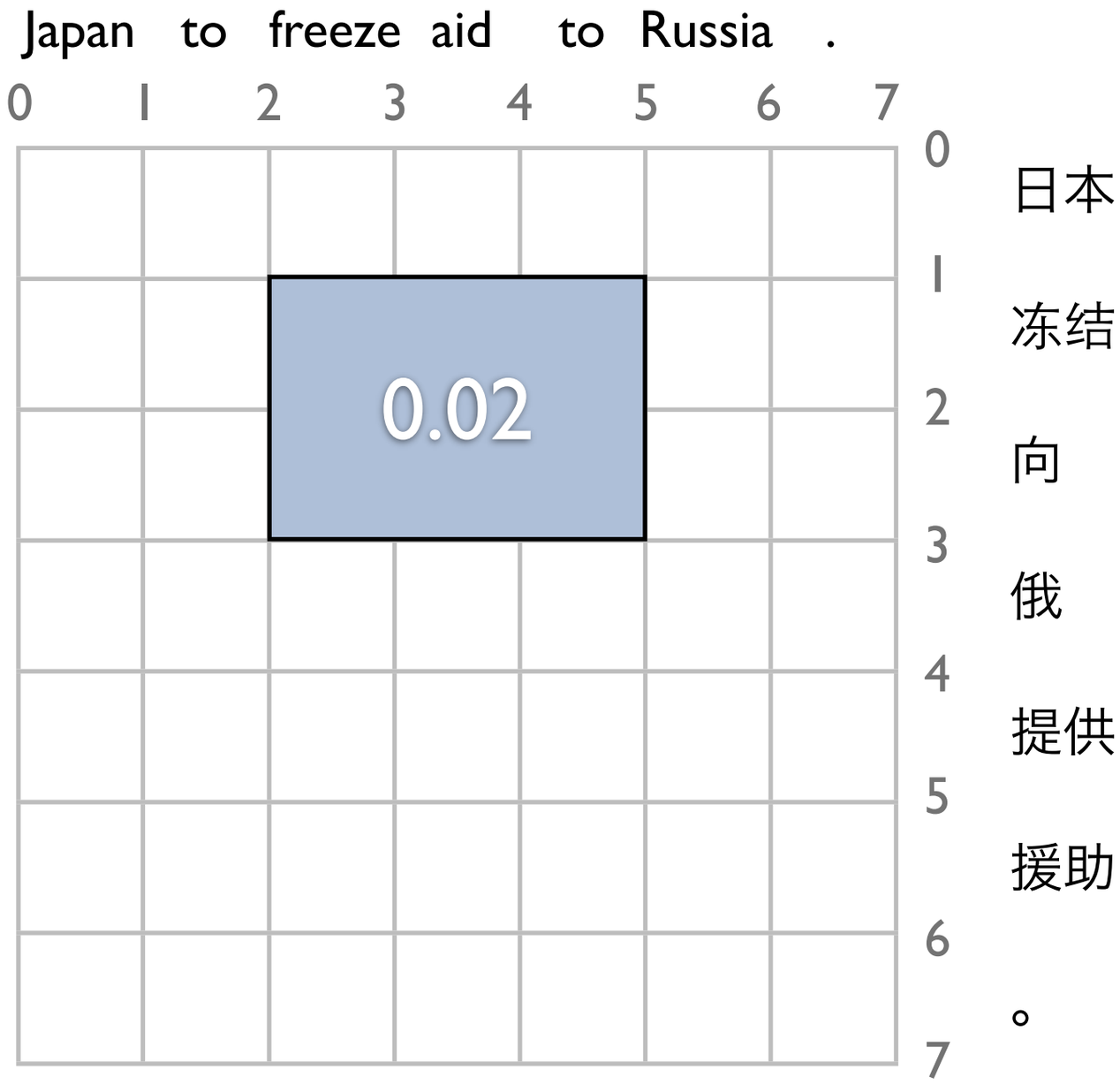
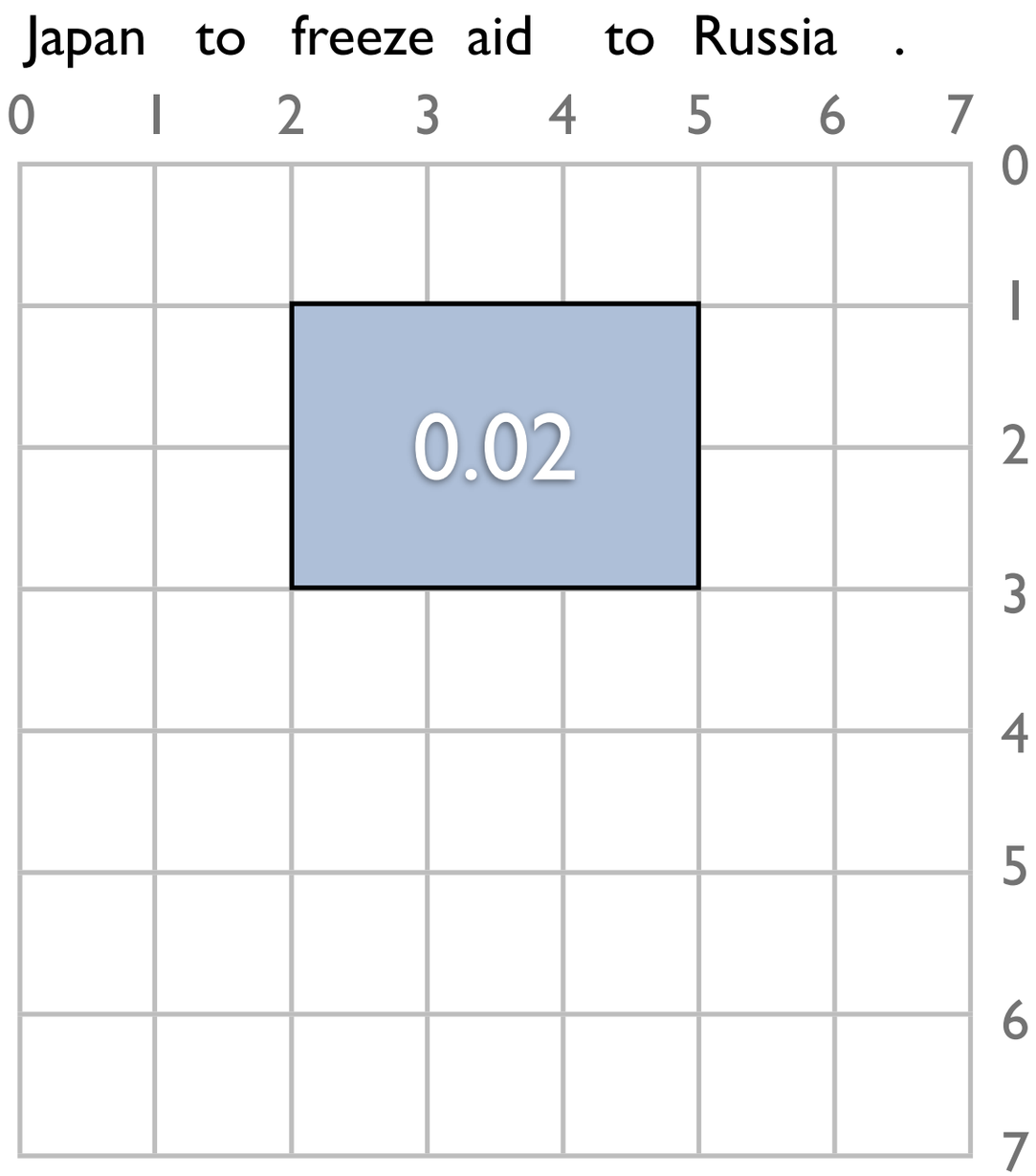
Phrase Alignment as Integer Programming



Phrase Alignment as Integer Programming



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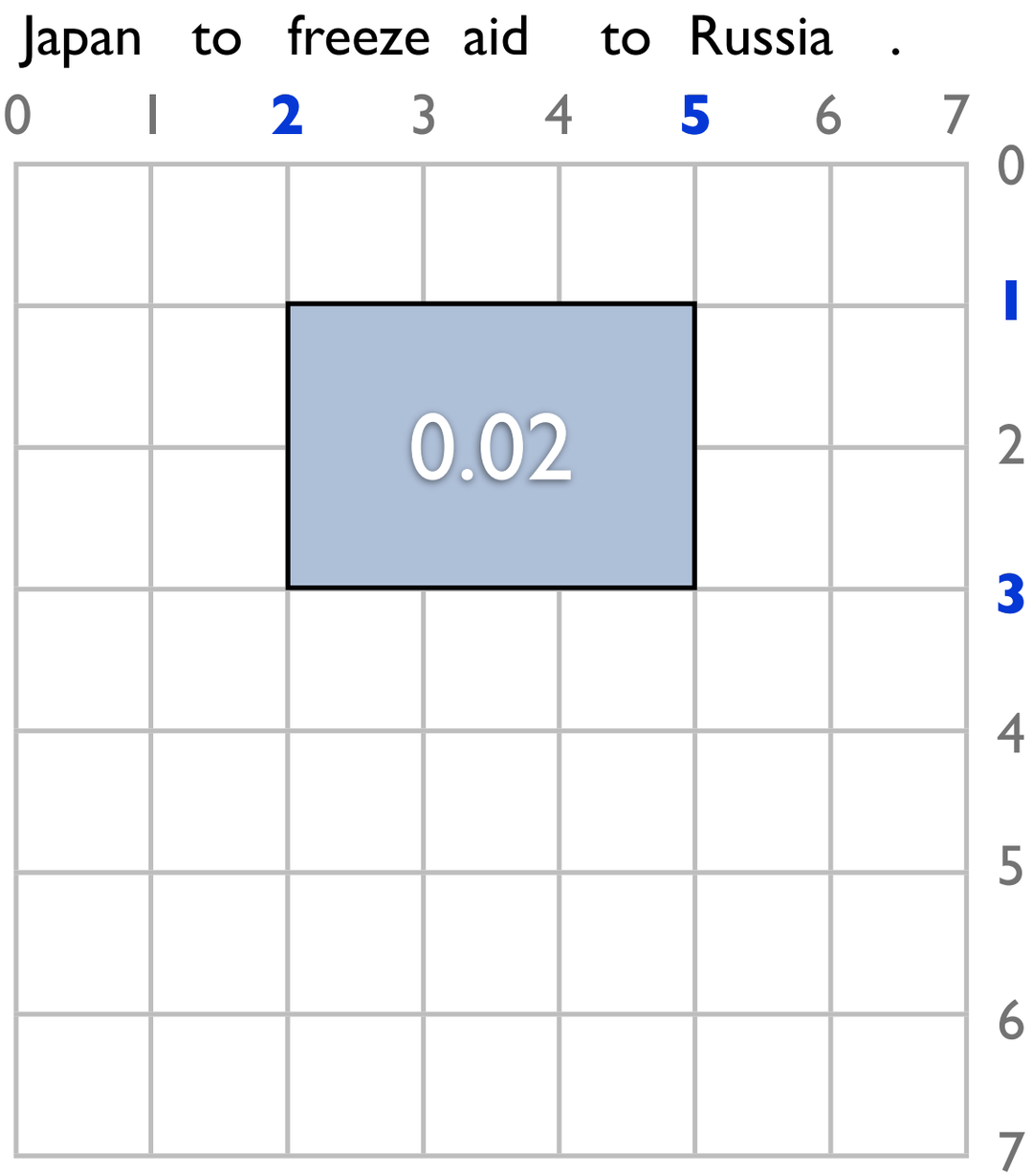
Constants:

$$w_{2,5,1,3} = \log 0.02$$

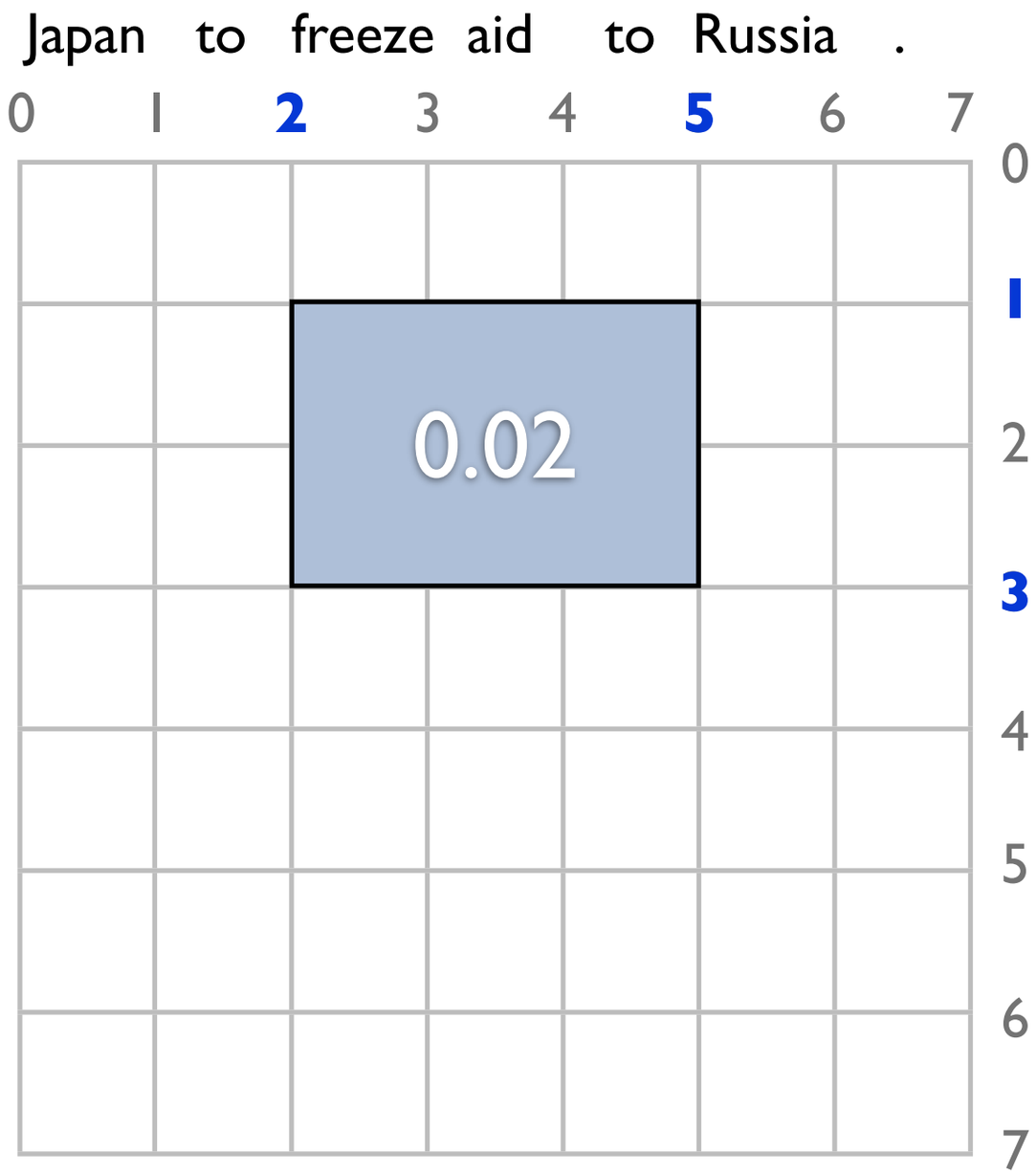
Phrase Alignment as Integer Programming



Constants:

$$w_{2,5,1,3} = \log 0.02$$

Phrase Alignment as Integer Programming



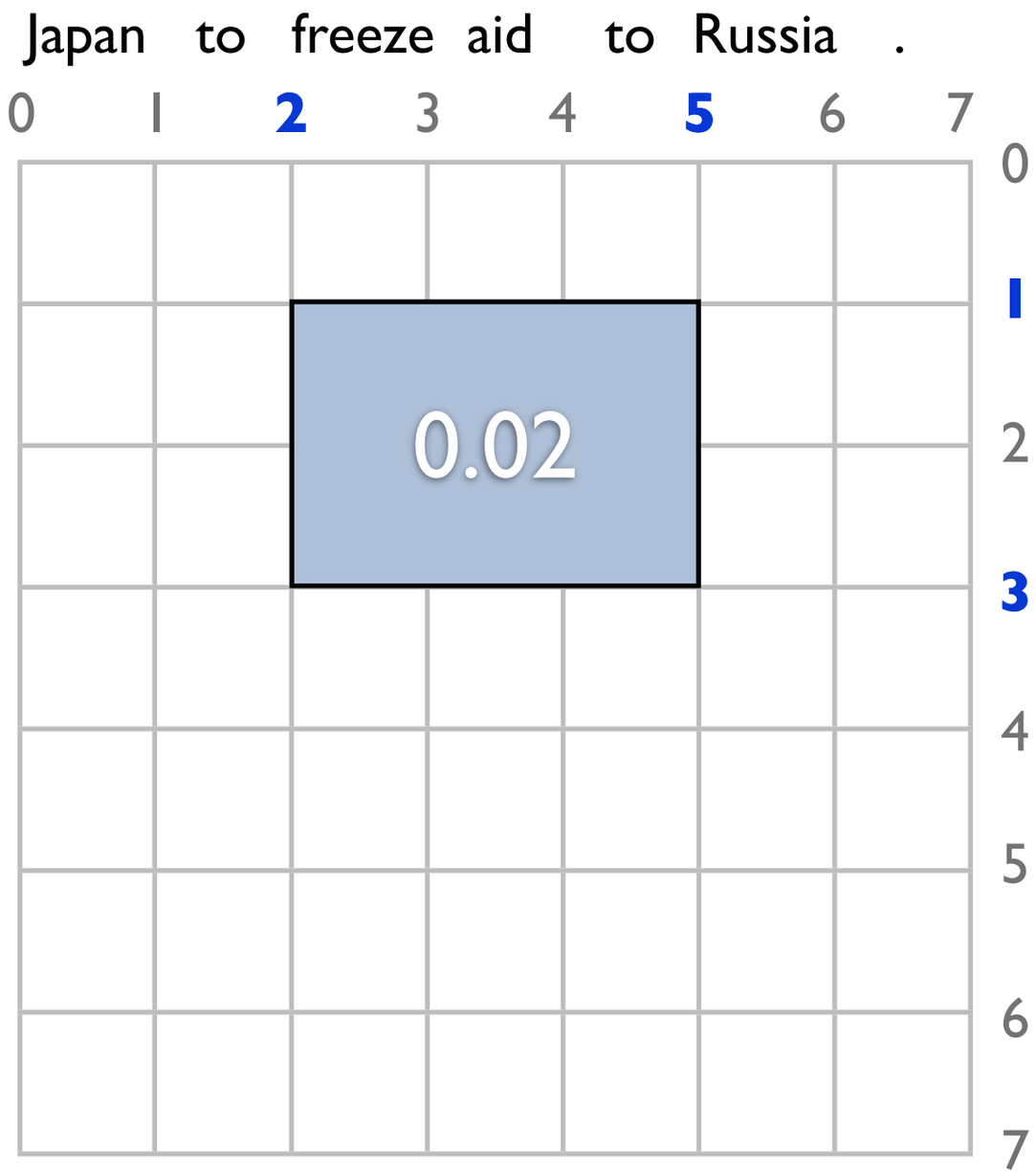
Constants:

$$w_{2,5,1,3} = \log 0.02$$

Indicator Variables:

$$a_{2,5,1,3} = 1$$

Phrase Alignment as Integer Programming



Constants:

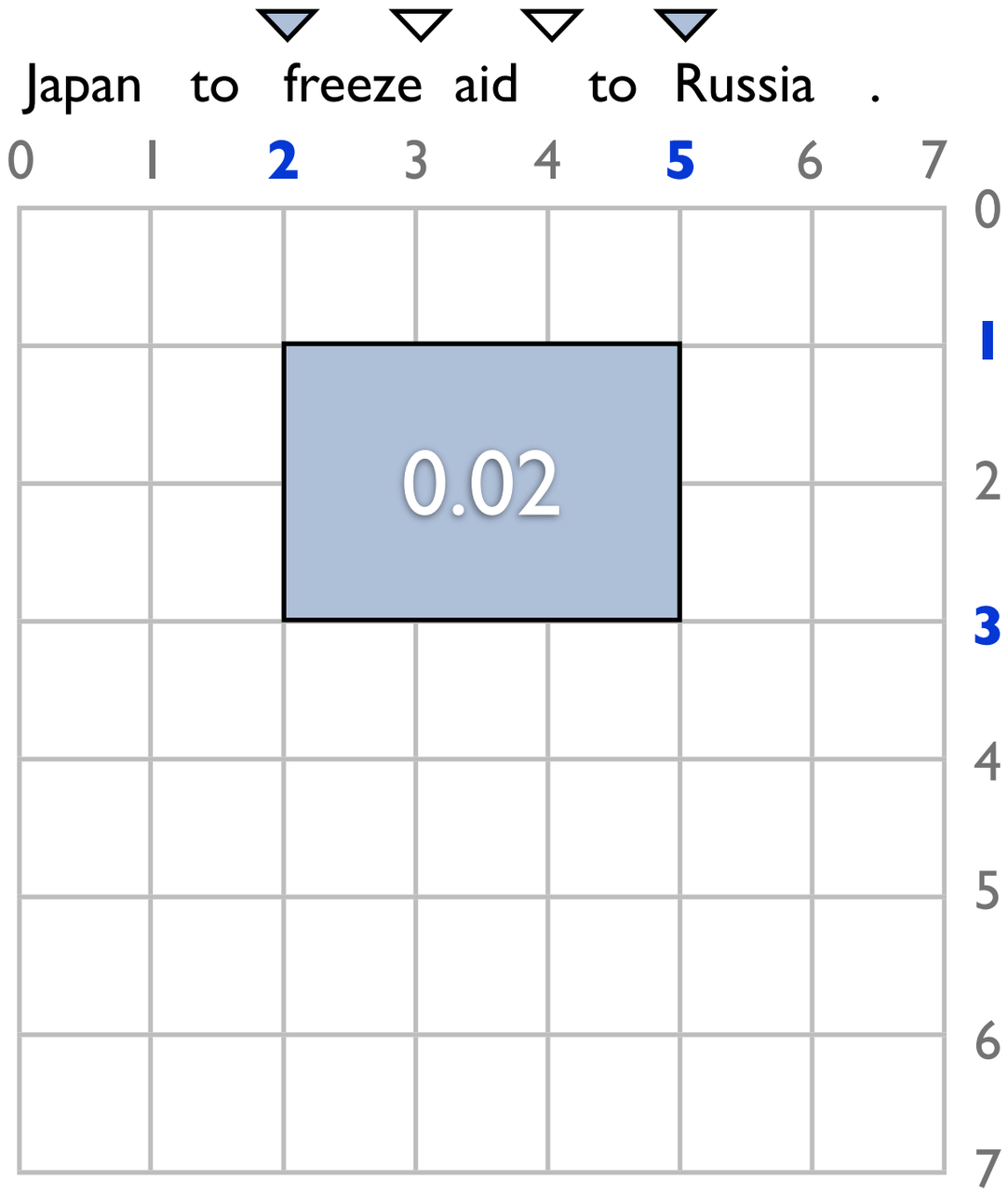
$$w_{2,5,1,3} = \log 0.02$$

Indicator Variables:

$$a_{2,5,1,3} = 1$$

$$e_{2,5} = 1$$

Phrase Alignment as Integer Programming



Constants:

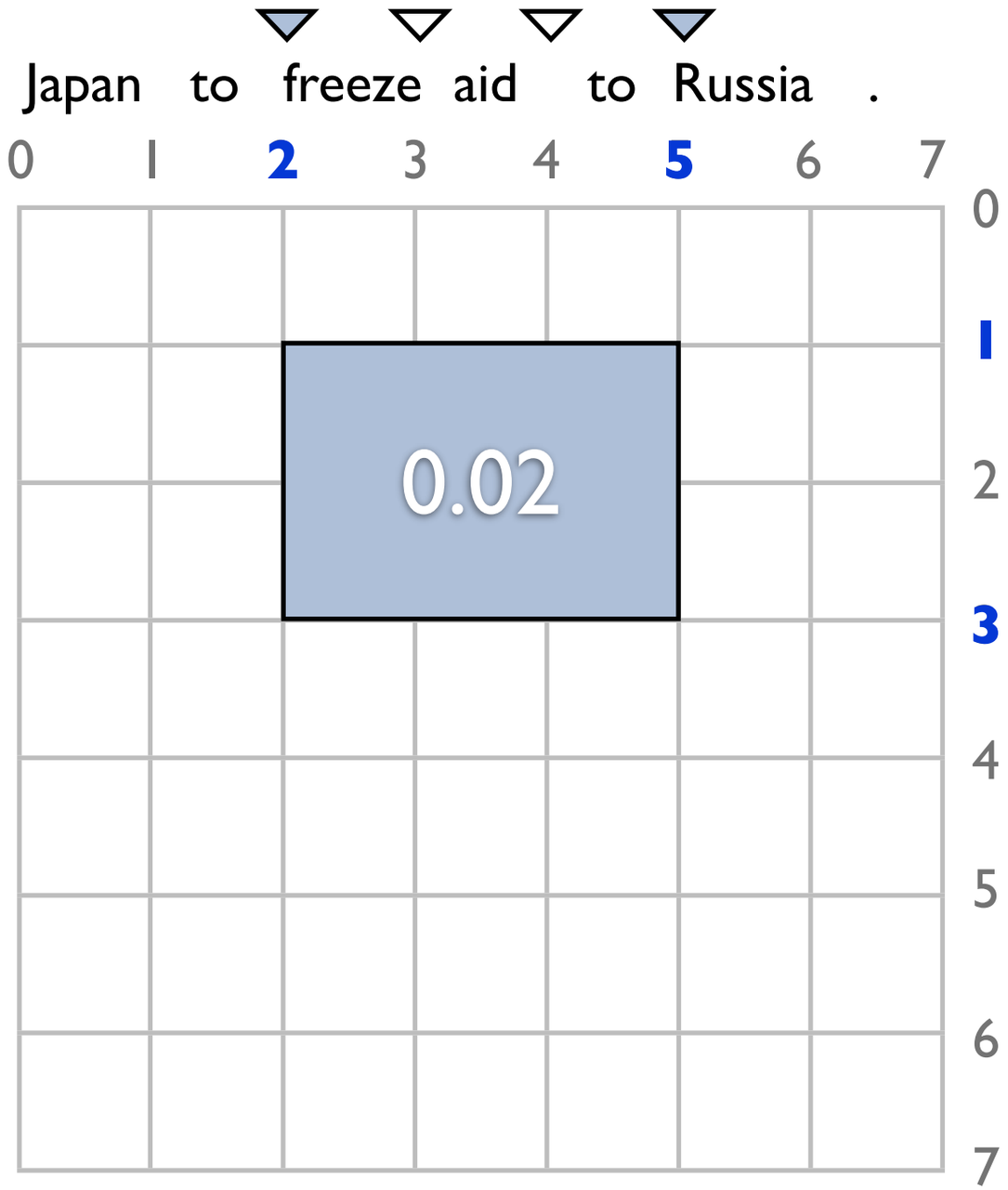
$$w_{2,5,1,3} = \log 0.02$$

Indicator Variables:

$$a_{2,5,1,3} = 1$$

$$e_{2,5} = 1$$

Phrase Alignment as Integer Programming



Constants:

$$w_{2,5,1,3} = \log 0.02$$

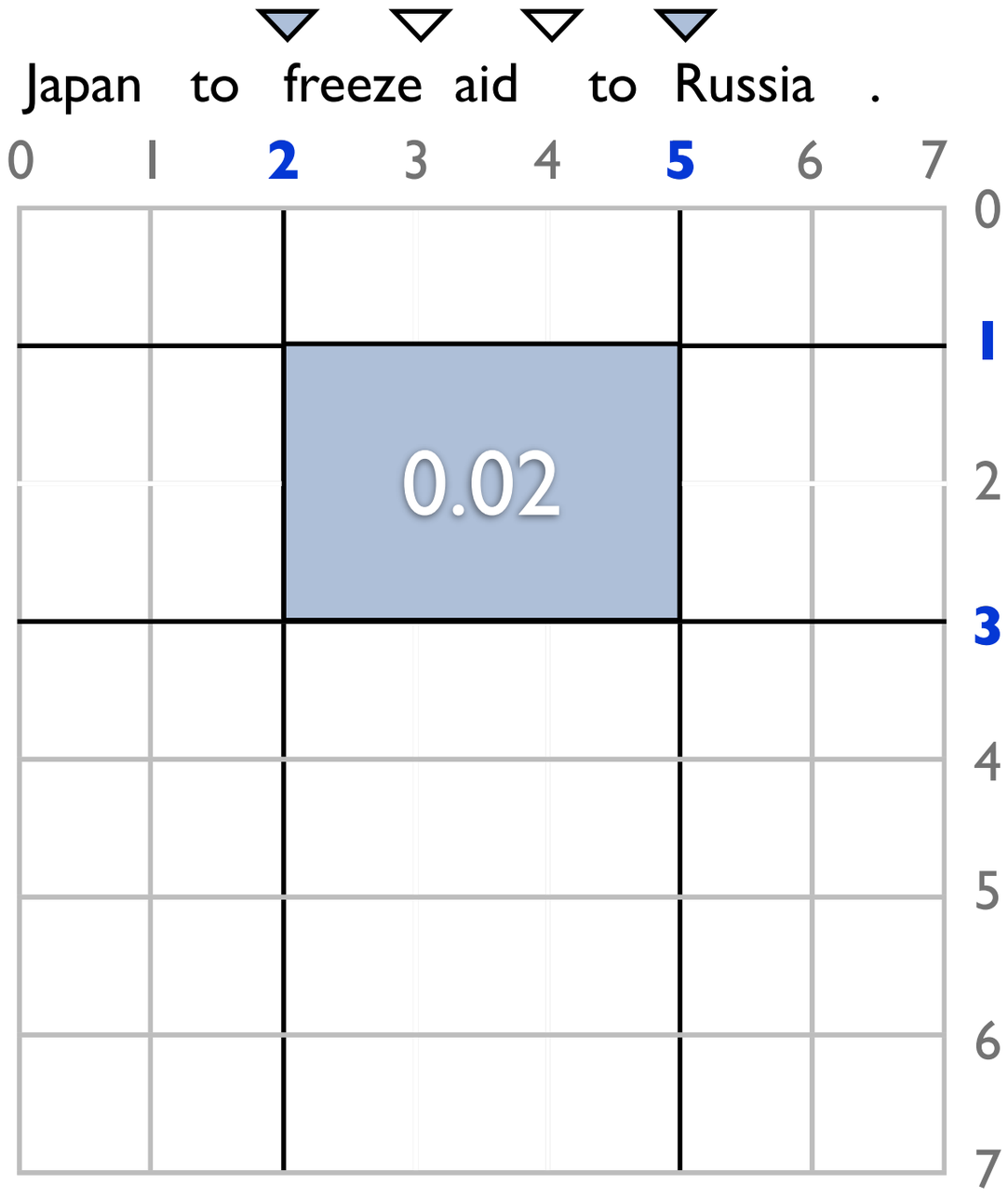
Indicator Variables:

$$a_{2,5,1,3} = 1$$

$$e_{2,5} = 1$$

$$f_{1,3} = 1$$

Phrase Alignment as Integer Programming



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Constants:

$$w_{2,5,1,3} = \log 0.02$$

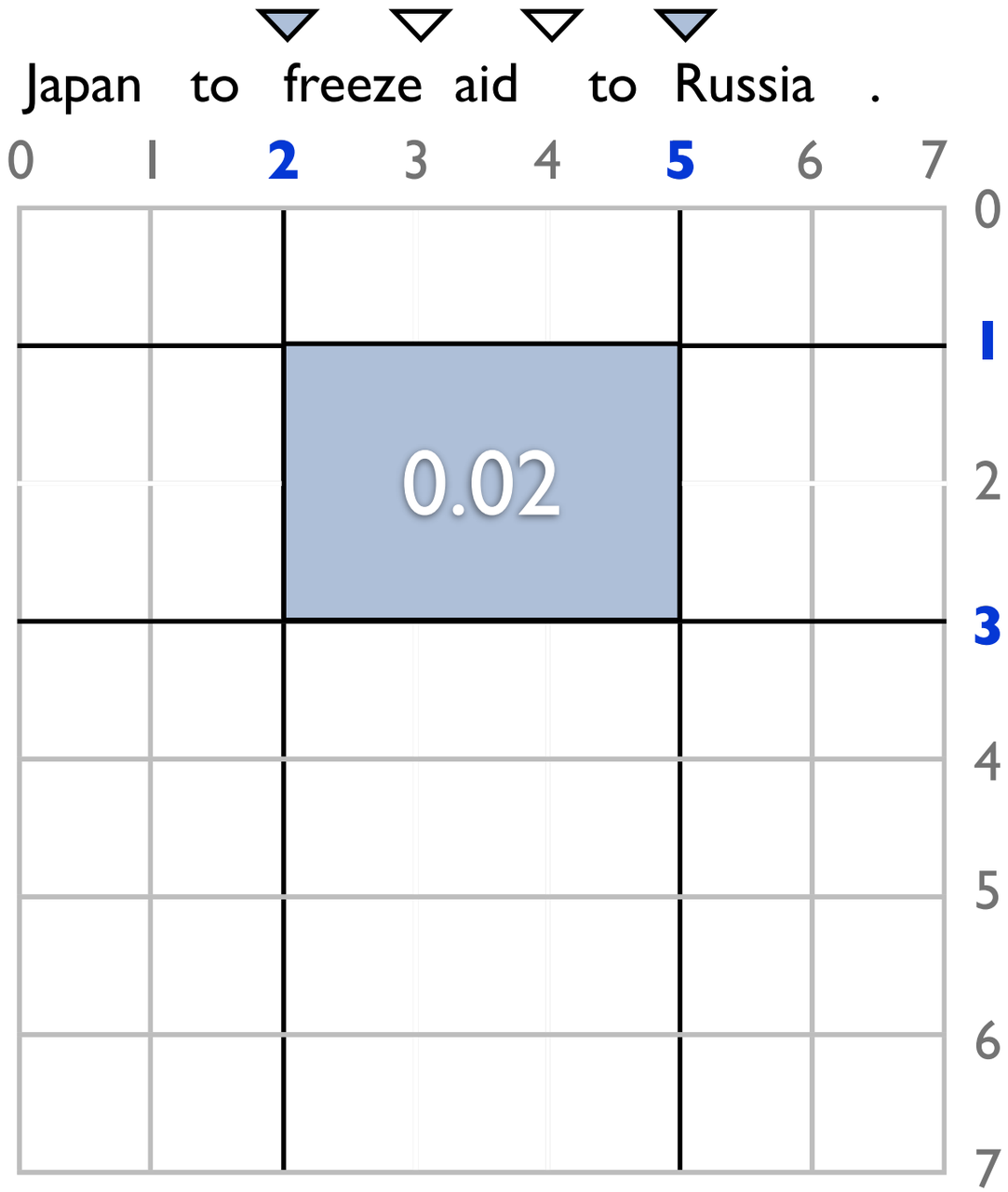
Indicator Variables:

$$a_{2,5,1,3} = 1$$

$$e_{2,5} = 1$$

$$f_{1,3} = 1$$

Phrase Alignment as Integer Programming



Constants:

$$w_{2,5,1,3} = \log 0.02$$

Indicator Variables:

$$a_{2,5,1,3} = 1$$

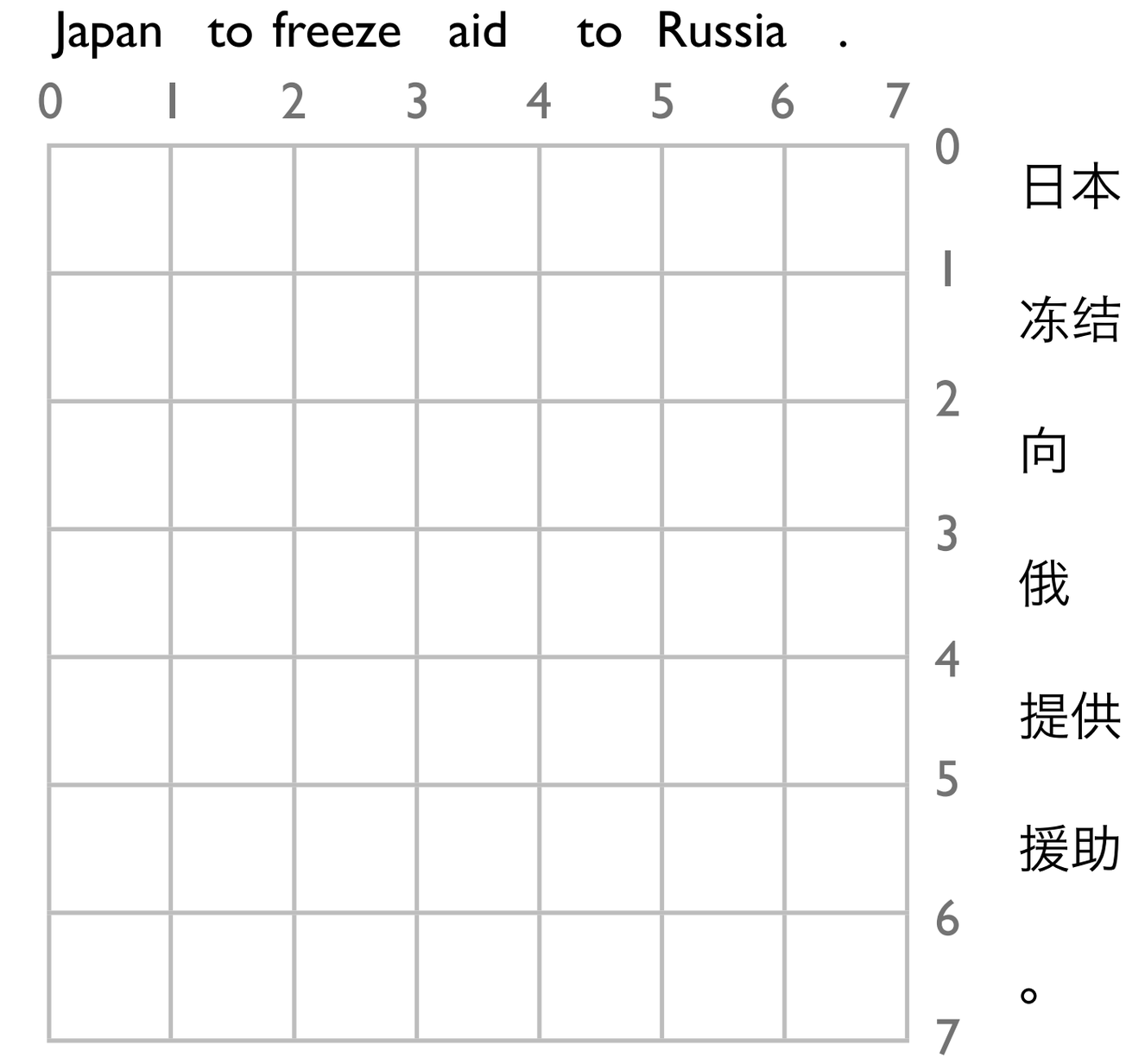
$$e_{2,5} = 1$$

$$f_{1,3} = 1$$

Indicator Variables:
a: phrase alignment **e**: English segmentation **f**: foreign segmentation

Constants:
w: weights

Phrase Alignment as Integer Programming



Indicator Variables:
a: phrase alignment **e**: English segmentation **f**: foreign segmentation

Constants:
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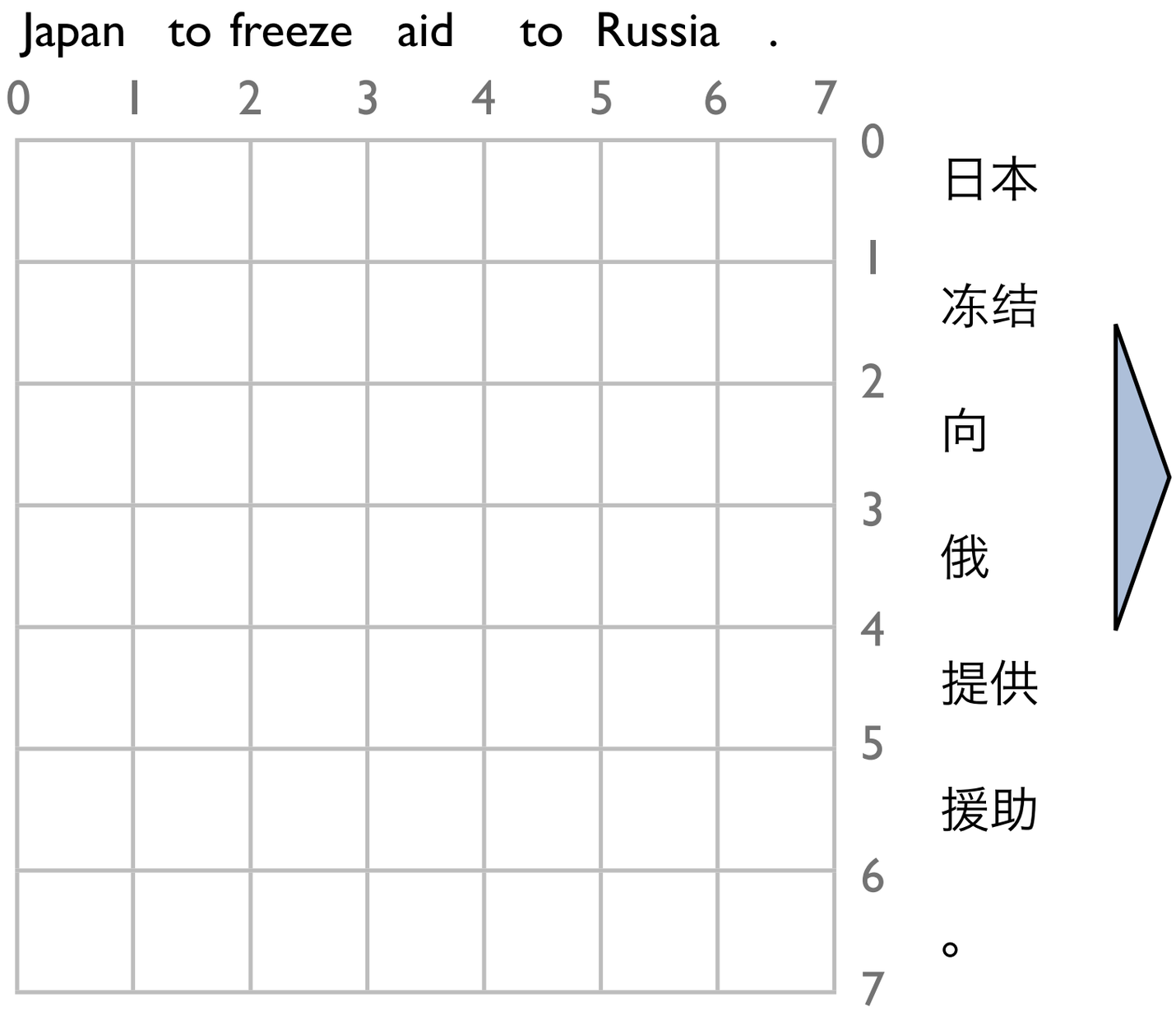
Phrase Alignment as Integer Programming



$$\max \sum_{i,j,k,l} w_{i,j,k,l} \cdot a_{i,j,k,l}$$

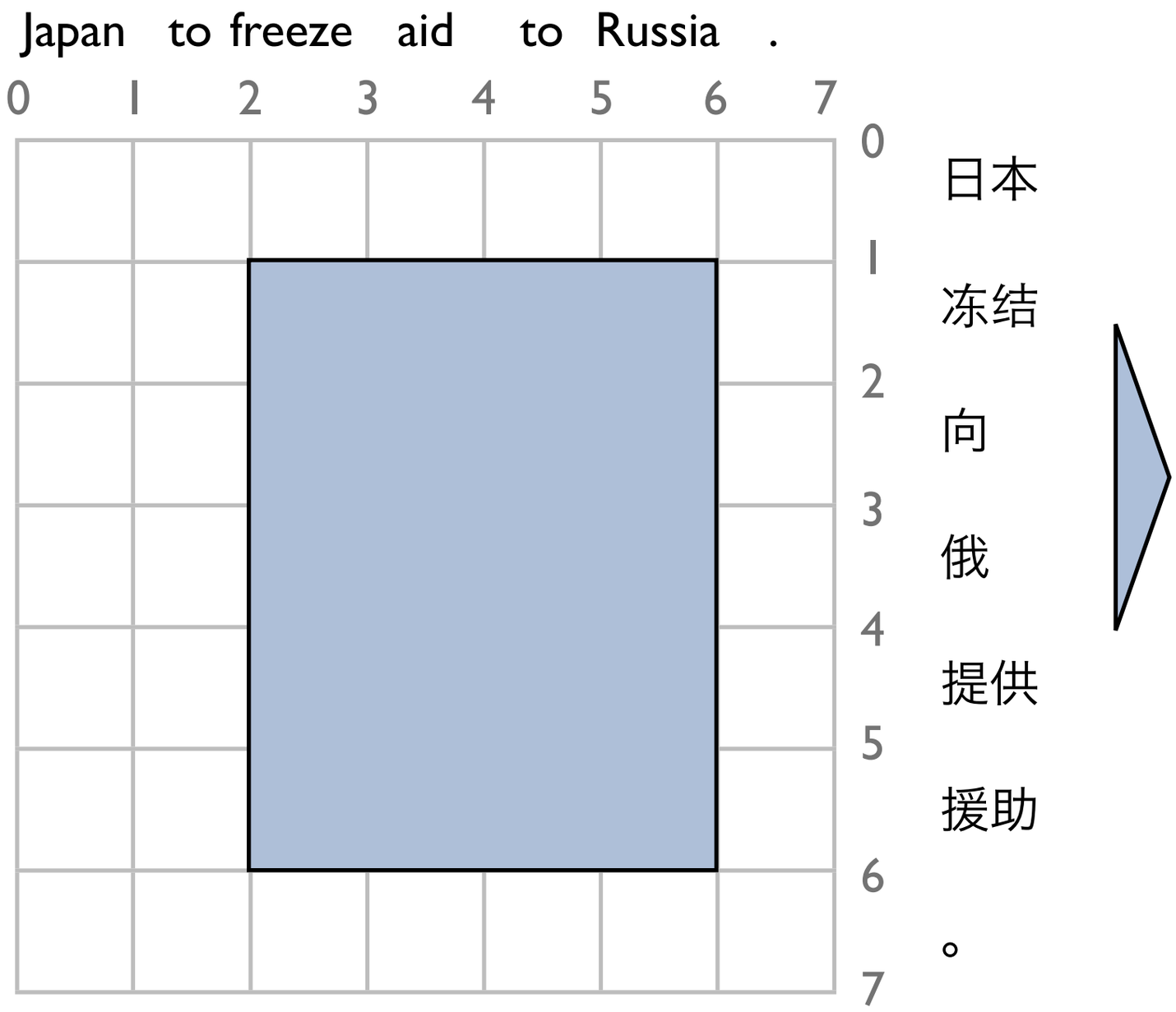
Indicator Variables:

a: phrase alignment **e**: English segmentation **f**: foreign segmentation

Constants:

w: weights

Phrase Alignment as Integer Programming



$$\max \sum_{i,j,k,l} w_{i,j,k,l} \cdot a_{i,j,k,l}$$

Indicator Variables:

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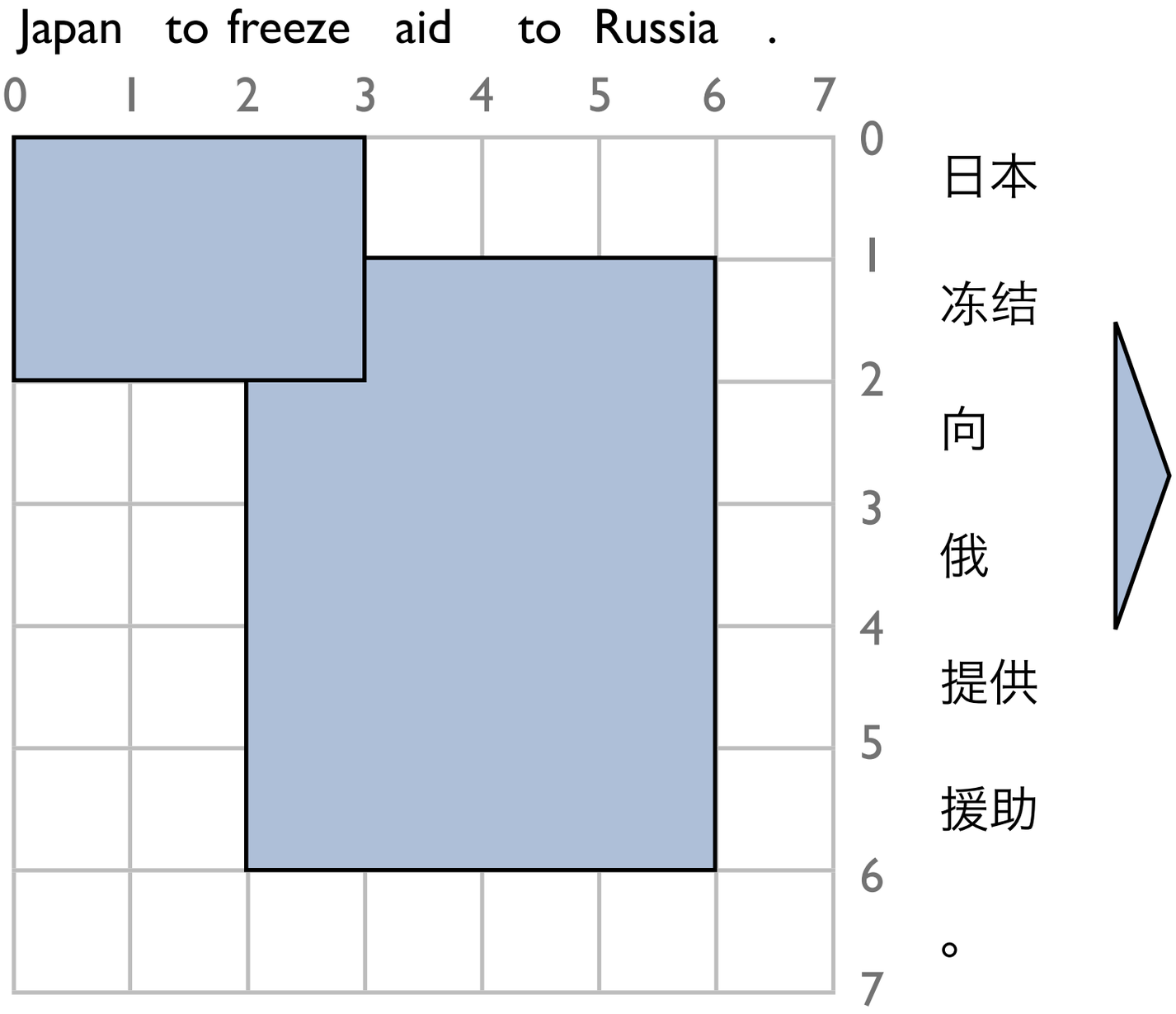
Phrase Alignment as Integer Programming



$$\max \sum_{i,j,k,l} w_{i,j,k,l} \cdot a_{i,j,k,l}$$

Indicator Variables:

a: phrase alignment **e**: English segmentation **f**: foreign segmentation

Constants:

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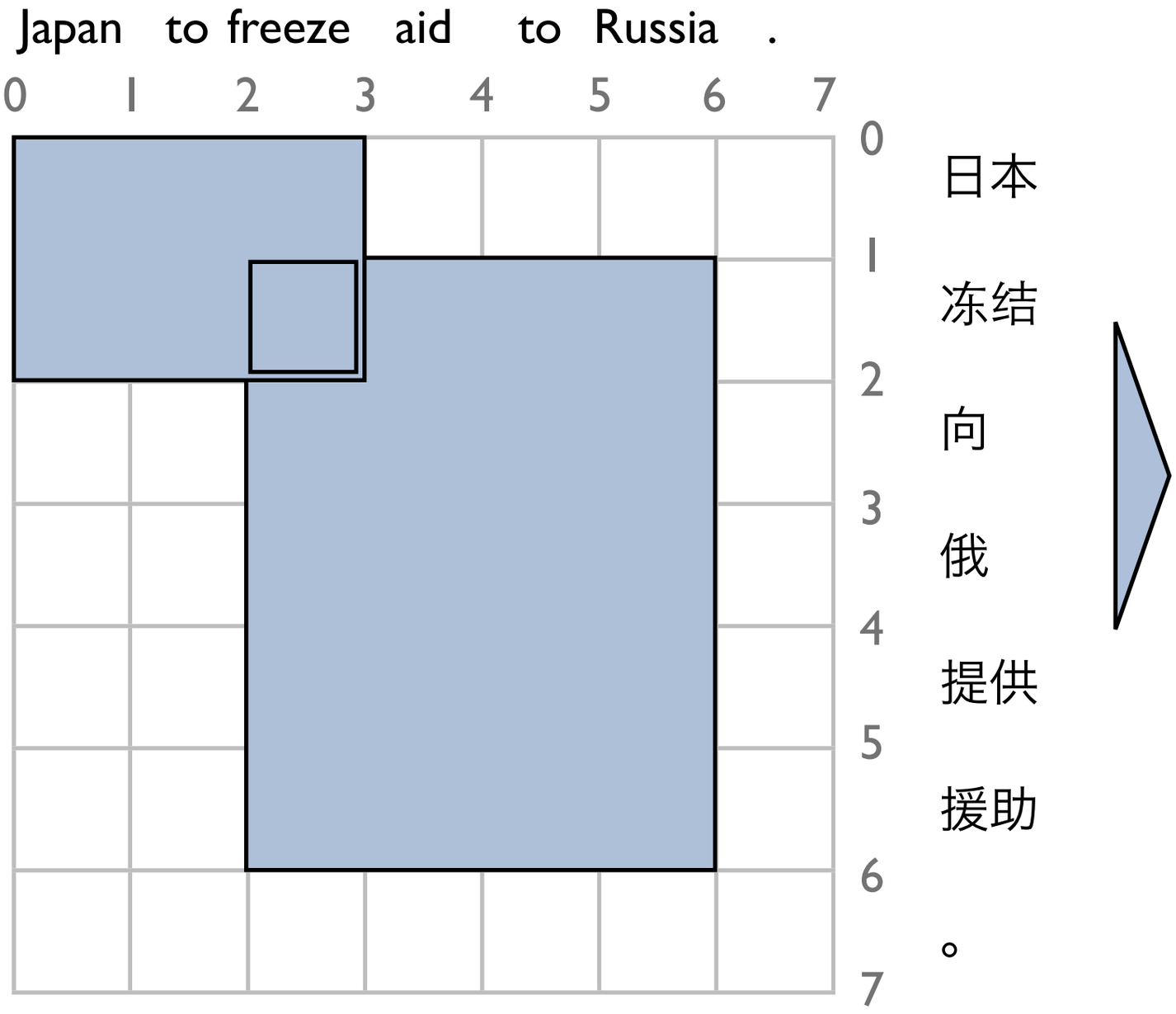
Phrase Alignment as Integer Programming



$$\max \sum_{i,j,k,l} w_{i,j,k,l} \cdot a_{i,j,k,l}$$

Indicator Variables:

a: phrase alignment **e**: English segmentation **f**: foreign segmentation

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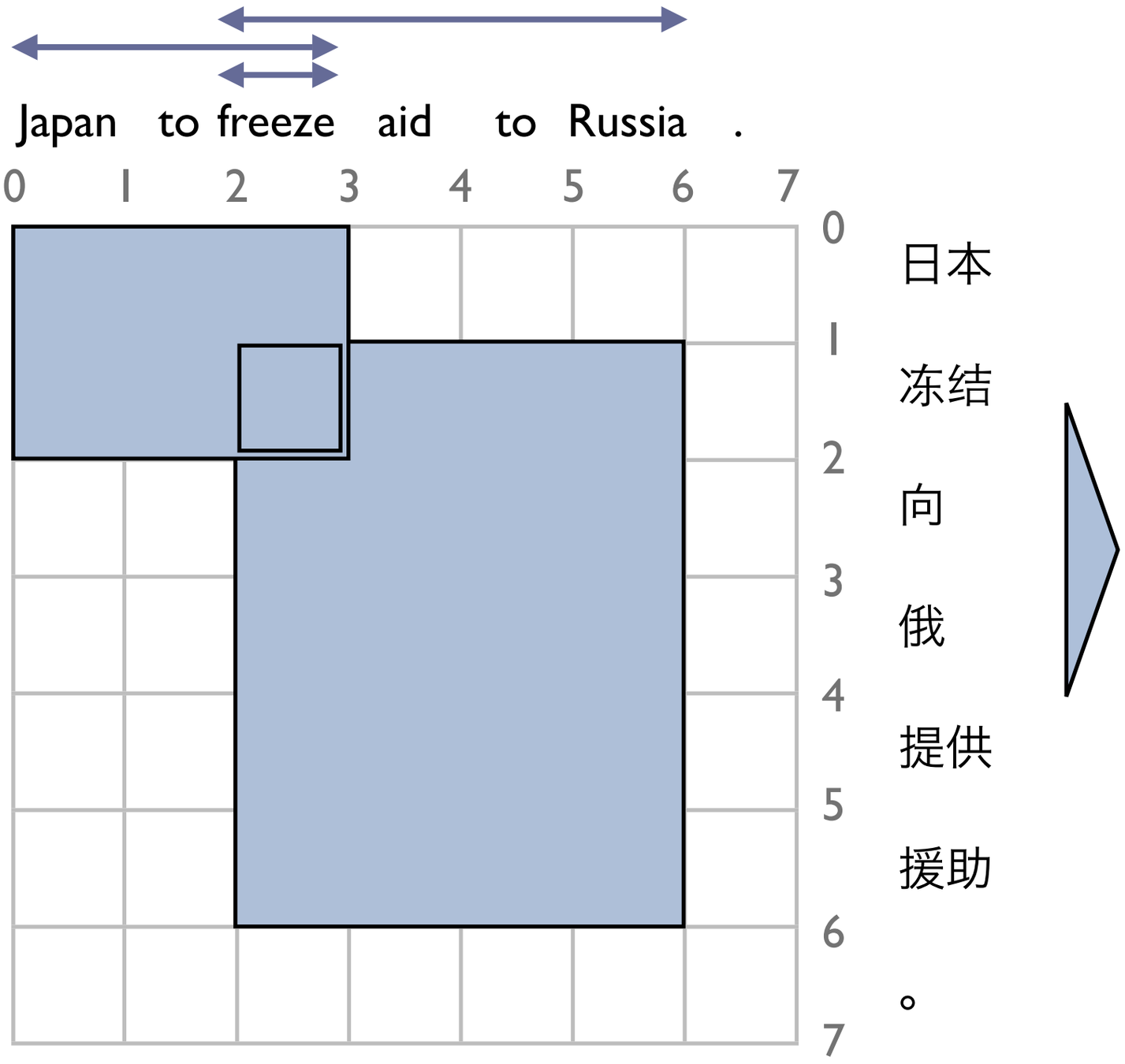
Phrase Alignment as Integer Programming



$$\max \sum_{i,j,k,l} w_{i,j,k,l} \cdot a_{i,j,k,l}$$

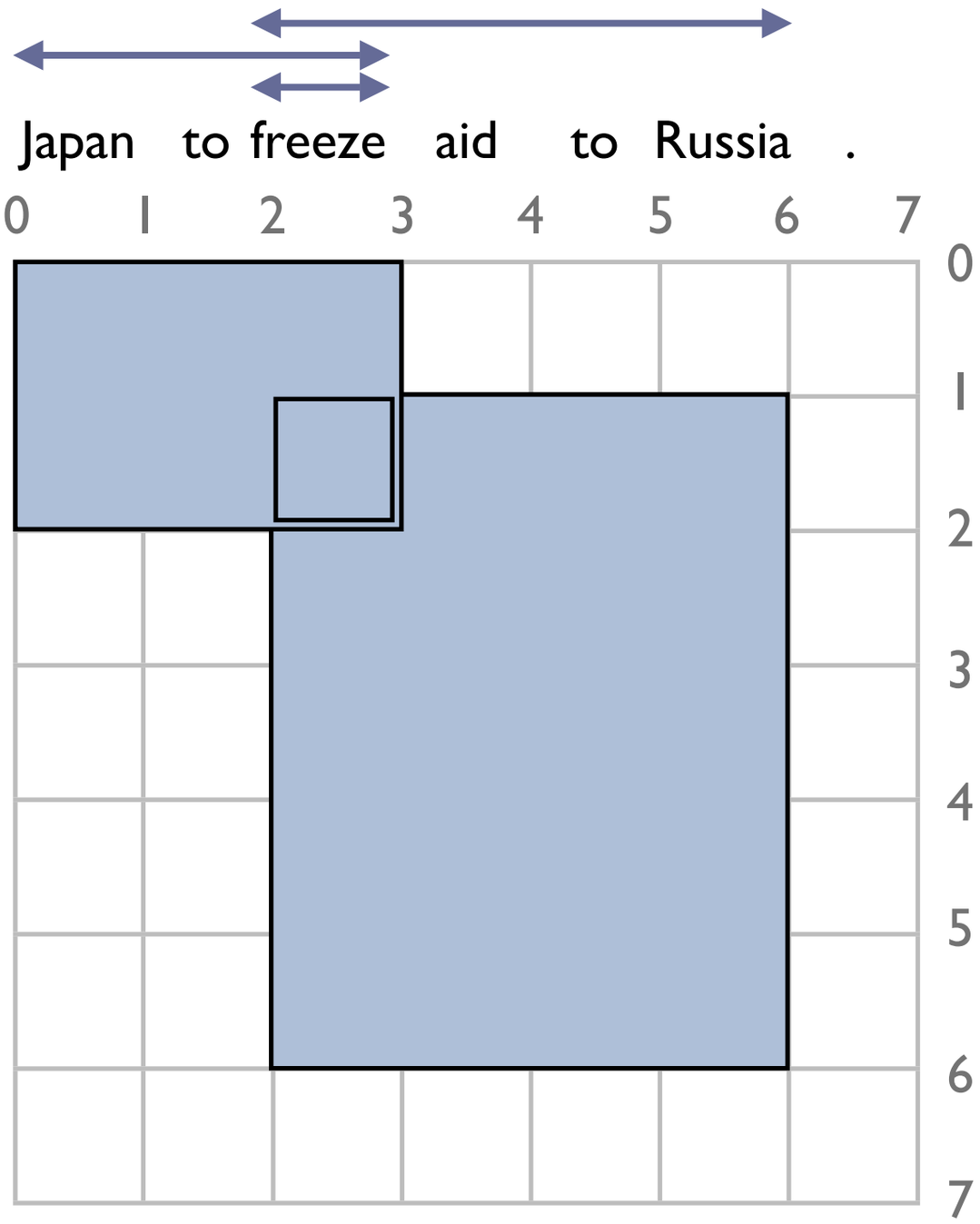
Indicator Variables:

a: phrase alignment **e**: English segmentation **f**: foreign segmentation

Constants:

w: weights

Phrase Alignment as Integer Programming



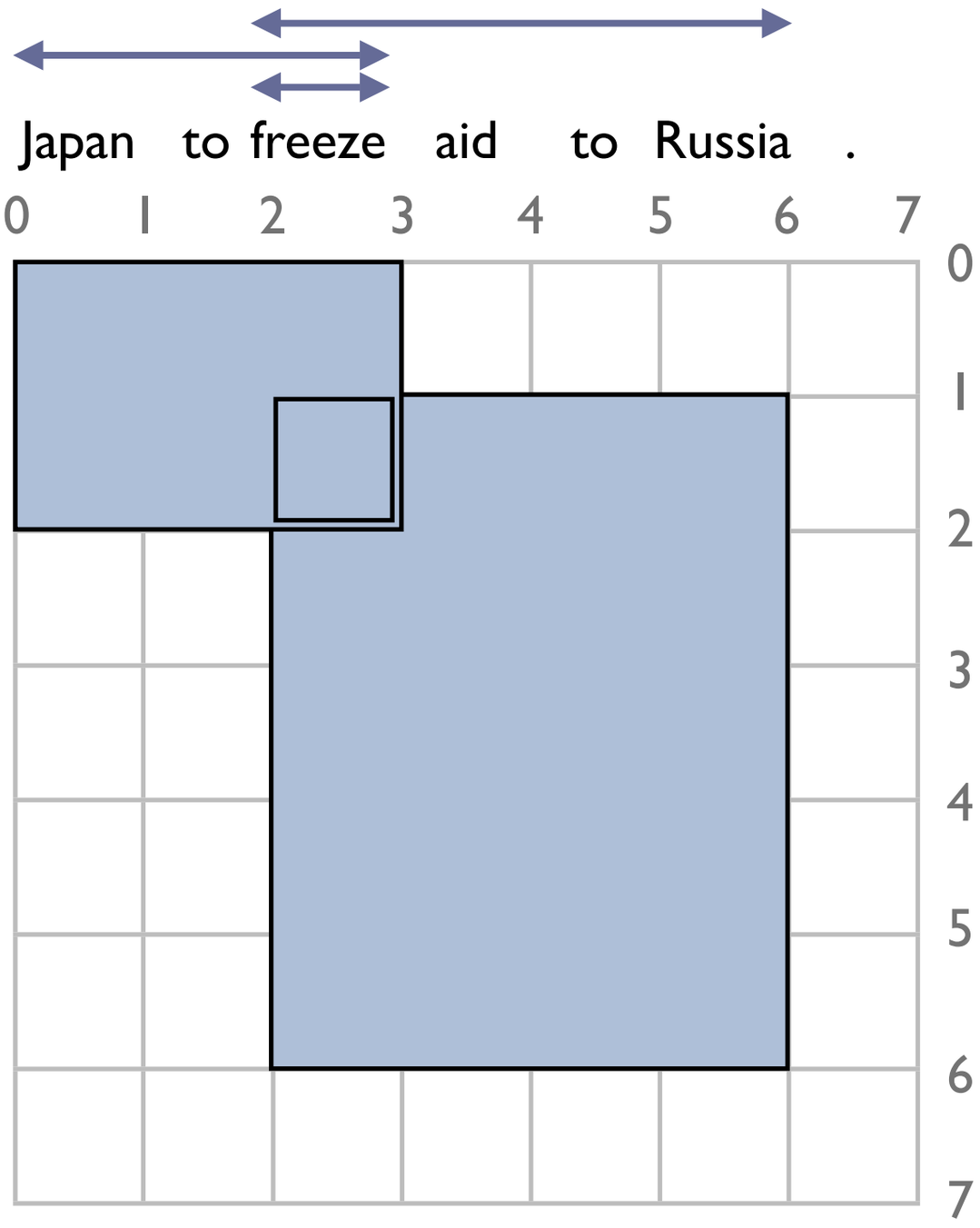
$$\max \sum_{i,j,k,l} w_{i,j,k,l} \cdot a_{i,j,k,l}$$

$$\text{s.t.} \sum_{i,j:i<x\leq j} e_{i,j} = 1$$

Indicator Variables:
a: phrase alignment **e**: English segmentation **f**: foreign segmentation

Constants:
w: weights

Phrase Alignment as Integer Programming



$$\max \sum_{i,j,k,l} w_{i,j,k,l} \cdot a_{i,j,k,l}$$

$$\text{s.t.} \sum_{i,j:i<x\leq j} e_{i,j} = 1$$

$$\sum_{k,l:k<y\leq l} f_{k,l} = 1$$

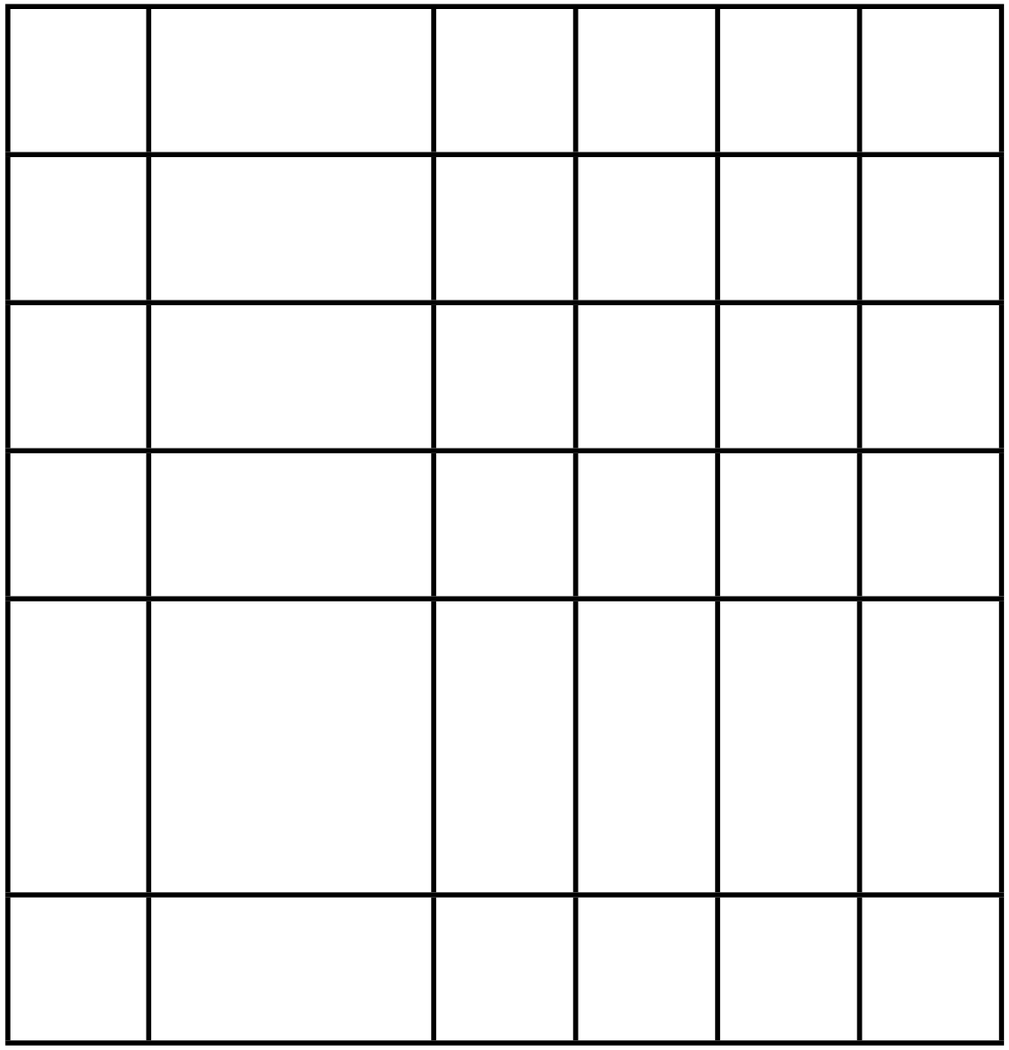
Indicator Variables:
a: phrase alignment **e**: English segmentation **f**: foreign segmentation

Constants:
w: weights

Phrase Alignment as Integer Programming

Japan to freeze aid to Russia .

1 2 3 4 5 6



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$$\max \sum_{i,j,k,l} w_{i,j,k,l} \cdot a_{i,j,k,l}$$

$$\text{s.t.} \sum_{i,j:i<x\leq j} e_{i,j} = 1$$

$$\sum_{k,l:k<y\leq l} f_{k,l} = 1$$

Indicator Variables:

a: phrase alignment **e**: English segmentation **f**: foreign segmentation

Constants:

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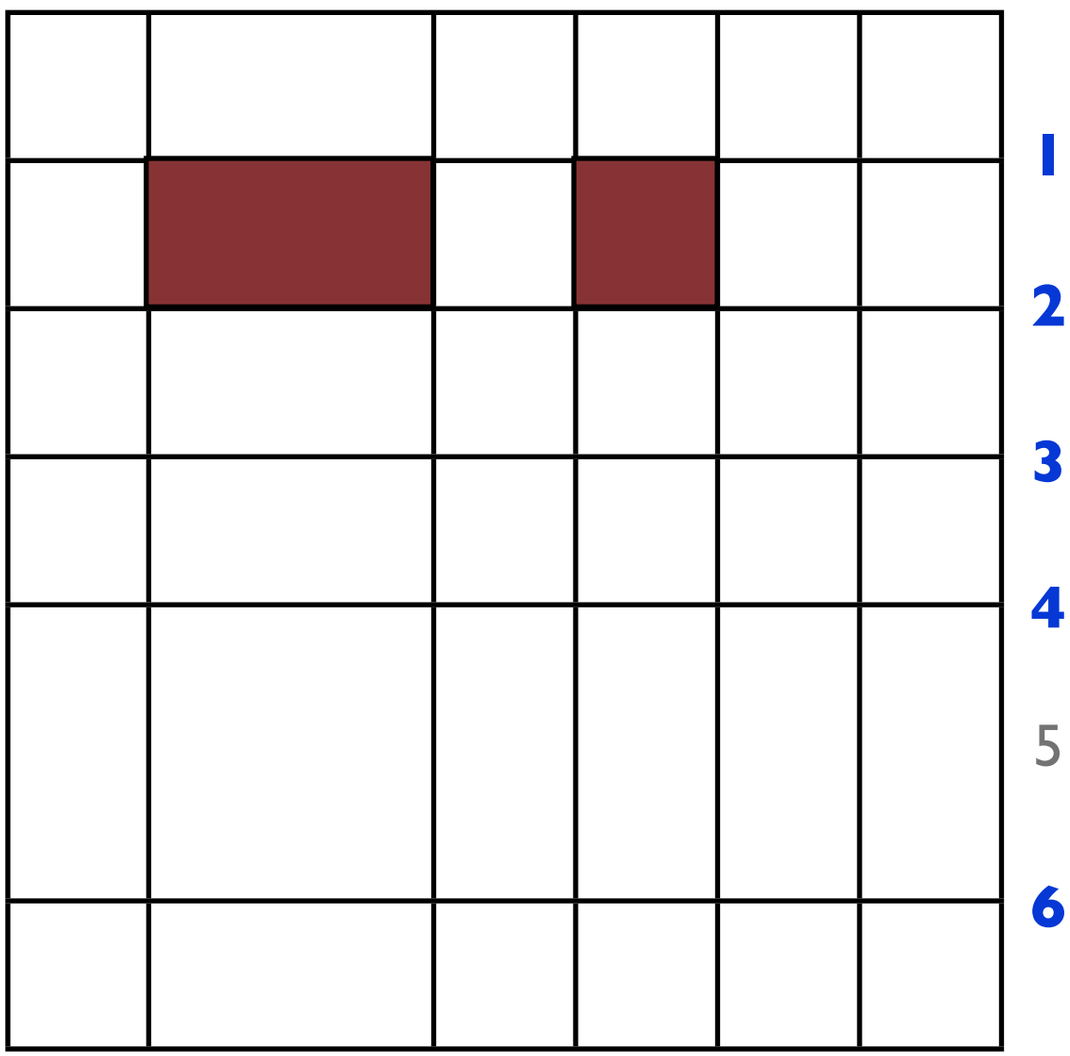
Phrase Alignment as Integer Programming

Japan to freeze aid to Russia .



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$$\max \sum_{i,j,k,l} w_{i,j,k,l} \cdot a_{i,j,k,l}$$

$$\text{s.t.} \sum_{i,j:i<x\leq j} e_{i,j} = 1$$

$$\sum_{k,l:k<y\leq l} f_{k,l} = 1$$

Indicator Variables:
a: phrase alignment **e**: English segmentation **f**: foreign segmentation

Constants:
w: weights

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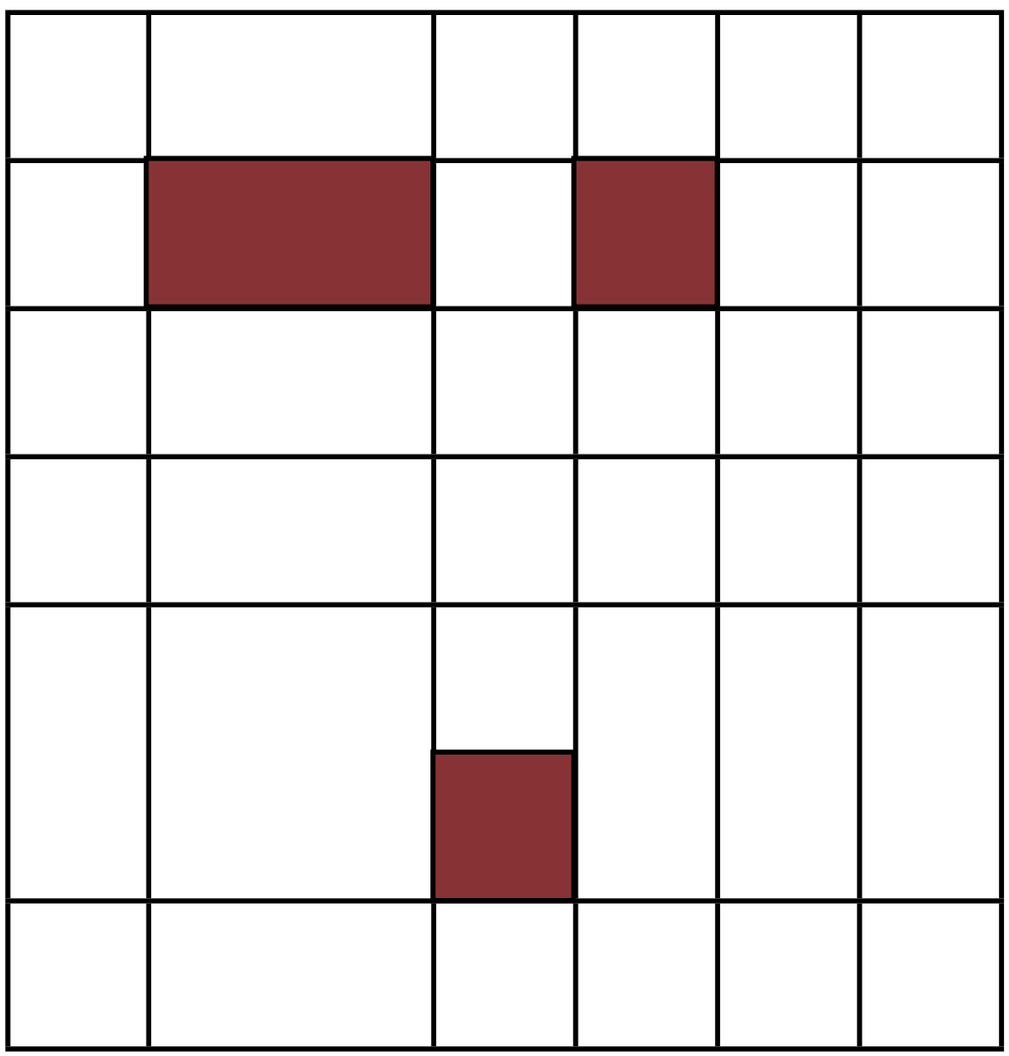

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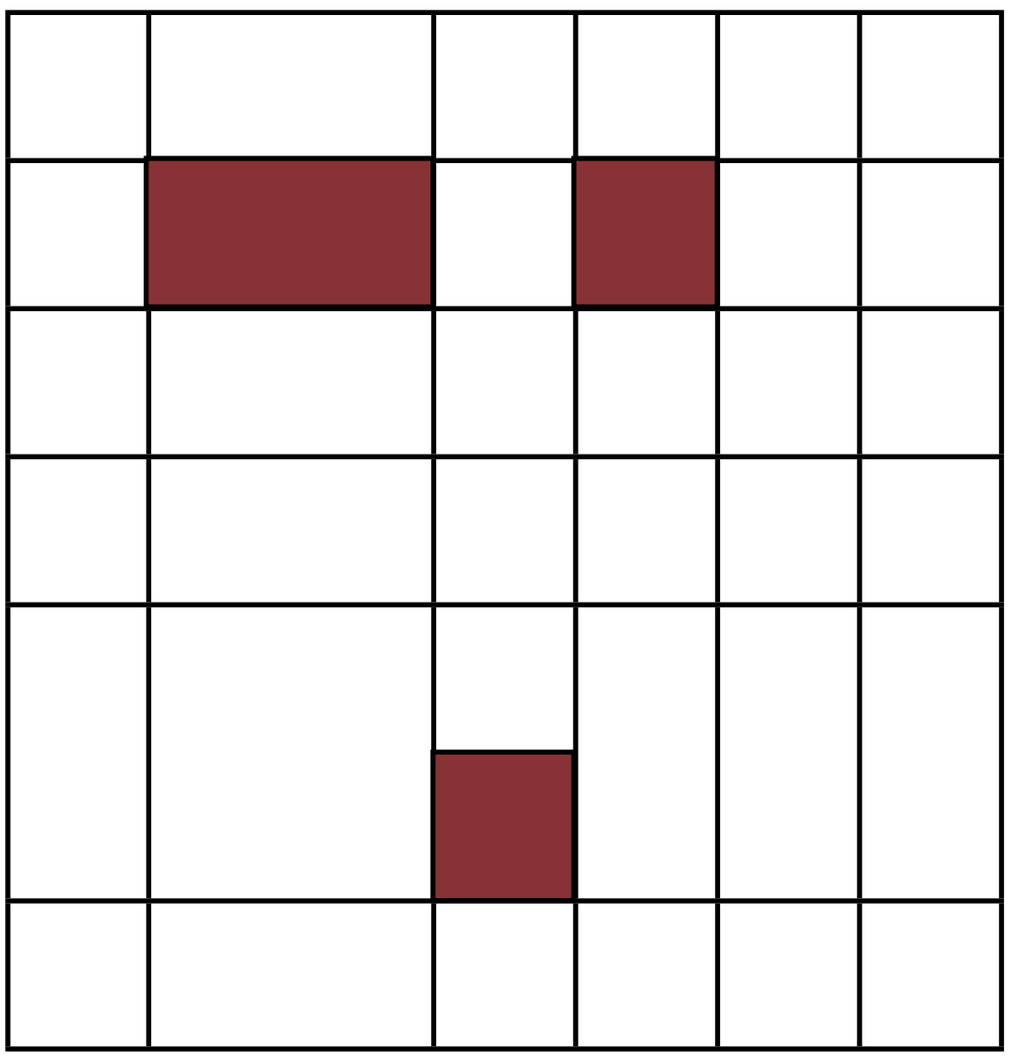

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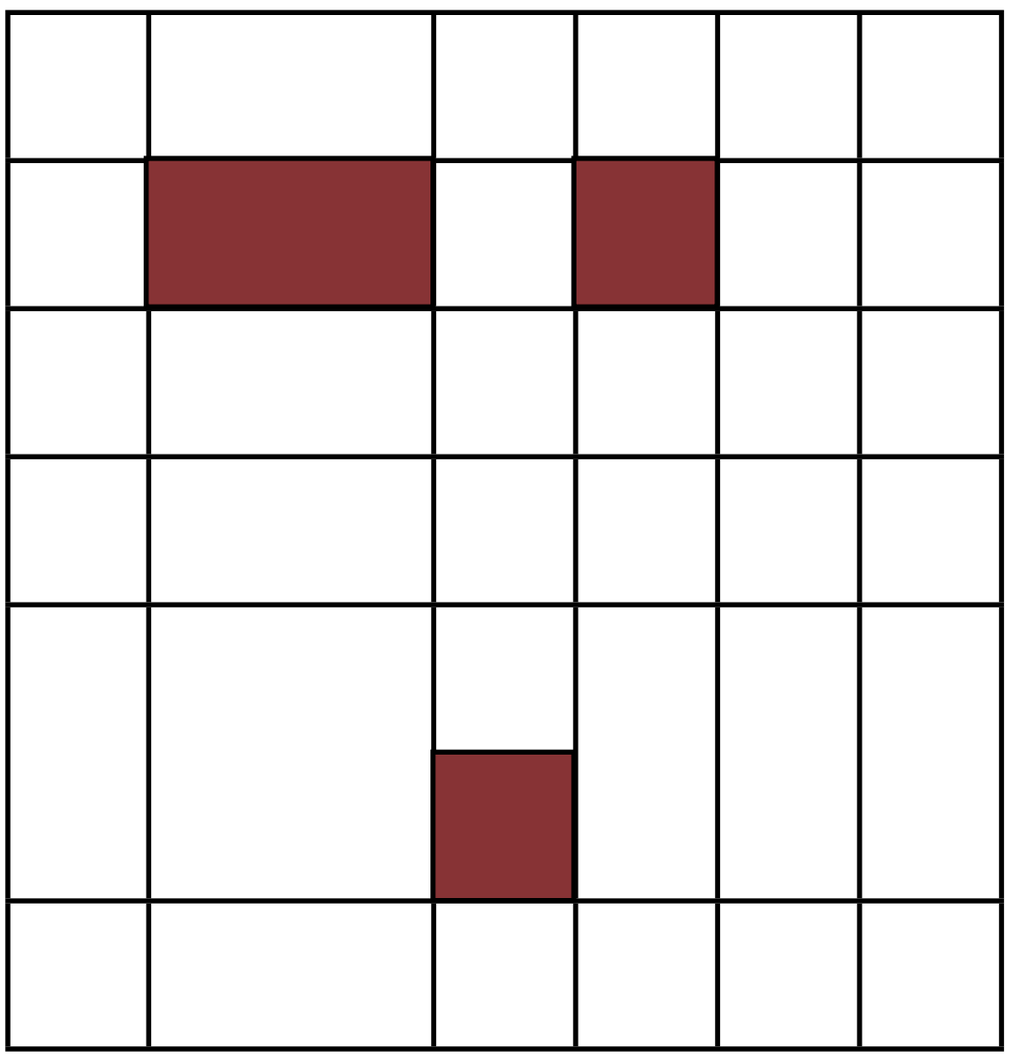

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