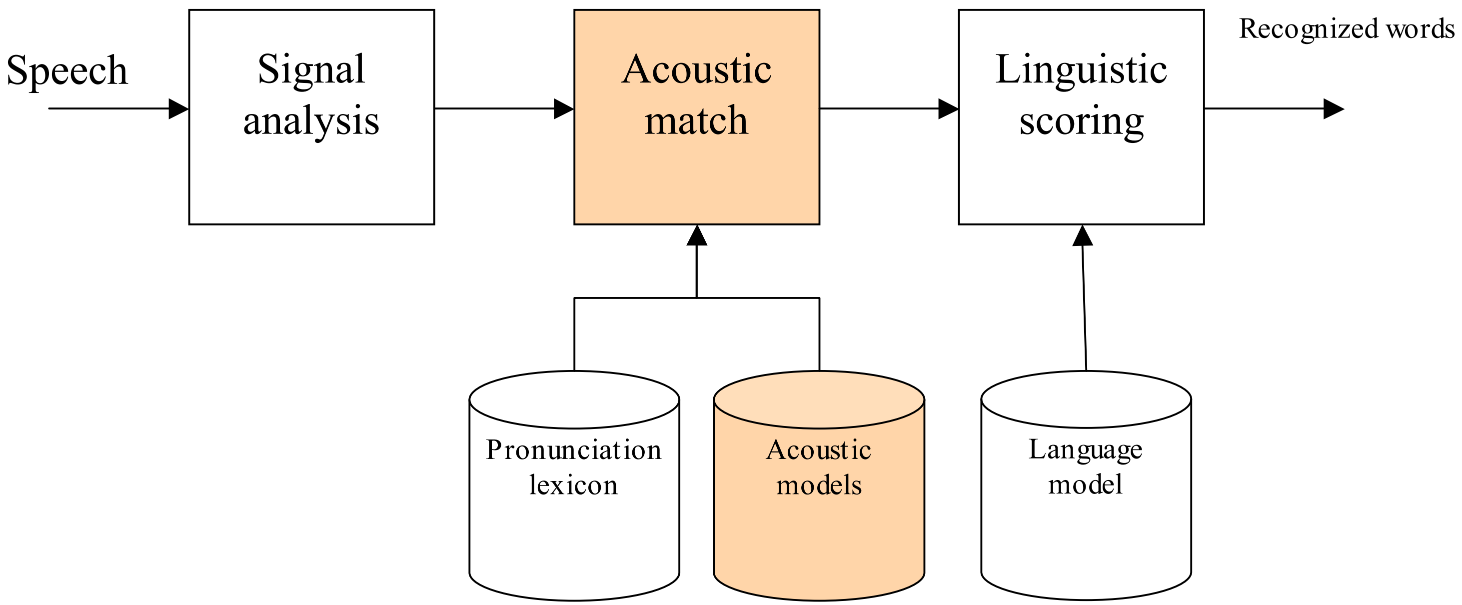
Acoustic match - templates: Outline

- Template based pattern matching
- Dynamic time warping
- Dynamic programming

ASR step-by-step: Acoustic match (1)



Template based pattern matching

- Speech *recognition* implies that a pattern has already been learned
  - Training
- In template matching techniques, the learned pattern is represented as a temporal pattern, e.g. a (typical) sequence of feature vectors
- Recognition basically consists of evaluating the match between the test pattern and the stored patterns and selecting the closest matching stored pattern as the recognized pattern
- The speech patterns will exhibit relativly large temporal variations
  - Non-linear dependency on speaking rate
- How to account for ”normal” temporal variations?
- Dynamic Time Warping (Sakoe and Chiba, 1978)

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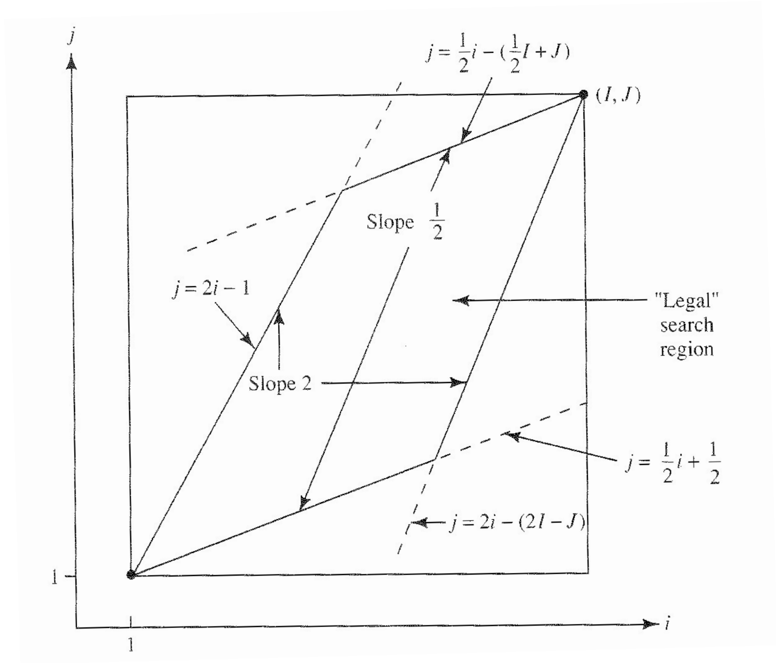
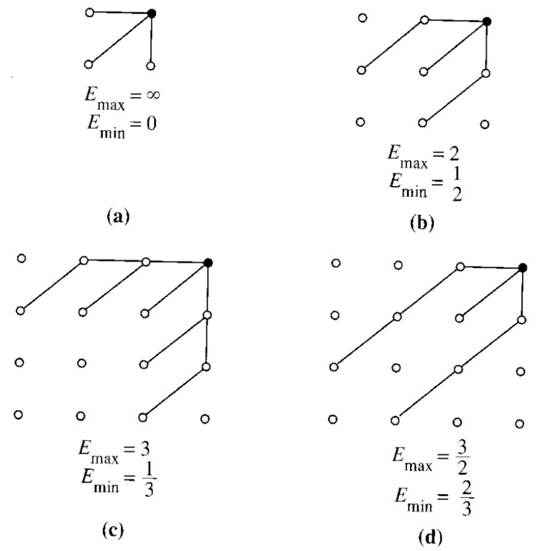
Dynamic Time Warping

- Method for aligning two temporal pattern series
- Based on Dynamic programming (Bellmann, 1957)
- Requires a metric for local distance, i.e. a measure of the dissimilarity between two feature vectors, $d(\mathbf{x},\mathbf{y})$
  - Should be meaningful
  - $d(\mathbf{x},\mathbf{x})=0$
  - $d(\mathbf{x},\mathbf{y})>0$ iff $\mathbf{x}\neq\mathbf{y}$
  - $d(\mathbf{x},\mathbf{y}) = d(\mathbf{y},\mathbf{x})$ (symmetry - desirable, not necessary)

Global and local constraints





Global constraints

Local constraints

- Restrict freedom of search to better correspond with natural temporal variations of speech whilst containing the left-right ordering of acoustic events

Dynamic programming

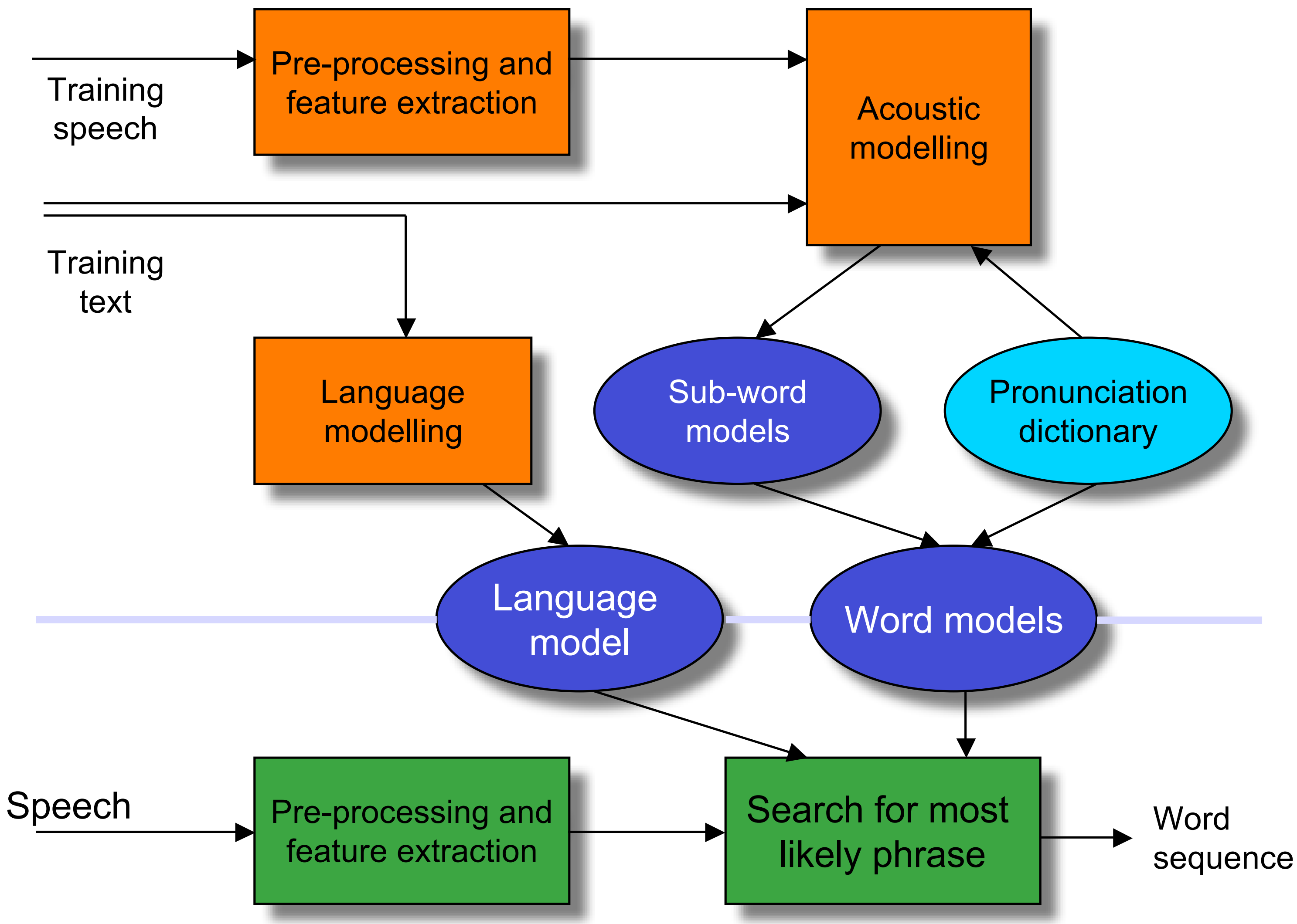
- Efficient method for search and matching
- Used in many ASR applications
- DTW: Given two sequences, $\{\mathbf{x}_i\}$ and $\{\mathbf{y}_j\}$, i=1,...,N; j=1,...,M.
  - Find the warping, w(j), such that the total distance

$$\mathrm{D}(\mathbf{X},\mathbf{Y}) = \sum_i d(\mathbf{x}_i, \mathbf{y}_{w(j)})$$

is minimized

- Based on Bellmann's principle: If the optimal path between (1,1) and (N,M) passes through (n,m), then the optimal path between (1,1) and (n,m) is a part of the overall optimal path.
  - Can evaluate iteratively instead of searching through all possible paths
  - Optimal path to (n,m) can be found by evaluating accumulated distance at all immediate predecessors of (n,m) (plus a transition cost). Accumulated cost at (n,m) is found by adding local distortion.

ASR overview



Dynamic programming example

- Match two word sequences (e.g. spoken and recognized)
- Spoken: ”The effect is clear”
- Recognized: ”Effect is not clear”
- Penalty factors in dynamic programming
  - Deletion: $P_D=3$
  - Insertion: $P_I=3$
  - Substitution: $P_S=4$

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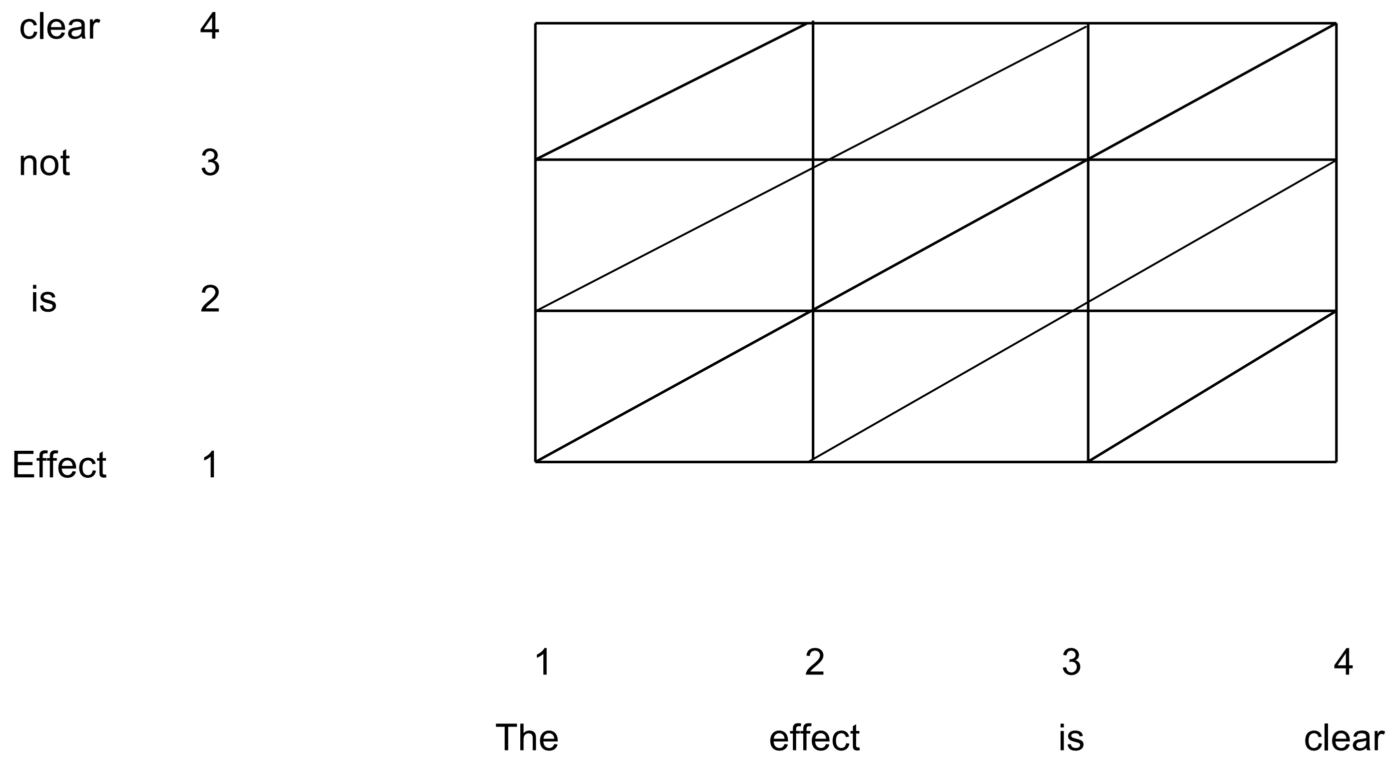
Dynamic programming example



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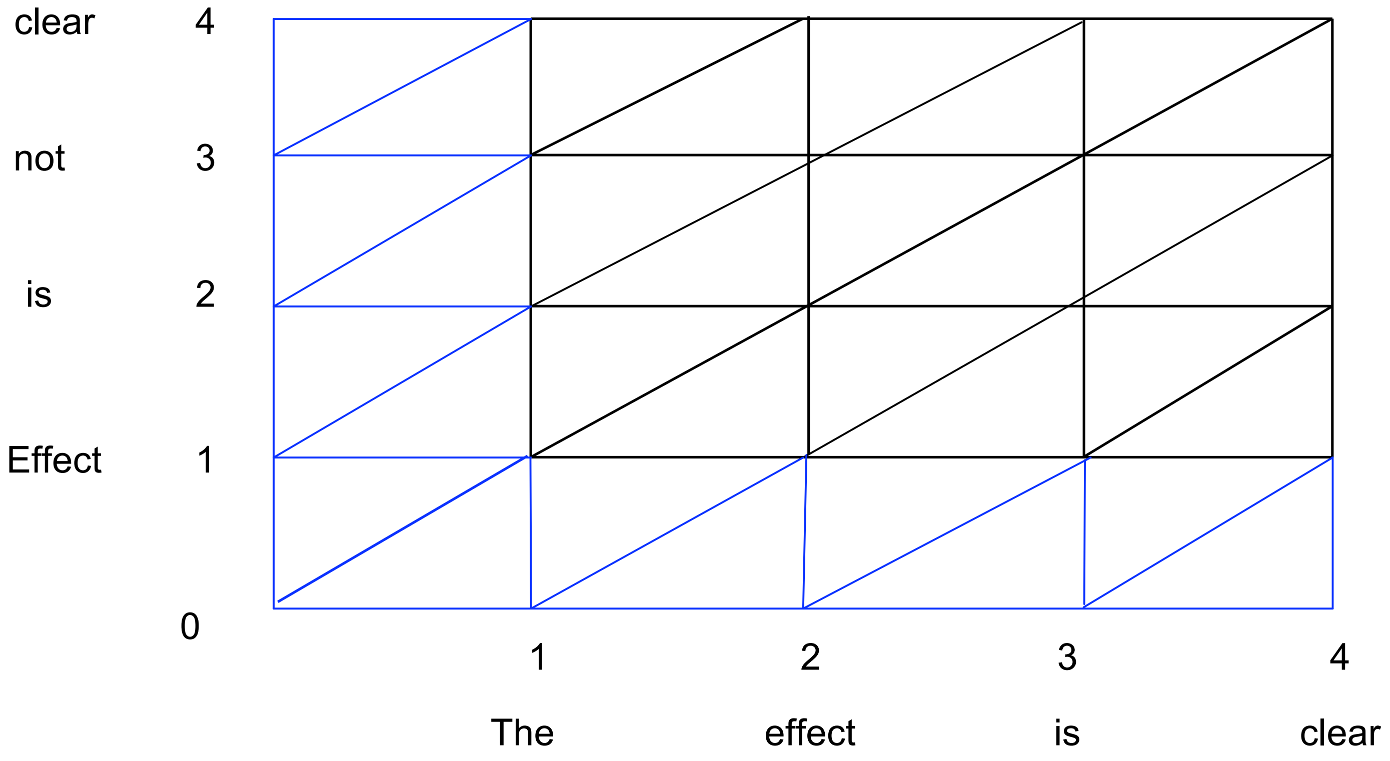

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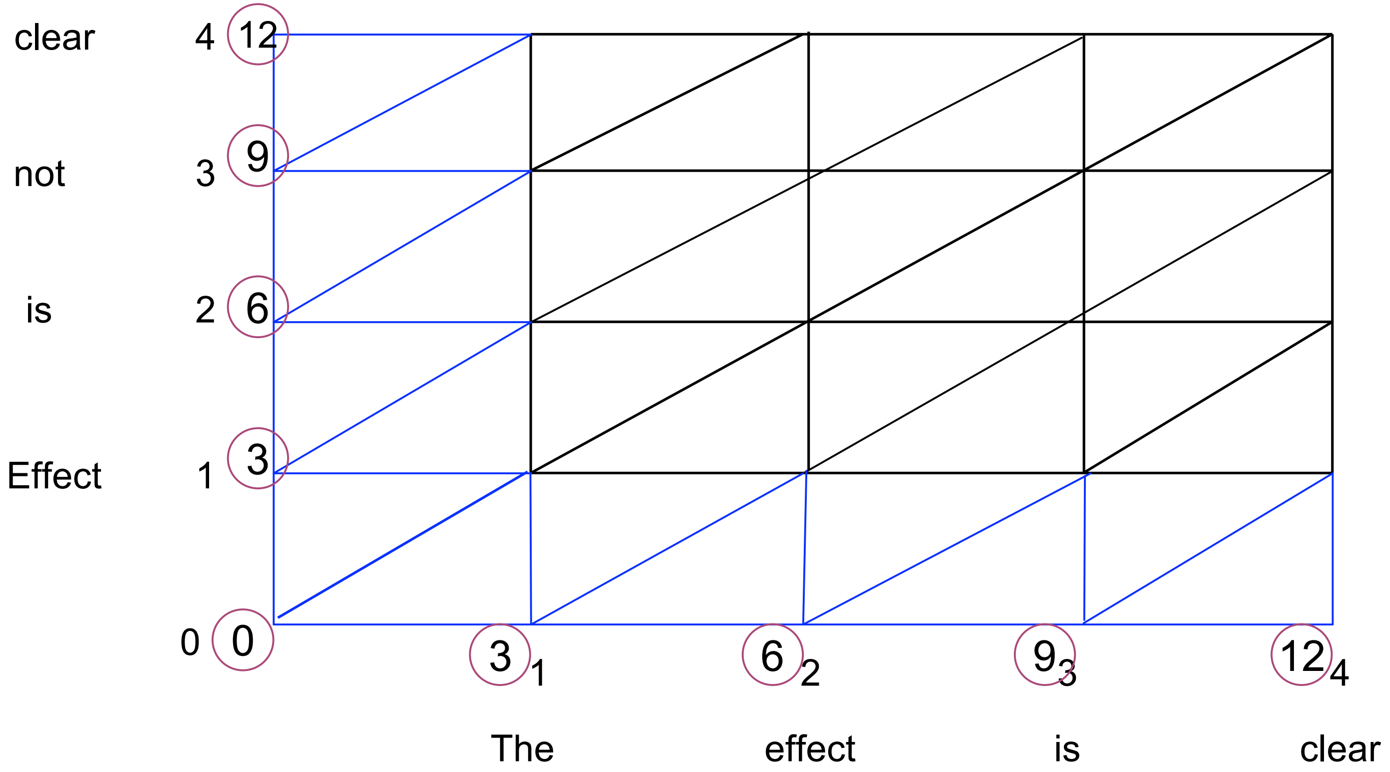

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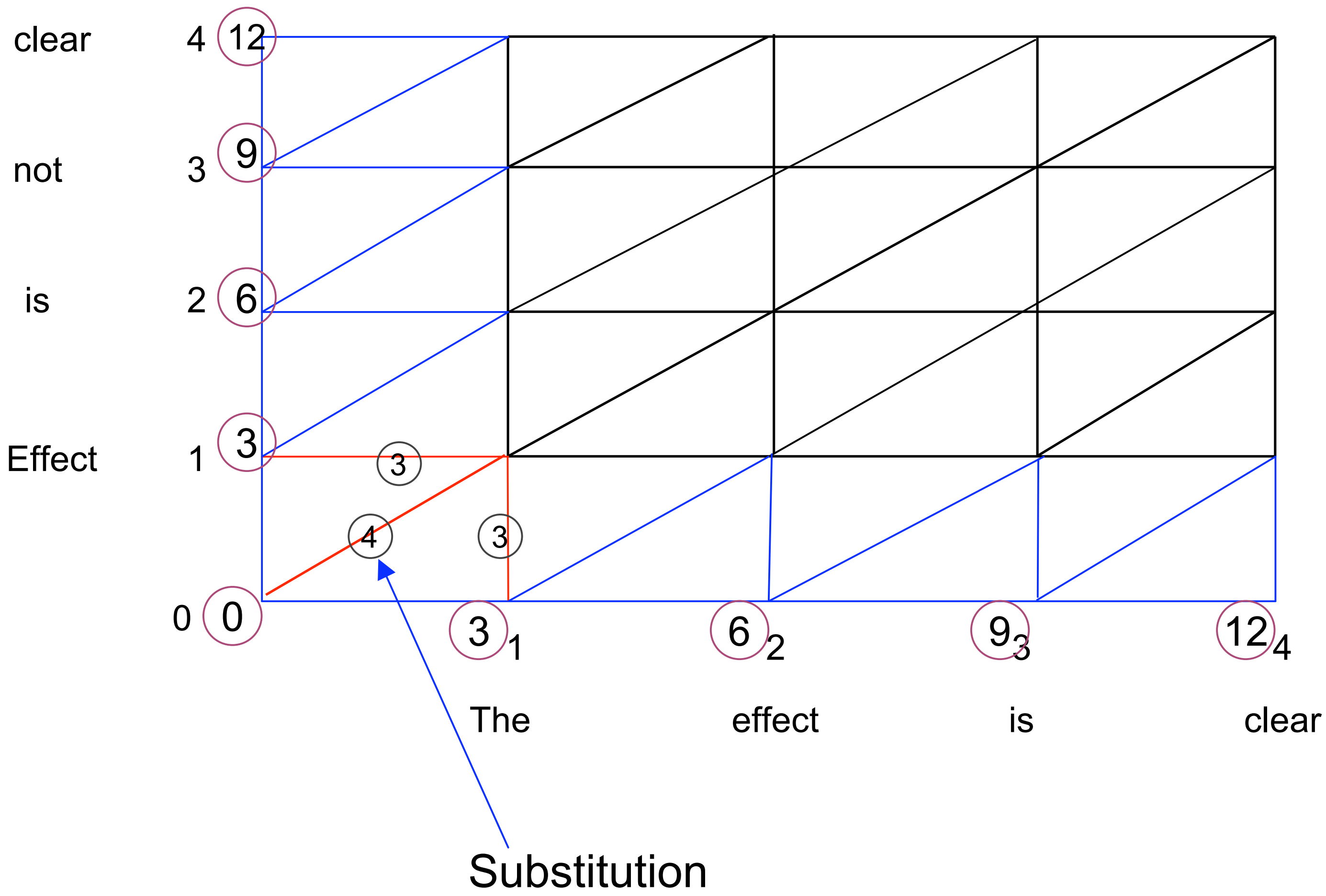

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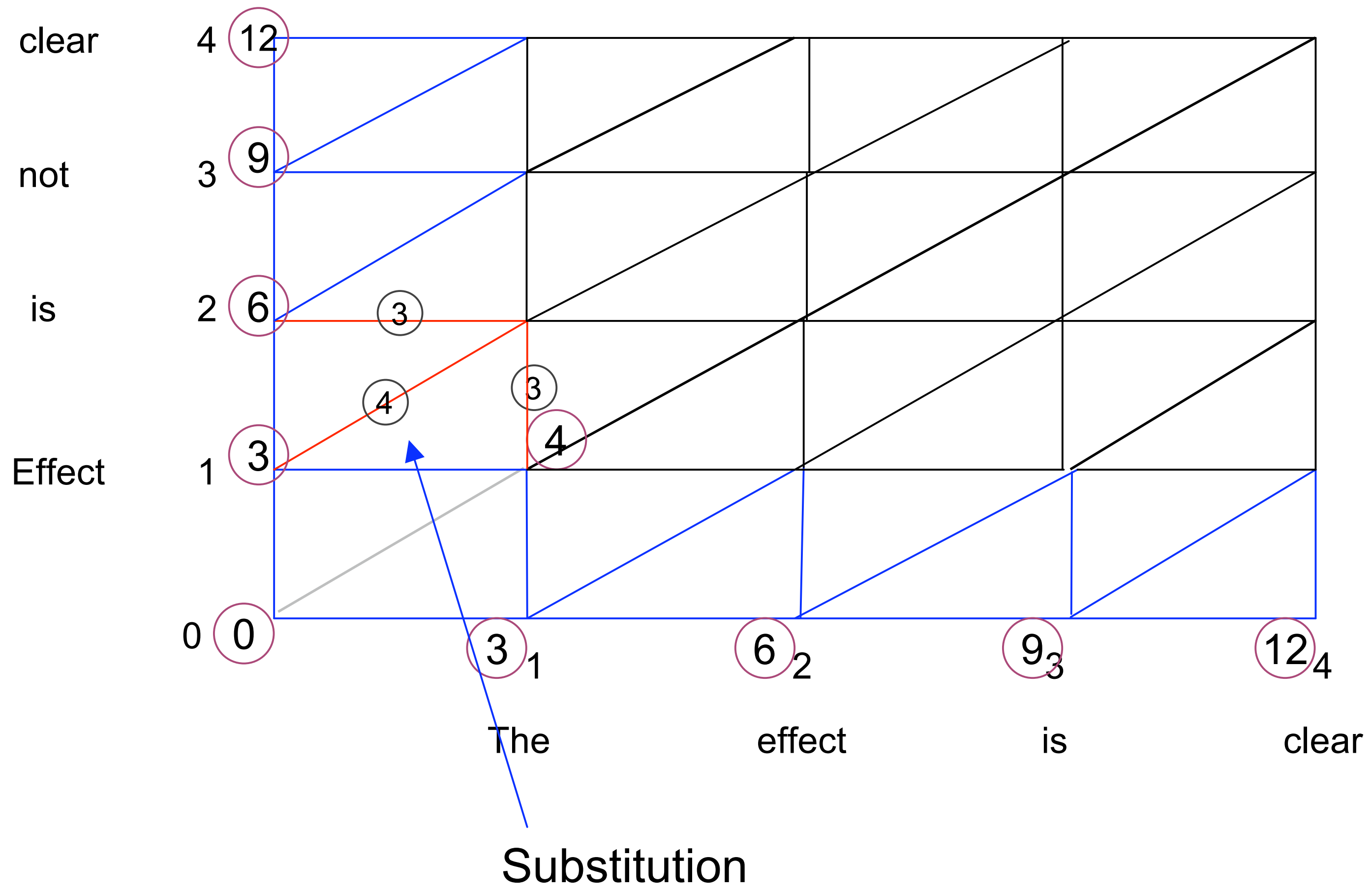

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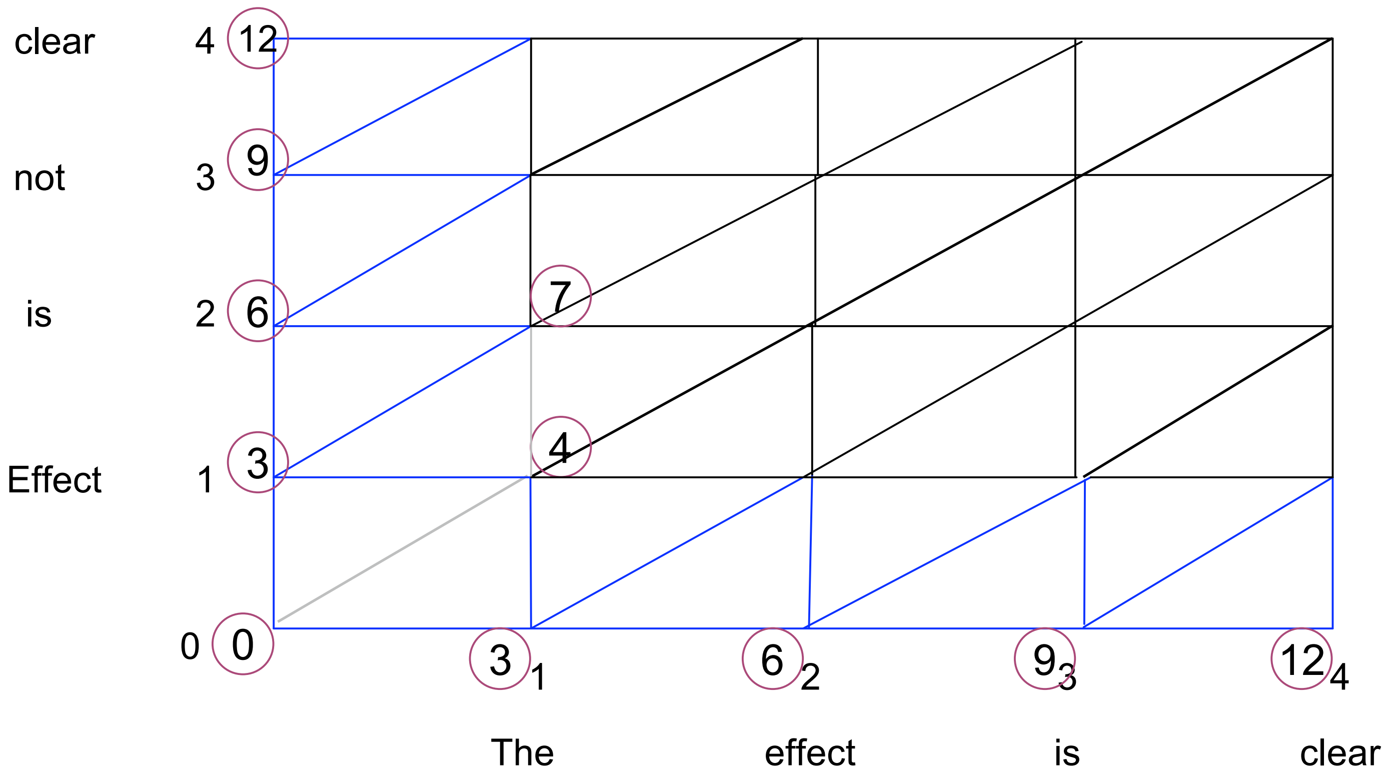

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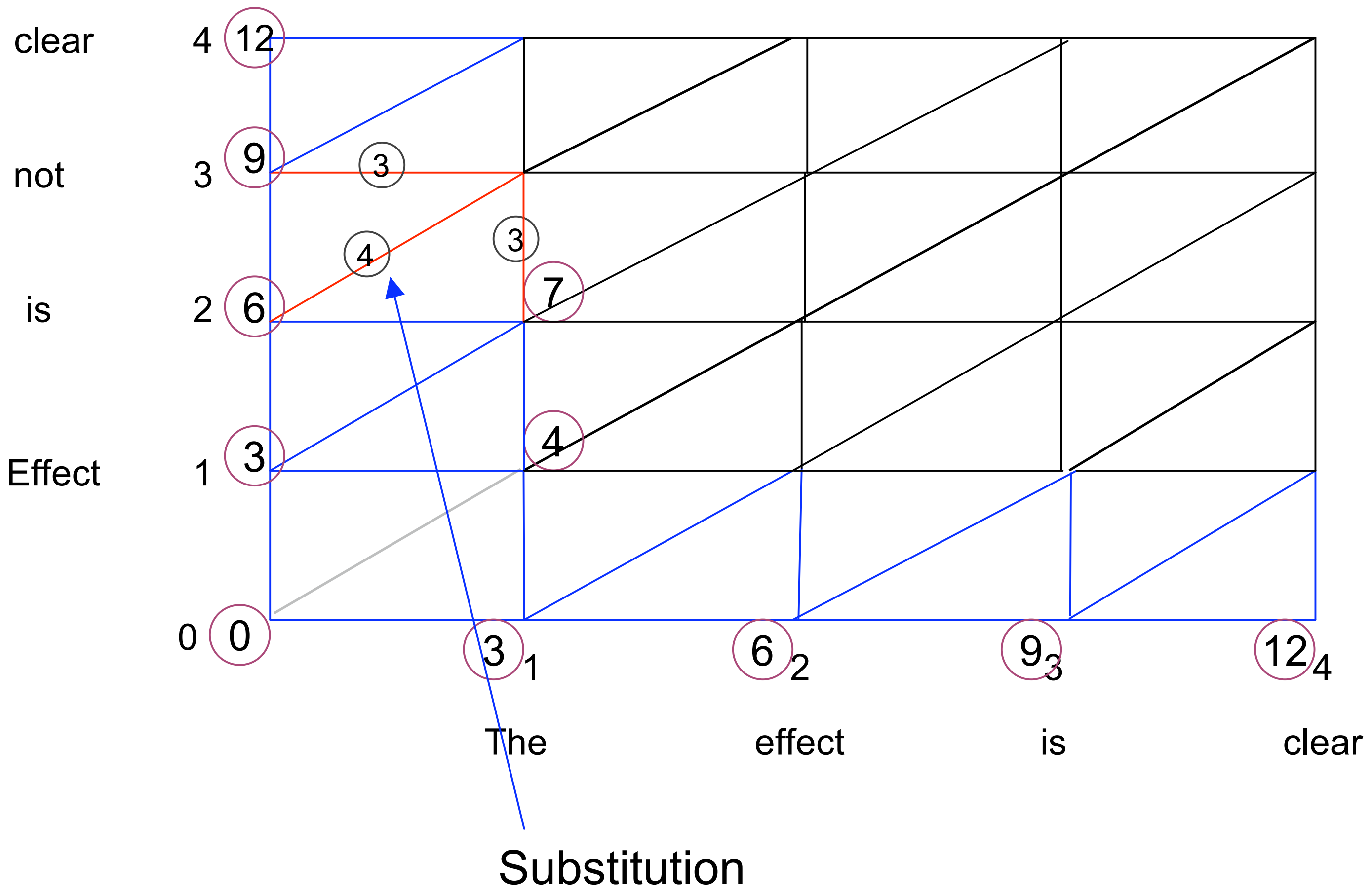

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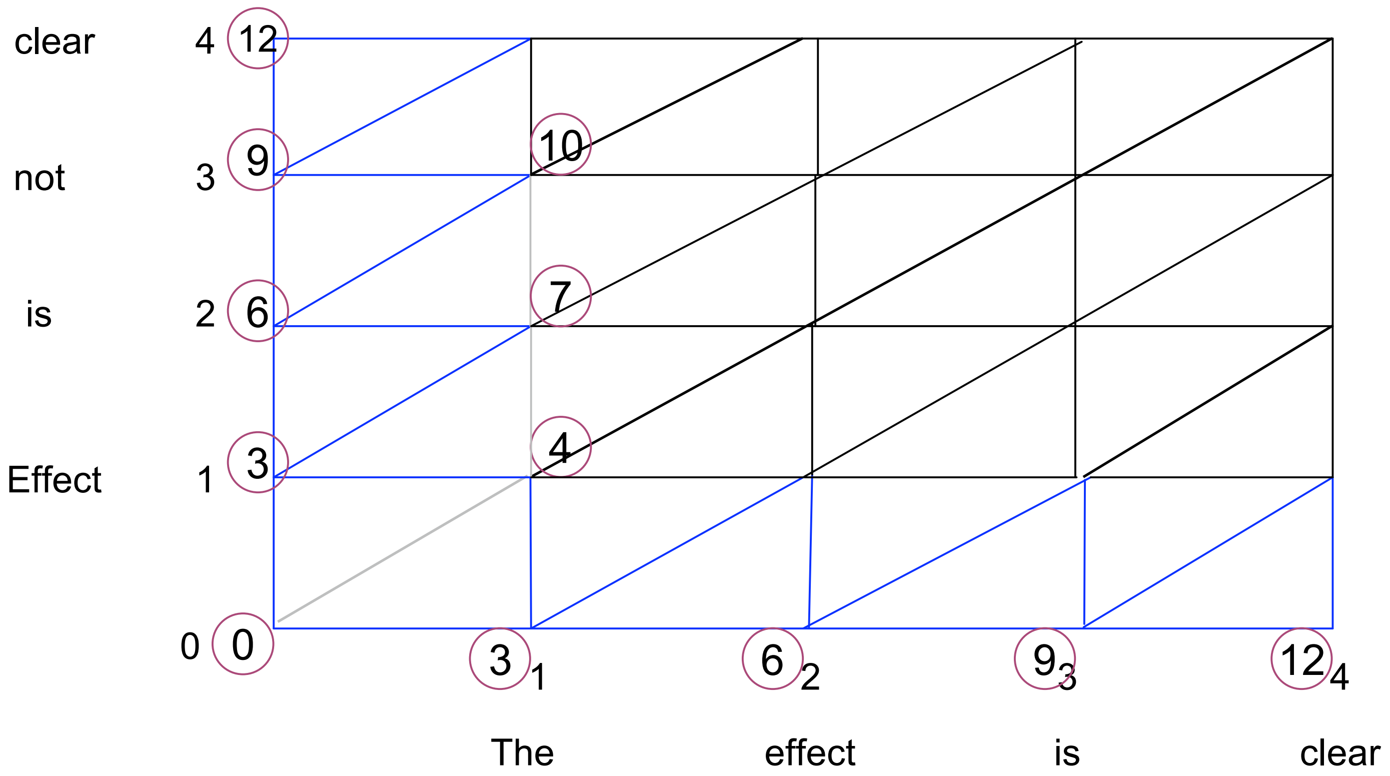

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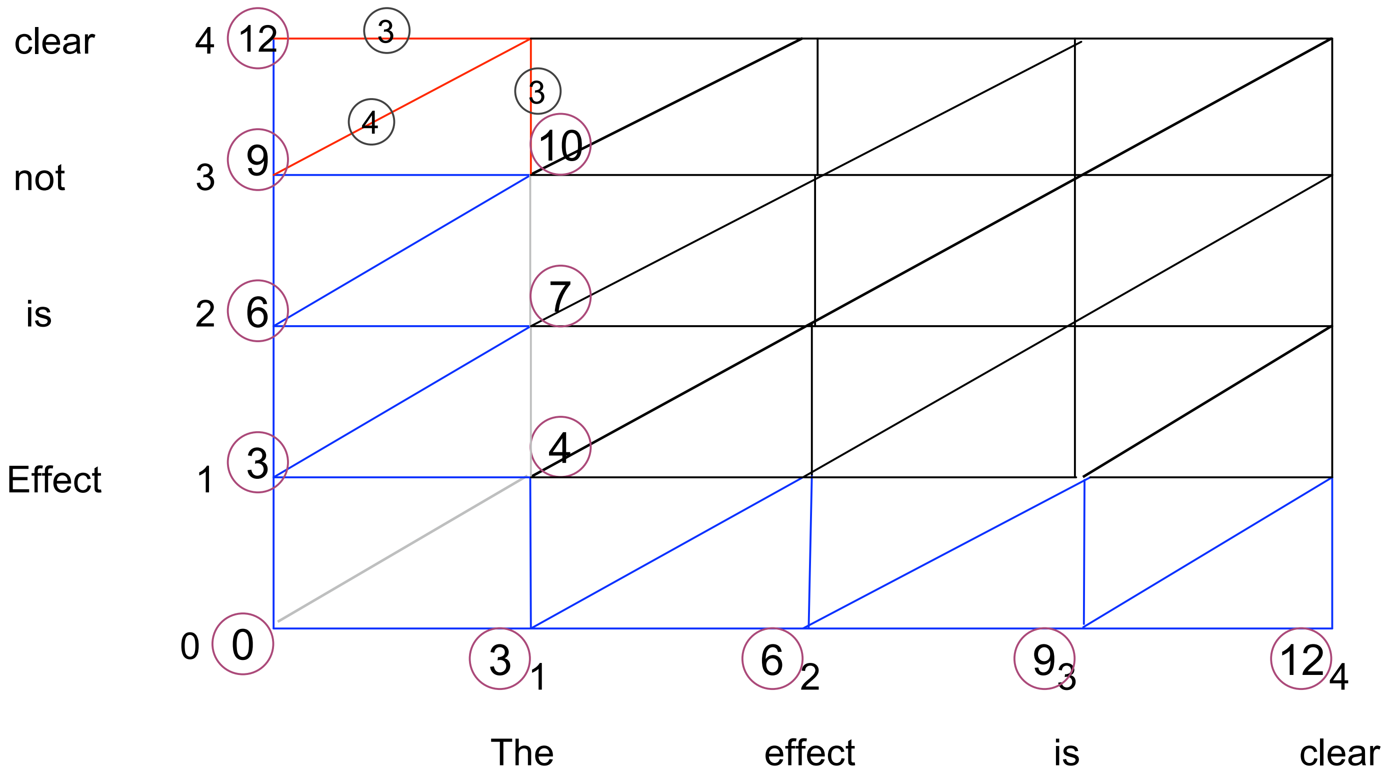

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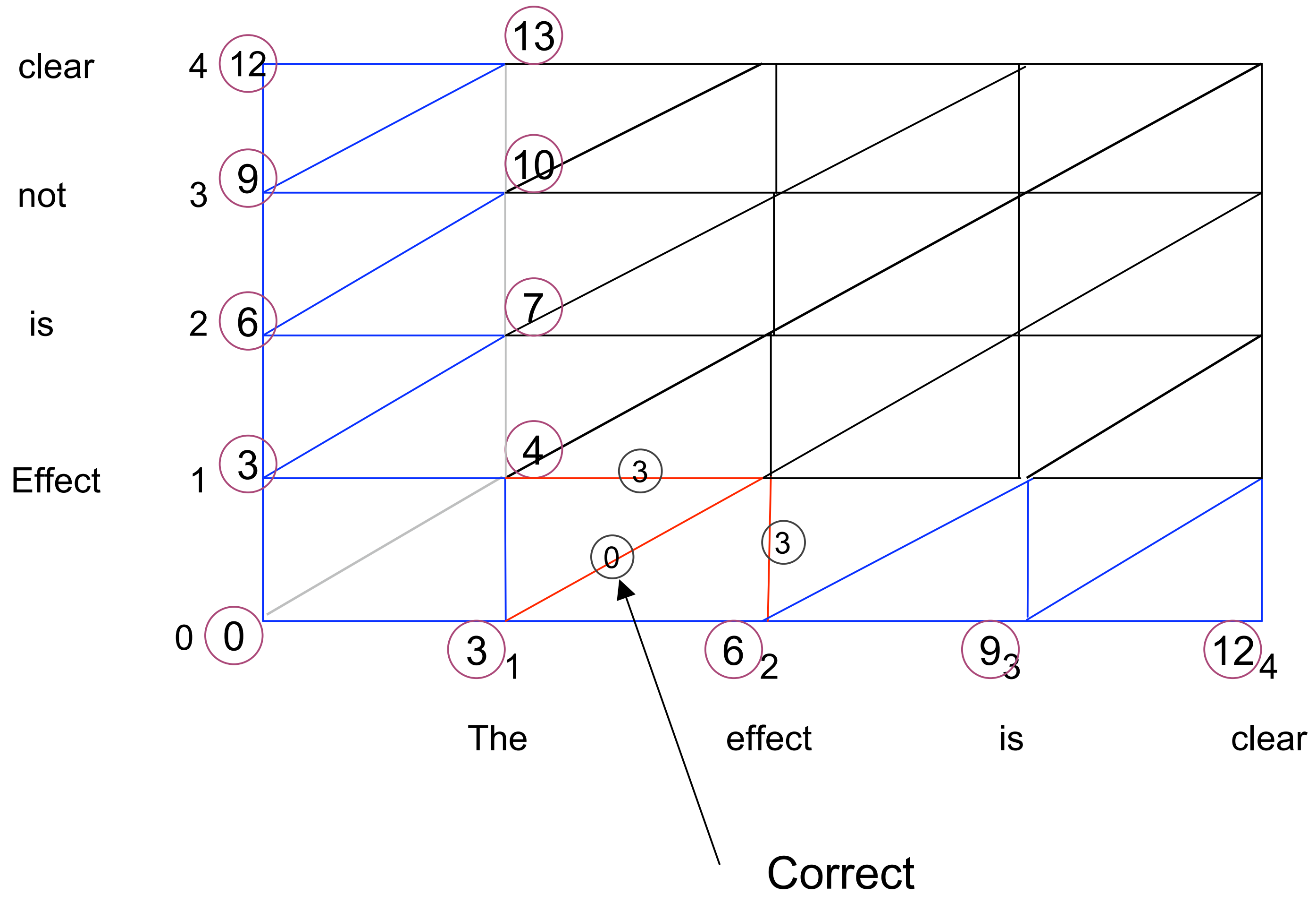

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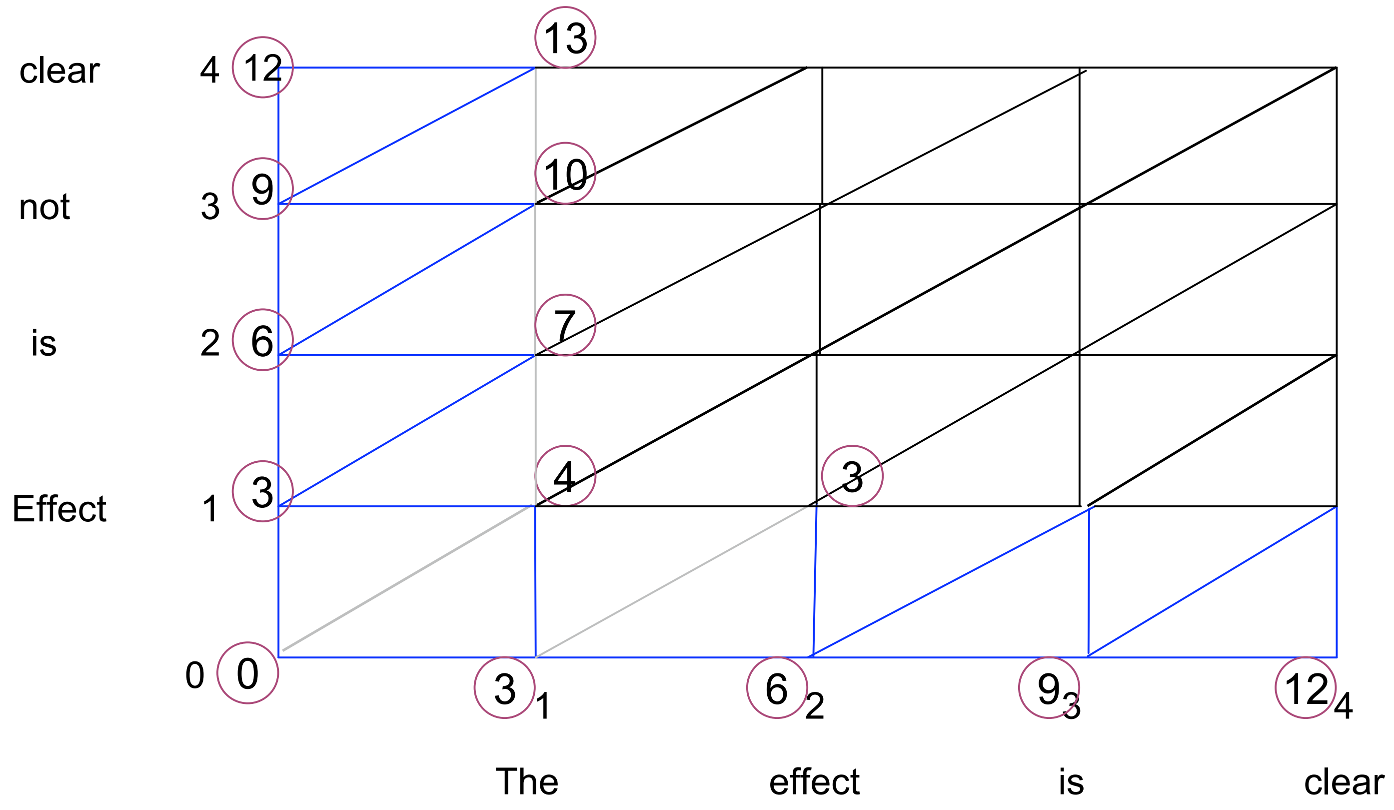

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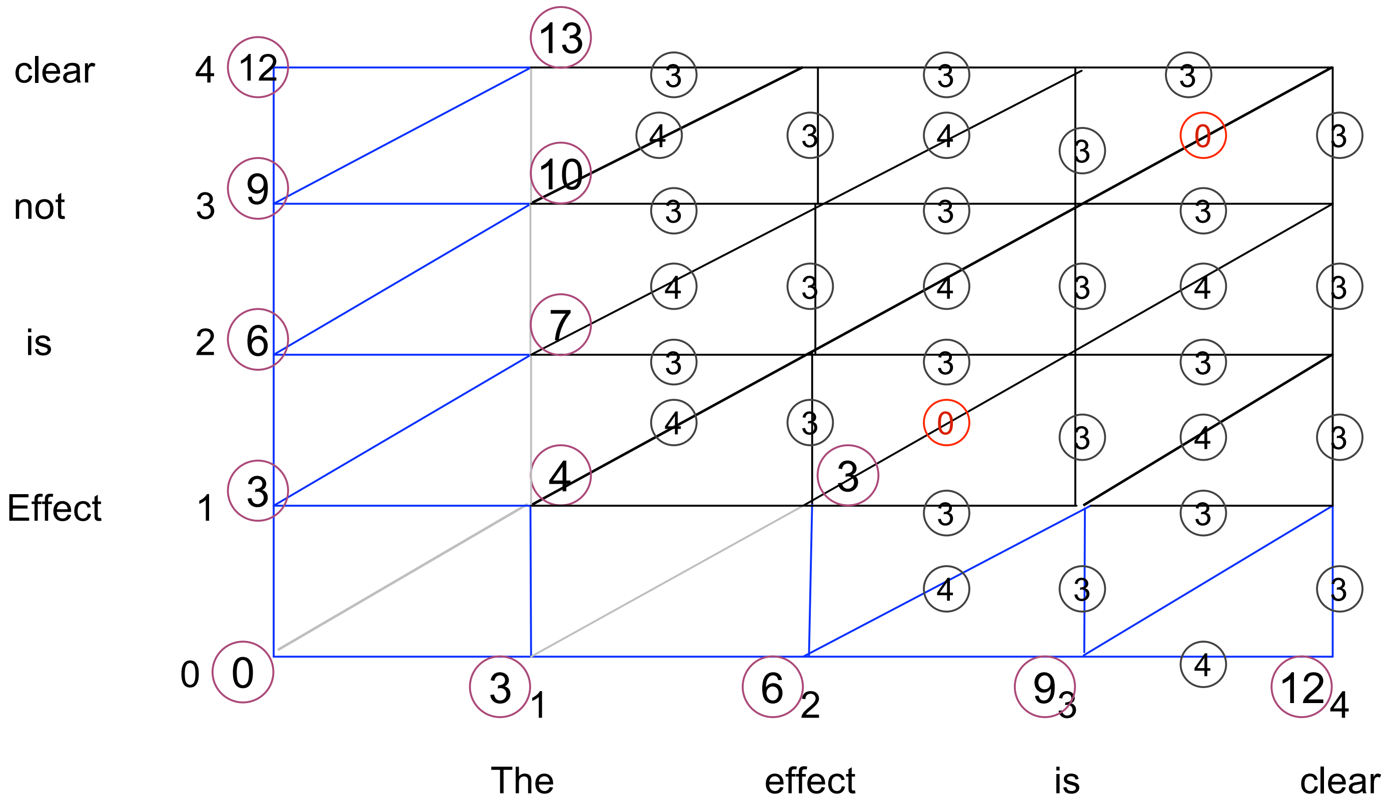

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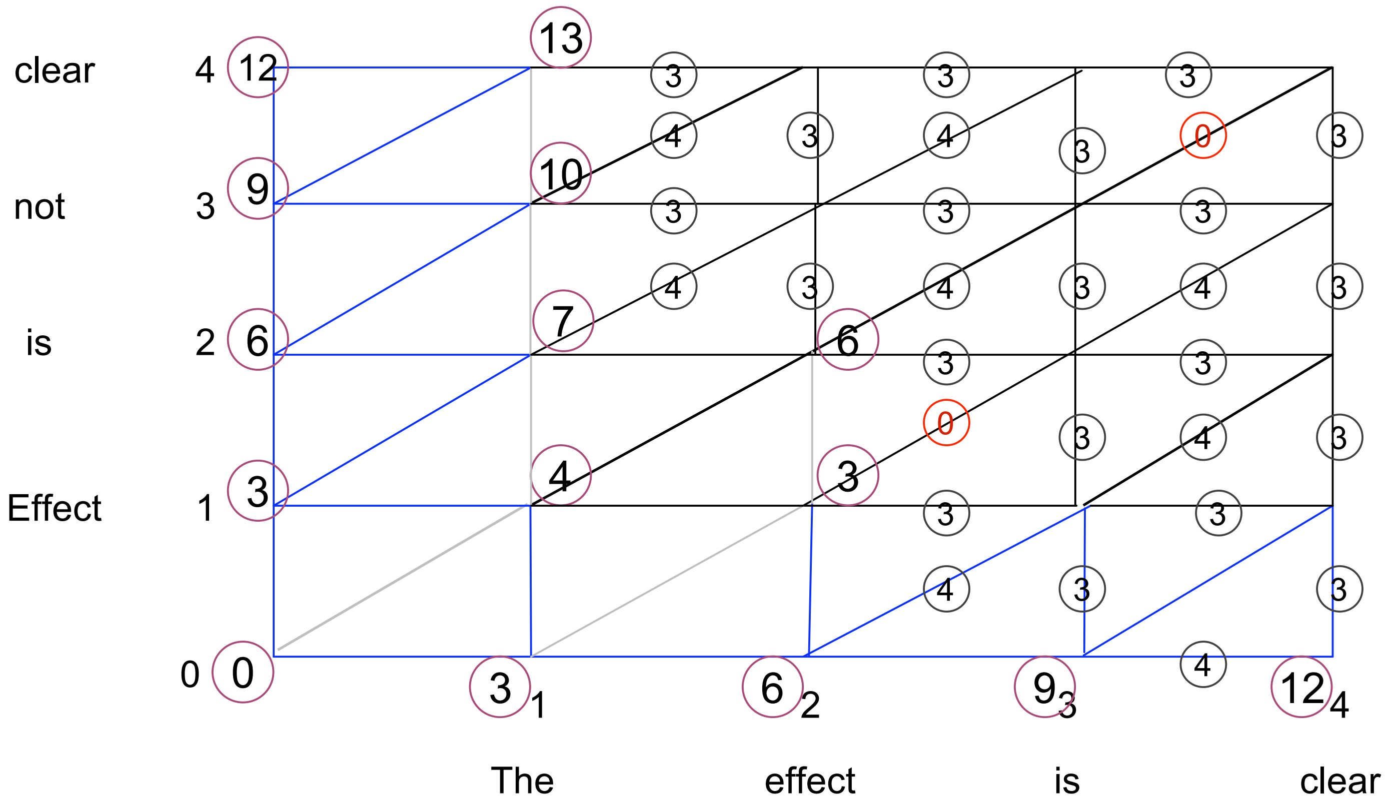

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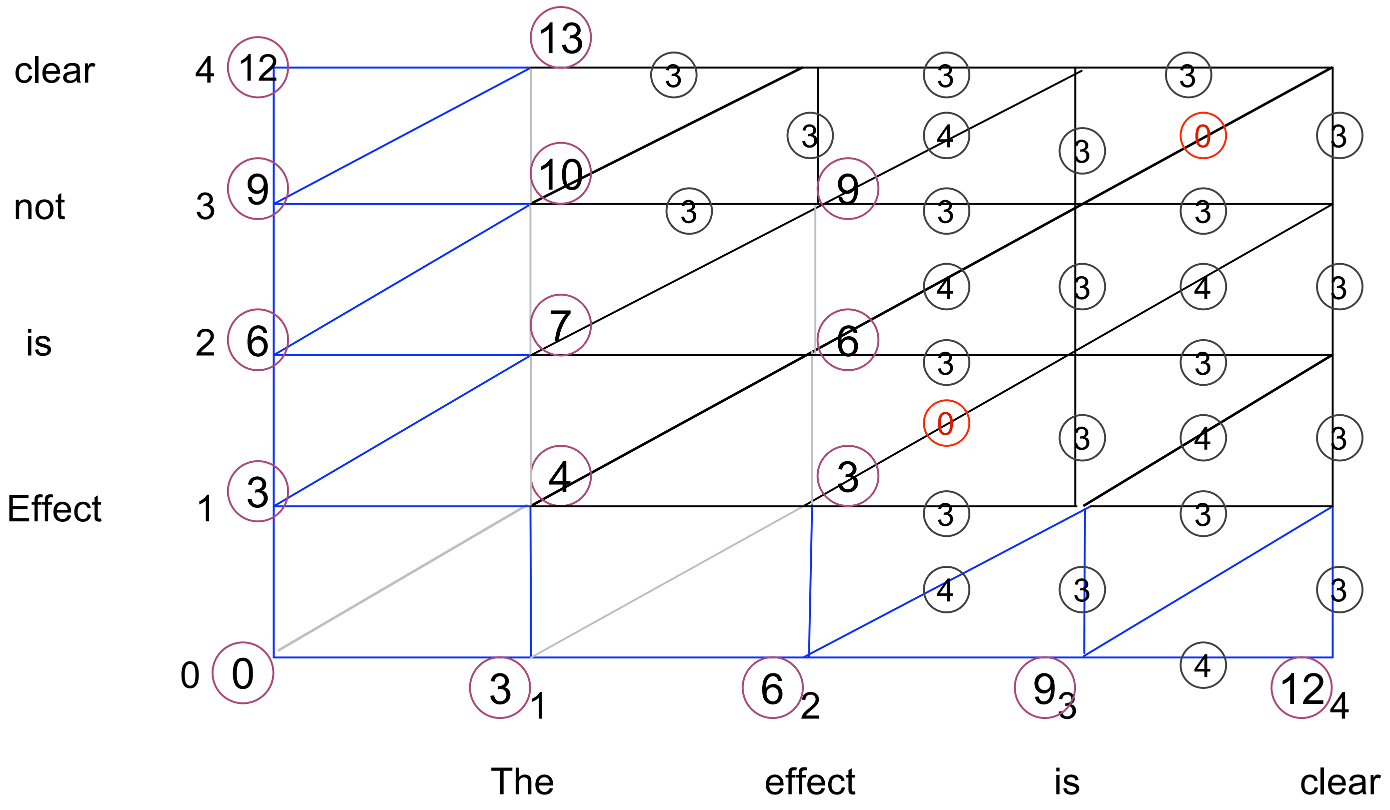

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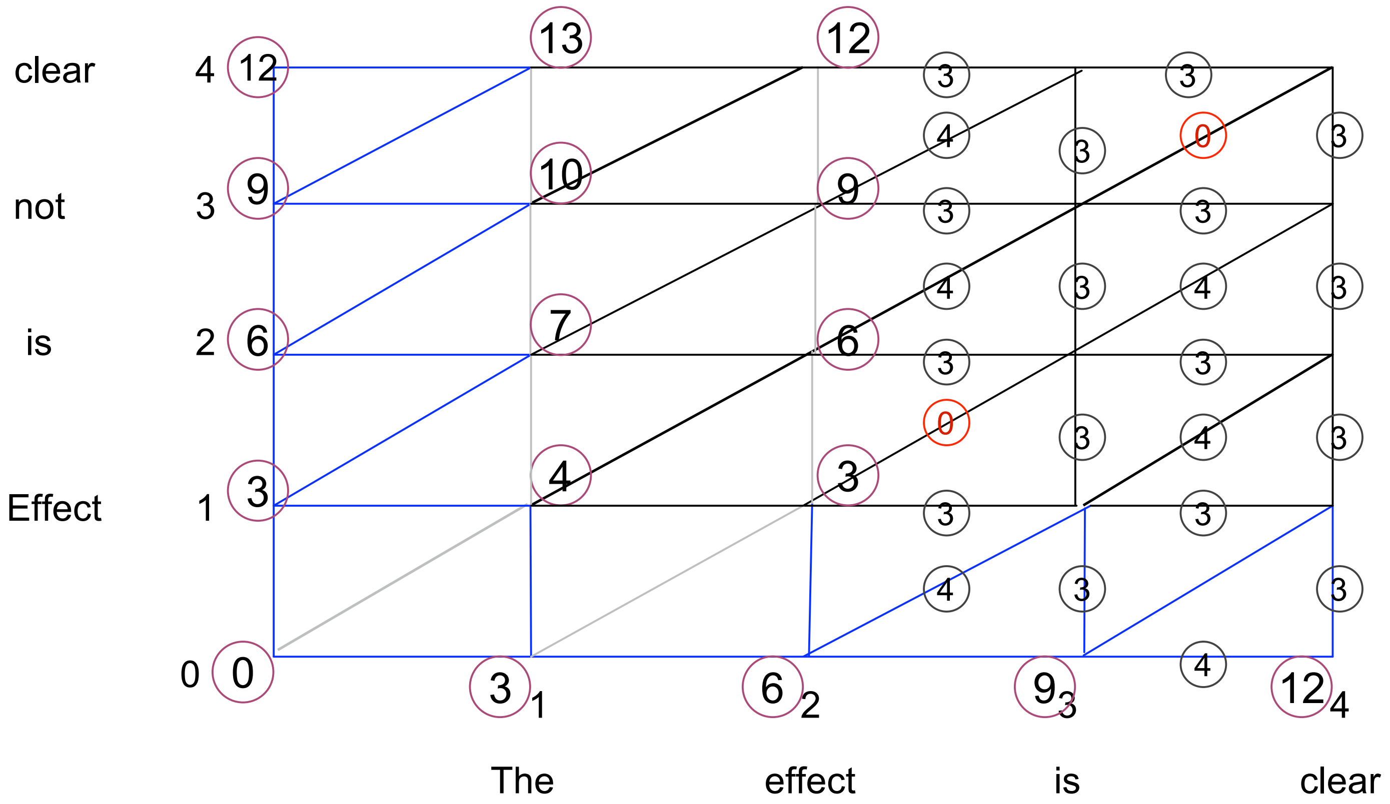

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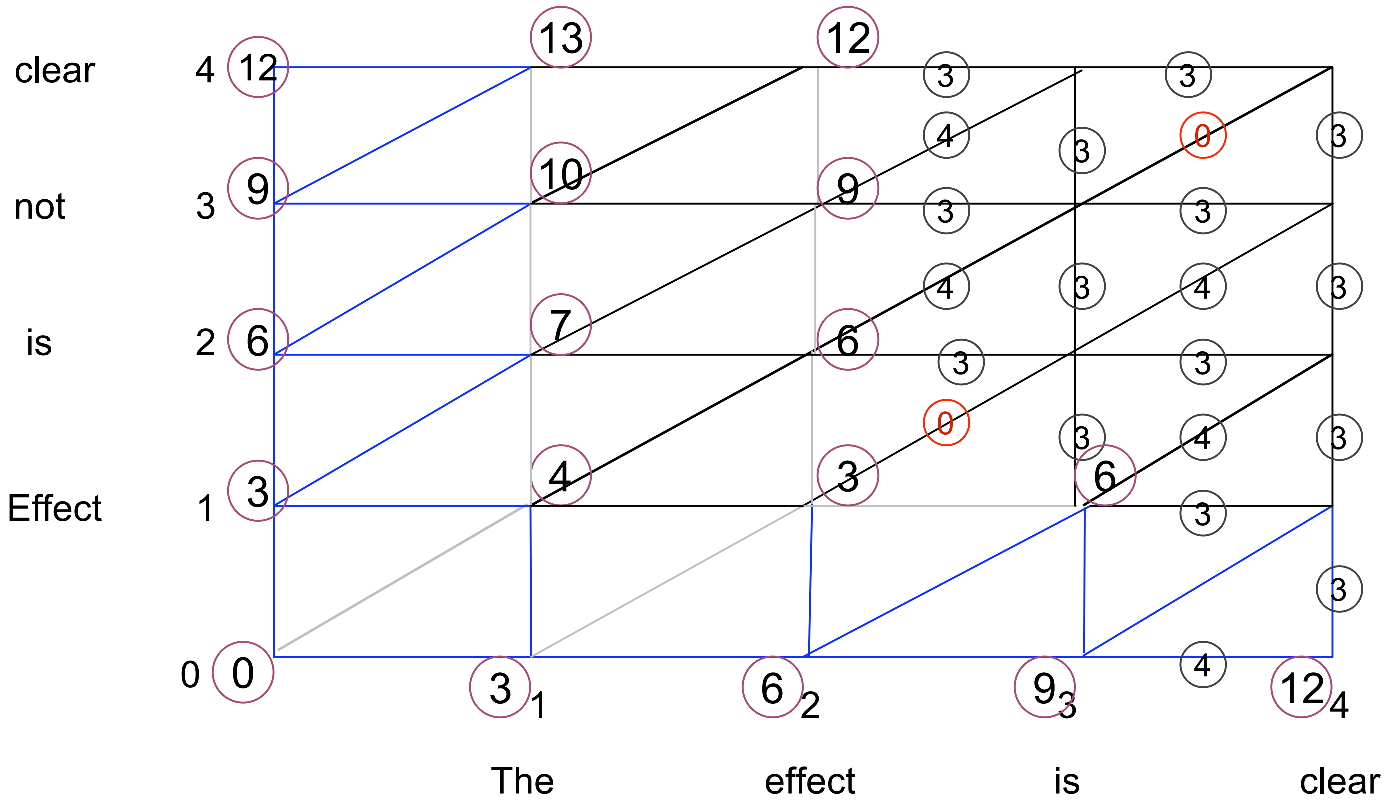
Dynamic programming example



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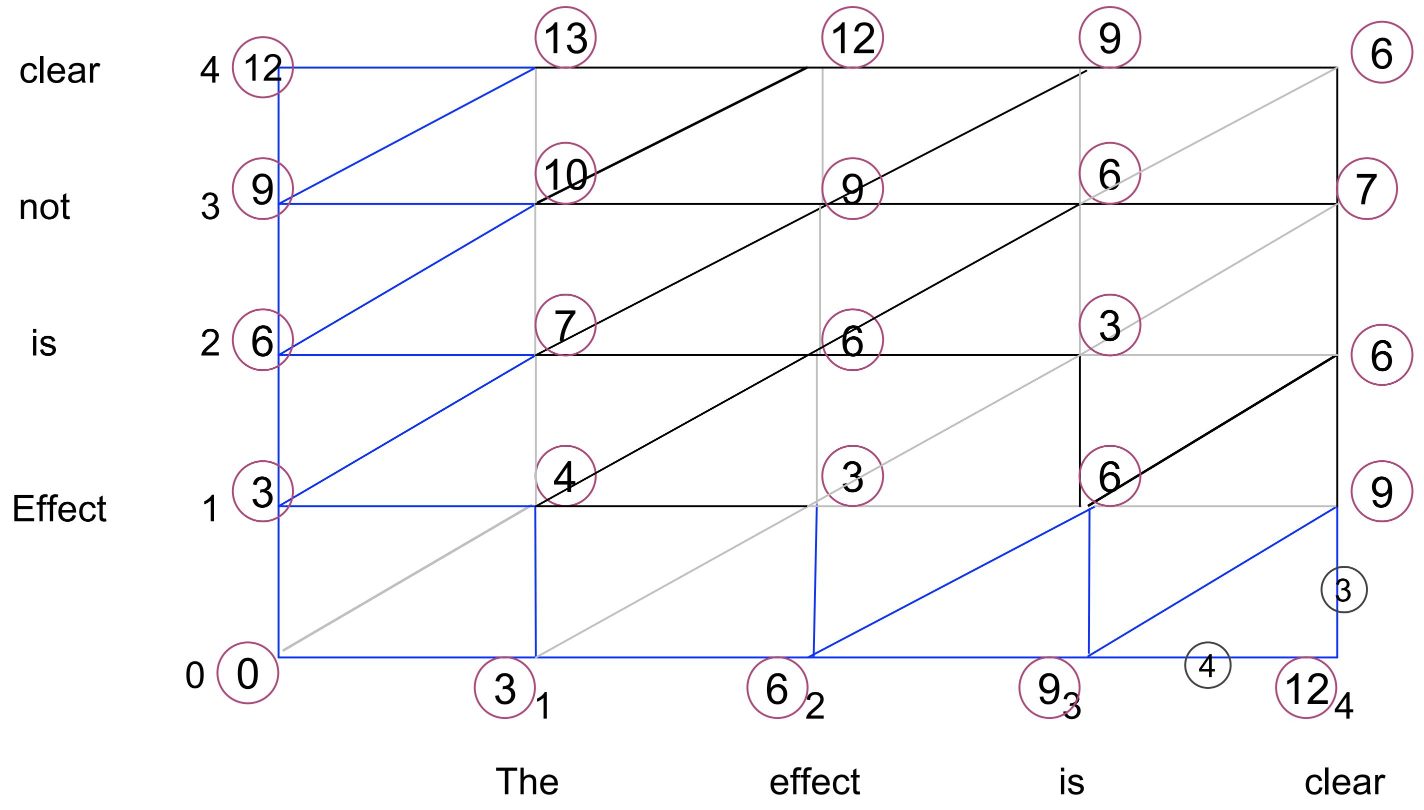

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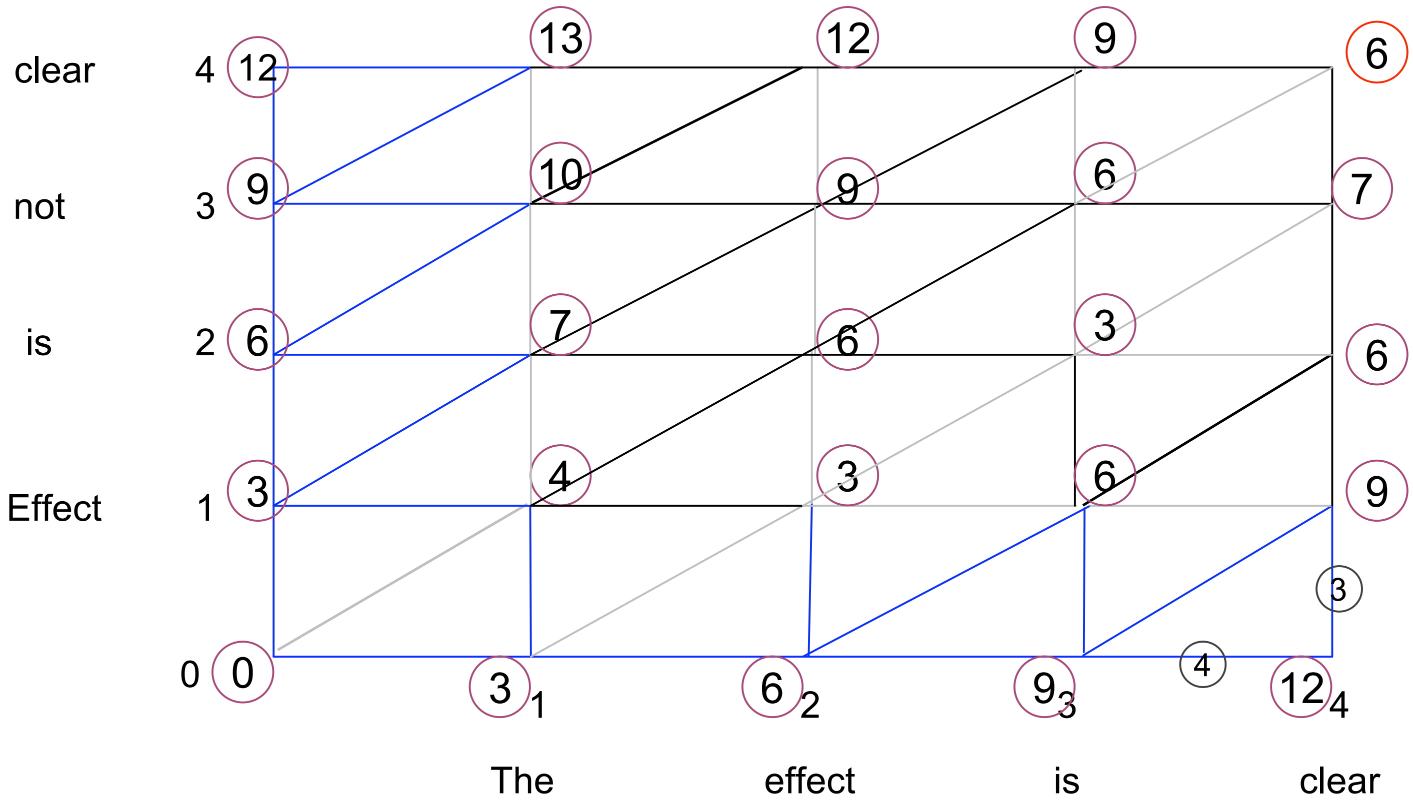

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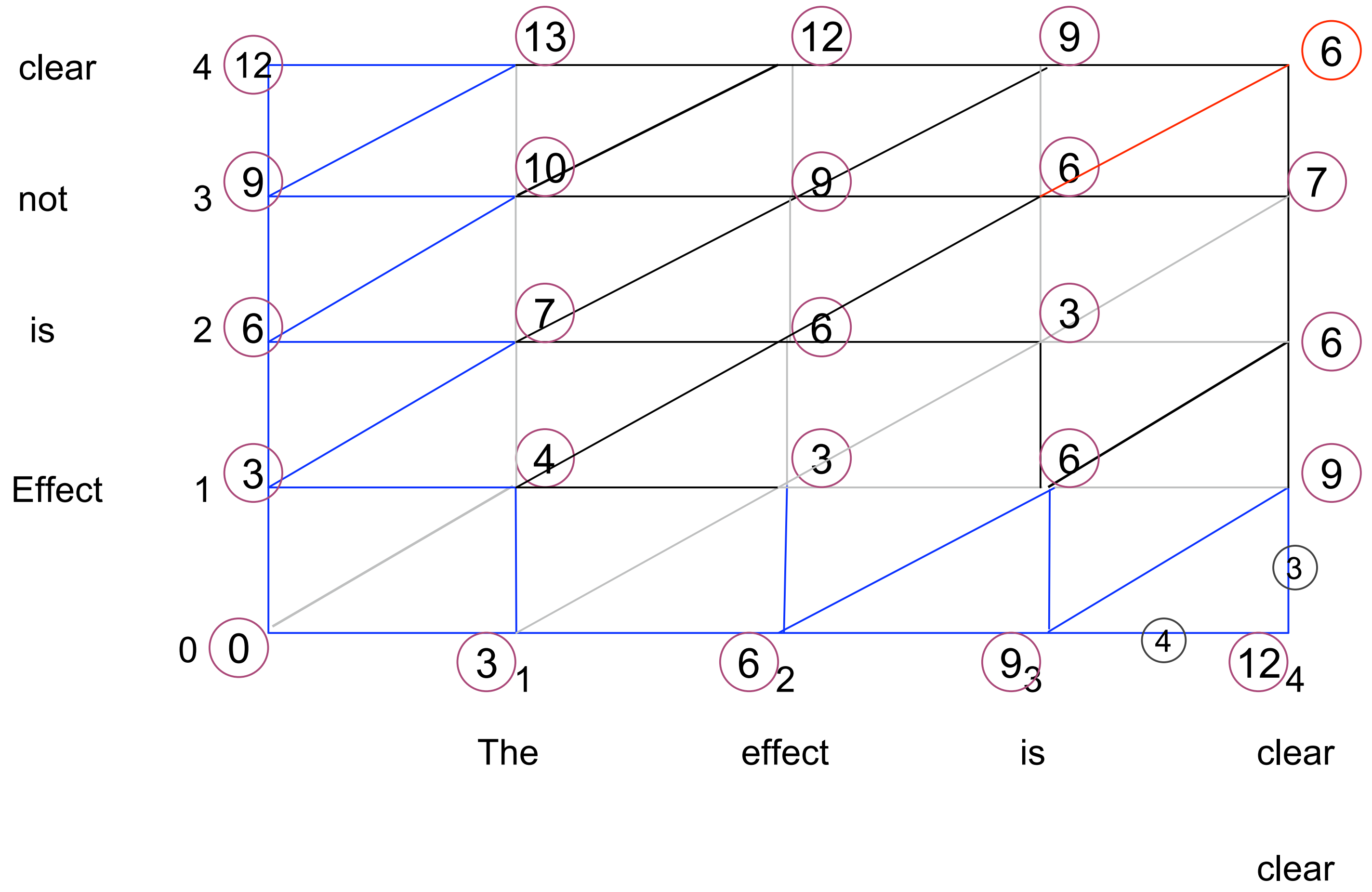

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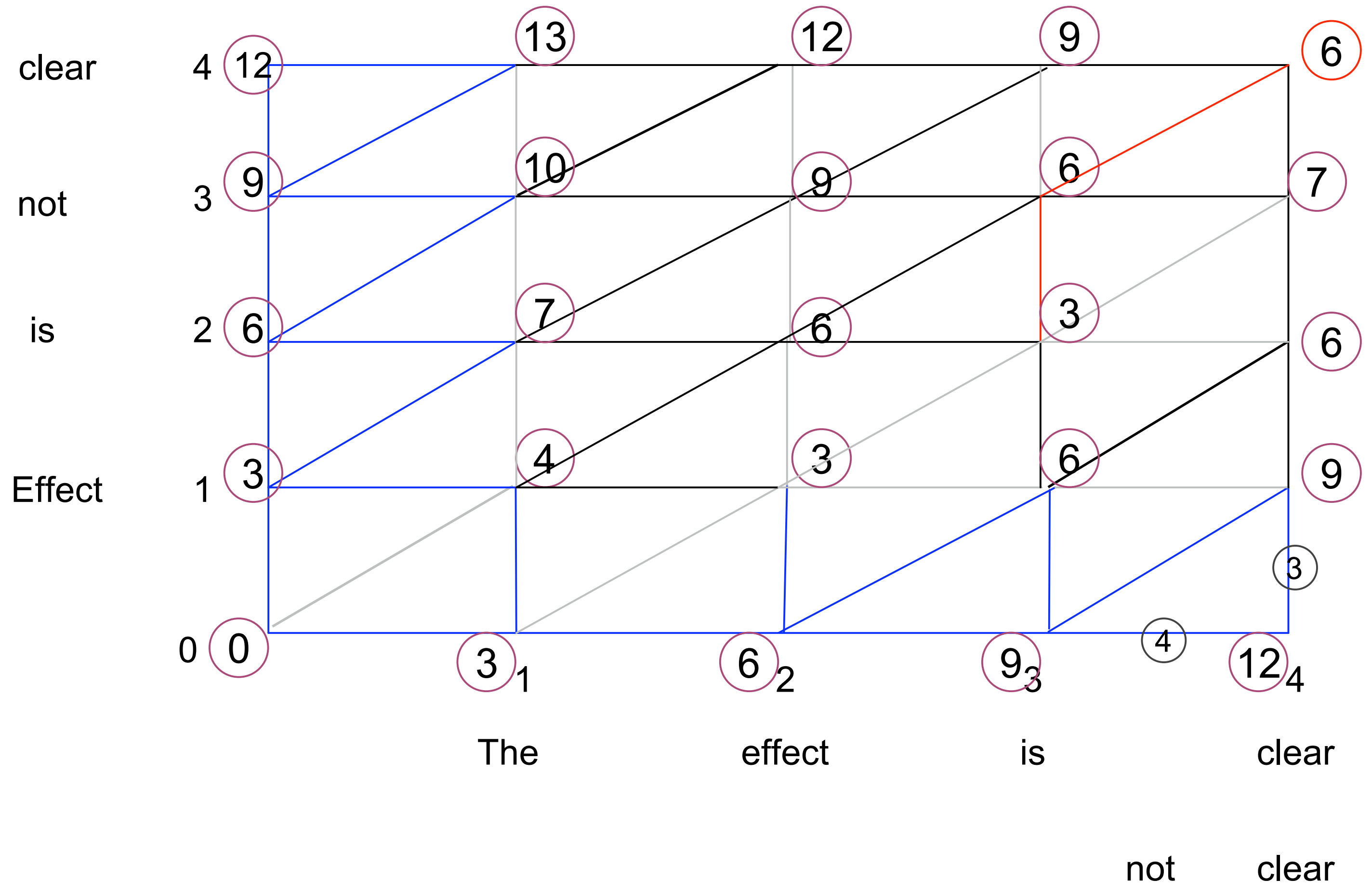

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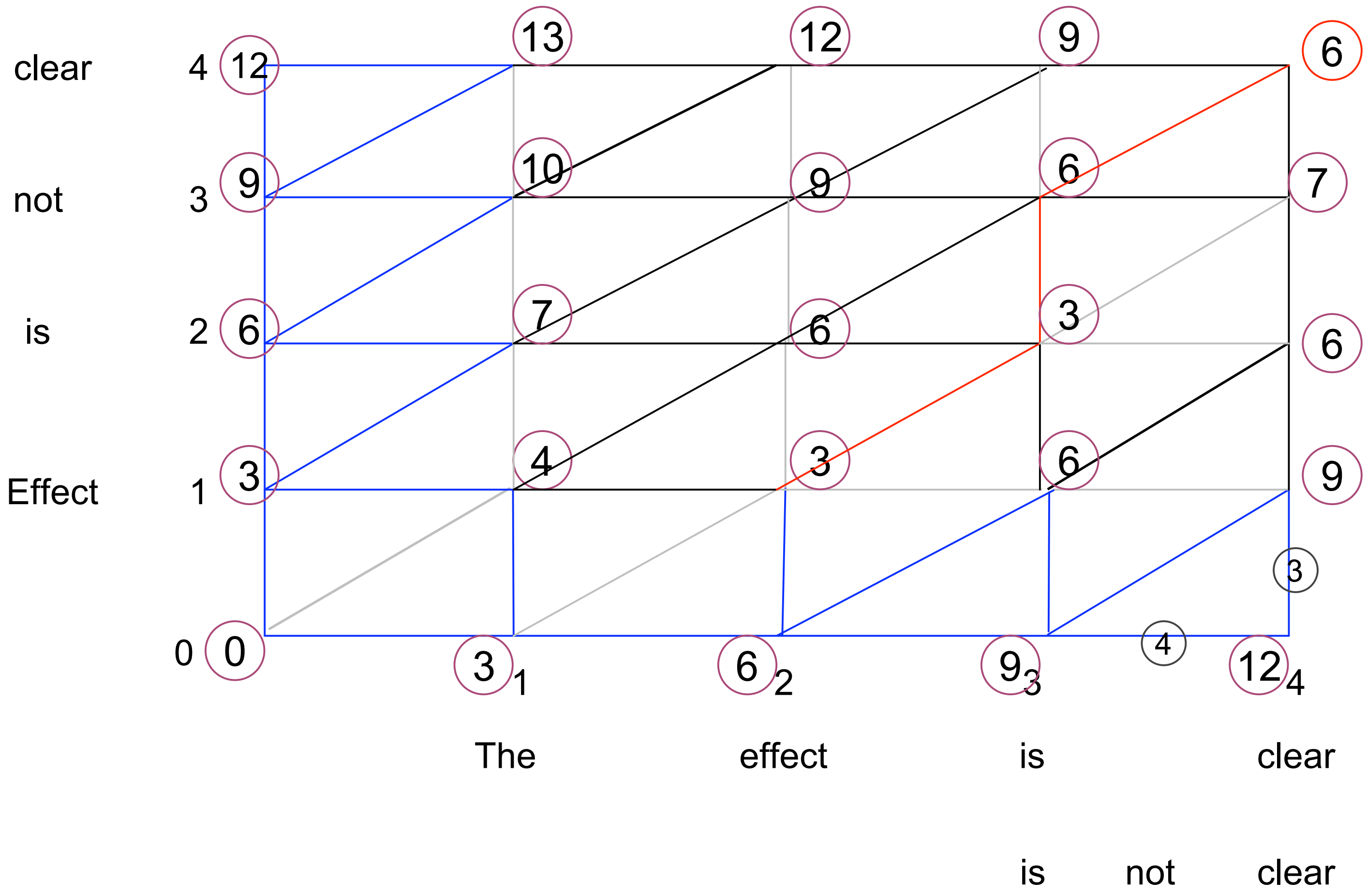

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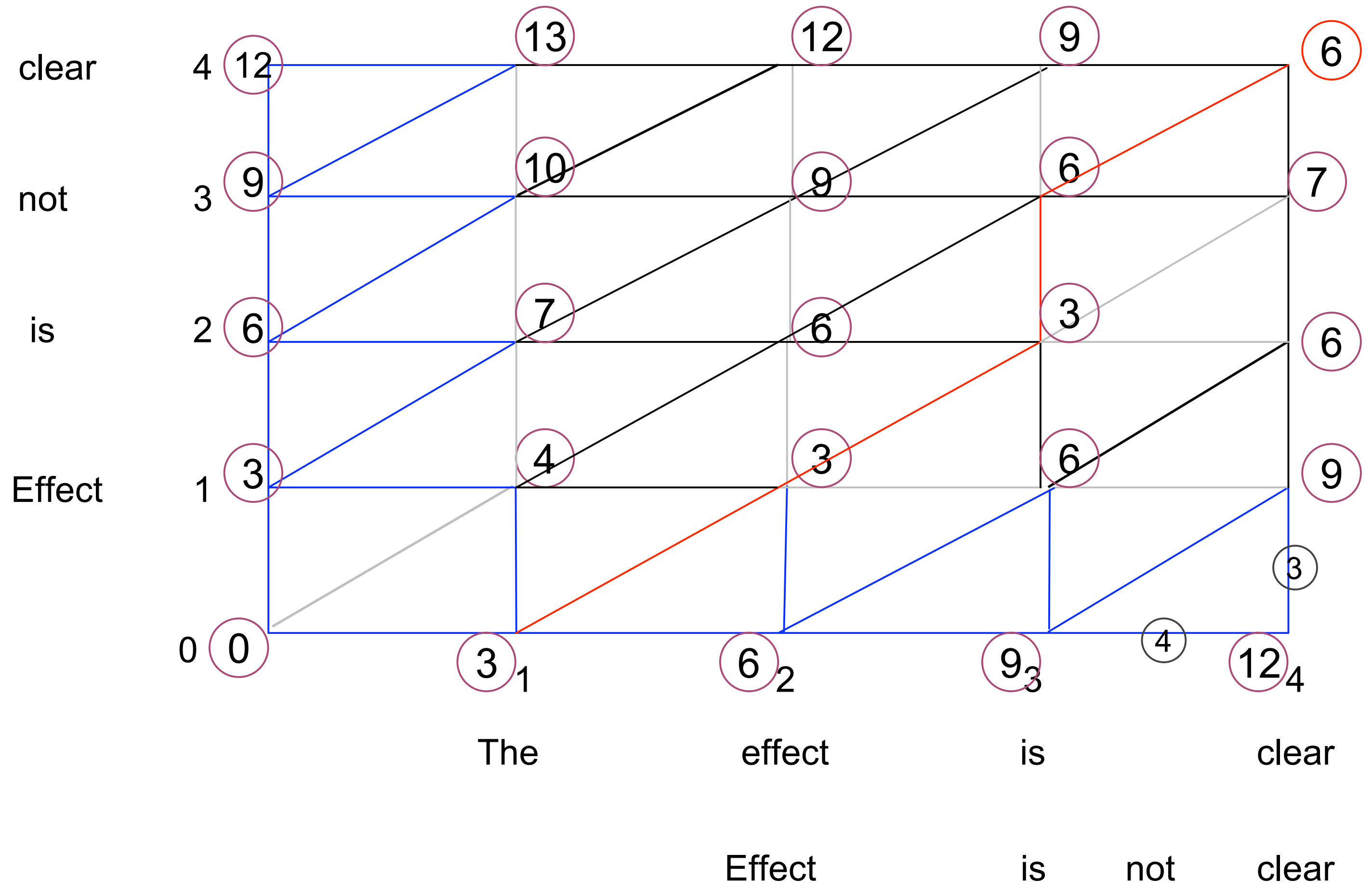

Dynamic programming example