Naive Substring Search
(Algorithms and Data Structures)

Naive Substring Search

- we would like to construct an algorithm thats capable of finding a **P** pattern in a given **S** string or text
- **brute-force search** is the naive approach
- keep iterating through the text and if there is a mismatch we shift the pattern one step to the right

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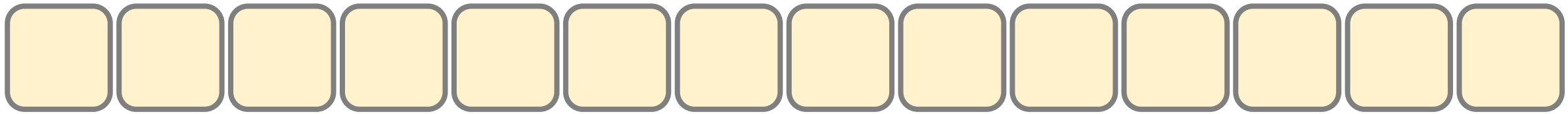
Naive Substring Search

- not so efficient especially when there are lots of matching prefixes
- main problem is that we need backup for every mismatch
- if there is a mismatch we jump back to the next character
- there are lot of comparisons – **O(NM)** where **N** is the length of text and **M** is the length of the pattern
- **linear running time** would be better

Naive Substring Search



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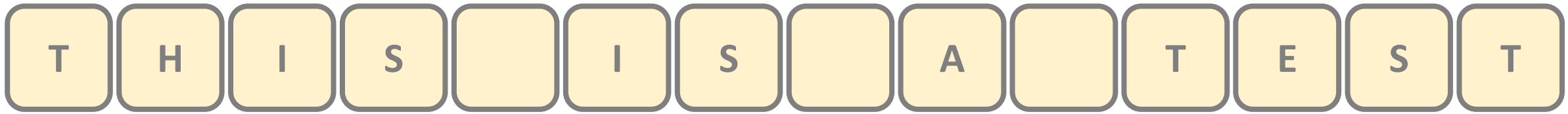

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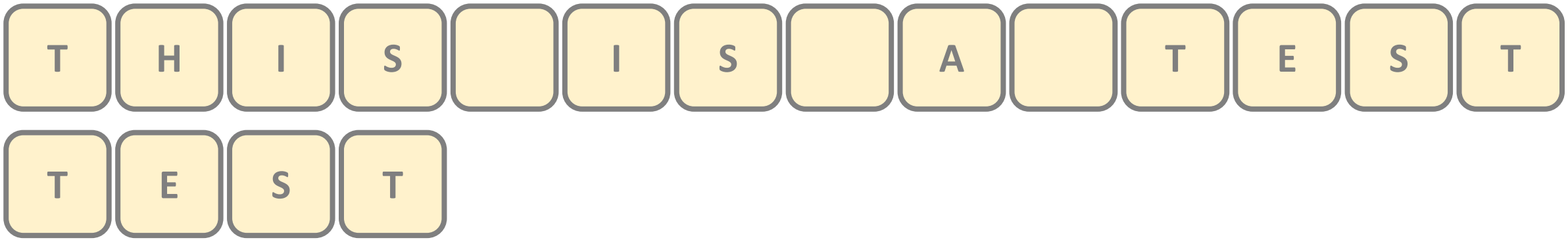

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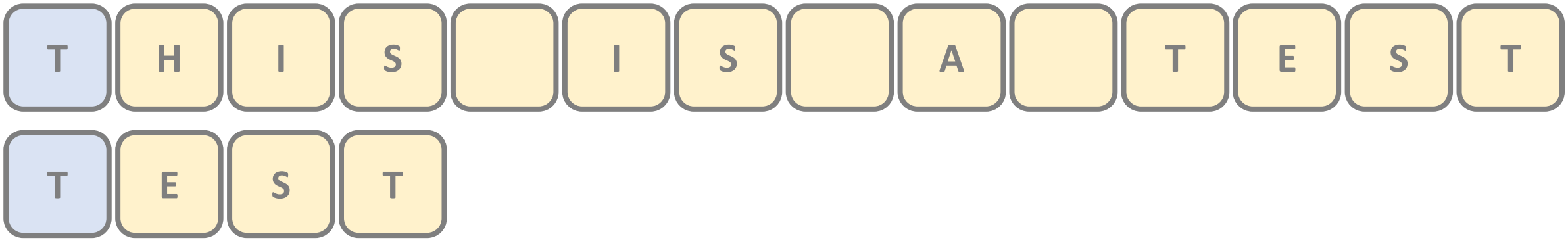

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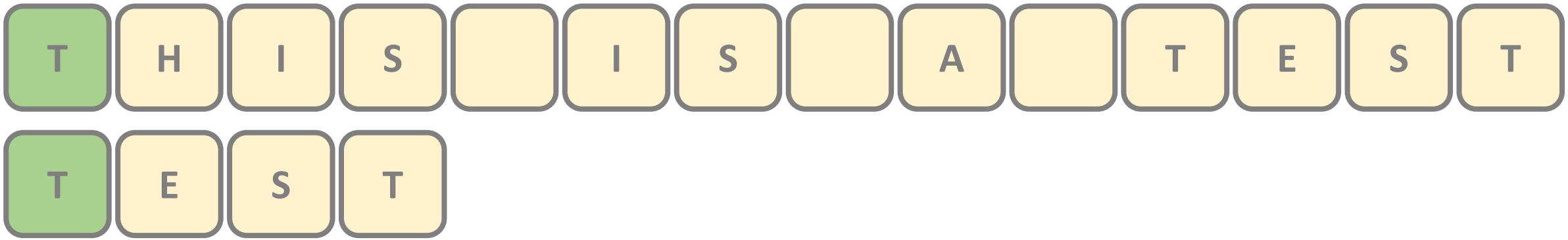

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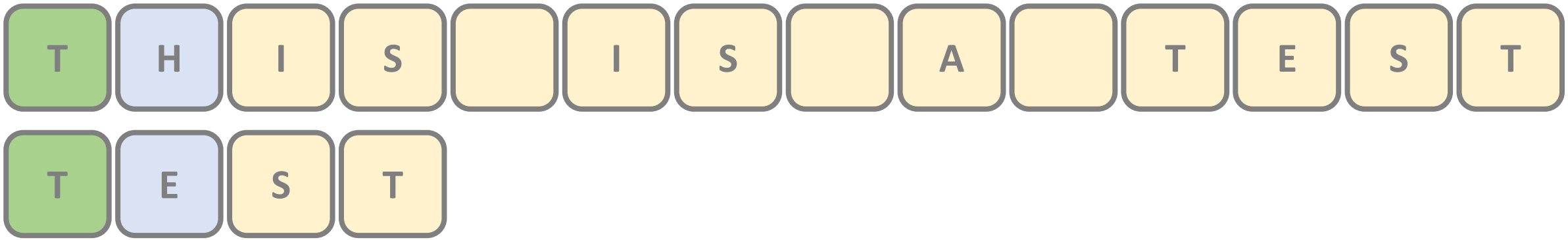

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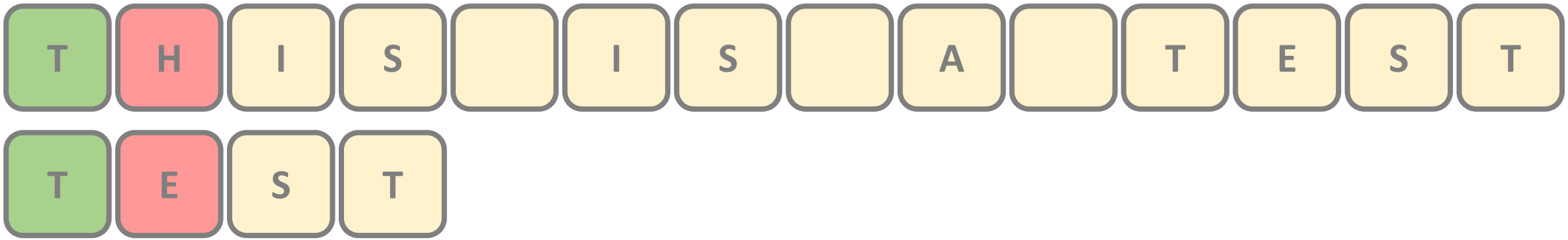

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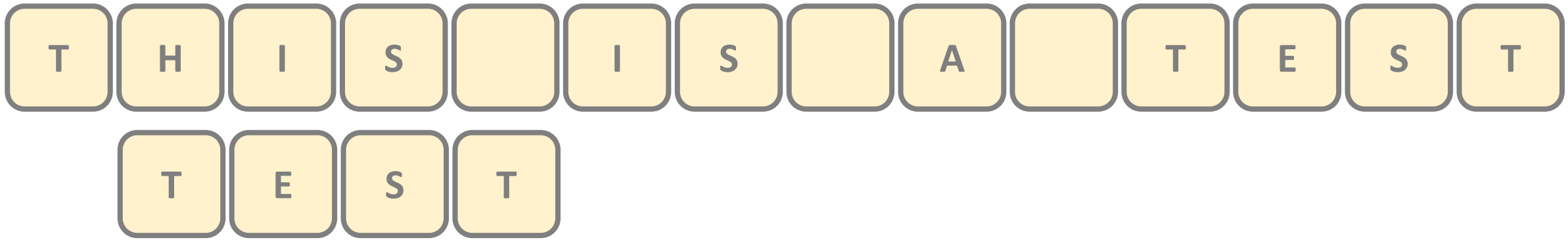

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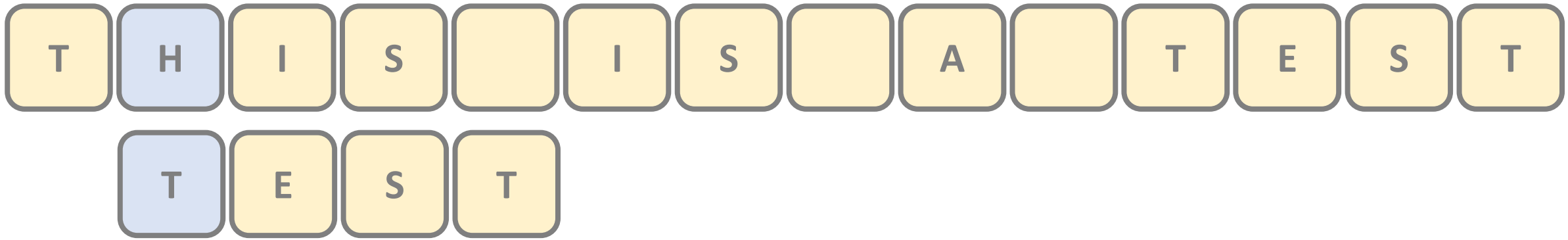

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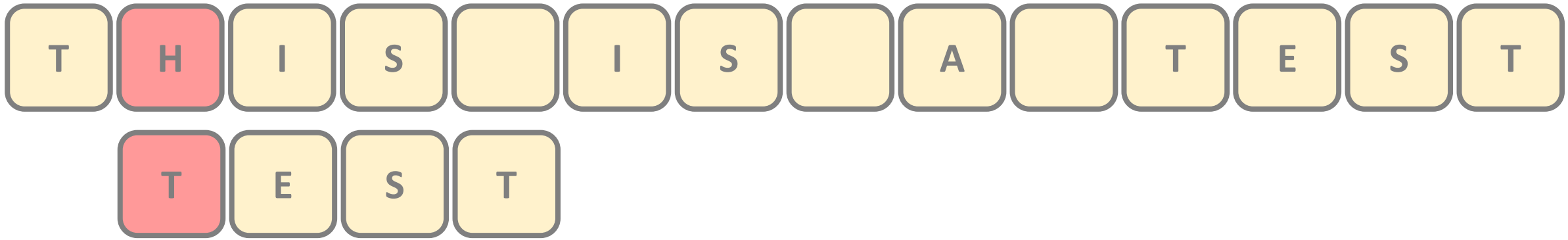

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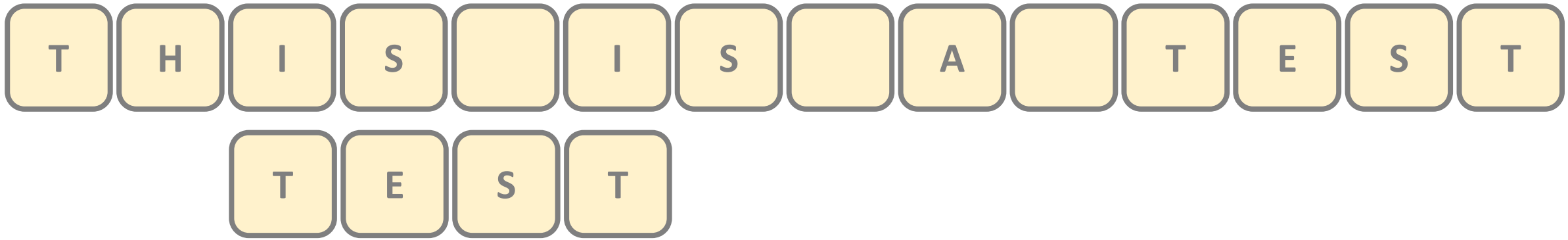

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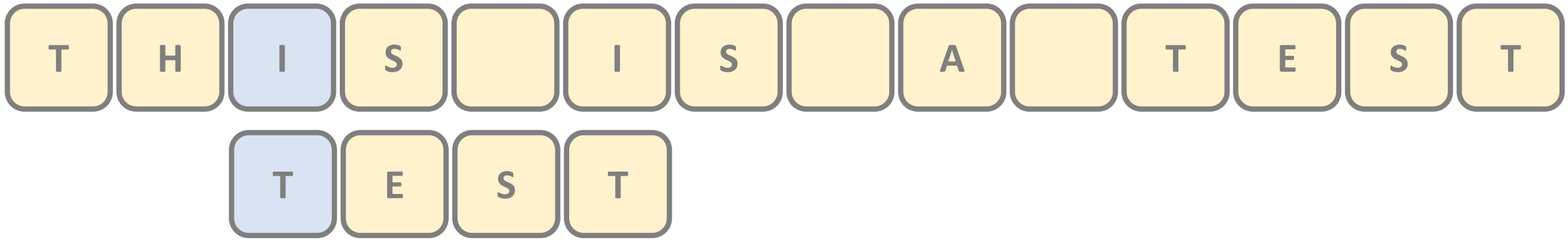

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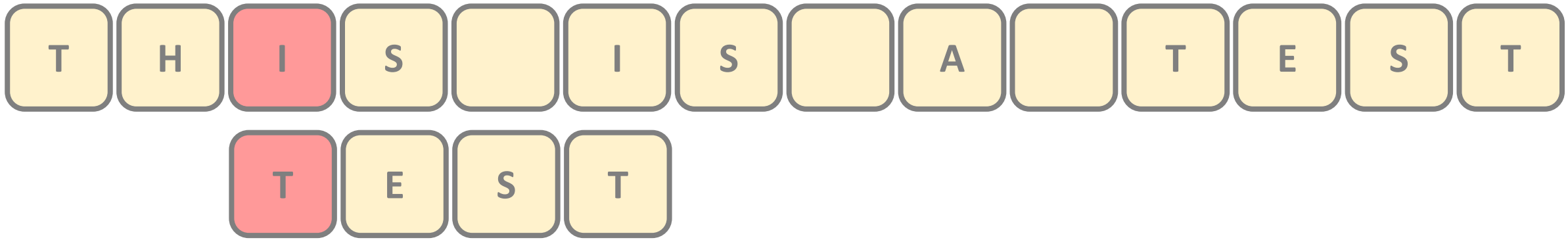

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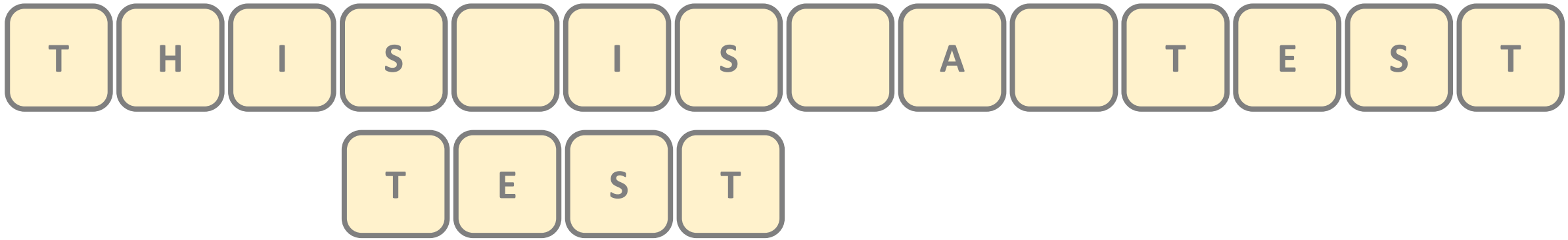

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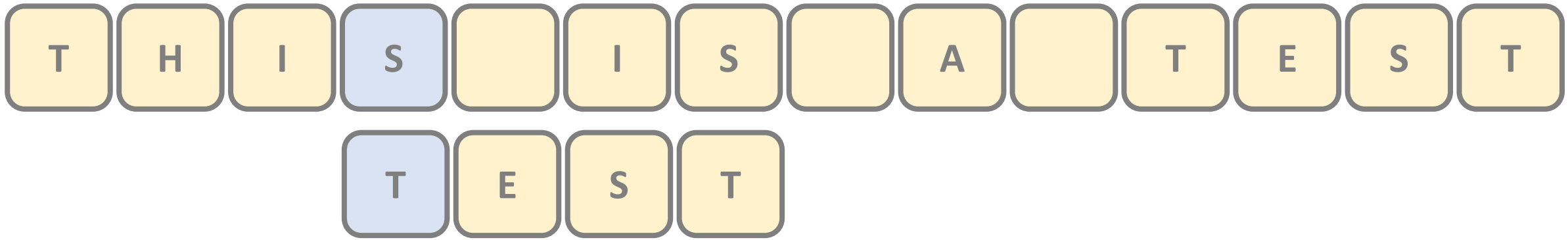

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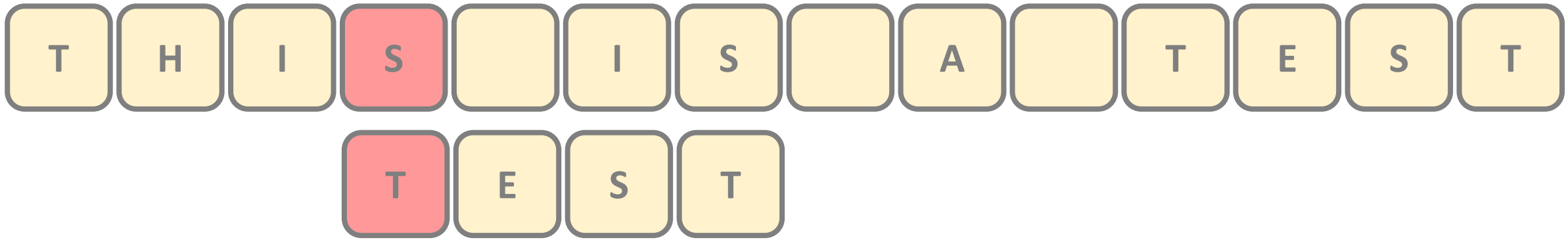

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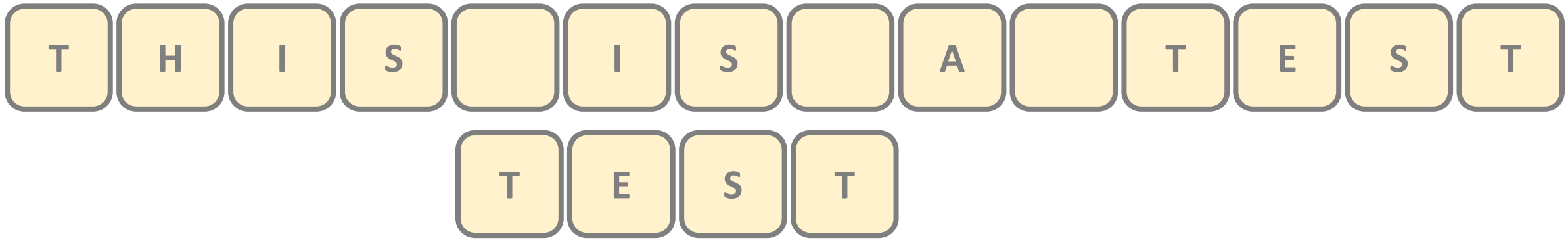

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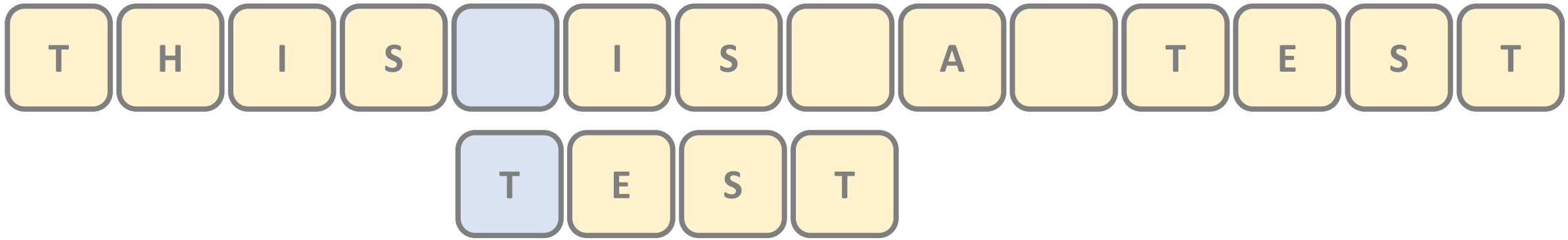

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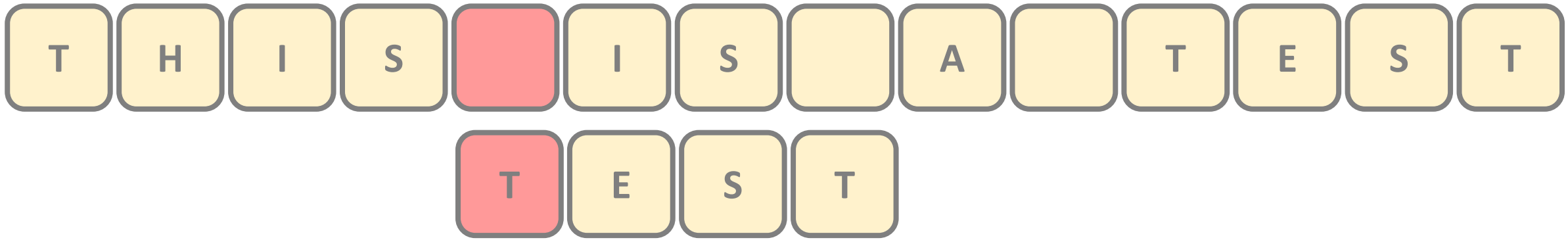

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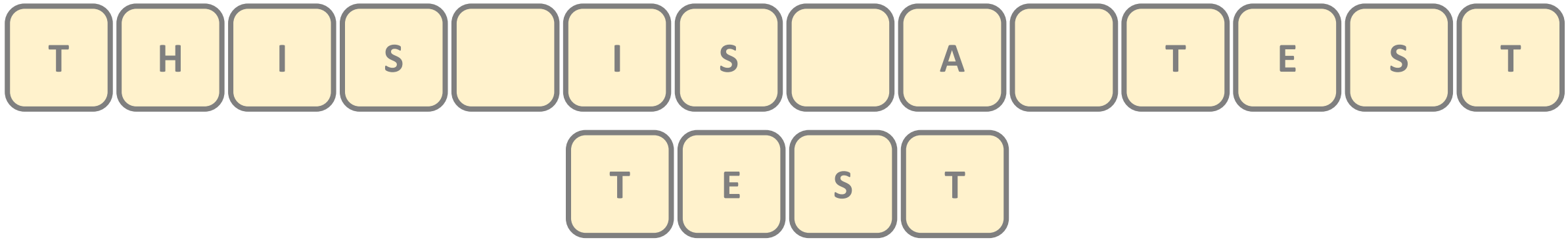

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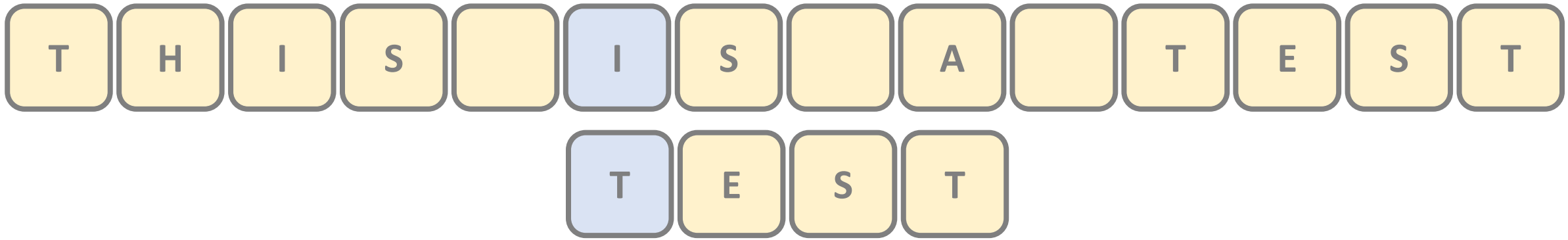

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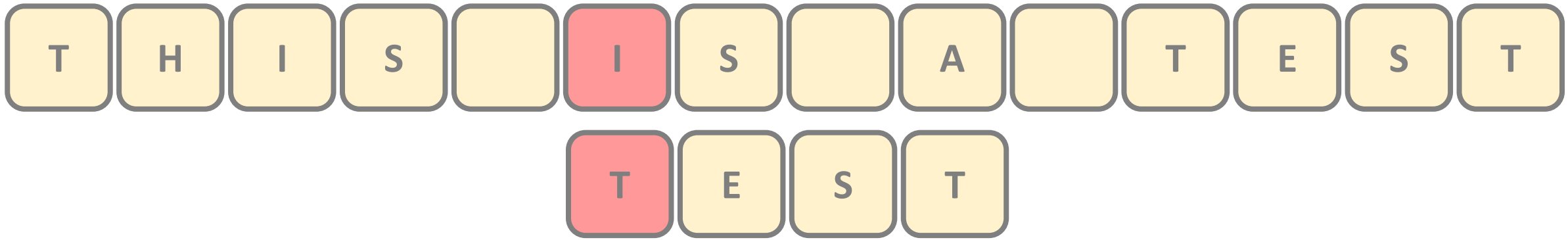

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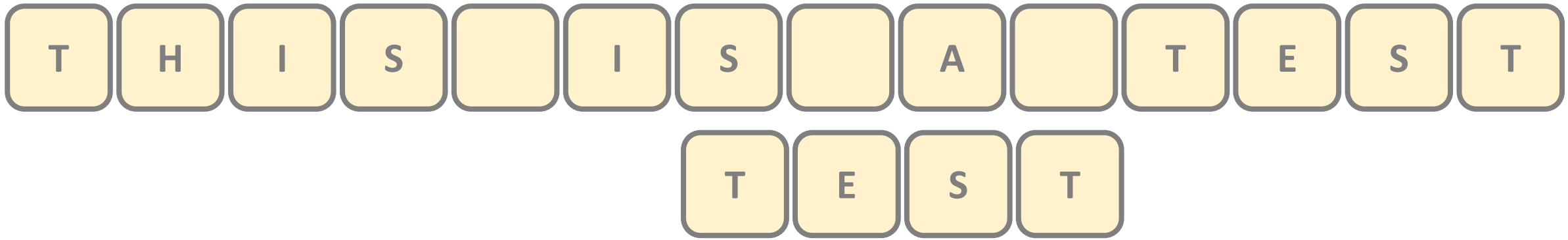

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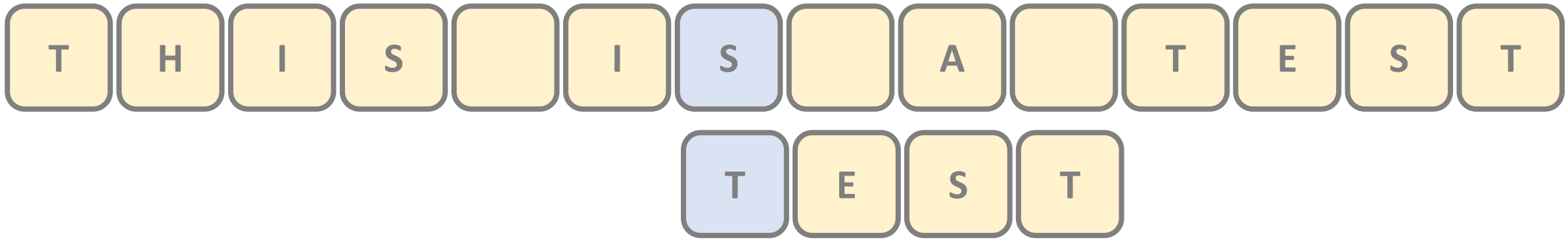

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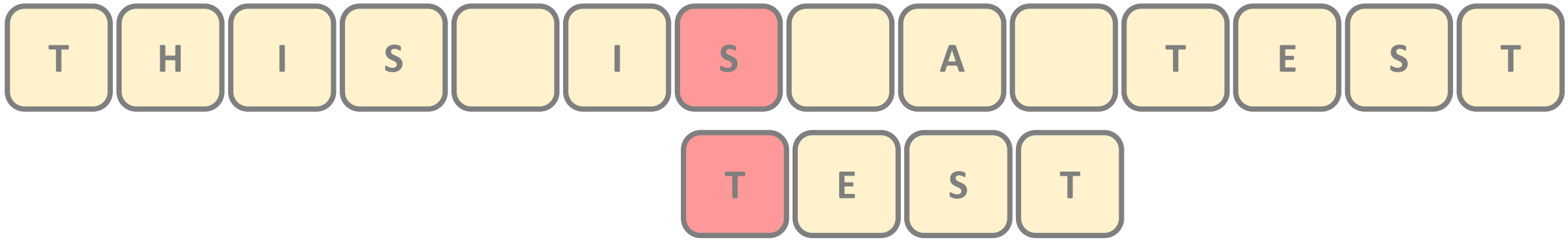

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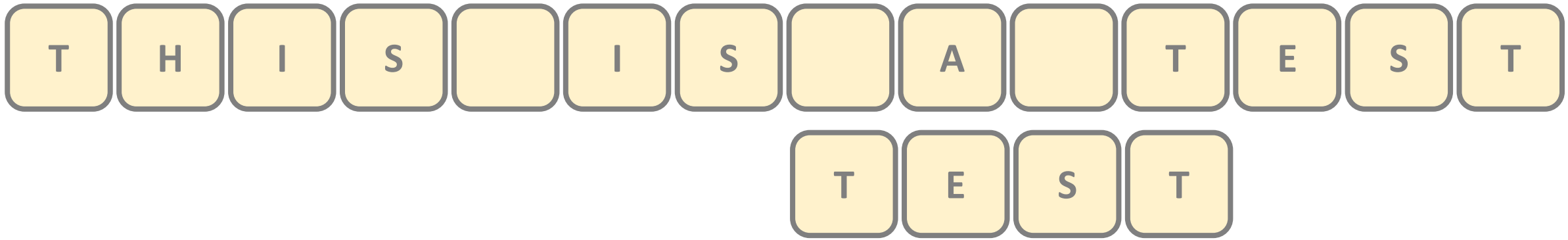

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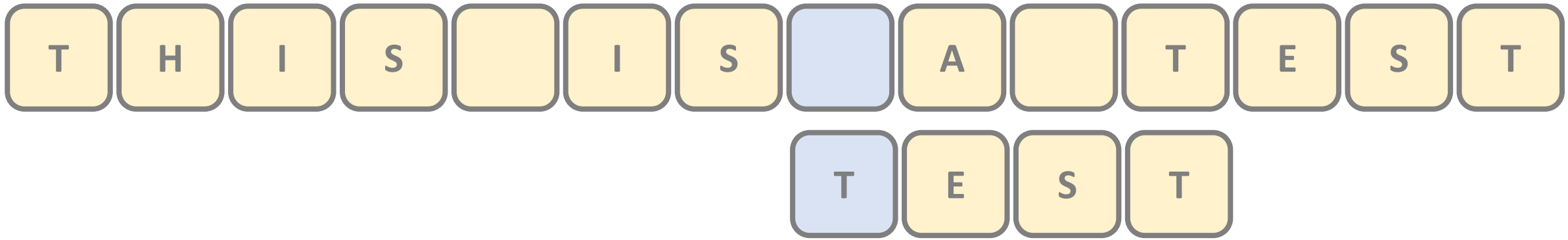

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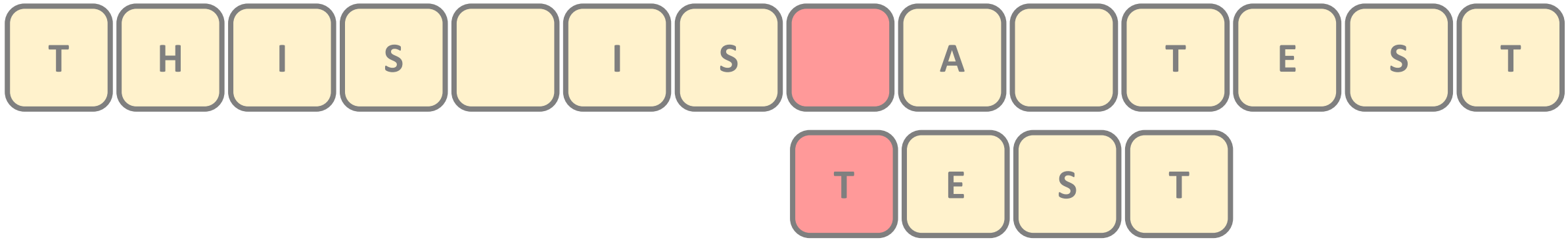

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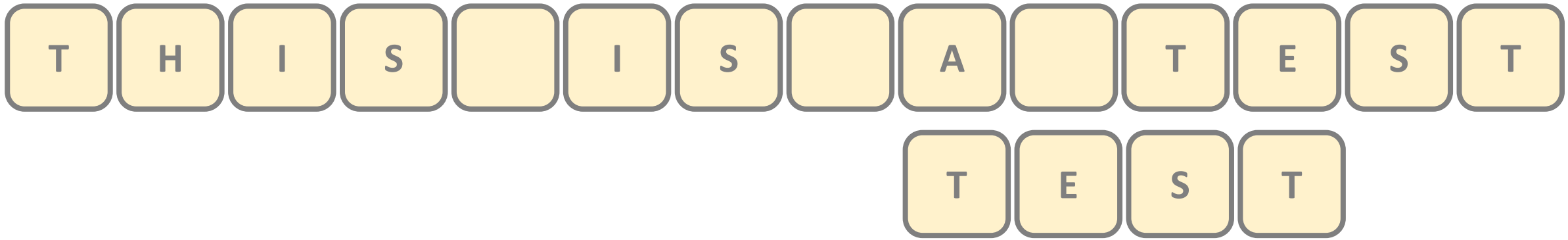

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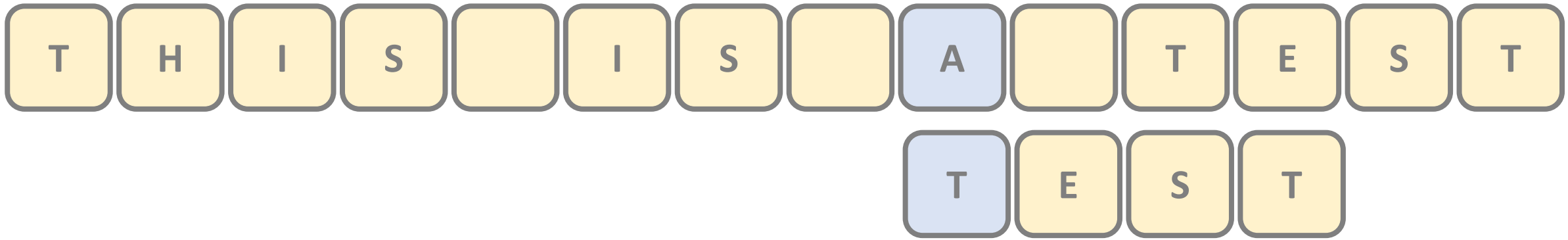

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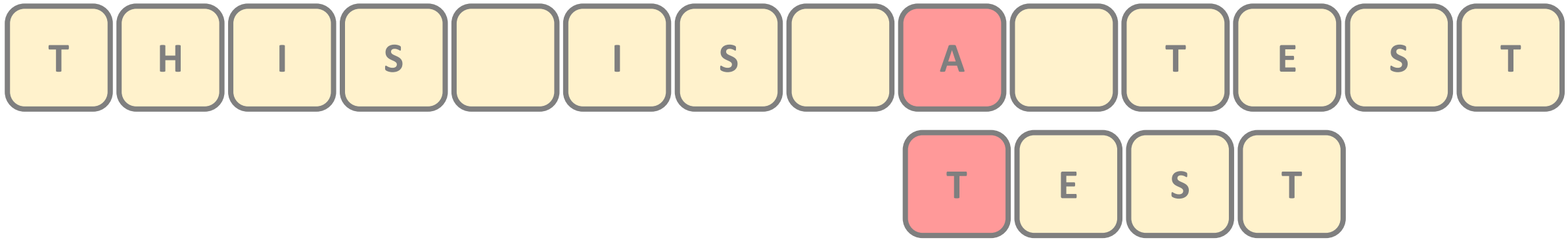

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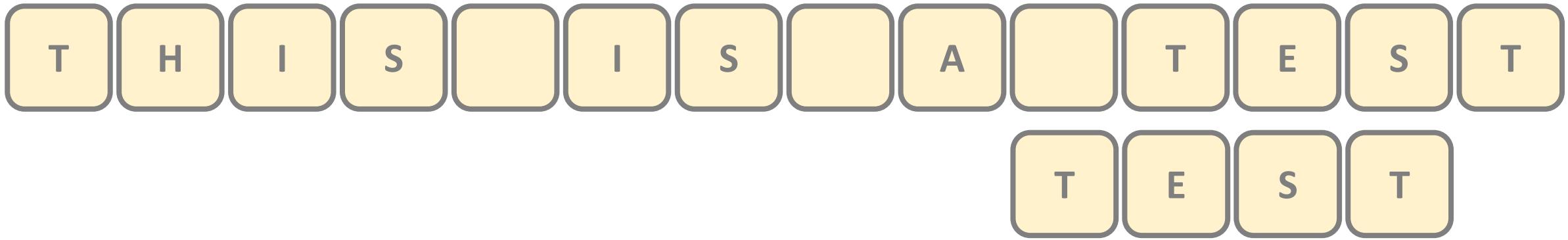

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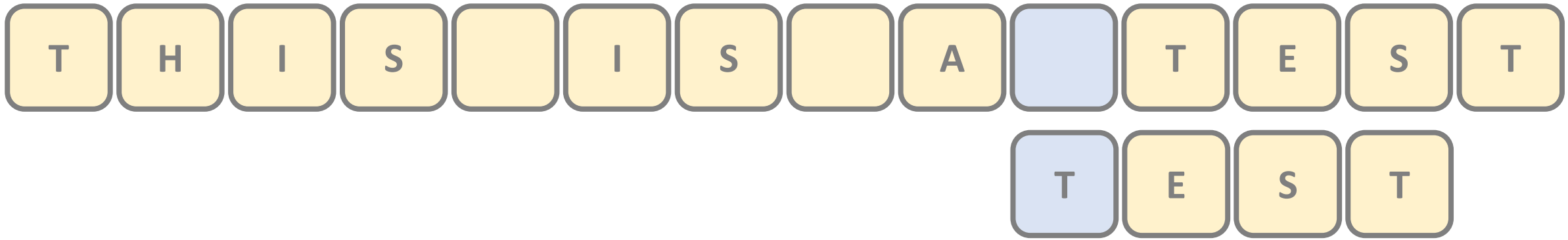

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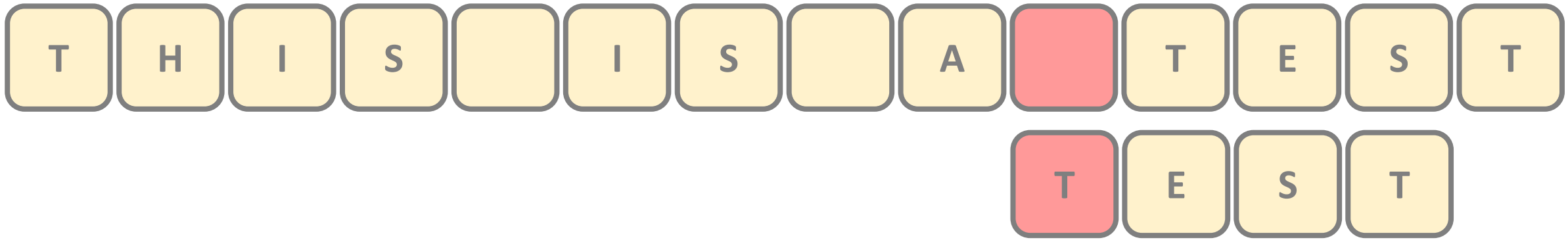

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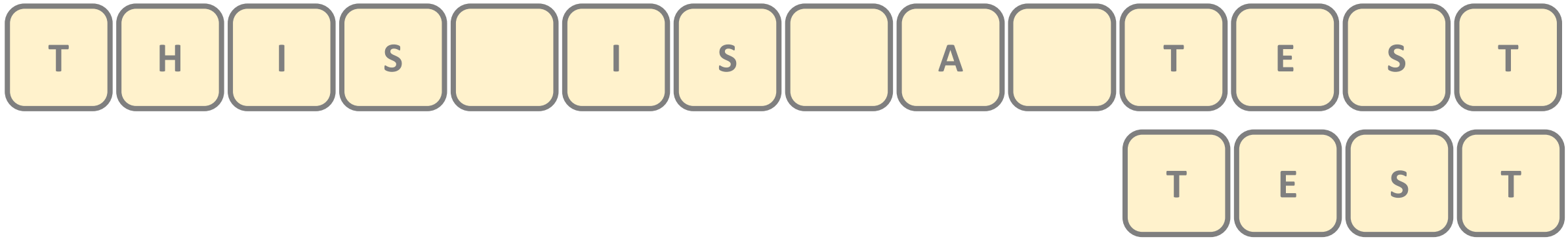

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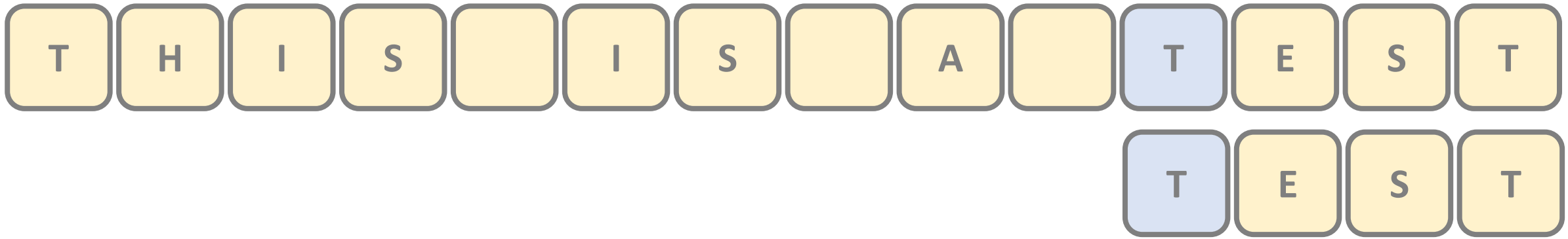

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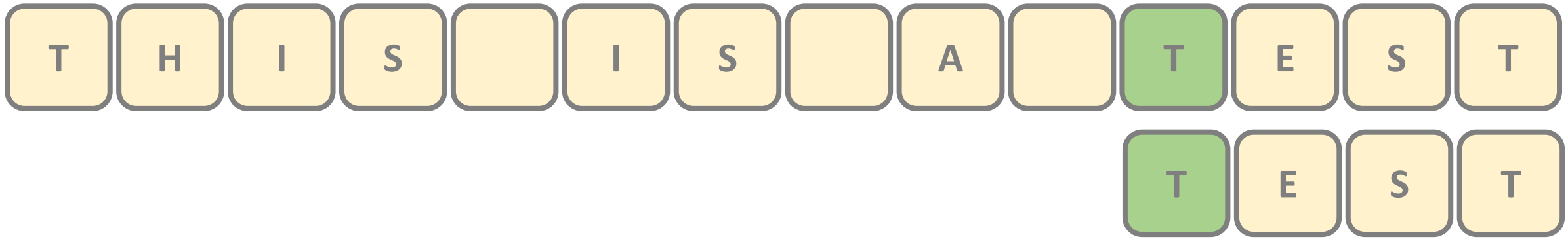

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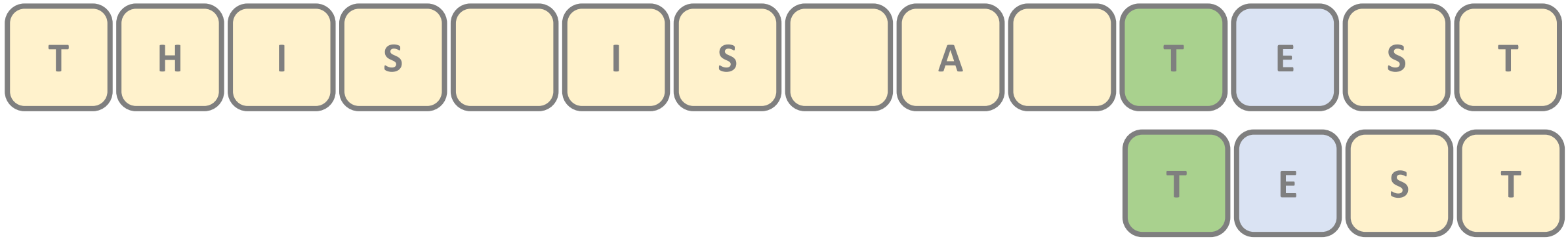

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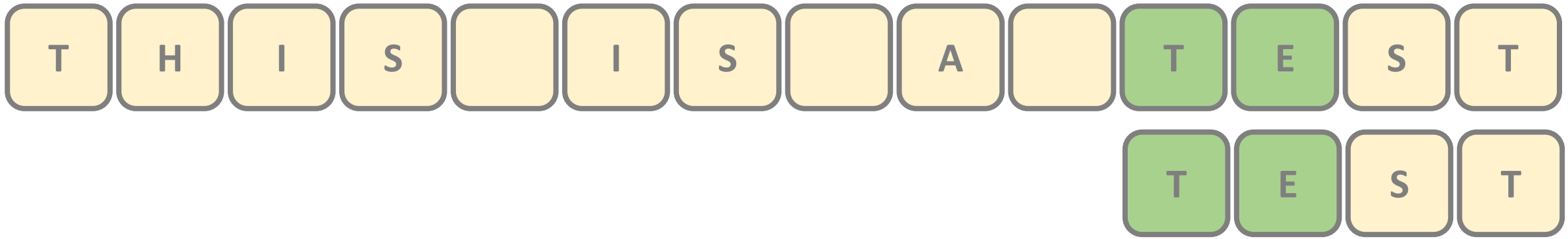

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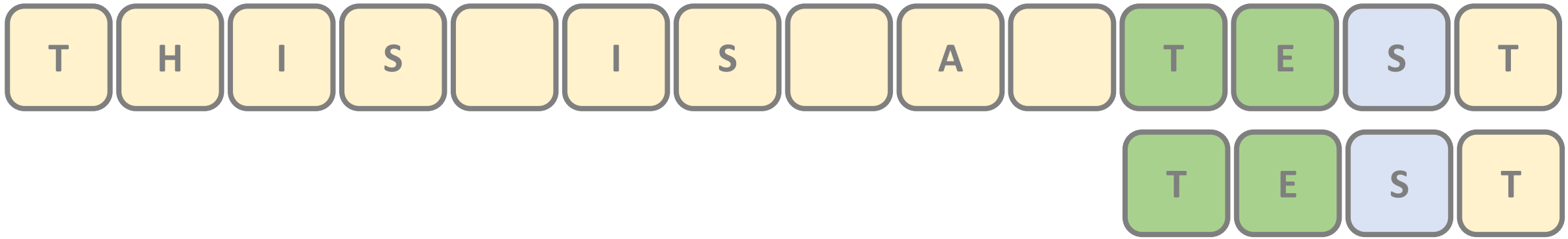

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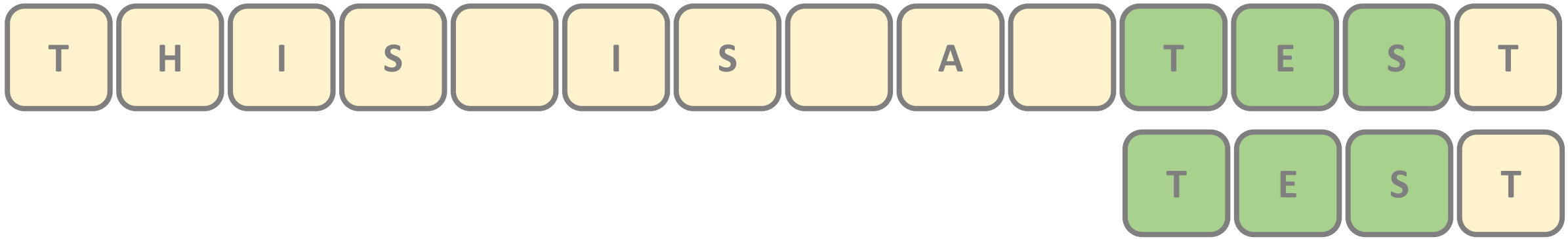

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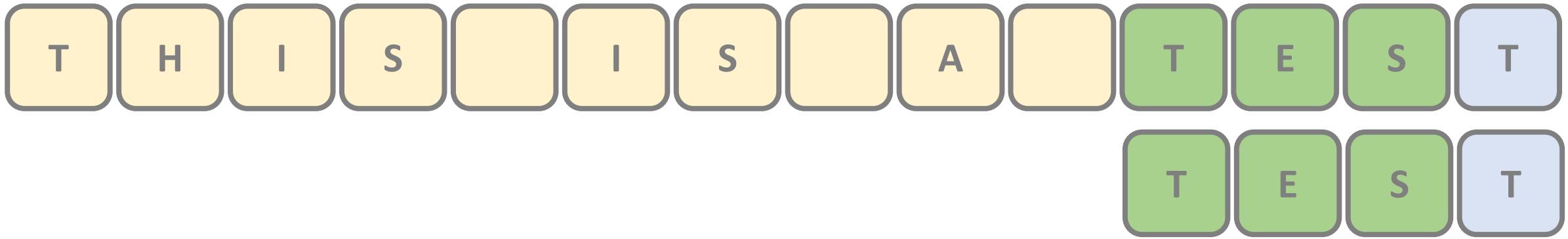

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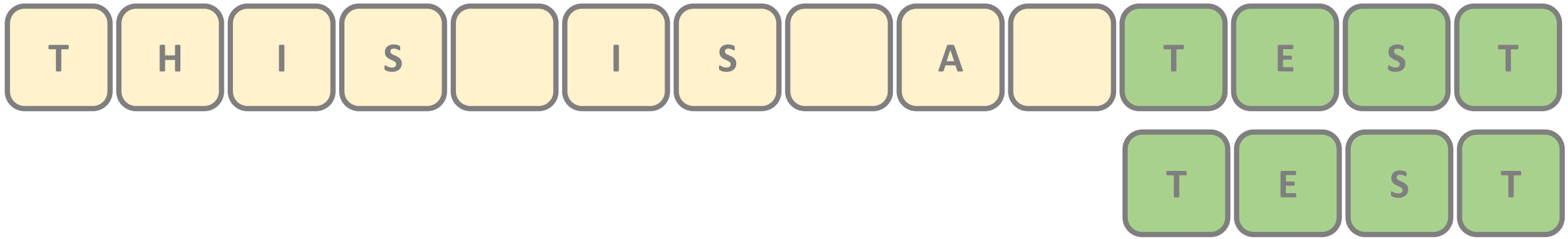

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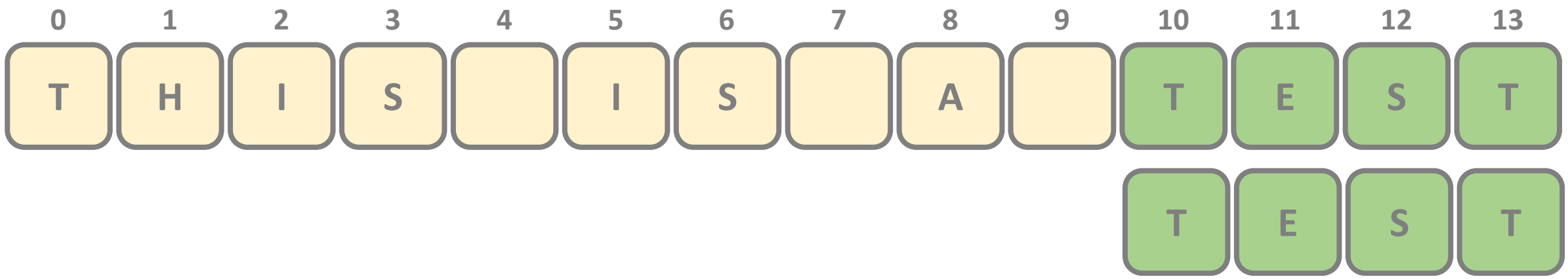

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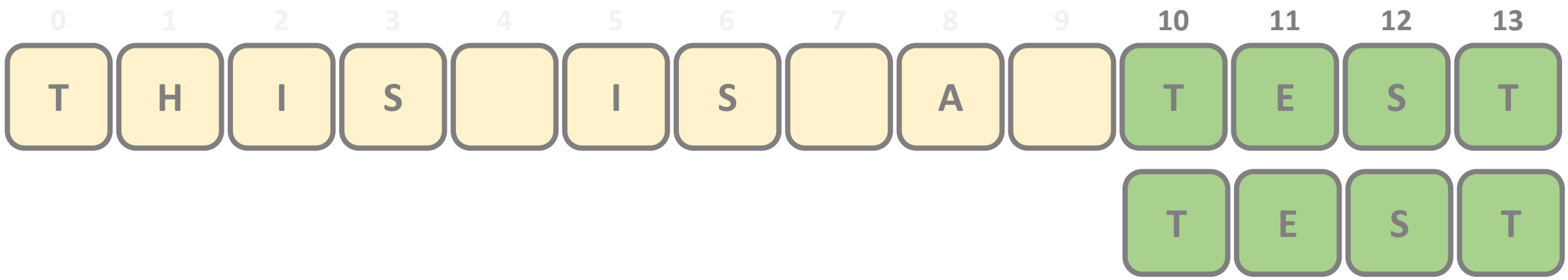

Naive Substring Search - Problem

*the **worst-case scenario***
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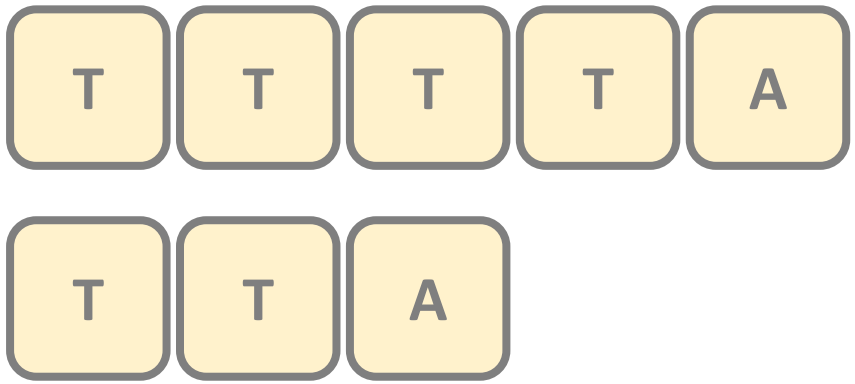
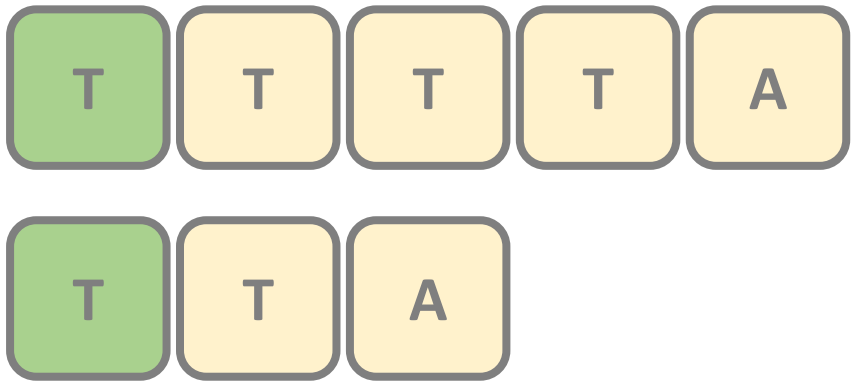


Naive Substring Search - Problem

*the **worst-case scenario** occurs when there are several matching **prefixes***



Naive Substring Search - Problem

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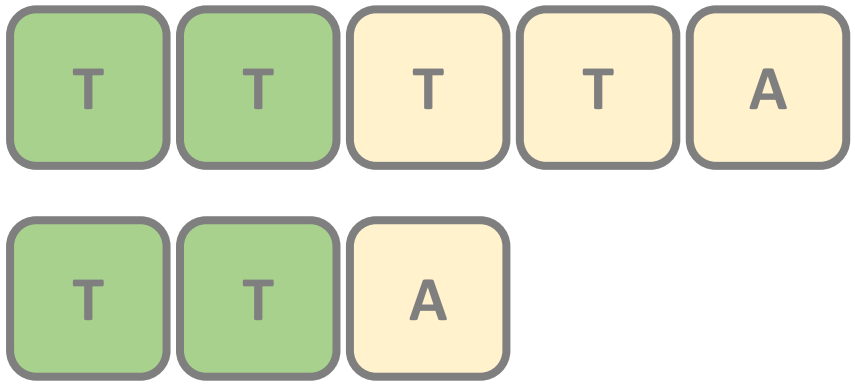

Naive Substring Search - Problem

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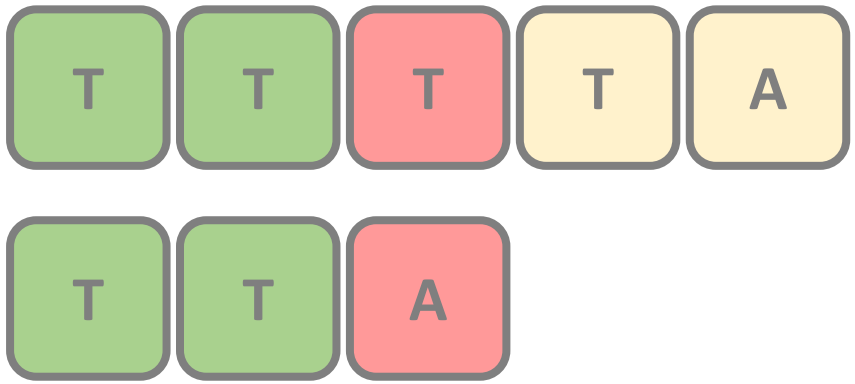

Naive Substring Search - Problem

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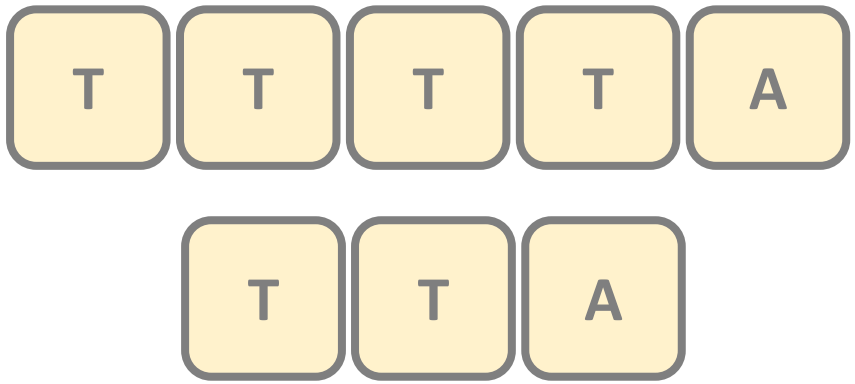

Naive Substring Search - Problem

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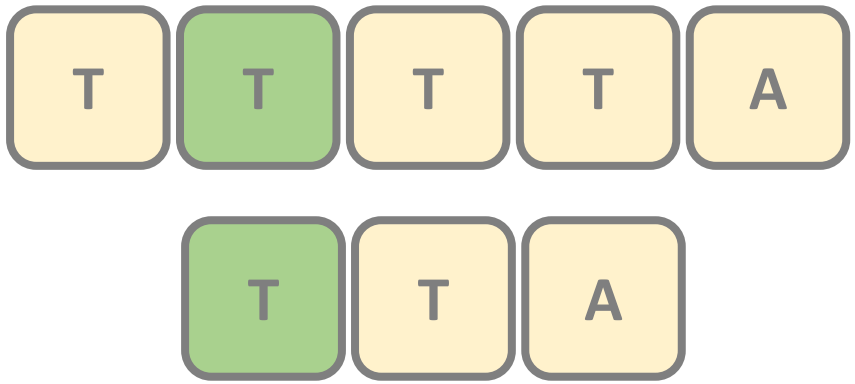

Naive Substring Search - Problem

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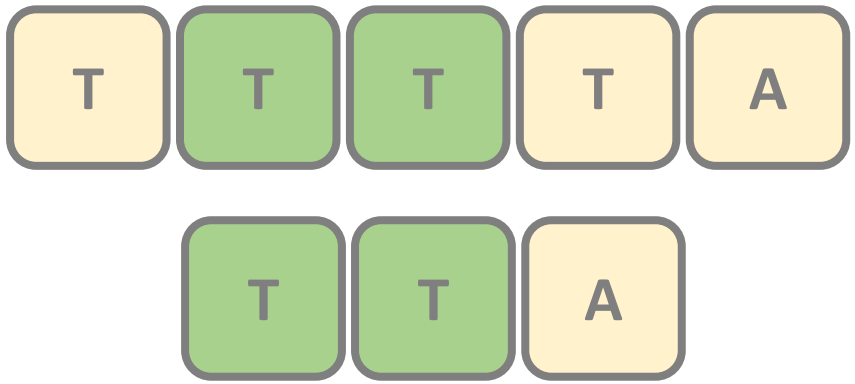
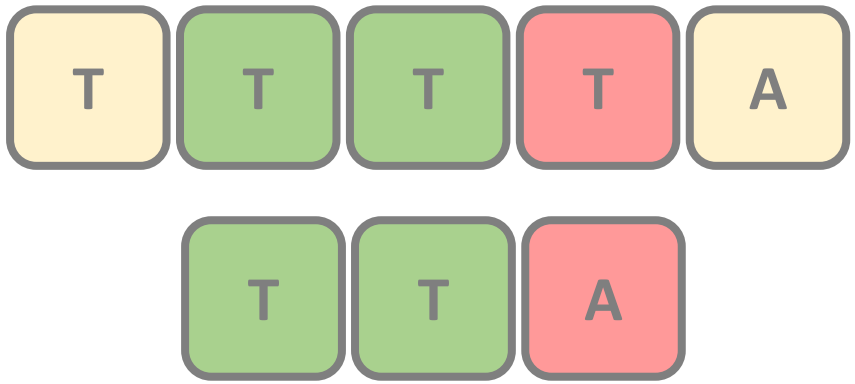


Naive Substring Search - Problem



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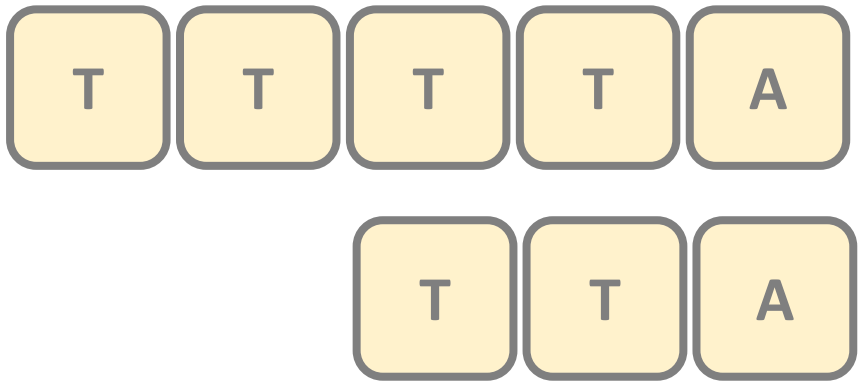
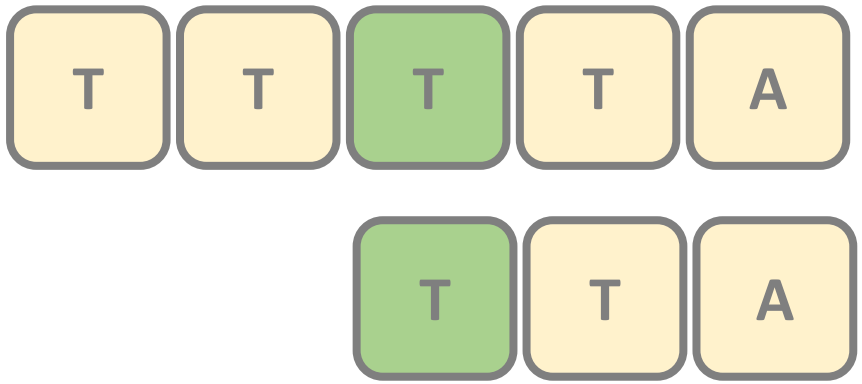
Naive Substring Search - Problem

*the **worst-case scenario** occurs when there are several matching **prefixes***



Naive Substring Search - Problem

*the **worst-case scenario** occurs when there are several matching **prefixes***



Naive Substring Search - Problem

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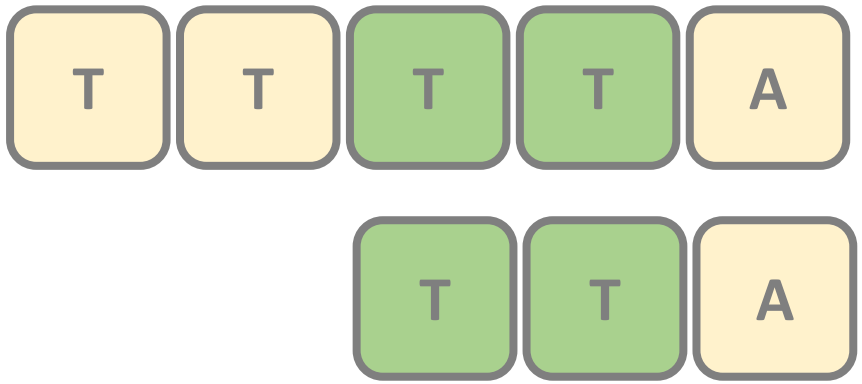
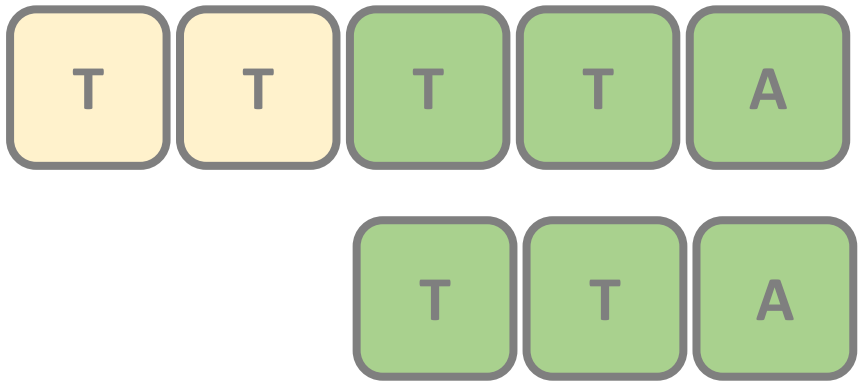


Naive Substring Search - Problem

*the **worst-case scenario** occurs when there are several matching **prefixes***



Boyer-Moore Substring Search
(Algorithms and Data Structures)

Boyer-Moore Substring Search

- we have considered brute-force substring search algorithm
- the problem that is have to make **too many comparisons** when there are matching prefixes
- **IS IT POSSIBLE TO SHIFT THE PATTERN MULTIPLE STEPS?**

Boyer-Moore Substring Search

This is exactly the logic behind **Boyer-Moore algorithm**

1.) REVERSE COMPARISON OF CHARACTERS

- we start comparing the letters starting with the last ones

2.) BAD CHARACTER HEURISTIC

- we can skip multiple characters of the original text by using the so-called **bad character heuristic**
- first we have to preprocess the pattern in **O(M)** where **M** is the length of the pattern

Boyer-Moore Substring Search

→ the original **Boyer-Moore** algorithm uses **2** heuristics

(**bad match table** and **suffix table**)

→ this is how we can gurantee that we always make the optimal number of shifts of the pattern

→ **Boyer-Moore-Horspool** algorithm uses the bad match table exclusively (it is working fine as well)

Bad Match Table

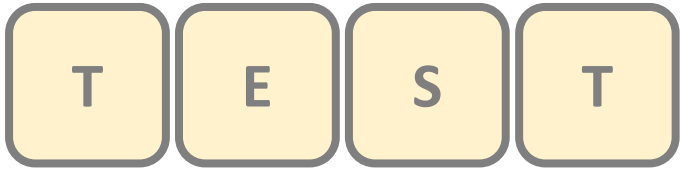
→ we construct a **table of the characters** out of the pattern

→ make sure the table does not contains repetitive characters

max(1 , pattern length – actual index – 1)

→ we iterate over the pattern (except for the last character) and compute the values to the bad match table and **keep updating the old values** for the same characters

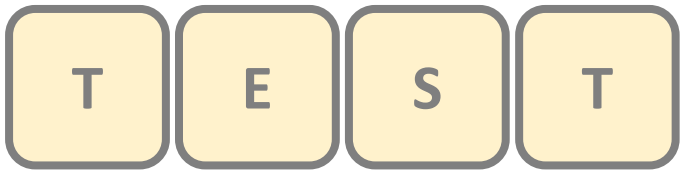
Bad Match Table



*first we have to **preprocess** the pattern in **O(M)** running time*

Bad Match Table

*first we have to **preprocess** the pattern in **O(M)** running time*

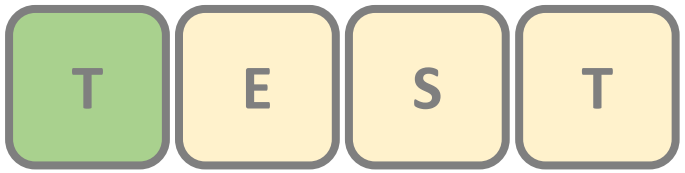


max(1 , pattern length – actual index – 1)

LETTERS	T	E	S	*
VALUES				

Bad Match Table

*first we have to **preprocess** the pattern in **O(M)** running time*



max(1 , pattern length – actual index – 1)

LETTERS	T	E	S	*
VALUES	3			

Bad Match Table

*first we have to **preprocess** the pattern in **O(M)** running time*

max(1 , pattern length – actual index – 1)

LETTERS	T	E	S	*
VALUES	3	2		

Bad Match Table

*first we have to **preprocess** the pattern in **O(M)** running time*

max(1 , pattern length – actual index – 1)

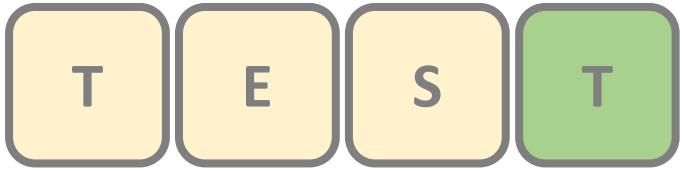
LETTERS	T	E	S	*
VALUES	3	2	1	

Bad Match Table

*last character is **special***

***1.)** if it is **not unique** then we can apply the formula (value is **1**)*

***2.)** if it is a **unique character** then we do not bother with it (it is the * case)*

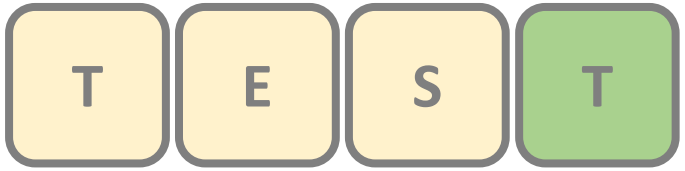


max(1 , pattern length – actual index – 1)

LETTERS	T	E	S	*
VALUES	3	2	1	

Bad Match Table

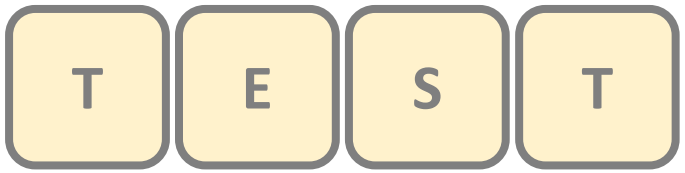
*first we have to **preprocess** the pattern in **O(M)** running time*



max(1 , pattern length – actual index – 1)

LETTERS	T	E	S	*
VALUES	1	2	1	

Bad Match Table

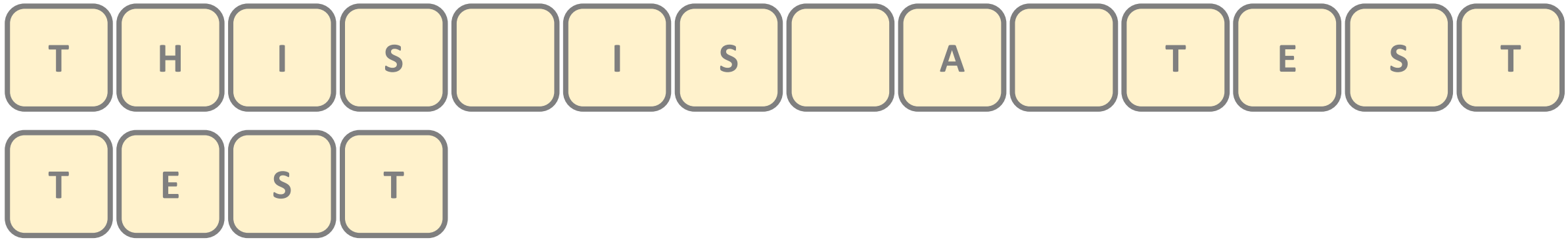


*first we have to **preprocess** the pattern in **O(M)** running time*

*this * represents all other characters with value **length of the pattern***

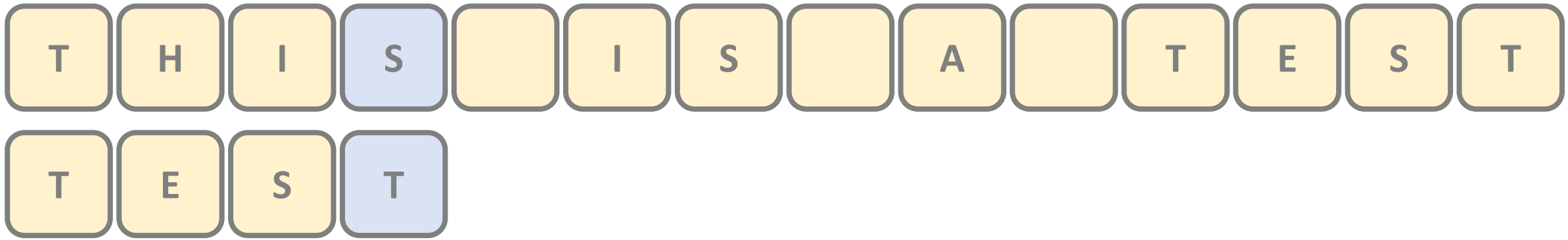
LETTERS	T	E	S	*
VALUES	1	2	1	4

Boyer-Moore Substring Search



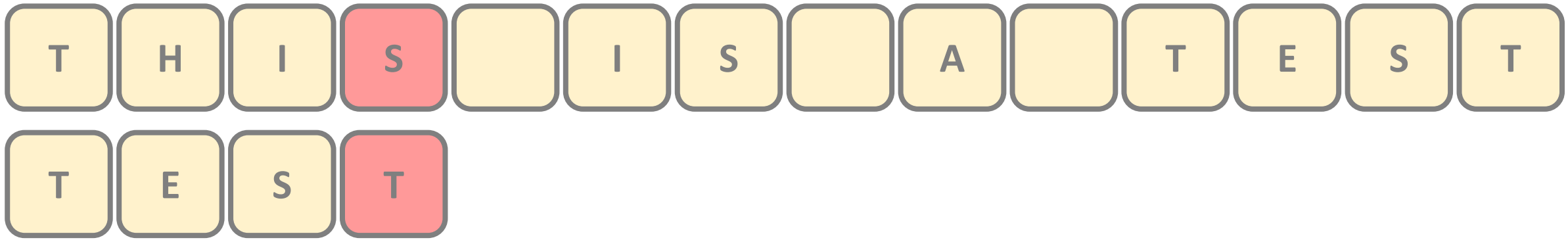
LETTERS	T	E	S	*
VALUES	1	2	1	4

Boyer-Moore Substring Search



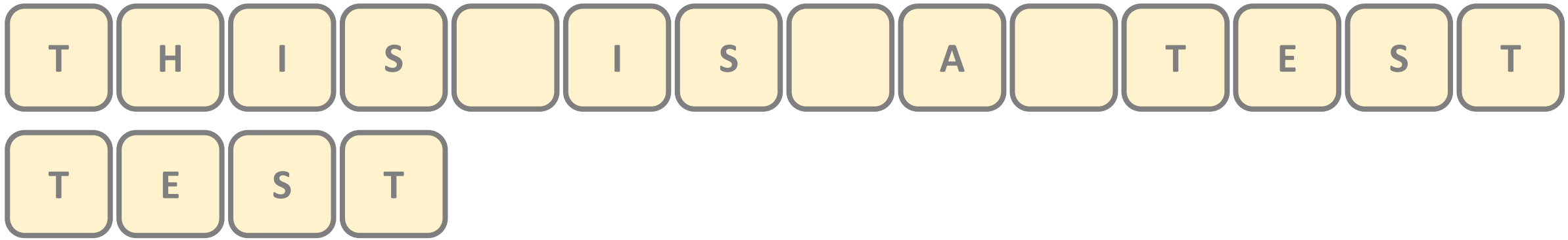
LETTERS	T	E	S	*
VALUES	1	2	1	4

Boyer-Moore Substring Search



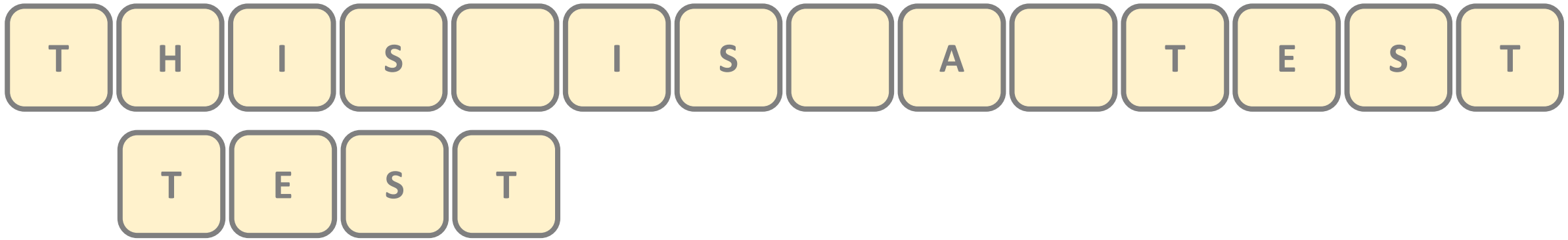
LETTERS	T	E	S	*
VALUES	1	2	1	4

Boyer-Moore Substring Search



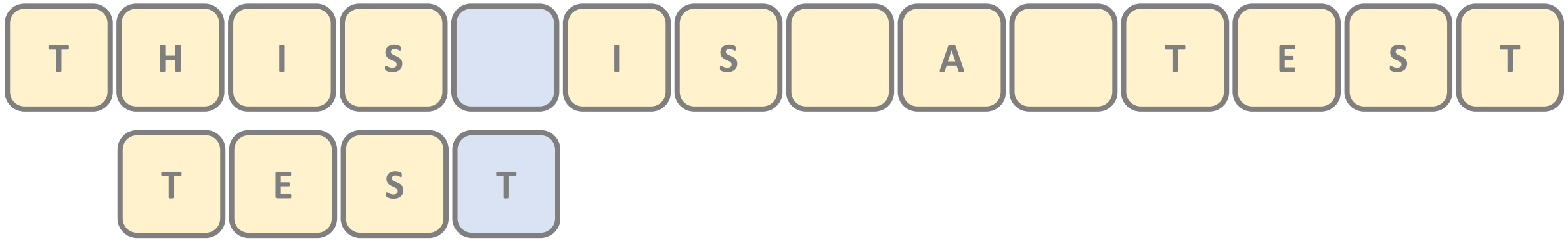
LETTERS	T	E	S	*
VALUES	1	2	1	4

Boyer-Moore Substring Search



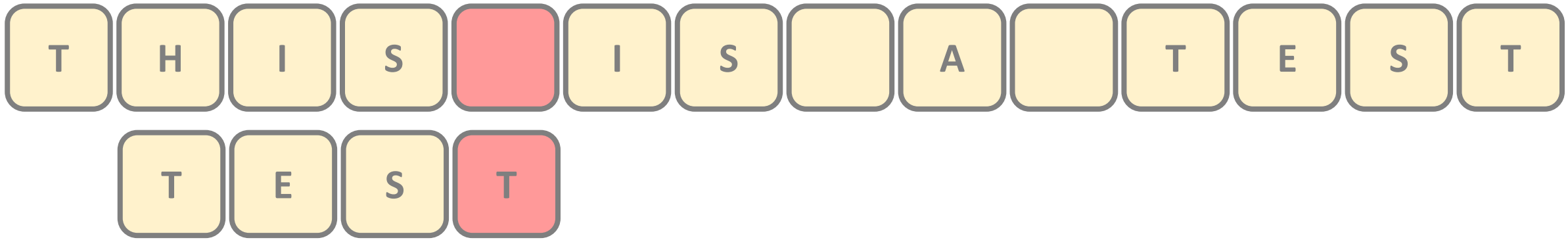
LETTERS	T	E	S	*
VALUES	1	2	1	4

Boyer-Moore Substring Search



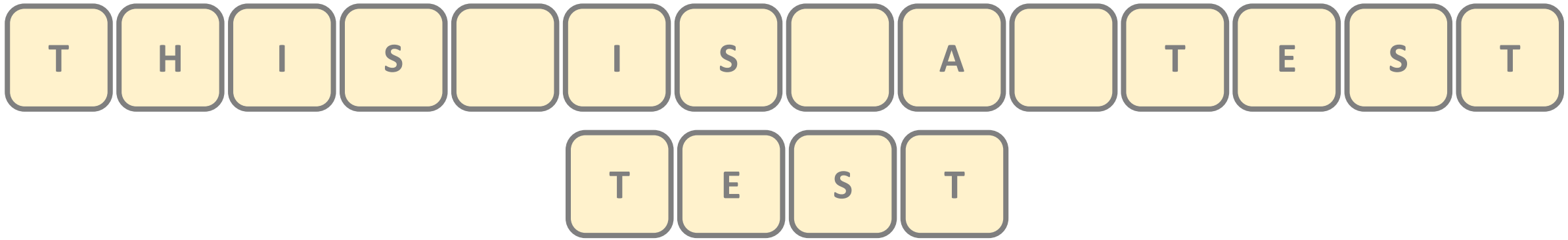
LETTERS	T	E	S	*
VALUES	1	2	1	4

Boyer-Moore Substring Search



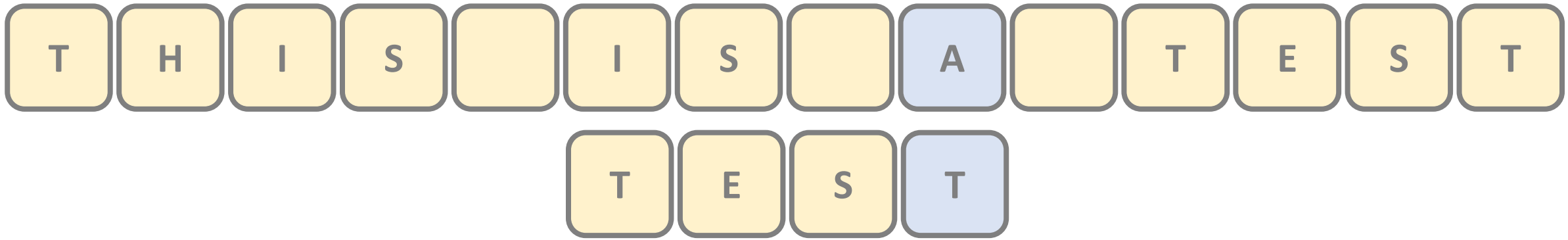
LETTERS	T	E	S	*
VALUES	1	2	1	4

Boyer-Moore Substring Search



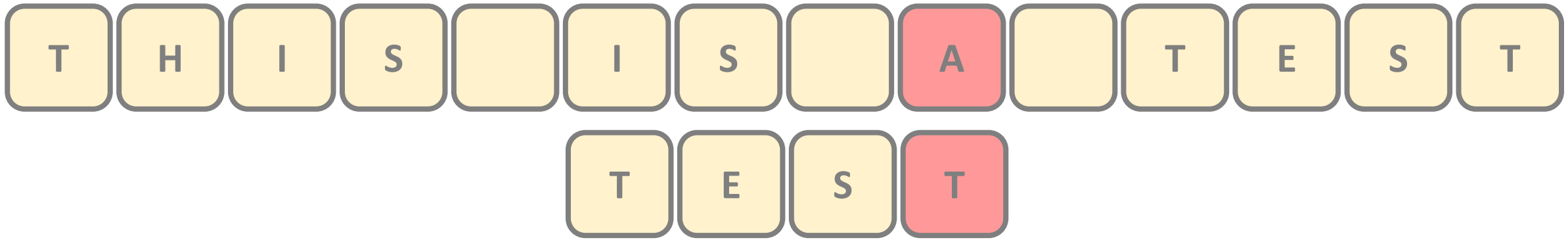
LETTERS	T	E	S	*
VALUES	1	2	1	4

Boyer-Moore Substring Search



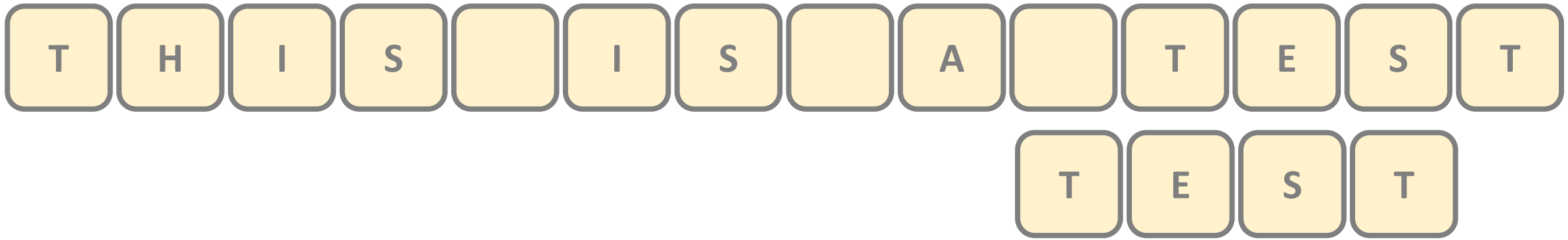
LETTERS	T	E	S	*
VALUES	1	2	1	4

Boyer-Moore Substring Search



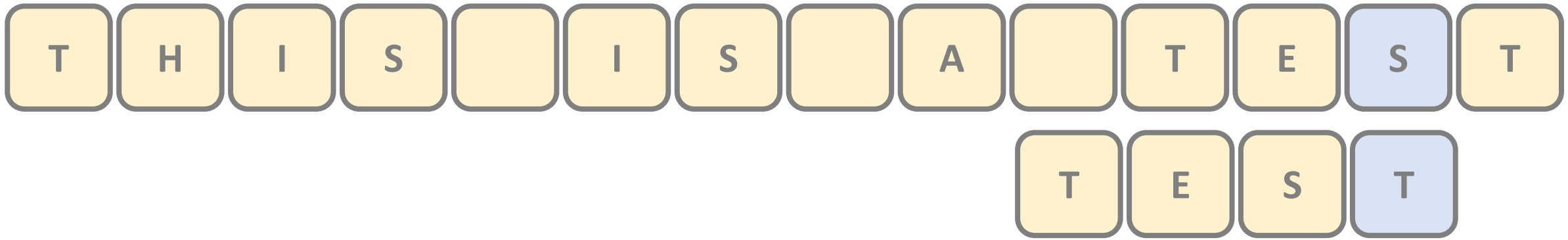
LETTERS	T	E	S	*
VALUES	1	2	1	4

Boyer-Moore Substring Search



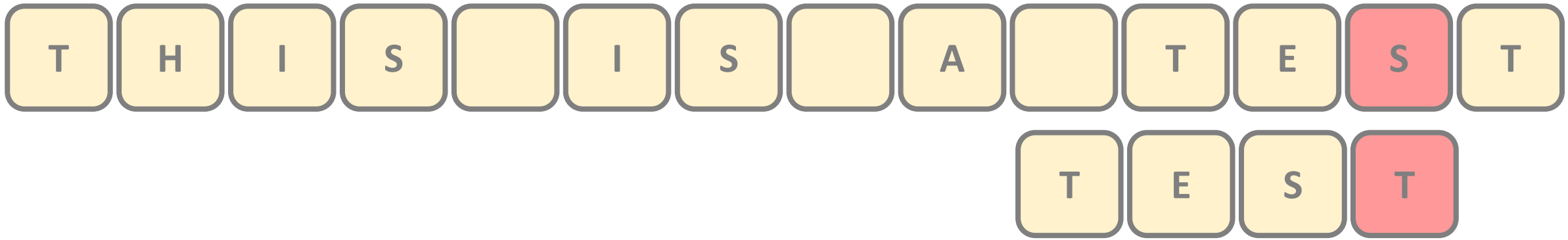
LETTERS	T	E	S	*
VALUES	1	2	1	4

Boyer-Moore Substring Search



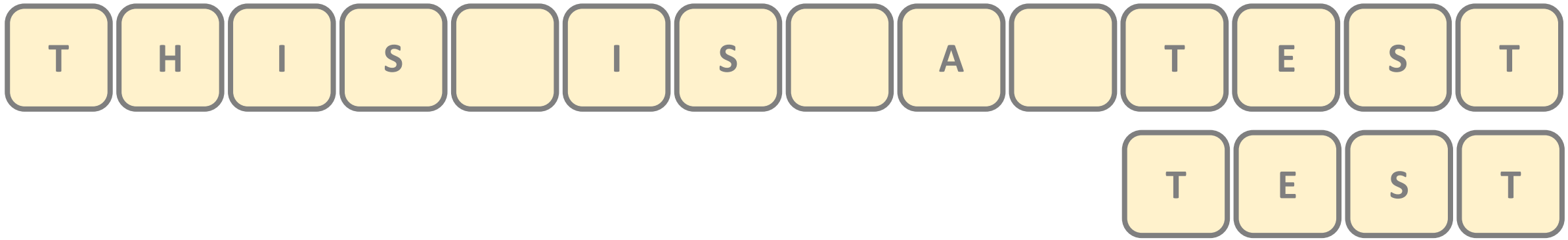
LETTERS	T	E	S	*
VALUES	1	2	1	4

Boyer-Moore Substring Search



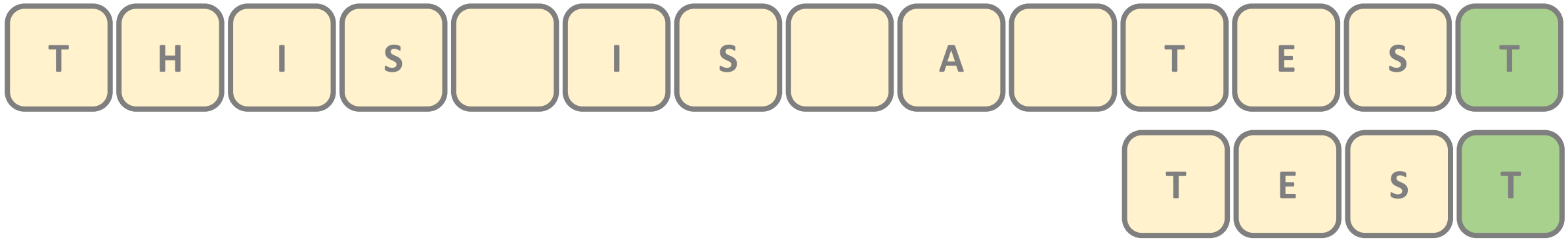
LETTERS	T	E	S	*
VALUES	1	2	1	4

Boyer-Moore Substring Search



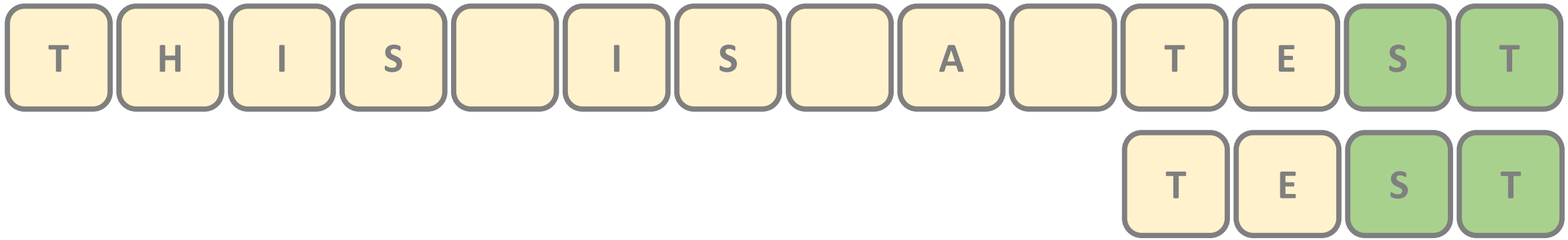
LETTERS	T	E	S	*
VALUES	1	2	1	4

Boyer-Moore Substring Search



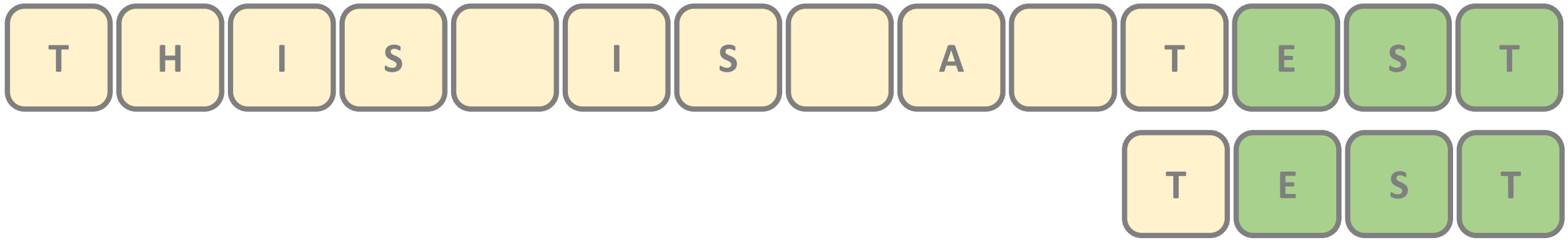
LETTERS	T	E	S	*
VALUES	1	2	1	4

Boyer-Moore Substring Search



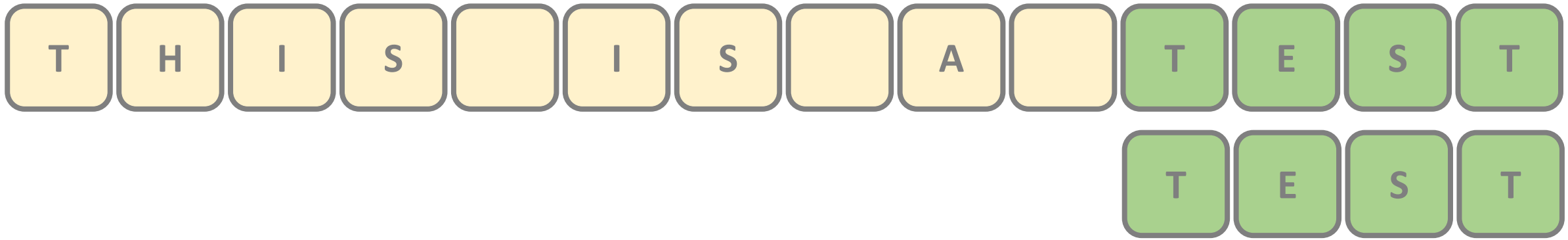
LETTERS	T	E	S	*
VALUES	1	2	1	4

Boyer-Moore Substring Search



LETTERS	T	E	S	*
VALUES	1	2	1	4

Boyer-Moore Substring Search



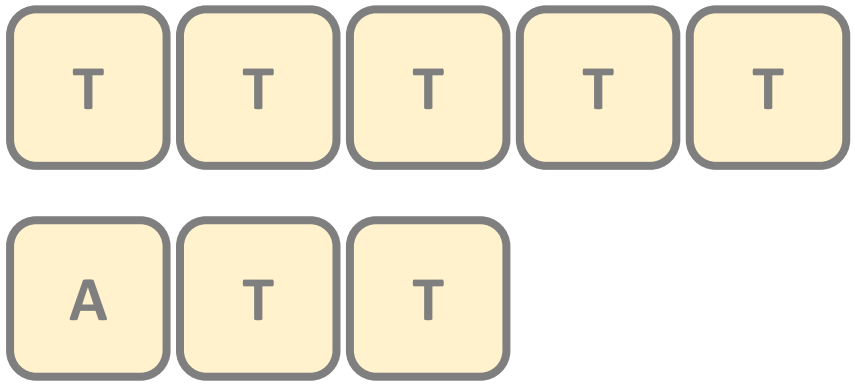
LETTERS	T	E	S	*
VALUES	1	2	1	4

Boyer-Moore Substring Search

- this approach turns out to be **quite efficient**
- mismatched character heuristics takes about **N/M** character comparisons where **M** is the length of the pattern and **N** is the length of the text
- it is not even linear – it is **sublinear**
- so the longer the pattern the faster the algorithm becomes
- it has **O(M+N)** average-case running time but the worst-case running time is still **O(MN)**

Boyer-Moore Substring Search

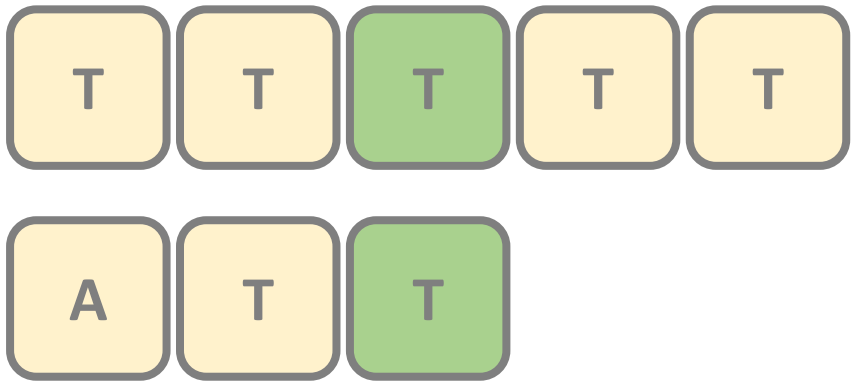
*the **worst-case scenario** occurs when there are several matching **suffixes***



LETTERS	A	T	*
VALUES	2	1	3

Boyer-Moore Substring Search

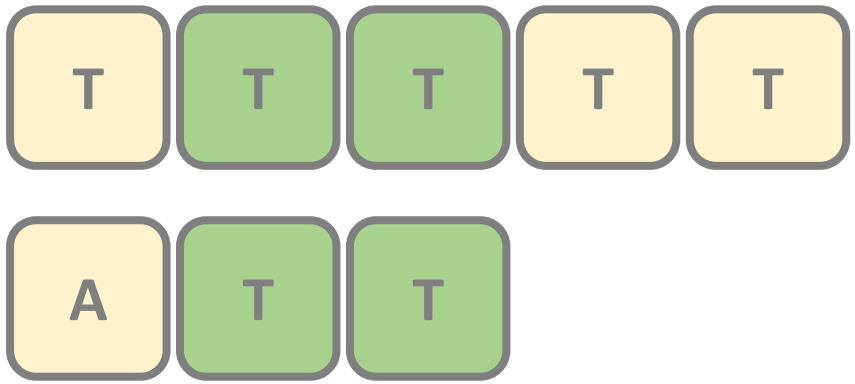
*the **worst-case scenario** occurs when there are several matching **suffixes***



LETTERS	A	T	*
VALUES	2	1	3

Boyer-Moore Substring Search

*the **worst-case scenario** occurs when there are several matching **suffixes***



LETTERS	A	T	*
VALUES	2	1	3

Boyer-Moore Substring Search

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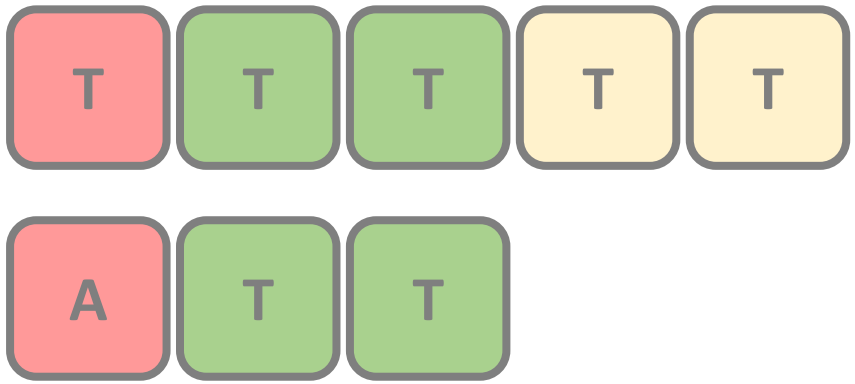

LETTERS	A	T	*
VALUES	2	1	3

Boyer-Moore Substring Search

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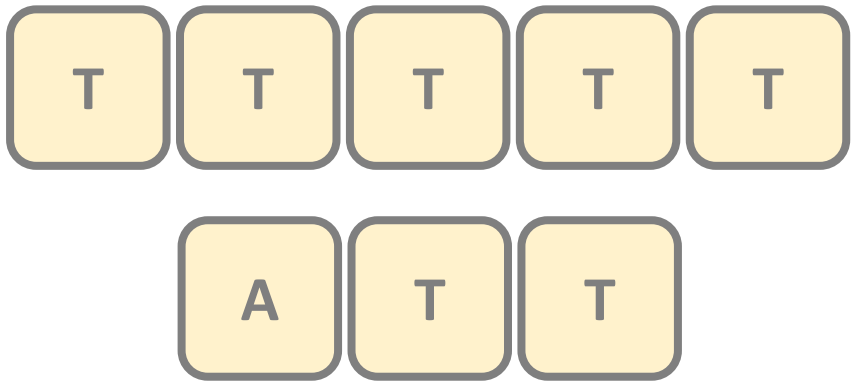

LETTERS	A	T	*
VALUES	2	1	3

Boyer-Moore Substring Search

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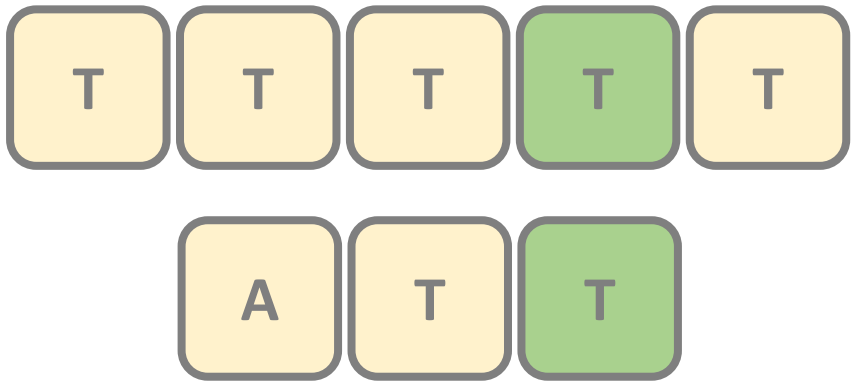

LETTERS	A	T	*
VALUES	2	1	3

Boyer-Moore Substring Search

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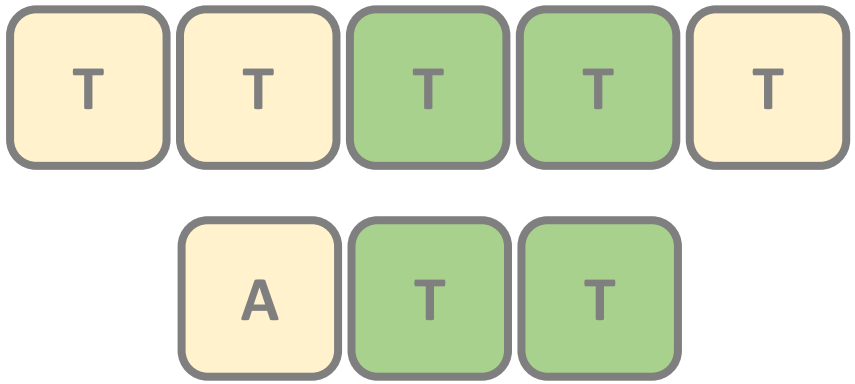

LETTERS	A	T	*
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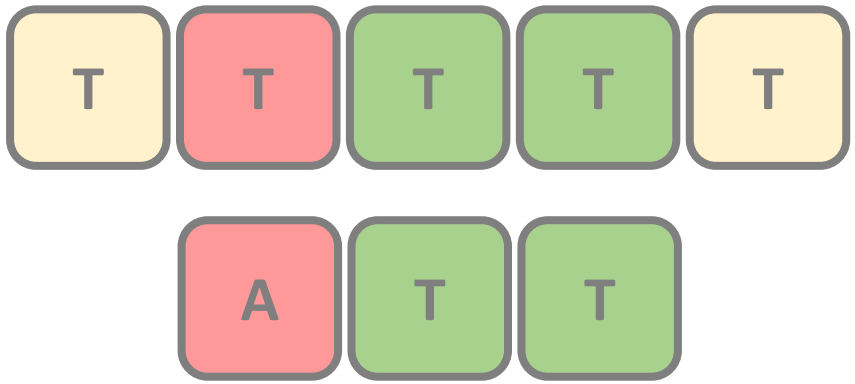

LETTERS	A	T	*
VALUES	2	1	3

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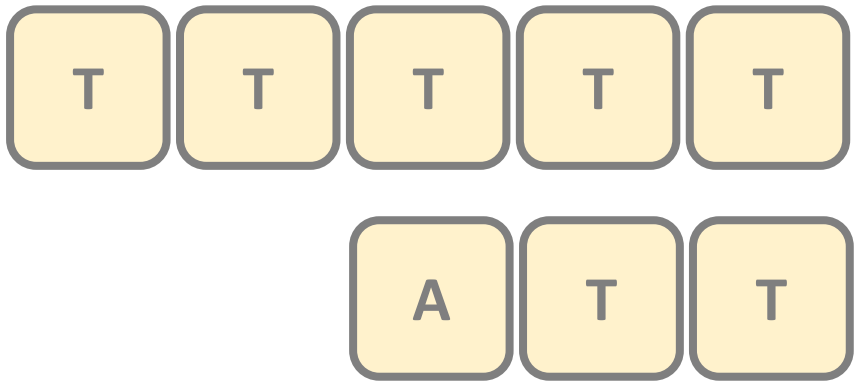

LETTERS	A	T	*
VALUES	2	1	3

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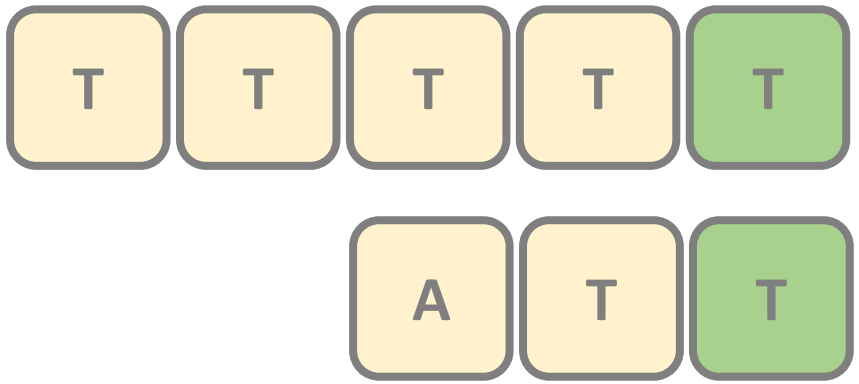

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VALUES	2	1	3

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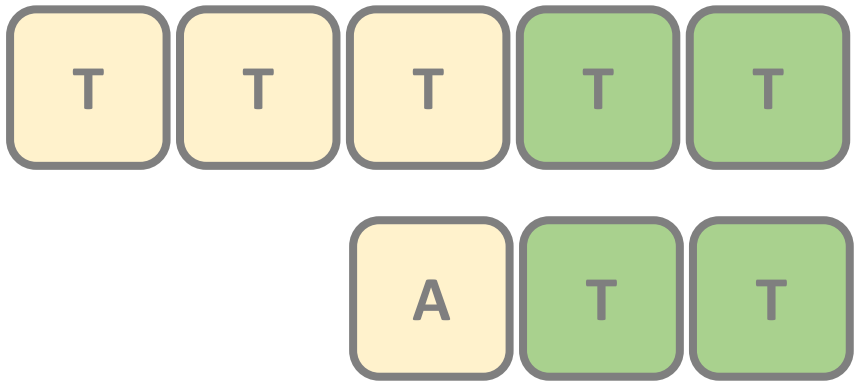

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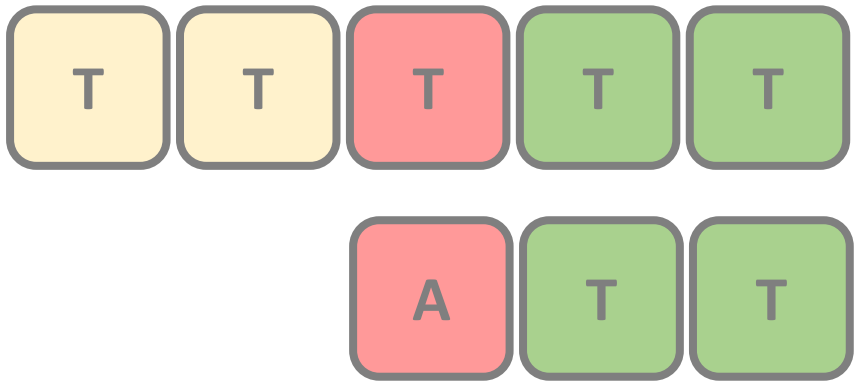

LETTERS	A	T	*
VALUES	2	1	3